HAWAII GEOTHERMAL

BLOWOUT PREVENTION MANUAL

Circular C 125

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January 1994

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ACKNOWLEDGEMENT

This document was prepared by R. A. Patterson & Associates, Kailua, Hawaii, for the Hawaii Department of Land and Natural Resources under Contract Agreement No. RCUH P. O. 4361021. The work was performed by **Ralph A. Patterson, William L. D'Olier, and Herbert E. Wheeler**. We wish to gratefully acknowledge the assistance of the staff of the Division of Water and Land Development, under the direction of **Manabu Tagomori**, and of the invaluable suggestions and assistance of all those who discussed the project with us.

Development of this Manual would not have been possible without the willing cooperation of many managers, technicians and professionals in the geothermal industry, various laboratories and academic institutions, and in other areas where their knowledge was helpful in presenting the review and recommendations of the Manual. The authors wish to acknowledge their help and candor, and their accumulated knowledge that has made our job easier.

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PREFACE

The prevention of an uncontrolled well flow, commonly known as a "blowout", is of vital importance for geothermal operators, drilling crews, state and county regulators, and the general public. Geothermal well blowouts have not been the cause of a significant number of fatalities, and the danger of fire, as in petroleum drilling, is quite low. However, blowout incidents may have a negative impact on surface and subsurface environments, cause resource waste, and develop unfavorable public perceptions of geothermal activity. These concerns are powerful incentives to operators and regulators to minimize the risks of a blowout.

This Manual has been developed to promote safety and good resource management by discussing and describing blowout prevention as it can best be practiced in Hawaii.

The intent of this Manual is to provide the necessary information to guide regulators and operators in the practices and procedures, appropriate to each drilling situation, that will minimize the risks of a blowout. The Manual is also intended to promote an informed flexibility in blowout prevention practices, and to supplement State and County regulations, especially those pertaining directly to drilling permits and operations.[1]

This first edition of the Blowout Prevention Manual is a likely candidate for revision as more drilling experience and information is gathered in the exploration and development of Hawaii's geothermal resources.

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[1] Department of Land and Natural resources (DLNR) Title 13, Subtitle 7. Water and Land Development; Chapter 183.

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I. SCOPE

The material in this Manual has been extracted from many key information sources in order to present a complete and accurate review of the practices of geothermal well control in Hawaii. In developing this Manual, a careful review of drilling to date in the Kilauea East Rift Zone (KERZ) was conducted. The KERZ is where nearly all Hawaii geothermal drilling has taken place, and is where most experts believe the geothermal resources will be developed.

The general belief in the industry is that each area is "unique", since each prospective geothermal area throughout the world has proven to have its own characteristics in terms of drilling conditions, resource chemistry, geology, etc. While this may be true in detail, some similarities do exist among geothermal areas located in, or nearby, active volcanic areas. Thus, it has been helpful to briefly review well control techniques and experiences from other similar volcanic areas around the world. Some of the information gathered may have an influence on geothermal drilling in Hawaii.

In order to review the experiences in Hawaii and in other geothermal areas where active vulcanism is prevalent, a great number of specific publications and selected references were consulted. Many of these are listed in **Appendix C, References.** In addition, much of the information and many recommendations contained in this Manual came from the accumulated experience of others who were consulted on various elements of the items presented. A partial list of those consulted is also contained in **Appendix C.**

This Manual defines a blowout prevention strategy for geothermal drilling in the State of Hawaii. The essential components of this strategy are:

1) **Improved risk analysis and well planning.**
2) **Sound selection of blowout prevention stacks and associated equipment.**
3) **Rigorous use of drilling monitoring procedures.**
4) **Expertise in kick control and blowout prevention equipment utilization.**
5) **Excellence in supervision and training of drilling personnel.**

II. GEOTHERMAL DRILLING RISKS IN HAWAII

THE VOLCANIC DOMAIN

The State of Hawaii consists of a chain of volcanic islands. Each island is a composite of several volcanic eruptive centers built up by a succession of basaltic lava flows, first as submarine deposits and subsequently as volcanic lands (or subaerial deposits.) These basaltic lava flows form a sequence of near horizontal layers consisting of hard crystalline flow rocks interbedded with lesser amounts of highly variable rock debris. These flow sequences are evident in extensive outcrops and in lithology logs from water well drilling.

Recently recognized geothermal resources in Hawaii are characterized by relatively small prospective areas which are strongly associated with active or recent volcanism. The highest probability areas for geothermal development overlie the volcanic rift zones which are, or recently were, deep conduits for magma transport away from the volcanic eruptive center. Hawaiian geothermal drilling to date has been confined to the active Kilauea East Rift Zone (KERZ). In the KERZ, the magma and lava processes (1900°F and higher) provide very high subsurface temperatures. Large amounts of meteoric water (groundwater) and seawater intrude into the KERZ geothermal resource zones, providing an abundant fluid supply for heat transfer.

Geothermal drilling in Hawaiian rift zones involves distinctive risks. A reasonable initial identification of hazards and risks is now possible due to KERZ drilling experience, combined with extensive studies by the Hawaii Volcano Observatory (HVO) of KERZ rift zone function, structure and dynamic processes. This experience and knowledge can be used to refine geothermal drilling programs and procedures to minimize the risks of upsets and blowouts.

KERZ DRILLING TO DATE

The most valuable subsurface information for this Blowout Prevention Manual comes from 12 deep geothermal wells and three exploratory slimholes drilled in the KERZ since

1975. Rotary drilling rigs appropriate to the drilling objectives were used on the twelve geothermal wells. Common drilling fluids used in this rotary drilling are mud, water, aerated fluids and air. The well depths range between 1,670 and 12,500 feet below the ground surface. Operators for the well drilling included four private resource companies and one public sector research unit.

As of mid 1992, nine wells had penetrated prospective high temperature rocks and seven of these were flow tested or manifested high temperature fluids. The resource discovery well, HGP-A, completed in mid-1976, provided steam to a 3MW demonstration electrical generation plant between 1981 and 1990. Two of the nine wells incurred casing contained blowouts in 1991 upon unexpectedly encountering high pressured geothermal fluids at shallow depths.

Three deep scientific observation holes (SOH) were drilled for resource evaluation as continuously cored exploratory slimholes to 5,500-6,800 foot depths in 1990 and 1991. These SOHs helped to prove that favorable high temperatures prevail over a ten mile interval along the KERZ. These holes did not encounter subsurface conditions that involved significant blowout risks; however, special blowout prevention equipment must be considered for future use of the slimhole technology in Hawaii.

SUBSURFACE CONDITIONS IN PROSPECTIVE AREAS

High temperatures, commonly in the 600-700°F range, are characteristic of production zones in the volcanically active rift zones. The prospective geothermal reservoir occurs in the roof rock above the deeper magma conduits. The well completion targets are loci of permeable, highly conductive fault and fracture zones which are generally enclosed by extensive secondary mineralization. Magma transport downrift and its planar injection upward into the roof rock are the primary heat sources for the geothermal resource.

The primary hazard of geothermal drilling in the volcanically active KERZ is the currently unpredictable distribution of fault planes and major fractures. The walls of these geologic structures are commonly sealed by secondary mineralization; thus creating conduits for geothermal fluids. These fault and fracture conduits, can present pressures in the range of 500 to 750 psi above normal hydrostatic pressure, particularly as they extend upward into cooler ground water regions. Unexpected entry into such over pressured fault planes and fractures can cause substantial upsets to all well control procedures.

Primary features such as lava tubes, irregular layers of ash, and rubble contribute to very high horizontal permeability, whereas secondary features such as fractures contribute to very high vertical permeability; both features can pose a problem with loss of drilling fluid circulation and low rock strengths. These features seem to diminish downward, but appear to extend to depths of about 2000 feet.

An important feature of the KERZ is the seaward slip-faulting of its southeastern flank caused by cross rift extensional stress. This seaward sliding of the roof rock, coupled with seismicity, results in molten dike intrusions and fracturing. Dike intrusions allow an abundant supply of heating and create prospective fracturing for the geothermal reservoir. All these features further contribute to low rock strengths in shallow, near surface volcanics, which can be a problem when attempting to locate a sound anchor for wellhead blowout prevention equipment.

The geohydrology of the KERZ involves large volumes of groundwater and seawater. The relatively cool groundwater body, located just above sea level, is maintained by high annual rainfall and a high rate of infiltration. The KERZ geothermal fluid system also may be fed by a major groundwater basin on Mauna Loa's eastern flank. Large volumes of seawater have the potential to penetrate the geothermal reservoir through fractures at depth. Earthquakes in the region may cause existing fractures to widen or may create new fractures. An increase in the salinity of the fluids produced by the HGP-A well may have been caused by earthquake induced fractures. High hydrostatic pressures prevail in active rift zones, but these can be escalated to higher fluid pressures in the temperature conditions prevailing. The fresh and saline groundwater body, shown to exist as deep as 2,500 feet in the Puna geothermal field, may prove to be a common condition, but not one that can be expected at every proposed well location.

SUMMARY

The KERZ geothermal drilling experiences prove two significant hazards that must be addressed in a blowout prevention strategy for every proposed well:

1. Significant fault and fracture planes can be sealed conduits for overpressured geothermal fluids. These features might eventually prove to be predictable or detectable by drilling precursors. Blowout prevention planning, equipments and procedures must be taken as a critical requirement, ready for immediate and proficient use.

2. Weak and broken near surface volcanic rocks. The recognition of this condition is a precursor to obtaining a reliable casing anchor, which is fundamental to safe blowout prevention by complete shut off (CSO) of the well.

III. GEOTHERMAL WELL PLANNING

INTRODUCTION

The proven higher costs and uncertainties of Hawaiian geothermal drilling operations are sound reasons to make an extraordinary investment in well planning. Detailed planning is a must for each and every type of well because of the paucity of subsurface information and the small base of drilling experience to date. Blowout prevention is an integral element of geothermal well planning.

WELL PLANNING OBJECTIVES

Safety The concept of safety must be carefully applied for all workers and activities at the well site and for the public. A blowout prevention strategy is a crucial part of any successful practice of safety in geothermal drilling; it is a necessity in Hawaii.

Well Function Geothermal wells, if beneficial development is to be attained, must convey and control very large quantities of fluid and energy, hopefully for the greater part of the 30-year life that is expected in electric power systems. The HGP-A discovery well demonstrated a reasonable performance in the production mode from 1983 to 1990.

