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MASTER

AN ASSESSMENT OF NON-DESTRUCTIVE TESTING OF WELL CASING, CEMENT AND CEMENT BOND IN HIGH TEMPERATURE WELLS

C. K. Knutson
C. R. Boardman

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SUITE A103, AIRPORT CENTER • 5030 PARADISE ROAD • LAS VEGAS, NEVADA 89119 • TELEPHONE 702/739-9630

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ABSTRACT

Because of the difficulty in bringing geothermal well blowouts under control, any indication of a casing/cement problem should be expeditiously evaluated and solved. There are currently no high temperature cement bond and casing integrity logging systems for geothermal wells with maximum temperatures in excess of 500°F. The market is currently insufficient to warrant the private investment necessary to develop tools and cables capable of withstanding high temperatures. Operators would utilize such tools if they were available, however.

The logs commonly used to evaluate cement/bond and the maximum operating temperature, °F, quoted by a number of logging companies are 1) acoustic cement bond (500), 2) nuclear cement (350), 3) noise (400), and 4) temperature (500). The most common types of surveys for assessing casing integrity and the maximum operating temperatures, °F, are 1) electromagnetic (350), 2) caliper (400), 3) spinner (500) and 4) radioactive tracer (400).

Field tests of a number of commercial logs in geothermal wells have shown that downhole problems occur around 300°F and most are unreliable around 400°F. Service company representatives polled indicated that they expected that the logs currently being utilized (except for electromagnetic surveys) can be adapted to the more hostile environments of geothermal wells.

Types of well failures documented include leaks, dog legs, channeling in the cement, wellbore communication (multiple completion), casing collapse, cement failure, wellhead movement, disengagement of couplings, fractures, cracks and buckled and sheared casing. One of the prime causes of the most expensive failures (casing collapse) is expansion of water pockets between sections with good cement.

Representatives of both geothermal and thermal oil recovery operating companies are unanimous in their conclusion that the maximum effort and funds should be placed in engineering high temperature wells to avoid failures. Some special techniques useful in preventing cement failures include 1) better cementing practices, e.g. 100% fill, 2) controlled opening and development of wells, 3) special cement formulations (high silica), 4) centralizers and 5) better squeeze cementing practices. Casing failures can be minimized by 1) better casing metallurgy and heavier wall pipe, 2) casing prestressed in tension, 3) controlled tightening of joints, 4) flush joints and 5) cathodic protection. Minimum problems have been encountered in hot wells with good cementing jobs.

It is concluded that a DOE-funded development program is required to assure that diagnostic tools are available in the interim until geothermal resource development activities are of sufficient magnitude to support developmental work on high temperature casing/cement logging capabilities by industry. This program should be similar to and complement the current DOE program for development of reservoir evaluation logging capabilities for hot wells.

I. INTRODUCTION

This report was prepared for the Lawrence Livermore Laboratory under P.O. 4332409. Dr. D. O. Emerson was the Project Technical Representative.

The Division of Geothermal Energy (DGE) of the Department of Energy recognized the desirability of identifying operational problem areas that might impede the development of geothermal energy, and of endeavoring to provide solutions in a time frame that would prevent these operational problems from inhibiting the orderly technical development of this major energy source. The lack of suitable high temperature logging capabilities was one of these identifiable operational problems.

DGE launched a multipronged approach toward the solutions. Some of the major government laboratories involved and their areas of interest are:

SANDIA - Steering committee, open hole logging, and instrumentation.

LASL - Field testing of high temperature logging, etc.

LBL - Instrumentation and equipment development, etc.

LLL - Cased hole logging evaluation, etc.

Many of the concepts are applicable to areas of interest of more than one laboratory. Efforts are being made to keep communication paths open between laboratories, and to work on complementary tasks.

The scope of the subtask addressed in this report is to summarize the information obtained by:

- A survey of casing and cement bond integrity assurance and assessment experience and capabilities of representative operating and service companies with hot well experience.

- An in-depth search and review of the U. S. literature concerning existing technology for evaluation of casing and cement bonds in high temperature (+300^{o}F) oil, gas, and geothermal wells.

The survey was carried out by contacting:

- The research or headquarters engineering groups of all the major logging service companies to obtain a summary of their capabilities for casing and cement bond integrity assessment and their ideas on the development work they will or might carry out in this area.

- Field offices of the service companies doing the hot well logging to get an account of their capabilities, experiences and in some cases, recommendations.

- The field offices of a couple of the major cementing service companies for their thoughts about cement bond integrity assessment and failures.

- The headquarters engineering or research groups of operating companies with active thermal or geothermal programs for their ideas and a summary of their experience.

- Division of field offices of these companies for their ideas and summaries of field experience.

Dr. R. H. Bossi, LLL, accompanied Dr. C. F. Knutson, C. K. GeoEnergy, on March 12, 13 and 14 during part of the service company and operating company interviews that were carried out in southern California.

The literature search was conducted as follows:

- The GeoRef search previously made by LLL was integrated with the Technical Information Center, Petroleum Abstract, and New Mexico Institute of Mining and Technology searches. SPE and SPWLA publications were reviewed, along with the proceedings of the UN and other geothermal symposia.

- Articles that seemed to be particularly relevant to either casing and cement bond integrity assurance and assessment or failure were read and annotated.

- The Plowshare file at the NVO Library was reviewed and articles were read and annotated that seemed relevant to this study.

II. CASING INTEGRITY ASSESSMENT CAPABILITY

Commonly used surveys for assessing casing integrity include 1) electromagnetic surveys, 2) caliper logs, 3) spinner surveys, 4) radioactive tracer surveys, and 5) differential temperature logs. Hole size limitations, maximum operating temperatures and pressure, and permissible hole conditions are shown in Tables 1 and 2 for a number of these logs that are currently offered by 5 major U. S. logging companies.

A. ELECTROMAGNETIC SURVEYS

Commercially available downhole electromagnetic surveys utilize a coil for generating a magnetic field. This magnetic field sets up eddy currents in the casing which in turn attenuate the magnetic field and shift its phase. The altered magnetic field is detected by another coil, and the differences in the original and altered fields are compared. The differences observed are related to casing wall thickness, frequency, magnetic permeability and casing resistivity. Variations in the latter two parameters are minimized by using a reference joint for determining a metal thickness scale.

These surveys are useful in measuring casing wall thickness, corrosion damage, holes, cracks, splits, etc. Other complementary electromagnetic surveys are available which enable discrimination between casing wear inside and outside the pipe. Maximum temperature for these logs is commonly quoted at 255° to 350°F.

B. CALIPER LOGS

Caliper tools have multiple expanding arms that make contact with the casing walls. The diameter recorded is that of a circle described by the tips of the arms. The caliper log is useful in analyzing corrosion damage, scale buildup, collapsed and parted casing and casing breaks. Tool temperature limitation is commonly 250°-400°F.

C. SPINNER SURVEYS

Spinner-type flowmeters can respond to and locate fluid flow through holes in the casing. Maximum quoted temperature is 500°F. Flow rates as low as 50 barrels/day in 3½" i.d. pipe can be accurately measured by Schlumberger's fullbore flowmeter, for example.

D. RADIOACTIVE TRACER SURVEY

Radioactive tracer surveys are useful in locating casing leaks by logging the movement of injected tracers. Both solid, liquid, and gaseous tracers are used. Injection of tracers can be accomplished downhole as well as in the surface lines. Gamma ray logs may be run simultaneously with injection or afterwards, depending upon the type of survey run. These surveys are very useful in detecting low flow rate leaks. Maximum temperature capabilities quoted range from 300° - 350°F.

E. DIFFERNTIAL TEMPERATURE LOGS

At a hole in the casing where water is leaking, temperature anomalies will occur. The differential temperature log is capable of pinpointing these anomalies even though they may be minute, since the curve produced describes the slope of the absolute temperature curve. Maximum operating temperatures quoted for the differential temperature log range from 325° - 500°F.

III. CEMENT AND BOND INTEGRITY ASSESSMENT CAPABILITY

The four basic logs used for cement and cement bond integrity assessment are (1) cement bond (CBL) and/or a wave train display, (2) modified density (either nonfocused or with a standoff), (3) noise and (4) temperature logs.

The cement bond log measures the amplitude of the pipe signal and in certain cases the amplitude of a later arrival which reflects the behavior of the pipe plus the cement bound to the pipe, which is a measure of the cement formation bond. An alternate CBL configuration is a display of a part of the wave train as a variable density output. Some wave train function, either variable density or a portion of the wave train displayed every 2 to 10 feet, is usually displayed with the common CBL amplitude outputs.

The nuclear cement log is a modified density log that is either non or spherically focused or is provided with a standoff, so that it is sensitive to the density of the material behind the pipe. Thus, if there is a density contract between the cement and the mud or fluid being displaced by the cement, the log allows an estimate of the amount of cement fill at any position in the well by indicating the material density.

The noise log is a display of the number of decibels of high frequency sound being recorded at any vertical location in the wellbore. Usually about four frequencies are recorded, i.e. 2000, 1000, 500, 200 hz. An evaluation of the log can pinpoint areas in a well where channels occur behind the pipe in which either gas or liquids are flowing. The logs may be set up in different configurations, so that some logs can be run in either gas-or liquid-filled holes.

The temperature logs provide a plot of temperature vs depth. The hydrating cement undergoes an exothermic reaction that provides a temperature anomaly which allows the top of cement to be determined, if no other anomalies are present. Unfortunately, temperature anomalies are common in geothermal wells, and the interpretation of cement tops are ambiguous. The log must be run while the cement is reacting. Therefore, this type of log provides no information about the position of cured cement behind the pipe.

The standard cement and cement bond evaluation logs run by five major logging service companies are presented in Table 3. This table provides a summary of the type log being considered (the logs are frequently identified by groups of initials or cryptic names in the company literature), the hole size limitations, the maximum operating temperature and pressure for the sonde, and the permissible types of fluid in the hole for definitive logging.

A number of additional configurations have been used, in conventional oil and gas wells, to detect channels in cement behind pipe. These are usually complex devices that are run with an orienting tool, and depend upon an anomaly produced by the increased water content in the non-cemented channels. The channels are frequently near vertical, and the orienting device, which allows the sonde to be rotated, provides information on the aximuthal location of the channel. Some of the configurations that have been used are:

1) Noise/differential temperature logs (requires flow in channel).
2) Oxygen or carbon/oxygen log.
3) Chlorine log (salt mud or saline water or flush)
4) Neutron Lifetime log.

These configurations are not standard and are not enumerated in Table 3.

Discussions with service company personnel has indicated an additional incentive requirement to allow redesign or "hardening" of a number of the cement and cement bond evaluation logs for use in hot wells.

IV. INDUSTRY/SERVICE COMPANY EXPERIENCE

A. INTRODUCTION

A number of contacts were made with companies providing services and with hot well operating companies. The bulk of this hot well experience is in the area of thermal recovery, since the number of these wells is in the thousands while the number of geothermal wells is in the hundreds. The information obtained during these contacts is summarized in the following section of this report under topical headings.

Probably the two most interesting generalities that evolved during these discussions were:

- Reliable tools are not available to evaluate cement and casing conditions in hot wells. Most evaluations are currently being carried out in cooled wellbores. This isn't an entirely satisfactory arrangement, and the operating companies would like to have hot well capabilities available. However, they generally concede that the potential number of hot well logging jobs doesn't warrant an extensive development program by the logging companies, since there is no apparent payout.

- The dollars spent on hot wells should best be spent in doing the job right the first time around. The bulk of the logging effort is directed to the few cases where problems have occurred in carrying out the well design program.

B. GEOTHERMAL OPERATORS

1. Company A

a. Western Division Office

The company policy is to react only to problems, hence little work is carried out aimed at evaluating what is going on in non-problem wells. Their effort is concentrated in getting the job done correctly the first time around.

Only one failure has occurred in a 4-year period involving 18 wells. It was determined that this failure probably resulted from a water filled annulus located between two areas of good cement. The water expanded when temperature rose during production and collapsed the pipe. They have attempted to prevent any further occurrences of this type by-

1) doing more sophisticated cement jobs,
2) using heavy wall K-55 casing, and
3) using a comprehensive pipe inspection program both in the yard and at the well site prior to running the casing.

The current practice is to run temperature and caliper logs after cementing primary casing. The CBL is run only as a problem-solving device. They feel that in general the CBL doesn't provide readily interpretable information. The "Dialog"-type caliper surveys are rerun during the subsequent drilling, and occasionally drilling has been terminated early because of casing wear. A baseline caliper is run when a well is put on production, and if corrosion of surface equipment is subsequently noted, an additional caliper run is made to evaluate casing corrosion.

They would like to have more sophisticated equipment available to provide information about casing condition. They feel that this equipment would have to be high temperature logging devices, because their management is opposed to setting plugs and cooling pipe in order to run available low temperature inspection logs.

b. <u>Field Office</u>

An initial base caliper log is run in the casing for comparison with logs to be run later. They once asked a service company to run a cement bond log in one well with a maximum temperature of about 500°F. The cable failed and no log was obtained. They believe that cables can be made to survive these kinds of temperatures. The chief problem with cement bond logs is that of interpretation because of thermal degradation of the cement and possibly the altered nature of the producing formation.

2. <u>Company B - Headquarters/Research Office)</u>

Company B took over some geothermal wells in the Imperial Valley a number of years ago and tested them. They were not able to develop a scale/corrosion mitigation technique to cope with these two problems and consequently abandoned the project. Temperatures ranged up to 600°F. Company B is now actively drilling and testing in Nevada and Utah.

The major problem encountered with respect to casing/bond integrity is that of water remaining behind the pipe after cementing. It can collapse the casing and has done so in one case for Company B. They have not seen any corrosion problems in Nevada and Utah. They are sure that scaling will occur, however.

Their completion procedure now entails an open hole but future wells may be completed either open hole or with slotted liner. They have had some sloughing.

Killing a "good" geothermal well generally doesn't hurt the productivity. Until logging tools are developed to withstand high temperatures, their wells would have to be shut in and cooled for logging.

Their spokesman feels that the caliper log may need to be improved. He cited one case where the log indicated that the casing was either almost collapsed or else badly plugged with scale. After putting a rig on the hole, they found that there was neither scale nor casing deformation. Small diameter (less than 2") caliper tools are needed for scale detection. Caliper logs will always be needed, although he doesn't anticipate a big demand for casing logs in general for geothermal wells.

They don't anticipate that logs will be "routinely" run, but rather only when a problem is in evidence from the production operations. They probably have run back-to-back bond logs, i.e. before and after testing, but the spokesman is unaware of any such results.

3. Company C (Headquarters/Research Office)

Company C is actively drilling geothermal test wells. They have drilled in California, New Mexico, Idaho and Nevada. They have not done any testing of bonds and casing yet. As far as their experience with logs is concerned, they have been pleased with the results of Company H's cement bond log in oil and gas wells.

They are most concerned about failure on start-up as the high temperature fluids start transmitting heat into the cooler pipe and cement. One casing failure occurred at a buttress thread joint in the pipe.

Their test well procedure is to set 13 3/8" pipe and hand 9 5/8" in the hole as a production string. The production interval is open hole. They could, however, decide to set a slotted liner (uncemented) or actually cement in pipe and perforate.

Their spokesman feels that the cement will probably undergo degradation with time and that it may be necessary to block squeeze after a number of years. Their temperature experience is 350° -550°F. He does anticipate that there will be more casing and cement bond failures in future geothermal wells than in oil and gas wells. However, he anticipates that, rather than periodically monitoring the wells with casing inspection/ cement bond tools, they would wait for a failure and then try to solve the problem.

His opinion is that when the demand for geothermal well logging capabilities arrives, the logging companies will come up with a workable monitoring capability.

4. Company D (Western Division Office)

They are willing to discuss some general topics. They have run CBL's before producing a well and after it has produced for a while. The followup CBL's were run after they had set a retrievable packer and had filled the casing with cold water. The CBL's registered no bond in all cases after cool down. They have perforated and tried to squeeze to no avail. They feel that a micoannulus is formed by thermal expansion and contraction, but that the space is so small that it will not conduct any appreciable volume of fluid, even though it destroys the apparent bond registered by the CBL. They are attempting to set up a jointly funded DOE project to evaluate this phenomena.

The CBL's are not temperature tolerant enough to check the pipe while it is hot. They feel that they may be able to get a bond back by utilizing pressure to approximate the thermal effect. Thus, if they set the packer, fill the well with cool water, then pressure up the casing with water and log through a lubricator, they may prove or disprove the microannulus effect.

They use spinners and RA tracers to locate holes in the pipe. They log after filling the hole with cool water.

They have had problems with running logging equipment at elevated temperatures, mostly from the lack of reliability of the "high" temperature devices even though they are run in the ranges stated by the logging companies as being "allowable" or within logging instrument operating ranges. They would be interested in using sophisticated casing and cement evaluation tools if they were available.

5. Company E (Headquareters Office)

Company E cools its geothermal wells before logging. Even with cooling runs they find it difficult to obtain good logs with certain tools for the entire interval of interest, e.g. 4,000 ft. In addition to the cooling run time and expense, it is, of course, necessary to run temperature surveys to assure that the well is below the temperature limitations of the logs to be run. For these reasons, they find that the logging temperature limitations are troublesome and costly.

Their wells are completed with slotted liner in the production interval and the casing is cemented to the surface from the top of the liner. They don't always run a CBL after cementing. They do, however, rely on this log if a problem develops. The caliper log is used to check casing condition, when required.

6. Company F (Division Office

The Company F Division Office operates their Imperial Valley Facilities. They have run casing and cement bond inspection logs. Their experience with these operations has been frustrating.

They routinely run sinker bars prior to running a logging sonde in the hole. On one occasion they stuck the sinker bar (scale) and wore a hole in the casing milling up the sinker bar. The cement seemed competent behind the pipe at the location of the hole, so they scabbed on a casing patch. This patch appears to be satisfactory at least to this point in time.

The CBL's they ran didn't show any bonding. The wells had been cooled down prior to logging, and the lack of bond under these conditions seemed to be the general experience of other operators in the area.

They have also run caliper and magnetic casing inspection logs. They have to cool down the holes prior to running these tools, and still they have seen a lot of instrumentation problems on the logging attempts.

They field check for holes and/or defects in the casing that are indicated by the casing inspection logs by tracing fluid egress from the pipe with spinners or radioactive tracers. This part of their program seems to have been reasonably smooth.

C. THERMAL OPERATORS

1. Company A

a. Western Division Office

This company has a number of steam wells in California. Their preferred program is to cement a production string completely up to the surface. This technique provides mechanical stability of the string as well as preventing external casing corrosion and steam break out. If they are able to circulate 50 cu. ft. of cement to the surface, they don't run a CBL (Otherwise, it is run).

In one area they have encountered thief zones associated with faulting which has prevented circulation of cement to the surface. In this situation they have run an intermediate casing string in order to be able to achieve a completely cemented production string. Their standard procedure is to sandblast bottom joints and to centralize the pipe. The number of centralizers is varied with the experience in the individual areas.

In cases with no cement to surface, they run a temperature log to find the top and then a CBL to evaluate bond quality. This is not always a satisfactory procedure.

In one example case, no cement was circulated to the surface, so a CBL log was run. Poor cement quality was indicated in a critical area, so the interval was squeezed. The squeeze operation appeared to go normally but the subsequent CBL indicated poor bonding. On the basis of the normal squeeze operation, the well was completed without further remedial work. The well has performed normally and the squeeze cement interval appears to provide a "normally" filled and bonded annulus.

In the one area, lack of cement to the surface usually results in the casing "growing" when the well is steamed. The procedure is to run a CBL and try to squeeze wells without cement to surface. This procedure generally is beneficial but usually doesn't result in cementing to surface. The failure rate for new wells is about 5%, and about 50% for old wells.

They have run some Vertilogs and some calipers to locate holes in casing. However, a tracer log is the usual evaluation tool used. If the hole is in a non-critical area, they may run a packer and ignore the problem. If the hole is in a critical area, they will usually squeeze it. If they feel that they don't have a high probability of a successful squeeze the first time, the well may be plugged and abandoned. Problems are more expensive to correct that the drilling of new wells.

