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SAND96-2629 • UC-900
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Printed January 1997

Wellbore Enlargement Investigation: Potential Analogs to the Waste Isolation Pilot Plant During Inadvertent Intrusion of the Repository

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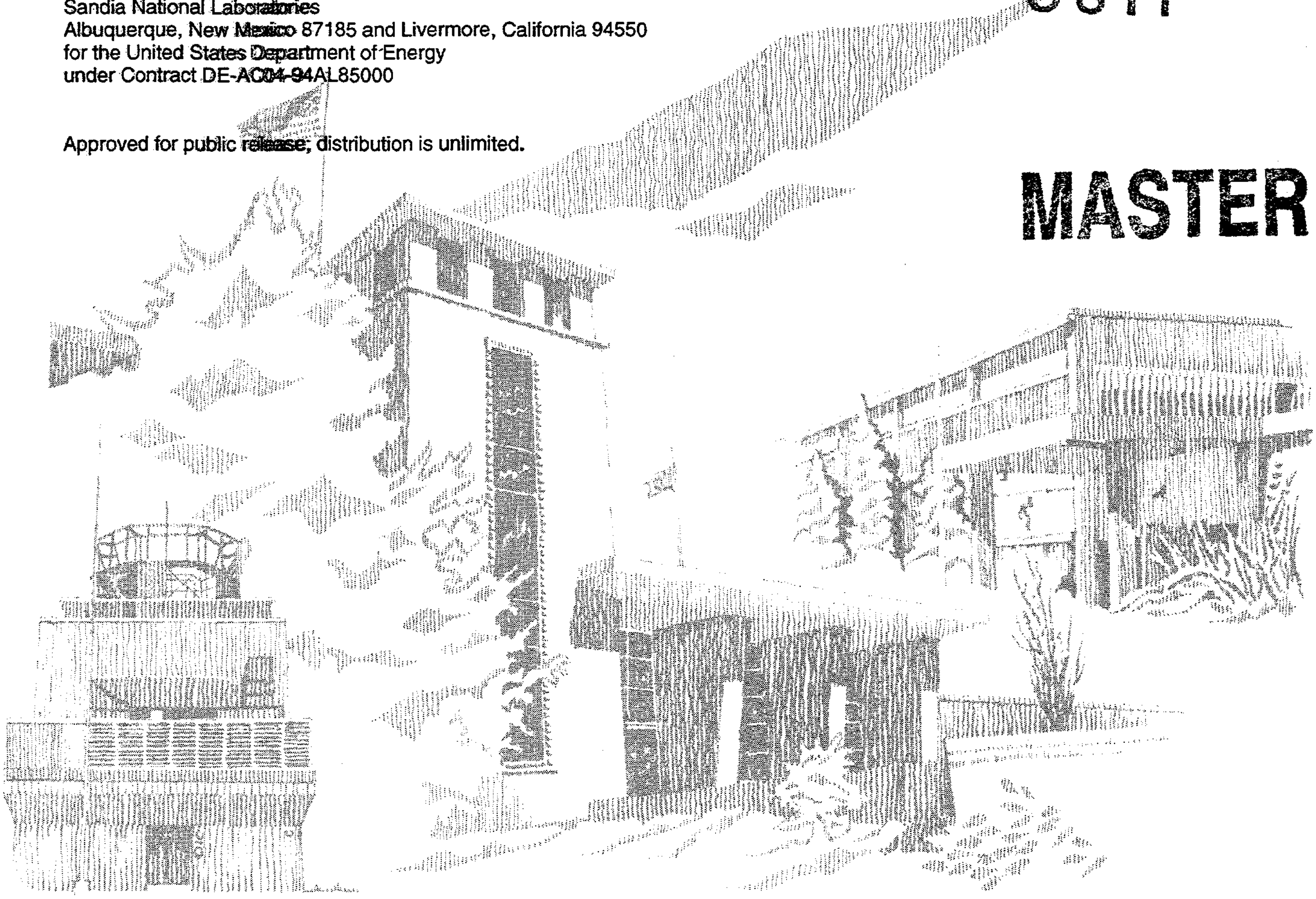
for the United States Department of Energy
under Contract DE-AC04-94AL85000



SF2900Q(8-81)

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Distribution
Category UC-900

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ABSTRACT

This study involved the evaluation and documentation of cases in which petroleum wellbores were enlarged beyond the nominal hole diameter as a consequence of erosion during exploratory drilling, particularly as a function of gas flow into the wellbore during blowout conditions. A

primary objective was to identify analogs to potential wellbore enlargement at the Waste Isolation Pilot Plant (WIPP) during inadvertent human intrusion. Secondary objectives were to identify drilling scenarios associated with enlargement, determine the physical extent of enlargement, and establish the physical properties of the formation in which the enlargement occurred. No analogs of sufficient quality to establish quantitative limits on wellbore enlargement at the WIPP disposal system were identified. However, some information was obtained regarding the frequency of petroleum well blowouts and the likelihood that such blowouts would bridge downhole, self-limiting the surface release of disposal-system material. Further work would be necessary, however, to determine the conditions under which bridging could occur and the extent to which the bridging might be applicable to WIPP. In addition, data on casing sizes of petroleum boreholes in the WIPP vicinity support the use of a 12-1/4 inch borehole size in WIPP performance assessment calculations. Finally, although data are limited, there was no evidence of significant wellbore enlargement in any of three blowouts that occurred in wellbores in the Delaware Basin (South Culebra Bluff Unit #1, Energy Research and Development Administration (ERDA) 6, and WIPP 12).

EXECUTIVE SUMMARY

The primary objective of this study was to identify analogs to potential wellbore enlargement at the Waste Isolation Pilot Plant (WIPP) and predict the greatest likely wellbore enlargement that could occur at WIPP during inadvertent intrusion by exploratory drilling. Data in the petroleum industry that could be used to quantify the extent of borehole enlargement during a blowout were limited, and a quantitative prediction of the greatest likely wellbore enlargement could not be developed at this time. Other interesting data from the petroleum industry were discovered, however, that provide qualitative insights into the typical causes, frequency, and consequences of petroleum-related blowouts.

A blowout can occur when the in situ pressure of the drilled formation becomes greater than the hydrostatic head generated by the drilling fluid in the wellbore. Data on blowouts in Canada suggest that only a small number of petroleum boreholes experiencing influx of formation fluids (kicks and blows) become actual blowouts with significant fluid flow to the surface and also suggest that a petroleum-related blowout is considered a low-probability event. Data from studies of U.S. (the Gulf Coast and Outer Continental Shelf) and Canadian petroleum operations in the mid-1980s indicate that blowouts occurred in approximately 2 to 9 wells per 10,000 drilled in these areas. These studies also indicate that the frequencies of blowouts occurring in petroleum-bearing formations have tended to decline over time, suggesting ongoing improvements in drilling and blowout control techniques. Moreover, virtually all petroleum blowouts have occurred while drilling into gas-bearing formations; about half occurred in exploratory wells, and the other half occurred in development wells. Additionally, data in one report indicate that 70 to 80% of the blowouts in wells drilled in Texas and Louisiana were controlled within five days.

Finally, WIPP performance assessment calculations for the 1996 compliance certification application (CCA) used a single borehole size of 12-1/4 inches for exploratory wells. Preliminary data gathered in the course of this investigation suggest that this borehole size is reasonably representative of the majority of petroleum boreholes that have been drilled within a 10-mile radius of WIPP. Note, however, that the results of this investigation cannot be used to directly corroborate the Cuttings results for the 1996 WIPP CCA since the CCA calculations used different mechanisms for blowout release than those investigated in this study.

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CONTENTS

TABLES

FIGURES

ACRONYMS

BOP	Blowout Preventer
CCA	Compliance Certification Application
ERCB	Canadian Energy Resource Conservation Board
GIS	Geographic Information System
NMBMMR	New Mexico Bureau of Mines and Mineral Resources
OCD	New Mexico Oil Conservation Division
OCS	Outer Continental Shelf
SFL	Spherically-Focused Log
SPM-2	Systems Prioritization Method - Second Iteration
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

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1. INTRODUCTION

This study involved the evaluation and documentation of cases in which petroleum wellbores were enlarged beyond the nominal bit size (hole diameter) as a consequence of erosion from a blowout[1] during exploratory drilling. The primary objective was to identify analogs to potential wellbore enlargement at the Waste Isolation Pilot Plant (WIPP) to predict the greatest likely wellbore enlargement that might occur at WIPP during inadvertent intrusion by exploratory drilling. Secondary objectives were to identify drilling scenarios associated with enlargement, determine the physical extent of enlargement, and establish the physical properties of the formation in which the enlargement occurred. It was assumed that future drillers at the WIPP site would use drilling practices consistent with those currently in use, and that drillers would be unaware of the WIPP repository. While enlargement can occur for many reasons, this task focused on cases of blowout resulting from drilling into gas-filled formations. While the focus of the study was on petroleum wells, erosion associated with coal gas production and other erosion research was also considered.

The approach following this introduction describes the specific subtasks of the study and sets forth the criteria that were used to identify the analogs. The next section discusses the results of the research. The report closes with a conclusions section.

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[1] A *blowout* is defined as "[a] complete loss of control of a flow of fluids from a well. [C]ontrol can only be regained by the installation of equipment to shut in or kill the well [i.e., operation of the blowout preventer (BOP) system], or by drilling a relief well" (ERCB, 1990).

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2. APPROACH

Specific subtasks for this study were to:

1. Investigate the likelihood and causes of blowouts and the typical control procedures.

2. Examine documented blowout occurrences to identify analogs to wellbore enlargement at WIPP. Blowout occurrences both in proximity to the WIPP site and outside the WIPP area were examined. A blowout was considered to be in proximity to WIPP if it occurred in the Delaware Basin in southeastern New Mexico. See Figure 1 for a map showing the Delaware Basin and surrounding areas. Key criteria used to determine the degree to which a documented blowout occurrence would be an appropriate analog to wellbore enlargement at WIPP appear in Section 2.1.

3. Review current drilling practices near WIPP that could affect the likelihood or severity of a blowout. This involved the development of a Geographic Information System (GIS) database to analyze information on petroleum wells in the vicinity of WIPP within the Salado formation. This information included well category, depth, and casing size. An analysis of the casing size data on petroleum wells near the WIPP site was also performed.

2.1. Criteria for Analogs to WIPP for Wellbore Enlargement

Key criteria used to determine the degree to which a documented blowout occurrence would be an appropriate analog to wellbore enlargement at WIPP during inadvertent intrusion by future exploratory drilling are described below. Note that, although the criteria focus on petroleum wells, erosion associated with coal gas production was also considered.

1. Whether the wellbore enlargement is unexpected, as would occur in an exploration of a largely undrilled area or when drilling into new, untested horizons. This could include drilling in a developed field if the operator is unfamiliar with the area.

2. Whether the formation is gas-filled.

3. The availability of information on the quantitative characteristics of the formation (such as permeability, porosity, degree of consolidation, presence of fractures, clastic or carbonate matrix, initial reservoir pressure, drilling depth, availability of open-hole geophysical logs and/or core data).

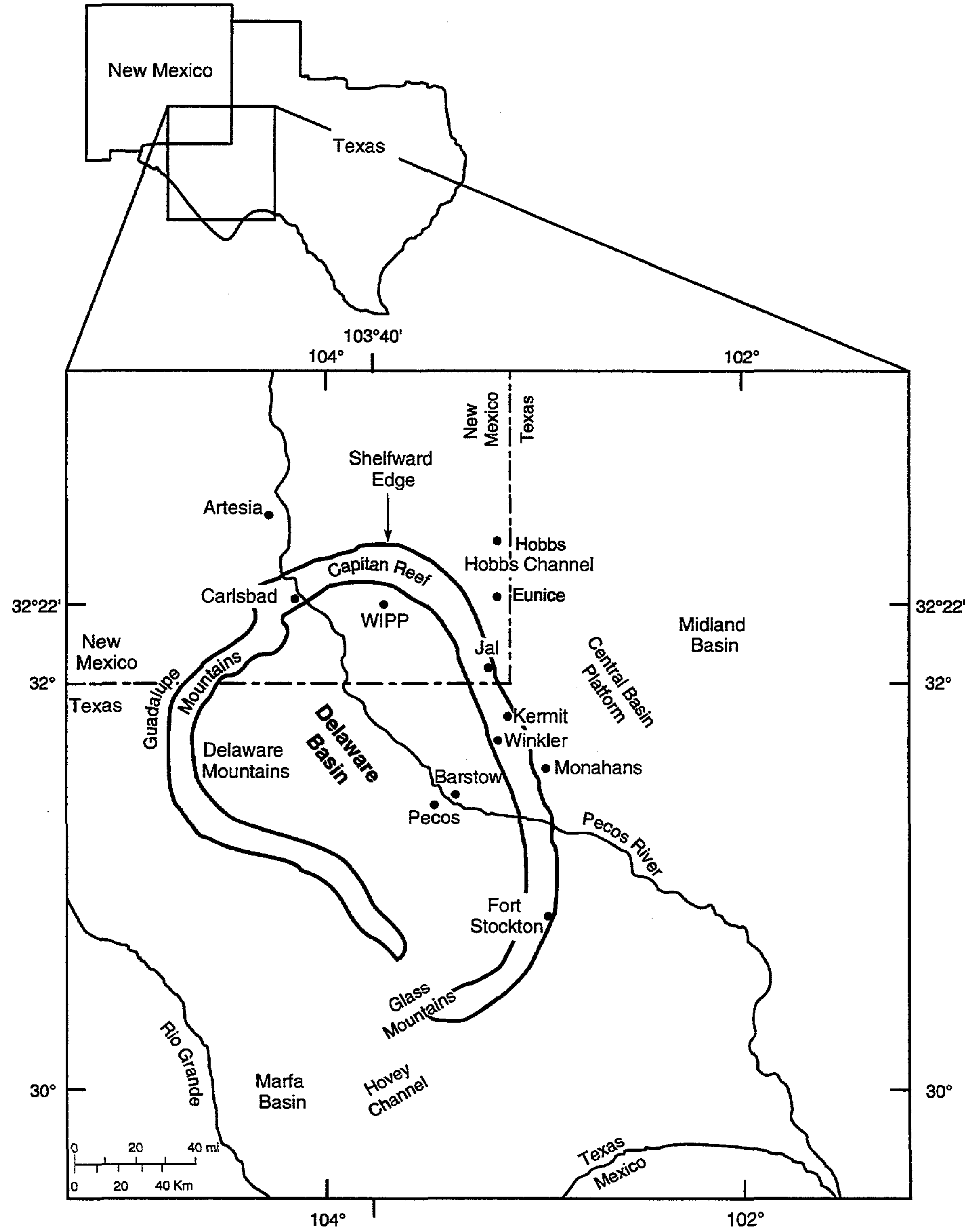

Figure 1. Map of the Delaware Basin and surrounding areas showing the location of the WIPP site.

4. The availability of information on drilling characteristics, such as casing program and mud type and density.

5. Proximity of the wellbore to the WIPP site; whether the wellbore is in the Delaware Basin.

6. Similarity of the overall geologic strata and general scenario to that associated with exploratory drilling at the WIPP site, which has entailed drilling through bedded salt to reach oil or gas in deeper horizons.

7. Capability of discussing the case in the open literature: some data may reside in confidential industry files.

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3. RESULTS

This section presents the results of investigations into 1) the likelihood and causes of blowouts and the procedures used to attempt to control them; 2) blowouts in proximity to the WIPP site; 3) blowouts outside the WIPP area; 4) current drilling practices near the WIPP site that could affect the likelihood or severity of a blowout; 5) and coal gas production and other erosion research.

3.1. Likelihood, Causes, and Control of Blowouts

3.1.1. Frequency of Blowouts

In general, a petroleum blowout is considered a low-probability event (Golob and McShea, 1981). Blowouts are dangerous and costly to the driller, and therefore every attempt is made to avoid them. As stated by Santos (1989), "[B]lowouts are catastrophic events....[M]illions of dollars are spent just bringing a blowing well under control."

Golob and McShea (1981) report that a U.S. Geological Survey (USGS) study of 7,553 wells drilled in the Outer Continental Shelf (OCS) found that 30 blowouts occurred over an eight-year period, a rate of five blowouts per year per 10,000 wells drilled. Blowout frequencies in 1984 (Hughes et al., 1990) were approximately two per 10,000 wells in Louisiana and nine per 10,000 in Texas.[2] The number of blowouts also declined in each state after 1978 when mandatory well control training became a requirement. Hughes et al. (1990) also reported approximately 27 blowouts per 10,000 wells in the OCS for this same period, suggesting that there is significantly greater risk involved with drilling in the OCS. Given the significant differences between deep, offshore drilling (typical of drilling in the OCS) and onshore drilling conditions in and around WIPP, however, OCS data are likely to be overly conservative and unrealistic if applied directly to WIPP.

USGS data on blowouts in oil and gas wells drilled in the OCS between 1971 and 1978 indicate that 56% of blowouts occurred in exploratory wells and 44% occurred in development wells; all of the blowouts occurred in gas wells (Golob and McShea, 1981). Hughes et al. (1990) found similar results in 425 Gulf Coast blowouts (predominantly in Texas, Louisiana, and the OCS) occurring between 1960 and 1985: 93% of blowouts in shallow wells (less than 3,280 feet) were in gas-bearing formations.

The Canadian Energy Resource Conservation Board (ERCB) published reports between 1989 and 1993 containing information on several blowouts in Canada, but no data on wellbore enlargement were provided. Several of the cases list quartzite or sandstone as the formation type, but very little information on reservoir characteristics appears in these reports. ERCB (1994) reported a blowout frequency of two blowouts per 10,000 wells drilled in Alberta, Canada, in

[2] Areas of Texas and Louisiana are noted for shallow, high-porosity, unconsolidated gas-bearing sandstones, which can cause blowouts.

1993; this is roughly equivalent to Louisiana blowout rates in 1986 (Hughes et al., 1990). Interestingly, the ERCB (1993) also reported a 10-year average of five blows[3] per 10,000 wells drilled and a 10-year kick rate of 37 per 1,000 wells drilled. Thus, the ERCB data suggest that only a very small portion of petroleum boreholes experiencing influx of formation fluids (kicks and blows) become actual blowouts with significant fluid flow to the surface.

3.1.2. Causes and Control of Blowouts

A blowout can occur when the in situ pressure of the drilled formation becomes greater than the hydrostatic head generated by the drilling fluid in the wellbore. The blowout occurs when the drilling system (including whatever portion of the wellbore is cased) cannot mechanically control fluid flow from the formation. Blowouts are of two types, surface and underground (Moore, 1975). A surface blowout is one in which downhole fluids flow from a subsurface reservoir to the surface. Reservoir fluids reach the surface through the drill string, through the annulus between the drill string and any casing, or between the casing and the formation. An underground blowout is one in which reservoir fluids flow from a formation uphole or downhole and into another formation.

Rocha (1993) describes the differences between a kick and a blowout and provides some detail on the steps an operator would generally take to attempt to control the kick and then (if unsuccessful) control the blowout.[4] The blowout might be "shut in" mechanically if the operator thought that a behind-casing failure could be avoided (for example, by having cased a significant portion of the wellbore and thus created a good bond between the casing and the upper formations). Alternatively, the operator might choose to divert (i.e., vent) the flow to the surface through the drill string, relieving the downhole pressure, if there is concern about casing failure. (Note: Rocha (1993) reports a U. S. Minerals Management Service study in which diverter systems failed 46% of the time when used to control gas flow.) A blowout might also be brought under control by weighting up the mud system and attempting to "kill" the flow. Finally, very serious blowouts may require control through the drilling of relief wells that are drilled from a safe surface location to a bottom hole target very close to the blowout zone; mud is then pumped downhole to kill the blowout in the vicinity of the first borehole.

