Radiological Health Aspects of Oil Well Logging

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ALONG WITH the rapid growth of the petroleum industry, techniques have been developed for locating new oil reserves and the recovery of crude oil and gas. For many years the industry sought a tool that, when lowered into the drill hole, would supply information quickly and accurately about the geologic stratum being drilled for oil.

In 1939, J. L. Gartner (*1*) was able to identify common sedimentary rocks by lowering into the drill hole a tool containing a radioisotope source and a radiation detector that measured secondary radiation produced in the geologic formations. The recording of the radiation pattern was referred to as a radioactivity well log, and the technique was made available commercially to the petroleum industry in 1940.

This study was made to determine the potential radiation exposure to workmen during handling techniques by measuring radiation intensities from the various sources that are used in oil well logging operations. Approximately 25 radiation sources used by 10 different oil well servicing companies were surveyed to derive the data reported here.

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Radiation Logs

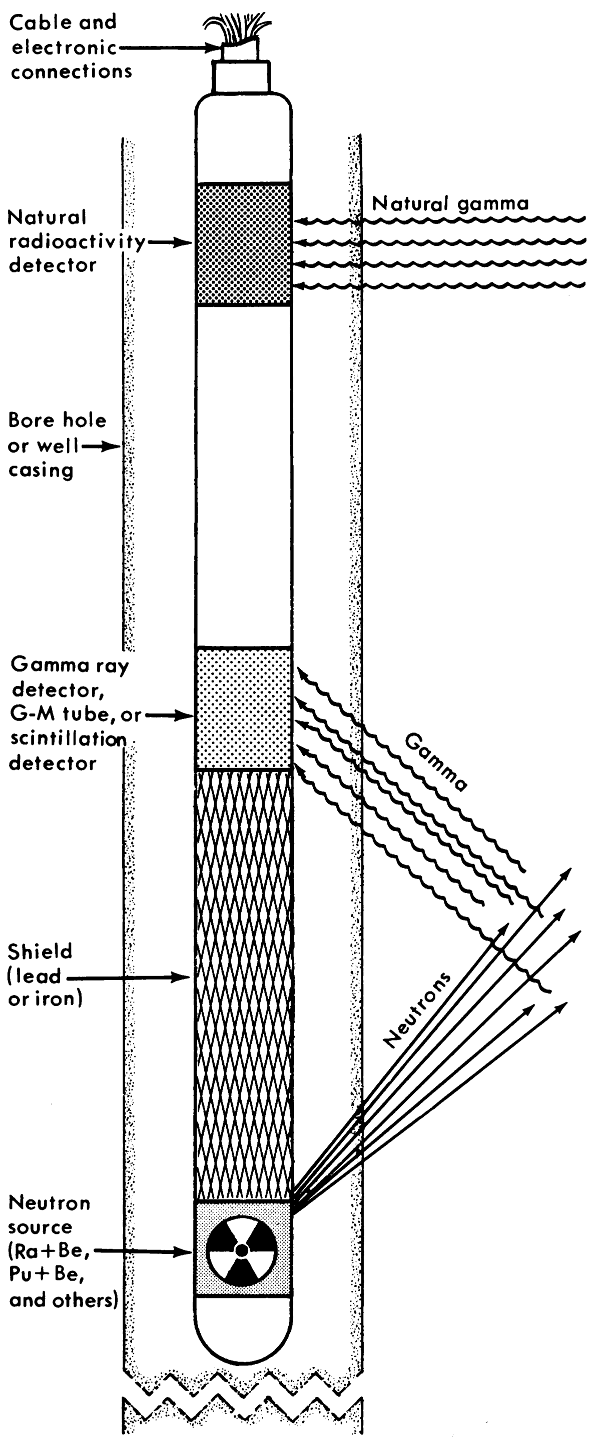
Since 1940 several types of radiation well logs have been developed and put into general use. The following are some types currently used in logging operations.

Type of radiation log	*Information obtained*
Gamma log	Measure of the natural radioactivity in each formation.
Gamma-gamma log	Formation density and porosity.
Neutron-gamma log, neutron-neutron log, and epithermal-neutron log.	Hydrogen concentration, porosity, distinguish between different rock formations, and distinguish between oil, gas, water, or brine.