They have avoided using the more exotic "cements" or resins in squeezing operations. They feel that the probability of a stuck tool and extra expenses and complications is too high.

They have had problems with using either caliper or magnetic inspection logs in wells with scaling tendencies. The scale is usually a mixture of heavy oil-clay and silt-rust and scale. This material is baked on the pipe by the high temperatures, and the calipers ride on top of the resulting encrustations. (The scale can be so hard that scrapers are not always effective in removing it.)

b. <u>Field Office</u>

Service companies run their standard equipment and there have been no problems that have been brought to their division petrophysical engineer's attention.

They have run a few cement bond logs, but very few, if any, casing inspection logs. The wells are cooled down to the operating temperature of the service company tools, so there have been no problems with tool or cable failure due to high temperatures.

The major problem with cement bond logs in their thermal wells is in connection with the interpretation. The cement degrades behind the pipe due to the high temperatures and changes the appearance of the wave train from that exhibited by the original log.

2. <u>Company B (Field Office)</u>

This company has been operating a steam flood in the Southwest since 1971. Their chief reservoir engineer reports that their injection wells are completed especially for high temperatures and that there have been no requirements to run any casing or cement bond logs after the wells were put on stream.

3. Company C

a. Western Division Office

They have had essentially trouble free experience with their steam flooding operations in their California fields. They are doing infill drilling on 1-acre spacing (the old spacing was 10 acres), hence, the majority of wells are new injectors/producers.

Their steaming procedure is to inject steam into a well for about 1 week, let the well soak for a couple of weeks, slowly blow the well down and then produce until the rate drops to a level that required another cycle. The steam is injected down the tubing at +500°F, so the wells see an extreme temperature variation during each cycle.

Their wells have an 8 5/8 in. casing string set on top of the pay and cemented to the surface with a 30-40% silica flour high - temperature cement. A CBL is run to verify casing-cement bonding and cement fill-up. (The casing is usually J-55 with API - Standard C couplings). A 6 5/8" slotted liner is hung opposite the pay, and a tubing string is landed on a packer set in the top of the liner. Production and injection is through the tubing.

b. Field Office

Company C's district engineer reported that their steam flood wells in the West are not hot when logged and that they had no problems with their cement bond and casing inspection logging. Their well casing and cement programs are, of course, engineered for high temperature condition.

4. Company D

a. Headquarters

This company has had problems with all logging operations they have tried where bottom hole temperatures were about 350°F, and recommend circulation and cool down before logging hot wells, at least with currently available tools.

They feel that calipers provide marginal data about casing integrity and feel other downhole techniques have problems. They have used eddy current magnetic inspection and believe this provides some information on ID of pipe, condition of the few mils of metal next to the inner wall, and some indication of metallurgy. Some of the service companies provide variable current frequency. Company D feels that the lower frequencies provide a deeper look into the pipe. Hence, they may request repeat runs at 15 and 400 hz, under certain conditions. Flux leakage surveys have been used to evaluate both transverse and longitudinal defects.

A summary of company philosophy might be "Do all the surveying, design and evaluation before the pipe goes into the hole. That's the place one can save the bulk of the dollars, time and trouble." Following these guidelines they concentrate on surface inspections and techniques for running and cementing pipe.

They feel that running most surveys is still art, and keep a "black book" on the personnel running the surveys. They will then request "good" operators and refuse "bad" operators on most wells. If they anticipate doing any casing or cement evaluation in a well, they will run a base log as soon as possible after completion, then run subsequent check logs using the same service company, same tool, same speed, same constants, etc. They evaluate logs more from a "different from base log" than from a "calculated effect" viewpoint.

Company D requires "expert" witnesses on their critical wells and have an extensive check list that the witness fills out, as well as requiring the service company to submit a second filled-in service company checklist with their invoice (payment of invoice is conditional on receipt of properly completed checklist).

The company has a headquarters engineering service staff that serves as experts to monitor company-wide operations.

b. Field Office

Company D field office has been conducting a steam flood in the Western U. S. since the early 70's. They have not run any casing inspection or cement bond logs in any of the steam injection wells.

After an injection well has been in use for a period of time, a service company is asked to inject a short half-life tracer into the steam stream and after about three weeks the well is shut in and logged with a gamma ray tool to determine where the steam has been going. Maximum temperature is about 550°F. Sometimes cool water must be introduced to enable the logging company to run the gamma ray probe. They have been satisfied with the results of these logging operations and have not had any particular problems in interpretation or with tool malfunction.

c. Western Division Office

This office has had 10-15% failure rates in their steam recovery operations. The failures are usually associated with lost cement either in a shallow or several deep "sands". Their recommended completion practice is to circulate cement to the surface behind their production casing string.

They use a prestressed casing string. The technique is to mix a 50% excess cement (30-40% silica flour) with the last few hundred feet of a fast-set aluminite mixture. After an initial 4 hour-set, a 200,000 lb. stretch is placed on the string and held for 24 hours. The bottom of the string is sandblasted and the entire string is centralized. Temperature logs are run to find cement top if cement doesn't reach surface. If a thief zone is shallow, the top of the hole is filled by means of a one-inch grout pipe lowered in the annulus from the surface. Deep thief zones are treated by squeeze cementing.

All logs are run in a cool hole and the operator is satisfied with logging results. Several types of calipers and magnetic inspection logs are used to evaluate casing problems. They have stopped using the CBL since it provides no useful information unavailable from other logs. The CBL's indicate good initial bonds in all cases below cement top and no bond in any place in the pipe after the first high temperature surge.

The bulk of failures are caused by external corrosion where incomplete cement coverage occurs in the annulus opposite zones containing corrosive water. The techniques currently being used to mitigate failures are: (1) using "Flocheck" or other lost circulation material in spear-hear water pumped ahead of cement, (2) using buttress threads, (3) using programed power tongs, threadlock on bottom joints, high temperature lubricants, and scratchers-centralizers to run pipe and (4) using higher stretches on pipe.

d. Field Office

This field operation currently is using both stationary and portable steamers providing steam at well head temperatures between 550-650°F. The wells that were cemented to the surface and used prestressed casing designs exhibited no casing growth under high temperature operating conditions Prestressed casing without completely cemented pipe exhibited small growths (1½ ft). Steam was injected in the old wells using packers and insulated tubing, well completed wells used only tubing without packers.

Articulated calipers are used in conjunction with the 64-arm maximum-recording calipers to evaluate egging of partically collapsed pipe. If pipe is not too far out of round it is swedged back as close as possible to initial i.d. Wells with swedged casing are not usually used for steaming.

The steaming cycle on wells is - (1) inject steam for about 3 weeks ($8x10^9$ BTU to formation), (2) soak for about 1 week, (3) bring back onto production slowly and produce for 6 to 9 months. Well spacing averages 1½ acres and one unit is being considered for a steam flood which will provide information on behavior under more regorous well conditions.

6. Company E-Field Office

This company's experience is shallow steam flooding in California. They have had a minimum amount of trouble with new wells.

They prestress their casing and cement it to the surface with 30-40% silca flour high temperature cement. They check cement bond and fill with a CBL. They run a liner and inject and produce through tubing that is clamped at the wellhead and landed in a special packer set above the top of the liner in the casing.

They evaluate leaks by setting a retrievable packer in the casing above the liner and inject water. They evaluate the location of the leak with either a spinner or a radioactive tracer survey.

The wells are cooled in order to run logs. There have been no problems in getting good logs and no problems in interpretation according to the district superintendent and the regional log expert. The key to their success has been the engineering that has gone into completing the wells.

7. Company F (District Office)

This company operates a number of fire floods and steam floods in the West. They have not had any requirement to run cement bond logs or casing inspection (electromagnetic) surveys. They do run radioactive tracer surveys in their stream injection wells, however. These are done about once per year as a means to determine where the steam is going. Their district superintendent feels that they certainly are worth the money. Leaks can be located easily. Their production wells in the fire flood fields have not had any really high temperatures.

They developed a borehole televiewer which they found useful in cases where the approximate depth of the casing problem is known. If the depth is not know, it is very difficult to locate a problem with a televiewer.

8. Company G (Headquarters Office)

This company has done experimental oil recovery by injecting hot methane and saturated steam into hydrocarbon-bearing strata. The steam injection wells were estimated to have experienced 550°-600°F maximum and the hot methane wells, 800-900°F. A special cement was developed for these wells so that they could withstand the extreme temperature. Although vertical expansion of the casing occurred, there were no known failures of the casing or bond which interfered with operations. Unfortunately, however, no cement bond or casing inspection logs were run after the termal operations were begun.

D. LOGGING SERVICE COMPANIES

1. Company A

This company provides a spectrum of cased hole services. They do not run a casing inspection log, however. Their representative said that the casing inspection tools that they have bought and tried do not provide believable logs except in cases where the particular casing problem depth is know. Blind logging is not very productive.

They do considerable work in high temperture environments, particularly in the deeper wells. Their cement bond log is believable up to 400°F. At higher temperatures there are problems with hydraulic coupling. The electrical components can be insulated, he believes, to take care of temperatures up to 700°F or so. Their work indicates that in order to properly insulate their tool (and cable) for 600°F, they would need at least a 5½" casing i.d.

The hydraulic coupling problem is particularly worrysome in that any fluid movement, whether gas bubbles or liquid molecules causes the signal to be "disarranged". The signal wanders and it becomes extremely difficult to identify the various signals. The representative stated that by applying a surface pressure of about 1 psi/ft. at the wellhead, the fluid movement can be minimized (for non-completed wells).

The market for specialty logs like high temperature geothermal is not sufficient to motivate service companies to develop the necessary hardware and techniques. This company does some specialty work, but only for companies that provide them with enough standard business to help offset the extra costs of the specialty work.

2. Company B

a. Headquarters/Research

Company B runs a cement bond log, a casing inspection log and an electronic casing caliper log.

Their acoustic cement bond log is rated now at 350°F and requires a fluid-filled hole. It provides an indication of the effectiveness of the bond between the casing and cement as well as between the cement and the formation. Scale should not affect the log's validity. They are trying for a 500°F limit on this log. Their electronics are good to about 450°F. It is expected that soon the log can be run in 400°F fluids. This tool can probably be adapted to run in geothermal wells. Gas in the well gives this log "fits".

The casing inspection log is good to 350°F. also. It relates the effects of eddy currents on a magnetic field to casing wall thickness. It utilizes an exciter and pickup coil. Scale should not affect it (even magnetic scale). It does not require a liquid-filled hole. Only one string of pipe can be inspected. Both metal loss inside and outside the pipe are detected. Current research is aimed at a 400°F limit for this tool. A cross check run by one of the above-ground loggers and Company B showed good agreement.

The electronic caliper will ignore scale. It also is good to 350°F and doesn't require a fuild-filled well. Current research is aimed at 400°F. It measures pipe ID and consists of a non-contacting coil system which generates an electromagnetic field that sets up currents on the inner surface of the pipe that are detected by another coil.

Their spokesman indicated that steam injection wells are cooled to 350°F for running cement bond and casing logs.

b. Field Office

This company injects radioactive tracers into steam injection wells in the West and logs the wells subsequently with a gamma ray probe. In one state in which they operate, operators are required to conduct such a survey (for casing integrity checks) once every 6 months to 2 years depending upon the volume of steam injected. Their gamma probe is good to 550°F for 1-2 hours. Some of the injection wells see 700°F.

They also conduct spinner surveys on producing steam wells and run static and dynamic temperature logs for casing integrity checks.

Their tracer logging experience covers 10-15 years. Three types of tracers used, liquid, gaseous, and 100 mesh sand. The demand isn't sufficient for them to develop the capability to adapt the tracer technique to geothermal production wells. However, they believe that it can be done with some development effort. They tried it once, releasing the tracer on the bottom with very little success.

In one state, this company has found that a conventional cement bond log (acoustic) is not acceptable to the appropriate state regulatory agency.

c. Branch Office

This branch office has logged wells with temperatures as high as 525°F although they have minimized the time on the bottom when running in wells that hot. The bulk of their hot well work is caliper and radioactive tracer logging.

They have run repeat tracer logs in the same well using steam, air, and water. The resulting profiles were different. These profiles were run on formations and not holes in pipe; however, the operator felt that multiple holes of varying size (and capacity) might have the same effect. Thus, a "standard procedure" should be developed to extract the maximum amount of information from radioactive tracer surveys to detect holes in casing.

This company also provides CBL and magnetic casing inspection logging services. They state their CBL will not work with any gas in the liquids in the well bore which precludes its use in just about any geothermal fluid (even if the tool could withstand the temperature). The CBL has been used in geothermal wells that have had a plug landed at the bottom of the casing and filled with cold water. They say these logs never show a bond so there is no sense in running them under these conditions.

The field personnel were extremely pessimistic about "hardening" their magnetic casing equipment for high temperature operations. They say that there is a lot of exposed electrical equipment on their mechanically complex sondes, and it would require a complete redesign to work in high temperature environments.

3. Company C

a. Headquarters/Research

This company fields a high temperature CBL that is rated for 500°F. However, they feel that the reliability is not satisfactory. They state that gassy fluids ruin the signals and fluid movement can cause problems.

One of the individuals taking part in the discussion said that Company C basically didn't have tools that were adequate for geothermal well logging. They have modified some tools for high temperature conditions. However, they just were not moving forward on the task of developing equipment and personnel that would provide geothermal well logging services equivalent to those provided for conventional oil and gas wells. Their concept is that the anticipated market will not pay out the development cost. They are cooperating with DOE and individual companies to provide some hot well service, but some additional incentives will be necessary to provide real geothermal logging capabilities.

b. Field Office

Company C has a 500°F CBL unit and some gamma detection tools on the West Coast as well as 450°F cable in routine service. However, the standard practice is to cool hot wells and log at temperatures below 350°F.

Casing corrosion logs are being run in some hot wells, but this requires further cooling, usually to about 250°F. The CBL shows a microannulus in hot wells and they feel that these wells must be logged through lubricators at high pressures to get a meaningful signal. Most operators are using inexpensive tracer or temperature logs in thermal operations.

The gas storage operations are the only ones that are really concerned with evaluating corrosion on a periodic basis. They have a real economic incentive because the stored gas is so valuable, and the prevention of a single failure could pay for all of the preventive logging carried out by the entire gas transmission system. The storage well evaluation technique generally involves use of a series of base logs-CBL, mechanical calipers, and magnetic inspection logs. The logging sequence is rerun every 6 months and questionable casing conditions that are indicated by differences in the logs will be checked by pressure testing to verify casing integrity. They have had success evaluating corrosion even when corrosion and scale deposition were occuring at the same time.

The geothermal operators usually log their intermediate casing strings to make sure they have a reasonable cement job.

They have tried using using density logs looking for cement as well as temperature logs and CBL's. However, in these cases, the wells are not hot.

Some of the operators have tired oriented tools inside the pipe. These have been noise, density, differential, temperature, C/O and neutron lifetime Logs. These systems are used to identify and remedy channels in cement behind the pipe. However, these also are not hot well operations.

In current geothermal operations it is frequently cheaper to redrill instead of repair. Thus, the motivation has been one of detecting failures, not maintaining well conditions. They feel that some economic incentive for tool development might be forthcoming if the EPA or California requires monitoring of geothermal or thermal wells whenever high salt content water or toxic fluids are being conducted up through valuable fresh water aquifers. They feel that maintenance logging of hot wells would require development of a completely redesigned set of tools (In one case the tool is so complex that it might not even be worthwhile to make a redesign attempt).

The economic incentive just mentioned could go the other way, i.e. stop all development. Currently, about half of the thermal operations in one area of the San Joaquin Valley are shut in because of air quality problems.

4. Company D (Headquarters/Research Office)

Company D no longer has its corrosion detector log on the market. It was only good up to about 130°F. Their cement bond log is good up to 325°F routinely and can be run up to 375°F for special cases. This is the full wave train log pioneered by Company D. They are attempting to increase its temperature tolerance up to 400°(+) F. Teflon-coated cables are available that will withstand 450°(+) F. The bond log is only numerically valid at 0% and 100% bond. It requires a fluid-filled hole.

5. Company E (Headquarters/Research Office)

Company E left one of the major wireline contractors in the early 70's. They have limited themselves strictly to above-ground testing of tubular goods. However, they did consider at one time developing a downhole adaption of their transverse defect inspection tool. This would have located all corrosion pits.

Their above-ground transverse defect inspection detects both internal and external defects. Two magnetic coils induce a uniform longitudinal magnetic field in the pipe. Detectors locate defects by measuring variations (flux leakage) in the field caused by these defects.

Company E has tested the pipe that has been used to case geothermal wells in the Geysers. They believe that their measuring technique could be adapted to down-hole conditions, if required.

6. Company F (Field Office)

Company F fields a caliper log that is widely used to evaluate casing corrosion, failure, scale buildup, etc. Their logs have a temperature limit of 375°F (but not for extended periods of time), and a hole size capability of 2 3/8" - 17".

The caliper has 64 arms and the maximum extension of any arm is the recorded "diameter". The tool is centered by devices located above and below the arms. The arms have an extending force of 12 pounds each. The blade width is 0.09", thus they will wipe through many types of scale. The tips are carbide coated and have a 45° leading edge. There is a little wear or tip loss during any one run.

A typical scenario would be to log a problem well. If no apparent break is detected, the well would be cleaned up, relogged, and then put back in service or tested with a tracer, depending upon results of the final logging run.

7. Company G

a. Headquarters/Research

This company has a "casing analyzer", an acoustic cement bond log, and a televiewer. The first two logs are good to about 300°F and the last to 200°F.

The casing analyzer doesn't require a fluid-filled hole. It utilizes knives which "bite" through scale to determine whether or not corrosion has occurred. It is only a relative measurement, but will pinpoint problem areas. It currently is equippped with a motor, but it could be renovated so that the knives and the cable are downhole, thus making the temperature problem much easier.

Their televiewer is 3½" I.D. It requires relatively clean, clear water.

Their bond log required fluid in the hole, of course. They tried a dry hole logger in the 1960's. This log gives both cement/pipe and pipe/formation bond effectiveness. Gas in the hole fouls up the log.

8. Company H

a. Headquarters/Research

Company H has some high temperature instrumentation. They have resorted to teflon insulation and packing the transistorized electronic components in a vacuum bottle. This allows them to handle well temperatures in the range of 400-500°F. Since heat conduction is a function of temperature differential and time, the actual maximum temperature they can tolerate is a function of time at that temperature. They try to handle wells near the maximum temperatures by doing all downhole calibration and repeat runs up the hole where the temperature is relatively low. Then they drop down and run the hot log before temperatures inside the vacuum bottle get too high.

Their method of handling hostile environments results in severe limitations on the types of high temperature tools they can field. They can't use tools with motors, vacuum tubes or other power-consumptive components that will raise temperatures inside the vacuum bottles. Their current high temperature logging capabilities consists of gamma-CBL, gamma-neutron, "steam" density, temperature caliper, bottom hole fluid sampler and bottom hole pressure bomb.

The CBL logs are unreliable in gassy fluids. This eliminates most geothermal wells. They are working on a pad type sonic system for gassy wells (not for high temperatures though). This device should be available within one to two years, and probably could be modified for high temperature (450°F) operations.

Company H feels that developing extensive high temperature logging capabilities is a specialized field and, at present, they do not see economic incentives that would cause them to commit heavily in this area.

b. Field Office

Company H has enough interest in hot well operation to have set up one logging unit with special U. S. Steel single conductor cable (550°F), "CalRes" connectors and their complete line of modified sondes. They have assigned one logging engineer to this unit to specialize in logging hot wells. They have also assigned a staff engineer to follow the hostile environment logging and technical developments.

They have developed a lubricator that will handle steam and have logged without any cable-connector-sonde problems.

Company H is doing an appreciable amount of casing and cement evaluation logging. The hot wells that are being logged are only entered after being cooled down to the operating limits of their instrumentation (250-350°F).