Reasonable Cost Hawaiian geothermal wells are in the very costly category; perhaps $2,500,000 per well is a representative minimal cost (1992$) if no significant problems impact a good drilling plan. Competent planning might cost only 1 or 2% of the total cost of a successful well.

High quality well planning will assure a greater degree of safety and improved well functions. Proper well planning will allow the Operator to be more confident in responding to the upset conditions that can't be avoided and actual drilling performance can be better assessed for continued improvements in future Hawaiian geothermal wells.

DRILLING TARGETS AND WELL TYPES

Geothermal drilling targets in the volcanic realm of Hawaii can be organized into three simple classifications:

Exploration targets - to discover the resource, are generally identified by a favorable combination of subsurface data indicating heat, fluids and fractures (voids). Targets that can win drilling funds, but which present a high risk exposure, are usually classified as exploratory by the Operator and participants.

Reservoir targets - to develop the resource, are generally qualified by high temperatures, indicated fault planes and fracture systems, or by nearby well production data. The probability of penetrating both high temperatures and fluid producing permeability intervals is high. Hawaiian geothermal reservoirs are of the hydrothermal type (the predominate type now in worldwide utilization.)

Supplemental targets - to conduct research on the resource, are comprised of scientific and/or observational objectives which can contribute to a better understanding of a geothermal resource and its enclosing subsurface environment.

At the present level of knowledge in Hawaiian rift zones, no class of geothermal drilling target can be confidently identified to have lower blowout risks. Off rift geothermal drilling targets may offer the perception of lower drilling risks, however, no such drilling has been undertaken as of 1992.

Geothermal wells can be categorized as to function and several additional features. The common types of wells include the following:

Exploration well. Any well drilled to evaluate a prospective geothermal resource target, usually at some significant distance from an established or proven geothermal reservoir. Hard and proximal subsurface data are not likely to be available for a blowout prevention plan; diligent drilling monitoring procedures (see Section VI) and casing plan flexibility are essential to blowout risk reduction in exploration wells.

Production well. Any well designed to exploit the energy and fluids of a geothermal reservoir for beneficial use or demonstration purpose. Blowout prevention plans for production wells can be better specified to more confidently known subsurface conditions.

Injection well. Any well designed to return geothermal effluent to the reservoir or other deep disposal zones. Injection wells will have blowout prevention requirements similar to nearby production wells.

Slimhole. This type of geothermal well is identified by its small diameter borehole, 6 to 4 inches, compared to the 17½ - 8½ inch hole diameter range commonly used worldwide in the geothermal industry. The slimhole technology, presently surging in evaluation and use in the petroleum industry, has a distinct blowout risk and prevention requirement. The technology has been safely introduced in the KERZ when HNEI accomplished three continuous boreholes between 5500 and 6000 foot total depths in its Scientific Observation Hole Program (1989-91). Discussion of the blowout prevention in slimholes is presented in Section XII.

Deep versus shallow wells. These are terms of convenience in their general usage; however, regulations may impose a legal definition on them. A historical point of interest in the KERZ should be noted; several early geothermal exploration holes, drilled safely with cable tools, encountered near boiling waters at very shallow depths next to recent lava flow fissures and vents. Depth seems to have no correlation with blowout risk in Hawaii's geothermal drilling to date. However, it should be evident that relatively shallow blowouts in the porous surface lava rocks and large fissures, broadly prevailing in Hawaii, could be particularly difficult to kill.

Vertical versus deviated wells. It appears that Hawaiian geothermal well fields will be extensively developed with deviated wellbores. Blowout prevention requirements are not altered in any type of geothermal well by the vertical or deviated course of its wellbore.

THE DRILLING PLAN

Every geothermal well proposed for funding and permitting will require a drilling plan. Regardless of the geothermal well type, the drilling plan is the specific technical document that should reflect the best thinking on how the well can be safely constructed and its function obtained at reasonable cost. Safety is considered on a broad front in a carefully prepared drilling plan. The deliberate actions to optimize safety in geothermal drilling commonly will be specified or reflected in four distinct sections of the drilling plan, as follows:

1. <u>Casing and cement.</u> The intended function of the proposed well will be a factor in casing design and cementing procedures selected. However, the best available subsurface data sets on geology, hydrology, pressure and temperature profiles, formation failure thresholds (fracture gradient), together with the well site elevation, comprise the basis for increased safety in drilling and quality of construction. The subsurface conditions and well site elevation are unique to each intended wellbore; the proposed casing and cement plan must reflect a reasonable response to these conditions. KERZ drilling experience reveals several special casing concerns for blowout prevention.

   a. A preference to cement the surface casing (commonly 20 inch diameter) below the water table can be acknowledged. Where the groundwater table is within 600-800 feet below the surface, an approximate 1,000 foot length of surface casing would meet this objective. Where the groundwater table is much deeper, it could be difficult to obtain a good cement sheath on surface casing set at, say

1,700 feet, because of the presence of lost circulation zones and incompetent rock in which to cement the casing shoe. Prudence suggests that it is better to obtain a quality cement sheath on a shorter length of surface casing.

b. Independent of the quality of cement sheath obtained on surface casing, the possibilities of fractures, other permeable paths to the surface, and low formation fracture gradients exist in the near surface volcanic rocks penetrated by the surface casing. This points to a serious risk in using a **complete shut off (CSO)** blowout prevention system on the surface casing while drilling to the intermediate casing depth. A CSO could force unexpected hot and possibly pressured formation fluids to an external blowout (outside the surface casing and cellar). External venting of this type can pose more complex and precarious kill operations, and also threaten the drilling rig's ground support. Accordingly, a diverting capacity and large diameter flow line from the wellhead to a distant disposal point is to be considered. This approach would contain such an uncontrolled flow inside the surface casing and afford a safer kill procedure confined to the wellbore.

c. Intermediate casing (commonly 13-3/8 inch diameter) may be set at depths between 1,000-2,500 feet below the surface casing shoe if no unexpected geothermal fluids or anomalies are encountered. The intermediate casing shoe depth should optimally be below the major groundwater body. It should also be below extensive fracturing that may reach up to the groundwater table, frequent occurrence of lost circulation zones, and less competent volcanic rock. Because the intermediate casing becomes the anchor casing for the complete BOP equipment stack required to drill to total depth, it is critical that the cement sheath in the open hole (17½ inch diameter) annulus be of the highest possible quality. The findings in the 17½ inch drilled hole should be carefully studied. Any adverse downhole conditions can be mitigated by cementing the bottom portion of the intermediate casing as a liner in the open hole interval (lapped several hundred feet into the bottom of the surface casing). The upper portion can be run and cemented as a tie back string inside the surface casing. Each of the two cement jobs required should be of enhanced quality, should offset the external natural hazards and should optimize the anchor for the complete BOP equipment stack with its multiple CSO capacity over a full range of drilling fluids.

2. **Drilling fluids**. The subsurface conditions encountered within the KERZ are prompting the use of many drilling fluids ranging from moderate to low density muds, water, aerated muds and water, to foam, and air. Additionally, the ability to switch drilling fluids promptly is being recognized as a cost effective advantage in greater well control. This practice demands the use of BOP equipment compatible with a broad range of drilling fluid options in a single wellbore. The diversity and flexibility of drilling fluid utilization in Hawaii is encouraging, not only because all fluids can be controlled by available BOP equipment, but because this approach should lead directly to advanced safety margins, reduced drilling times and lower costs. Drilling fluids and geothermal well control are further discussed in Section VI.

3. **Drilling Monitoring.** This activity is usually integrated in thorough drilling plans at many points. It is, however, quite important and deserves more recognition as an effective method to reduce blowout risks. A detailed consideration of drilling monitoring procedures is presented in Section VI.

4. **Blowout Prevention.** Drilling plans may contain minimal specific discussion of blowout prevention; a graphic sketch of the proposed BOP equipment stack may be the lone obvious recognition of the subject. However,

a competent drilling plan will reflect, in its detailed provisions, an Operator's blowout prevention strategy. The implementation of risk reduction will be evident in the casing, cementing and drilling fluid provisions, in the drilling monitoring procedures, in proper training, and finally in the BOP stack and its supplemental equipment. The drilling plan should reveal the Operator's awareness that a blowout can happen, and reflect the drilling supervisor's responsible determination that it has been given the least possible chance to occur in the proposed well. Blowout prevention is every Operator's final responsibility; it is achieved first in the thinking and actions of all drill site personnel through training, by the practice of sound procedures, and by the use of reliable, proper equipment.

IV. BLOWOUT PREVENTION STACKS AND EQUIPMENT

INTRODUCTION

Hawaii's geothermal drilling industry, still in a formative stage, has gained sufficient experience and information to provide reasonable guidance to the identification of more reliable and safer blowout prevention stacks and equipment. The blowout prevention stack on the wellhead, when all other well control procedures have failed, must function reliably to obtain a complete closure or effective control of unexpected fluid flows from the wellbore. Blowout prevention stacks and related equipment are not simple systems; they rely on integrated mechanical, hydraulic and electrical processes to operate. Both redundancy and sophistication exist; however, the risks of human error in critical situations have not been eliminated. Blowout prevention systems require careful selection, maintenance, and repetitive training of drilling crews to attain the reliability and safety which are essential in the final defense against an actual blowout.

BOP DEFINITIONS AND FUNCTIONS

1. Definitions

- The term **blowout prevention equipment (BOP)** here means the entire array of equipment installed at the well to control kicks and prevent blowouts. It includes the BOP stack, its activating system, kill and choke lines and manifolds, kelly cocks, safety valves and all auxiliary equipment and monitoring devices. (see Glossary in Appendix D for these terms).

- The **BOP stack,** as used here, is that combination of preventers, spools, valves, and other equipment attached to the wellhead while drilling.

- A **diverter stack** is a BOP stack that includes an annular preventer, with a vent line beneath. A valve is installed in the vent line so that the valve is open whenever the annular preventer is closed, thus avoiding a complete shut off (CSO), and diverting the flow of fluids away from the rig and personnel.

• A **full BOP stack** is an array of preventers, spools, valves, and other equipment attached to the wellhead such that complete shut off (CSO) is possible under all conditions.