Gamma log. The gamma log is made by measuring the natural radioactivity of the geological formations with a Geiger-Mueller tube or a scintillation detector, and it does not employ a radiation source in the logging tool (*2*). Shale formations contain more U^{238}, Th^{232}, and K^{40} than sandstone, limestone, or anhydrites. By making a gamma log, shale formations that often contain oil can be distinguished from other formations (*3*).

Scatter radiation logs depend on the lowering of a radioactive source into the drill hole and recording the induced or secondary radiation produced in the surrounding formations. To distinguish between the different types of scat-

Figure 1. Logging tool (sonde) for making a neutron-gamma log



A gamma log can be obtained from the detector at the top of the tool and a neutron-gamma log at the lower end of the tool. The tool also houses the electronic circuits for the detector.

ter radiation logs, they are designated by the type of radiation source used and the scatter radiation component that is measured with a suitable detector. The radioactive sources used vary according to the information desired, type of recording instrumentation, and other factors.

Gamma-gamma logs. These logs are generally made to determine formation density and have a gamma source in the tool as well as a gamma detector. High-energy gamma photons penetrate into the formation and the secondary photons produced are detected by the gamma detector. If the detector records an increase of secondary gamma radiations, the formation is more dense (*2*).

Neutron-gamma log. If a neutron source such as radium plus beryllium is placed in a logging tool, such as shown in figure 1, and lowered into a drill hole, the neutrons emitted are slowed down and captured by atoms in the surrounding formation. The secondary gamma photons produced from this interaction are recorded by the gamma detector in the logging tool (*4*). This logging technique is quite useful in determining the density and porosity of formations in wells that have been previously drilled and cased (*5*).

Neutron-neutron log. This method differs from a neutron-gamma log in that instead of a gamma detector in the logging tool, a neutron detector is employed. Since neutron scattering can be related to density and hydrogen atom concentration, it is possible to distinguish between brine, oil, and fresh water. Some indications of formation porosity may also be obtained (*6*). One outstanding advantage of the neutron-neutron log is that the log is not influenced by the variation of neutron capture cross-section of elements in the formation as in the neutron-gamma log technique.

Epithermal-neutron log. This log differs from the neutron-neutron log in that the neutron detector is adjusted to detect neutrons just before they are thermalized. The information derived from this log is related to the degree the formation will moderate or slow down the neutrons before they are detected (*7*).

Radiation Sources

The sources of gamma and neutron radiations used in well logging operations are generally well known. The safety precautions necessary for proper handling are also well understood. Sources commonly used are listed in the table.

Neutron sources of radium-beryllium for logging usually range from 300–600 millicuries and plutonium-beryllium sources are commonly 5 curies. Gamma sources, such as cobalt 60 or cesium 137, may range from a few millicuries to several curies, depending upon the application and the type of detection instruments used in the logging operations.

The radium-beryllium neutron sources are potentially more hazardous because both gamma and neutron radiations are emitted; therefore, the shielding for a source must be designed to attenuate both the neutrons and the gamma radiations. Also, a leaking source may contaminate employees and equipment with alpha-, beta-, and gamma-emitting isotopes, which may contribute to both internal and external radiation doses. Because the sources are normally used in locations (at the well site) that are not always ideal for proper handling, the chances of damage to the source or prolonged exposure of personnel to the unshielded source are more likely than in a controlled area such as a laboratory.

Plutonium-beryllium sources are less difficult to shield because high-energy gamma activity is negligible. However, leaking sources can be extremely hazardous, especially if alpha detection instrumentation is not available to make field tests for leakage or to detect the contamination from a leaking source. Because plutonium has a lower specific activity than radium, a larger source is required to produce the same neutron flux. A 500-millicurie radium + beryllium source will produce approximately 7.5×10^6 neutrons per second. Production of the same neutron flux with a plutonium + beryllium source requires about 5 curies of plutonium (*8*). However, when we compare these two neutron sources with respect to total radiation dosage to employees, the plutonium + beryllium source dose rate is much less since the gamma component that is associated with the radium + beryllium is not present.

