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# POLICY ISSUE
## (Information)

SECY-81-516

For: The Commissioners

From: William J. Dircks
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Subject: RISK ANALYSIS FOR PREVIOUSLY ABANDONED WELL-LOGGING SOURCES

Purpose: To respond to a Commission request for a risk analysis to determine if the proposed rule regarding abandonment procedures for irretrievable well-logging sources should be applied to well-logging sources that will have been abandoned prior to the effective date of the final rule.

Background: During Commission review of SECY 78-411, "Proposed Amendments to 10 CFR Parts 30 and 70, Requirements to be Accomplished in the Event of an Irretrievable Well-Logging Source," questions concerning the status of well-logging sources that had been previously abandoned were raised. The proposed regulations would require each licensee to provide for sealing each irretrievable source in place with a cement plug, setting a whipstock or drill deflection device at the top of the cement plug and mounting a permanent identification plaque at the surface of the well. Previously abandoned sources would not be subject to these requirements. The proposed amendments were published for public comment in the Federal Register on September 28, 1978 (43 FR 44547). The Commission asked for the rationale for not assuring that these procedures would be complied with for previously abandoned sources. The Commission felt that this rationale would be useful if future questions concerning the status of the sources should be raised.

Discussion: The staff has prepared the attached analysis of the additional radiological risk to public health and safety for the previously abandoned sources if accomplishment of the proposed procedures is not assured. The analysis shows that about 21 wells, of which only 10 are subject to NRC jurisdiction, may be

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affected, that the probability of actually striking a source in one of these wells is small, and that if a source were struck only 1.3 person-rem would result. The analysis concludes that the reduction in the radiological risk does not warrant the effort of assuring that the proposed procedures are accomplished for previously-abandoned sources.

NRC and Agreement State regulations require a licensee to report any lost radioactive source. As part of this risk analysis, the staff has been conducting a survey to determine what abandoned well-logging source incidents are noted in the records of the State regulatory agencies. This notation is considered to be an important safety factor since it will alert persons who reenter a well to the existence of a source downwell.

In addition, the NRC, as a policy matter, has not exercised regulatory authority over owners or operators of wells containing abandoned sources. The well owner or operator has not been considered to possess or use the source and, hence, not subject to the licensing requirements of 10 CFR Parts 30 and 70. However, under the proposed regulations, control will be imposed on the unlicensed well operator or owner through the licensed well-logging company by requiring the licensee to obtain advance agreement from the well owner or operator.

Conclusion: The reduction in radiological risk does not warrant the accomplishment of the proposed procedures for previously abandoned well-logging sources. However, the staff is completing the survey of previously abandoned well-logging sources and will assure that appropriate regulatory agencies are notified of the survey so that a proper notation can be made in the records. Finally, the analysis will be incorporated as supporting material in the paper to be sent to the Commission in December 1981 for final action on the well logging regulations.

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Executive Director for Operations

Enclosure:
Risk Analysis for Previously
Abandoned Well-Logging Sources

# RISK ANALYSIS FOR PREVIOUSLY ABANDONED WELL-LOGGING SOURCES

## SUMMARY

Over the past 20 years, 248 known incidents have occurred in which well-logging sources (cesium, cobalt, iridium, americium, plutonium, or radium) have been abandoned in wells. This risk analysis shows only a small radiological risk to public health and safety from the potential release of radioactive material due to damage from drilling into sources that have been abandoned. The reduction in that risk that would be effected by assuring that all previously abandoned sources have had the following procedures performed: (1) sealed in place with a cement plug, (2) a deflection device set at the top of the plug, and (3) a permanent identification plaque mounted at the surface of the well, as will be required by NRC's regulations, does not warrant the cost of obtaining such assurances. However, a survey to determine that all known incidents of abandoned sources have been properly noted in the records of the appropriate State oil and gas regulatory agency will be undertaken by the staff.