2. Functions

The main function of the BOP equipment is to safely control the flow of fluids at the surface, either by diversion or by complete shut off. The equipment must be adequate to handle a range of fluid types, pressures, and temperatures, and to accommodate different drilling situations such as active drilling and tripping, or while the drill string is out of the hole. The requirements of the BOP stack are to:

a. Close the top of the wellbore to prevent the release of fluids, or, to safely divert the fluids away from the rig and personnel.

b. Allow safe, controlled release of shut in, pressured fluids through the choke lines and manifold.

c. Allow pumping of fluids (usually mud or water) into the wellbore through kill lines.

d. Allow vertical movement of the drill pipe without release of fluids.

Selection of BOP stacks and equipment should be made jointly by an experienced geothermal drilling engineer and drilling supervisor. It is preferable to employ a supervisor that is experienced in Hawaii geothermal drilling experiences and conditions.

THE BOP ANCHOR

Complete shut off capability with a BOP stack requires the existence of a BOP anchor Three key factors are required for a sound BOP anchor:

1. A mechanically sound, continuous steel casing of reasonable length, which probably wil be 1000 feet or more, attached to the BOP stack.

2. A continuous and solid cement sheath in the annulus between the casing and the rock wall of the wellbore.

3. An impermeable rock interval around the wellbore and cement sheath. The entire section of rock need not be impermeable but priority is given to placing and cementing the casing shoe in a thick interval of competent and impermeable rock.

IMPACTS OF SUBSURFACE RISKS

Hawaii geothermal drilling has inherent risks due to the unpredictability of subsurface conditions. Recognizing the risks and being prepared for all possible conditions is the best form of blowout prevention. Subsurface conditions that may pose the risk of a well blowout are listed below:

1. The almost certain inability to obtain a sound BOP anchor with surface casing in the weak, often broken, and vertically permeable near surface volcanic rocks. As discussed in **Section II**, if a "kick" occurs, these shallow rocks will not allow a CSO at the wellhead without posing a significant risk of creating an externally vented well casing blowout. (For discussion of externally vented blowouts, see **Section VIII.)**

2. The unexpected entry, while drilling, into a major fault and fracture conduit which is charged with overpressured geothermal fluids. Termination and control of such events requires the certainty of a wellhead CSO with a full capacity BOP stack. [1]

The risk factors cited above reveal the importance of knowing when a BOP anchor and consequent CSO capacity are available to prevent a blowout. If they are not available, diversion

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[1] In the KERZ, sudden geothermal fluid flows, which subsequently registered 500 to 700 psi shut-in wellhead pressures, were encountered at depths shallower than expected; in one case as shallow as 1,400 feet.

of uncontrolled flows is judged to be the more prudent response. On these fundamental considerations, two basic BOP stacks are recommended for Hawaii geothermal wells which are drilled with rotary rigs for exploration, production or injection purposes.

BOP STACK RECOMMENDATIONS

1. Diverter Stack (Figure 1-Appendix B)

A diverter consisting of an annular preventer and a vent line should be installed on the surface casing. In Hawaii, this casing is typically 20 inches in diameter and is cemented in the 800 - 1,100 foot depth range. Incompetent near surface volcanic rock and the high risk of cementing failure will not provide an adequate BOP anchor for the surface casing. CSO is not intended with this equipment; diversion of fluids is deliberate to avoid creating externally vented blowouts, and for personnel and rig safety.

2. Full BOP Stack (Figure 2-Appendix B

A full BOP stack should be installed on the intermediate casing. In Hawaii, this casing i: typically 13-3/8 inches in diameter, and is cemented in the 2,000 - 3,500 foot depth range This deeper casing, cement sheath, and host rock serves as a BOP anchor. The selectioı and arrangement of this stack allows for the use of a full range of drilling fluids (muc water, aerated fluid, foam, air) and should be a geothermal industry premium stack that i capable of confident, immediate CSO over the range of temperatures and pressure anticipated. If a sufficient BOP anchor is not obtained, this stack also has diverter capacit because of the flow "T"/vent line, or banjo box/blooie line, included in the stack.

The BOP stack arrangement shown in Figure 2 is one of several combinations availabl Another possible arrangement is to remove the lowermost pipe ram shown in Figure 2 aı install it above the choke and kill lines, in tandem with the blind ram. A full BOP sta should be maintained at all times while drilling in the vicinity of the production zone.

ADDITIONAL RECOMMENDATIONS

1. Diverter stack. The diverter stack should have the following characteristics:

a. A minimum pressure rating of 2,000 psi for all components.

b. Minimum vent line diameter of 12 inches.

c. A full opening valve on the vent line that opens automatically when the annular preventer is closed; OR a 150 psi rupture disk and a normally open valve.

d. The vent line directed through a muffler.

e. H_2S abatement capability connected to the vent line.

2. Full BOP Stack. The Full BOP Stack should have the following characteristics:

a. A minimum pressure rating of 3,000 psi for all components. A pressure rating of 5,000 psi is recommended when indicated by the risk analysis of the well. **For temperature impacts on pressure ratings, see Figure 3 - Appendix B.**

b. Lower spool outlets - 2 inch diameter for a kill line and 4 inches for a choke line.

c. The pressure ratings for the kill and choke lines the same as the stack.

d. All preventers should have high temperature rated ram rubbers and packing units.

BOP EQUIPMENT RECOMMENDATIONS

1. Kill Line. 2 inch diameter kill line from pumps to spool. Two full opening

valves and one check valve at the spool. Fittings for an auxiliary pump connection; pressure rating for the kill line the same as the stack. The kill line is not to be used as a fill up line.

2. Choke Line and Choke Manifold. 4-inch choke line and manifold; pressure rating the same as the stack. Two full opening gate valves next to the spool; one of these valves remotely operated.

3. Actuating system. The actuating system should have an accumulator that can perform all of the following after its power is shut off:

a. Close and open one ram preventer.
b. Close the annular preventer on the smallest drill pipe used.
c. Open a hydraulic valve on the choke line, if used.

The actuating system is to be located at least 50 feet from the well, with two control stations - one at the drillers station on the rig and one at the actuating system location. Valves shown may be hydraulically or manually operated, as appropriate for the intended service. However, valves should be operable from a remote hydraulic control, or by mechanical extensions, if they are located where they are not readily accessible during a well control incident.

4. Other equipment. During drilling the following miscellaneous BOP equipment i to be provided:

a. Upper and lower kelly cocks and a standpipe valve.
b. A full opening safety valve, to fit any pipe in the hole. Kept on th rig floor.
c. An internal preventer, kept on the rig floor, with fittings to adapt to the safety valve.

d. Accurate pressure gauges on the stand pipe, choke manifold, and other suitable places that may see wellbore pressure.

e. All flow lines and valves rated for high temperature service.

V. EQUIPMENT TESTING AND INSPECTION

In general, a visual inspection and an initial pressure test should be made on all BOP equipment when it is installed, before drilling out any casing plugs. The BOP stack (preventers and spools, choke and kill lines, all valves and kelly cocks) should be tested in the direction of blowout flow. In addition to the initial pressure and operational test at time of installation, periodic operating tests should be made.

Pressure tests should subject the BOP stack to a minimum of 125% of the maximum predicted surface pressure. If the casing is tested at the same time then the test should not be more than 80% of minimum internal yield of the casing at the shoe. If a test plug is used, the full working pressure of the BOP stack can be tested; a casing test would be made separately. Testing of the actuating system should include tests to determine that:

1) The accumulator is fully charged to its rated working pressure;
2) The level of fluid is at the prescribed level for that particular unit;
3) Every valve is in good operating condition;
4) The unit itself is located properly with respect to the well;
5) The capacity of the accumulator is adequate to perform all necessary functions including any kick control functions such as hydraulic valves that are using the same unit for energy;
6) The accumulator pumps function properly;
7) The power supply to the accumulator pump motor will not be interrupted during normal operations;
8) There is an adequate independent backup system that is ready to operate properly; and
9) The control manifold is at least 50 feet from the well and a remote panel is located at the driller's station.
10) All control valves are operating easily and properly, have unobstructed access and easily identifiable controls.

The sequence of events to test the BOP stack and all other valves depends on the stack configuration, but it is important that all equipment is tested, including the annular preventer, pipe rams, CSO rams, upper and lower kelly cocks, safety valves, internal preventers, standpipe valve, kill line, choke manifold and choke control valve, pressure gauges, and any other items that are installed as part of the BOP equipment.

In addition to the testing of BOP equipment when it is first installed, there should be frequent BOP testing and drills. The closing system should be checked on each trip in or out of the hole and BOP drills should be held at least once a week for each crew. It is most important that every member of the crew be familiar with all aspects of the operation of the BOP equipment, along with all of the accessories and monitoring devices that aid in detection of a kick. The main purpose of drills is to train the crew to detect a kick and close the well in quickly. BOP drills should cover all situations while drilling, tripping, and with the drill string out of the hole.

VI. DRILLING MONITORING PROCEDURES

INTRODUCTION

Operators commonly provide for some level of monitoring in the drilling of most geothermal wells. All types of monitoring procedures will incur additional costs, which may limit the selection of specific procedures. However, most Operators determine the specific procedures in the context of what is known and not known about the subsurface environment to be penetrated by the wellbore. This discussion of monitoring will use the broad sense of the term, including mud logging.

Monitoring procedures may be defined as an array of continuous sensing actions which attempt to accurately indicate subsurface conditions as the drill bit is advancing through the rock formation.

MONITORING RATIONALE

Geothermal wells drilled within the prospective, active volcanic rift zones of Hawaii, merit carefully planned and integrated monitoring procedures. This view is supported by two primary concerns. First, the subsurface geology, hydrology, temperatures and pressures in the rock roof above the deep magma conduits, which create the rift zone, are only partially known. Only 14 deep geothermal bores (11 wells and three scientific observation holes) have provided hard, factual subsurface data as of mid-1992. Secondly, two geothermal wells have demonstrated that fault or fracture conduits, charged with high pressure, high temperature fluids can extend upward to relatively shallow depths from a deeper subsurface domain of >600°F temperatures. These near vertical and planar conduits present both blowout risks and significant geothermal energy production potential. This recent finding, proven by drilling, has major implications. Geothermal drilling requires the evaluation and more effective utilization of monitoring procedures as a supplemental strategy for blowout prevention.