The same reactions of neutrons with matter that are important in the well logging application are also important in the public health precautions needed to use neutron sources safely. When a light element such as beryllium is bombarded with alpha particles, neutrons are produced:

$$_4Be^9+{}_2He^4\rightarrow{}_6C^{12}+{}_0n^1\sim5\text{ Mev.}$$

The radium, plutonium, actinium, or other alpha emitting isotopes are the source of the alpha particles for the reaction with the beryllium which produces the neutrons.

The neutrons in well logging operations react with hydrogen or other elements producing gamma photons that are detected by the logging instrumentation, giving a relationship of the hydrogenous material concentration of the formations in the oil well:

$$_1H^1+{}_0n^1\rightarrow{}_1H^2+\gamma(2.2\text{ Mev}).$$

This same reaction can occur in tissue of the body and thus produce tissue injury by interaction of neutrons with the hydrogen or other atoms in the body. Neutrons, if allowed to enter the body, may interact with body tissue in a variety of reactions, such as elastic or inelastic scattering, and neutron capture. For neutrons with 4–5 Mev energy, the principal interactions with body tissue are by neutron capture, such as

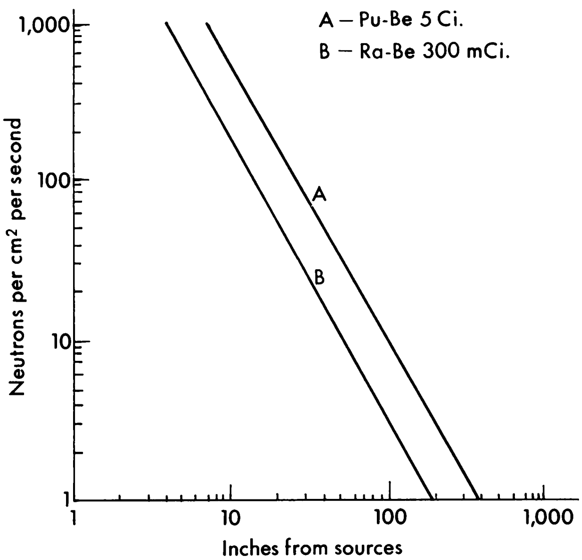
$$_1H^1(n,\gamma)_1D^2 \text{ and the } {}_7N^{14}(n,p)_6C^{14}$$

reactions (*9*), but elastic and inelastic scattering also contribute to tissue damage. If the

Radiation sources used in well logging

Source	Type of radiation	Energy Mev	Intensity per curie	Half-life (years)
CO^{60}	Gamma	1.33, 1.17	2.65 r. per hr. at 1 ft	5. 3
Cs^{137}	do	.66	3.31 r. per hr. at 1 ft	30
Ra^{226}	do	.186–2.43	9.03 r. per hr. at 1 ft	1, 620
Ra^{226}+Be	Neutron	4.5 (average)	1.5×10^7 n. per sec	1, 620
Pu^{239}+Be	do	4.5	1.5×10^6 n. per sec	24, 300
AC^{227}+Be	do	4.6	2.5×10^7 n. per sec	22
AM^{241}—Be	do	5	2×10^6 n. per sec	458

Figure 2. Neutron flux densities



Curve A is the average neutron emission rate from 5-curie plutonium-beryllium logging sources. Curve B is the average neutron emission rate from 300-millicurie radium-beryllium logging sources. Measurements were made at various distances from unshielded sources.

neutrons are captured by hydrogen atoms of the tissue, the gamma photons produced interact with other atoms by photoelectric effect, Compton scattering, or ion pair production. Since the gamma photons produced by the (n, γ) reaction with hydrogen are 2.2 Mev all three of these reactions may take place, resulting in damage to the tissue by ionization.