## SCOPE

The purpose of this risk analysis is to determine an incremental level of risk to public health and safety for previously abandoned well-logging sources if the sources are not sealed in place with cement, a deflection device is not set above the source, and a warning plaque is not mounted at the well head. The analysis was initiated during Commission review of proposed regulations in SECY-78-411, which would require those procedures. The requirements as a proposed rule were published in the FEDERAL REGISTER on September 28, 1978 (43 FR 44547). This analysis reviews the readily available information, such as

incident reports and notifications, for details concerning the total number of previously abandoned sources, the type and activity of the sources, the abandonment procedures used, the location of the wells, etc. From this information, a general risk level is estimated for previously abandoned well-logging sources.

## INTRODUCTION

Current well-logging operations involve the use of a well-logging tool. This tool is a heavy steel device from 2 to 6 inches in diameter and 6 to 20 feet long that contains measuring devices and in many cases sealed radioactive sources. A tool is worth several thousand dollars. The tool is lowered into and raised out of wells on a wireline that may be several thousand feet long for the purpose of obtaining a graph or log of information on the underground strata. Occasionally, the well-logging tool is pulled off or becomes disconnected from the wireline in the well. In many cases, the tool is unrecoverable and is left in the hole. A well in which a tool (and source) is lost may continue in production and other operations may be performed in that well.

The radioactive sources used in well-logging tools are normally less than 1 inch in diameter by 2 inches in length and, as such, the sources themselves constitute a very small volume compared to the entire logging tool volume. The sources most commonly used are cesium gamma sources and americium- or plutonium-beryllium neutron sources. Cesium sources are typically incorporated into an inorganic ceramic matrix that is sealed by firing at high temperature to form a hard, insoluble, and radiation and thermally-resistant pellet or slug. Americium or plutonium sources as oxides are typically mixed with beryllium powders; this mixture is pressed into pellets. Both types of sources are doubly encapsulated in stainless steel housings and are sealed by inert gas arc welding.

Typically, these sources will withstand pressures exceeding 25,000 psi and temperatures to at least 800°C. The sources will maintain their integrity under accident conditions that might be expected to occur during use.

The well-logging companies who use radiation sources subject to NRC or Agreement State licensing are licensed and regulated by the NRC or State. However, the well operator whose well is being logged is not regulated since the operator does not possess or use a radiation source. Thus, in those cases in which a source is abandoned in a well, the source is considered to be lost and "not possessed" and no license is required. As a result, wells operated with abandoned or irretrievable sources in them are not regulated by the NRC.

Under the proposed regulations, when a tool containing a source is lost downwell and all reasonable effort at recovery has been expended, the source will be called an irretrievable well-logging source. The proposed regulations would require each licensee to provide for sealing each irretrievable source in place with a cement plug, setting a deflection device at the top of the cement plug, and mounting a permanent identification plaque at the surface of the well, among certain other requirements. Some of these same requirements have been accomplished for sources lost downwell in the past. Placing a plaque on the well head and/or plugging the well with cement has been carried out since about 1965; however, deflection devices probably were not used extensively before the early 1970's. Another aspect of control required by the NRC is that a notation be made in the well records that are maintained by the State oil and gas regulatory agency when a radioactive source is abandoned downwell. The Commission presently implements procedures similar to the proposed procedures by license application requirements and by individual license conditions. Agreement States, in general, also have similar requirements in their regulatory procedures.

The primary purposes of the procedures mentioned above are the following: (1) sealing the source in place with a cement plug is meant to immobilize the source, to provide some measure of protection against abrasion and corrosion from fluids, and to provide resistance to the migration of radioactive material in the event that the integrity of the source capsule deteriorates at some future time; (2) setting a deflection device at the top of the cement plug is meant to deflect a drill bit away from the general area where the source is located in the event that some future drilling operations are performed in that particular location; and (3) mounting a permanent identification plaque at the surface of the well near the well head is meant to alert anyone planning to enter the well for additional operations to the existence of a source downhole. Although "permanent" is not defined in the requirements, this identification plaque is one aspect of continuing control and it is intended to indicate for many years that there is a sealed source in the well. Because a closed well has only a limited life before it begins naturally to close in, the life of the plaque may exceed the life of the well itself.