VITAL SECTORS

Monitoring focuses on three vital sectors during the drilling of a geothermal well:

1. Drilling penetration rate and drill bit performance measurements. The penetration rate, commonly measured and recorded in feet per hour, indicates the mechanical progress of drilling in the host rock. Weight on bit, rotational speed and torque are additional measurements that are made to better understand the variations of the drilling penetration rate.

2. Drilling fluid circulation in the wellbore which clears the newly made hole of drilled rock debris, cools and lubricates the rotating bit, and drilling string. Importantly, the density and hydrostatic pressure gradient of the drilling fluid are commonly used to control the formation fluids and pressures encountered.

3. Physical conditions and resource potential of the newly penetrated rock formation. The array of information gathered in this sector is commonly presented in a continuous "mud log" graphic record over the entire interval drilled.

The information products from the sectors discussed above have important potential applications. Possible immediate improvements might be indicated in drilling procedures, drilling fluid properties or casing plan in the well itself. Enhancements in well design, drilling programs and/or cost reductions can be determined for future wells. The information provided by way of monitoring procedures, with careful integration and evaluation, can make important contributions to an Operator's blowout prevention strategy.

OPTIMIZING BLOWOUT PREVENTION

Any effective reduction in blowout risks is primarily contingent upon accurate interpretation of monitoring data, and ultimately depends on the decisions made based on this data. This must be achieved by the Operator. Having made the risk analysis, written the drilling plan and obtained the funding for the well, the Operator's geologist and drilling engineer presumably would be the most qualified persons to establish the method by which the selected monitoring procedures would be used to contribute to a blowout prevention plan. In prospective Hawaiian rift zones, the prudent Operator, making careful use of monitoring information, can better identify the potential for hot and overpressured fault and fracture conduits, and can better prepare for penetration of such conduits and reduce impacts of kicks and lost circulation. Alternatively, the Operator can make the decision on whether or not to set casing, particularly if a long open hole section is exposed above the interval of concern.

Critical data that may reveal the degree and/or immediacy of a blowout risk are probably first observed by key personnel of the drilling and mud logging contractors. Exercising personal control of drill bit performance in making hole, drillers are the first to sense change at the bottom of the wellbore. Additionally, drillers must have an accurate, real time knowledge of the drilling fluid upflow in the annulus between drill pipe and the wall of the open hole. Gain or loss departures from 100% of the drilling fluid pumped down the drill pipe and through the bit orifices are critical indicators that, alone or with other corroborating information, signal a disruption of a normal drilling mode.

The mud logger and a supporting multiple sensor system continuously survey the changing rock features, formation fluids and temperature variations reflected in the returning drilling fluid. This work is both time critical and time short because it focuses evaluation on the narrow window of freshly exposed hole behind the continuously advancing drill bit. Accordingly, good quality, competitive mud logging has become a highly automated, computer assisted service with an impressive reliability. The mud logger is the first to evaluate the formation gas and liquid entries, via the returning drilling fluid, that may signal the penetration of high temperature, high pressure conditions.

Operators of Hawaiian geothermal drilling projects need to assure that a high level of cooperation in comprehending the norm and the upset hole conditions are mutually practiced by their contracted drillers and mud loggers. The Operator's drilling engineer and geologist should establish and maintain active communications with these key specialists throughout the drilling process. It is essential that drillers and mud loggers have reliable, instantly available electrical communication between their work stations if monitoring procedures are to more effectively contribute to the reduction of blowout risks. These simple procedures are intended to eliminate a common problem: too often a key piece of new information is received, but is not properly read, understood or communicated. Operators must lead their drillers and loggers to consistent cooperation in monitoring procedures as an important protection against the loss of well control. Inadequate responses to new well monitoring information must be minimized in Hawaiian geothermal drilling.

DRILLING FLUIDS AND GEOTHERMAL WELL CONTROL

All authoritative publications on blowout prevention (which to date exclusively address oil and gas drilling) stress the role of drilling fluids in minimizing, if not precluding, entries of normal or high pressured formation fluids into the wellbore during the active drilling process. This is achieved by circulating a weighted mud or salt water drilling fluid which creates an excess or overbalance of internal hydrostatic pressure on every square inch of the open wellbore. The normal hydrostatic pressure gradient for the formation fluids in Hawaii rift zones should approximate 433 psi per 1,000 feet of vertical depth for fresh water and 442 psi per 1,000 feet for salt water. This range of pressure gradients may prevail over much of the KERZ in the deep geothermal zones; several geothermal wells were drilled through 2,500 foot intervals of hot (600-700°F) prospective rock interval by circulating fresh water as a wholly satisfactory drilling fluid. Well control was maintained confidently in these operations and, subsequently, these fresh water drilled intervals yielded proven geothermal fluids during flow tests following well completion. It should be noted that the greater cooling capacity of water, as compared with mud drilling fluids, played a positive role in these achievements.

Cooling by the circulation of drilling fluid is an inherent physical process in geothermal well drilling. Where accelerated or optimized, the cooling process itself can be recognized as a well control function. The efficient cooling of circulating drilling fluids particularly will require an adequate surface cooling facility in the loop. Mud cooling towers which allow the hot returning mud to fall in a baffle system against a cool air draft are a standard equipment option for geothermal drilling. It is important that mud cooling towers be adequate for the heat load anticipated and that they be carefully maintained and monitored during use to assure that cooling is being effectively accomplished. Additionally, geothermal well control in Hawaiian rift zones requires ready access to an ample supply of cool water for wellbore circulation as a well control option.

Both the specific KERZ drilling experience and the practice of world wide geothermal drilling demonstrate the disinclination to drill with heavily weighted muds or saline solutions as a preferred means of well control. This follows from the expectation of fractures in the prospective hot zones which have much higher permeability and production potential than a bulk rock interval of some uniform primary (commonly lower) permeability. Fractures present the immediate risk of lost circulation and a possible well kick, particularly when overpressured fracture fluids are released. The perceived benefits of significantly weighted drilling fluids (significant overbalance -where the hydrostatic head of the fluid column exceeds the formation fluid pressure) usually is lost immediately in geothermal wells which successfully penetrate fractures. The loss of drilling fluid from the wellbore into formation fractures is accelerated in direct proportion to the overbalance due to excessively weighted mud. If, as indicated to date, blowout risks in Hawaiian rift zones are predominantly fracture controlled and fracture specific, it does not appear that excess weighting of drilling fluids will be a common means of blowout risk reduction.

MONITORING INDICES FOR BLOWOUT PREVENTION

Monitoring procedures, taken as an aid to blowout risk reduction in Hawaii drilling, can be focused on a group of five categories, as discussed below. The sequence of the categories is believed to be in order of importance when examined with the assumption that the sudden encounter of high pressured geothermal fluids in fractures constitutes the primary blowout hazard in these volcanic rift zones.

A. DRILLING WITH MUD OR WATER CIRCULATION

1. Bottom hole temperature variation. The blowout hazards in Hawaiian rift zones have a strong correlation with high subsurface temperatures. A working impression that 600°F and higher temperatures were present below 4,000-foot depths under the Kapoho-State geothermal leaseholds, and at greater depths uprift in KERZ, may have prevailed before the KS-7 and 8 blowout events. These wells respectively vented 500°F fluids from below 1,400 feet and 620°F from below 3,476 feet in uncontrolled flows at the wellheads. Bottom hole temperatures (BHT) cannot be measured in the active drilling process because of the cooling induced by the drilling fluid circulating around the rotating bit.

Alternatively, the exit temperature of the drilling fluid vented at the wellhead annulus is continuously recorded. The sharper excursions of increasing temperature with depth are the features of interest in the automated plot of exit temperature. The mud logger can immediately read such temperature increases in the context of the complete temperature profile (surface to current depth) and detect possible correlations with events on other indices. A supplemental temperature:depth record is frequently obtained by measuring with maximum reading thermometers inside the drill pipe at a stop immediately above the drill bit for some consistent time interval (say 20 minutes) at some regular frequency the Operator finds appropriate. This independent survey does not obtain equilibrated BHTs; however, it provides a more discriminate reference for the exit temperature plot. With respect to blowout risk reduction, neither the existing BHT value or any specific high temperature value has primary importance. Rather, it is sharply rising temperatures, coincident with other dynamic events observed in an integrated monitoring procedure, that are to be taken as a caution or evidence that a blowout threshold is being approached.

2. <u>Drilling penetration rate.</u> Variations in drilling rate commonly reflect rock conditions encountered by the drill bit, provided such factors such as weight on bit, rotational speed, and torque are uniform, or their coincident variations are understood. Increases in drilling rate (a drilling break) can indicate a porous and permeable interval containing formation fluids; fractured rock can cause sudden erratic perturbations in all these mechanical drilling indices. Major fractures in the KERZ can allow the drilling assembly to free fall into open voids. The consequences of such a fracture encounter are frequently immediate. Competent drillers will quickly determine the status of their drilling fluid return flow in appraising the situation and apply an appropriate response, if required. Increases in drilling rates coincident with the penetration of high pressure zones are described in some blowout prevention treatises on the conclusion that bits drill faster in underbalanced mud weights approaching high pressured zones. It should be determined by studies of well logs if KERZ drilling experience, past or future, suggests any basis for reading drilling rate variations as an indicator of penetration of high pressure zones. One prudent option in drilling fractured, high temperature intervals, especially with initial formation fluid entries identified in the return drilling fluid, is to deliberately reduce penetration rate or briefly hold in a full circulation mode to confirm drilling fluid system status and to observe more of the impact of the formation fluids encountered.

3. <u>Drilling fluid circulation.</u> Accurate knowledge of the drilling fluid

condition, particularly its weight in pounds per gallon, and its functioning in the wellbore, is critical to drilling with effective well control. Any departure (gain or loss) from a 100% return of the pumped circulating volume, delivered through the drill pipe to the drill bit, needs to be promptly evaluated as to magnitude and meaning. Continuous measurement and recording of the drilling fluid gain, loss, or 100% return is made in specific tanks (mud pits) included in the fluid circulation loop. Either gain or loss of drilling fluid must be taken as a warning of increasing blowout risk. A gain is a reliable indicator of formation fluid entry into the wellbore (kick). If well flow is indicated or suspected following a gain, drilling should be halted, the kelly pulled above the rotary table, the mud pump shut down and the exit flow line visually examined for possible flow. If the well is flowing in these circumstances, the annular preventer should be closed to identify pressure buildups on both annulus and drill pipe. These pressures, when stable, would identify the increases in mud weight and wellbore hydrostatic pressure necessary to terminate the formation fluid inflow. An evaluation of the option of circulating cool water in the wellbore should be made if the kick is associated with a temperature increase.