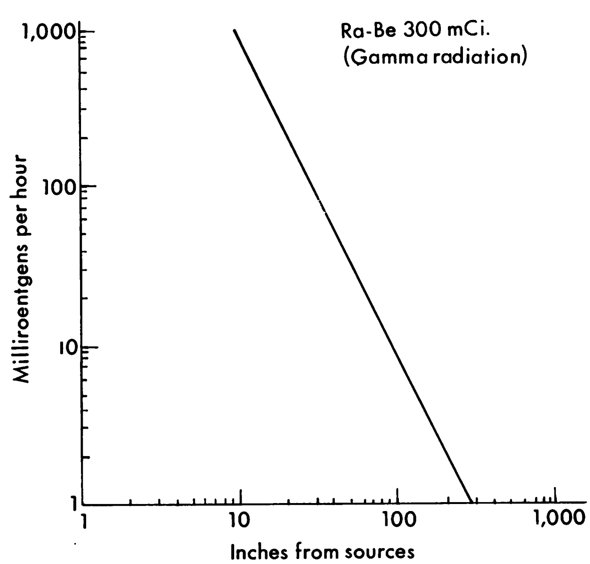
The greatest amount of radiation exposure from logging sources occurs during the transfer of the source to the logging tool. The time necessary for this operation varies a great deal from one logging company to another because of the different methods used in storage of the source and the method of transferring the source to the tool. While observing field operations, an employee may receive radiation exposure from the source for some 5–20 minutes during a source-changing operation. If difficulties with source handling are involved, longer exposures will result.

The neutron and gamma dose rates were measured in the field at various working distances from a large number of neutron logging sources. A wide range of dose rates was obtained per curie of activity in neutron sources because of the geometry of the source capsule, the type of tongs used, and the configuration of the source. The neutron curve shown in figure 2 gives the average neutron intensities at working distances from two neutron sources commonly used in well logging, 300 millicuries of radium-beryllium and 5 curies of plutonium-beryllium. These values are important in assessing the potential radiation exposure, but they do not give the total radiation hazard because a great deal of the radiation exposure is caused by the gamma activity from the radium.

The plutonium-beryllium sources, when encapsuled for logging, will produce relatively insignificant gamma activity. The gamma intensity of a 5-curie plutonium-beryllium source, due to container attenuation, is usually less than 10 milliroentgens per hour at 1 foot; therefore, the neutron dose overshadows the gamma dose when radiation dose rates are calculated.

The gamma intensities plotted in figure 3 are for 300-millicurie radium-beryllium sources that have been encased to protect them from damage during logging operations. Field measurements of gamma intensities varied widely, depending on the angle at which the survey meter was held in relation to the source. This variation is due largely to the geometry of the source capsule, and the size, shape, and thickness of

Figure 3. Gamma radiation from radium-beryllium sources



Gamma intensities measured at various distances from unshielded sources encapsulated for logging operations.

the source holder. For example, the gamma intensity from a 300-millicurie radium-beryllium source varied from 50 to 400 milliroentgens at 1 yard from the source in different directions.

In obtaining data for figures 2 and 3 the measurements were made at points where an operator would normally work with the source. With this procedure, in almost all instances the reading obtained represented the minimum reading rather than the maximum that could be obtained at the same distance from the source at a different angle.

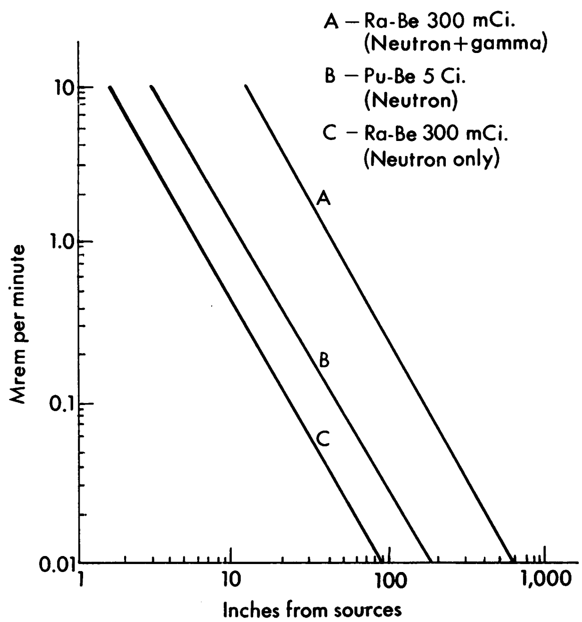
As shown in figure 2, at a 40-inch working distance a 5-curie plutonium-beryllium source will yield about 30 percent more neutrons per square centimeter than a 300-millicurie radium-beryllium source. (The 5-curie plutonium-beryllium and the 300-millicurie radium-beryllium neutron sources are in general use.) If, at this distance, we were only concerned with the exposure of workmen to neutrons, we could say that the radium-beryllium source would be much safer to work with.