According to Hughes et al. (1990), the formation fluid that caused most Gulf Coast wells to blow out was gas. Hughes et al. (1990) found that the most common operations associated with blowouts were 1) tripping (bringing the drill bit off the bottom and back to the surface) for 27% of Texas wells and 34% of shallow wells and 2) drilling (57% of Louisiana wells). It is important to note that the frequency of blowouts has decreased over the years, and that blowout prevention and control technology is expected to continue to improve (Hughes et al., 1990).

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[3] A *blow* is a flow of fluids (gas, oil, water, mud, etc.) to the atmosphere from a well, which can be or is brought under control in a very short time-frame by closing equipment (control is gained almost immediately). A *kick* is any entry of water, gas, oil, or other formation fluid into the wellbore. Therefore, a blowout is an uncontrolled blow or kick. The term *blow* is not widely used in the U.S.

[4] Further detail on BOP systems and well control techniques is available in the International Association of Drilling Contractors *Drilling Manual* (IADC, 1992).

According to the ERCB in Calgary, the leading cause of blowouts in Alberta, Canada, from 1984 to 1993 was human error (e.g., failing to maintain hydrostatic pressure on the formation). Other causes of blowouts include equipment failure (e.g., damaged valves), inadequate well design (e.g., insufficient mud density), or encountering an abnormally pressurized formation.

3.1.3. Self-Limiting Nature of Some Blowouts

Downhole bridging[5] is mentioned in numerous articles as a means by which blowouts can be self-limiting. Interestingly, Hughes et al. (1990) found that 51% of shallow blowouts, 55% of OCS blowouts, and 57% of Louisiana blowouts (of the 37% that were brought under control in one day) were self-limited by bridging off. Hughes et al. (1990) also found that 52% of Texas blowouts, 37% of Louisiana blowouts, and 49% of OCS blowouts were under control within one day. Eighty percent of Texas blowouts and 71% of Louisiana blowouts were controlled within five days. Golob and McShea (1981) describe the Funiwa 5, a development well in the Niger River delta that took three weeks to bridge off.

3.2. Blowouts in Proximity to WIPP

An information search was conducted on blowouts in the Delaware Basin in southeastern New Mexico. This search included investigation and documentation of blowouts that occurred during oil and gas exploration and during WIPP site exploration and characterization. The full report appears in Appendix A (D.W. Powers, "Blowouts During Oil and Gas Exploration in Southeastern New Mexico," letter report to L. R. Hill, July 24, 1995).

In his report, Powers first described the blowouts that occurred while drilling wellbores Energy Research and Development Administration (ERDA) 6 and WIPP 12 during WIPP site exploration and characterization, when pressurized brines were encountered in the Castile Formation. ERDA 6 was not equipped with a BOP, and a blowout occurred that lead to an uncontrolled discharge of brine. The wellbore diameter did not change significantly as a result of the incident. A blowout also occurred in WIPP 12, and the wellbore reportedly did enlarge somewhat in the lower Salado, but Powers noted that the enlargement was "not significant." Note that a blowout in a pressurized brine formation is not an accurate analogy to a blowout in a gas formation.

Powers also identified a blowout that occurred during gas exploration at the South Culebra Bluff Unit #1 in 1978, approximately 16 miles west-southwest of the WIPP site. This blowout did not appear to produce significant enlargement in the zones examined.[6] The blowout occurred

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[5] Bridging has been described (Gatlin, 1960) as a process by which particles travel into a void space and accumulate to create a mechanical barrier to flow thereby sealing off the void space. Gatlin discusses the process mainly in terms of designing systems to seal off formations experiencing an unwanted loss of drilling mud through fractures, but the mechanism is applicable to blowouts as well.

[6] Numerous geophysical logging runs were made in this borehole, but only the September 14, 1978, runs occurred in a portion of the borehole exposed to erosion during the blowout and were made at a time before the well was worked over. There are numerous minor problems with the geophysical logs, but it appears that the borehole was not significantly enlarged *in the zones examined*. Note in particular the zone between the depths of 11, 250 feet and approximately 11,620, which is within

in the Atoka gas formation at a depth of 11,769 feet and continued for 11 days before being brought under control on January 14, 1978. The well was allowed to produce from the blowout zone, which exposed the open hole from the base of the casing (at a depth of 6,355 feet) to erosion for approximately eight months. The Atoka produced at an initial rate of approximately 50 million cubic feet of gas per day, a very substantial rate. A total of approximately four billion cubic feet of gas was produced from the hole over a five month period that ended in June 1978. Table 1 provides basic reservoir properties of the Atoka formation.

Table 1. Atoka Reservoir Information (from the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) Reservoir Database included in the Atlas of Major Rocky Mountain Gas Reservoirs (NMBMMR, 1993))

Reservoir Characteristic	Values
Average porosity (percent)	4.5
Minimum porosity (percent)	5.0
Maximum porosity (percent)	8.5
Temperature (degrees Fahrenheit)	178.5
Initial reservoir pressure (psia)	9,664
Initial reservoir pressure gradient(psi/ft)	0.71

Powers (Appendix A) also searched the New Mexico Oil Conservation Division (OCD) files for the period 1991 through 1995, but found no corresponding records of blowouts in southeastern New Mexico.

In summary, data from wells in the Delaware Basin in southeastern New Mexico indicate that even rather prolonged blowouts did not seem to result in significant wellbore enlargement.

3.3. Blowouts Outside the WIPP Area

The investigation turned to potential analogs outside the Delaware Basin where shaley, unconsolidated sands that could better approximate the behavior of degraded waste might exist. Several prominent individuals in the petroleum industry were contacted by telephone in an attempt to obtain information on blowouts outside the WIPP area. Nineteen knowledgeable individuals in industry (including Amoco and Mobil), academia (including Louisiana State University, Colorado School of Mines, and the University of Texas), the Gas Research Institute, and various consulting firms were interviewed. Five of the individuals contacted are considered experts in the area of blowouts. A list of these telephone contacts appears in Appendix B. The information obtained is summarized below.

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approximately 150 feet of the blowout interval feet (see Run Two of the Dual Laterolog Micro–Spherically-Focused Log (SFL) in Appendix A).

None of the individuals who were contacted had ever obtained (or were aware of) any wellbore erosion or enlargement data associated with blowouts. Included among the contacts were Dr. Dave Powley and Dr. John S. Bradley, both retired from Amoco Production Company; these two individuals spent their careers working on research related to blowouts, and both individuals are widely published. Dr. Tony Podio of the University of Texas Department of Petroleum Engineering, one of the coauthors of a report on 425 Gulf Coast blowouts, also had not seen wellbore erosion or enlargement data. Dr. Adam Bourgoyne of Louisiana State University, a prominent figure in the field of petroleum drilling with 20 years of experience, was not aware of any wellbore erosion data. Similarly, Dr. Bill Mitchell of the Colorado School of Mines was not aware of any wellbore erosion or enlargement data.

Most of the individuals contacted believed that wellbore enlargement resulting from a blowout would be minimal. When drilling an oil or gas well, some upper portion of the borehole would typically be cased. A blowout would only erode the lower (uncased) portion of the wellbore unless it occurred between the casing and the formation. The most likely scenario is that the wellbore would collapse, leaving a smaller, not a larger, hole. Gas would escape from the wellbore, and solids would settle to the bottom of the collapsed hole. Dr. Adam Bourgoyne noted that gas is far less erosive than liquid. Brian Tarr of Mobil Exploration stated that the enlargement would depend on how strong the rock is; if the formation doesn't collapse, for example, it is probably also strong enough to not erode.

Some of the individuals contacted were not sure to what extent a wellbore might erode and noted that borehole enlargement would be difficult or impossible to measure because the hole is usually "lost" during the attempt to control the blowout. That is, the fluid (drilling mud) used to control the blowout destroys the productive capacity of that portion of the hole experiencing the blowout. Moreover, wellbore erosion data is generally not available, according to Steve Melzer of the University of Texas, because it is generally too dangerous to run caliper logs after a blowout.[7]

According to Roger Anderson of the OCD in Santa Fe, New Mexico, blowouts that were not associated with a serious accident or that did not impact the ground water supply are not required to be reported. He also stated that information on wellbore enlargement would not be reported to the OCD.

It is clear from these interviews that quantitative information on wellbore enlargement resulting from blowouts is not commonly available in the petroleum industry. There is a consensus that caliper log data (an initial focus of the investigation) does not generally exist for downhole zones that have undergone blowout. Moreover, many of the individuals contacted expressed concern that, even if caliper logs did exist, the borehole size information would be limited to the maximum extended diameter of the caliper arms used, which might be less than the diameter of the enlarged borehole diameter. Under these circumstances, the maximum limits of enlargement would remain unknown.

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[7] See Section 3.2, for an example of a blowout for which both before- and after- caliper logs were available (South Culebra Bluff Unit #1).

Other than the investigations by Powers, time limitations precluded detailed investigation of wellbores outside the Delaware Basin.

3.4. Current Drilling Practices

3.4.1. Casing and Cementing Standards

Controls on current drilling practices near the WIPP site are more stringent than in many areas of the state because WIPP is located in proximity to an area of large potash reserves known as the Carlsbad Potash District (Barker and Austin, 1993). Oil and gas wells drilled in the Potash District must meet special casing and cementing standards to protect the salt strata (including the Salado and Castile formations) from water, oil, and gas intrusions. A typical producing oil well in the vicinity of WIPP has three casing strings, as shown in Figure 2. Casing strings are hung from the surface, and the annular space between the casing and the hole is filled with cement, providing multiple barriers that limit both the likelihood of kicks and the potential loss of fluids during secondary production or disposal operations.

3.4.2. GIS/ArcView Database and Analysis

Information on well category, depth, and casing size for petroleum wells drilled through the Salado formation was obtained from the commercially available Dwights/Petroleum Information Discover Scout database. The petroleum well information was downloaded to a Windows Excel spreadsheet and then transferred into an ArcView GIS database containing data associated with surface characterization boreholes for the WIPP Project. (See Appendix C for a description of the development of the GIS database.) The GIS was used to generate information on well location distribution, category, depth, and casing size in the form of maps, statistical plots, and tables. The results of this effort are described in Appendix C. Considerable efforts were made to verify data on the WIPP characterization boreholes. The petroleum data, however, have only been verified at a preliminary level.

3.4.2.1. DISTRIBUTION OF WIPP CHARACTERIZATION SURFACE BOREHOLES AND PETROLEUM INDUSTRY WELLS

Figure 3 shows the distribution of surface boreholes drilled for the WIPP site characterization and petroleum industry (oil and gas) wells (including exploratory, production, disposal, injection, and abandoned wells) within a 10-mile radius of WIPP. The distribution pattern of the petroleum wells reflects their groupings within approximately twelve established industry fields, shown in Figure 4. For example, the cluster of wells to the northwest of the WIPP land withdrawal boundary in Figure 4 is associated with the Cabin Lake field. The cluster of wells aligned from north to south just east of WIPP is within the Livingston Ridge field. The WIPP surface boreholes, drilled to characterize the general geology, stratigraphy, and hydrology of the WIPP site, are fairly well distributed within and around WIPP. Note that Figure 3 shows several

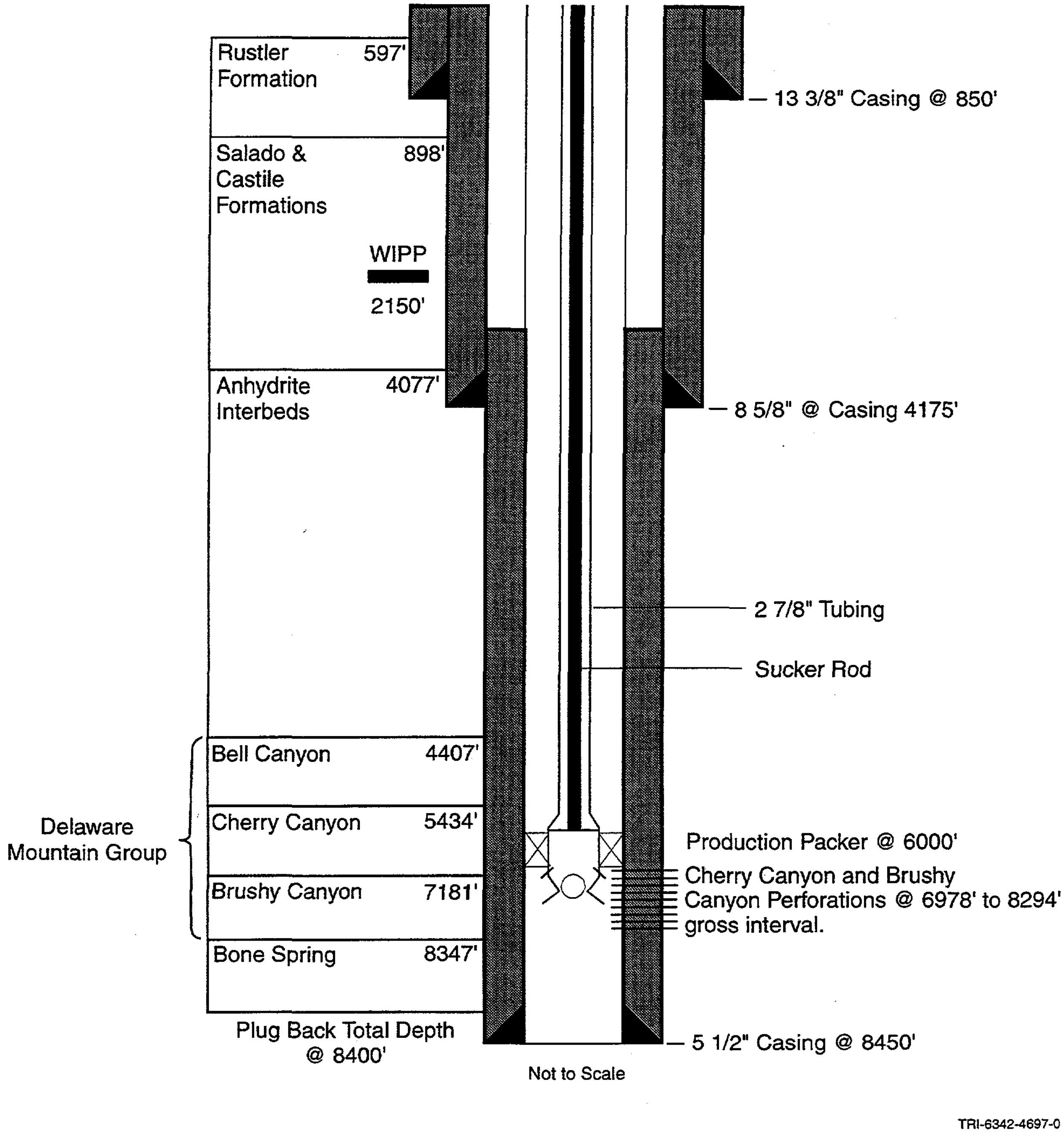

Figure 2. Schematic profile of typical producing oil well in the Livingston Ridge/Lost Tank field. (Depths indicated are approximate and are in feet below ground level.)

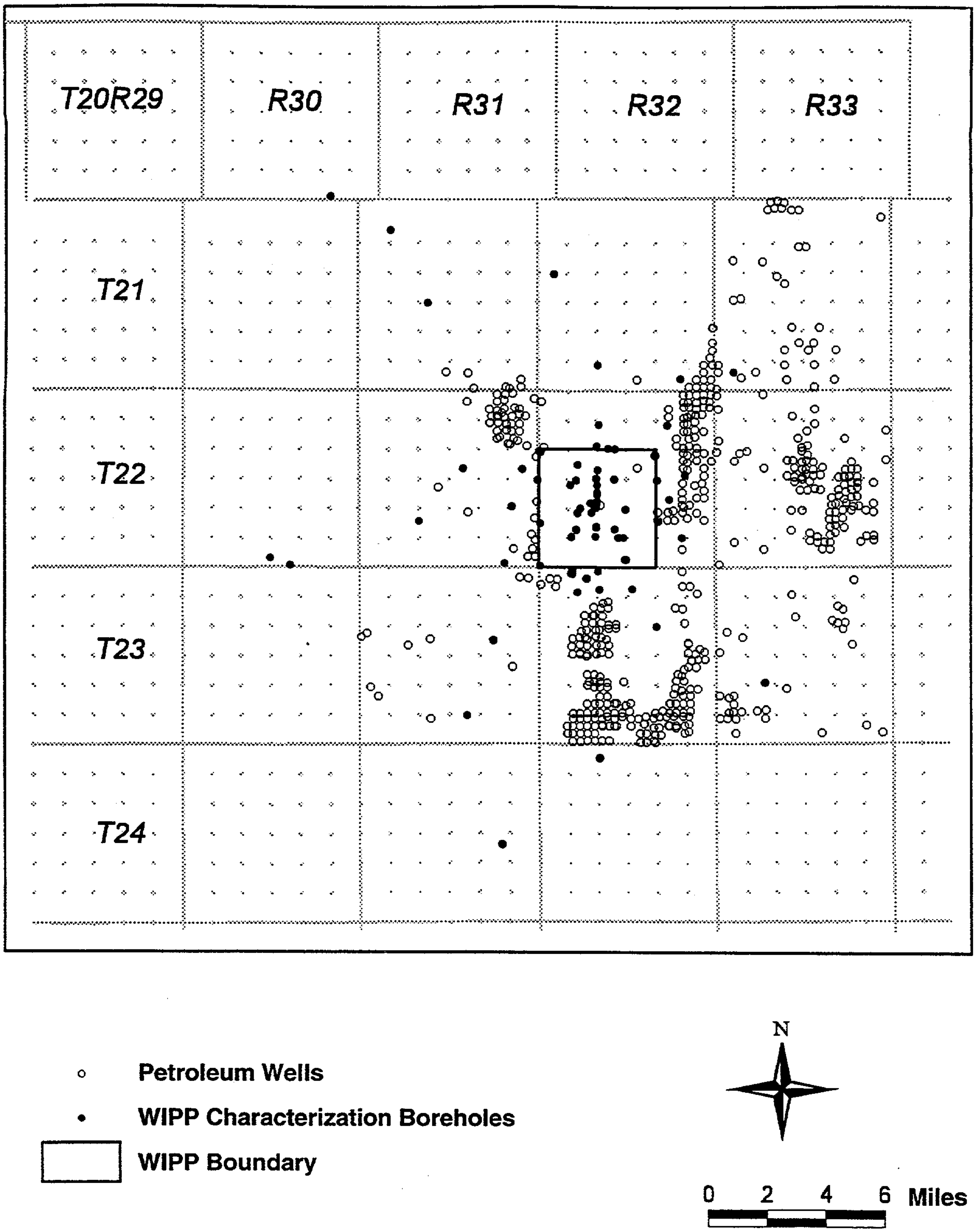

Figure 3. Distribution of WIPP characterization boreholes and petroleum wells (including exploratory, production, disposal, injection, and abandoned wells) within a 10-mile radius of WIPP.