They are currently checking a "substance" tool developed by Long Beach Oil Development Co. This tool measures stretch or compression joints of pipe (sensitivity 0.01 ft) as well as changes in spacing (subsidence or rebound) between radioactive bullets fired into the formation at various depth in the well.

Their general recommendations for logging are to run a series of baseline logs as early in the well's life as possible, then run appropriate tools when problems occur. Some of the type of logs suggested are

1) Natural current logs to evaluate galvanic corrosion.
2) The full suit of magnetic logs (flux leakage and flux density).
3) Caliper logs.
4) CBL or other cement evaluation logs (spherically focused density log, multi-spaced neutron log)
5) Noise and temperature to evaluate flow behind pipe.
6) Flow logs to detect leaks (flowmeter, radioactive tracer logs, temperature log)

Most of these logs would have to be run in a cooled well bore.

Company H high temperature logs are (1) a gamma-CBL, (2) a gamma-neutron ("compensation" for the neutron is handled by eccentering the tool and placing a shield on the back of the tool behind the detector), 3) the spherically focused density and 4) a temperature caliper log. This suit of logs was run for LASL in a Utah well with a bottom hole temperature of about 450°F. They reported no problems with cable, connectors, etc.

Their observation on problem wells is that they haven't been called out to help evaluate many problems where the well casing was initially cemented in an adequate manner.

9. Company I (Headquarters/Research Office)

This company developed a downhole electromagnetic casing inspection log which they ran for a while. However, they elected not to compete with the wireline companies and subsequently made their tool available to another company, which is now running it. This tool can discriminate between corrosion damage both inside and outside the casing.

They continue to field a very comprehensive casing inspection service for surface applications. They feel that adequate surface inspection of pipe, coupled with good running and cementing practices, will mitigate the bulk of casing/cement bonding problems. They feel this procedure is especially important in critical (hot or deep) wells.

E. CEMENTING SERVICE COMPANIES

1. Company A (Field Office)

Geothermal wells encountered in Company A's West Coast operations have had temperatures below 550°F while thermal wells have experienced temperatures about 650°F. In addition, some of the technical problems encountered in thermal operations are more complex (San Ardo high and low pressure aquifers), and the number of wells is much greater than geothermal wells with applications. Hence, thermal experience should be factored into geothermal well design.

They also believe that conventional cement can be modified to handle geothermal applications. The research dollars should be spent for understanding the problems and how to cope with them instead of looking at exotic concoctions. A number of well-cemented steam wells have been going for 15 years, cycling between 100 and 650°F at least once a year, and still have adequate cement jobs. Poor cement jobs really promote most of the failures.

Procedures that help achieve good cement jobs are:

- Condition the hole so it is as round and as uniform in diameter as possible.
- Condition mud and modify, if necessary so it has reasonable viscosity at bottom hole temperatures.
- Remove mud with a spacer that has a density between mud and cement and contains necessary chemicals to promote good bond between formation and cement and provide any necessary lost circulation capability.

- Displace cement in such a manner (and have necessary scratchers, centralizers, baffles, etc. on the casing string) that complete fill between formation and pipe is achieved.

- If there is a tendency for formation to break down or thief zones are present, casing should be cemented in stages. The best procedure is to pump cement above stage collar, open collar and circulate excess cement to surface.

Their philosophy on areas that need additional work is that they feel that the bulk of the dollars seem to be going toward the material aspects, and that they could be better spent for knowledge about the systems being cemented and understanding the reasons for the problems.

They have been involved in the attempts by several operators to evaluate the quality of the cement jobs. One operator looked at the loss of apparent bonding on CBL's after taking pipe/cement to high temperature. The operator ran the CBL cold and found no bond, landed a retrievable plug at the bottom of the casing, filled the casing with water and started to pressure up the pipe while making repeat runs with the CBL. The bond appeared on the log with a surface pressure between 700 and 800 psi. This behavior indicated the formation of a microannulus between the cement and the casing after a high to low temperature cycle. The operator calculated that the good bond should be developed before the system reached high temperature on the next thermal cycle, and that no liquid flow would occur between the pipe and the cement either through the microannulus under the cool condition, or under the high temperature conditions when at least a mechanical bond was reestablished.

One operator felt that they achieved better bonding during thermal cycling by sandblasting at a bottom anchor section of the casing and letting the cement set up with the casing under tension.

Another operator attempted to find the cement top with a temperature log. He encountered a number of anomalies that weren't related to cement hydration and concluded this technique was unreliable in hot wells.

Yet another operator tagged the last third of the cement with a radioactive material, then used a shielded directional gamma tool to evaluate channels in the cement behind the pipe. This operation took place in an area with a channeling problem. He felt that shooting and squeezing the channels resulted in a better success ratio than the more conventional technique of randomly shooting holes and squeezing areas indicating a poor cement bond on CBL evaluations.

An Imperial Valley operator is running simulated cement/casing tests under downhole conditions. This information has been reported, in part, in the literature (Gallus, et al, 1978). Several Portland cement formulations seem to be performing adequately, at least through test periods of one year.

Attempts at reverse circulation generally result in higher fluid pressures in the annulus and a higher probability of formation breakdown.

To summarize, they feel that adequate casing/cement operations are attainable. The big problem is to understand the system and tailor casing and cement designs to take care of the problems inherent in that system.

2. Company B (Field Office)

Company B field personnel felt that CBL logs they had seen run on geothermal wells were next to useless. They felt that a number of operators were not being conservative enough in "overdesigning" the cement jobs on the hot wells. They felt that, in the case of thermal wells where every penny was counted, there may be some justification for a "close" design job, but they felt this should not be the case on geothermal wells.

Some of the factors that seemed to yield better casing bond/cement "life" are:

- Condition hole before setting pipe so that no ledges, etc., are present to catch pipe or restrict pipe movement.

- Condition mud so it will remain liquid and removable.

- Centralize pipe. They feel you can't do a good job of cementing pipe that is against the side of the hole.

- Remove mill scale from pipe. Sandblasted or rusted pipe is best.

- Use a spacer to remove mud ahead of cement.

TABLE 1 SPECIFICATIONS OF SOME SURVEYS FOR ASSESSING CASING INTEGRITY
5 MAJOR LOGGING COMPANIES

COMPANY/SURVEY	DIAGNOSTIC CAPABILITY	CASING SIZE, in.	MAX.TEMP, °F/ PRESSURE, 1000 psi	Borehole Condition *
BIRDWELL				
Caliper - 6 arm	Casing i.d. and variations to ¼"	4-30	250/10	W,E
Caliper - 3 arm	Casing i.d. and variations	2-24	250/	W,E
DRESSER ATLAS				
Vertilog	Locates and discriminates between isolated and circumferential defects to 1/8" and penetrating > 20% of pipe thickness-discriminates between external & internal corrosion.	4½-8 5/8	250/10	W,E
Magnelog	Average casing thickness-location of active corrosion and holes-distinguishes external and internal metal loss.	5 min.	300/20	W,E
Casing Potential Profile	Location of casing corrosion. Determines current necessary for cathodic protection.	4½-13 3/8	275/3	E
Through-Tubing 3 arm caliper	Casing diameter, detection of breaks, corrosion damage, and scaling	2-30 5-30	350/9 400/20	W,E W,E
Caliper-4 arm (4" od)	Casing diameter, detection of breaks, corrosion damage, and scaling	5-30	400/20	W,E
Caliper- 4" (3½" od)	Casing diameter, detection of breaks, corrosion damage, and scaling	3½-20	400/20	W,E

TABLE 1 SPECIFICATIONS OF SOME SURVEYS FOR ASSESSING CASING INTEGRITY 5 MAJOR LOGGING COMPANIES (continued)

COMPANY/SURVEY	DIAGNOSTIC CAPABILITY	CASING SIZE, in.	MAX. TEMP. °F/ PRESSURE 1000 psi	BOREHOLE CONDITION *
NL MCCULLOUGH				
Casing Inspection Log (CIL) (Electromagnetic system)	Calipers casing wall thickness by measuring internal and external metal loss.	2 3/8-9 5/8	350/18-20	W,E
Electronic Casing Caliper (ECC)	Measures i.d. and shows damage	2- 11 3/4	350/20	W,E
Combination CIL/ECC	Extent of damage or metal loss and discrimination between outer and inner damage.	2- 9 5/8	350/18-20	W,E
Caliper - 3 arm (1¼" o.d.)	Gauges casing size and irregularities.	1½ - 36	300/12	W,E
Caliper - 3 arm (1 3/4" o.d.)	Gauges casing size and irregularities.	1.995-36	300/15	W,E
SCHLUMBERGER				
Pipe Analysis Log (PAL)	Locates corrosion damage, discriminates between damage on outside and inside casing.	5-7 5/8	255/10	W,E
Electromagnetic Thickness-Log plus PAL	Detects and locates severe corrosion in outer casing of double string.	5-7 5/8	255/10	W,E
Caliper-2,3,4 arm	Casing i.d., variations	Not available	Not available	W,E
WELEX				
Caliper-4 arm (3"o.d.)	Casing i.d., irregularities	Not available	300/20	W,E
Caliper-4 arm (3 3/8"-3 7/8" o.d.)	Casing i.d., irregularities	Not available	350/20	W,E

* W: Waterfilled, E: Empty

TABLE 2 SPECIFICATIONS OF SOME SURVEYS USEFUL IN LOCATING CASING LEAKS
5 MAJOR U.S. LOGGING COMPANIES

COMPANY/SURVEY	CASING SIZE, in	MAX. TEMP. °F/ PRESSURE 1000 psi	BOREHOLE CONDITION*
BIRDWELL			
Radioactive Tracer	2 min.	350/15	W
Differential Temperature	2 min.	400/10	W
Spinner	2 min.	300/10	W
DRESSER ATLAS			
Nuclear Flolog	(1½"od tool)	350/12	W
Continuous Flowmeter	1 25/32-9 5/8	300/18	W
Differential temperature (1½" o.d.)	1 11/16 min.	325/20	W
Differential temperature (1 11/16" o.d.)	1 25/32 min.	400/17	W
(1 11/16" o.d.)	1 25/32 min.	325/18	W
N L MCCULLOUGH			
Tracer (Isotope Injector)	1.995 min.	350/13	W
Tracer (Solution Isotope Inj.)	1.0 min.	300/15	W
Tracer (Surface Injection) (1 3/8 o.d.)	1.5 min.	350/18	W
Tracer Surface Injection (3½" o.d.)	3.920 min.	350/13	W
Differential Temperature (7/8" o.d.)	1.0 min.	350/15	W
Differential Temperature (1 3/8" o.d.)	1.5 min.	350/20	W
Spinner (1 3/8" o.d.)	1.5 min.	300/12	W

TABLE 2 SPECIFICATIONS OF SOME SURVEYS USEFUL IN LOCATING CASING LEAKS (Continued)

COMPANY/SURVEY	CASING SIZE, in.	MAX. TEMP. °F/ PRESSURE 1000 psi	BOREHOLE CONDITION*
SCHLUMBERGER			
Radioactive Tracer	1.5 min.	300/6	W
Packer Flowmeter (1 11/16" or 2 1/8" od)	to 9 5/8"	285/10	W
Continuous flowmeter	(1 11/16" or 2" o.d. tool)	350/14	W
High Resolution Thermometer	(1 11/16" o.d. tool)	350/15	W
Flowmeter - Temperature	(1 11/16" o.d. tool)	500/20	W
WELEX			
Fluid Travel	(1.5" o.d. tool)	325/20	W
Radioactive Tracer	(3 5/8" o.d. tool)	300/10	W
Radioactive Tracer	(2 1/8" o.d. tool)	300/15	W
Radioactive Tracer	(1.66 o.d. tool)	300/15	W
Radioactive Tracer	(1 5/8" o.d. tool)	400/20	W
Precision Temperature	(1 5/8" tool)	400/20	W

* W: Waterfilled, E:Empty

TABLE 3 CEMENT AND CEMENT BOND INTEGRITY ASSESSMENT CAPABILITIES OF FIVE MAJOR LOGGING SERVICE COMPANIES

COMPANY/SURVEY	DESCRIPTION OF SURVEY[1]	CASING SIZE, in	MAX.TEMP. °F/ PRESSURE 1000 psi	BOREHOLE * CONDITION
BIRDWELL				
CBL (Cement Bond Log)	Records variable density plot of wave form which allows interpretation of (1) free pipe, (2) good bond to pipe and formation, (3) good bond to pipe no bond to formation, or (4) partial bond	2-18 3-18 4½-18	250/7,5 250/7,5 350/15	M,O,W M,O,W M,O,W
CNT (Cement Top Locator, Nuclear)	Focused with stand off or non focused density log.	4-10	250/10	G,M,O,W
TL (Temperature Log)	Detects the temperature anomalies that can be associated with the hydration of cement behind the pipe.	2-20		G,M,O,W
WSS (Noise Log)	Records noise levels that could relate to fluid flowing in channels in the cement behind the pipe.	3-16	Not Available	G
DRESSER ATLAS				
ACBL (Cement Bond Log)	Records compressional wave amplitude and either half wave trace or variable density trace of wave train.	4-15 4½-15 2- 15	500/20 350/20 450/20	M,O,W. M,O,W M,O,W

TABLE 3 CEMENT AND CEMENT BOND INTEGRITY ASSESSMENT CAPABILITIES OF 5 MAJOR LOGGING SERVICE COMPANIES (Cont'd)

COMPANY/SURVEY	DESCRIPTION OF SURVEY [1]	CASING SIZE, in.	MAX. TEMP. °F/ PRESSURE 1000 psi	BOREHOLE CONDITION*
Photon (Spherical Density Log)	Records density of material behind pipe as well as fluid levels in borehole, liner tops, casing seats, etc. via non focused gamma-gamma density tool.	4½- 15 2- 15	300/20 300/18	G,M,O,W G,M,O,W
Sonan (noise log)	Records noise levels that can be related to fluid flow in channels behind pipe.	2-15	350/17	G
Temperature Log	Records temperature profile down well, anomalies could relate to cement hydration.	2-20 2-15 2-15	325/20 400**/17 325/18	G,M,O,W G,M,O,W G,M,O,W
MCCULLOUGH				
Cement Bond Log	Records two different amplitudes and either wave train (2 or 10 ft. intervals) or variable density traces.	2-15 4	350/13 350/15	M,O,W, M,O,W
Nuclear Cement Log	Records density of material behind pipe with non focused density tool.	2-15 4-15	350/13 350/15	G,M,O,W G,M,O,W
Noise Log	Records noise levels that can be related to flow behind pipe.	2-15 2-15	350/15 400/20	G G,M,O,W,
Temperature Log	Records temperature profile that can be related to cement top.	1-20 1½-20 ½-20	350/15 350/20 510/15	G,M,O,W G,M,O,W G,M,O,W

** 2 hours

TABLE 3 CEMENT AND CEMENT BOND INTEGRITY ASSESSMENT CAPABILITIES OF 5 MAJOR LOGGING SERVICE COMPANIES (Cont'd)

COMPANY/SURVEY	DESCRIPTION OF SURVEY	CASING SIZE, in.	MAX.TEMP. °F/ PRESSURE 1000 psi	BOREHOLE CONDITION*
SCHLUMBERGER				
CBL/VDL (Cement Bond Log)	Records amplitude of casing signal and variable density trace.	2-13½	300/16 5	M,O,W
		4½-13½	350/20	M,O,W
		4½-13½	500/20	M,O,W
Temperature	Records temperature profile	2-20	350/15	G,M,O,W
		2-20	500/20	G,M,O,W
WELEX				
Acoustic Cement Bond/Micro seismogram	Records amplitude of casing signal and variable density trace.	3-15	325/20	M,O,W
		4½-15	325/20	M,O,W
Temperature	Records temperature	2-20	400/20	G,M,O,W

* W: Water, G: Gas or Steam, M: Mud O: Oil

V. RELEVANT LITERATURE PUBLISHED IN CONNECTION WITH THE PLOWSHARE PROGRAM AND DOE GEOTHERMAL WELL PROGRAMS

The Plowshare Program and geothermal literature searched consisted of the open-filed and unclassified material contained at the DOE Nevada Operations Office library or referred to in their card file. The pertinent information published in the general literature appears in the general literature search portion of this report.

The open file publications reviewed are listed in Table 4. A brief summary of the points that may have application to geothermal engineering (casing and cementing) from the Plowshare Program are presented below after the designation of the source documents.

PNE-G-9 - A leak was detected in the casing that was associated with a stage collar failure. It was apparent that a poor cement fill-up and bond were present at or near the stage collar or water would not have entered the well bore. The poor cement job and a mechanical failure that occurred on this very conservatively designed rigorously-managed and tightly procured emplacement well point out the difficulty in successfully turning a well plan into a finished product.

PNE-G-36 - API ST10-A, and STM STD-C150, C 350-65T and D 98-59 requirements were used in this cementing specifications document. In addition, laboratory and field verification of quality control and cement properties were required. Despite these tight specifications, a cement bond failure occurred.

PNE-R-8 - The casing was run on this well with a special crew using a computer controlled set of power tongs and utilizing optimum make-up conditions (8 turns & 7500 ft-lbs). The casing was "ruff coated" in critical areas and centralized at each joint, and cemented, utilizing "optimum" rates, densities, and composition. Casing bond logs and density logs verified adequately cemented casing. The casing was emptied of all liquids after cement cleanout and had no leaks (it was found to be completely dry), indicating the accuracy of bond data and the efficiency of the make-up technique.

PNE-R-38 - The specifications called for witnessed testing of each element by manufacturers, and field testing of assembly to working pressure.

PNG-RB-18 - The specifications called for shop testing all components and individual units to rated pressures. In addition all assemblies were field tested in place before being used in any field operation. In addition pipe and collars were magnetically inspected on site before being run into hole.

PNG-RB-40 - Casing program utilized very conservative design as far as specifications for weight, metallurgy, and type of thread. Casing was "ruff-coated" for conservative distances above critical cement bond areas in production and fractured zones. The casing was measured and graded on the rack at the well site and thread seal and lock was used. A parasite string was run outside casing as an aid to cementing upper sections of hole. Casing was centralized in every joint in critical areas and every third joint in all other non critical open hole areas. CBL, temperature, nuclear cement top, and radioactive tracer logs were run using three different companies (Schlumberger, Birdwell and Dresser) to provide cross-check on logging results. The cement delivered to the site was field tested prior to being used to make sure it met set time specifications.

PNE-RB-73-"Ruff-coat" was used at all critical areas. Cement collars, shoe and every third joint was centralized, and cementing baskets were run below stage collars. Shallow casing strings were cemented to surface and producting string was cemented with cement up into the intermediate string.

PNG-RB-75 - Computerized power tong unit was used to run production casing. Each joint of string was centralized up to cementing stage collar. All joints expected to see torque were thread-locked.

PNG-MHF-3 - First three joints and shoe of surface casing were thread locked and centralized. Intermediate string was run with computer-controlled power tongs. Bottom 30 joints were sand-blasted and centralizers and cement baskets were used. Production casing was also run with computer controlled power tongs. A conservative casing design (P-110) was used and casing was equipped with scratchers and centralizers. The bottom 94 joints were sand-blasted, and cementing was attempted in two stages, with 10-fold reciprocation during displacement of first stage. Circulation was lost during both stages. During first stage cementing, formation breakdown occurred even though mud was displaced by a gasified water to reduce pressure. The second stage breakdown may have been associated with the collapse of the cementing basket below the cementing stage collar. Final cementing was carried out by perforating and squeezing the "lost circulation" zone. Complete cement fill in the annulus was not obtained even with the squeeze cementing, and casing integrity was compromised with the miltiple perforations.

"Measuring Ground Movement in Geothermal Areas of Imperial Valley, California", Ben E. Lofgren.

Subsidence associated with geothermal fluid withdrawal has produced shear failures as well as tensile and compressive failures. Thus, geothermal well design must take into account all of these possible failure modes. Geothermal production has also affected water production from aquifers, so this factor must be considered in the overall design.

