# Radioactive Markers in Oil-field Practice

By H. G. Doll,* Member AIME and H. F. Schwede*

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Abstract

This paper describes a method to provide identification of particular depths in a borehole through the use of radioactive markers. The correlation of a marker, placed in the wall of a borehole, with known points of the electrical log and with the casing collars in the cased hole permits accurate positioning of tools with respect to a formation, regardless of absolute depth. Such a process is particularly useful in gun perforation of a casing in a well. Technique and equipment are discussed and illustrated. Examples are given of practical application in the field.

## Introduction

During the past decade the search for petroleum has increased the importance of testing zones at depths in wells which have become progressively deeper. The development of new techniques, such as electrical logging, has permitted the identification of producing formations which consist of comparatively thin strata. When thin beds are to be produced at great depths, the problem of positioning tools accurately to place the well in production becomes acute.[1]

Continuous consideration is being given in the petroleum industry towards the improvement of depth measurements in a borehole. The accuracy in absolute depth measurements, whether made in an open or cased hole, whether determined by a cable or a drill pipe, depends upon a number of factors, such as tension, temperature, and calibration.

For example, the effects of tension from the weight of 10,000 ft of drill pipe and the thermal expansion of this length of pipe, where its average temperature has increased 50°F, will produce an elongation as much as 8 ft.[2] The effects of such factors can be minimized through the use of care in depth measurements, the application of corrections based on experience, and continuous calibration or checking.

The fact that different methods and different tools are used to determine the depths of formations in wells will sometimes give rise to a difference between measurements. It is evident that an important requirement in a well is the ability to locate at will any subsurface point. While absolute depth measurements have improved in recent years, it is reassuring to have other means to verify, for example, that a casing is perforated at a particular place with reference to a zone within a formation. Such a check on measurements may be had by placing a reference marker at a point known with respect to the electrical log of the borehole. That point is usually chosen to be in proximity to the zone to be perforated. Thus, only short relative depth measurements are made and any inaccuracy becomes very small and of minor importance.

The use of reference markers located at fixed points predetermined in each zone where future operations are contemplated enables the operator to position any tool

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* Director of Research and Member Technical Department, respectively, Schlumberger Well Surveying Corporation, Houston, Texas.

[1] References are at the end of the paper.

with great confidence. The positioning of the tool now requires the measurement of only a short interval, less than 100 ft, a measurement that can be accomplished easily. The elongation of cable or of pipe, caused by tension, temperature and other effects, which are difficult to estimate when dealing with long lengths, can be neglected.

The preference for short relative measurements is evident when it is recalled that an accuracy of 0.50 pct in depth discrimination will amount to only 6 in. when applied to an interval of 100 ft, but it will amount to 50 ft when applied to an absolute depth measurement at the bottom of a hole 10,000 ft deep.

The reference marker should be a simple device, easily placed at the proper position in the borehole and able to be identified for a long time after casing has been cemented. It should be of small size in order to permit very accurate location at a definite position. Several types of markers have been considered; namely, radioactive, magnetic and temperature markers.

For practical reasons the preference has been toward the use of a radioactive marker. Such a marker may consist of a compact source of gamma rays originating from a radium salt. The rays are able to pass through several inches of cement and steel, and they can be easily detected by suitable equipment. The source will outlast the life of the well inasmuch as half of the amount of radium salt used will still be active after 1590 years.

The location of the artificial marker after casing has been set will identify the depth of a point whose position is known with reference to the formations. Then, regardless of absolute depth, a tool or device may later be set in the casing at a given distance from the known point. To that point may also be tied in the casing collars which thereby provide another permanent set of references. It has already been mentioned that relative differences in depth over a short distance can be determined with greater satisfaction than absolute depths from a datum plane far removed.

The method outlined above consists essentially of three steps; namely, the placement of the marker with respect to known points on the electrical log, its location behind the casing, and its subsequent use as a reference point, such as for the location of the casing collars and the positioning of tools in the hole.

## Apparatus

The apparatus comprises several main parts; namely, the radioactive marker, the instrument to place the marker in the open hole, the instrument to detect the marker after the casing has been cemented, including the detector sonde, its control panel, and a recorder.

The radioactive marker is a small brass capsule containing $\frac{1}{10}$ of a milligram of radium. The intensity of the gamma rays from such a point source, even as far as 2 ft, away is ample to register easily, through the casing and the cement, on the detecting apparatus employed. The radiation from the source overrides the background due to the natural gamma radiation in the hole and gives a distinctive reading regardless of the position of the marker when lodged in the wall of the hole.