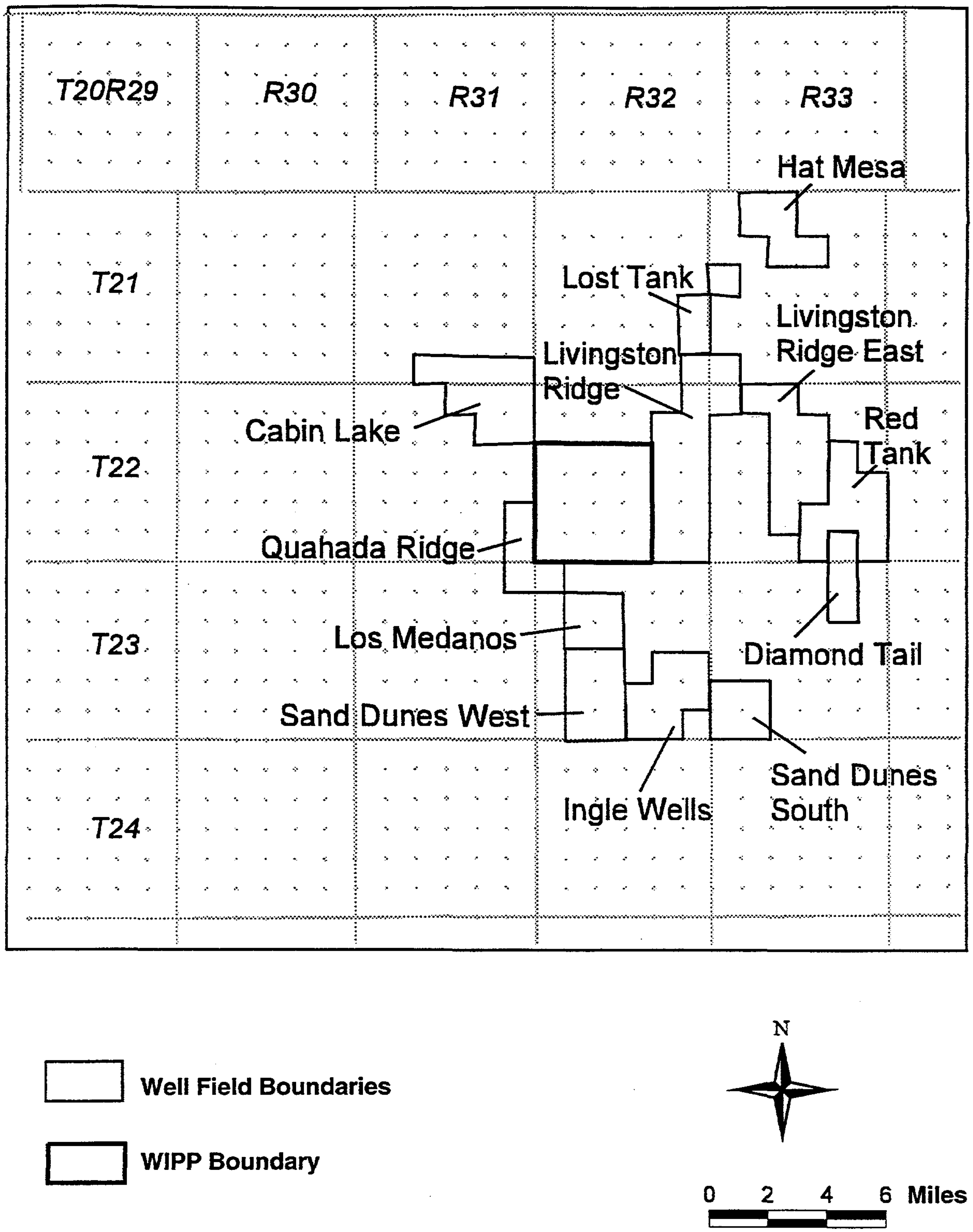

Figure 4. Established petroleum (oil and gas) fields in the WIPP vicinity.

characterization boreholes outside the WIPP land withdrawal area. These were drilled to investigate the presence or absence of specific geologic features or processes (e.g., regional faulting, anticlinal structures, breccia pipes, and salt dissolution in the rocks near the proposed repository) that might affect the performance of WIPP.

The distribution of oil- and gas-producing wells in the WIPP vicinity is shown in Figure 5. (Note that Figure 5 does not include other petroleum-related wells such as dry and abandoned, disposal, injection, plugged and abandoned, and shut-in wells.) Gas is produced in deeper formations (such as the Morrow and Atoka formations, about 14,000 ft deep) than oil, which is typically produced in the Delaware Mountain Group formations (such as Cherry Canyon and Brushy Canyon, about 7,000 to 8,300 ft deep) in the Livingston Ridge/Lost Tank field.

Figure 6 shows the distribution of the wells classified as injection and disposal wells. The three injection wells, located within the Cabin Lake, Livingston Ridge, and Livingston Ridge East oil fields, respectively, are those where brine or other waters are injected into oil-producing formations to stimulate production. Disposal wells are used by the various petroleum companies for discarding brine and other waters generated during the pumping of oil reserves. Disposal wells may be shared by several petroleum companies operating within one or more of the industry petroleum reservoir fields (see Figure 4).

3.4.2.2. CASING SIZES

Mean borehole diameters and casing sizes (nominal internal diameter) were calculated from data from 548 well records in the Dwights/Petroleum Information Discover Scout database. (See analysis in Appendix C.) The database included information on petroleum (oil and gas) exploratory, production, disposal, and injection wells. The analysis showed that the most typical casing diameter for wells drilled within a 10-mile radius of the WIPP is 8.625 inches (71.5% of all 548 well records) (see Figure 7). Three hundred and sixty-one of these are oil wells—88% of all oil wells in the database (n = 409) (see Figures 8 and 9). This casing size is approximately equivalent to a 12-1/4 inch wellbore in the Salado Formation at a depth of approximately 2,150 feet (the depth of the WIPP repository). Wellbore casing sizes identified in this study were not uniform. Rather, the casing sizes were not normally distributed, with a minimum of 5.5 inches and a maximum of 13.375 inches.

Performance assessment calculations for the 1996 WIPP compliance certification application (CCA) used a single borehole size of 12-1/4 inches for exploratory wells; this is consistent with the data from Dwights database for oil wells within a 10-mile radius of the WIPP. Note, however, that the results of this investigation cannot be used to directly corroborate the Cuttings results for the 1996 WIPP CCA since the CCA calculations used different mechanisms for blowout release than those investigated in this study.

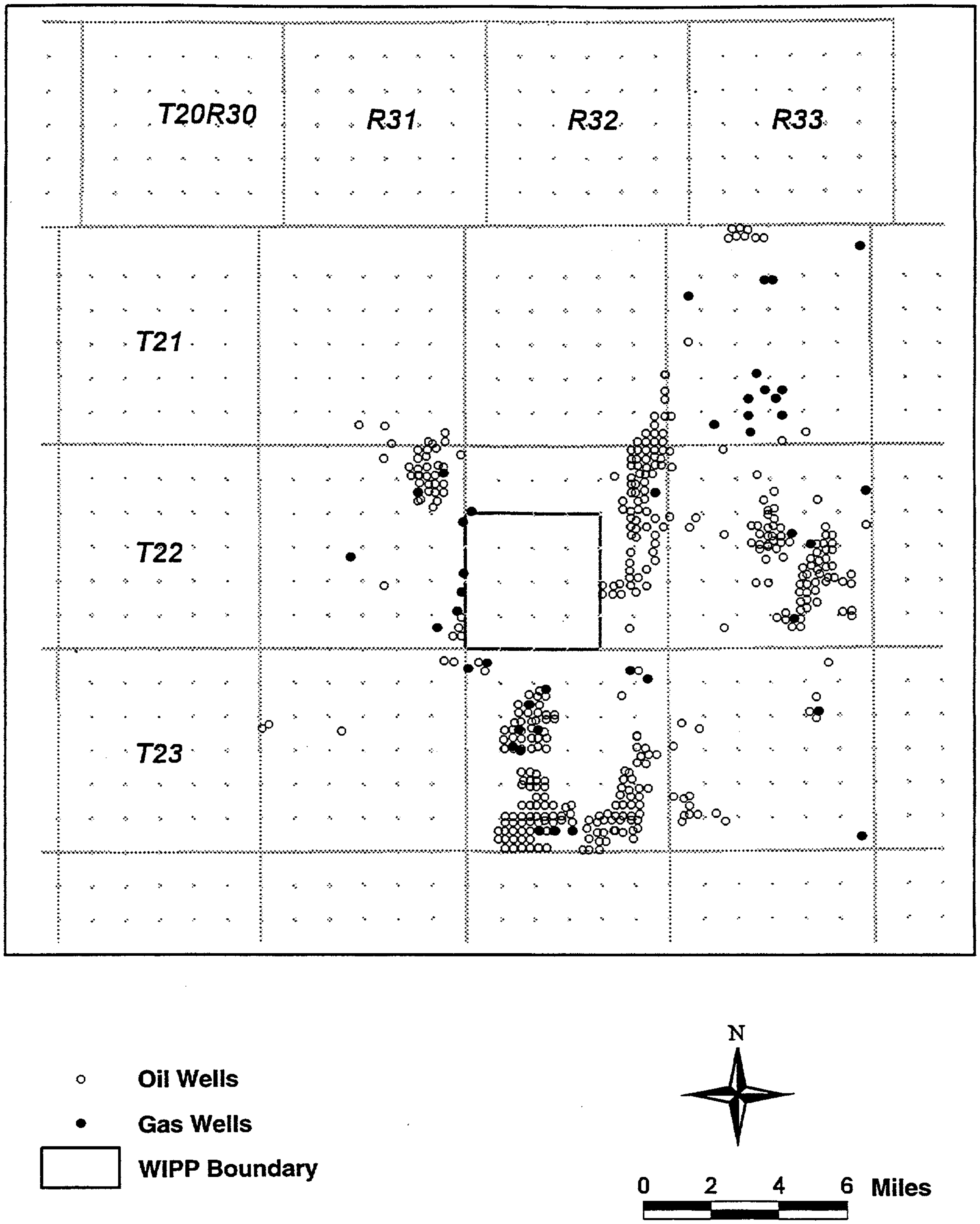

Figure 5. Distribution of oil- and gas-producing wells drilled in the WIPP vicinity (not including exploratory, disposal, injection, and abandoned wells) (based on information from Dwights/Petroleum Information Discover Scout database).

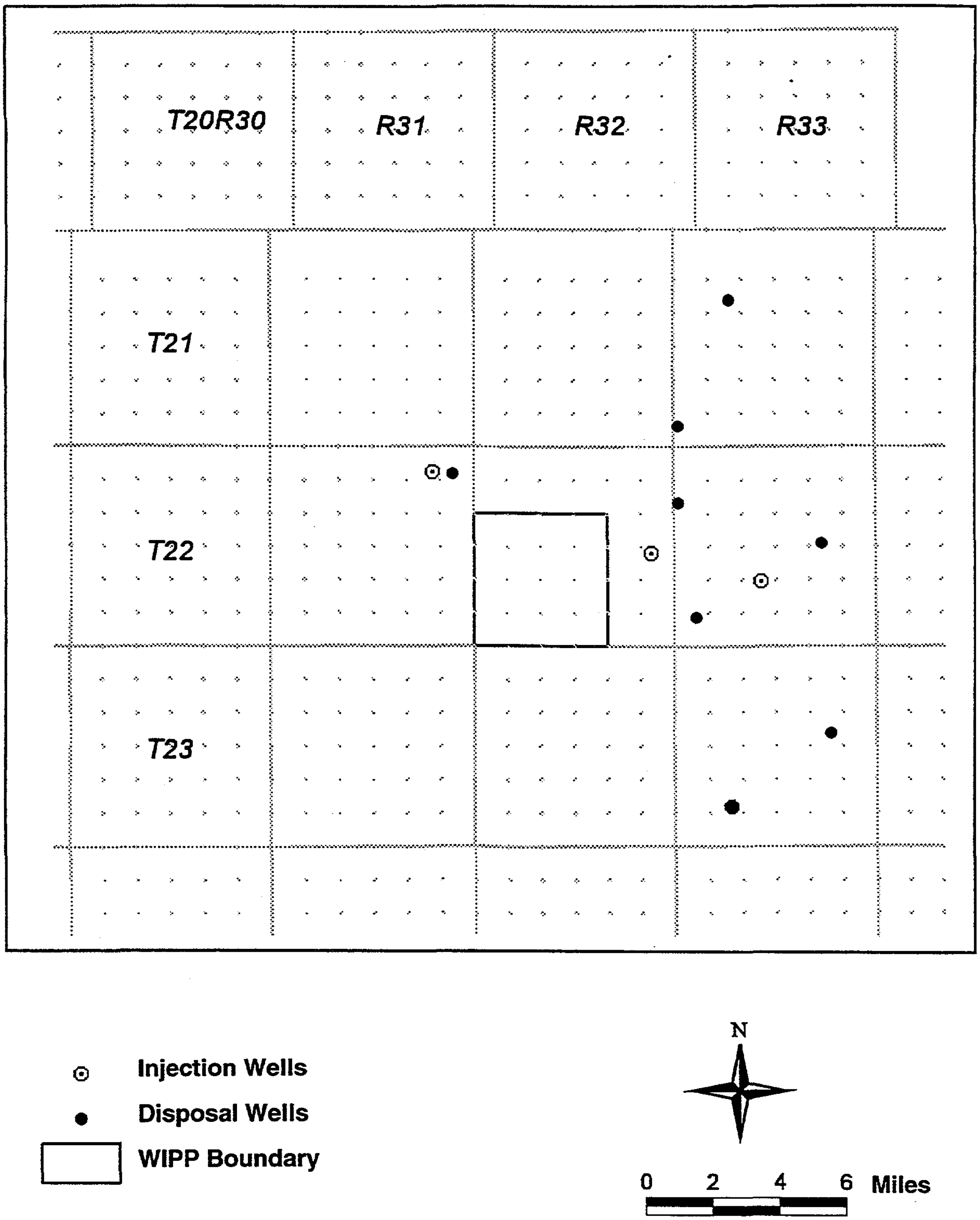

Figure 6. Distribution of water disposal and injection wells in the WIPP vicinity associated with petroleum production (based on information from Dwights/Petroleum Information Discover Scout database).

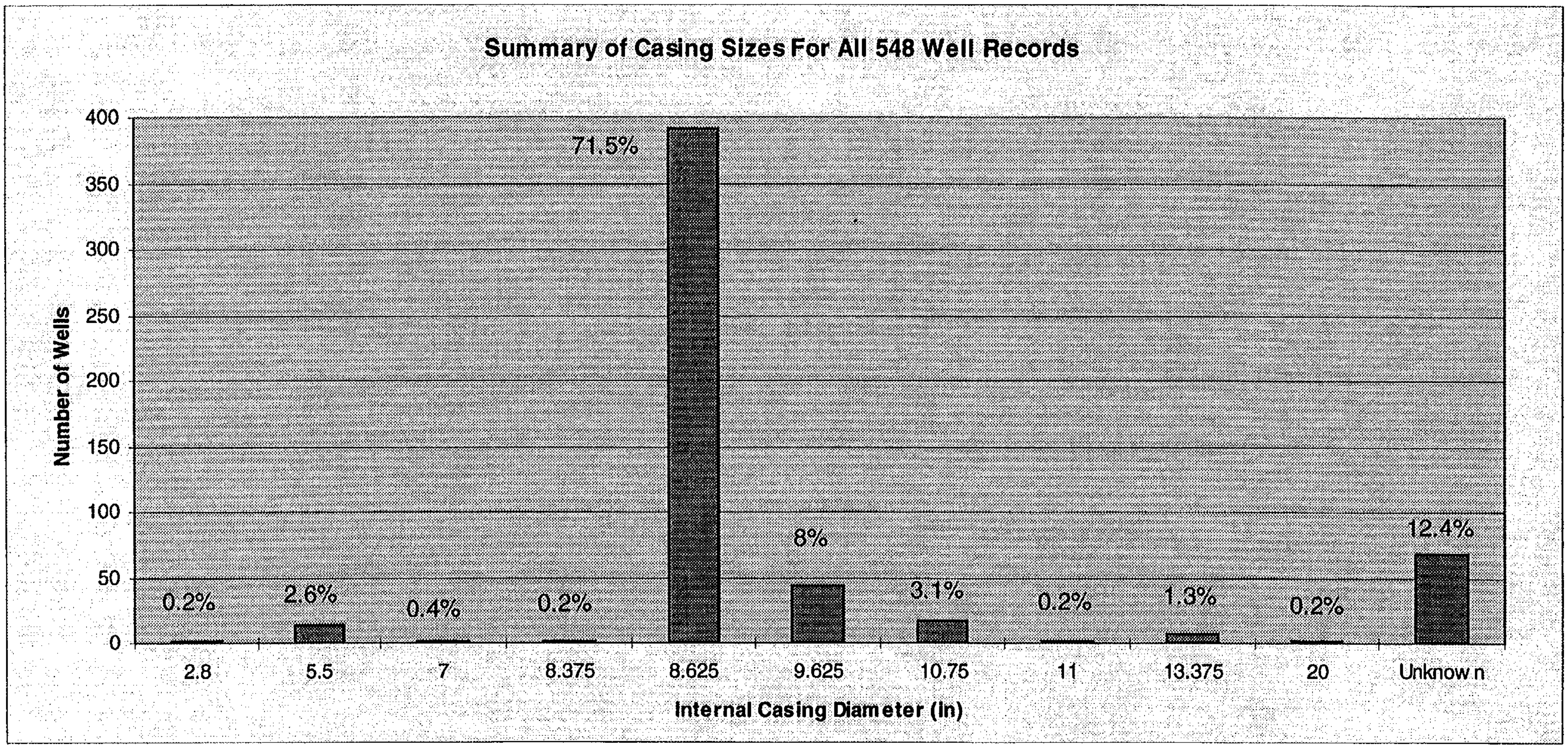

Figure 7. Summary of internal casing diameters for all 548 well records (based on information from Dwights/Petroleum Information Discover Scout database. casing sizes for all 548 well records).

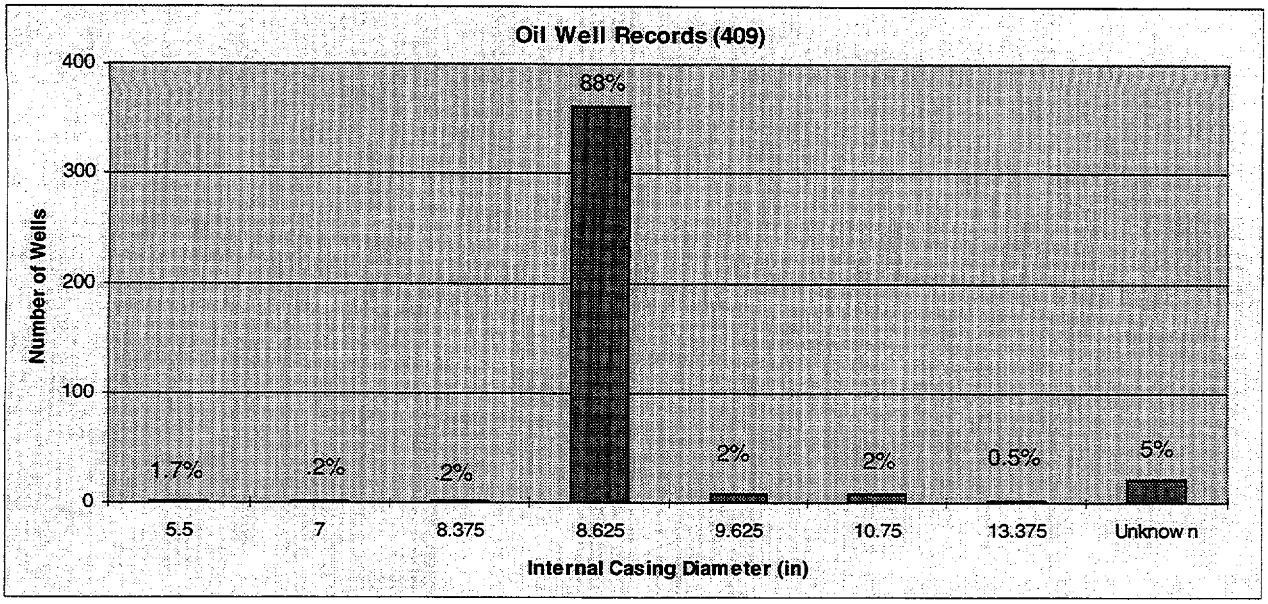

Figure 8. Summary of internal casing diameters for oil wells within a 10-mile radius of WIPP (based on information from Dwights/Petroleum Information Discover Scout database).