L.A.-5689-MS - An evaluation of geothermal well behavior mentioned that cement channels were reported in 50% of the Geysers Wells and four modes of casing failures had been identified: (1) water between cement blocks expands and collapses pipe, (2) compression failures due to heating, (3) tensile failures due to cooling, and (4) wellhead connection failures. Author feels many failures could be avoided if single diameter retrievable production tubing were used.

BNL - 50621 - Evaluation of cement requirements for geothermal wells indicated following minimum values: (1) 100 psi compressive strength within 24 hours, (2) permeability to water less than 100 md, (3) steel-cement bond greater than 10 psi, (4) chemically stable for prolonged exposures to 25% brine, flashing brine, or dry steam at 400°C, (5) capable of 3-4 hr. retardation at reservoir temperatures, (6) compatible with drilling mud, and (7) noncorrosive to casing.

SAN/1269-1 - Inclinometers can measure buckling or offset in casing. The sensitivity is 1:10,000. They also report ability to measure changes in distance between collars with extensometers. However, instrumentation is not suitable for hostile environments.

TABLE 4. Plowshare Open file Publications

PNE-G-9	Drilling and Testing Operations for Project Gasbuggy. 1968 (EPNG) (Conf-680926-3). NSA-23:490
PNE-G-28	Project Gasbuggy Operational Experiences. January 10, 1969 (UCRL) (UCRL-71356) (CONF-690103-2). NSA-23:15998
PNE-G-34	Specifications for Emplacement Hole GB-E Gasbuggy. May 1967 (F&S) (Specifications). NSA-Not Cited
PNE-G-36	Specifications for Cementing Services: Project Gasbuggy. July 1967 (F&S) (Specifications). NSA-Not Cited
PNE-G-38	Specifications for Post-Shot Drilling and Re-Entry, GB-2: Project Gasbuggy. May 1968 (F&S) (Specifications). NSA-Not Cited
PNE-G-40	Specifications for Drilling, Emplacement, and Instrumentation: Project Gasbuggy. July 1967 (F&S) (Specifications). NSA-Not Cited
PNE-G-48	Answers to Questions Posed by the Colorado Committee for Environmental Information Relating to the Forthcoming Rulison Underground Nuclear Explosion in Western Colorado. August 27, 1969 (NV) NSA-23:47663
PNE-G-71	Project Gasbuggy Hole Histories GB-E; GB-E-R; GB-1; GB 2R & 2RS; GB-D; GB-10-36. (F&S) NSA-25:21221
PNE-R-8	Emplacement and Cementing of Hole 25-95A (Emplacement Hole) Hayward Well in Garfield County, Colorado. 1969 (Austral Oil Co., Inc.). NSA-24:2333
PNE-R-38	Description and Specifications of the Rulison Christmas Tree Installed on the R-EX Well. July 1970 (Austral Oil Co., Inc.). NSA-Not Cited
PNE-R-60	Project Rulison Final Report--Phase II. December 28, 1972 (CER) NSA-27:22445
PNE-R-63	Project Rulison Manager's Report. April 1973 (NV) (NVO-71). NSA-28:8108

PNE-R-67-1	Project Rulison Well-Plugging and Site Abandonment Plan (NVO-174 , Rev. 1)
PNE-RB-6	Project Rio Blanco-LLL Technical Studies. August 2, 1971 (CER). NSA-26:15161
PNE-RB-16	Project Rio Blanco Definition Plan. Volume I-Project Description. February 14, 1972 (CER). NSA-26:36033
PNE-RB-18	Project Rio Blanco Definition Plan. Volume III-Reentry-Related Detailed Tasks. February 28, 1972 (CER). NSA-26:33317
PNE-RB-35	Planning and Operations Directive - Project Rio Blanco. February 1973 (NV) (NVO-125). NSA-27:11950
PNE-RB-40	Project Rio Blanco Emplacement Well - RB-E-01 As Built Report. June 22, 1972 (CER). NSA-27:27537
PNE-RB-57	Definition Plan: Alternate Reentry and Testing, Project Rio Blanco. September 1975 (NV) (NVO-145 Rev. 1). NSA-31:5943
PNE-RB-69	Project Rio Blanco Data Report- Production Testing-Alternate Reentry Hole RB-AR-2 (NVO-154)
.NE-RB-73	Project Rio Blanco Formation Evaluation Well (RB-U-4) Drilling, Completion and Initial Testing Report (NVO-168)
PNE-RB-75	Project Rio Blanco Alternate Reentry Well RB-AR-2 Hole History (NVO-38-33)
PNE-WW-13	Technical Studies Report Number Two-Project Wagon Wheel. October 1, 1972 (EPNG). NSA-27:11951
PNE-WW-15	Project Wagon Wheel-Interim Report of Wagon Wheel No. 1 at Casing Point Depth of 12,106 Feet. April 1970 (EPNG). NSA-27:7544
PNE-MHF-3	Rio Blanco Massive Hydraulic Fracture Well RB-MHF-3, As Built Report

IDO-100069	Completion Report, Raft River Geothermal Well Number 3
LA-5689-MS	Geothermal Well Technology and Potential Application of Subterrane Device. 30 p (1974)
LMSC-D 177630 (Vol. I)	Study of Nuclear Explosion Services Fielding System. Vol. I - Analyses and Results, Final Report, Phase II. June 24, 1971 (Lockheed Missiles & Space Company). NSA-26:2004
NSD-RA-N-74-159	Proceedings-Conference on Research for the Development of Geothermal Energy Resources, Sept 23-25 Pasadena, Ca. Jet. Prop. Lab 349 p (Dec. 31, 1974)
NVO-28	Safety Involving Detonation of Nuclear Devices, May 1966 (REECo). NSA-20:39149
NVO-40 (Rev. 2)	Technical Discussions of Off-Site Safety Programs for Underground Nuclear Detonations. May 1969 (NV). NSA-23:45426
NVO-48 (Rev. 2)	Reviews to Insure Safety of Nuclear Operations. August 1971 (NV). NSA-26:9063
NVO-170	Plan, Raft River Geothermal Well Number 3, 44 p (1976)
NVO-184	Operations Plan COSO Geothermal Exploration Hole Number 1, 48 p (1976)
NVO-0655-04	COSO Geothermal Exploration Hole Number 1, CER 26 p (1978)
NVO-1528-1	Geothermal Well of Opportunity Program Gruy and Associates 12 p (1978)
PNE-1550	Plowshare Geothermal Plant 5004P & F Construction Techniques and Costs.
TID-24996	Safety of Underground Nuclear Testing. April 1969 (NV). NSA-23:21845
TID-25708	Public Safety and Underground Nuclear Detonations. June 1971 (AEC, Washington, D.C.). NSA-25:44468

VI. LITERATURE AND PATENTS

Annotated bibliographies are presented in Appendices A-E for the following subject areas:

Subject Area	Appendix
High Temperature Logging in General	A
Cement Testing	B1, B2
Casing Testing	C1, C2
Casing/Cement Failures	D
Special Completion and Protective Treatment Techniques	E

These references are presented in reverse chronological order and the key points gleaned from the annotations are summarized in the foregoing sections.

A. HIGH TEMPERATURE LOGGING IN GENERAL

The cited references in Appendix A cover actual logging experience in the Matsukawa geothermal wells in Japan (Takaki, et al-1968, Nori-1965), the Raft River geothermal system (Applegate et al-1979) in Idaho, the Cerro Prieto Field in Mexico (Ershaghi and Phillips-1979), Roosevelt Hot Springs KGRA in Utah (Glenn and Hulen-1979), deep boreholes in Hungary (Jesch-1968), the COSO-BDH-1 geothermal well in California (Sheff-1979) and the "Hot Rock" Geothermal Wells GT-1 and GT-2 in New Mexico (Smith, et al-1975).

Also included are references to studies of the material and component requirements for high temperature logging (primarily for formation and reservoir analysis) currently being funded by the Department of Energy. These studies provide valuable data that are also applicable to high temperature cement and casing logging.

Research organizations include (among others) Sandia, Los Alamos Scientific Laboratory, University of Arizona, Battelle Pacific Northwest Laboratories, Mechanics Research, and Westinghouse Electric. Projects include work on a downhole fluid injector (Archulta, et al 1978), an amplifier (Cannon-1976), microelectrics (Palmer et al 1978, Palmer and Heckman-1978, Palmer and Gangard 1977, 1979, Palmer and Krauss-1976), a reference electrode and conducting probe (Danielson-1977), passive electronic components (Raymond, et al, 1977A, 1977B), temperature, flow rate, pressure, caliper, and fracturing mapping probes, corrosion resistant elastomers, ceramics and metals, borehole televiewer, and a sonde refrigerator to operate downhole for 100 hours (Veneruso and Stoller-1978).

Two problems specifically cited in this bibliography include the increasing conductivity of insulting materials with higher temperatures (Jesch-1968) and the magnitude of error caused by high temperature (250-300°C) on neutron logs (Kozhevnikov-1964). The hot rock geothermal well logging experience (Smith et al-1975) showed that most commercial equipment experienced downhole problems at 150°C and that most of the logs were unreliable at temperatures approaching 200°C.

B. CEMENT TESTING

Techniques are discussed in Appendix B1 (literature) and B2 (patents) for evaluating:

- the bond between well casing and cement and between formation and cement,
- the location and/or movement of fluids in the cement annulus, and
- cement condition.

1. Cement Bond to Casing and Formation

Indications of the integrity of cement bonds can be obtained from temperature logs (Anon-1967), and from acoustic cement bond logs (Brown, et al-1970, David-1973, Fertl,et al-1974, Fertl and Pilkington-1975, Fons-1968, Grisolva-1973, McNeeley-1973, Moore and Bird-1962, Muir-1964, Muir and Rollman -1970, Pardue, et al-1963, Pilkington and Fertl-1975, Pilkington and Scott-1976, Szytel-1974, App-1966, Walker-1965, 1967, 1968, Williams 1970).

Except for the Davis reference, the acoustic technique described involves the transmission of an acoustic sinusoidal wave train from the sonde into the borehole fluid which moves through the casing, cement, and formation, and is reflected and received by the sonde. The presence of gas and movement of the borehole fluid distort the signal and make interpretation difficult. The Davis patent involves electrical plusing whereby a magnetic field is generated, which in turn causes the pipe to vibrate and an acoustic wave to be transmitted by the pipe.

2. Location and/or Movement of Fluid Behind Casing

Techniques cited for determining the presence of fluid channels in the cement include sound (noise) logging (Britl-1976, Robinson-1973,1974,1976A, 1976B McKinley-1973, Stone 1977), temperature logging (Smith and Steffenson-1973, Dale-1942), radial differential temperature logging (Cooke-1978A, 1978B), neutron irradiation and gamma ray logging (Anon-1978, Ahmen-1977, Arnold and Papp-1977, 1978, Peelman and Langford-1977, Arnold and Peelman-1977, Schultz and Smith-1974, Smith and Schultz-1974), gamma ray logging (Killion-1965, Doering and Smith-1974), acoustic cement bond logging (Pickett-1966), oriented density logging (Holm and Kleinegger-1976), combination radioactive tracer injection and gamma ray logging (Mott and Dempsey-1968), combination acoustic/neutron logging (Muir and Zoeller-1967, Pennebaker-1971, 1972), combination temperature/sound logging (Pennebaker and Woody-1977), and combination noise/temperature/oriented density logging (Pennebaker and Woody-1977).

For the noise, tracer injection/gamma ray and temperature logging techniques to be effective, fluid must be moving behind the pipe, while the neutron irradiation/gamma ray logging, oriented density logging, and acoustic cement bond logging techniques will detect both mobile and stationary fluids. The fluid must have, at least, been mobile behind the casing for the gamma ray logging technique to be effective.

3. Cement Condition

Indications of cement condition can be obtained by acoustic bond logging (Zoeller and Muir-1969, Bell-1973)

C. CASING INTEGRITY TESTING

The types of flaws for which the testing techniques cited in Appendix C1 (literature) and C2 (patents) are applicable include 1) fractures/splits/cracks, 2) leaks, 3) casing wall thickness reduction, 4) axial and radial discontinuities, 5) pits, 6) holes, 7) lateral deflections (kinks), 8) scale build-up, 9) collapsed casing, 10) separations and, 11) departure from right cylinder configuration.

1. Fractures/Splits/Cracks

Testing techniques for which fractures/splits/cracks are specifically mentioned in the literature include: 1) magnetic casing logging in which an intense magnetic field at a crack induces voltage in a search coil (Murphy, et al-1968, Patterson, et al-1970), televiewer (Zemanek-1968 Anon.-1968), seisviewer (Caldwell and Strabola-1970), acoustic scanning (Shaller, et al-1972), caliper (Howell and Hille-1969), impression packers (Howell and Hille-1969, McKinely-1975), camera surveying (Carney-1971, Howell and Hille-1969), scattered X-ray intensity measurements (Youmans-1971), and electromagnetic logging (Edwards and Stroud-1963).

2. Leaks

Leaks can be identified by:

a) wireline packers and pressure tests (Anon.-1970A, Conover-1965, Bateman-1968, Loomis-1965B, 1965C, Rome and LaRussa-1978),

b) radioactive tracer injection with gamma ray logging (Alekseev & Screbrodolskii-1968, Fishman-1968, Singh-1973, Mott and Dempsey-1968),

c) dye=photo survey (Helander-1966),

d) differential temperature logging (Riley-1967), and

e) multiple temperature logging after injection of cold water (Innes-1964).

3. Casing Wall Thickness Reduction

Corrosion/erosion wear which results in thinning of the casing wall can be identified with electromagnetic logging (Bradshaw-1976, Cuthbert-1974, McCullough and Stroug-1970, Smith-1978, Edwards and Stroud-1963, Kirklen-1972), the electronic casing caliper (Edwards and Stroud-1965, Simmons, 1968), the casing potential profile,which also provides an indication of current requirements for cathodic protection (Curry-1970), a profilograph which utilizes a pickup transformer (Kiselman, et al-1973), a non-contacting caliper with a magnetizer (Wood and Walters-1969), a conventional caliper log (Heinricks,et al-1977, Dench-1973, Innes-1974, Bradley and Fontlenst-1973), and scattered X-ray intensity logging (Youmans-1971).

4. Axial and Radial Discontinuities

The use of a rotating magnetic source is put forth as a method of locating axial and radial discontinuities (Copeland-1967) as well as an expandable impression packer (Hutchinson, et. al-1974).

5. Pits

Pits were specifically mentioned as being detectable with a "Seisviewer" (Caldwell and Strabola-1970) and an electric potential measuring device (Lindsey-1974 and Heinricks, et., al.-1977) which locates the electric potential that cause corrosion pits.

6. Holes

Holes can be located with a plug pumped into the well which will stop just beyond the hole (Hubbard-1972) and by acoustic scanning (Shaller, et al-1972).

7. Lateral Deflections

A "kinkmeter" is recommended for locating buckled casing (Suman, et. al-1969, 1970, and Suman-1974).

8. Scale Buildup

Scale buildup can be determined with ring gauges (Wilson-1975, Innes-1964, Dench-1973).

9. Collapsed Casing

Collapsed casing can be determined by caliper logging (Kodiny-1977, Innes-1964).

10. Separations

Techniques for identifying casing separations include acoustic scanning (Scholler, et. al-1972), caliper logging (Kading-1977), an induction-tuned device for measuring pipe length (Marsh and Parijek-1968), and surveying with a search coil for magnetic fields (Patterson, et al-1970).

11. Departures from Right Cylinder Configuration

Such departures of the casing can be determined with a scanning probe with a feeler arm which is pivoted about a pivot axis while the pivoting axis rotates (Murphey and Sheffied-1972).

D. CASING AND CEMENT FAILURES

Failures of cement and casing are described in Appendix D for oil and gas production wells, steam injection wells, waste disposal wells, in situ combustion wells, and geothermal wells.

Types of failures described include casing leaks, dog legs, channeling in cement, wellbore communication (with multiple completions), casing collapse, cement failure, wellhead, disengagement of couplings, fractures, cracks, and buckled and sheared casing. Causes of failures have been attributed to:

1. water pockets in cement (Matsuo-1973, Fooks-1964, Smith-1964),

2. erosion (Smith-1964, Matsuo-1973),

3. cycling temperatures after appreciable time at high temperature (Cigni et al-1975),

4. bad cement jobs (Cigni, et al-1975, Ani-1974, Matsuo - 1970),

5. sudden increases in temperature (Bateman and Crawford-1970, Dominguez-1975),

6. changes in velocity and pressure (Smith-1973),

7. poor cement bond (Volek and Pryon-1971),

8. corrosion (Yosutake and Hiroshima-1975, Wheeter-1970, Shannon-1975, Marshall and Tombs-1969, Hill, et al - 1972, Hill, et al-1971, Endean-1976, Cross-1972, Glegg-1970, Clark-1969, Burrows-1971, Bradley & Bates-1966, Anonymous-1977, Sergio-1975, Owens-1975, Motuka-1968, Heinrichs, et al-1977),

9. subsidence (Wilson-1968),

10. thermal effects in general (Smith-1964, Dietrich and Willhite-1966, Gates and Sklar-1970),

11. fault zone movements (McCauley-1973),

12. holes (Gates and Jung-1977),

13. landslide (Bacon-1976),

14. high energy torque applied with drill string when drilling out cement plugs, cement, and floating equipment (Shuh-1967) and

15. axial loads induced by compaction as reservoir depletes (Suman-1974).

E. SPECIAL WELL COMPLETION AND PROTECTIVE TREATMENT TECHNIQUES

Annotated references to special well completion and treatment techniques required to avoid cement/casing failures presented in Appendix E were obtained as a product of the literature search for well casing failure data.

Problems for which special techniques are recommended include corrosion, wellhead failures, poor cement bond, casing breaks and collapse, sustained high temperature effects, casing offset, coupler failure, sulphur plugging, erosion, cement degradation, cyclic elevated-temperature effects, leaks at joints, thermal shock, cement gaps and channels and extensive casing and tool joint wear. These problems, the recommended special treatments, and cited references are presented as follows:

1. Corrosion: Cathodic protection (Warr-1976, Heinrichs, et al-1977, Sergio-1975, Weeter-1970, Motyka-1968, Anonymous-1971, Simmons-1966, and Kirklen-1973); special pipe coatings (Anonymous-1971), and improved casing metallurgy (J. Riedl and Baldauf-1974,

Swanson and Tralmer-1969).

2. Wellhead failures: Thorough cementing of the surface pipe (AlAni-1974).

3. Poor cement bond: Sqeeze cementing (Altseimer-1975).

4. Casing breaks/collapse: Heavier casing, special metallurgy (Altseimer-1975), 100% cementing, grout surface 5' diameter 100' deep (Craig-1964), liner type completion, limited perforated interval and larger diameter casing (Nelson-1975).

5. Sustained high temperature effects: Liquid-filled annulus (Cornelius-1970), special metallurgy (Schuetz, et.al-1964), hydraulically prestressed casing (Holmquist-1970), strengthening bottom joints and minor restrictions on drill-out practices (Shuh-1967) and improved cementing practices, high strength casing, controlled opening and development of wells (Dominguez and Vital-1976).

6. Casing offset: Welded centralizers on collars (Fooks-1964, Craig-1964).

7. Coupler failure: Special buttress threads (Craig-1964).

8. Sulphur plugging: Chemical wash (Lechler, et al-1978).

9. Erosion: Flush casing joints (Matsuo-1970)

10. Cement degradation: Fly ash mixed with the cement (Matsuo-1970) and API Class G cement with 40-80% silica to facilitate formation of truscottite (Gallus, et.al-1978).

11. Cyclic elevated temperature effects: Allowance for free expansion of casing, prestress of casing in tension and improved casing metallurgy (Stracke, et.al.-1969).

12. Leaks at joints: Thread lubricants/seals, specific tightening torques (Boyd-1977) and minimum torque with minimum turns and a limit on maximum turns (Weiner and True-1969).

13. Thermal shock: Slow heating and cooling (Fooks-1964).

14. Cement gaps and channels: Squeeze cementing (Boyd-1977).

15. <u>Excessive casing and tool joint wear</u>: Protective rubbers and smooth-ground tungsten-carbide hard facing on tool joints (True and Weiner-1974).