The brass pellet is placed inside a steel projectile which is fired either by a sample-taker gun or a perforating gun. One type projectile used fits into a regular gun-perforator cannon. Another projectile used is placed in an aluminum oversized sleeve and fired from the large diameter cannon of the sample-taker gun. In this manner, either type of gun may be used according to field conditions. These projectiles are shown in Fig 1.

The assembly containing the detector for the radioactive markers is made up of a number of sections suitably coupled mechanically and electrically. The lower section contains a casing-collar locator including a bottom-hole indicator. Next is the radioactive marker-detector sonde. Occasionally a weight may next be used between the detector and the fishing head at the top. The outside diameter of this equipment is 3½ in., while its overall length, without a weight, is 8½ ft. Fig 2 shows the apparatus made up.

When the sensitive element in the sonde passes by a marker in the hole, a sharp deflection occurs on the meter and a peak is recorded on the photographic log. It will then be a very simple operation to position any tool, which can be attached to the cable conjointly with the radioactive detector, at a given depth computed from the location of the marker. Usually the casing-collar locator is connected to the detector sonde so that the position of the radioactive marker and the position of the casing collars, which will be passed by the assembly, are recorded on the same film. The apparatus has been subjected to extensive field use for over two years. It has operated successfully under conditions in a borehole at a temperature over 300°F and at hydraulic pressures approximately 12,000 psi.

## Field Technique

1. *Placing the radioactive marker*—The radioactive markers are usually placed immediately following the electrical logging survey. The geologist at the well, after comparison of the electrical log with his core record, frequently finds it advisable to supplement his data by taking some sidewall cores.[3] In the cases where the operator also desires to use markers, both the taking of cores and the placing of radioactive markers can be accomplished during one round-trip in the hole. A combined run of that type is becoming standing operating procedure in the completion of a well by many operators.

The sections where markers should be placed are to be determined considering not only the immediate zone to be tested, but also all other zones, elsewhere in the hole, which show production possibilities. The number of markers, their approximate interval and the type of formation in which to place them are next considered. The proper procedures vary with the field and the geological strata. Wherever the formations are soft and the boreholes are rela-

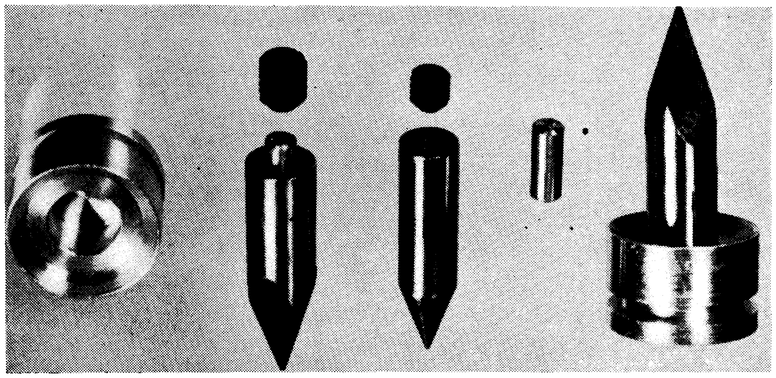

Fig 1—Projectiles.
Reading right to left: projectile made up with sleeve for sample-taker gun; small brass pellet containing radioactive salt; projectile used with gun perforator; projectile used with sample-taker gun showing pellet inside and retaining plug; aluminum sleeve.

tively free from cavities, as shown by a record of the hole size, for example, or from general knowledge, then placement of markers in shale is quite satisfactory. In other areas, however, where shales crumble easily in contact with mud of the borehole and give large cavities, placement in sands have proved best. A shaly break within the sand to be tested is a good place.


FIG 2—ASSEMBLY CONTAINING DETECTOR FOR RADIOACTIVE MARKERS.

The powder charge in the sample-taker gun is usually ample to lodge the projectile in the wall of the borehole, even for limy formations. It has been found, however, that occasionally the use of a gun perforator for greater penetration of the projectile is required for some hard sands and limes.

For each zone to be tested, practice has indicated the advisability of placing three or more markers at short intervals over a section that straddles the zone. Their proper placement increases the likelihood that at least two will remain after casing has been set. This aspect is discussed further in the section on locating the markers.

In view of the importance of the marker position, a thorough study has been made to ascertain its reliability. Statistics were compiled on the results of placement. The collected data indicate that the proportion of markers lost during placement is about 1 in 20 for soft formations, while in harder formations the proportion lost may be higher.