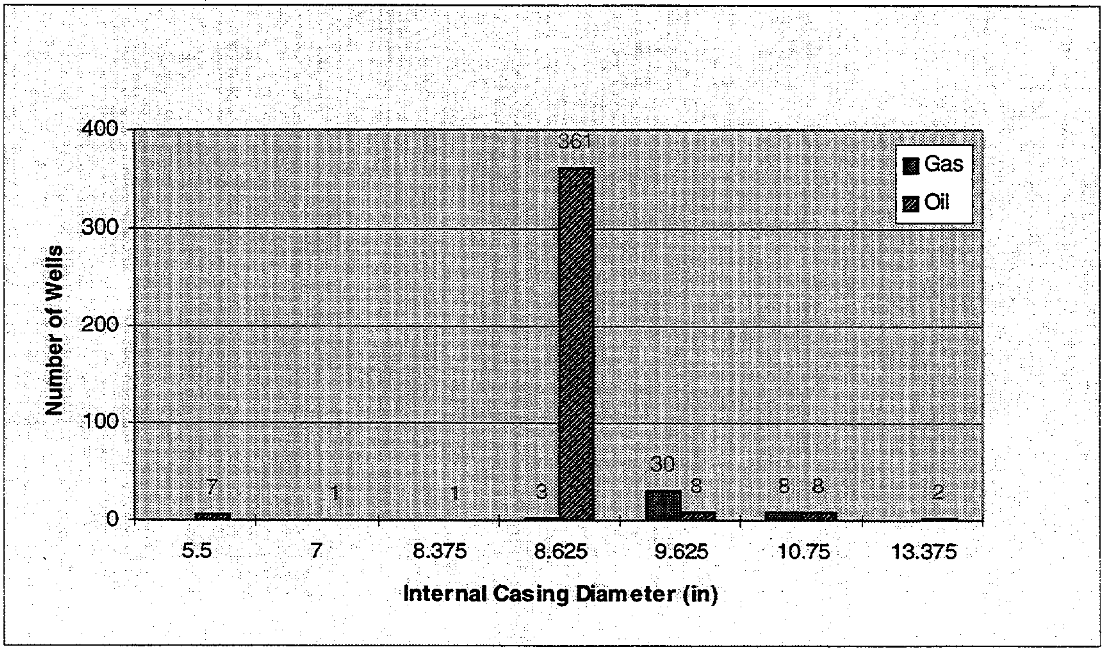

Figure 9. Summary of internal casing diameters for oil and gas wells with known casing size (based on information from Dwights/Petroleum Information Discover Scout database). (Note that the data for oil casing size 5.5 are questionable for six of the seven wells indicated.)

3.5. Coal Gas Production and Other Erosion Research

References on erosion during gas production from coal seams (Mavor, 1991a; Mavor et al., 1991; Mavor, 1991b; Mavor et al., 1992; and Mavor and Logan, 1994) were investigated. Although research in this area initially seemed promising, none of the material provided information that was directly relevant to this investigation.

More promising information was found in Rocha (1993), who mentions the potential for research in civil engineering on erosion of river bottoms to provide insights into erosion under blowout conditions. Kamphuis and Hall (1983) investigated the erosion of cohesive materials by unidirectional currents. Rocha also describes similar work by Gaylord (1983) on erosional effects of fluid flow on clay-containing materials. Gaylord (1983) showed that erosion first increases slowly with increasing fluid velocity and then increases rapidly after some critical velocity is reached. Further work may be warranted to address the implications of these studies.

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4. CONCLUSIONS

Petroleum analogs of sufficient data quality for establishing limits on wellbore enlargement during blowout at the WIPP disposal system resulting from inadvertent human intrusion by exploratory drilling were not identified in this investigation. However, qualitative information was obtained that provides some basis for concluding that petroleum blowouts can bridge downhole, self-limiting the blowout duration. Further work would be needed, however, to investigate the conditions under which bridging might occur and the extent to which this phenomenon might be applicable to predicted conditions in the WIPP disposal system. In addition, data gathered during the course of this investigation support the use of a 12-1/4 inch borehole for WIPP performance assessment calculations for the 1996 compliance certification application (CCA). Note, however, that the results of this investigation cannot be used to directly corroborate the Cuttings results for the 1996 WIPP CCA since the CCA calculations used different mechanisms for blowout release than those investigated in this study.

Finally, based on a review of three blowouts that occurred in the Delaware Basin, particularly at the South Culebra Bluff Unit #1, significant wellbore enlargement was not found.

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APPENDIX A

D. W. POWERS, "BLOWOUTS DURING OIL AND GAS EXPLORATION IN SOUTHEASTERN NEW MEXICO," LETTER REPORT TO L. R. HILL, JULY 24, 1995

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Dennis W. Powers, Ph.D.

Consulting Geologist
HC 12 Box 87
Anthony, TX 79821

Business: (915) 877-3929
Home: (915) 877-2417
Fax: (915) 877-3929

Environmental Geology
Evaporite Geology
Frontier Sulfur

07/24/95

FAX: (505) 848-0881 17 pages total

L.R. Hill
Department 6747 M.S. 1341

Dear Les:

This is a letter report on my initial findings on the data available from some sources on blowouts during oil and gas exploration in southeastern New Mexico.

Blowouts During Oil and Gas Exploration in Southeastern New Mexico

Summary

Purpose

The general purpose of examining blowouts is to determine the likely events that should be considered for drilling scenarios, conditions that are conducive to blowouts, and drillhole enlargements from these releases.

Objectives

There were several objectives for this activity:

- summarize some data on WIPP drilling of pressurized brine and gas reservoirs in the Permian Castile Formation,
- summarize some data on blowouts from oil and gas exploration in the Delaware Basin, and
- determine sources of information such that other staff members might be able to more efficiently collect and collate information.

Sources of Information

Waste Isolation Pilot Plant (WIPP) reports in the Sandia WIPP Central File (SWCF) provide most details about the drilling and testing of brine reservoirs in the Permian Castile Formation in the area of the WIPP. Alternative sources not yet checked include the Project Records System (PRS) of the WIPP located in Carlsbad and the WIPP library on site. My personal files include some of the same reports but do not contain additional information that I believe is relevant to this issue.

For oil and gas exploration, I examined maps from the Midland Map Company, log listings by Riley Electric Logs, and files for Eddy County drilling in the Artesia offices of the Oil Conservation Commission of New Mexico.

I also spoke to residents near Loving, NM, to obtain initial information and location of the South Culebra Bluff #1 blowout in 1978.

There are other sources not yet checked, pending a decision about who (e.g., Rich Aguilar, John Keesey, or I) should check further and obtain more information. The OCC office in Hobbs, NM, covers the Lea Country area. The Texas Railroad Commission, Oil and Gas Division, has a field office at 2509 N. Big Spring in Midland (tel: 915/684-5581). It is responsible for 36 counties in west Texas adjacent to New Mexico or nearby. The Midland field office maintains files of Form D6, on which blowouts and other incidents are reported; the form gives basic information that is normally further reported in individual operator/well files. I spoke to Michael Pearson; the other knowledgeable person is Bill Hartsell. Norbert Rempe (Westinghouse) and Keith McKamey (NMED) were asked about their personal knowledge of blowouts in southeastern New Mexico. They had some general information; further discussion might yield additional details or specific events.

Summary of WIPP Brine Reservoir Information

Two drillholes, ERDA 6 and WIPP 12, encountered brine and gas in the upper Castile Formation during site exploration and characterization. Each had sufficient pressure to flow at the surface over extended testing periods. The Castile is not a hydrocarbon exploration target, and these occurrences are not taken as equivalent to a blowout from a high-pressure gas reservoir.

The principal sources of information on these events are data and analysis reports from project participants. Basic data and hole histories are included in Sandia National Laboratories and US Geological Survey (1983), Sandia National Laboratories and D'Appolonia Consulting Engineers (1982), Black (1982), and D'Appolonia Consulting Engineers, Inc. (1982). Further analyses of brine reservoirs are reported in Popielak and others (1983), Rose (1977), Register (1981), Powers and others (1978), Barr and others (1979), and Lambert and Harvey (1987), though this is not a complete list of references.

Pressurized brine and gas (including H_2S) were encountered at a depth of 2711 ft (in anhydrite from the Castile Formation) in ERDA 6 while drilling in 1975. Because the drillhole was not intended for exploration of hydrocarbon-bearing zones, it was not equipped for containing high-pressure brine and gas. The flow was eventually controlled with mud that at some times was increased to 13.8#. The hole history shows a variety of work and testing over a period of about a month in 1975 before a cement plug was placed. The hole was re-entered when WIPP 12 was being tested so that the ERDA 6 reservoir could be monitored and further tested.

Pressurized brine and gas in WIPP 12 were encountered in the Castile Formation during a second drilling phase to deepen the drillhole. The drilling was to examine evaporite deformation, and it was anticipated there would not be any pressurized brine because the evaporites were less deformed at WIPP 12. The basic data report on the testing of WIPP 12 and ERDA 6 shows the extensive activities, including episodes of geophysical logging.

The principal point I checked was whether there were sources of information that could indicate if borehole diameters were affected by flow episodes during testing of the brine reservoirs in ERDA 6 and WIPP 12. Caliper logs are available for checking. For ERDA 6, I found comparable caliper logs before and after flow (D'Appolonia Consulting Engineers, Inc., 1982; Activities 6.2 and 6.5). The problem is that there was also drilling between the caliper logs, and we cannot determine how much the drill string may have affected the borehole diameter. Large-format copies of these logs are available from SWCF as WP03841 and 03842. WIPP 12 caliper logs (Activities 12.5 and 12.16) bracket about 30,000 bbls of flow during testing, with no drilling during this time. The earlier log was taken 11/27/81 and the later log was taken 1/1/82. It appears from the caliper logs that the drillhole diameter increased through the lower Salado (e.g., the vicinity of 2500 to 2700 ft depth) while borehole in the upper Salado (e.g., about 1000 ft) does not appear to have changed. The log scale differs, and we do not know the details of the caliper tool (3-arm, 4-arm, etc.). Nonetheless, these borehole character changes do appear to be significant in this instance.

Summary of Blowout at South Culebra Bluff Unit #1
(sec 23, T23S, R28E, 1980' fnl, 1650' fel)

At 10:30 am on January 3, 1978, Delta Drilling Company intercepted a high-pressure zone in the "Atoka" at a depth of 11, 769 ft in South Culebra Bluff Unit #1. The automatic choke failed, pressurizing the separator until it failed, disabling the choke and kill manifold. The crew was unable to get to the manifold valves to shut the well in. It ignited about 5:10 am on January 4, 1978, and the derrick fell 8:12 am on January 5, 1978. On January 11, a crew from Red Adair's company used 400# of nitroglycerine to blow off the damaged BOP and also blew out the fire. By January 14, the crew had regained control of the well and it was tested on the 18th. Gas was piped to an El Paso Natural Gas Company pipeline. Initial production estimates were 50 MMCFD. The well produced more than 4 billion cubic ft of gas from January 27 through June 7. The well was allowed to flow for several months because initial data indicated mud weights sufficient to control the gas flow would exceed the fracture gradient for the Bone Spring Limestone. In September, 1978, Delta plugged the hole to 11, 670 feet, installed additional casing, and drilled around the plug and drillpipe that had been left in the hole. The re-completed well tested 14.6 MMCFD.

Extensive records were available at the OCD office in Artesia relative to this blowout. I took additional notes, but they largely concern more details of actions and some of the institutional response. A form called "Notification of Fire, Breaks, Spills, Leaks, and Blowouts" was filed within a few hours of the occurrence. OCD keeps records by year of these forms. The drillhole file includes extensive correspondence and notification of the activities before and after the blowout occurred, and there are many details that can be added to my summary. There are several pages of test data, but I did not find any direct reference to the reservoir characteristics. OCD also maintains files of geophysical logs, and I am faxing a few pages from the relevant depths. The gamma and density logs show the shale zone over the producing horizon that likely cause over-pressuring, as commented on by both McKamey and Rempe.

The caliper logs for the South Culebra Bluff #1 appear to be composite logs from different episodes at different depths. There is limited information, probably of no value, about possible borehole enlargement during nearly uncontrolled high-pressure gas flow over a period of about 8 months. Any overlapping information is also likely to be suspect because of the workover required before it was possible to re-drill and log the lower part of the borehole.

Other Blowouts or Incidents

I inspected the annual records of "Notification of Fire, Breaks, Spills, Leaks, and Blowouts" for the years 1991 through 1995 and found no record of any blowouts during that period. The records mainly include fires and spills when tank batteries are struck by lightning, pipeline breaks during construction, equipment failures at tank batteries, and human error incidents (valves left open, minor spills). With additional time, these records can be searched further. All of the equivalent files at the Hobbs office of the OCD remain to be checked for Lea County and the extreme eastern side of New Mexico. As a side note, the Artesia office of OCD charges $0.25/page for copying.

I haven't inspected records at the Texas Railroad Commission Midland office, but they should be about the same as the NM OCD.

South Culebra Bluff #1 as an Analog for WIPP

Eight criteria were listed for analogs to WIPP. South Culebra Bluff #1 meets certain of these.

1. This was an unexpected encounter. The initial target was the Morrow, below the Atoka. Though the Atoka was known from other areas, this was not designated as a field or reservoir for the area. I haven't checked whether Delta was a new driller to the area, but I doubt it. Amoco was not a novice.
2. I don't know what the specific criteria are for a US independent. It's probably not relevant here.
3. The Atoka was principally a gas-producer, though there was apparently condensate as well. I don't have the data on proportions. I think the condensate must have been small to pipe the flow directly to EPNG's pipeline. Later tests undoubtedly determined the condensate.
4. Some of the data on the formation are available, and there is enough file data and geophysical log information that much of the required characteristics should be determinable within reason.
5. There is considerable information on mud programs and casing.
6. The South Culebra Bluff #1 well is about 16 miles from WIPP and is likely to be the nearest and best documented blowout in geology similar to that at the WIPP.
7. The geology is very similar to the WIPP, although the near-surface units have been more affected by dissolution.
8. The response at OCD was very good, and I don't think any of the information in the files I saw is confidential.

In summary, the South Culebra Bluff #1 well may be the best single analog available to WIPP. Additional information might be obtained, with permission, from Delta Drilling Company, Box 866, Odessa, TX 79760. The current operator of the well is RB Operating Company (Reading and Bates Petroleum Company), 2412 N. Grandview, Suite 201, Odessa TX 79761.

Meeting Objectives

I have summarized some data on WIPP drilling of pressurized brine and gas reservoirs in the Permian Castile Formation. There are additional data that may be useful for specific purposes in performance assessment, and some have been included in PA. Some information on borehole size changes were reviewed, and WIPP 12 may indicate changes in diameter with brine production.

With limited research, I was able to summarize data and events on a blowout from oil and gas exploration in the Delaware Basin near Loving, NM. I think there is little likelihood of getting borehole enlargement data, though a careful reconstruction of logging events might yield further possibilities. There is other information to be obtained about the geology, the specific events of this blowout, and both industry and institutional responses to the blowout.

From this brief foray, it is clear that sources of information exist in Artesia and Hobbs on New Mexico occurrences. In addition, the Midland office of the Oil and Gas Division of the Texas Railroad Commission has generally equivalent information. Sandia staff members could collect and collate this information, but there may need to be some training before someone without background in these areas attempts it.

My efforts are well within the estimates of time I gave for this task; there are some minimal expenses as well because I had to stay over an extra night in Carlsbad. I consider my efforts to end with this letter report unless you specifically direct that I should follow up on the information available in Artesia, Roswell, and Midland. I can do this if priorities under my existing contract change.

Attachments

I am attaching:

- a copy of part of the map from Midland Map Company so you can easily identify the South Culebra Bluff #1 location on your own MMC maps.
- 3 pages of information from the OCD files on South Culebra Bluff #1
- 4 legal size pages of part of the compensated neutron-formation density log from South Culebra Bluff #1.
- 3 legal size pages of part of the dual laterolog micro-sfl log from South Culebra Bluff #1.

References Cited

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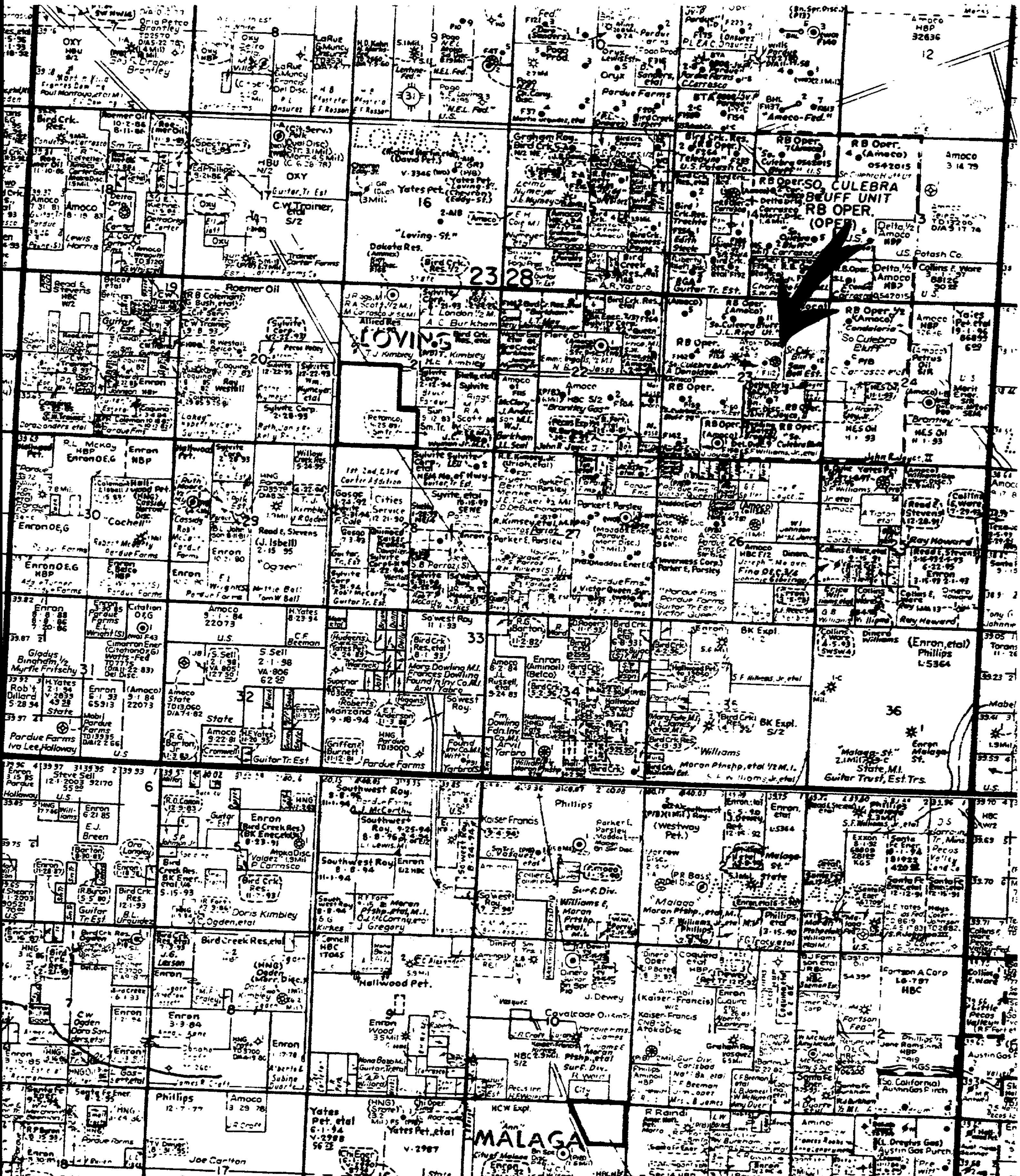
If there are clarifying data or points that you need, please don't hesitate to let me know. As I noted elsewhere, if priorities for my consulting for Sandia change and you want me to pursue some of these data and sources further, I will be glad to work out a program.