Partial or complete loss of drilling fluid returns is the more common problem consequent to fracture penetration. Complete loss of circulation, followed by a falling fluid level in the wellbore annulus is a most likely trigger for a blowout event. Drilling must be halted, the drilling string pulled up <u>(only to the first drill pipe tool joint)</u> and the preventer closed until the situation is evaluated and a response determined.

4. <u>Formation fluid entry.</u> All geothermal fluid bearing zones, both high and normally pressured, will be first identified by the drill bit penetration, with a subsequent charge of gases into the drilling fluid upflow in the annulus. Mud logging systems will automatically measure and record

carbon dioxide, hydrogen sulfide, methane and ethanol in parts per million on a log scale whenever the drilling fluid is being circulated. Although this information has a time lag compared to the immediacy of a drilling break, it is the most positive specific indicator that geothermal fluids have been encountered. Gas-cut drilling fluid returns, coupled with temperature increases, are a clear warning that a high pressure zone of considerable flow potential may be at hand. With additional penetration, geothermal formation liquid fractions may cause detectable salinity increases in the return drilling fluid. Salinity determinations are not an automated monitoring procedure, but are optionally performed by the mud logger in evaluating fluid entry events.

5. <u>Secondary mineralization.</u> Geothermal fluid bearing faults, fractures and zones are predominantly enclosed in a sheath or seal of secondary minerals. Secondary minerals are continuously identified and recorded in geothermal mud logging with the intent of discerning, in correlation with the wellbore temperature profile, the most prospective intervals for fluid production. Logic would suggest that the larger hot fluid conduits, which present both significant production potential and blowout risk, would likely have a thicker sheath of secondary minerals. The extent to which this prevails in the Hawaiian rift zones and to which it may be a particular precursor to high pressured geothermal fluids in fractures is not well known. Natural variations in the secondary mineralization process, consequent to a new fracture opening for geothermal fluid conduction, may be extreme; any secondary mineral sheath could presage a fluid filled fracture or a fracture that is completely sealed by mineralization, particularly in the active faulting and fracturing of the KERZ. Whatever may be the present view of this apparent index, it appears to merit careful evaluation within the concept of integrated monitoring as a logical part of blowout prevention strategy.

B. DRILLING WITH AIR, AERATED LIQUIDS OR FOAM

These drilling fluids are utilized in the underbalanced drilling option, which is often employed in geothermal drilling, particularly in known vapor dominated reservoirs. Air or aerated liquids drilling, signified by substantial additional equipment and service requirements, (air compressors, rotating head, banjo box, blooie line, drilling muffler and H_2S abatement backup) has been employed on a geothermal exploration well in the KERZ. Expectedly, air and aerated fluids drilling will be used and further evaluated in the Hawaii environment. Air drilling eases the driller's concern with circulated fluid controls on formation fluids; the formation fluids, with relatively unrestrained entry to the annulus, are transported to the surface and through the drilling muffler for chemical and noise abatement before release to the atmosphere. The mud logger's interpretation of rock and mineral cuttings is degraded somewhat by the much reduced rock particle size produced by air drilling. Otherwise the drilling monitoring procedures discussed above will apply for the same objective of blowout risk reduction.

SUMMARY

An optimal use of monitored drilling information in a blowout prevention strategy requires the informed participation and responses of competent drillers and mud loggers. A logical assignment of primary responsibility for the categories discussed above would be:

Driller	Logger
drilling penetration rate	temperature variations
drilling fluid circulation	secondary mineralization
	formation fluid entries

Computer based graphic data presentations are increasingly used at the driller's stations to quickly provide both present status and cumulative record on the drilling and fluid circulation processes. Both caution and alarm thresholds can be set on the incoming real time information streams to alert drillers and supervisors to upset conditions. Such systems offer an advantage to the blowout prevention objectives necessary to Hawaiian geothermal drilling, provided that competence in their use is created by diligent training.

The mud logging services contracted to most of the geothermal drilling operations in the KERZ have been state of the art quality at the time of every execution. Very substantial improvements in reliable automation have been made since the mid-1980s. In summary, Operators have adequate monitoring procedures at hand to reduce blowout risks. The driller's main focus is on immediate deviations from the controlled drilling process, and the mud logger's main focus is on subsurface physical consequences of borehole advancement. Blowouts are commonly preceded by multiple warning signs of increasing risks. The Operator's drilling engineers and geologists, with the close cooperation of drillers and mud loggers, can more accurately recognize such risks and more quickly act to control or reduce them with the drilling monitoring procedures discussed here.

A final comment should be made on drilling fluid monitoring requirements while tripping the drilling string. Frequently in geothermal well drilling with mud and water, the hydrostatic pressure of the fluid has only a moderate overbalance on the formation fluids. This is further reduced with the cessation of circulation immediately before pulling the drill string, as for a new bit. In hot, prospective rock zones, the large diameter drilling assembly moving up hole can swab, or pull, formation fluids into the borehole, by further reducing the hydrostatic pressure below the bit. The greatest danger of swabbing occurs when pulling the first few stands of drill pipe (drilling assembly just pulling off bottom). At this point, a careful confirmation of the drilling fluid fill-up volume, required to hold the fluid level at the wellhead, is essential. If the well fill-up volume is less than the volume of drill pipe pulled, swabbing should be inferred, the bit returned to the bottom and the hole recirculated to clear the formation fluids from the well. In summary, swabbing is a mechanism that can and has caused blowouts. A slower pulling of the initial stands and the fill-up check are the defensive procedures to use.

VII. KICK CONTROL

INTRODUCTION

In drilling terms, a 'kick' is often the first indication at the wellhead that there are problems with control of formation pressure. A kick is defined as the entry of formation fluids (water, steam, or gasses) into the well, which occurs because the hydrostatic pressure exerted by the drilling fluids column has fallen below the pressure of the formation fluids. If prompt action is not taken to control the kick and to correct the pressure underbalance, a blowout may follow. Some of the main causes of these pressure imbalances are:

1. Insufficient drilling mud weight.
2. Failure to properly fill the hole with fluids during trips.
3. Swabbing when pulling pipe. If the drill string is pulled from the hole too rapidly, the pressure may be reduced, allowing formation fluids into the bore.
4. Lost circulation.

KICK IDENTIFICATION

There are a number of warning signs that indicate that a kick is occurring or that it may soon occur. Some of these signs, which may not be present in all situations, are:

1. An increase in the returning drilling fluids flow rate, while pumping at a constant rate.
2. An increase in mud pit volume.
3. A continuing flow of fluids from the well when the pumps are shut down.
4. Hole fill up on trips is less than the calculated amount.
5. A pump pressure change and a pump stroke increase while drilling.
6. An increase in drill string weight.
7. A drilling break. (A sudden increase in penetration rate)

8. Gas cut mud or reduced mud weight at the flow line.
9. Lost circulation.
10. A rapid increase in flow line temperature.

Each of the above warning signs individually does not **positively** identify a kick. However, they do warn of a potential for a kick. Every driller and derrickman should be expert in recognizing these indicators and all crew members should be trained to take action. In geothermal drilling, in addition to being alert to the above warning signs, it is of prime importance to: 1) monitor drilling fluid temperatures in and out while drilling; 2) maintain a frequent and close analysis of the formation cuttings for a change in mineralization; and 3) exert caution when drilling through formations where lost circulation zones are expected. Difficulties or abnormal conditions with any of these indications or procedures can also indicate a potential kick.

SHUT IN PROCEDURES

The severity of a kick depends on the volume and pressure of the formation fluid that is allowed to enter the hole. For this reason, it is desirable to shut the well in as quickly as possible. When one or more warning signs of a kick are observed, procedures should be started to shut in the well. If there is doubt as to whether a kick is occurring, shut in the well and check the pressures and other indicators.

Specific shut in procedures when one or more kick warning signs are observed:

1. WHILE DRILLING
   a. Pick up kelly until a tool joint is above the table.
   b. Shut down the mud pumps.
   c. Close the annular preventer.
   d. Notify the company supervisor.
   e. Record the drill pipe and annular pressure build up.

2. WHILE TRIPPING

a. Pick up kelly until a tool joint is above the table.

b. Install the full opening safety valve.

c. Close the safety valve; close the annular preventer.

d. Notify the company supervisor.

e. Make up the kelly; open the safety valve.

f. Record the drill pipe and annular pressure build up.

3. WHILE OUT OF THE HOLE

a. Close the well in immediately.

b. Record the pressure build up.

c. Notify the company supervisor.

d. Prepare for snubbing or stripping into the hole.

4. WHILE USING A DIVERTER

a. Pick up kelly until a tool joint is above the table.

b. Shut down the mud pumps.

c. Open the diverter line valves.

d. Close the annular preventer.

e. Start pumping at a fast rate.

d. Notify the company supervisor.

KICK KILL PROCEDURES

Several proven kick killing methods have been developed over the years, based on the concept of constant bottom hole pressure. Two of the most common methods are know as the "drillers" method and the "wait and weight" method. Rig personnel should be familiar with, and trained in, these procedures.

Selection of the method to be used in a particular kick situation should be made by an experienced, qualified drilling supervisor. The actual method used will depend on knowledgeable considerations of surface pressure, type of influx, the time required to execute the procedure, complexity of the procedure, down hole stresses that may be present or introduced, and available equipment.

All of the above are suggested procedures, to be modified by a knowledgeable drilling supervisor to suit the particular conditions existing at the time of the kick.

VIII. BLOWOUT CLASSIFICATION

INTRODUCTION

Any uncontrolled flow of steam, brine or other well fluids constitutes a blowout. A discharge of these fluids at the surface is usually taken as the basic identifier of a blowout. However, surface discharge, if it occurs, is only the symptom or consequence of the fundamental upset condition that results in a blowout.

In the context of Hawaii geothermal activities, a broader, yet more precise, definition of a ***blowout*** can be stated as a "loss of control of the natural pressures and fluids encountered in the drilling of a geothermal well."