Since some of the above proposed requirements may not have been accomplished for all previously abandoned well-logging sources, the following analysis is intended to estimate the general risk to public health and safety resulting from these previously abandoned sources if these procedures are not accomplished or if assurance of their completion is not given.

## ANALYSIS

Well-logging sources have been abandoned downwell during at least the last 20 years. NRC and Agreement States' reports and records indicate that 248 occurrences have been documented during this period. Of this number, 57 known abandonments have occurred in non-Agreement States (NRC jurisdiction). Table 1 summarizes the known sources lost downwell in the U.S.

Some of the incidents in Table 1 involve both a gamma source (Ir-192, Co-60, or Cs-137 and a neutron source (Po-210, Am-421, Pu-239, or Ra-226). Of the 248 occurrences in Agreement and non-Agreement States, 104 involve the loss of neutron source while the remaining 144 involve the loss of gamma source only. The half-lives and approximate radiation levels associated with various radionuclides are shown in Table 2. Sources containing Po-210 and Ir-192 rapidly decay to insignificant activity because of their short half-lives and any of these sources that have been abandoned downwell have negligible activity levels remaining at this time. Cobalt 60 sources listed in Table 1 are in the millicurie range and have decayed through several half-lives and also present little hazard. Thus, the most significant sources in Table 1 are sources of Cs-137, Pu-239, and Am-241.

An abandoned well-logging source may present a hazard if the radioactive material should reach the surface. This situation is most likely to occur if a tool is broken and the source dislodged during a redrilling operation in which the drill bit actually strikes and ruptures the source. To ascertain whether these occurrences will create a problem, the likelihood that the source will be struck and brought to the surface must be considered.

To accomplish this, the probability that a reopened well will contain an abandoned unmarked or unplugged source must be studied; additionally, the probability of actually striking a source if such a source is found must also be calculated. The total probability then is the product of these two factors.

In the State of Texas, for example, the Texas Railroad Commission records 239,000 closed wells and 270,000 open wells for a total of 509,000 wells drilled for the period 1955-1980. The Commission estimates that 70% of the abandoned sources are in closed wells. The remaining 30% of the sources are in open wells and it is assumed here that the operators of open wells will be aware of the

presence of the sources. The Texas Railroad Commission further estimates that they currently issue about 2000 permits annually to enter closed wells, and that all but 8.4% of the number of irretrievable sources have been abandoned according to some procedure.

If the Texas values for open, closed, and reentered wells are extrapolated to the entire country, the following assumptions can be used:

1) 47% of the total number of wells are closed,

2) 0.8% of the number of closed wells are being reentered annually.

3) 70% of the abandoned sources are in closed wells, and

4) 8.4% of the number of abandoned sources in closed wells have not been abandoned according to some procedure.

For the entire country, there are approximately $2.45 \times 10^6$ open and closed wells. Records indicate that 248 wells with abandoned sources exist nationwide, 57 of which are in NRC jurisdiction. In all but 21 cases, it is expected that well-logging operations have instituted abandonment procedures designed to alert future redrilling operations to the presence of a source downwell.

If random entry of the wells is assumed, a Poisson model may be used to calculate the probability of entering a closed well with an abandoned unmarked or unplugged source. From Appendix 1, Chart 1 the probability of finding a well with such a source is about 0.11. This factor does not include a probability for actually striking a source if a well with a source is drilled.

This aforementioned factor must necessarily be small. No cases of abandoned sources being drilled through as a result of reentering a well have been recorded. This situation may be partially explained by the following facts.

Logging tools represent a considerable financial investment. They are not abandoned without serious attempts at recovery when they become detached from the wireline. The fact that the tools are unrecoverable usually implies that they are out of reach of fishing tools, typically off to one side.

Few tools with sources are lost in cased holes because they are relatively easy to recover if the tools become unattached. Thus, most sources are abandoned in uncased holes. In many cases, uncased holes "heal" after a number of years, that is, the hole closes in and ceases to exist. Whether or not a hole closes in is determined to a great extent by the composition of the substrata at the drill site.