Sincerely,

Dennis

Dennis W. Powers

please make copy for D. Boak


LOVING
MALAGA
SO. CULEBRA BLUFF UNIT
RB OPER.
(OPER)
U.S. Potash Co.
C.W. Trainer, S/2
Yates Pet.
"Loving-St."
Dakota Res.
Roemer Oil
Sylvite Corp.
Allied Res.
A.C. Burkham
Parker E. Parsley
Guitar Tr. Est.
Pardue Farms
Enron
Amoco
Phillips
Southwest Roy.
Bird Creek Res.
Kaiser-Francis
Williams
BK Expl.
S.F. Williams, Jr., etal
Guitar Trust, Est. Trs.
Hallwood Pet.
Doris Kimbley
Joe Carlton
Santa Fe Ener.
City of Malaga
HCW Expl.
Cavalcade
Aminoil
Austin Gas Purch.
Fortson A Corp
HBC
HBP
State
U.S.

Copy to ST

Dennis

NEW MEXICO OIL CONSERVATION COMMISSION

NOTIFICATION OF FIRE, BREAKS, SPILLS, LEAKS, AND BLOWOUTS

NAME OF OPERATOR Delta Drilling Company				ADDRESS Box 866 Odessa, TX 79760			
REPORT OF	FIRE X	BREAK	SPILL	LEAK	BLOWOUT X	OTHER*	
TYPE OF FACILITY	DRLG WELL X	PROD WELL	TANK BTTY	PIPE LINE	GASO PLNT	OIL RFY	OTHER*

NAME OF FACILITY South Culebra Bluff Unit #1				
LOCATION OF FACILITY (QUARTER/QUARTER SECTION OR FOOTAGE DESCRIPTION)	SEC. 23	TWP. 23S	RGE. 28E	COUNTY Eddy

DISTANCE AND DIRECTION FROM NEAREST TOWN OR PROMINENT LANDMARK 2 miles East of Loving, N. M.

DATE AND HOUR OF OCCURENCE 10:30 A.M. January 3, 1978				DATE AND HOUR OF DISCOVERY Same
WAS IMMEDIATE NOTICE GIVEN?	YES X	NO	NOT REQUIRED	IF YES, TO WHOM Local Conservation Office
BY WHOM Elmer Pope, Consultant				DATE AND HOUR 1/3/78 Approx. 1 P.M.
TYPE OF FLUID LOST Gas				QUANTITY OF LOSS unknown / VOLUME RECOVERED
DID ANY FLUIDS REACH A WATERCOURSE?	YES	NO X	QUANTITY	

IF YES, DESCRIBE FULLY**

RECEIVED

JAN 30 1978

O.C.C.

ARTESIA, OFFICE

DESCRIBE CAUSE OF PROBLEM AND REMEDIAL ACTION TAKEN**

See Attachment

DESCRIBE AREA AFFECTED AND CLEANUP ACTION TAKEN**

The burning gas posed no immediate danger to the surrounding area. Red Adair was called in to contain and control the well.

DESCRIPTION OF AREA	FARMING X		GRAZING	URBAN	OTHER*		
SURFACE CONDITIONS	SANDY X	SANDY LOAM	CLAY	ROCKY	WET	DRY X	SNOW

DESCRIBE GENERAL CONDITIONS PREVAILING (TEMPERATURE, PRECIPITATION, ETC.)**

Temperature approx. 45^{o} and no precipitation.

I HEREBY CERTIFY THAT THE INFORMATION ABOVE IS TRUE AND COMPLETE TO THE BEST OF MY KNOWLEDGE AND BELIEF

SIGNED Ron Lechwar TITLE Projects Manager DATE 1-23-78

*SPECIFY **ATTACH ADDITIONAL SHEETS IF NECESSARY

ATTACHMENT

DRILLING AT 11,769 FEET, A HIGH PRESSURE GAS ZONE WAS ENCOUNTERED. BOP AND HYDRIL WERE CLOSED AND KICK WAS BEING CIRCULATED OUT WHEN THE AUTOMATIC CHOKE FAILED FOR REASONS UNKNOWN AT THIS TIME, ALLOWING THE FULL PRESSURE TO ENTER SEPARATOR.

THE SEPARATOR WAS UNABLE TO HANDLE THE FULL PRESSURE AND SUBSEQUENTLY FAILED, WHICH IN TURN DISABLED THE CHOKE AND KILL MANIFOLD. AT THIS TIME THE WELL WAS STILL UNLOADING WATER AND GAS. THE RIG CREW STATED THAT THEY WERE UNABLE TO REACH ANY OF THE FOUR VALVES GOING TO THE MANIFOLD FROM THE BOP TO SHUT THE WELL IN. THE CREW THEN LEFT THE LOCATION FOR A PLACE OF SAFETY. THE WELL CONTINUED TO BLOW GAS AND CONDENSATE UNTIL APPROXIMATELY 5:10 A.M. THE FOLLOWING MORNING, AT WHICH TIME IT IGNITED ITSELF.

DELTA DRILLING COMPANY

BOX 2012 TELEPHONE 214 595-1911

TYLER, TEXAS 75710

RECEIVED

JAN 26 1978

O. C. C.
ARTESIA, OFFICE

January 24, 1978

New Mexico Oil Conservation Commission
Drawer DD
Artesia, New Mexico 88210

RE: Report of Blowout
South Culebra Bluff No. 1 Well
Eddy County, New Mexico

Gentlemen:

This letter will confirm the prior notification given to Mr. Bill Gressett (Artesia office) and Mr. Dan Nutter (Santa Fe office) on January 4, 1978, concerning the blowout and subsequent fire at the Delta Drilling Company South Culebra Bluff No. 1 Well located 1980' FNL and 1650' FEL of Section 23, T23S, R28E, NMPM, Eddy County, New Mexico.

The South Culebra Bluff No. 1 Well was spudded by Amoco Production Company on November 6, 1977, pursuant to a Drilling Contract between Amoco Production Company, as Operator, and Brahaney Drilling Company, Inc., whose address is P. O. Box 1694, Midland, Texas, 79701, as Drilling Contractor.

On November 17, 1977, at 12:00 noon, Delta Drilling Company assumed operation of the well at a depth of approximately 4400' below the surface. Rig No. 7 of Brahaney Drilling Company, Inc. continued the drilling of such well until January 3, 1978, on which date such well, at a depth of 11,769' below the surface, encountered a gas kick, blew out and subsequently caught fire.

Operations for the drilling of a relief well and efforts to gain control of the well at the surface were commenced immediately. Control equipment has been installed on the wellhead and at present gas is being flared through two lines. Arrangements have been made to sell such gas to El Paso Natural Gas Company pursuant to an emergency gas sales contract, and it is anticipated that deliveries of such gas will be commenced on or about January 25, 1978.

Additional information concerning such well is being furnished to the New Mexico Conservation Commission pursuant to your forms C-103 and C-104.

Very truly yours,

Carl E. Haskett

Carl E. Haskett
Mgr. Corporate Engineering
and Research

cc: New Mexico Oil Conservation
Commission
P. O. Box 2088
Land Office Building
Santa Fe, New Mexico 87501

Con Cll

Schlumberger

COMPENSATED NEUTRON-FORMATION DENSITY

COUNTY EDDY
FIELD WILDCAT
LOCATION
WELL SOUTH CULEBRA BLUFF UNIT #1
COMPANY DELTA DRILLING CO.

COMPANY DELTA DRILLING COMPANY ✓

OH 11750-11879, ATOKA (GAS), OIL CONS. OK

WELL SOUTH CULEBRA BLUFF UNIT #1

FIELD ~~WILDCAT~~ S. CULEBRA BLUFF Atoka

COUNTY EDDY STATE NEW MEXICO

LOCATION 1980' FNL & 1650' FEL

API SERIAL NO.	SEC.	TWP.	RANGE
\	23	23-S	28-E

Other Services:
BHC
DLL-MSFL
CYBERLOOK

Permanent Datum: G.L. ; Elev.: 2996
Log Measured From K.B. 21 Ft. Above Perm. Datum
Drilling Measured From K.B.

Elev.: K.B. 3017
D.F.
G.L. 2996

Date	9-14-78	9-30-78	10-12-78	RECEIVED
Run No.	ONE	TWO	THREE	
Depth—Driller	11677	11750	11873	OCT 31 1978
Depth—Logger	11670	11744	11879	
Btm. Log Interval	11658	11743	11877	O. C. C.
Top Log Interval	6125	9743	11746	ARTESIA, OFFICE
Casing—Driller	9 5/8 @ 6358	9 5/8 @ 6350	7" @ 11745	
Casing—Logger	6354		11746	
Bit Size	8 3/4	8 3/4	6 1/8	
Type Fluid in Hole	BRINE	*	SALT GEL, STARCH	
Dens. / Visc.	10.2 / 28	10.4 / 38	11.6 / 48	
pH / Fluid Loss	11 / ml	12 / 10 ml	10.5 / 17.4 ml	ml
Source of Sample	PIT	PIT	PIT	
Rm @ Meas. Temp.	.041 @ 93 °F	.088 @ 73 °F	.059 @ 85 °F	@ °F
Rmf @ Meas. Temp.	.031 @ 93 °F	.078 @ 73 °F	.046 @ 85 °F	@ °F
Rmc @ Meas. Temp.	.062 @ 93 °F	.132 @ 73 °F	.089 @ 85 °F	@ °F
Source: Rmf / Rmc	M / C	M / C	M / C	
Rm @ BHT	.026 @ 145 °F	.041 @ 154 °F	.030 @ 167 °F	@ °F
TIME Circulation Stopped		1200 9-30	1900 10-12	
TIME Logger on Bottom	1930	0745 10-1	0600 10-13	
Max. Rec. Temp.	145 °F	154 °F	167 °F	°F
Equip. / Location	7721 / HOBBS	8067 / HOBBS	8042 / HOBBS	
Recorded By	DANIEL	THURSTON	MOBARAK	
Witnessed By Mr.	OLSON	SWIFT	GALLICK	

FOLD HERE — The well name, location and borehole reference data were furnished by the customer.

RUN NO.	ONE	TWO	THREE	
Service Order No.	22229			
Fluid Level			FULL	
Salinity, PPM CL.	167000	147000	145000	
Speed - F.P.M.	30	30	30/60	
EQUIPMENT DATA				
Dens. Panel	1141	8067		
Dens. Cart.		"		
Dens. Skid.	1077	"	125	
Dens. Sonde	305	"		
Dens. Source	3334	"	3351	
Dens. Calibrator	696	"	1083	
Neut. Panel	652	"		
Neut. Cart.	485	"	1278	
Neut. Source	1441	"	2333	
Neut. Calibrator	549	"	1390	
GR Cart.		"		
Memorizer Panel	792			
Tape Recorder (TTR)	853			
Depth Encoder (DRE)	953			
Pressure Wheel (CPW)	1938			
Centralizers: Enter Spring, Standoffs, In-line, or None — Type	**			
No.	1 EACH			
S. O. — Inches	ECCEN.			
CALIBRATION DATA				
GR BKG. CPS	70	22	SEE CAL	
GR Source CPS	530	186		
GR Sens. - Cal	165	165	165	
GR T. C. - Cal	6			
CNL Short Spacing - Before Log	RATIO	RATIO	SEE CAL	
CNL Long Spacing - Before Log	2.34	2.07		
CNL Short Spacing - After Log	RATIO	RATIO	.	
CNL Long Spacing - After Log	2.34	2.05		
FDC P1 — Before Log	126.1	335		
FDC P2 — Before Log	198.7	533		
FDC P1 — After Log	126	337		
FDC P2 — After Log	199	528		

Type Log	Depth			

REMARKS:
RUN 1- RIG #2: K.B.= 3009
CSG. = 6350
TD= 11669
** TYPE OF CENTRALIZERS USED: BOWSPRING AND CALIPER
RUN 2- * TYPE FLUID IN HOLE SALT GEL, MYLOGEL

RUN 3- NO CENTRALIZERS USED DUE TO BOREHOLE SIZE

LOGGING DATA

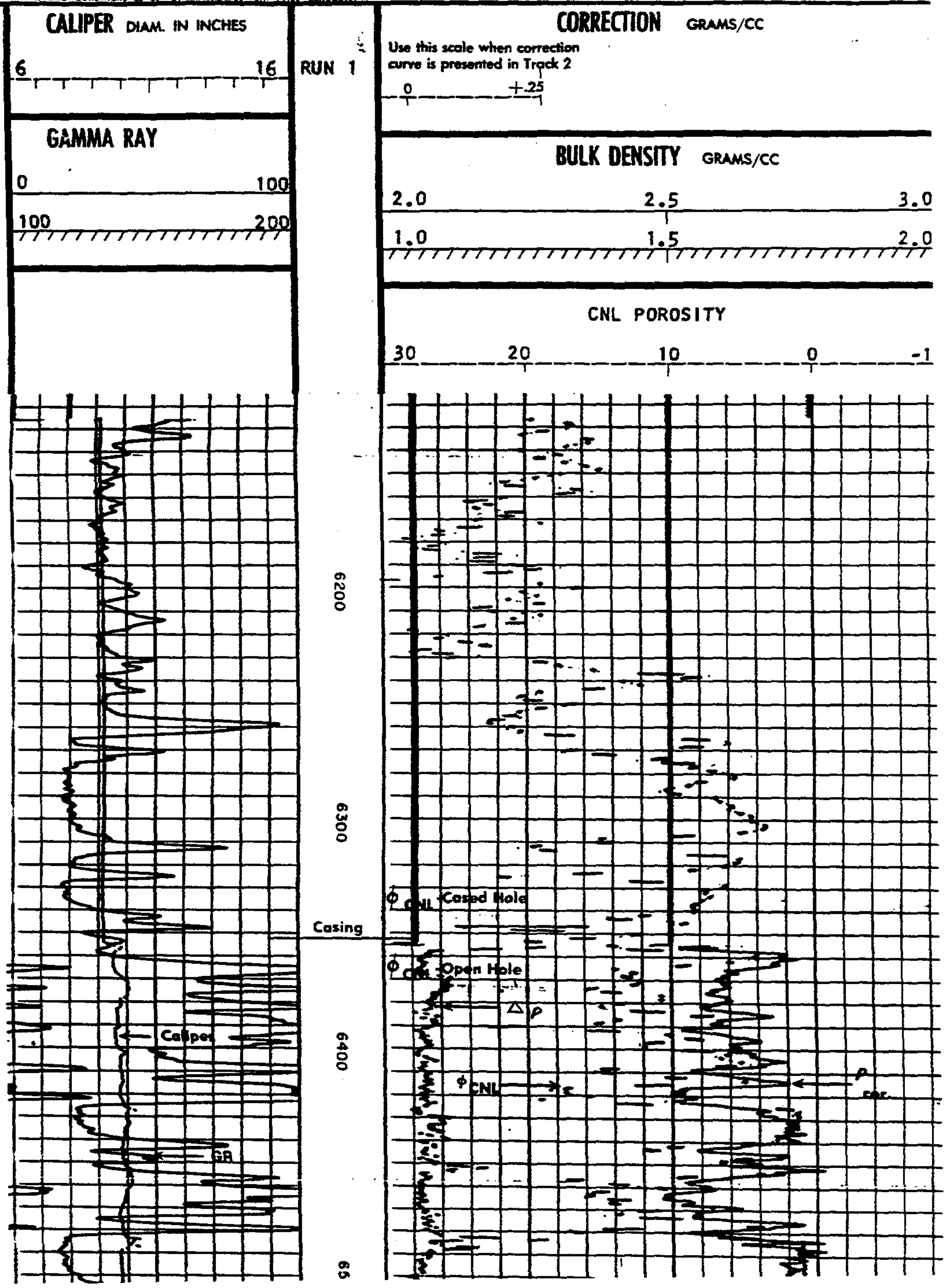
DEPTH Top	DEPTH Bottom	CNP Porosity Scale	CNP Matrix	CNP Auto Corr. or Hole Size Setting	FDC Porosity Scale	FDC Grain Density	FDC Liquid Density	FDC Hole Fluid	GR Sens. Logged	GR T. C.	GR Zero. Div. Left
6354	11658	30 -10	LS-OH	AUTO	30 - 10	2.71	1.10	L10	100	2	0