Furthermore, during the early phases of experimental work, the placement of the markers was checked by several location runs before casing was set. Occasionally a marker was found to have moved where cavities were likely present. Other check runs have indicated that trips in the hole with drill pipe after placement will sometimes disturb the location of the marker. Accordingly, it is advisable, whenever possible, to place the radioactive markers just prior to the running of the casing in the hole.

The section of the open hole chosen for the location of the radioactive marker is correlated with the SP (Spontaneous Potential) log. The projectiles are fired when the gun is in uniform motion. Since it is quite necessary to know exactly where the markers are placed, a log of the SP is taken during the operations. A break in the recorded curve of the SP is made at the moment the projectile is discharged, thus indicating the position of the SP electrode.

From a knowledge of the constant physical separation on the apparatus in the hole between the recording electrode and the cannon discharged, the engineer determines the actual depths of the markers placed with respect to the electrical log. An illustration of an SP log made during such an operation is given in Fig 3. Breaks on the curve occur at 9945½ ft and at 9979½ ft, showing the position of the markers to be at 9966 ft and at 10,000 ft. The first marker at 9966 ft is in the shaly section above the sand while the second marker is in the sand body. The positions of the markers are then entered on the original log and thus become a permanent record in the company's files.

2. *Locating the radioactive markers*—The location of the markers is a separate operation made usually after casing has been set, often in conjunction with a gun-perforating job. It involves the detection of

the markers and their correlation with the depths of the casing collars in the vicinity of their placement.

The radioactive marker detector has been designed to be sensitive principally to strong localized sources of radioactivity. The sensitivity of the detector is relatively low; it is adjusted by means of a standard radioactive pellet at the surface, prior to the survey. At that low sensitivity, the natural gamma radiation from the formations will not be recorded on the film.

The low sensitivity, together with the small size of the sensitive elements of the detector sonde, compared to the characteristics of the usual gamma-ray logging apparatus, permits the positive identification of a marker and allows its position in the well to be determined sharply.

To have good accuracy, a low recording speed is used; it is usually of the order of 1500 ft per hour over the section of the hole wherein the markers and casing collars are to be found. The recorded section being generally short, this low speed does not appreciably increase the time necessary for the operation. The major part of the time of a survey is spent going down to the section of the hole to be logged and then bringing the apparatus back up to the surface. The elapsed rigtime may vary from 1 to 2½ hr for a complete operation.

The shape of the recorded trace for locating the marker is determined, among other things, by the recording speed and by the characteristics in the detector circuits. In the instruments used in the field, the characteristics have been chosen to give a sharp peak on the film as the sonde passes by a marker, thus permitting the marker to be ascertained accurately. At a recording speed of 1500 ft per hour, and for a survey made coming up the hole, the position of the marker is 6 in. below the point midway between the steep portions of the recorded trace.

The depths obtained during the location of the markers are given in reference to the SP curve of the electrical log used during placement. The position of each marker relative to the electrical log and

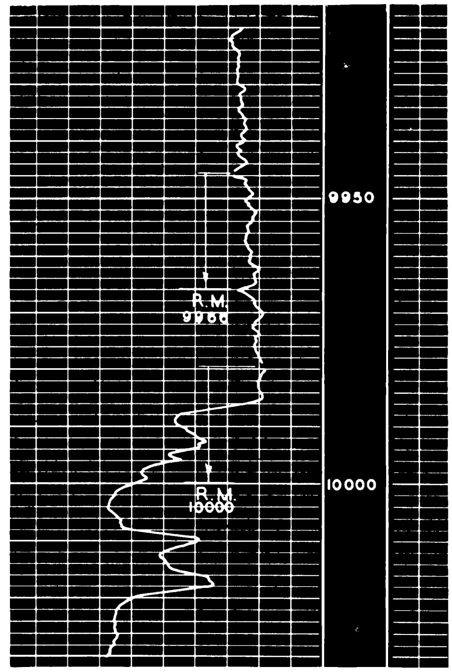


FIG 3—PLACEMENT OF RADIOACTIVE MARKER BY SP LOG.
R.M. 9966 and 10000

thereby to the geological column is fixed as a primary reference point available throughout the production history of the well.