If a well was originally drilled in hard rock such as is found in midcontinent U.S., casing is generally unnecessary, except when the borehole passes through a potable aquifer, because the subsurface formations are very stable. In this situation, if the well is left uncased and reentered at a later date, the probability that the drill bit will follow the original bore hole is about 1.0, i.e., almost certainty, and may thus strike a tool in its path.

Conversely, because of the instability of the substrata in coastal areas, uncased holes invariably heal. Even in cased holes, the shifting of the substrata can cause the borehole to shift from its original geometry. In this situation, the drill bit tends to wander away from the original shaft and, at thousands of feet, the probability of actually hitting a source is virtually zero.

Since most of the well drilling is performed in coastal areas of Texas, Louisiana, Florida, Mississippi, etc., the average probability of actually striking an abandoned source is very small. However, for the purpose of this report, a conservative value a 0.50 will be used. Calculations in Appendix 1, Chart 2,which are based on this value, indicate a probability of about 0.05 of actually striking abandoned unmarked or unplugged source in a well.

If a source is struck and ruptured, it may present a radiation hazard only if the radioactive material within the source reaches the surface. The primary pathway for a source to reach the surface is in the contained and relatively

small volume of drilling mud associated with further drilling operations in a particular well that contains an abandoned source. Since this pathway leads to the highest possible concentrations of radioactive material in substances that could reach the surface, calculations are made below to assess the potential radiation hazard.

Although no records of accidental rupture during redrilling operations exist, several sources have been ruptured during fishing operations. In these cases, no more than 30-40% of the radioactive material was released from the encapsulation. The remaining source either remains intact downwell or is brought intact to the surface where it is deposited in the drilling mud pit away from the crew on the well head, and thus reduces that radiation hazard.

The worst case then would be to assume that an abandoned source (and the well-logging tool) is completely demolished in a short time by a drill bit or milling tool, dispersed, and brought to the surface in a small volume of drilling mud. Particles from the radioactive source could range in size from small particles to pieces of the source. Drilling mud has a special consistency to entrain particulates. The mud is continuously cycled from the surface down the hole and back to the surface at the drilling rig. Radiation exposure of drill-rig operator personnel could occur when the source in the small volume of mud first reaches the surface. Within a short time, however, the source would become dispersed throughout the mud as it is recycled. Estimated exposures to personnel are shown in Table 3. It is assumed that personnel are exposed for 30 seconds each time the mud is recycled and that the mud is recycled 100 times. Personnel consists of two operators at the well head within 1 meter of the mud, two operators on top of the drilling rig within 5 meters of the mud, and one operator in the power plant within 10 meters of the mud. Intervening shielding that would reduce the exposure is neglected.

Neutron shielding by the mud, which is aqueous in nature, has also been neglected. A simple inverse square law is used to determine the dose rate at the various operator positions using the dose rates at 1 meter given in Table 3. Well-logging sources can include both a gamma source and a neutron source. From Table 3, a worst case would consist of a source composed of Cs-137 and Am-241-Be. For this worst case, the total population exposure would be 1.3 person-rem. The likelihood of ingesting any significant amount of the material in the mud is negligible.

In summary, the small incremental increase in the radiological risk that results from not assuring that the proposed procedures are accomplished for previously abandoned well-logging sources does not warrant accomplishment of the procedures for the following reasons:

(1) NRC and Agreement States' Programs and licensee procedures have minimized the number of sources abandoned without regard to some procedure.

(2) The probability of unknowingly finding a well with an abandoned unmarked or unplugged source and actually striking the source is about 0.05. The probability of hitting more than one of these sources is 0.003.

(3) The radiological impact of the release is comparable with the exposure allowed for a low probability release of radioactive material from products containing exempt quantities.

(4) NRC has no regulatory authority over wells containing previously abandoned sources.