There are several types of geothermal well blowouts, varying in their severity and in the techniques needed to control them. The impacts on surface and subsurface environments, resource waste, and public perceptions of these incidents demand that Operators and regulators minimize the risks of blowouts. The types of blowouts that may be experienced in Hawaii include the following:

A. SURFACE BLOWOUTS

1. Casing Contained. An uncontrolled flow of steam or other fluids through the casing and wellhead will result in the escape of fluids to the atmosphere. This may result in unabated gas emissions and noise disruptive to the surrounding community and the surface environment surrounding the well. This type of blowout may cause minor to major damage to the wellhead, BOP equipment stack, or drilling rig. Response to the blowout will depend on the specific situation. Efforts will focus on wellhead repairs, control of fluid discharge, and access to the area for specific procedures. The availability of drilling fluid supplies (including water), and the condition of the drilling string and casing

will be key elements in an effective operation to regain well control.

2. Externally Vented.

- Moderate case - low-to-moderate fluid venting outside the casing or the cellar; the drilling rig, wellhead and BOP are generally undamaged and operable. May or may not be disturbing to surrounding community. Responses may include grouting at the leak to terminate surface flow.
- Worst Case - venting volume and/or velocity leads to rig collapse and/or cratering around or near the wellhead. Response will probably require a relief well if the hole doesn't bridge or collapse on its own, thus terminating the flow.

B. UNDERGROUND BLOWOUTS

Although this class of blowout lacks any surface display, the event could escalate into a surface blowout if not recognized and resolved at an early time.

1. High pressure fluid upflows, in the open hole, from a deep zone to a shallower permeable zone (lower temperature reservoir or groundwater). Such events may range from serious degradation or destruction of the open hole, to minor resource loss and conservation problems. Response is generally to subdue the flow with water, weighted muds, or cement plugs as required. Additional casing/liner probably will be required, or the well may be plugged with cement for redrill or suspension.

2. High pressure fluid upflows, in the open hole, from a deep zone to an escape by hydraulic fracturing at the deepest casing shoe, where the formation (pressure) gradient is exceeded by higher fluid pressure from the deep zone. Response as above in 1.

IX. SUPERVISION AND TRAINING

INTRODUCTION

The major cause of most blowouts is human error; either none of the crew or the Operator's advisors recognizes an existing well control problem, or steps to control the situation are not performed soon enough. Most blowouts are fully preventable by properly trained drilling personnel. Thus, proper training of the crew is as important to successful well control as is the proper selection and use of blowout prevention equipment, as discussed in the preceding sections. The Hawaii conditions for geothermal drilling require that every Operator recognize its prime responsibilities to provide supervision and training that is several levels above the industry average.

Hawaii's geothermal drilling industry is still in a formative stage. Because there is no pool of operators and drilling personnel thoroughly familiar with all potential problems in Hawaii's geothermal resource areas, there is a need for operators, drilling contractors and regulators to pay extraordinary attention to all elements of training for their personnel. There must be a proper balance between practical, on-the-job-training, operational drills, and formal study for a wide range of individual experience levels. In a few cases, drilling and monitoring crews will have worked together closely in other geothermal areas, some of which may exhibit well control challenges similar to Hawaii's. In other instances, crews will be made up of a mixture of individuals that have not worked as a team before, and may have a larger percentage of new workers, especially at lower skill levels in the drilling and production jobs.

An additional consideration in the Hawaii case is the known occurrences of relatively high levels of H_2S gas in the geothermal resource. Proper well planning and equipment selection can mitigate many of the hazards of H_2S drilling in the well control sense, but it is necessary that all drilling crews have a clear understanding of the dangers and rules that accompany drilling in known H_2S zones.

SUPERVISORY EXPERIENCE

Although complete training for specific crews that will drill in Hawaii's geothermal zones is of primary importance, the art of well control is not learned from classroom training alone. Therefore, experienced supervisory personnel are vital to the process of training the drilling crews, as well as in lending their experiences to the ongoing supervision of the drilling. Drilling plans submitted should discuss the levels of experience of the drilling crews, supervisors, consultants and managers, with comment on the methods to be taken to ensure that such experienced persons will be directly involved while drilling activities are underway in Hawaii.

DRILLING TEAM TRAINING AND DRILLS

The training of drilling teams, including supervisory, management and operating personnel, in well control and blowout protection can be discussed in three basic levels. Level one:training through formal courses that are infrequently offered by industry and regulatory organizations, often at a regional or national level; level two: the training that an Operator conducts on a more or less formal, or classroom, basis with its drilling supervisors, drilling crews, and others who directly support its Hawaii drilling operations; level three: Operators must have a program of drills that ensure all personnel actually have 'hands-on' experience with the installed blowout prevention equipment.

A number of organizations conduct training and certification in well control, mainly directed toward the petroleum drilling industry. However, recent classes in the specifics of geothermal well control have been held by a cooperative effort of the **Geothermal Resources Council** and the **National Geothermal Association**, with funding in part by the **Federal Department of Energy**. This course has been approved by the **Federal Minerals Management Service** for training and certification in well control subjects, and is recommended for supervisory and other drilling personnel, as an indication of the level of specific well control training and experiences of these personnel assigned to Hawaii drilling tasks. There are no plans to hold these formal courses often, and most certainly not in concert with specific drilling schedules of individual projects. Therefore, each Operator and drilling contractor will need to supplement the experiences of their supervisory personnel with direct team training pointed toward developing an integrated effort for Hawaiian projects.

Operators should outline the formal (classroom) training proposed for drilling personnel, with specific references to 'kick' recognition and blowout prevention, including monitoring systems, equipment, and drilling procedures. A number of study guides and references are available for these purposes; publications to be used should be listed in drilling plans so that they can be reviewed by regulatory review personnel. A list of specific references is not included in this Manual because these publications may become obsolete by newer editions. Appendix C, **References**, contains documents and sources used in preparing this Manual, and should be consulted for suitability to each drilling plan.

In addition to classroom training and periodic updates as drill crews may shift or the drilling may enter new phases, blowout prevention drills should be conducted on a regular (but unannounced) basis to provide further training, and to keep crews focussed on the possibilities of well kicks, and blowouts. Crews should be familiar with the equipment in use, and be able to properly and safely shut in the well before a control problem becomes dangerous to personnel or the well itself. These drills should be directed at well control and proper blowout prevention procedures in three basic situations - when drilling ahead, when 'tripping out' of the well, and when the drill pipe is out of the wellbore.

Other blowout prevention and general safety training - both informal and on-the-job situations, should be outlined in the drilling plan. Subjects covered should include new employee orientation, visitor briefings and general safety training. Formal training sessions, regular review training and blowout prevention drills held should be noted in the daily reports of the drilling operation.

X. POST COMPLETION BLOWOUT PREVENTION

It is important to realize that blowout risks are not restricted to the initial drilling and completion of a geothermal well. At a much lower incidence rate, blowouts can occur at producing wells and at shut-in idle wells. Wellhead equipment should be recognized as vulnerable to natural surface conditions and vandalism. The capacity, integrity, and security of geothermal wellhead equipment are all the responsibility of a production engineering expertise which is not within the scope of this Blowout Prevention Manual.

Two areas of subsurface risks to casing string integrity in existing Hawaiian geothermal wells should be noted. The corrosion potential of wellbore fluids, in both the production and shut-in (static) modes should be identified. Baseline chemistry and casing evaluation procedures should be established shortly after well completion. The objectives here are to assure and prolong casing integrity, and to preclude any blowout consequent to a casing failure due to corrosion. Wells that have been tested or have produced high temperature fluids, and then are shut-in for periods of time, particularly require regular and accurate monitoring of casing conditions. Temperature decreases imposed by the active Hawaiian ground water regime can accelerate H_2S corrosion in shallow casing strings in idle wells. Finally, the risk of casing failure in rift zone eruptions and earthquakes (shallow fault movements, ground disruption or rotational failures) should be recognized.

Blowout prevention requirements during remedial work, redrills, recompletions and abandonments, in all geothermal wells, must be evaluated and provided for by the same process of consideration required in every new geothermal well drilling permit proposal.

XII. BLOWOUT PREVENTION IN SLIMHOLES

INTRODUCTION

Deep drilling with slimhole (approximately 4-6 inch bit diameters) technology and equipment has achieved major advances in the mining industry in the last several decades. However, the mining drilling environment does not present pressure control problems comparable to those encountered in petroleum and geothermal drilling. For this reason, well control practices in slimholes were poorly understood until recently. This hindered an expanding use of the technology. However, the technical and economic advantages of slimholes have recently registered with several petroleum companies; Amoco Production Company has particularly investigated the requirements of well control and blowout prevention in slimhole drilling.[2]

KEY ATTRIBUTES

Much smaller volumes of drilling fluids are circulated in slimholes. Kicks of any volume are of more consequence, and immediate detection of fluid entry, or lost circulation, is critical. Quantitative electromagnetic flow meters are used to measure drilling fluid entry and exit volumes at the wellhead. These flow meters are reliable and accurate, measuring gains of one barrel or less as compared to pit gains of 15 barrels or more as frequent kick events in the standard drilling mode. Unfortunately, the much greater size of this type of meter required for standard diameter wellbores make them cost prohibitive. Another feature of importance is the high annular pressure loss (APL) incurred by drilling fluid circulation in slimholes. The higher rotary speeds (RPM) used in slimholes also adds, with the APL, a substantial increase (overbalance) above the hydrostatic pressure of the drilling fluid on the

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[2] **Well Control Methods and Practices in Small-Diameter Wellbores**; D. J. Bode, et al Amoco Production Co., October 1989. (Available from the Society of Petroleum Engineers, P. O. Box 833836, Richardson, Texas 75083-3836; Telephone 214-669-3377.)

borehole while actively drilling or coring. This physical phenomena relates to the very small annuli between drill tubulars and the rock wall. The high APL can be used advantageously to effect a dynamic kill and control of formation fluid entry below 2,500-foot depths in slimhole by accelerating the pumping rate to maximum levels in circulating out the intruding fluids. In summary, blowout prevention in slimholes requires special training, precision flowmeters, real time data presentation and dynamic kill proficiency. It is likely that additional slimhole drilling will be considered in Hawaii geothermal exploration and development; Operators should carefully evaluate the Amoco paper referenced when developing plans for these boreholes.

APPENDIX A

MANUAL REVIEW AND REVISIONS

APPENDIX A.