An important measurement is the interval between markers. Where three or more markers are located after casing has been set, a comparison of the relative separations between each with their separations at placement will permit the operator to determine if any have subsequently moved. If one marker has moved, its amount and direction of displacement can definitely be determined from the other two undisturbed markers, regardless of their absolute depth. If only two markers remain, with their separation the same as at placement, then the likelihood is that neither has moved from their point of placement with respect to the electrical log, for otherwise it would be necessary for both to have been displaced the same amount in the same direction during the period of time between placement and location.

From the foregoing discussion the conclusion is that each marker of any two that have retained the same interval is obviously at its original position. In order to be reasonably certain that two undisturbed markers remain, it is considered desirable to place three or more throughout each of the zones likely to be tested.

In order to give further reference standards, the positions of casing collars with respect to the markers are also logged over the important section of the hole. That information is desired by the operators whereby they may later make use of the casing collars as a check on their own casing measurements and also to position tools with respect to a formation, if later tests have to be made.

## Application

Radioactive markers are being used at present in connection with several types of problems where the question of accuracy in depth measurements is important. In this connection, many production engineers will recall instances where difficulties arose after the well was cased; difficulties which could have been eliminated by the use of a dependable depth reference-point. Illustrations of the employment of radioactive markers are all instances of the general requirement that the well be tested or completed from a specific section in the borehole. The specific section picked for completion in the oil column is frequently critically determined by the location of the oil-water and oil-gas contacts.

In one case a field under a water drive has a producing zone in which the permeability of the formation in a vertical direction is quite low and variable. The horizontal permeability is appreciably greater. The formation is perforated selectively only a few feet at a time at the bottom of the sand just above the water level. In this way, trapping of some oil in a lower stratum is less likely to occur, as compared to completion initially by production over a long vertical zone. When the well becomes noncommercial, then it is squeezed with cement and reperforated in the next short interval, using a radioactive marker as a reference point for the series of operations. Tubing measurements thereby need be relied upon only as a gross check. Furthermore, regardless of any later changes of equipment above the ground, such as a new derrick floor, a permanent and consistent reference point is now available for depths within the well bore.

In another field it was found that wells completed in the oil column above a thin shale streak about 1 ft thick gave appreciably higher gas-oil ratios compared to those completed below the streak. The use of radioactive markers as reference points provided the necessary assurance that all perforations were made below this break, compared to the earlier practice of using depth measurements from a reference point at the surface. The subsequent improved gas-oil ratios were evidence of successful completion where markers were used.

Other cases occur frequently, such as, where the electrical log indicates that a thin sand streak, with good production possibilities, needs to be tested, or where the efficient placement of perforations is required for a cement squeeze job at the water-oil contact in a producing horizon.

The following summary will indicate the type of problems wherein the markers have been used in cased holes:

1. Correlation of a definite point in the well bore with the formations on the electrical log.
2. Production from specific zones within the oil column, and in known relation to any oil-gas or oil-water contacts.

3. Perforations for cement squeeze jobs opposite:
   *a.* oil-water contact
   *b.* oil-gas contact
   *c.* specific formations.
4. Increased efficiency in placement of perforations for zones to be tested.