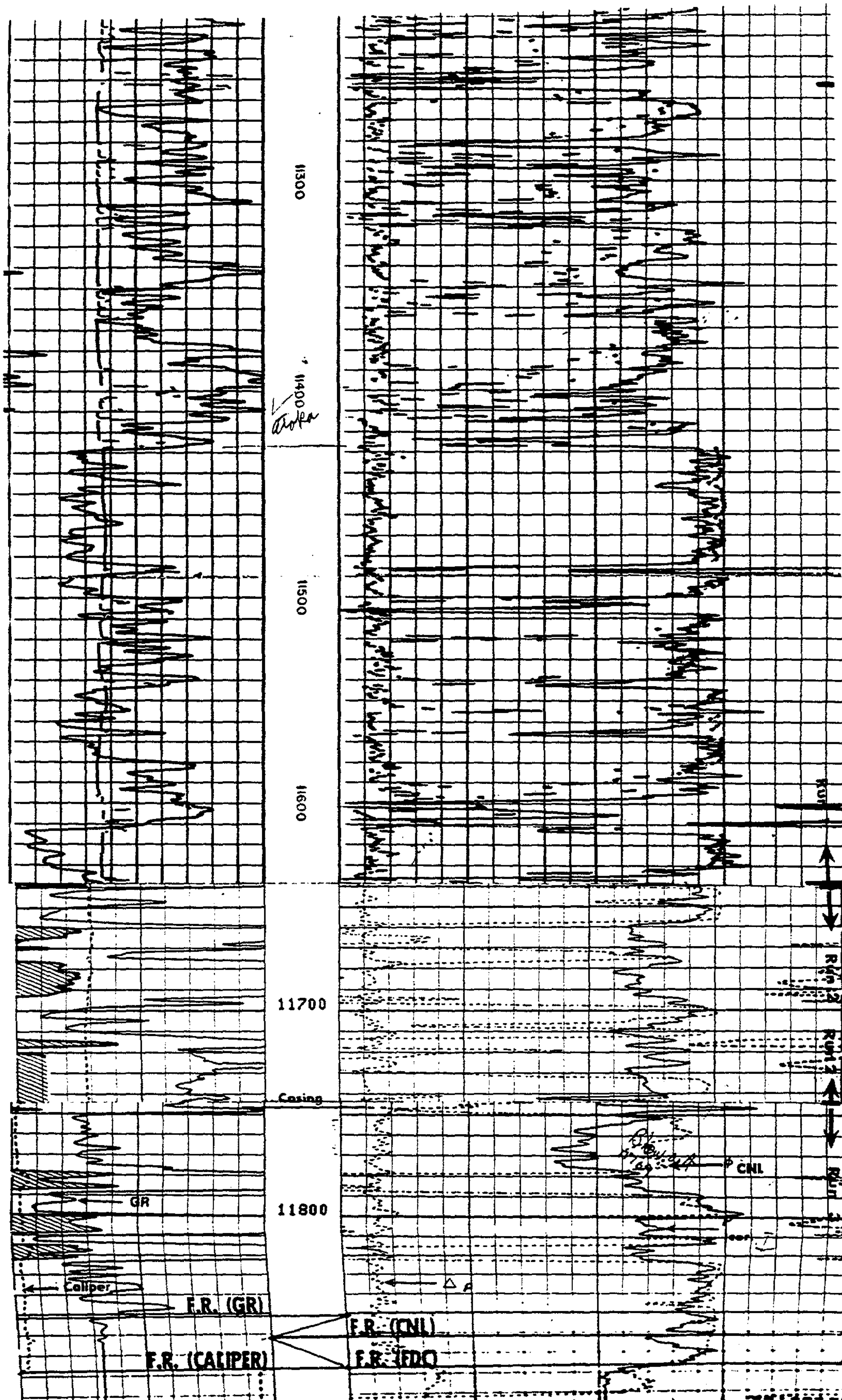
FDC						
P^2 — Before Log	198.7	533				
P^1 — After Log	126	337				
P^2 — After Log	199	528				

LOGGING DATA

DEPTH		CNP			FDC				GR		
Top	Bottom	Porosity Scale	Matrix	Auto Corr. or Hole Size Setting	Porosity Scale	Grain Density	Liquid Density	Hole Fluid	Sens. Logged	T. C.	Zero. Div. Left
6354	11658	30 -10	LS-OH	AUTO	30 -10	2.71	1.10	LIQ.	100	2	0
6125	6354	30 -10	LS-CH						100	2	0
9743	11743	30 -10	LS-OH	AUTO	30 -10	2.71	1.10	LIQ.	165		0
11600	11746	30 -10	LS-CH	CH					100		0
11746	11877	30 -10	LS-OH	AUTO	30 -10	2.71	1.10	LIQ.	100		0

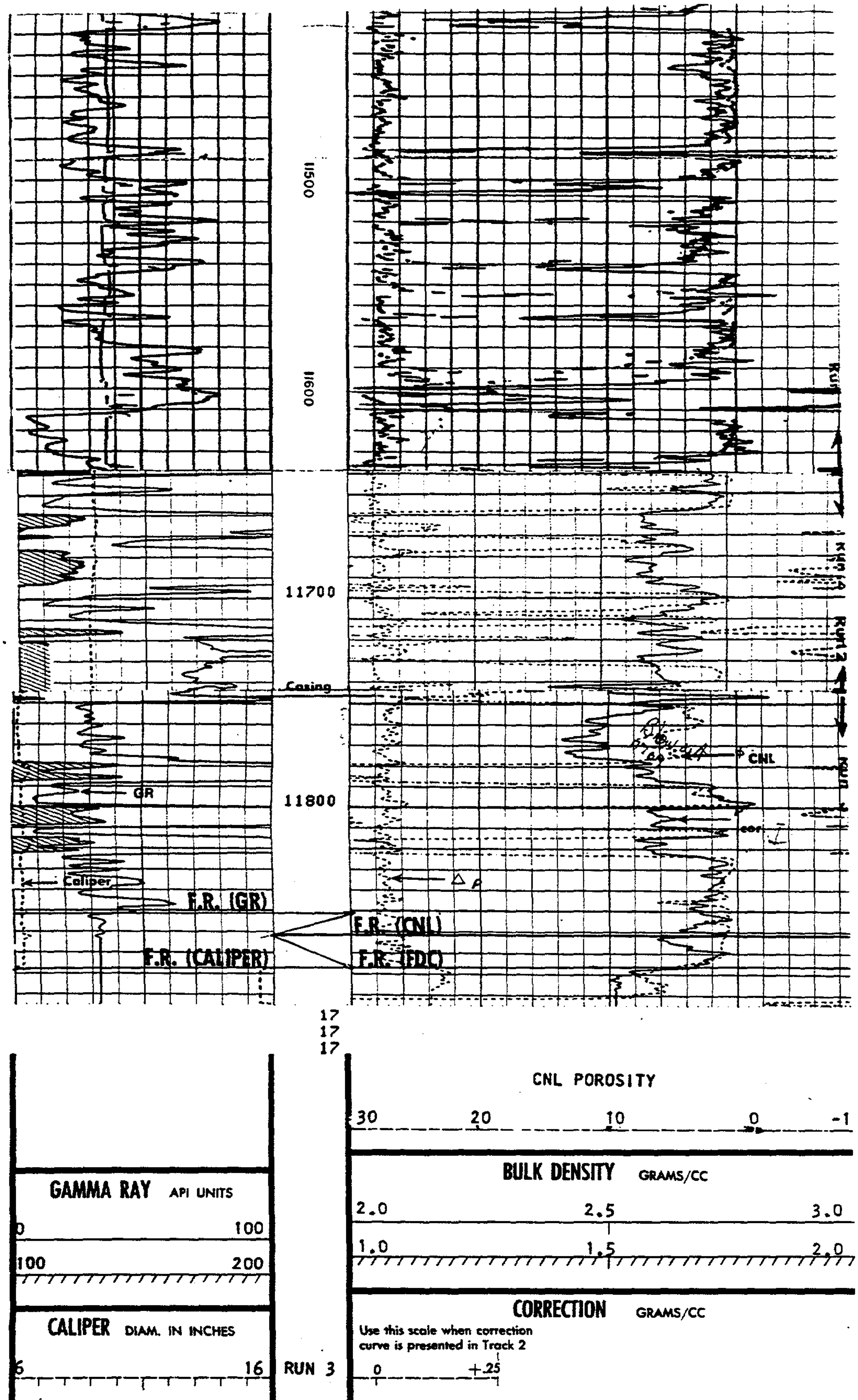
All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretations, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule.





11300
11400
11500
11600
11700
Casing
11800
GR
CNL
Caliper
F.R. (GR)
F.R. (CNL)
F.R. (CALIPER)
F.R. (FDC)
Run 2

17


11500
11600
11700
Casing
11800
GR
Caliper
CNL
F.R. (GR)
F.R. (CALIPER)
F.R. (CNL)
F.R. (FDC)
17
17
17
GAMMA RAY API UNITS
0 100
100 200
CALIPER DIAM. IN INCHES
6 16
RUN 3
CNL POROSITY
30 20 10 0 -1
BULK DENSITY GRAMS/CC
2.0 2.5 3.0
1.0 1.5 2.0
CORRECTION GRAMS/CC
Use this scale when correction curve is presented in Track 2
0 +.25

DETAIL LOG

SIMULTANEOUS
DUAL LATEROLOG MICRO-SFL

Schlumberger

COUNTY EDDY
FIELD WILDCAT
LOCATION
WELL SOUTH CULEBRA BLUFF #1
COMPANY DELTA DRILLING CO.

COMPANY DELTA DRILLING COMPANY
WELL SOUTH CULEBRA BLUFF UNIT #1
FIELD WILDCAT
COUNTY EDDY STATE NEW MEXICO

LOCATION: 1980' FNL & 1650' FEL

API SERIAL NO	SEC	TWP	RANGE
	23	23-S	28-E

Other Services: CNL-FDC, BHC, CYBERLOOK

Permanent Datum: G.L. ; Elev.: 2996
Log Measured From K.B. 21 Ft. Above Perm. Datum
Drilling Measured From K.B.

Elev.: K.B. 3017, D.F., G.L. 2996

Date	12-6-77	9-14-78	9-30-78	10-12-78
Run No.	ONE	TWO	THREE	FOUR
Depth—Driller	6355	11669	11750	11873
Depth—Logger (Schl.)	6288	11657	11744	11879
Btm. Log Interval	6286	11655	11730	11866
Top Log Interval	415	6354	9730	11746
Casing—Driller	13 3/8 @ 418	5358 @ 9 5/8	9 5/8 @ 6350	7" @ 11745
Casing—Logger	415	6354		11746
Bit Size	12 1/4	8 3/4	8 3/4	6 1/8
Type Fluid in Hole	BRINE	BRINE	*	**
Dens. / Visc.	10.1 / 27	10.2 / 28	10.4 / 38	11.6 / 48
pH / Fluid Loss	8.5 / ml	11 / ml	12 / 10 ml	10.5 / 17.4 ml
Source of Sample	PIT	PIT	PIT	PIT
Rm @ Meas. Temp.	.052 @ 60 °F	.041 @ 93 °F	.088 @ 73 °F	.059 @ 85 °F
Rmf @ Meas. Temp.	@ °F	.031 @ 93 °F	.078 @ 73 °F	.046 @ 85 °F
Rmc @ Meas. Temp.	@ °F	.0615 @ 93 °F	.132 @ 73 °F	.089 @ 85 °F
Source: Rmf / Rmc		M / C	M / C	M / C
Rm @ BHT	.03 @ 105 °F	.026 @ 145 °F	.041 @ 154 °F	.030 @ 167 °F
Time: Circulation Stopped	2100 12-6		1200	1900 10-12
Time: Logger on Bottom	0115 12-7	1030	2300	0300 10-13
Max. Rec. Temp.	105 °F	145 °F	154 °F	167 °F
Equip. / Location	7732 / HOBBS	7721 / HOBBS	8067 / HOBBS	8042 / HOBBS
Recorded By	SANCHEZ	DANIEL	THURSTON	MOBARAK
Witnessed By	LECHWAR	OLSON	SWIFT	GALLICK

FOLD HERE — The well name, location and borehole reference data were furnished by the customer.

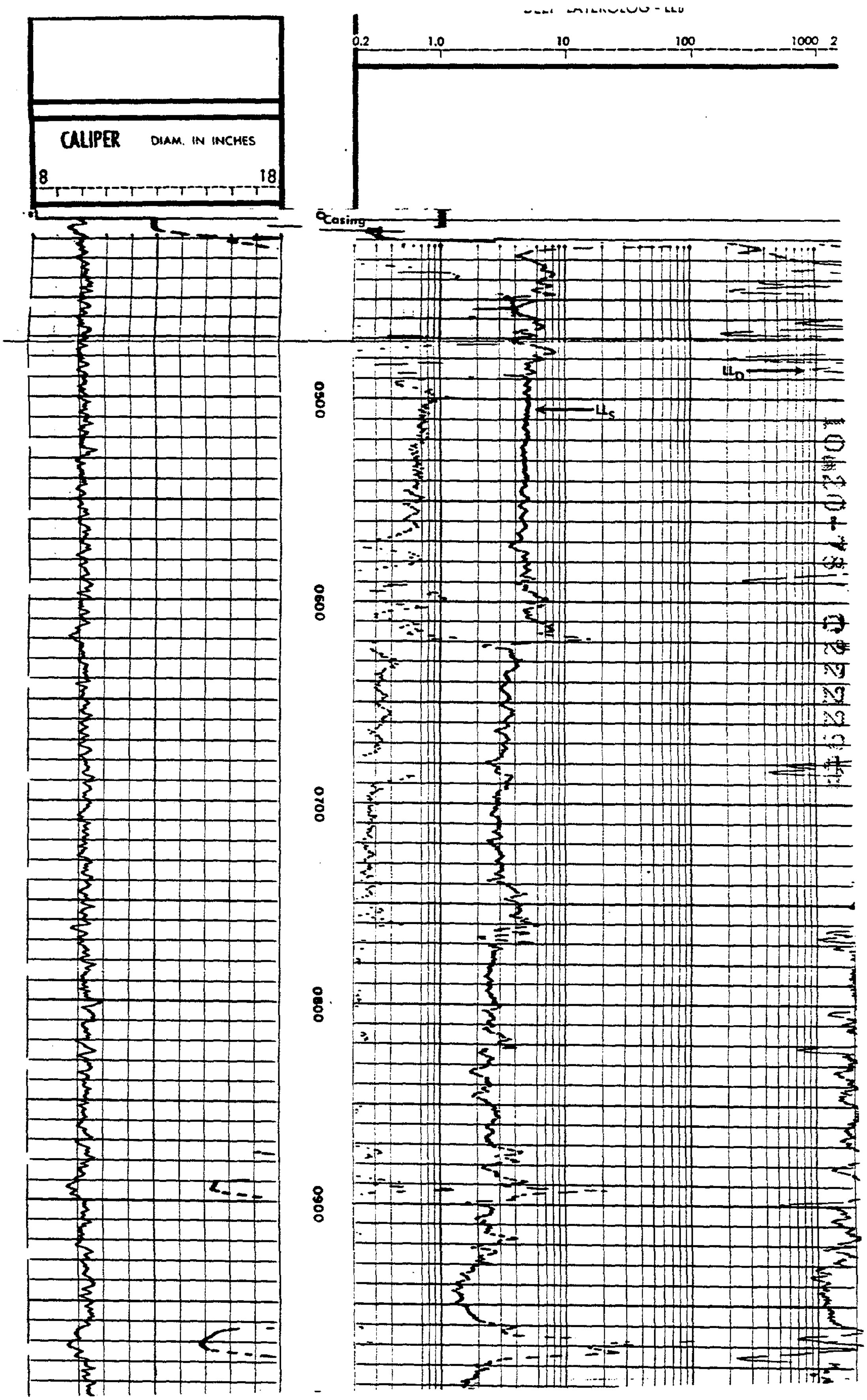
			ONE	TWO	THREE	FOUR
Run No.			ONE	TWO	THREE	FOUR
Service Order No.			22229			
Fluid Level						FULL
Salinity, PPM CL.			189000	167000	147000	145000
EQUIPMENT DATA						
Panel (DLP)			808	965		
Panel (SRP)			970	945		
Cartridge (DLC)						
Cartridge (SRE)						
Sonde (DLS)					853	831
Sonde (SRS)						
Lower Electrode (DLE)						
Memorizer Panel			792	792		
Tape Recorder (TTR)			809	853		
Depth Encoder (DRE)				953		
Pressure Wheel (CPW)			1473	1938		
Centralizers: Enter Spring, Standoffs, In-line, or None	Type		***	CME-H	CME-H	
	No.		1	ONE	ONE	
	S. O. Inches			CENTERED	CENTERED	
CALIBRATION DATA						
GR	BKG. CPS				54	SEE CAL
	Source CPS				187	
LOGGING DATA						
GR	Sensitivity			165	165	165
	Scale -100 Div.			100	100	100
	T. C. - sec			1		
Speed FPM				40	50	40
BOTTOM HOLE TEMPERATURE						
Time Entering Hole			0100	1330		0030
Time Bottom Reached			0130	1430		0230
Time Last Off Bottom			0145	1500		0300
Time Out of Hole			0445	1300		0530
Distance TD to Therm.			32	37		37
Thermometer #1			105 °F	145 °F	°F	167 °F
Thermometer #2			°F	°F	°F	°F
Thermometer #3			°F	°F	°F	°F
Rw FROM DRILL STEM TEST						
DST #1 - Rw @ 100 °F			ΩM	ΩM	ΩM	ΩM
DST #2 - Rw @ 100 °F			ΩM	ΩM	ΩM	ΩM

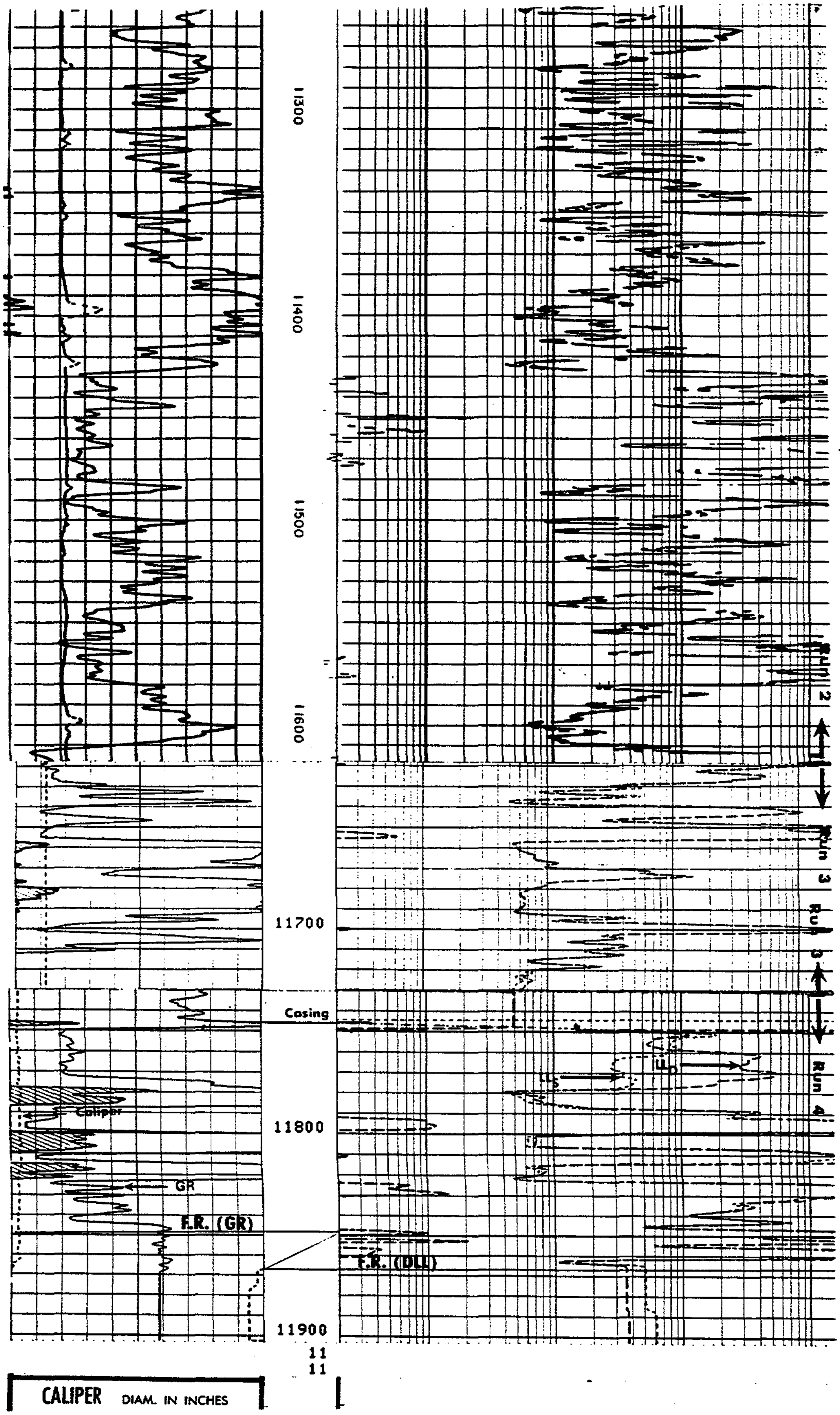
SCALE CHANGES

Type Log	Depth	Scale Up Hole	Scale D...