VIII. SUMMARY AND CONCLUSIONS

Currently, there are no high temperature cement bond and casing integrity logging systems for geothermal wells with maximum temperatures in excess of 500°F. As a consequence, operators of high temperature wells must cool them in order to run commercially available surveys. The market for such high-temperature surveys is currently insufficient to warrant private investment in the necessary development work to provide tools and cables capable of withstanding high temperatures. Operators would utilize such tools if they were available, however, since cooling runs cut down on production time and are, therefore, expensive.

The time lost in cooling the well in order to run logs could be sufficient for substantial well damage to occur. Because of the extreme difficulty in bringing geothermal well blowouts under control, any indication of a casing/cement problem must be expeditiously evaluated and solved. DOE-funded research and development is currently being carried out to develop capabilities for logging geothermal wells, primarily for formation evaluation. The results of these efforts are also applicable to the development of tools and cables necessary for the non-destructive testing of casing cement and cement bond.

The logs commonly used to evaluate cement/bond and the range of maximum operating temperatures (°F) quoted by a number of logging companies are:

1. Acoustic cement bond logs: 250° - 500°
2. Nuclear cement logs: 250° - 350°
3. Noise logs: 350° - 400°
4. Temperature logs: 325° - 500°

The most common types of surveys for assessing casing integrity and the range of maximum operating temperatures (°F) are:

1. Electromagnetic surveys: 250° - 350°
2. Caliper logs: 250° - 400°
3. Spinner surveys: 285° - 500°
4. Radioactive tracer surveys: 300° - 400°

Actual field tests of a number of commercial logs in geothermal wells have shown that downhole problems occur around

$300^{o}F$ and most are unreliable around $400^{o}F$. Service company representatives polled indicated that they expected that the logs currently being utilized (except electromagetic survey equipment) can be adapted to the more hostile environments of geothermal wells.

The types of well failures documented include leaks, dog legs, channeling in the cement, wellbore communication (multiple completion), casing collapse, cement failure, wellhead movement, disengagement of couplings, fractures, cracks and buckled and sheared casing. One of the prime causes of the most expensive failures (casing collapse) is espansion of water pockets between sections with good cement.

Representatives of both geothermal and thermal oil recovery operating companies are unanimous in their conclusion that the maximum effort and funds should be placed in engineering high-temperature wells to avoid failures. Some believe that casing and cement integrity surveys should be run routinely, while others prefer to wait until a problem is indicated before running logs. Some special techniques that are useful in preventing failures, expecially in geothermal wells, include:

Cement

- Better cementing practices, e.g. 100% fill
- Controlled operning and development of wells
- Special cement formulations (high silica)
- Centralizers
- Better squeeze cementing practices

Casing

- Better casing metallurgy and heavier wall pipe
- Casing prestressed in tension
- Controlled tightening of joints
- Flush joints
- Cathodic protection

Minimum problems have been encountered in hot wells with good cementing jobs, i.e., those wells with the annulus between the casing and formation completely filled with cement.

It is concluded that a DOE-funded development program is required to assure that diagnostic tools are available in the interim until geothermal resource development activities are of sufficient magnitude to support developmental work on high temperature casing/cement logging capabilities by industry. This program should be similar to and complement the current DOE program for development of reservoir evaluation logging capabilities. Such a program would support and assist in encouraging the development of geothermal energy. It could also help prevent undesirable environmental effects from occurring as a result of catastrophic cement or casing failures.

IX. REFERENCES

The complete list of references for all subject categories is presented in alphabetical order by senior author in Appendix F.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

HIGH TEMPERATURE LOGGING IN GENERAL

PERSONAL COMMUNICATION, Mathews, Mark; Los Alamos Scientific Laboratory, March 1979

> Los Alamos is responsible for obtaining baseline logs for 2 geothermal wells, one at the BuRec test site in the Imperial Valley and the other at Roosevelt Hot Springs, Utah. The California well is 6,175 feet deep and cased. From 5,420'-6,175' it is slotted in places. The Utah well is cased to 4,200' and open to 6,900'. Maximum temperatures are 440°F and 330°F, respectively, in the Utah and California wells. Logs run in the Utah well include Dresser Atlas' thermal neutron, density, CBL, caliper, and temperature and Schlumberger's induction gamma ray, thermal neutron and CBL. Logs were run in the California well by GO Int'l., Schlumberger, N.L. McCullough (casing inspection) and Dresser Atlas. Plans called for 7 logs by all 4 companies. Numerous problems were encountered.

TECHNOLOGY DEVELOPMENT FOR HIGH TEMPERATURE LOGGING TOOLS, Veneruso, A. F.; Sandia Laboratories, to be presented at the Society of Professional Well Logging Analysts Tulsa Symposium, June 1979.

A STUDY OF WELL LOGS FROM ROOSEVELT HOT SPRINGS, KGRA, UTAH, Glenn, W.E. and J. B. Hulen; University of Utah Research Institute, to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979.

APPLICATION OF OILFIELD WELL INTERPRETATION TECHNIQUES TO THE CERRO PRIETO FIELD, Ershaghi, I. and L. Phillips; University of Southern California, to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979.

WELL LOGGING CASE HISTORY OF THE RAFT RIVER GEOTHERMAL SYSTEM, IDAHO, Applegate, J.K., P.R. Donaldson and T. A. Moers; Boise State University, to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium; June 1979.

COMMENTS ON UTILITY OF GEOTHERMAL WELL LOGS FROM COSO-BDH-1, Sheff, J.R.; University of Lowell, to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979.

WELL LOGS FOR GEOTHERMAL DEVELOPMENT, BENEFIT ANALYSIS, Rigby F.A. and P. Reardon; Science Applications, Inc., to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979.

EXTREME TEMPERATURE RANGE MICROELECTRONICS, Palmer, D.W. and Richard C. Heckman; IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol CHMT-1 #4, Dec. 1978

Down-hole geothermal instrumentation must operate over a large temperature range to 300°C. Hybrid and printed-circuit (PC) board electronics that were developed during the last two years to meet that need are summarized. To ensure rapid widespread commercialization, this technology was developed, insofar as possible, using commercially available components, devices, and materials. Initial extensive high-temperature characterization revealed that selected thickfilm passive components and silicon junction-field-effect transistors had electrical parameters sufficiently insensitive to temperature change and sufficiently constant in time at high temperatures to form the backbone of this circuitry. Attachment techniques needed to be developed, since standard methods failed at high temperatures. Similarly, circuit design innovations were needed because of the restricted list of parts. Voltage regulators, line drivers, voltage comparators, special purpose amplifiers and multiplexers were constructed and operated over the 25-300°C temperature range. Temperature and pressure monitoring instruments using these circuits have been used for down-hole measurements in geothermal wells. Methods of fabrication, circuit performance, and the scope of future work are discussed.

EVALUATION OF A GEOTHERMAL WELL-LOGGING, DST AND PIT TEST, Tansev, Erdal O., Stanford University Geothermal Symposium, Dec. 1978

Several existing formation evaluation logs are capable of being run in 400° & 500°F environments. 400° maximum logs: 1) Hot Hole BHC with GR, 2) FDC, 3) CNL. 500° maximum logs: 1) Hot Hole Single Induction & 2) Hot Hole BHC.

ALUMINUM WIRE TO THICK-FILM CONNECTIONS FOR HIGH-TEMPERATURE OPERATION, Palmer, David W. and F.P. Ganyard; IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol CHMT-1 #3, Sept 78

One-mil aluminum wire connections to thick-film gold remain stable at 350°C for 1000 hr if a kovar diffusion barrier pad is affixed between the wire and the thick film. For direct wire-to-thick-film bonding, the modified fritless gold thick films, DuPont 9910, AVX 3520, and TFS A328 were found satisfactory for temperatures below 300°C. The wire alloy of choice for high-temperature operation is aluminum with 1 percent silicon.

RESEARCH AND DEVELOPMENT OF IMPROVED GEOTHERMAL WELL LOGGING TECHNIQUES, TOOLS AND COMPONENTS (CURRENT PROJECTS, GOALS AND STATUS) Michael D. Lamers; SAN/1380-1, Measurements Analysis Corp., Jan. 1978.

Most logging attempts in geothermal wells greater than 400°F have been unsuccessful, even with tools hardened for operations at 400°F-500°F. Current DOE logging r & d research projects include: 1) materials and components 2) high temperature electronic components, circuits, thermal protection devices, 3) cable-communications systems, 4) cable head connectors, 5) new measurement-sensor techniques and 6) improvement of existing tools and sensors.

HIGH TEMPERATURE INSTRUMENTATION FOR GEOTHERMAL APPLICATIONS, Veneruso, A.F. and H.M. Stoller; Transactions, Geothermal Resources Council, Vol. 2, July 1978

Near term goals are 275°C temperature and 7,000 psi pressure for up to 100 Hrs. Subsequent goals are being developed. Tools being worked on are temperature, flow rate, high resolution pressure, caliper and fracture mapping. Specific developments under way are 275°C electronics, Hi Temp pressure transducers, acoustic transducers, and Hi Temp corrosion resistant elastomers, ceramics, and metals. Sufficient line of 275°C commercial electronic devices & fabrication techniques are available for amplification, switching, filtering. Promising components have been identified for seals and wire insulation. Cables, cableheads & tool seals will be tested in coming months. Westinghouse is improving and temperature hardening transducers for borehole televiewer for DOE/DGE. Sonde refrigerator are being developed for 100 hours operation. Prototype temperature tool has been tested to 189°C downhole.

EQUIPMENT DEVELOPMENT REPORT: DOWNHOLE FLUID INJECTOR, Archulets, J.R., Fink, C.F., Kurtenback, J.; Los Alamos Scientific Lab., N.M. USA. Contract W-7405-Eng-36., Feb 1978. 27 p.

The development, design, fabrication, and operation of a tool used for injecting a discrete quantity of fluid (e.g. a dye) at a desired depth in a borehole are described. Assembly and operating instructions are included.

ACTIVE DEVICES FOR HIGH TEMPERATURE MICROCIRCUITRY, Palmer, D.W., Draper, B.L., McBrayer, J.D., White, K.R.; Sandia Labs, Albuquerque, N.M. USA . Contract EY-76-C-04-0789. 122p Feb. 1978. 122 p.

As part of a program to develop high temperature electronics for geothermal well instrumentation, a number of solid state diode and transistor types were characterized from room temperature to 300°C. The temperature dependence and aging stability of transport and leakage properties were measured. Included in the study were silicon diodes, bipolar transistors, JFETs, MOSFETs, and GaAs MESFETs and JFETs. In summary the results are: diodes and bipolar transistors became extremely leaky at high temperature and are therefore of limited use; silicon MOSFETS and GaAs devices showed unacceptable aging instabilities at high temperatures; silicon JFETs from certain manufacturers were sufficiently stable and had suitable temperature dependent characteristics so that operational circuits could be made. Comparisons were made of experimental device characteristics and those predicted by theory. The theoretical calculations were done using standard equations revised to include appropriate temperature dependent parameters. Close agreement between theory and experiment was found, indicating that unexpected high temperature effects were insignificant. In order to facilitate the use of devices in high temperature hybrids, it was necessary to develop bonding and prescreening techniques. A large variance of JFET 300°C operating parameters was found even within a single production lot. Consequently, high temperature prescreening allowed each circuit to be specifically "pretuned." Standard solder, epoxy, and chip and wire attachment technologies were not functional at 300°C. Gold-geranium solder,aluminum wire to DuPont 9910 gold film, and diffusion barrier pads were developed to allow high temperature attachment.

SENSOR APPLICATION SURVEY. TECHNICAL REPORT, TASK 1. Westinghouse Electrical Corp., Pittsburgh, Pa. USA Contract EY-76-C-02-4082., 1978 57 p.

Task 1 is a survey of well logging instrumentation undertaken to determine to what extent various tools can make use of severeenvironment acoustic sensor technology. The major goal was to establish the most appropriate tool for Task 2-Sensor Development and Optimization. Subject tools are borehole televiewer (BHTV), acoustic caliper, acoustic velocity logger, down hole flowmeter (DHFM), and passive listening monitor. This report describes the investigation of tool capabilities, applications, operation, and limitations under present and anticipated geothermal conditions. The results of Task 1 suggest that development of a combination BHTV/Caliper tool would have the most favorable impact on improved geothermal well logging capabilities and of nearly equal significance to DHFM. Acoustic velocity logger and passive listening devices are viewed as playing an important but lower priority role in geothermal resource characterization and development.

GEOTHERMAL DOWN-WELL INSTRUMENTATION-FINAL REPORT, Anon.; Sperry Research Center SCRC-CR-77-11, 1977 75 p.

Deals with transmitting downhole pump conditions uphole via acoustic transmission.

DEVELOPMENT OF ELECTRICAL AND ELECTROCHEMICAL PROBES FOR DOWN HOLE AND IN-LINE CHEMICAL ANALYSIS OF HIGH PRESSURE, HIGH TEMPERATURE GEOTHERMAL FLUIDS. INTERIM REPORT: PERIOD ENDING OCTOBER 1977, Danielson, M.J., Koski, O.H., Shannon, D.W.; Battelle Pacific Northwest Labs., Richland, Wash. USA, Contract EY-76-C-06-1830, Nov. 1977, 41 p.

Research progress in studies to develop a reference electrode and conductivity probe that would operate in the geothermal environment and provide data is reported. The conditions of the geothermal environment to which the probes must operate were defined as 250°C, widely varying salinity, large amounts of dissolved CO_2, and H_2S, and the potential for deposition of mineral scale. This work also involved a study of sealing materials. Midway through the work, a field test was carried out at East Mesa 6-1 Well, which involved the reference electrode, electrodeless conductivity probe, redox electrode, and instantaneous corrosion rate measurement (by linear polarization). A high temperature -pressure, thermodynamic reference electrode was developed which was demonstrated to be operative in a simulated geothermal environment up to 250°C containing the contaminants that would affect its operation. An electrodeless conductivity probe was developed for use in the geothermal environment. The design is particularly resistant to the effects of scale deposition. The probe should be useful for measuring salinity, steam/brine ratios in two-phase flow, flashing point, and as a liquid-level control. A large number of sealing materials were investigated for use in the 250°C geothermal environment. The field test of the conductivity probe and reference electrode at East Mesa was a success. The conductivity probe successfully predicted the total dissolved solids content of the brine, and the redox probe data coupled with Pourbaix diagrams indicated FeS and FeS_2 as surface film present on the electrodes and test loop. Instantaneous corrosion rate methods were demonstrated to be easily set up and convenient to operate.

DEVELOPMENT OF PASSIVE ELECTRONIC COMPONENTS FOR INSTRUMENTATION OF IMPROVED GEOTHERMAL LOGGING TOOLS AND COMPONENTS. Raymond L. S., Hamilton, D. J. Kerwin, W. J.; ANNUAL PROGRESS REPORT Arizona Univ., Tucson USA Contract EY-76-S-02-4081 Oct.20, 1977., 39 p.

Short term objectives for well-logging instrumentation are circuits which can operate at temperatures in the range 275°C-350°C; the medium term goal is operation up to 500°C, and the long term goal is to achieve operation at 1000°C. It is apparent that useful electronic circuits will require the combination of both passive components and active devices. In order to meet the compatibility requirements, the basic technology which has been selected in this project is the chemical vapor deposition of metal interconnections, resistor material, dielectric material and passivating materials. It is to be emphasized that this is a thin-film, not thick-film, technology which is compatible with the processing methods used in fabricating either semiconductor or integrated thermionic devices, and produces components which are electrically compatible with those devices. The investigation in this project is primarily directed toward tungsten metallization, tungsten-silicon resistors, and silicon nitride dielectric and passivation.

SUMMARY OF MINUTES OF SECOND GEOTHERMAL LOGGING STEERING COMMITTEE & SANDIA LAB, Anon.; June 28 1977..

operated over a temperature range of 400°C to greater than 1200°C, and at any pressure between atmospheric and 1 x 10^{-3} torr. Tungsten and tungsten-silicon nitrate were successfully deposited on oxidized silicon wafers. The tungsten is used for interconnects, capacitors and as a passivation layer. The materials are currently being studied in terms of their deposition parameters and electrical characteristics.

ALUMINUM WIRE TO THICK FILM CONNECTION (FOR) HIGH TEMPERATURE OPERATION, Palmer, D.W., Ganyard, F.P. Sandia Labs, Albuquerque N.M. USA Contract EY-76-C-04-0789 - 1977, 15 p.

From IEEE Proceedings, Electronic Components Conference; Anaheim, CA, USA (24 Apr 1978).

Portions of document are illegible.

Hybrid microcircuits in geothermal instrumentation must operate from room temperature to 300°C. High-temperature operation initially caused aluminum wire-to-gold composition bond problems. To remedy this problem, two wire bonding techniques have been qualified in high temperature aging tests: (1) ultrasonic bonding of aluminum wire directly to modified fritless gold conductor inks DuPont 9910, AVX 3520, and TFS A328, and (2) Insertion of a 1 mil diffusion barrier pad between the thick film and the aluminum wire. Both systems allow 100 to 1000 hours of geothermal circuit operation at 300°C. Three alloys of wire were tested, pure aluminum, aluminum with 1% silicon, and aluminum with 1% magnesium. The degradation rates differed greatly, with pure aluminum being the least tolerant to temperature aging, and wire with 1% silicon faring the best. Because thick film surfaces tend to be harder than thin film surfaces, hardened aluminum wire (elongation 0.5%) formed bonds with less pad deformation and, consequently, with higher pull strengths than standard bonding wire (elongation 1 to 3%). Comparison of wire bonds aged at three temperatures (250, 300 and 350°C) demonstrated several orders of magnitude spread in degradation rates; for 1000 hour bond lifetime, 300°C was found to be about the highest allowed operational temperature. Disks of kovar and nickel of 1 mil thickness and 30 mils in diameter were used as diffusion barriers between the gold and aluminum. Deposited on one side of each disk was a 1 pm gold film for thermocompression bonding to the thick film; the other side received an aluminum film for wire bonding. Aging for 1000 hours up to 350°C produced no increase in bond resistance for any of the three wire alloys tested. Some decrease in bond strength with time was noticed, but was attributed to annealing of the wire.

275°C MICROCIRCUITRY: RESISTORS, CAPACITORS, CONDUCTORS, SUBSTRATES, AND BONDING. Palmer, D.W., Knauss, G.L. Sandia Labs Albuquerque, N.M. USA Contract E(29-1)-789 - Dec. 1976 60 p.

High temperature electronics are needed for geothermal well logging tools. A survey of materials and passive components required for high temperature printed circuit boards and thick film hybrid circuits is summarized. Commercially available resistors, capacitors, substrates, conductors, and bonding techniques were tested over the temperature range of 25-300°C. Thick film resistors were found to have a total change in resistance of 1-5% from 25-300°C, and a resistance drift of less than 1 percent during 1000 hours at 300°C. Several types of capacitors were found that showed total capacitance change from 25 to 300°C of about 5 percent, high-temperature dissipation factors of less than 10 percent, 300°C insulation resistances of 10 megohm-microfarad, and high temperature lifetimes greater than 1000 hours. Polyimide board with the Ni plated Cu cladding, and alumina ceramic with thick film Pt-Au conductor paths were shown to be suitable for high temperature microcircuit frameworks.

BOREHOLE GEOPHYSICS IN GEOTHERMAL WELLS-PROBLEMS AND PROGRESS, Keys, W. Scott, Summaries 2nd Workshop Geoth Res. Eng. Stanford, p. 66-74 Dec. 1976

USAS has following logs rated at 250°C: 10,000 psi temp. fluid cond. caliper, gamma, spectral gamma, non-comp. gamma-gamma, non-comp. neutron, 16" & 64" resistivity (normal), SP, single point resistivity televiewer. Tools are on 2 trucks w/ digital and/or analog record. Tools usually are in stainless steel vacuum flask which isolates outside heat buildup for a 10 hour internal (heat causes instrument drift). Televiewer could be used as an inspection device for cracks etc. (used to 200°C).