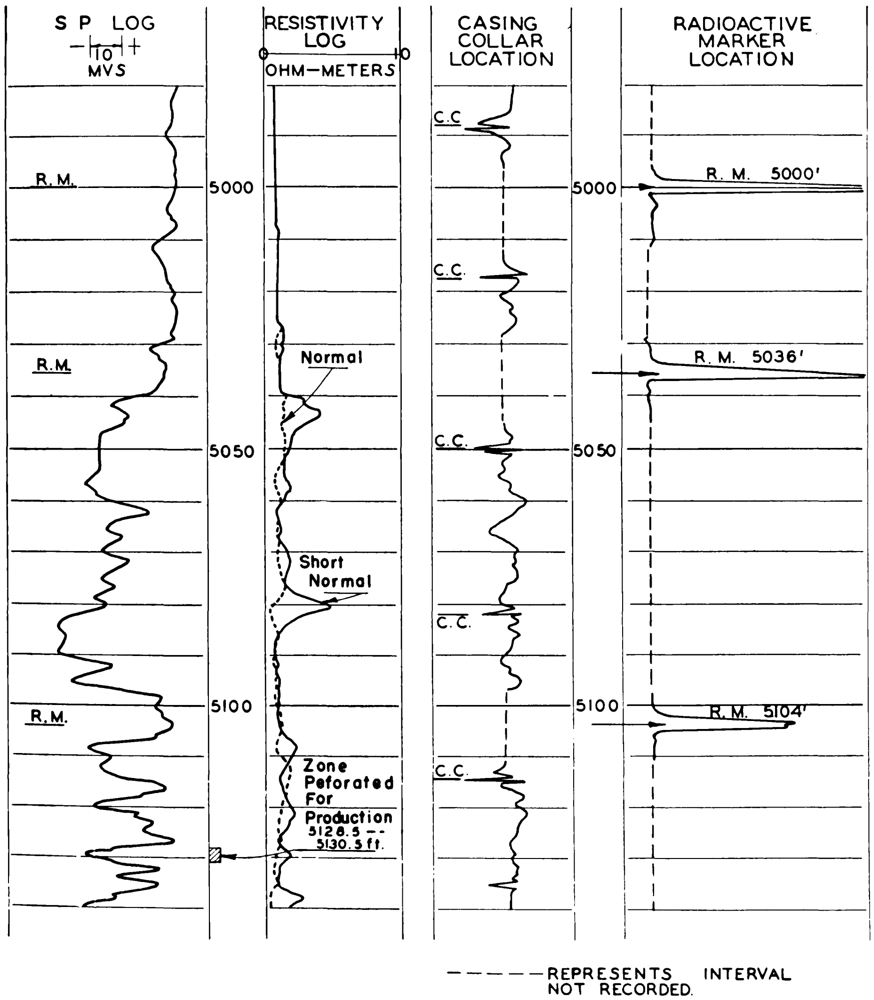


FIG 4—DRILL-STEM TESTS USING RADIOACTIVE MARKERS.

5. Testing and production from thin beds at great depths sub-surface.
6. Constant reference point for use in workover of wells, regardless of subsequent changes in surface equipment.
7. Permanent markers, which are indicated on the electrical log, as insurance against loss of other well records.

FIELD EXAMPLES

The illustrations in Figs 4 and 5 are given as examples to show the use of radioactive markers to assist in the solution of some production problems. These illustrations are tracings of the radioactive-marker log, casing-collar log, and of the electrical log recorded over the same section of the hole. The positions where the radioactive markers (RM) were placed are indicated on the SP log. It can be seen that the location of the markers and the casing joints are definitely tied into the position of any strata in the borehole.

permits a depth discrimination in perforating, for example, which is much beyond that obtainable if the derrick floor were used as the sole reference plane for depth measurements.