## FURTHER ACTION

The staff believes that an important safety factor associated with abandoned well-logging sources is the notation of the incident that is made or filed in the records of the State oil and gas regulatory agencies. Later, if a particular well is reentered, the well history will alert the new well operator to the existence of an abandoned source. Since about 1975, the NRC by standard license condition has required the licensee to report how a notation of an event of an irretrievable well-logging source will be placed in the public records. A small effort then could assure that these notations have been made for the incidents documented in NRC records. Therefore, the staff is planning to conduct a survey to determine that all of these incidents of abandoned well-logging source are properly noted in the records of the appropriate State oil and gas regulatory agency. At the same time this survey is being conducted, information can be compiled on any additional incidents of abandoned well-logging sources that may be contained in State records and not contained in NRC records. This action would also update information on the total number of abandoned well-logging incidents.

TABLE 1

SUMMARY OF ABANDONED RADIOACTIVE WELL LOGGING SOURCE DATA IN THE UNITED STATES

| STATE | TOTAL AFFECTED WELLS | ISOTOPE | | | | | | | | | | | | | | | | | | TOTAL[d] REPORTED SOURCES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H-3 | | Co-60 | | Cs-137 | | Ra-226[e] | | U[a] | | PuBe | | AmBe | | PoBe | | RaBe[e] | | |
| | | NO. | AMT.[f] | NO. | AMT.[f] | NO. | AMT.[f] | NO. | AMT.[f] | NO. | AMT.[f] | NO. | AMT.[f] | NO | AMT[f] | NO | AMT[f] | NO | AMT[f] | |
| ALASKA | 2 | | | | | 1 | 1.5 | | | | | | | | | | | | | 1[c] |
| CALIFORNIA | 15 | | | | | 12 | 13.0 | | | | | | | 4 | 30 | | | | | 16 |
| FLORIDA | 2 | | | | | 2 | 3.5 | | | | | | | 2 | 20.5 | | | | | 2 |
| KANSAS | 6 | | | | | | | 1 | .025 | | | 1 | 5 | 3 | 13 | 1 | 3.9 | | | 4 |
| LOUISIANA | 81 | 4 | 36 | 6 | .016 | 59 | 83 | 1 | .0001 | 3 | - | 9 | 67 | 24 | 357 | | | | | 106 |
| MISSISSIPPI | 1 | | | | | 1 | 2 | | | | | | | | | | | | | 1 |
| NEW MEXICO | 8 | | | | | 3 | 6 | 1 | .0005 | | | | | 4 | 21 | | | | | 8 |
| OKLAHOMA | 12 | | | 1 | .0004 | 10 | 12 | | | | | 1 | 5 | 2 | 21 | | | | | 14 |
| TEXAS | 83 | 1 | 7 | 3 | .326 | 38 | 55 | 15 | .66 | 2 | - | 7 | 35 | 29 | 226 | | | | | 95 |
| WYOMING | 10 | | | | | 8 | 12 | | | | | | | 4 | 43 | | | | | 12 |
| OTHER STATES[b] | 28 | | | 1 | .025 | 16 | 19.7 | | | | | 5 | 23 | 6 | 44.9 | 1 | | 1 | 7 | 30 |
| TOTAL | 248 | 5 | 43 | 11 | 0.367 | 150 | 207.7 | 18 | 0.91 | 5 | - | 23 | 135 | 78 | 706.4 | 2 | 3.9 | 1 | 7 | 293 |

[a] These sources are depleted uranium "sinker bars". Although they weigh several tens of pounds each, their radioactivty is quite low, on the order of a few millicuries.

[b] These sources are exclusively those reported to the Nuclear Regulatory Commission.

[c] The source characteristics were not reported for one of the two reported losses.

[d] Some abandoned logging tools contained more than one source so the value in the "total reported sources" column may exceed the value in the "total affected wells" column.