DEVELOPMENT OF A PROTOTYPE HIGH TEMPERATURE AMPLIFIER FOR GEOTHERMAL WELL LOGGING. FINAL REPORT. Cannon, W.; Mechanics Research, Inc., Los Angeles, Calif. USA 53 p May 1976. 53 p.

A high temperature amplifier for use in geothermal well logging was developed. This development was based on the use of ceramic vacuum tubes as the active circuit element, since these tubes have the capability to operate in the high ambient temperature environment. The primary goal of this program was to design, build, and deliver a prototype amplifier capable of continuous operation in a 250°C environment. A development program designed to meet this goal covered four phases. These phases were 1) development of the basic circuit configuration with conventional, low cost glass envelope vacuum tubes; 2) modification of the circuitry to accommodate the ceramic vacuum tubes; 3) a 1000-hour duration temperature cycle (48 hours at 260°C and 2 hours at 20°C; and 4) development of a prototype, deliverable amplifier. The following sections discuss the high temperature amplifier development program. Section 3 describes the amplifier performance, including design requirements circuit design, development program, and the prototype amplifier. Section 3 presents test results from two breadboard models, one with conventional glass tubes and one with ceramic tubes, and the prototype amplifier, Section 4 describes the operation of the prototype amplifier. Circuit equations used for analysis and tube characteristics are contained in the appendices.

HOSTILE ENVIRONMENT LOGGING, Martin, C.A., Rust, D.H.; The Log Analyst, Vol 17, No 2. p. 3-10 March/April, 1976.

"Hostile environment" is defined as 350^{o}F + temperature and 20,000 + psi, pressure and/or H_2S or gas cut mud occurences which render impractical standard logging techniques. The "HEL" project called for temperature capability up to 500^{o}F and a subproject called for 600^{o}F monocable and temperature/flowmeter tool as well as a 600^{o}F logging cable.

At 500^{o}F, solder joints fail, many plastics melt, warp occurs, electric motors and relays arc, and semiconductor devices cease funtioning. 500^{o}F cable is teflon-insulated, neoprene bonded. Dewar flask insulation is used for electronics. Electronics heat dissipation had to be reduced with a special logic system based on complementary-Symmetry Metal Oxide Semiconductors. Metal components had to be scrutinized to avoid failures due to differential thermal expansion. O-rings were improved.

The temperature-flowmeter has been successfully run at 600^{o}F. CBL has been successfully run at 500^{o}F. A fiber-glass-filled monocable has been tested to 600^{o}F and is expected to survive to 650^{o}F.

They conclude that "... when wells go past over (Schlumberger) present logging capability, new equipment with yet higher ratings will be ready."

WELL LOG ANALYSIS IN THE GEOTHERMAL INDUSTRY (ABSTRACT), Sanyal, S.K., Meidav, T.; Paper RR, SPWLA Symposium, 1976.

REPORT OF GEOPHYSICAL MEASUREMENTS IN GEOTHERMAL WELLS WORKSHOP Baker, L. E., et al ; Sandia Corp., 1976.

GEOTHERMAL WELL LOGGING: AN ASSESSMENT OF THE STATE OF THE ART Baker, L. E., A. B. Campbell, and R. L. Hughen; The Log Analyst, p. 21-24, November/December, 1975.

Pertinent conclusions include: 1) Logging problems differ with geothermal well type 2) Attempts to log geothermal wells often have been marginally successful, 3) Special corrosion problems may be encountered and 4) there is insufficient economic incentive at present for private industry to provide adequate logging capability.

REPORT OF THE GEOPHYSICAL MEASURES IN GEOTHERMAL WELLS WORKSHOP-Albuquerque, N.M., L.E. Baker, R.P. Baker and R.L. Hughes; SAND 75-0608, Dec. 1975.

Some of the recommendations of this workshop were that:

1) Specific existing tools be upgraded to 480°F and higher.
2) Limitations and failure mechanisms be determined for existing tools, cables, seals, electronics, and other components.
3) Materials and components to be developed for the future including high temperature (greater than 660°F) elastomeric materials and active electronics with an extended temperature range.
4) Logging of geothermal wells should be funded to obtain data for evaluation of equipment capability.

WELL LOGGING TECHNOLOGY AND GEOTHERMAL APPLICATIONS-A SURVEY AND ASSESSMENT WITH RECOMMENDATIONS, Leonard E. Baker, Alan C. Campbell, Robert L. Hughen; SAND 75-0275, May,1975.

Contract Goals

1) Determine the basic downhole measurements that must be made to evaluate formation and the associated environmental limits.

2) Assess the current state of the art as it is currently applied in well logging.

3) Identify research that is presently being conducted in the private sector to extend the capabilities of logging instruments.

4) Suggest research areas to assure that formation evaluation tools are available as required in the development of geothermal resources.

The bulk of the work under this contract was aimed at formation evaluation. Some related logs were:

Induction casing log - casing thickness	3 1/2"	145°C	(285°F)
Radioactive tracers- fluid movement	1 3/8"	150°C	(300)
Televiewer-corrosion, brakes, shoes, etc.	3 3/8"	--	--
CBL - Cement Bond quality	1 11/16"	190	375
Caliper-hole diameter	1 1/4"	150	300
Flowmeter-"thief" zones	1 11/16"	315	600
Temp Log			

Some hostile environment tools exist, but no economic incentive for general hi temp. tool development exists.

Logging companies limiting development to reach 500^{o}F. P.26, 27, 31, 32, 33, 35, 37, 38-41.

PROBLEMS RELATED TO THE USE OF TRANSDUCERS IN THE FIELD OF GEOTHERMAL RESEARCH, Danesi, G., Manetti, G., Neri, G.; Ente Nezionale per l'Energia Elettrica, Florence (Italy), Ente Nazionale per l'Energia Elettrica, Pisa Italy . Centro di Ricerca Geotermica, (in Italian), 1975, 4 p.

For the determination of factors such as structural permeability or porosity, degree of fracturing, or mutual interference of wells, pressure and temperature measurements must be made within boreholes. One of the most sensitive methods for fracture detection is the absorbance (flow) test, in which the hydraulic and thermal equilibrium of the well is disturbed. This is accomplished by injecting a defined quantity of fluid into the well, thereby successively enhancing the thermal profile along the borehole axis. Interference tests normally involve the capping of one well and simultaneous measurement of others. These techniques require extremely sensitive temperature and pressure transducers for accurate measurement. Mechanical transducers are inadequate for the task. Transducers such as quartz thermometers and various solid-state thermocouple devices with subsequent amplification are necessary. Seven references are provided.

MAN-MADE GEOTHERMAL RESERVOIRS, Smith, Morton C., R. Lee Ammodt, Robert M. Potter, Donald W. Brown; 2nd UN Symp. Dev. Use Geoth. Res. pp 1781-87 1975

Standard Logs run in GT-1 & GT-2, Caliper logs worked well. Most commercial logging equipment experienced downhole problems at 150°C and most were unreliable at temperatures approaching 200°C.

RESEARCH AND DEVELOPMENT OF IMPROVED GEOTHERMAL WELL LOGGING TECHNIQUES, TOOLS AND COMPONENTS (CURRENT PROJECTS, GOALS AND STATUS), Michael D. Lamers; SAN/1380-1, MAC-TR-7047-1, Final Report, 1975.

One of the key needs in the advancement of geothermal energy is availability of adequate subsurface measurements to aid the reservoir engineer in the development and operation of geothermal wells. This report describes some current projects being sponsored by the U.S. Department of Energy's Division of Geothermal Energy pertaining to the "development of improved well logging techniques, tools and components." The report attempts to show how these projects contribute to improvement of geothermal logging technology in forming key elements of the overall program goals.

MAXIMUM TEMPERATURES RECORDED IN WELLBORES, Hilchie, D.W., Log Analyst, Vol IX, Issue 5, 1968, p 21.

ELECTRICAL LOGGING AND TEMPERATURE SURVEYS AT MATSUKAWA GEOTHERMAL WELLS (Japanese, English Summ.), Takaki, Sin-Ichiro and Tanaka, Sin-Ichi; Geol. Surv. Bull., v.19 n.8 p 507-518, 1968.

Electrical and temperature logging was carried out in 4 producing geothermal steam wells in Matsukawa area, Iwate perfecture, Japan, the S. P. resistivity and temperature probes are described. Resistivity logs show the presence of a conductive layer; from the surveys to 500 M is a zone of higher resistivity corresponding to weakly altered dacite lava, welded tuff, and green tuff. Bottom temperatures in the four wells with depths of 945, 1,080, 1,207.2 and 1,135 M were 182 degrees. 195 degrees, 171 degrees and 179 degrees C respectively V.S.N. From Geophys Abs. 271 U.S. Geol. Survey, n 271-303, p 1164

LOGGING OF ULTRADEEP BOREHOLES, Magyar, Geofiz, Jesch, A., v 9 n 2, p 60-68, 1968

This article discusses the conditions to be expected in logging ultradeep boreholes in Hungary. The high temperatures raise problems in connection with the electrical aspects, particularly the increasing conductivity of the insulating material. Finally, the necessity of preliminary testing of the logging instruments under borehole conditions is stressed. From Geophys. Ab. 265 U. S. Geol. Surv. p 269 n 265-677

EXPLOITATION OF MATSUKAWA GEOTHERMAL AREA, IWATE PERFECTURE, Mori, Yoshitaro; Internatl. Symp., Volcanol, N.Z., p. 117-118 1965.

Drilling of production wells began in October 1963. Bore 1 was blown in January 1964. Next bore 2 was drilled and blown in July 1964. Bore 3 was blown in January 1965. Each bore was erupted by swabbing after measuring downhole temperature and electrical logging by the help of geological survey of Japan. Bore 4 is under drilling now and will be discharged in July 1965. From Interntl. Symp., Volcanol, N.Z., p.117.

TEMPERATURE LOGGING, Peacock, D.R.; 6th Ann. Soc. Prof. Well Log Analysts Logging Symp., Dallas Tx., 1965.

The use of new, highly-sensitive, and stable temperature logging systems has produced data which correlate earlier theoretical predictions and and stimulated the application of of temperature logging into areas other than the conventional cement top location. Innovations lie chiefly in the concepts of combining gradient differential logs to get different views of a given temperature anomaly. Also, the techniques of changing conditions during a series of logs are effective in creating temperature anomalies which can reveal considerable information about downhole conditions. These techniques are particularly effective in producing injectivity profiles in secondary recovery programs and in evaluating fracturing operations. Field examples are supplied to illustrate the various procedures. Authors, ABS. From Geophys. Abs. 226, U.S. Geol. Surv. n 226-223. p. 910.

THE EFFECT OF HIGH TEMPERATURES ON THE SPATIAL DISTRIBUTION OF THERMAL NEUTRONS IN ROCKS FOR THE SETTING UP OF GEOPHYSICAL INVESTIGATIONS OF DEEP AND EXTRA-DEEP WELLS, Kozhenikov, D. A., (IN PROMLEMY YADERNOY GEOFIZIKI). Izdatel Stv. "Neora", 1964, p 26-40.

It is shown that 1) temperature effects begin to exceed the measurement error at about 250 degrees C-300 degrees C and therefore must be taken into account in neutron logging; 2) maximum temperature effects should be expected in rocks with high hydrogen content and low concentration of elements with high thermal neutron capture cross sections, and vice versa; 3) other things being equal, the temperature effect is magnified as the size of the sonde increases; 4) at temperatures of about 300 degrees C or more, a temperature inversion effect is to be expected, a result of the fact that at a given temperature two rocks of different composition and hydrogen content might give the same readings but with further increase in temperature will give anomalties of different sign. D.B.V. From Geophys. ABS. 219 U.S. Geol. Surv. n 219-324, p.329.

APPENDIX B 1

ANNOTATED BIBLIOGRAPHY
OF LITERATURE
CEMENT INTEGRITY TESTING

LOG COMPARISON FROM THE GEOTHERMAL CALIBRATION/TEST WELLS C/T-1 & T-2, Mathews, Mark; to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979

NOISE LOGGING IN FRACTURED GEOTHERMAL RESERVOIRS, Murphy, H.D., R.M. Potter, R.L. Aamodt, E.G. Pennebaker; Los Alamos Scientific Laboratory, to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1969.

PERSONAL COMMUNICATION, Mathews, Mark; Los Alamos Scientific Laboratory, March 1979.

> Los Alamos is responsible for obtaining baseline logs for 2 geothermal wells, one at the BuRec test site in the Imperial Valley and the other at Roosevelt Hot Springs, Utah. The California well is 6,175 feet deep and cased. From 5420 - 6175' it is slotted in places. The Utah well is cased to 4200' and open to 6900'. Maximum temperatures are 440°F and 330°F respectively in the Utah and California wells. Logs run in the Utah well include Dresser Atlas thermal neutron, density, CBL, caliper, temperature, Schlumberger's induction gamma ray, thermal neutron, and CBL. Logs were run in the California well by G.O.Int'l., Schlumberger, N.L., McCullough (casing inspection), and Dresser Atlas. Plans called for 7 logs by all 4 companies. Numerous problems were encountered.

RADIAL DIFFERENTIAL TEMPERATURE (RDT) LOGGING--A NEW TOOL FOR DETECTING AND TREATING FLOW BEHIND CASING, C.E. Cooke, Jr.; SPE 7558, Exxon Production Research Co., 1978

> Discusses new surface-recording logging tool designed to detect vertical flow of gas or liquid behind pipe by measuring differential temperature radially around casing walls. Details ability of device to outline vertical extent and azimuth angle of such channels, thus providing data

valuable in assessing reservoir performance and in diagnosing problem well behavior. Tool can be coupled with perforating gun to orient perforations into flow channels to improve success of remedial cementing operations.

A STUDY OF THE EFFECTS OF DIFFUSION ON PULSED NEUTRON CAPTURE LOGS, Russell Randall, Eric Hopkinson, and A.H. Youmans; J. Pet Tech., 1788-1794, Dec. 1978.

The response of the Neutron Lifetime Log is studied in view of the diffusion of thermal neutrons in wellbore geometry. Qualitative theoretical arguments are given for the diffusion effects of a log, inject-log, (LIL) procedure. Experimental verification that diffusion exactly cancels out the LIL procedure is presented.

APPLICATION OF ELECTRONIC DATA PROCESSING TO SONIC ANALYSIS (SOUND LOGGING) DATA IMPROVES INTERPRETATION, G.M. Stone, R.W. Schlotterback, G. Garrett and W.H. Fertl; Dresser Industries Inc., 24th Annu. Southwestern Petrol. Short Course Ass. Mtg. (Lubbock, Texas 4/21-22/77 Proc., pp 49-54 1977

SONAN (sonic-analysis) logging resulted primarily from the research and development of a practical logging sonde by McKinley et al. of Esso Production Research Co. (EPRC). McKinley primarily confined his research to the use of this system for documenting fluid flow behind cement casing but also described the potential of this system as a flowmeter. Following the publication of his findings in 1973, several service companies, including Dresser Atlas, began field testing equipment varying slightly from the EPRC designs. Additional applications of this system have been noted, including its use to: (1) find zones of lost circulation in drilling wells; (2) locate points in casing and tubing; (3) locate the source of fluid entry in uncased well bores; and (4) use of this system in calculating perforation productivity profiles. Because of the present method of data reporting and the potential quantitative nature of the data, Dresser Atlas found that the processing of the field-recorded data is best performed with the aid of digital computers.

THE TEMPERATURE-SOUND LOG AND BOREHOLE CHANNEL SCAN FOR PROBLEM WELLS, E.S. Pennebaker, Jr. and R.T. Woody; Dia Log Co ; 52 Annu. SPE of AIME Fall Tech. Conf. Denver 10/9-12/77 Preprint No. SPE-6782, 1977 11 p. .

The diagnosis of down-hole communication problems in producing and injection wells has long benefited from use of the temperature log. In recent years, however, the noise logger has added a new dimension through its ability to hear the down-hole problem in action. However, each tool has its limitation, and each log by itself is often difficult to interpret. This study discusses a survey during which, in a single trip into the hole, both temperature and sound profiles are measured. The two reinforce each other and enhance interpretation. If the problem is a behind-casing fluid leak, the temperature and sound anomalies can only point out the depth and order-of-magnitude. Successful repair depends upon direct access to the channel by the squeeze cement. Examples are shown illustrating the use of the borehole density scanner, or density-orienting tool, commonly used in oriented perforating, for directing the perforations into the channel for repair. New tools for pinpointing the channel also are discussed. Field examples are presented.

SCANNER ORIENTER HELP SOLVE CASING LEAKS, E.S. Pennebaker, Jr. and R.T. Woody Dia Log Co ; Oil Gas J. v 75 No. 49 pp 75-80 November 28, 1972.

Diagnosis and repair of behind-casing leaks has long been one of the industry's most persistent and difficult problems. The temperature-noise log is particularly useful in searching for fluid movement in channels in the cement behind the casing. Both temperature and sound profiles reinforce each other and enhance interpretation. A log format using condensed and expanded-depth scale presentations of both temperature and sound data have proved helpful in diagnosing well problems, particularly those producing subtle changes in sound and temperature. Successful repair depends upon direct access to the channel by the squeeze cement. The use of the borehole-density scanner, or density-orienting tool commonly used in orienting perforating, directs the perforations into the channel for repair. The leak source behind casing or within the well bore is located from the noise amplitude, as indicated in a schematic drawing.

NEUTRON LOGGING METHOD FOR LOCATING THE TOP OF CEMENT BEHIND BOREHOLE CASING, AHMED, A.E., Oil & Nat. Gas Comm. Madras, India, J. Pet. Technol. vol 29, Sept 1977. p. 1089-1090

The use of neutron logs to locate the top of the cement around a casing is described. The theory is that presence of liquids in the annulus outside the casing will increase absorption of the neutrons and reduce secondary gamma radiation compared with a cemented portion. An example neutron log is interpreted to show the cement top. 4 refs.

OPEN-HOLE POROSITY LOGS CAN BE USED IN CASED HOLES, Fertl, Walter H., Wichmann, Paul; Oil Gas J. vol 75, n 14, Apr. 4 1977. p. 84-86

All standard open-hole porosity logging devices can be used successfully for porosity determinations behind pipe, provided the proper bore-hole environment, such as good cement bond, absence of severe washouts, etc., are present in the subject well under consideration. Acoustic log applications in evaluating open-hole porosity, and, also, the use of the density-neutron combination logging system are discussed. 1 ref.

A HIGH FREQUENCY CEMENT BOND LOG TOOL TEST, Pilkington, P.E.; The Log Analyst, Vol. XVII, Issue 5, 1976, p 25

THEORY AND APPLICATIONS OF THE BOREHOLE AUDIO TRACER SURVEY, E.L. Britt GO International Inc., 17th Annu. SPWLA Logging Symp. (Denver, 6/9-12/76) Trans. 1976 Paper No. BB, 35 p

The borehole audio tracer survey (BATS or sound survey) is a new surveying device which can be used to locate and quantify fluid flow outside of casing. Additionally, the sound logger can be utilized as a flowmeter (without moving parts) to measure fluid flowing past the tool. Part 1 illustrates use of the BATS log to locate and evaluate the quantity of fluid flow outside of casing. It is demonstrated that an index of flow magnitude can be determined and, as a result, a monetary value can be placed on this lost production. Part 2 demonstrates the use of the BATS log to determine the relative flow rate of individual perforations in limited entry completion, where mass flow rate through the perforation is sufficient to produce turbulent flow. An additional technique for evaluating perforated zones (e.g. 4 per ft. etc.) also is shown. Part 3 demonstrates use of the BATS device as a downhole flowmeter having no moving parts.

FIELD RESULTS FROM THE NOISE-LOGGING TECHNIQUE, W.S. Robinson; J. Pet. Tech., 1370-1376, Nov. 1976

An early attempt to establish a noise-logging system was made in 1955. The noise logging technique presented in this paper was introduced to the oil industry in 1972. This paper presents logging results obtained during 1973 using this technique. Included is a brief review of the principles of operation, current field equipment, and some laboratory data. Several examples of field results in different areas are presented, with interpretation based on experience from various well conditions.