To evaluate the total radiation dose rates, the neutron and gamma intensities were converted to milliroentgens equivalent man per minute (1 mrem. per min. $=2.6\times10^4$ n. per cm.^{2} per min.) (*10*). When the total radiation dose rates (neutron + gamma) are plotted for 5-curie plutonium-beryllium and 300-millicurie radium-beryllium sources, the dose rate in mrem. per min. for the radium-beryllium source is about 10 times that of the plutonium-beryllium at a 40-inch working distance (fig. 4).

If, for instance, it takes a man 10 minutes to transfer a source to the logging tool and, after the operation, he transfers it back to the storage pit, with a working distance of about 40 inches, the exposure dose from a 5-curie plutonium-beryllium source would be 1.2 mrem. and from a 300-millicurie radium-beryllium source it would be 11.4 mrem. If this operation is repeated 10 times a week by the same person, the maximum permissible dose of 100 mrem. would be exceeded with the radium-beryllium source.

Because of these potentially hazardous exposure levels, all persons working with logging sources should have personal monitoring dosimetry capable of measuring neutron and gamma radiation dosages. In surveying logging companies, it was found that very few of the film badges worn by workmen showed a measurable amount of radiation exposure; however, the potential overexposure is present when working with these sources and personal radiation monitoring is necessary. Film badges should be capable of monitoring neutron as well as gamma radiation.

Figure 4. Radiation dose rates from well logging sources (milliroentgens equivalent man per minute)



Curve A is the total dose rate for 300-millicurie radium-beryllium sources (neutrons + gamma). Curve B is the neutron dose rate from 5-curie plutonium-beryllium sources. Curve C is the dose rate due only to neutrons from 300-millicurie radium-beryllium sources. A RBE (relative biological effectiveness) factor of 10 was used to calculate the rem (roentgen equivalent man) dose rate from neutron intensities, and a RBE factor of 1 for gamma intensities.

Care of Logging Sources

When considering the public health aspects of well logging sources, one cannot overlook the possibility of source leakage. The sources should be leak-tested at regular intervals and at any time damage is suspected.

There are several ways to detect source leakage. For radium + beryllium sources, a piece of filter paper may be placed alongside the source in the storage container or in a jar. The paper can be checked with an alpha meter or a Geiger-Mueller instrument. If the radium-beryllium source is stored in a tight storage pig, the interior of the pig may be checked with a

Geiger-Mueller probe that is protected against contamination with a thin plastic sleeve.

Another leak test that can be performed easily in the field is to wipe the source with tissue moistened with acetone or alcohol. After allowing the tissue to dry, a count can be made to determine the alpha or gamma count rate above background levels. Plutonium + beryllium sources can best be leak-tested by the "tissue" method; however, an alpha meter or neutron counter must be available to determine if activity is removed from the outside of the source. To prevent personal exposure, the sources should be wiped, using tongs, and the operation completed as rapidly as possible.

The storage of sources while they are not in use or when they are being transported to the well site is an important consideration. They can be stored satisfactorily in a piece of well casing buried 5–6 feet in the ground. The source can be suspended in the casing attached to the handling tongs or from a chain. The method used for retrieving the source when needed should be such that minimum exposure will result. In some cases, the sources are stored on the logging trucks. This storage is advantageous because it eliminates transferring of sources from storage areas prior to transporting them to the well site. It has been observed, however, that the storage shields mounted on the truck may be effective shields for the gamma activity from a radium + beryllium source but are not effective neutron shields. For radium + beryllium sources, an effective shield with minimum weight must have lead, steel, and paraffin to reduce the radiation to acceptable levels. When workmen ride or work near the source storage on the truck, particular emphasis should be given to effective shielding of gamma and neutron radiation.

Severe damage or rupture of a well logging source can cause gross contamination of personnel, equipment, and vicinity of the source. For this reason it is important that personnel performing logging operations have portable radiation detection equipment available while the sources are being transferred from storage, transported, or in use at the well site. Gamma and alpha survey instruments are necessary to determine if a source is leaking or to evaluate the extent of contamination.