REMARKS:
RUN 1- ***- TYPE OF CENTRAL...
USED CME-H & CALIPER.
RUN 2- RIG # 2 K.B. 3029
CSG. 6359
TD-11669
RUN 3- * TYPE FLUID IN HOLE
SALT GEL-MYLOGEL. NO MSFL D...
TO CSU PROBLEM. NO CALIPER ...
TO TOOL FAILURE.
RUN 4- NO CENTRALIZERS USED
DUE TO BOREHOLE SIZE.
** TYPE FLUID IN HOLE:
SALT GEL STARCH.

GAMMA RAY API UNITS | DE | RESISTIVITY


CALIPER
DIAM. IN INCHES
8
18
0.2
1.0
10
100
1000
2
Casing
LLD
LLS


1300
1400
1500
1600
Run 2
Run 3
11700
Casing
Run 4
LLs
LLd
Caliper
11800
GR
F.R. (GR)
F.R. (DLL)
11900
11
11
CALIPER DIAM. IN INCHES

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APPENDIX B

TELEPHONE CONTACTS FOR WELLBORE ENLARGEMENT INVESTIGATION[1,2]

1. Steve Melzer, University of Texas, Midland, TX, (915) 552-2477.
2. Dennis Beckman, Amoco Corporation, Tulsa, OK, (918) 660-4177.
3. Dr. Bill Mitchell,* Colorado School of Mines, Golden, CO, Department of Petroleum Engineering, (303) 273-3740.
4. Darien O'Brien, Solutions Engineering, Lakewood, CO, (303) 233-9185.
5. Dr. Adam T. Bourgoyne,* Louisiana State University, Baton Rouge, LA, (504) 388-3202.
6. Richard McBane, Gas Research Institute, Chicago, IL, (312) 399-8284.
7. Gene Schmidt, Amoco Research Center, Tulsa, OK, (918) 660-3424.
8. Brian Tarr, Mobil Exploration, Dallas, TX, (214) 951-2945.
9. Dr. Dave Powley (Retired),* Amoco Production Company, Tulsa, OK, (918) 494-4821.
10. Dr. John S. Bradley (Retired),* Amoco Production Company, Tulsa, OK, (918) 743-5283.
11. Dr. Tony Podio, University of Texas, Austin, Department of Petroleum Engineering, (512) 471-3260.
12. Dr. Martin Chenevert, University of Texas, Austin, Department of Petroleum Engineering, (512) 471-7270.
13. Dr. Jean-Claude Roegiers,* University of Oklahoma, Norman Department of Petroleum Engineering, (405) 325-2921.
14. Wolfgang Wawersik, Sandia National Laboratories, Albuquerque, NM, (505) 844-4342.
15. Lawrence Romero, Oil Conservation Division, Santa Fe, NM, (505) 827-7131.
16. Roger Anderson, Oil Conservation Division, Santa Fe, NM, (505) 827-7152.
17. Dr. Dennis W. Powers, Consulting Geologist, Anthony, TX, (915) 877-3929.

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[1] An asterisk denotes an individual considered an expert in the area of petroleum blowouts.

[2] For a record of the telephone conversations, see Dotson, Lori J., "Draft Report on Borehole Enlargement Information Search," Sandia National Laboratories memorandum to Barry M. Butcher. (Copy on file in the Sandia WIPP Central Files, Sandia National Laboratories, Albuquerque, NM, as WPO#27412.)

18. John J. Keesey, Williamson Petroleum Consultants, Houston, TX, (713) 750-7215.

19. Dan Stoelzel, Sandia National Laboratories, Albuquerque, NM, (505) 848-0153.

APPENDIX C

DEVELOPMENT OF GIS DATABASE AND ANALYSIS OF DATA ON PETROLEUM WELLS IN THE WIPP VICINITY

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APPENDIX C

DEVELOPMENT OF GIS DATABASE AND ANALYSIS OF DATA ON PETROLEUM WELLS IN THE WIPP VICINITY

Introduction

An integrated graphic personal computer (PC) database platform using Environmental Systems Research Institute's products, Arc/Info and Arcview, and the Microsoft products Access, Excel, Powerpoint, and Word, was used to compile and manipulate data associated with Waste Isolation Pilot Plant (WIPP) Project surface characterization boreholes and petroleum industry wells within a 10-mile radius of WIPP. The petroleum well data was compiled and summarized to assist with the identification of analogs to potential wellbore enlargement at WIPP during inadvertent human intrusion. Arc/Info is a software tool used in geographic information system (GIS) applications that allows a user to design and automate spatial databases, link datasets, and create maps using line, point, and polygon topology. Arcview is a software tool that creates a computerized environment to display and query the contents of a spatial database created in Arc/Info.

The WIPP surface borehole drilling program, sponsored by the U.S. Department of Energy (DOE) and conducted between 1974 and 1995 primarily by Sandia National Laboratories (SNL), included exploratory drilling, hydrologic testing, and the use of geophysical techniques to determine the site's suitability for a nuclear waste repository. The information compiled from this program for the GIS database included hydrologic, geologic, geochemical, and environmental data, and well completion and status information. The data on petroleum wells within a 10-mile radius of WIPP were obtained from the commercially available Dwights/Petroleum Information Discover Scout database.

A user-interface communication screen was developed by Sandia for the Access database to allow the user to interactively query data (in both text and numerical form) for a particular surface borehole or petroleum well. Access data and spatial map display information created by Arc/Info were then linked to Arcview for visual inspection of their relationship to other boreholes, wells, or geographic features within the WIPP site. Additionally, spatial relationships among the various boreholes and surficial features in the vicinity of the WIPP site can be displayed and manipulated using Arcview. Using the commercial Microsoft PC software products in combination with the more complex ESRI Arc/Info and Arcview programs allows scientific data about any particular borehole or petroleum well in the database to be effectively and interactively communicated to interested users in varying degrees of detail and complexity.

Coverages

Arc/Info was used to generate information on petroleum wells within the Salado formation in the vicinity of the WIPP, including well category, depth, and casing size. Arc/Info generates points, lines, and polygons to represent various geographic features on a map. The information is arranged in "coverages," digital analogs of single map sheets that form the basic units of data storage in Arc/Info.

Township Range and Section Locations

Township, range, and section point locations for the WIPP characterization boreholes and the petroleum wells were generated in Arc/Info using information obtained from the U.S. Geologic Survey (USGS) digital file "Main.Rep." Main.Rep contains the state-plane coordinates for New Mexico's east zone for sections within the area consisting of Townships 20 through 26 south and Ranges 28 through 33 east. Figure C-1 is a section of the Main.Rep file and shows the data's format.

USGS SURVEY Water Resources Division Albuquerque, New Mexico NE Section coordinates in the Vicinity of WIPP 8/20/87				
Township Range Section (tt.rr.ss)	UTM X (meters)	UTM Y (meters)	State Plane X (feet)	State Plane Y (feet)
20.28.01	582,435	3,608,204	565,250	585,696
20.28.02	580,826	3,608,189	559,970	585,681
20.28.03	579,209	3,608,165	554,664	585,633
20.28.04	577,590	3,608,151	549,350	585,622
...to.........26.33.36	640,065	351,976	753,005	367,199

Figure C-1. USGS Main.Rep file format.

The WIPP borehole location data also appears in Gonzales (1989). New Mexico state-plane coordinates (in feet) for the northeast corners of each section were used as X and Y location points and were generated in Arc/Info to produce the point coverage "TRSpnts." The state-plane coordinates were used rather than the Universal Transverse Mercator (UTM) coordinates to make it easier to convert the borehole and well locations that were initially given in feet from the nearest quarter section lines.

Township/Range/Section Lines

Township, range, and section lines were generated in Arc/Info as a line coverage to accurately define the location of the WIPP characterization boreholes and the petroleum wells within a 10-mile radius of WIPP. The coverage name is "TRSlines."

WIPP Characterization Borehole Location Points

WIPP characterization borehole locations were initially compiled in spreadsheet format using Microsoft Excel. The spreadsheet digital information was obtained from numerous sources including the basic data reports for the characterization boreholes, hydrologic/hydraulic testing reports, potash resource test drilling reports, and other DOE, USGS, Sandia, and private industry reports (see Hill et al. (1997) for a comprehensive list of these sources). The Excel file was slightly modified to include a unique identification number for each borehole location point (consisting of an X and a Y value). The spreadsheet was then saved as a comma-delimited file and imported into Arc/Info to generate the point coverage "Borehole" (titled "SNL Boreholes" using Arcview software).

Petroleum Well Location Points

Petroleum well locations were also initially compiled in spreadsheet format using Excel. The information was obtained digitally from the Dwights/Petroleum Information Discover Scout database in May 1995. The spreadsheet file contained the township, range, and section numbers for each well location and the distance in feet of the well location from the nearest north, south, east, or west section borderline. For example, the location of the *James Federal #6* well was given as *T22, R30*, and *S1*, and *2247 fsl* and *1558 fel*. (The *fsl* and *fel* units refer to the distance in feet from the section's south and east lines, respectively.)

Section boundary lines running north/south and east/west are not exactly parallel with the boundary lines of adjacent sections due to meridian convergence and error that occurred during the original surveys. Furthermore, the lines that converge along the boundaries of adjoining sections may not intersect at the same point because the surveys may have been completed at different times and by different surveyors. As a result, coordinates for sections along the same north/south or east/west axes deviate considerably from what would be expected from a perfectly rectangular grid. For example, T21, R31, S01 has a northeast X state-plane coordinate of 688,308, and T21, R31, S36, located approximately five miles (five sections) directly south of S01, has a northeast X state-plane coordinate of 688,460.

These inconsistencies made it difficult to accurately plot the well locations on a computer-generated map using the TRSlines coverage. To reduce plotting errors, location coordinates were assigned to each well using the nearest USGS-established northeast section corner in the file

"Main.Rep" as a reference point from which the distances (in feet) from the x- and y-axis section lines were calculated. To ensure that the appropriate section corner in the "Main.Rep" digital file was used, the section the well was located in was divided into four quadrants (labeled A, B, C, and D) (see Figure C-2).

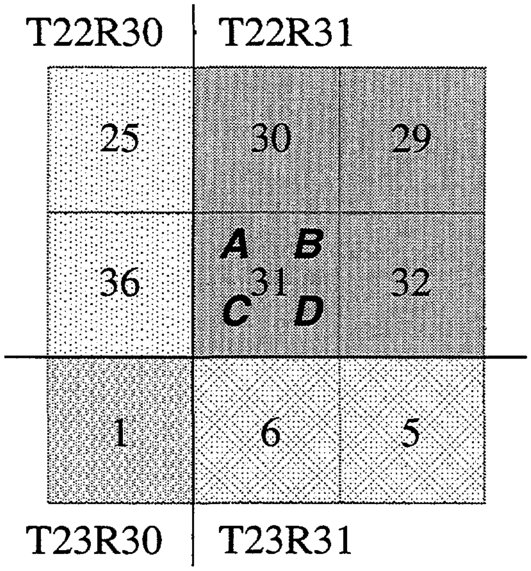

Figure C-2. Example of township, range, and section quadrants used to define state-plane coordinates for well locations.

The following procedure was used to assign the location coordinates to each well:

If a well location was originally designated a certain distance from the section's north and east lines (e.g., Y-ft *fnl*, X-ft *fel*), the well was assumed to be located in that section's B quadrant. Thus, referring to the example in Figure C-2, the northeast corner of T22, R31, S31 would be used as the coordinate reference point. The coordinates for this point would be calculated as follows:

Section 31 northeast corner X coordinate - (X-ft *fel*) = X coordinate of well location,

and

Section 31 northeast corner Y coordinate - (Y-ft *fnl*) = Y coordinate of well location.

If a well location was originally designated a certain distance from the section's south and east lines (i.e., *fsl,* and *fel*), the well was assumed to be located in the section's quadrant D. Thus, again referring to Figure C-2, the northeast corner of Section 6 would be used as the reference point to determine the X and Y coordinates for the well. These would be calculated as follows:

Section 6 northeast corner X coordinate - (X-ft *fel*) = X coordinate of well location,

and

Section 6 northeast corner Y coordinate + (Y-ft *fsl*) = Y coordinate of well location.

If a well location was originally designated a certain distance from the north and west lines (*fnl, fwl*), the well was assumed to be located in quadrant A. Thus, using the northeast corner of Section 36 as the reference point, the well's X and Y coordinates would be calculated as follows:

Section 36 northeast corner X coordinate + (X-ft *fwl*) = X coordinate of well location,

and

Section 36 northeast corner Y coordinate - (Y-ft *fnl*) = Y coordinate of well location.

Finally, if a well location was originally designated a certain distance from the south and west lines (*fsl, fwl*), the well was assumed to be located in quadrant C. Thus, the northeast corner of Section 1 would be used as the reference point to determine the well's X and Y coordinates, as follows:

Section 1 northeast corner X coordinate + (X-ft *fwl*) = X coordinate of well location,

and

Section 1 northeast corner Y coordinate + (Y-ft *fsl*) = Y coordinate of well location.

It should be noted that, in some cases, the sections south or west of the well location were in a different Township or Range. This was taken into account in the calculations when determining the X and Y coordinates of these wells.

Data Reformatting and Standardization

Information from the 548 well records in the Dwights database was originally downloaded onto an Excel spreadsheet. Much of the information needed to be reformatted prior to importing to Arcview. Dates originally entered as string characters were reformatted to date values. Data strings consisting of numbers were reformatted to numeric values. In addition, elevation and depth fields were standardized so that all measurements were represented as feet below ground level rather than using the reference points in the Dwights database (kelly bushing (KB) and derrick floor). KB standard adjustment factors (see Table C-1) were used in calculating the new depths because many wells did not have recorded KBs. These adjustment factors were derived from typical rig sizes used to drill wells of various depths. New well depths and elevations were calculated as follows:

The KB adjustment was subtracted from the total depth recorded on the USGS spreadsheet. For example, a well with a depth recorded as 8,050 feet was assumed to have a KB height of 15 feet. The new depth would be calculated as 8,035 feet (8050 ft – 15 ft) below ground level. Similarly, the depth at the base of each casing string was converted into a depth below ground level.

Table C-1. KB Adjustment Factors Used to Standardize the Well Depths from the Dwights/Petroleum Information Discover Scout Database

Depth (ft)	KB Adjustment (ft)
0 - 7,000	11
7,001 - 9,999	15
10,000 - 13, 999	20
≥ 14,000	25

Analyses

Analyses were performed on the well data obtained from the Dwights/Petroleum Information Discover Scout database. This is the most comprehensive commercially available database available on petroleum wells drilled within a 10-mile radius of WIPP. Well data from Dwights was incorporated into a GIS for map display and query purposes using Arc/Info and Arcview software. The Dwights well data consisted of well category and hydrologic, geologic, geographic, and drilling parameters. Examples include total well depth, stratigraphic units encountered and their depths, porosity of the various strata, latitude and longitude coordinates, drilling company, dates of drilling activity, casing sizes, and depths installed.

Arcview allowed for defining the spatial relationships between attribute data in the Dwights database and provided a graphic interface that could be used to develop queries and display the well information in a variety of different formats. For example, it is possible to query information on oil, gas, and injection wells drilled to depths greater than 2,000 ft prior to 1990 within two miles of the WIPP repository and then display and print the results in a combination of formats (e.g., tables, bar-charts, pie-charts, line graphs, scatter plots) and/or as a map. Spatial relationships evaluated in this study included those for geographic references to various well categories, stratigraphic unit depths, and well casing sizes.

Dwights Database

The Dwights/Petroleum Information Discover Scout database contained 11 well types: 1) gas, 2) oil, 3) dry and abandoned, 4) disposal, 5) wells in progress (currently being drilled but not yet completed), 6) injection, 7) plugged and abandoned, 8) shut-in, 9) suspended, 10) canceled (permit issued but then canceled), and 11) unknown wells. The database contained 548 records for wells located within a 10-mile radius of WIPP. These 548 records consisted of 517 unique well locations. There were more well records than actual well locations for two reasons: 1) some wells were redrilled at later dates to greater depths, and 2) some wells were recharacterized after drilling (e.g., some wells originally categorized as gas wells were later recategorized as oil wells if they were drilled to new horizons after depletion of the original reservoir). In either case, records pertaining to the same well location were assigned different names (e.g., American Petroleum Industry (API) numbers or Dwights ID). Information on all 548 well records can be plotted in the Arcview program so that if a specific well location is selected using Arcview's interface, data associated with several well records in the same location can be observed simultaneously.

Data on the total depths for each well type were generated directly from information queried through Arcview. The minimum and maximum total depths were recorded, and the median total depth for each well type and the standard deviations were calculated (see Table C-2). Note that approximately 5% (29 of 548) of the well records in the database did not have recorded total depths.

Table C-2. Summary of Well Types and Total Depths for Well Records in the Dwights Petroleum Well Database

	Number of Well Records			Well Total Depth Values for Wells with Depths > 0 (feet below ground level)			
Well Type	Total	Wells with Unrecorded Total Depth	Wells with Recorded Total Depth	Maximum Total Depth	Minimum Total Depth	Median Total Depth	Standard Deviation (feet)
Canceled	1	1	0	-	-	-	-
Dry & Abandoned	16	0	16	15,200	650	6,366	5,103
Disposal	8	0	8	15,935	5,040	8,435	3,518
Gas	49	1	48	17,624	8,877	14,786	1,027
In Progress	13	13	0	-	-	-	-
Injection	4	0	4	10,133	4,933	6,342	2,421
Oil	409	0	409	16,275	4,901	8,410	1,831
Plugged & Abandoned	25	1	24	15,375	44	8,120	4,387
Shut in	1	0	1	14,808	14,808	14,808	-
Suspended	5	0	5	14,690	6,371	9,035	3,052
Unknown	17	13	4	14,175	7,545	8,596	3,015
Total	548	29	519				

Well records in the ArcView database were summarized for each well category by maximum internal casing diameter in the Salado formation (the formation in which the WIPP repository is located). The following assumptions were made prior to performing the analysis:

1) The Salado formation exists between the depths of 1,500 and 4,500 feet below ground level within a 10-mile radius of WIPP.

2) All well depth values are measured from the KB.

3) The largest casing diameter per well also contains a nested set of smaller casings. The maximum well casing diameter that existed between the depths of 1,500 and 4,500 feet below ground level for each well record was used in the analyses.

Table C-3 shows the number of wells for each well type by maximum recorded internal casing diameter between the depths of 1,500 and 4,500 feet below ground level for well records in the database. As shown in Table C-3, 71% of the wells in Dwights database had a casing diameter of 8.625 inches between 1,500 and 4,500 feet below ground level, 8% had a casing diameter of 9.625 inches, and all known other casing diameters accounted for less than 12% of the total. Oil wells with a casing diameter of 8.625 inches accounted for 66% of the total well records in the database.

Bar graphs showing the number of wells for the various casing size categories are represented in Figures C-3 through C-6. Figures C-7 and C-8 are summary bar charts of all casing size categories for all 548 well records and for 409 oil well records, respectively. Figure C-9 summarizes the casing sizes for oil and gas wells of known casing size.