NEW TECHNIQUES FOR ORIENTED-DENSITY EVALUATION, A.E. Holm and J. Kleinegger; J. Pet. Tech. 1151-1156, Oct. 1976.

Since earlier tools could give only a qualitative evaluation of the densities surrounding the casing, a digital readout panel with electronic modifications was used with the motorized oriented-density tool. Calibration of the tool was achieved using a simulated well calibrator and careful operating procedures. A depth of investigation outside of 2 7/8 in. casing was found to be 4.5 in. in neat cement. The log evaluation was confirmed by subsequent drilling books for chemicals in cement.

RECENT APPLICATION OF THE NOISE LOG, Robinson, W.S.; SPWLA 17th Annual Logging Symposium Trans.. Pap Y., Denver, Co., June 9-12, 1976, 25 p.

The Noise Log was introduced to the oil industry in 1972. Since that date, several hundred logs have been run. The log has been useful in five different applications involving all phases of field operation. This paper includes recent examples of these applications, which include: producing wells having communication problems behind cemented casing; new wells that develop channels in the cement before perforating or after squeezing underground blowouts; wells associated with an injection procedure; and determination of relative flow rates from perforated zones. Several field examples from representative sections of the United States are given. The interpretation of each log is presented to illustrate that the log is interesting and informative. 3 refs.

COMPARING CEMENT BONDS AFTER TEN-PLUS YEARS, P.E. Pilkington and J.B. Scott Continental Oil Co. ; Petrol Eng.,vol 48 No. 5, pp 52, 54, 58, 60, 62, April 1976.

One area which previously had not been evaluated was how long the initial cement-to-casing bond is maintained after well-completion operations such as perforating, fracturing or acidizing, and normal stresses applied during production. In order to properly evaluate the bonding characteristics, it was necessary to analyze wells that had been completed both with and without the resin-sand coating and in production for a number of years. Continental Oil Co.'s Sacatosa field in Maverick County, Texas, satisfied all requirements for a good field test. Conclusions of the field test are (1) resin-sand-coated casing provided better quality cement to casing bond over an extended period of time than normal mill-varnished casing; (2) resin-sand-coated casing withstood the

the shock from perforating operations better than mill-varnished casing; (3) gamma ray log correlation on all wells did not show any communication behind the casing; (4) fracture zones in those wells that had good bonding between casing cement and cement formation were well defined on the VDL; and (5) in the bottom 3 joints of casing, 60% of the wells without the resin-sand coating showed areas of poor bonding, whereas 100% of the wells with resin-sand coating showed excellent bonding.

FIELD TESTS OF CEMENT BOND LOGGING TOOLS, Pilkington, Paul E., Fertl, Walter H.; Log Anal.vol 16,n.4 p 13-18 Jul-Aug 1975.

A field test of various Cement Bond Log tools was run to evaluate the effect of varying signal frequencies and tool diameters. Two larger diameter sondes with different frequencies were run and results are presented. One higher-frequency, smaller-diameter tool was run and results are compared with the other logs. Problems that occurred during the test (and that also occur in the field) include the microannulus effect, centering and gating difficulties. Data are presented in graphical form. 5 refs.

FIELD TESTS OF CEMENT BOND LOGGING TOOLS, Pilkington, Paul E. and W.H. Fertl; 5th Formation Evaluation Symposium, Canadian Well Logging Society, Calgary, May 5-7, 1975.

The authors tested one company's CBL tools - a 1 11/16" diameter and a 3 5/8" diameter. The smaller diameter tool (with a higher frequency) gave pessimistic results compared to the 3 5/8" tool. Microannulus effects can be created even in small diamater casing by reducing hydrostatic head on casing. Both amplitude and VDL curves are needed for proper interpretation.

CEMENT LOGGING IN THE NORTH SEA, W.H. Fertl, and P.E. Pilkington (Continental Oil Co) and R.A. Odd (Conoco Europe Ltd); Petrol Eng. 47, No.5 pp 80, 86, 88, 92 95, May 1975.

Usually, the cement bond log (CBL) consists of an amplitude curve measuring a specific part of the acoustic signal and, since interpretation of the amplitude curve alone may be inconclusive and misleading, some supplemental data are needed. The latter may include transit time to the first event of the acoustic signal reaching a minimum or predetermined amplitude, amplitude of the formation signal, variable intensity or oscilloscope pictures. Additional measurements, although not directly related to cement bonding, include the gamma ray curve and casing collar log. With insufficient knowledge of how the CBL tool works and how the log was run, erroneous conclusions will result. Several other factors also have a large effect on the tool response. These are listed and described.

DESIGN OF A PRIMARY CEMENT SLURRY SYSTEM FOR THERMAL RECOVERY WELLS UNDERLYING BOTH HIGH AND LOW PRESSURE SANDS AT SAN ARDO FIELD, T. Saytel, Texaco Rpt. 1974, 23 p.

Discusses use of CBL'S to pinpoint problems and generate acceptable new completion system.

FIELD EXPERIENCE IN DETERMINING OIL SATURATIONS FROM CONTINUOUS C/O and Ca/Si LOGS INDEPENDENT OF SALINITY AND SHALINESS, Smith, H.D. Jr. and Schultz, W. E.; Log Analyist vol 15, n-6 P 9-18, Nov-Dec.1974.

A carbon/oxygen well logging system, capable of both 5 ft/min continuous logs and also stationary measurements, has been developed at the Texaco Bellaire Research Laboratories. The technique utilizes a pulsed 14MeV neutron source and a gamma ray detector, both similar to those employed in thermal neutron die-away logs, although operating at much higher neutron burst repetition rates and employing different detector time gates and energy ranges. Gamma rays from neutron inelastic interactions with carbon, oxygen, calcium, and silicon are developed into C/O and Ca/Si rations which are employed to determine oil saturation and lithology, both independent of formation water salinity and shaliness. The system has been run in 77 cased field wells, and has also been extensively studied in laboratory test formations. The effect of variations in borehole parameters, such as cement thickness, fluid type, and mud type, have been investigated, as have the effects of variations in formation parameters, including shaliness, porosity, water salinity, and lime content. Oil zones have been identified in both clean and shaly intervals with water salinities ranging from less than 1000 to over 125,000 ppm NaCl.

A LOOK AT CEMENT BOND LOGS, Walter H. Fertl, P.E. Pilkington and James B. Scott; J. Pet. Tech; pp607-617, June 1974.

Cement bond logs are reviewed as to how they are interpreted and what information is obtainable with them. Also discussed are pitfalls and possible misinterpretations that may arise from poor design or misuse. Field examples illustrate the effects of poor sonde centering, differing gating systems, spacing frequency and miscalibration, as well as the effect of using resin-sand coated casing to improve casing-cement bonding. An appendix gives cement bond logging guidelines and a checklist.

EXAMPLES OF DUAL SPACING THERMAL NEUTRON DECAY TIME LOGS IN TEXAS COAST OIL & GAS RESERVOIRS, McGhee, B.F., McGuire, J.A. Vacca, Herman L.; Soc. of Prof. Well Log. Anal. Logging Symp. 15th Annu. Trans. Paper, McAllen, Tx. Pap. R, June 2-5 1974, 33 p.

The Dual Spacing Thermal Neutron Decay Time log provides measurements useful for cased-hole formation evaluation. This paper presents the following examples of its application in Texas coast wells; 1) location of gas-oil and oil-water contacts; 2) selection of a zone for recompletion from a series of productive sands; 3) detection of gas accumulation in tubing-casing annulus and casing-formation annulus; 4) detection of gas chanelling behind casing; 5) gas identification in shallow formations where formation water is fresh; 6) gas identification in shaly sands; 7) gas identification in low-resistivity sands; 8) response in gas sands versus those in low-porosity sands; 9) matrix effect of carbonates 10) response in gravity drainage reservoirs; 11) monitoring of gas-oil contact in a pressure-maintenance project; 12) correlation measurements inside stuck drill pipe; 13) detection of gas-oil contacts in reservoirs where oil has migrated into the gas cap; 14) and detection of oil and gas which has migrated into a water sand.

FIELD RESULTS FROM THE NOISE LOGGING TECHNIQUE, W.S. Robinson (Baroid Div. N L Inds. Inc); 49th Annu. SPE of AIME Fall Mtg. Houston 10/6-9/74 Preprint No. SPE 5088, p.8, 1974

This noise-logging technique was introduced to the oil industry in 1972. The downhole tool and recording technique were developed by Exxon Production Research; additional engineering by McCullough Services Research and Development resulted in this present tool and surface equipment. An early attempt to establish a noise logging system was made in 1955 by Enright. The purpose of this paper is to present the logging results obtained during 1973. It is necessary to briefly review the principles of operation, present field equipment and some laboratory data. Included in this report are several examples of field results in different areas with interpretation based on experience from various well conditions. A new surface panel has been built which results in faster recording in shallow wells and more data in deep wells.

EXTRANEOUS WATER SOURCES WITH THE GAMMA RAY LOG, Doering, M.A. and Dan. P. Smith; SPE. 49th Annual Fall Mtg. SPE-AIME, Houston, Oct. 6-9, 1974.

In areas where radioactivity increases consistently occur in intervals where large amounts of fluid production has taken place, use of the gamma ray log can serve as the sole diagnostic tool for identifying cement channels. (Radioactivity is believed to be deposited when radioactive salts in the fluid react with iron oxides of the casing) Gamma ray log and CBL were run in one case and were diagnostic. It is good to have an initial gamma ray log for reference.

LOOK AT CEMENT BOND LOGS, Fertl, Walter H., Pilkington, P.E., and Scott, James B.; J. Pet. Tech. vol 26, p 607-617, June 1974

Cement bond logs are reviewed as to how they are interpreted and what information is obtainable with them. Also discussed are pitfalls and possible misinterpretations that may arise from poor design or misuse. Field examples illustrate the effects of poor sonde centering, differing gating systems, spacing, frequency and miscalibration, as well as the effect of using resin-sand coated casing.

A STATISTICAL ANALYSIS OF THE CEMENT BOND LOG, McNeely, W.E., (Mobil Oil Corp); SPWLA Transactions, 1973

Completion and producing data from 33 Louisiana offshore wells are used. It is concluded that 1) the CBL's reliability is above 90% "when run and interpreted properly "; and 2) the full-wave recording type log is required. This evaluation uses 3 criteria of comparison-CBL interpretation, remedial squeezes done as a result of CBL interpretation, and well-performance data. Of 96 remedial squeezes, composite analysis showed:

- -82 were necessary
- - 4 were conclusive
- -5 were not necessary
- -5 were not necessary but done because of incorrect interpretation at well site

A LOOK AT CEMENT BOND LOGS; SPE 4512, 48th Fall Mtg. SPE-AIME, Las Vegas, Oct. 1973.

A variety of tool calibrations and logging procedures are used by different service companies. Interpretation is not as simple and straightforward as often assumed. Necessary information on cementing & logging operations are often not available. Maximum benefit from CBL's can be obtained by standardization of logging technqiues used by different logging companies. Tool response is affected by 1) frequency, 2) gating systems and bias settings 3) spacing options, 4) sonde centralization and tool calibration; and 5) logging speed, etc.

FIELD RESULTS FROM THE NOISE LOGGING TECHNIQUE; SPE 5088 49th Fall Mtg., SPE-AIME, Las Vegas, Oct. 1973.

An offshore Louisiana oil well with leaks behind the pipe was logged with the noise log. It determined location of flow behind pipe. Log stations in the suspected leak interval were spaced at 5' to 15'.

THE IMPORTANCE OF JOULE-THOMSON HEATING (OR COOLING) IN TEMPERATURE LOG INTERPRETATION - SPE4636, 48th Fall Mtg. SPE, Las Vegas, Nv. Sept.30-Oct.3, 1973.

Shut-in temperature profile is influenced by previous flow rate profile and permeability profile. Joule-Thomson heating of water influences the flow zone temperature distribution around a well during flow.

IMPROVED INTERPRETATION GUIDELINES FOR TEMPERATURE PROFILES IN WATER INJECTION WELLS, Smith, R.C. and R.J. Steffensen (Amoco Production Co.); SPE 4649, 48th Fall Mtg., Las Vegas Nv. Sept.30 - Oct.3, 1973.

If water channels behind the pipe, on the shut in curve, a shift occurs where the water makes contact with the formation.

THE STRUCTURE AND INTERPRETATION OF NOISE FROM FLOW BEHIND CEMENTED CASING, R.M. McKinley, F.M. Bower and R. C. Rumble; J. Pet. Tech., p.329-338, March 1973

The paper presents a noise-logging technique for finding behind casing leaks. The leak source is located from a noise-amplitude log and the type of leak (whether from single- or two-phase flow) is determined from a spectrum of noise at the source. Appropriate frequency cuts are then used to estimate leak rate.

LOCATING CHANNELS IN MULTIPLE TUBINGLESS WELLS WITH ROUTINE RADIOACTIVITY LOGS, Pennebaker E.S.; J.Petrol. Technol.vol24 p 375-84, Apr.1972.

Finding channels in primary cement is a new use for old tools. The paper explains how to use neutron depth correlation logs in conjunction with open- hole acoustic logs to help spot poorly placed cement in multiple tubingless completions. It also explains how to use the down- hole rotated density orientor to locate and define channels in the cement and guide the placement of shots to penetrate the channels for repair work. 2 refs.

PROJECT RIO BLANCO EMPLACEMENT WELL-RB-E-01 AS BUILT REPORT, PNE-RB-40, June 22, 1972. (CER)

LOCATING CHANNELS IN MULTIPLE TUBINGLESS WELLS WITH ROUTINE RADIOACTIVITY LOGS, E.S. Pennebaker, Jr. (Humble Oil & Refining Co); 46th Annu. SPE - AIME Fall Mtg. New Orleans, 10/3-6/71, preprint No. SPE 3506 1971, 12 p.

Neutron depth correlation logs run in each string of a multiple tubingless well have been used in combination with open-hole acoustic logs to point out places in the well bore where cement may have failed to completely displace the drilling mud during the primary cementing operation. The density orientor, a downhole rotated focused density scanning tool, used for directing a perforating gun away from other strings defines the location and a real extent of channels in more detail by means of 360^{o} density scans of the well bore and adjacent formation at selected depths of interest. The described technique has been used to evaluate efficiency of primary cement placement and to orient the perforations for completion either in the direction of the best cement or into a channel for repair operations if necessary. It should have further utility in evaluating and repairing suspected channels in old multiple tubingless wells where normal squeeze cementing methods are sometimes difficult.

NEW DEVELOPMENTS IN SONIC WAVE TRAIN DISPLAY AND ANALYSIS IN CASED HOLES, H.D. Brown, V.E. Grijalva, and L.L. Raymer (Schlumberger Surenco SA); 11th Annu. SPWLA Logging Symp. Los Angeles ,5/3-6/70) Trans., Paper No. F 1970, 25 p.

The usefulness of acoustic information for the analysis of cementing quality has been enhanced by the simultaneous recording of the full-wave display (variable density log) with first-arrival amplitude (cement bond log). The optimum-spacing requirements of the 2 logs are somewhat different. For the cement bond log, a short spacing is desired in order to show more clearly the attenuation rate of the casing arrival. For the VDL, a longer spacing is desired in order to show the formation arrivals in well-bonded intervals. To satisfy these differing requirements, a 2-receiver system is being used to provide a 3-ft. spacing cement bond log (CBL) and a 5 ft. spacing variable density log (VDL) simultaneously. New recording equipment permits the VDL and CBL signals to be recorded directly on the same film. Problems of separate film processing and depth mismatch are thus eliminated.

Field examples show that this combination of the long-spacing VDL with the short-spacing CBL can provide a more thorough understanding of cementing quality. Cases of microannulus and cement channeling, as well as good and poor cement bond, can be recognized.

SONIC PRINCIPLES APPLIED TO FORMATION FRACTURE LOCATION AND CEMENT BOND LOGGING, Williams, G.B.; Canadian Well Logging Journal, Vol. 3, Issue 1, p 7, 1970.

NEW LOOK AT BOND LOGGING, D.M. Muir and E.E. Rollman (Dresser Industries Inc.); Petrol Eng. vol 42, No. 2, pp. 72, 78, Feb. 1970.

The acoustic cement bond log was introduced to the industry in 1959. Soon afterward, nearly every company in the oil-well completion and logging business developed equipment to produce these logs. Some were good, but most were ill-conceived and poorly designed. As a result, many early cement laboratory experimentation and practical field experience increased the value of the bond log, so that today it is a sophisticated, reliable service. Improvement in interpretation came when photographic means were used to record the oscilloscope display. Recordings were made either on 16 mm or 32 mm film. Interpretation was cumbersome and time consuming. Then, the presentation of the acoustic signal was made as a variable density recording on 70 mm film and further improvement resulted. It is still possible to produce a cement-bond log that is misleading. This is unlikely if certain quality controls are observed, such as the recording of the free pipe should be presented on each log. The general appearance of the acoustic signal is influenced by tool electronics, cable length, and many other factors. The free casing signal is an excellent reference standard for use in evaluating the other signals recorded on each particular log. Today, the best cement-bond logs available are those which include recordings of the acoustic wave train and are run by a reputable company.

ACOUSTILOG-NUCLEAR LOGGING IN CASED WELLS, Amer. Petrol Inst. Div. Prod. Drilling Prod. Pract. Pap for meeting 1969 p 61-7

The development of a superior Acoustilog instrument has made it possible to obtain porosity and lithology data from cased wells. At the same time, a valuable evaluation of the cement condition can be made from the data recorded. Recent advancements in electronic technology as well as improvements in acoustic transducers, made the design of this acoustic equipment feasible. The versatility of the Acoustilog and the nuclear logging equipment makes it possible to simultaneously record the acoustic, gamma ray, neutron, caliper and collar logs. These data are obtained routinely in both open and cased wells. 3 refs.

ACOUSTIC-NUCLEAR LOGGING IN CASED WELLS, W.A.Zoeller and D.M. Muir (Dresser Industries Inc); APISW. Dist. Prod. Div. Spring Mtg. Lubbock, Tex. 3/12-14/69 Preprint No. 906-14-J, 1969, 12 p.

The development of a new acoustic tool has made it possible to obtain porosity and lithology data from cased wells. At the same time, a valuable evaluation of the cement condition can be made from the data recorded. Recent advancement in electronic technology as well as improvements in acoustic transducers made the design of this acoustic equipment feasible. In most situations, no more than 40 to 50% cement bond is required to make possible the accurate recording of formation travel times. Under certain fast velocity formation conditions, accurate time logs have been obtained with even a smaller percentage of bonding. The versatility of the acoustic as well as the nuclear logging equipment makes it possible to simultaneously record the acoustic log, gamma ray, neutron, caliper and collar logs. These data are being obtained routinely in both open and cased wells. This report is based on information collected from over 400 recordings, a number of which are shown and discussed.

TEMPERATURE SURVEYS. THE ART OF INTERPRETATION, Kading, H.W., and Hutchins, J.S.; Amer. Petrol. Inst. Div. Prod. Drilling Prod. Pract. Pap for meeting, p 1-20, 1969

Six accepted temperature survey uses which are covered in detail are: cement tops; gas entry or channels; water-production logs; fluid- injection profile; fracture-evaluation logs; and acid- evaluation logs. Each of these temperature- log applications is discussed from the standpoint of procedural prerequisites to obtain a quality log. 5 refs.

EMPLACEMENT AND CEMENTING HOLE 25-95A (Emplacement Hole); Hayward Well in Garfield County, Colorado, PNE-R-8, Austral Oil Co Inc., 1969

HOW TO INTERPRET TEMPERATURE SURVEYS 1, 2, Hutchins, J.S., and Kading, H.W.; Oil & Gas J. 67, n. 32, p 137-41, p 96-103, August 11, 1969.