The importance of developing emergency procedures to be followed in the event of an accident cannot be overemphasized. These procedures are complicated by the fact that the sources are frequently moved and are often used under adverse conditions in the field. State radiological health programs can be of valuable assistance to the logging companies in drafting emergency procedures or provide field assistance after an accident.

Conclusions

The size of the sources used, the nature of the isotopes, and the conditions under which they are used are factors that must be considered in making a radiation survey of field practices employed by a logging company.

Radium-beryllium neutron sources are potentially more hazardous than plutonium-beryllium sources; however, radiation exposure can easily exceed the maximum permissible dose to workmen if precautions are not carefully followed.

Since relatively large sources of radium and byproduct materials are used under field conditions widespread contamination could result from an accident, and emergency procedures as well as normal operating procedures should be established by the logging companies.

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Program Notes

Less Infant Mortality

The death rate for nonwhite infants in Baltimore, Md., dropped in 1965 by 13.5 percent over 1964, according to Dr. Robert S. Farber, Commissioner of Health of Baltimore. In his October 14, 1966, weekly letter to the Mayor, he reported that the greatest decline in infant deaths occurred in nonwhite infants whose mothers had had prenatal care within the first 3 months of pregnancy. This group experienced a drop in the death rate of 44.6 percent.

No Poliomyelitis or Diphtheria

No case of poliomyelitis or diphtheria has been reported in Maryland in more than a year, according to the Maryland State Department of Health.

These spectacular advances have been brought about by the widespread use of vaccines, stated Dr. John H. Janney, chief of the division of communicable diseases of the Maryland State Department of Health.

Detection of Phenylketonuria

Wisconsin had an estimated 32,400 births during the first 5 months of 1966, according to Dr. E. H. Jorris, State health officer. Tests of these newborn infants under the State's new PKU (phenylkentonuria) law resulted, he reported, in the detection of phenylketonuria in five infants, who are now under dietary supervision to prevent mental retardation.

"As a result of prompt and cooperative planning," Jorris said, "Wisconsin has been covered with an effective network of 89 approved laboratories for the performance of PKU tests on newborn infants for the physicians in every area of the State."

The State law, which became effective January 1, 1966, requires that the attending physician shall cause every infant born in a hospital or maternity home, before discharge therefrom, to have a test for PKU and such other causes of mental retardation as the State board of health directs.

More Beds for General Patients

Illinois hospitals will soon be permitted to admit certain gynecological patients to their maternity departments. This ruling will free approximately 1,800 additional beds in 226 hospitals for use by general patients.

A special study revealed that with proper safeguards selected gynecological patients could be admitted to the maternity department without jeopardizing the health of mothers and babies.

About 1,800 maternity department beds in Illinois have been largely unused because of the declining number of births in recent years and because hospital licensing regulations heretofore permitted only maternity patients to be admitted to the maternity department.

Philadelphia's Skid Row Program

Philadelphia, Pa., hopes that it can eliminate skid row and ensure that it will not reappear. The city began to implement a comprehensive skid row program as part of a total redevelopment effort when the Greater Philadelphia Movement became interested in redeveloping the downtown area for office buildings and light industry.

A 1959 census, supported by the movement, revealed nearly 3,000 men on the city's skid row. Most of them were middle-aged or elderly, had unskilled and semi-skilled working class backgrounds, experienced difficulty in finding suitable employment, and lacked family ties. About 35 percent were uncontrolled drinkers, but 16 percent were nondrinkers.

On the basis of the 1959 study, pilot projects were established. A diagnostic and relocation center was opened near skid row and, for men unlikely to maintain independent living, a halfway house well away from skid row. A domiciliary is also being developed.

The pilot projects enabled an action-research team to be established and persuaded civic leaders that such comprehensive facilities should be continued.

Sewage Treatment Construction

Pennsylvania ranked first in the nation for 1965 in the total dollar value and the number of contracts awarded for the construction of new sewage treatment plants.

Dr. C. L. Wilbar, State Secretary of Health, said that approximately 77 percent of the State's population—including most of the major cities—are served by sewage treatment plants.

Pennsylvania provides a yearly grant of 2 percent of the total eligible costs of constructing these sewage treatment facilities toward the cost of operating the plants.

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