Note that, because the petroleum well data was compiled and summarized to assist with the identification of analogs to potential wellbore enlargement at WIPP during inadvertent intrusion, the use of the maximum recorded casing size was considered sufficient to generate this preliminary statistical information.

Table C-3. Number of Records for Each Well Type by Maximum Recorded Casing Size Between the Depths of 1,500 and 4,500 Feet Below Ground Level for Well Records from the Dwight's Petroleum Well Database

Well Type	Total	Number of Well Records: Maximum Casing Size Between the Depths of 1,500 and 4,500 Feet Below Ground Level (inches)										
		2.8	5.5	7	8.375	8.625	9.625	10.75	11	13.375	20	Casing Size Unknown
Canceled	1	-	-	-	-	1	-	-	-	-	-	-
Dry and Abandoned	16	1	-	-	-	1	-	-	1	3	1	9
Disposal	8	-	3	-	-	1	-	-	-	1	-	3
Gas	49	-	-	-	-	3	30	8	-	-	-	8
In Progress	13	-	2	-	-	2	-	-	-	-	-	9
Injection	4	-	1	-	-	2	-	-	-	-	-	1
Oil	409	-	7	1	1	361	8	8	-	2	-	21
Plugged & Abandoned	25	-	-	1	-	12	2	1	-	1	-	9
Shut-In	1	-	-		-	-	1	-	-	-	-	-
Suspended	5	-	1	-	-	2	1	-	-	-	-	1
Unknown	17	-	-	-	-	4	2	-	-	-	-	11
Total Number of Wells	548	1	14	2	1	389	44	17	1	7	1	72
Percent of Total	100	<1	3	<1	<1	71	8	3	<1	1	<1	13

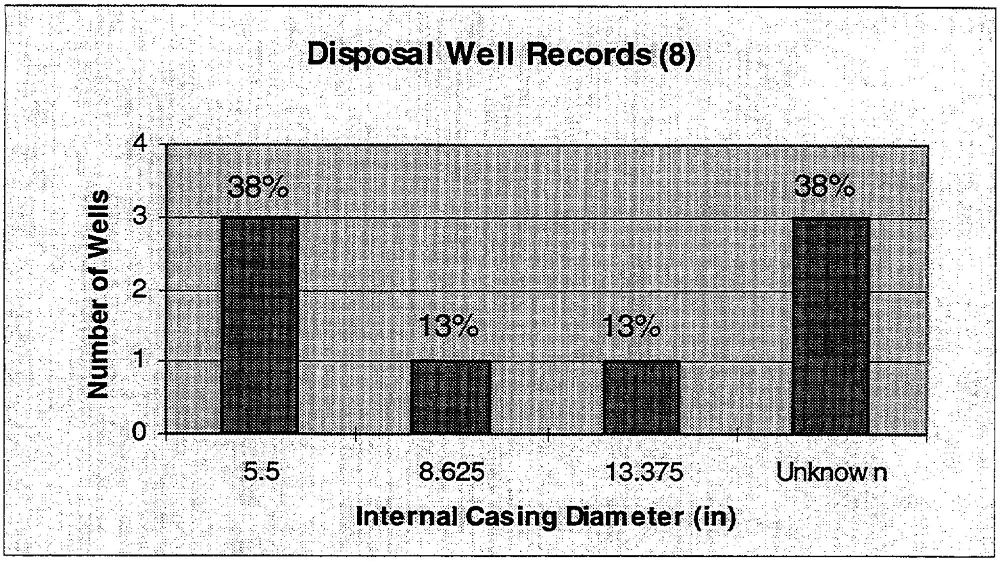

Figure C-3. Number of disposal wells within a 10-mile radius of the WIPP site by internal casing diameter (based on information from Dwights/ Petroleum Information Discover Scout database).

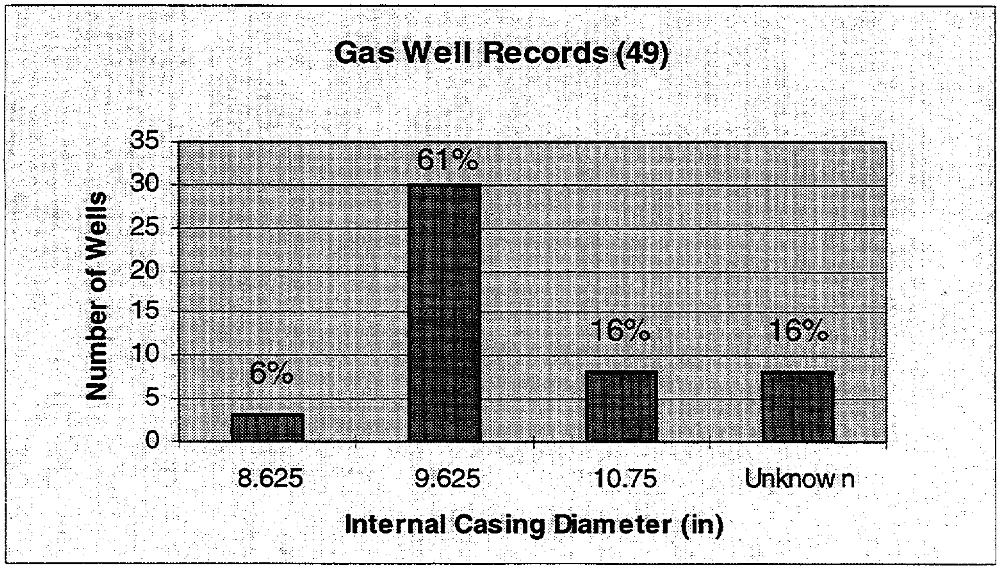

Figure C-4. Number of gas wells within a 10-mile radius of the WIPP site by internal casing diameter (based on information from Dwights/ Petroleum Information Discover Scout database).

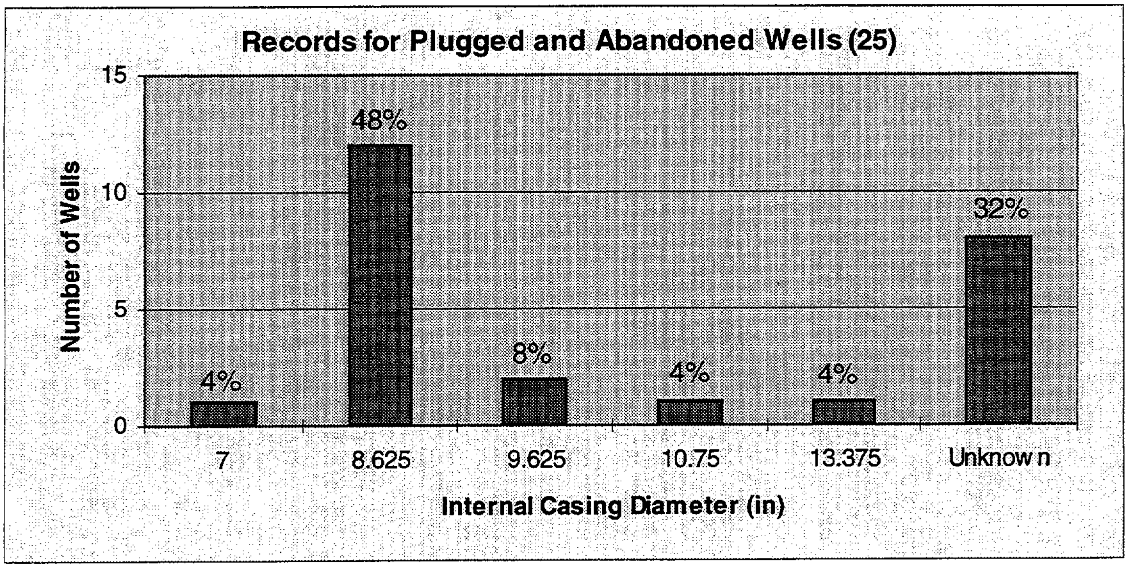

Figure C-5. Number of plugged and abandoned wells within a 10-mile radius of WIPP by internal casing diameter (based on information from Dwights/Petroleum Information Discover Scout database). Casing diameter is the largest recorded for each well record between 1,500 and 4,500 feet below ground level.

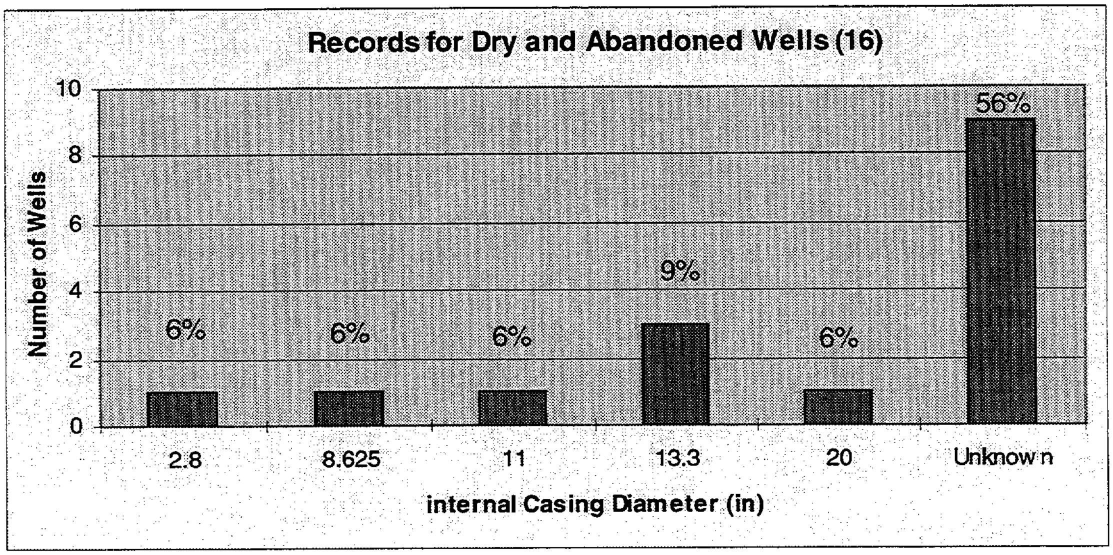

Figure C-6. Number of dry and abandoned wells within a 10-mile radius of WIPP by internal casing diameter (based on information from Dwights/Petroleum Information Discover Scout database). Casing diameter is the largest recorded for each well record between 1,500 and 4,500 feet below ground level.

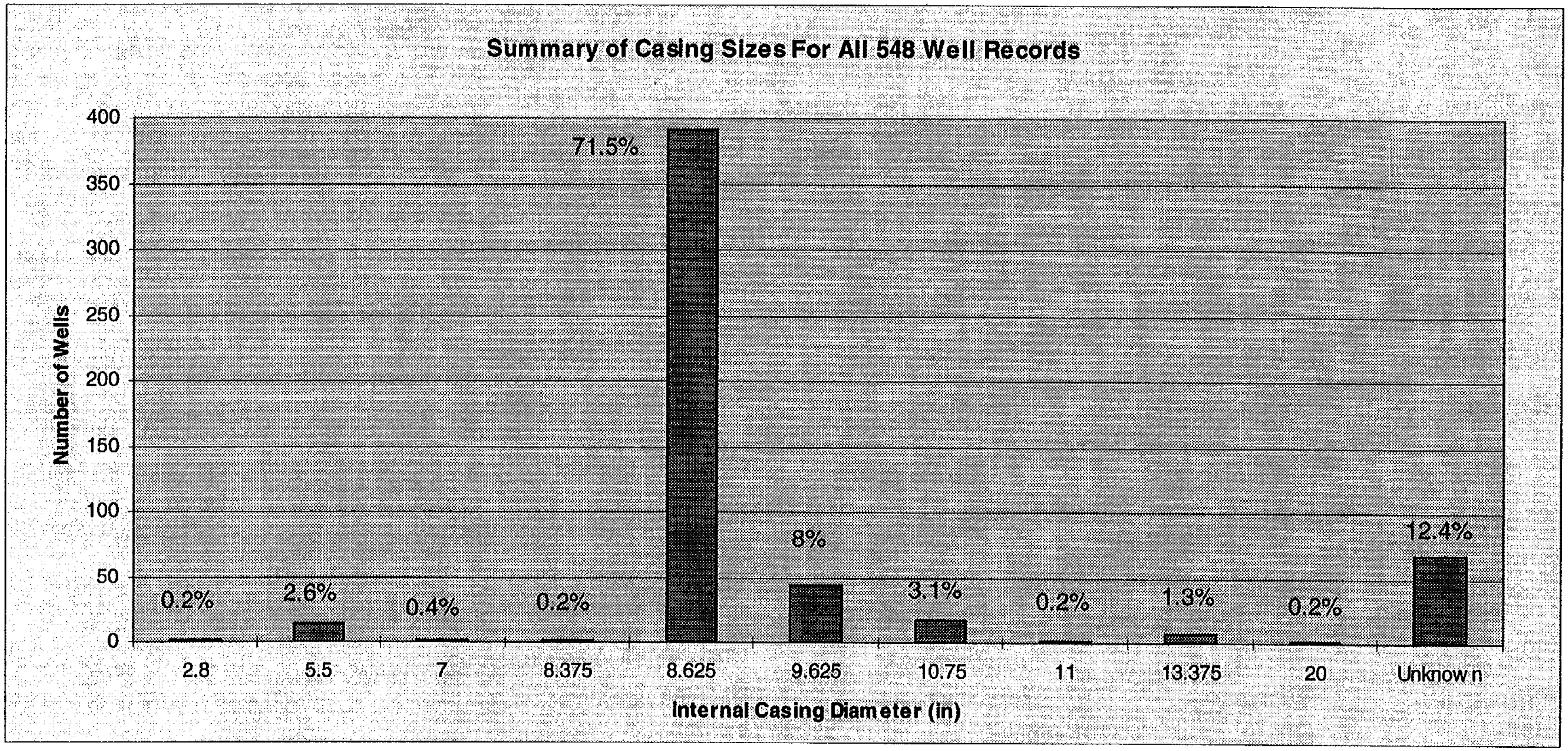

Figure C-7. Summary of internal casing diameters for all 548 well records (based on information from Dwights/Petroleum Information Discover Scout database). Casing diameter is the largest recorded for each well record between 1500 and 4500 feet below ground level.

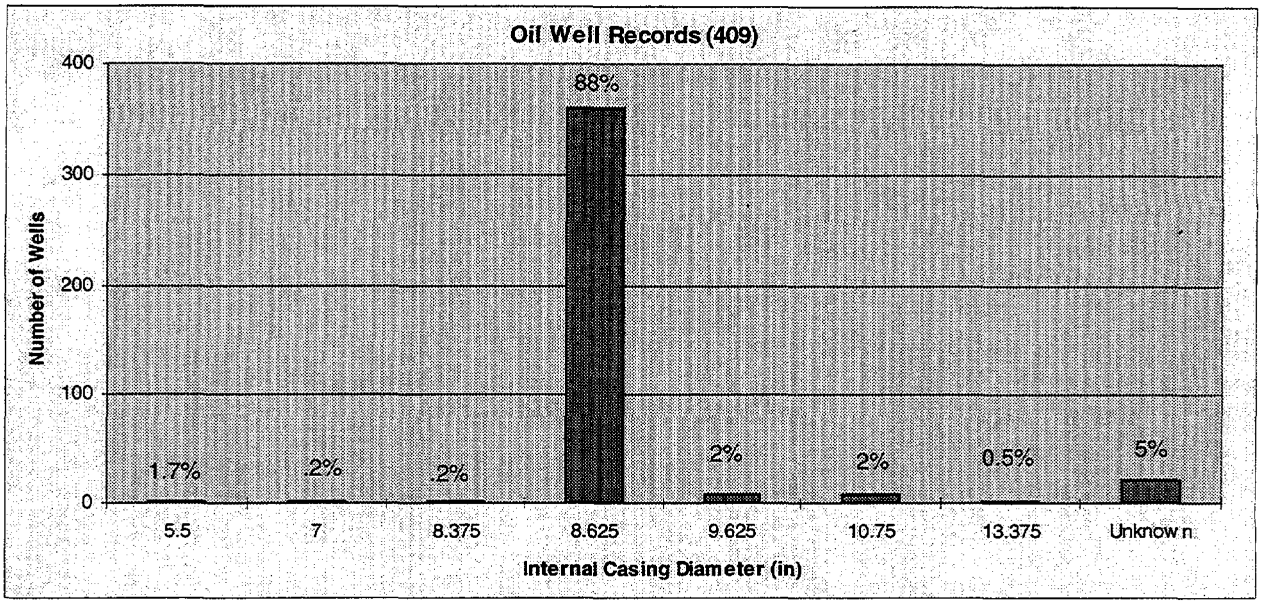

Figure C-8. Summary of internal casing diameter for oil wells within a 10-mile radius of WIPP (based on information from Dwights/Petroleum Information Discover Scout database). Casing diameter is the largest recorded for each well record between 1,500 and 4,500 feet below ground level.

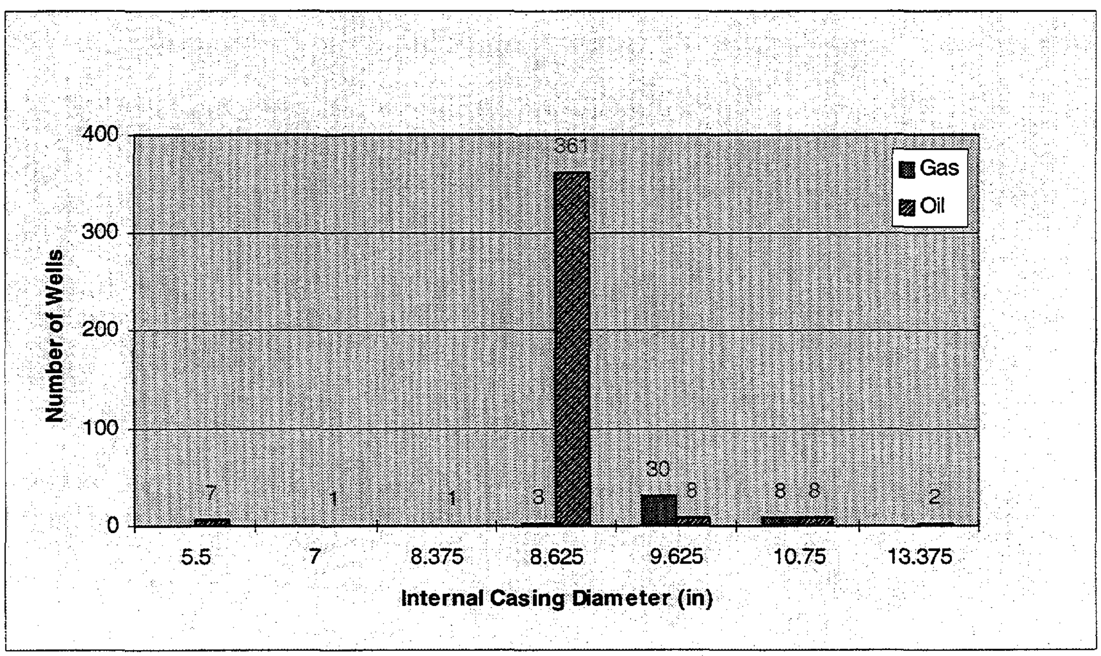

Figure C-9. Summary of internal casing diameter for oil and gas wells with known casing size (based on information from Dwights/Petroleum Information Discover Scout database). Casing diameter is the largest recorded for each well record between 1,500 and 4,500 feet below ground level. (Note that the data for oil casing size 5.5 are questionable for six of the seven wells indicated.)

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