[e] Radium is not regulated by the NRC

[f] Amount in Curies

TABLE 2 RADIATION CHARACTERISTICS OF SOME WELL-LOGGING SOURCES

| Source | Radioactive half-life | Gamma-ray exposure rate at 1 meter from bare 1 Ci source | Neutron dose rate at 1 meter from bare 1 Ci source |
|---|---|---|---|
| | | mr/hr | mrem/hr |
| Co-60 | 5.26Y | 1320 | - |
| Cs-137 | 30Y | 330 | - |
| Ir-192 | 74.4d | 480 | - |
| Po-210 Be | 138d | 0.1 | 2.77 |
| Ra-226 Be | 1620Y | 910 | 14.43 |
| Pu-239 Be | $2.4 \times 10^4$Y | 3.7 | 2.00 |
| Am-241 Be | 458Y | ~2.5 | 2.20 |

TABLE 3 CALCULATED DOSES TO OPERATORS FROM UNINTENTIONAL DRILLING INTO ABANDONED WELL-LOGGING SOURCES

| Source | Strength Ci | Gamma dose (mrem) | | | Neutron dose (mrem) | | |
|---|---|---|---|---|---|---|---|
| | | Well head | top of rig | Power plant | Well head | top of rig | Power plant |
| Co-60 | 0.2 | 220 | 8.8 | 2.2 | - | - | - |
| Cs-137 | 2 | 550 | 22 | 5.5 | - | - | - |
| Ir-192 | 2 | 800 | 32 | 8.0 | - | - | - |
| Po-210 Be | 4 | 0.33 | 0.013 | 0.0033 | 9.2 | .37 | .01 |
| Ra-226 Be | 2 | 1500 | 16 | 15 | 24 | .97 | .24 |
| Pu-239 Be | 5 | 15 | .62 | .15 | 8.3 | .33 | .08 |
| Am-241 Be | 16 | 33 | 1.33 | 0.33 | 29.3 | 1.17 | .29 |

## APPENDIX 1

## METHOD FOR CALCULATING PROBABILITIES

The basic probability, P, that a randomly selected closed well has an abandoned unmarked or unplugged source in it is given by the following expression:

$$P = \frac{\text{number of closed wells with abandoned unmarked or unplugged sources}}{\text{total number of closed wells}}$$

If n wells are reentered per year and if the reentry is independent of whether or not the well has a source in it, the expected number of reentered wells that contain a previously abandoned source would be simply nP. The following data is used:

(1) $2.45 \times 10^6$ wells have been drilled,

(2) 47% of the total number of wells are closed,

(3) 0.8% of the number of closed wells are being reentered annually,

(4) 248 wells with abandoned sources exist nationwide.

(5) 70% of the abandoned sources are in closed wells,

(6) 8.4% of the number of irretrievable sources have not be abandoned according to some procedure, and may thus be unknowingly struck.

(7) 50% of the unknown abandoned sources may actually be struck during redrilling operations.

Using these values, the expected number of reentered wells that contain a previously abandoned unmarked or unplugged source is 0.12. If random entry of the well is assumed, a Poisson distribution function may be used to calculate the

probability of entering a closed well with an unmarked or unplugged abandoned source. This probability can be calculated from the following equation:

$$\rho_m = \frac{(nP)^m e^{-nP}}{m!}$$

where:

m = number of wells with abandoned sources

nP = expected number of reentered wells with an abandoned source

$\rho_m$ = probability for finding m wells with an abandoned unmarked or unplugged source

Using the value, nP = 0.12, the following chart is produced:

CHART 1

PROBABILITY OF REENTERING A WELL WITH AN ABANDONED UNMARKED, OR UNPLUGGED SOURCE

| m | $\rho_m$ |
|---|---|
| 0 | 0.887 |
| 1 | 0.106 |
| 2 | 0.006 |
| 3 | <0.001 |

The probabilities, $\rho'_m$, of unknowingly entering a well and actually striking the source are given by the expressions

$$\rho'_{m\neq 0} = \rho_{m\neq 0} \times \rho_s$$

and

$$\rho'_{m=0} = 1 - \sum_{m=1}^{n} \rho'_m$$

where

$\rho_m$ = is as defined earlier

$\rho_s$ = probability of actually striking a source

= 0.5

Thus the probabilities that an abandoned source will be unknowingly struck in a reentered well are given in Chart 2.

CHART 2

PROBABILITIES FOR STRIKING A SOURCE IN A REENTERED WELL

| m | $\rho'_m$ |
|---|---|
| 0 | 0.943 |
| 1 | 0.053 |
| 2 | 0.003 |
| 3 | <0.001 |