MANUAL REVIEW AND REVISION

Geothermal drilling experience in Hawaii, as of mid 1992, has been quite limited. Only 14 deep geothermal boreholes had been drilled, and these were located on only one prospective feature, the KERZ. Reasonable increases in geothermal drilling in the KERZ, and perhaps other areas, can be anticipated. New operational and regulatory experiences should accumulate in the next few years.

This Blowout Prevention Manual can best be accepted as a first edition. Ideally, it should serve as a working reference for operators and regulators in a cooperative approach to the achievement of blowout risk reduction.

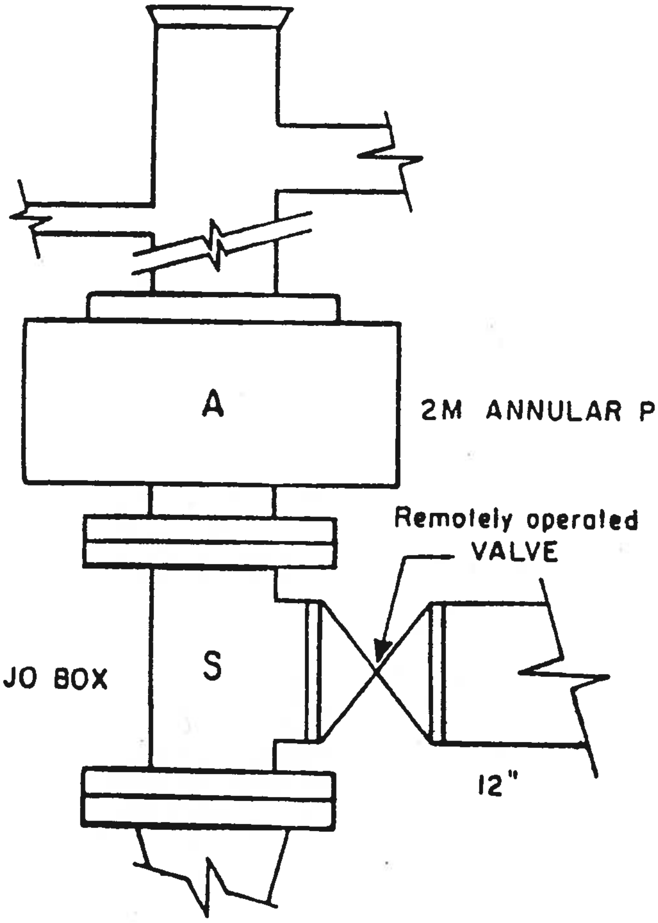
It is recommended that this Manual be reviewed and revised within 5 years of its date of issue by DLNR. Such a time interval seems ample for the collection of new operating information and for a reasonable application of the blowout prevention procedures recommended in the Manual. Frequent and informed discussion of blowout prevention procedures between operators and regulators could prove to be one of the most important consequences of the use of this Manual.

APPENDIX B

ILLUSTRATIONS

Figure 1.

HAWAII GEOTHERMAL
DIVERTER STACK



API ARRANGEMENT SA

2000 PSI

Figure 2.

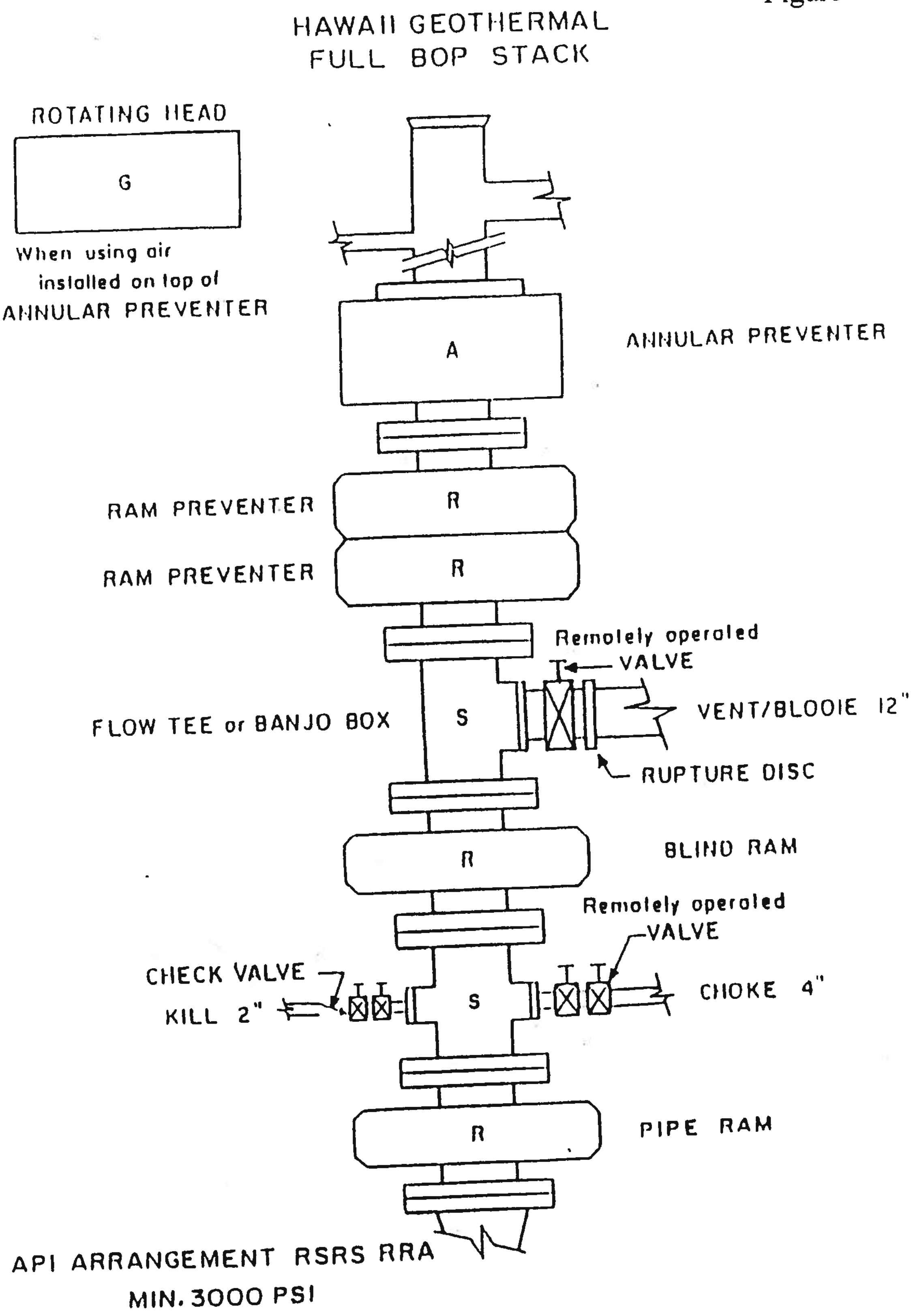

HAWAII GEOTHERMAL
FULL BOP STACK
ROTATING HEAD
G
When using air
installed on top of
ANNULAR PREVENTER
A
ANNULAR PREVENTER
RAM PREVENTER
R
RAM PREVENTER
R
Remotely operated
VALVE
FLOW TEE or BANJO BOX
S
VENT/BLOOIE 12"
RUPTURE DISC
R
BLIND RAM
Remotely operated
VALVE
CHECK VALVE
KILL 2"
S
CHOKE 4"
R
PIPE RAM
API ARRANGEMENT RSRS RRA
MIN. 3000 PSI

FIGURE 3

In Hawaii, where wellhead temperatures in excess of 600°F may occur, Operators must consider the pressure derating of steel due to elevated temperatures when selecting wellhead equipment. The table below, from the **American Petroleum Institute (API)** Specification 6A, provides the recommended working temperatures for steel at high temperatures; this table goes only to 650°F.

In addition to the steel in wellhead equipment, the temperatures found in Hawaii far exceed the temperature ratings of elastomers found in most BOP equipment. Operators often use all steel rams in ram type preventers for a more effective seal. The API recognizes temperature ratings of elastomers up to 250°F, but some manufacturers can now produce elastomers that are rated to 420°F.

RECOMMENDED WORKING PRESSURES
AT ELEVATED TEMPERATURES

E.1 Pressure-Temperature Derating. The maximum working pressure ratings given in this section are applicable to steel parts of the wellhead shell or pressure containing structure, such as bodies, bonnets, covers, end flanges, metallic ring gaskets, welding ends, bolts, and nuts for metal temperatures between 20F and 650F (-29 and 343°C). These ratings do not apply to any non-metallic resilient sealing materials or plastic sealing materials, as covered in Par. 1.4.4.

TABLE E.1
PRESSURE-TEMPERATURE RATINGS OF STEEL PARTS
(See Par. 1.2.4)
(1 BAR = 100 kPa)
(See Foreword for Explanation of Units)

	1	2	3	4	5
	Temperature, F (°C)				
	-20 to 250 *(-29 to 121)*	**300** *(149)*	**350** *(177)*	**400** *(204)*	**450** *(232)*
Maximum Working Pressure, psi (Bar)	**2000** *(138.0)*	**1955** *(134.8)*	**1905** *(131.4)*	**1860** *(128.2)*	**1810** *(124.8)*
	3000 *(207.0)*	**2930** *(202.0)*	**2880** *(197.2)*	**2785** *(192.0)*	**2715** *(187.2)*
	5000* *(345.0)*	**4980** *(336.5)*	**4765** *(323.5)*	**4645** *(320.3)*	**4525** *(312.0)*

*Does not apply to 5000 psi 6BX connections

TABLE E.1-Continued
PRESSURE-TEMPERATURE RATINGS OF STEEL PARTS
(See Par. 1.2.4)
(1 BAR = 100 kPa)

	6	7	8	9
	Temperature, F (°C)			
	500 *(260)*	**550** *(288)*	**600** *(316)*	**650** *(343)*
Maximum Working Pressure, psi (Bar)	**1735** *(119.6)*	**1635** *(113.7)*	**1540** *(106.2)*	**1430** *(93.6)*
	2605 *(179.6)*	**2455** *(169.3)*	**2310** *(159.3)*	**2145** *(147.9)*
	4340 *(299.2)*	**4090** *(232.0)*	**3850** *(285.5)*	**3575** *(246.5)*

APPENDIX C

REFERENCES

APPENDIX C

REFERENCES

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APPENDIX D

GLOSSARY

APPENDIX D

GLOSSARY

A

accumulator n: 1. on a drilling rig, the storage device for nitrogen-pressurized hydraulic fluid, which is used in closing the blowout preventers.

annular blowout preventer n: a large valve, usually installed above the ram preventers, that forms a seal in the annular space between the pipe or kelly and wellbore or, if no pipe is present, on the wellbore itself.