In the well illustrated by Fig 4, drill-stem

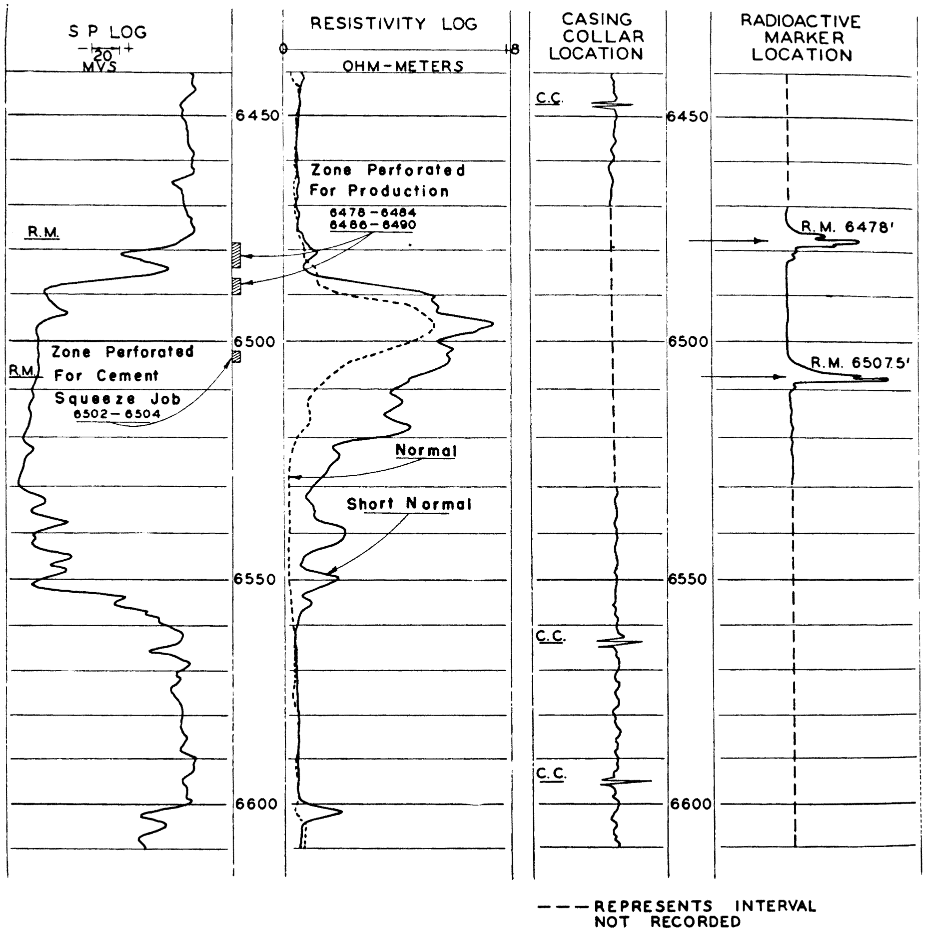


FIG 5—USE OF RADIOACTIVE MARKERS FOR EFFICIENT PLACEMENT OF PERFORATIONS.

The radioactive-marker survey logs are recorded such that the depths on the logs correspond to the position of the sensitive element of the radioactive-marker detector. The markers are thereby at a position corresponding to the depths of their deflections on the log. This knowledge

tests in open hole from the section around 5050 ft gave dry gas, while a test in the interval from 5131 to 5135 ft gave a mixture of oil and water.

After consideration of the electrical log and the results stated, the company decided to perforate an interval of 2 ft from 5128.5

to 5130.5 ft on the electrical log. They desired to avoid perforating lower than 5132 ft or higher than 5127 ft.

Three radioactive markers were placed in the formation at depths corresponding to 5000, 5036 and 5104 ft on the log. Thus, the marker at 5104 ft was 24½ ft above the top of the zone desired to be perforated, regardless of absolute depth measurements.

A comparison of the total depths measured during the electrical survey and the perforating operations is as follows:

TABLE 1—*Comparison of Total Depths Measured*

| Company | Electrical Survey, Total Depth, Ft | Gun Perforation, Total Depth, Ft |
|---|---|---|
| Schlumberger...... | 5140 | 5139 |
| Driller............ | 5142 | 5135 |

Since the difference of 4 ft in total depth during the perforation operation was in opposite sign to that which would occur if the bottom of the casing had settlings, there was a real difference in measurements. This was quite important as a difference of only 2 ft would miss the sand zone. Moreover, no reconciliation would be possible between the relation of the depths in the cased hole and the formation to be perforated without the use of a common reference point such as is provided by the radioactive marker at 5104 ft. on the electrical log.

Using the radioactive-markers to position the gun, the zone was perforated with eight shots from 5128.5 to 5130.5 ft. The well came in at 170 bbl per day with a gas-oil ratio of 400 to 1 on a 1⁹⁄₆₄-in. choke.

The example in Fig 5 also shows the use of radioactive markers for efficient placement of perforations.

Perforations were first made over the interval of 6502 to 6504 ft, using the marker at 6507.5 ft. Cement was then squeezed through these perforations to be certain of a seal-off from the water in the sand below this interval.

Perforations for production were then made in two sections at depths of 6478 to 6484 ft and 6486 to 6490 ft. The use of the radioactive markers allowed perforations within the shaly interval from 6484 to 6486 ft to be omitted.

The well came in with initial production of 180 bbl per day with a gas-oil ratio of 300 to 1 on a ⁹⁄₆₄-in. choke.

## Conclusion

The increased need for better depth discrimination, particularly for the deeper horizons, may be satisfied through the use of radioactive markers placed at chosen points in the wall of the borehole with respect to known strata.

Successful apparatus for the detection of such radioactive markers has been designed to be lowered in the borehole and withstand the highest temperatures and pressures encountered. The operation of the apparatus is safe, reliable and does not require any appreciable rig time.

Radioactive markers assist the production engineer in the solution of problems involving depth measurement met during testing, production and remedial workover jobs. These markers, being placed in a known relationship to a given geological horizon, permit the accurate positioning of tools in the cased well with respect to formations previously located by an electrical log, regardless of the depth of the formations from the surface. The markers also become part of the well record as primary reference points for future production problems throughout the history of a well, regardless of changes in reference points with respect to surface equipment.

## Acknowledgments

We wish to acknowledge the kind cooperation of F. M. Boykin, Jr., Carleton B. Wood, Lynn Oil Co. and others whose courtesy made available examples of actual radioactive-marker surveys in the field.

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