API *abbr*: American Petroleum Institute

B

BHP *abbr*: bottom hole pressure.

BHT *abbr*: bottom hole temperature.

blowout n; A blowout is an uncontrolled flow of formation fluids or gas from a well bore into the atmosphere or into lower pressure subsurface zones. A blowout occurs when formation pressure exceeds the pressure applied by the column of drilling fluid.[1]

BOP equipment n: The entire array of equipment installed at the well to detect and control kicks and prevent blowouts. It includes the BOP stack, its actuating system, kill and choke lines, kelly cocks, safety valves and all other auxiliary equipment and monitoring devices.

bottom hole temperature n: The temperature of the fluids at the bottom of the hole. While drilling, these temperatures may be measured by minimum reading temperature devices, which only record temperatures above a designed minimum, and may not provide an accurate bottom hole temperature. Bottom hole temperature readings should be recorded after a period of fluids circulation at a particular depth, in order to stabilize the reading.

blowout preventer n: the equipment installed at the wellhead to prevent or control the escape

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[1] Rotary Drilling BLOWOUT PREVENTION Unit III, Lesson 3; Petroleum Extension Service, The University of Texas at Austin, Austin Texas, in cooperation with the International Association of Drilling Contractors, Houston Texas. 1980; 97 pages.

of high pressure formation fluids, either in the annular space between the casing and drill pipe or in an open hole (i.e., hole with no drill pipe) during drilling and completion operations. The blowout preventer is located beneath the rig at the surface. See annular blowout preventer and ram blowout preventer.

BOP *abbr*: blowout preventer

BOP stack n: The array of preventers, spools, valves and all other equipment attached to the well head while drilling.

borehole n: the wellbore; the hole made by drilling or boring.

C

cap rock n: 1. relatively impermeable rock overlying a geothermal reservoir that tends to prevent migration of formation fluids out of the reservoir.

casing n. steel pipe, cemented in the wellbore to protect it against external fluids and rock conditions, and to facilitate the reliable and safe production or injection of geothermal fluids.

cellar n: a pit in the ground to provide additional height between the rig floor and the wellhead, and to accommodate the installation of blowout preventers, rathole, mousehole, and so forth. It also collects drainage water and other fluids for subsequent disposal.

cementing n: the application of a liquid slurry of cement and water to various points inside or outside the casing.

competent rock n. (in wellbores) any rock that stands without support in the drilled wellbore can be described as *competent*. Beds of ash, or loose volcanic clastics, are vulnerable to failure in open wellbores, and are thus considered to be *incompetent rock*.

complete shut off n. a full closure and containment of wellbore fluids and pressure at the wellhead.

conductor n: 1. a short string of large-diameter casing used to keep the top of the wellbore open and to provide a means of conveying the up-flowing drilling fluid from the wellbore to the mud pit. 2. a boot.

CSO *abbr*: complete shut off.

D

diverter n: a system used to control well blowouts when drilling at relatively shallow depths by directing the flow away from the rig. The diverter is part of the BOP Stack that includes an annular preventer with a vent line beneath. A valve on the vent line is installed so that it is opened whenever the annular preventer is closed.

drill collar n: a heavy, thick-walled tube, usually steel, used between the drill pipe and the bit in the drill stem to provide a pendulous effect to the drill stem.

drilling fluid n: a circulating fluid, one function of which is to force cuttings out of the wellbore and to the surface. While a mixture of clay, water, and other chemical additives is the most common drilling fluid, wells can also be drilled using air, gas, or water as the drilling fluid. Also called circulating fluid. See mud.

drilling spool n: a spacer used as part of the wellhead equipment. It provides room between various wellhead devices (as the blowout preventers) so that devices in the drill stem (as a tool joint) can be suspended in it.

drill pipe n: the heavy seamless tubing used to rotate the bit and circulate the drilling fluid. Joints of pipe are coupled together by means of tool joints.

drill string n: the column, or string, of drill pipe with attached tool joints that transmits fluid and rotational power from the kelly to the drill collars and bit. Often, the term is loosely applied to include both drill pipe and drill collars. Compare drill stem.

F

flange n: a projecting rim or edge (as on pipe fittings and opening in pumps and vessels), usually drilled with holes to allow bolting to other flanged fittings.

formation pressure n: the force exerted by fluids in a formation, recorded in the hole at the level of the formation with the well shut in. Also called reservoir pressure or shut-in bottom-hole pressure. See reservoir pressure.

J

joint n: a single length of drill pipe or of drill collar, casing, or tubing, that has threaded connections at both ends. Several joints, screwed together, constitute a stand of pipe.

K

kelly n: the heavy steel member, four-or six-sided, suspended from the swivel through the rotary table and connected to the topmost joint of drill pipe to turn the drill stem as the rotary table turns. It has a bored passageway that permits fluid to be circulated into the drill stem and up the annulus, or vice versa.

kelly cock n: a valve installed between the swivel and the kelly. When a high-pressure backflow begins inside the drill stem, the valve is closed to keep pressure off the swivel and rotary hose. See kelly.

kick n: an entry of water, gas, or other formation fluid into the wellbore. It occurs because the hydrostatic pressure exerted by the column of drilling fluid is not great enough to overcome the pressure exerted by the fluids in the formation drilled. If prompt action is not taken to control the kick or kill the well, a blowout will occur.

kill line n: a high pressure line that connects the mud pump and the well and through which heavy drilling fluid can be pumped into the well to control a threatened blowout.

L

L.C. *abbr*: lost circulation

log n: a systematic recording of data, as from the driller's log, mud log, electrical well log, or radioactivity log. Many different logs are run in wells to obtain various characteristics of downhole formations. v: to record data.

lost circulation n: the loss of quantities of any drilling fluid to a formation, usually in cavernous, fissured, or highly permeable beds, evidenced by the complete or partial failure of the fluid to return to the surface as it is being circulated in the hole. Lost circulation can lead to a kick, which, if not controlled, can lead to a blowout.

M

manifold n: an accessory system of piping to a main piping system (or another conductor) that serves to divide a flow into several parts, to combine several flows into one, or to reroute a flow to any one of several possible destinations.

mud n: the liquid circulated through the wellbore during rotary drilling and workover operations. In addition to its function of bringing cuttings to the surface, drilling mud cools and lubricates the bit and drill stem, protects against blowouts by holding back subsurface pressures, and prevent loss of fluids to the formation. Although it was originally a suspension of earth solids (especially clays) in water, the mud used in modern drilling operations is a more complex, three-phase mixture of liquids, reactive solids, and inert solids. The liquid phase may be fresh water, and may contain one or more conditioners. See drilling fluid.

mud logging n: the recording of information derived from examination and analysis of formation cuttings suspended in the mud or drilling fluid, and circulated out of the hole. A portion of the mud is diverted through a gas-detecting device. Cuttings brought up by the mud are examined to detect potential geothermal production intervals. Mud logging is often carried out in a portable laboratory set up near the well.

mud pits n pl: a series of open tanks, usually made of steel plates, through which the drilling mud is cycled to allow sand and sediments to settle out. Additives are mixed with the mud in the pits, and the fluid is temporarily stored there before being pumped back into the well. Modern rotary drilling rigs are generally provided with three or more pits, usually fabricated steel tanks fitted with built-in piping, valves, and mud agitators. Mud pits are also called shaker pits, settling pits, and suction pits, depending on their main purpose. Also called mud tanks.

mud weight n: a measure of the density of a drilling fluid expressed as pounds per gallon (ppg), pounds per cubic foot (lb/ft^3), or kilograms per cubic meter (kg/m^3). Mud weight is directly related to the amount of pressure the column of drilling mud exerts at the bottom of the hole.

P

permeability n: 1. a measure of the ease with which fluids can flow through a porous rock. 2. the fluid conductivity of a porous medium. 3. the ability of a fluid to flow within the interconnected network of a porous medium.

pipe ram n: a sealing component for a blowout preventer that closes the annular space between the pipe and the blowout preventer or wellhead. See ram and ram blowout preventer.

pit-level indicator n: one of a series of devices that continuously monitors the level of the drilling mud in the mud pits. The indicator usually consists of float devices in the mud pits that sense the mud level and transmit data to a recording and alarm device (called pit-volume recorder) mounted near the driller's position on the rig floor. If the mud level drops too low or rises too high, the alarm sounds to warn the driller that action may be necessary to control lost circulation or to prevent a blowout.

pounds per gallon n: a measure of the density of a fluid (as drilling mud).

ppg abbr: pounds per gallon.

pressure n: the force that a fluid (liquid or gas) exerts when it is in some way confined within a vessel, pipe, hole in the ground, and so forth, such as that exerted against the inner wall of a tank or that exerted on the bottom of the wellbore by drilling mud. Pressure is often expressed in terms of force per unit of area, as pounds per square inch (psi).

R

ram n: the closing and sealing component on a blowout preventer. One of three types - blind, pipe, or shear - may be installed in several preventers mounted in a stack on top of the wellbore. Blind rams, when closed, form a seal on a hole that has no drill pipe in it; pipe rams, when closed, seal around the pipe; shear rams cut through drill pipe and then form a seal.

ram blowout preventer n: a blowout preventer that uses rams to seal off pressure on a drillpipe, casing annulus or an open hole. It is also called a ram preventer. See blowout preventer and ram.

reservoir pressure n: the pressure in a reservoir under normal conditions.

S

surface casing n: the first string of steel pipe (after the conductor) that is set in a well, varying in length from a few hundred to several thousand feet.

survey n: a continuous wellbore measurement of a parameter such as pressure or temperature.

T

trip n: the operation of hoisting the drill stem from and returning it to the wellbore. v: shortened form of make a trip.

W

wellbore n: a borehole; the hole drilled by the bit. A wellbore may have casing in it or may be open (i.e., uncased), or a portion of it may be cased and a portion of it may be open. Also called borehole or hole.

wellhead n: the equipment installed at the surface of the wellbore. A wellhead includes such equipment as the casing head and tubing head. adj: pertaining to the wellhead (as wellhead pressure).