Series of two articles analyzes six accepted temperature surveys that provide sound information for most normal or routine temperature applications in producing wells, namely cement tops, gas entry of channels; water production logs, fluid- injection profile; frac- evaluation logs, and acid evaluation logs. Current interpretation of shut- in temperature profiles in water- injection wells can supply valuable data to forecast flood response times and estimates for water- bank positions.

A FULL-WAVE DISPLAY OF ACOUSTIC SIGNAL IN CASED HOLES, T. Walker (Welex Div. Halliburton Co); J. Petrol Technol. vol 20, No. 8 pp. 811-824, Aug. 1968.

The technology of the oil industry today is such that more rigid requirements are placed upon cement isolation in wells. Acoustic cement bond logging is one of the tools in well completion technology that can be used to insure the best possible completion by insuring isolation of all zones before a completion attempt is made. It shows the degree of isolation. Under many conditions the cost of the log is small in comparison with squeezing, reperforating, refracturing, decreased production, or even loss of a well. Field examples illustrate a number of cases where considerable extra completion expense arose because the information from the bond log was not used. Basic bond log interpretation is included in the Appendix.

ACOUSTIC LOGGING THROUGH CASING, L. Fons (Pan Geo Atlas Corp); 2nd Can. Well Logging Soc. Formation Evaluation Symp. (Calgary, 5/6-10/68) Pap., Abstr., Can.Petrol vol 9, No. 5, pp 13-14, May 1968.

Until recently gamma ray-neutron logging was the only method for porosity and lithology evaluation in cased wells. Hole enlargement, gypsum, dolomite and other factors produce large errors in the interpretation of these logs. Acoustic interval time logs, previously limited to open holes, can now be obtained in cased wells. High quality acoustic logs can easily be obtained in cased wells where the cement is attached to the entire surface of the casing. Statistical studies indicate that this is 85% of the casing in most wells. A combination of a formation in which sound travels with a velocity comparable to that inside the casing and poor cement bonding may produce a hard-to-interpret log. With conditions of no cement bonding it has, to date, not been possible to directly record formation travel-time. Where open hole logging conditions are poor, the acoustic log through casing may produce better results than the open hole log. Best results have been produced with long spacing and low transmission frequencies.

REVIEW OF RADIOTRACER APPLICATIONS IN GEOPHYSICS IN THE UNITED STATES OF AMERICA, W.E. Mott and J.C. Dempsey (US Atomic Energy Comm); LAEA Radioisotope Tracers Ind. & Geophys. Symp., Prague, 11/21-25/66 Proc. pp 111-130 1967; Rept. No. STI/PUB-142; Abstr No. 14689, NUCL SCI Abstr v.22, No.8, p.1516, April 28, 1968.

Radiotracers are extensively used in the drilling, completion, and treatment of oil wells and in secondary recovery operations. They have proved particularly effective for following the movements of fluids in, adjacent to, and between well bores and for following and pinpointing the stopping-place of materials introduced into well bores. Specific applications include: the determination of production profiles; the determination of injectivity profiles and the rate and path of travel between injection and production wells; the location of cement tops; thief zones, channels, and casing leaks; the control of the placement of plugging materials; and, the determination of the number, type and extent of fractures following stimulation. The application of radiotracers to geophysical problems in the U.S.A. is reviewed. An aim is to evaluate the present position of the radio tracer technique with emphasis on extent of use, practical limitations and competition from alternative techniques.

APPLICATION OF GAMMA-GAMMA LOGGING TO THE CONTROL OF WELL CEMENTATION UNDER THE CONDITIONS IN WESTERN SIBERIA (Primenenie Gamma-Gamma-Karotazha dlya Kontrolya Cementirovaniya Skvazin v Uslovyakh Zapandnoi Sibiri); Trans. of Razvedochnaya Geofizika (USSR) vol23, p112-114, 1967.

UTILITY OF THE MICRO-SEISMOGRAM BOND LOG; SPE 1751, SPE Regional Mtg., Fort Worth, 1967.

Crystal transmitter emits vibration pulse which is picked up by the receiver. If pipe is free, it will vibrate and carry a large signal to the receiver. If bonded, there is no pipe vibration. If cement isn't bonded to formation, very little formation signal is received. Tool must be centralized.

NEW ACOUSTIC TOOL LOGS CASED HOLES, Muir, D.M. and W.A. Zoeller; Oil & Gas Journal, Oct.23,1967.

"Indications of channeling or cement failure can be based on empirical conclusions derived from ... (acoustic-neutron combination recordings)". A neutron and caliper log of the open hole is necessary for a baseline. Intervals of abnormally high neutron porosity in cased holes can be attributed to water behind the pipe.

GULF SETS 13 3/8 INCH CASING TO RECORD DEPTH OF 11,853 FEET; WORLD OIL, vol 165, No.1, pp.92-93, July 1967.

Gulf Oil Corp. recently set and cemented 13-3/8 in casing at 11,853 ft in the Delaware basin area of West Texas. A summary of precautions and procedures used is given, emphasizing the problems confronted and techniques applied in Delaware basin deep drilling. The casing string was cemented with 7,890 sacks of cement in 3 stages. Electrical and caliper logs were run to determine the location of a hard limestone stringer to be used as a casing seat. All casing runs were completely checked by a combination mechanical-optical and full-length magnetic particle inspection plus a drift inspection. A final temperature survey was made to evaluate the cement bond. A schematic drawing of the final casing setting is shown.

THE USE OF THE CEMENT BOND IN WELL REHABILITATION, Upp, J.,Jr.; Paper X, SPWLA Symposium, 1966.

PREDICTION OF INTERZONE FLUID COMMUNICATION BEHIND CASING BY USE OF THE CBL, Pickett, G.R. (Shell Oil Company); Paper J, SPWLA Transaction, 1966.

Quantitative criteria for predicting interzone fluid communication using the CBL are derived for conditions on Cedar Creek Anticline. These are 1) a critical amplitude interzone distance below which communication will take place. CBL quality control depends on 1) acoustic properties of fluid in casing; 2) satisfactory repeatability; 3) satisfactory centralization; and 4) appropriate response in unbonded casing and in unbonded casing collars. CBL run under pressure exhibits significantly lower amplitudes. Gas cutting will render CBL useless. "Early arrivals" opposite high velocity formations can significantly affect amplitudes recorded by floating gate systems.

FLUID MIGRATION BEHIND CASING REVEALED BY GAMMA RAY LOGS, Killon, H.W.; The Log Analyst, Vol. VI, Issue 5, p.46, 1965.

NOTE ON ACOUSTIC BOND INCREASE WITH TIME, Walker, T., The Log Analyst, Vol XI, Issue 4, p.11, 1965.

WELL COMPLETION: A PROGRESS REPORT- Drilling vol.26, No.5, pp 43-46, 48-49, 51-55, March 1965.

The subjects of this report are as follows: 1) the pay string; (2) the cement slurry placement; (3) slurry placement; (4) in-casing logging; (5) formation exposure; (6) sand control; (7) testing productivity; (8) well stimulation; and (9) tubing installations. Pay string miniaturization, marked by wide-spread use of 4-1/2 in. for "conventional" completions and 2-7/8 in. for "tubingless" and "multiple tubingless" completions, continued during the past 12 mo. but there were indications that the trend to smaller casing sizes may have slowed down. Resin-sand coats improve bonding of cement to the casing. In a slurry placement, it is pointed out that drilling methods may materially affect zone isolation, but that improved methods of slurry placement cut costs. The preflush is perhaps one of the most beneficial of today's cementing aids. The cement-bonding log has remained a focal point of well-completion attention during the past year. Last year saw increasing use of the Neutron-Lifetime Log. A new multi-purpose, well-completion tool has become available to the industry in a device called the "Selective Completion Cementer." Two epoxy resin, sand-control systems have been developed and have been applied successfully to wells on the Gulf Coast and in California.

EVALUATION OF CEMENTING CONDITIONS BY USE OF THE PHOTOGRAPHIC RECORDING OF THE COMPLETE ACOUSTIC WAVE, Muir, D.M.; The Log Analyst, Vol. V, Issue 2, p.18, 1964.

CEMENT BOND LOG-A STUDY OF CEMENT AND CASING VARIABLES, Pardue, G.H., R.L. Morris, L.H. Gollwitzer, and J. M. Moran; Journal of Pet. Techn., p.545-555, May 1963.

The Cement Bond log has proved to be a valuable tool for evaluating casing cement jobs. As a result of the study described in this paper, a scientific basis has been established for a quantitative interpretation of the logs. A relationship was experimentally established between cement compressive strength and the attenuation rate in casing surrounded by a bonded cement sheath at least 3/4-in. thick. This relationship is influenced by the casing thickness but is independent of cement type. This relationship forms the basis for a quantitative interpretation of the Cement Bond logs. A nomograph is presented which permits an estimate of the cement compressive strength from the log. This value may be checked against the compressive strength expected with a good cement job for the particular cement under the given conditions. Field results have confirmed the validity of the nomograph. Data are given which permit allowances to be made for channeling contamination, etc.

CEMENT BOND LOGGING, AN AID TO BETTER COMPLETION PRACTICES, Moore, E.J., and Bird, J. M.; The Log Analyst, Vol. III, Issue 1, p.20, 1962.

THERMAL LOGGING OF PRODUCING OIL WELLS, Dale, C. P., Oil World, Vol. 35, n.5, p 13-15, n.7, p 24-55, 1942

Interpretation of temperature anomalies observed and recorded in producing oil wells can be employed as an aid in solving such problems as locating the source of water, gas, and oil production, tracing the migration of fluids from one zone to another and locating casing or tubing leaks.

The temperature record must be taken when the well conditions are under careful control in order to recognize and locate the anomalies. A normal geothermal gradient may serve as a basis for interpretation, but if one is not available or cannot be relied upon a technique of making two successive temperature traverses, one while the well is flowing and the other with the well shut in, will permit accurate interpretation of the record. Six graphs and descriptions of problems involved in producing wells are shown. Author's abs. from geophys. Abs. 110, U.S. Geol. Surv. Bull 939-C. n 6648, p. 83.

ANNOTATED BIBLIOGRAPHY OF PATENTS

CEMENT INTEGRITY TESTING

APPENDIX B2

BEHIND CASING WATER FLOW DETECTION USING CONTINUOUS OXYGEN ACTIVATION--U.S. 4,032,780, c. 6/28/77, f. 11/3/75 (Appl. 628,174) Papp, H. J., Arnold, D. M. and Peelman, H. E., assrs. (Texaco Inc.);

A method is described for the measurement of the volume flow rate and linear flow velocity of water flowing behind a well casing. A well tool having a 14 mev neutron source is used to continuously irradiate earth formations behind well casing. The continuous neutron irradiation activates elemental oxygen nuclei comprising the molecular structure of any undesired water flow to be detected. Dual-spaced gamma ray detectors located above or below the neutron source detect the decay of unstable isotope nitrogen 16 and from these indications the linear flow velocity of the undesired water flow is deduced. By then estimating the distance R to the desired flow region, the volume flow rate V may be calculated. (16 claims)

DETERMINATION OF BOREHOLE WASHOUT BY USE OF INELASTIC NEUTRON SCATTERING GAMMA RAY MEASUREMENTS--U.S. 3,838,279 c. 9/24/74, f. 4/3/73 (Appl. 347,518), Schultz, W. E and Smith, H. D., Jr.

A method is described for locating zones of borehole washout behind the casing in a cased borehole. The formations in the vicinity of the borehole are repetitively irradiated with short duration bursts of fast neutrons. Gamma rays produced by the inelastic scattering of the fast neutrons are observed in at least 4 different energy regions in the gamma ray spectrum and are corrected for any lingering thermal neutron captured gamma-ray background. The 4 energy regions include inelastic scattering gamma rays from carbon, oxygen, silicon, and calcium. A first output signal related to the porosity (hydrogen index) is derived by summing the inelastic gamma rays in all 4 energy regions. Second and third output signals are formed by taking the carbon/oxygen and silicon/calcium ratio signals. The 3 output signals are then combined according to pre-determined empirically derived relationships to produce an estimate of the location of zones of borehole washout behind the casing. (5 claims)

METHODS AND APPARATUS FOR ACOUSTIC LOGGING IN CASED WELL BORES--U.S. 3,729,705, c. 4/24/73, f. 12/29/69 (Appl. 888,695), Grijalva, V. E., . asr., (Schlumberger Technol Corp);

A technique is described for obtaining well-logging information which is especially suitable for the evaluation of cased well bores. More particularly a well logging tool has 2 acoustic receivers spaced apart from a repetitively energized acoustic transmitter. The amplitude of a selected portion of each electric signal produced by the receiver nearest the transmitter in response to the emitted energy is measured to produce a log of the bonding of the casing to the cement surrounding the casing. The electric signals produced by the receiver farthest from the transmitter are used to produce a variable density log which can be used in conjunction with the cement bond log to evaluate the bonding of the cement to both the casing and the formations which surround the cement. (8 claims)

ACOUSTIC WELL LOGGING METHOD AND APPARATUS USING PIPE AS AN ACOUSTIC TRANSMITTER--U.S. 3,752,257, c. 8/14/73, f. 3/7/72 (Appl. 232,377), Davis, M.,asr. (Dresser Industries Inc.);

A well logging tool using high voltage pulses coupled into a coil surrounding a high permeability material traverses an earth borehole having a metal pipe therein. The magnetic field resulting from the voltage pulses passing through the coil distorts the pipe and causes the pipe to be an acoustic transmitter. The acoustic pulses are passed through the earth formation to one or more acoustic receivers within the well-logging instruments. The tool is used to measure acoustic velocity within the formations and also to measure the quality of the cement bond between the pipe and the earth formations. (3 claims)

CEMENT EVALUATION LOGGING UTILIZING REFLECTION COEFFICIENTS--U.S. 3,747,702 c. 7/24/73, f. 5/25/70 (Appl 40,021), Beil, R.G., asr., (Schlumberger Technol Corp);

Methods and apparatus are described for evaluating the cement effectiveness in cased boreholes. Acoustic energy is used to excite the borehole casing-annulus-formation system and the radial transfer of energy into the formation is determined by examining the reflection coefficients of the system in a number of relatively wide frequency bands over the spectrum of the acoustic energy used to excite the system. The spectrum analysis is carried out by passing electric signals representative of the reflected acoustic energy through a number of relatively wide band-pass filters whose center frequencies are selected according to the size of the casing being logged. A relatively low magnitude of the reflection coefficient in a majority of these filters is indicative of a good cement condition. (45 claims)

RESOLUTION OF THROUGH TUBING FLUID FLOW AND BEHIND CASING FLUID FLOW IN MULTIPLE COMPLETION WELLS--U.S. 4,047,028, c. 9/6/77, f. 11/3/75 (Appl 628,173); Arnold, D.M., asr. (Texaco Inc);

Nuclear well-logging techniques are described which determine the presence of undesired water flow in cement voids or channels behind steel well casing in a cased well. A method is useful for resolving undesired fluid flow in one producing zone of a multizone completion well operating on gas lift from the fluid from lower producing zones in the same well. The method utilizes gamma rays which are characteristic of the decay of the unstable isotope nitrogen 16 produced by activation of elemental oxygen nuclei comprising the molecular structure of both the tubing fluid flow and the undesired fluid flow. These gamma rays are detected in at least 2 energy bonds at 2 longitudinally spaced detectors in a well borehole. By appropriately combining the 4 count rate signals so produced according to predetermined relationships. the 2 fluid flow components in the same direction may be uniquely distinguished on the basis of their differing distances from the gamma ray detectors. (9 claims)

BEHIND WELL CASING WATER FLOW DETECTION SYSTEM--U.S. 4,028,546 c. 6/7/77, f. 11/3/75 (Appl. 628,172); Peelman, H.E. and Langford, O. M., asrs. (Texaco Inc.) ;

A well-logging sonde having a modular fluid tight structure is described for the detection of undesired behind casing water flow in a producing well. Three modules which when joined together to form a fluid-tight assemblages comprise the sonde. A first module houses a 14 mev neutron generator and a 125 kv high-voltage power supply for operating the neutron generator. A second module houses dual-spaced gamma ray detectors for detecting characteristic gamma rays from the decay of radioactive nitrogen 16 at 2 different longitudinal distances from the neutron source. A third module houses control electronics and data transmission circuits for controlling the neutron generation and receiving detected signals from dual gamma ray detectors and for transmitting data to the surface from the sonde. The modules are constructed so that they may be assembled with the neutron generator either above or below the dual detectors while maintaining the same spacing distances from the generator to the detectors. Surface instrumentation for receiving and interpreting the gamma ray measurements also are provided. (12 claims)

TUBING TESTING TOOL -U.S. 4,083,230, c. 4/11/78, f. 2/3/77 (Appl. 765,407); Rome, D.J. Sr. and Cooke, C.E., ars. (Romco Pipe Testing Inc.);

A tool for testing tubing well casing or other pipe is described. Longitudinally spaced packers are expanded to isolate a portion of the tubing string for subjecting the isolated portion to test pressure. Hydraulic fluid is supplied to the isolated portion through flow controllers, which include a fluid diffuser which prevents direct impingement of the testing fluid onto the inside coating on the tubing, thus preserving the integrity of the coating. The spaced sealers are expanded by piston and cylinder assemblies constructed and arranged so that the tool does not move when in operation, that is, it does not change in length in order to compress the sealers. The tool has a head which enables it to be used inside the tubing or above the tubing. A foot or lower end is provided with a swab, which precludes testing fluid from going downhole and contaminating the mud, thereby enabling the same testing fluid to be continuously reused. (14 claims)

APPARATUS AND METHOD FOR WELL REPAIR OPERATIONS--U.S. 4,074,756, c. 2/21/78, f. 1/17/77 (Appl 759,941); Arnold, D.M. Jr., asr., (Exxon Production Res. Co);

A method is described for plugging flow channels behind the casing in a well. A circumferential temperature anomaly is detected on the casing. The casing is perforated in the direction of the anomaly, and cement is squeezed through the perforations into the flow channels. The apparatus employs (1) a temperature-sensing assembly capable of detecting temperature differences as low as 0.01°F, and (2) an attached perforating gun having a fixed orientation in relation to the temperature-sensing assembly. The temperature -sensing assembly can have a number of temperature-sensing elements, and the perforating gun can have a number of charges spaced longitudinally to form a helical firing pattern. The method involves lowering the apparatus into a zone of interest by means of a multiconductor cable. The temperature-sensing probes contact the casing wall at circumferentially spaced points, and are caused to rotate around the axis of the casing at a given depth. Differential temperature measurements are made and recorded as a function of circumferential direction. The perforating gun is discharged in the direction of a channel, as indicated by the recorded temperature gradient. (15 claims)

DETECTION OF BEHIND CASING WATER FLOW AT AN ANGLE TO THE AXIS OF A WELL BOREHOLE--U.S. 4,071,757, c. 1/31/78, f. 6/21/76 (Appl. 698,398); Arnold, D.M. and Cooke,C. asrs. (Texaco Inc.);

Methods and apparatus are described for detecting undesired water flowing at an angle to the axis of a cased borehole, the water flow being behind the casing. The borehole is irradiated with 14 mev neutrons, resulting in the in situ creation of the radioactive tracer element N^{16} in the flowing water. Two spaced gamma ray detectors are used to sense gamma rays produced by the decay of this radioactive isotope. The distance from the center of each detector to the center of the flowing water is used to establish the angle of flow with respect to the well tool, the linear flow rate of the flow, and the volume flow rate of the undesired water flow. (12 claims)

APPENDIX C 1

ANNOTATED BIBLIOGRAPHY OF LITERATURE

CASING INTEGRITY TESTING

PERSONAL COMMUNICATION, Mathews, Mark; Los Alamos Scientific Laboratory, March 1979.

Los Alamos is responsible for obtaining baseline logs for 2 geothermal wells, one at the BuRec test site in the Imperial Valley and the other at Roosevelt Hot Springs, Utah. The California well is 6,175 feet deep and cased. From 5420' to 6175', it is slotted in places. The Utah well is cased to 4200' and open to 6900'. Max. temperatures are 440°F and 330°F respectively in the Utah and California wells. Logs run in the Utah well include Dresser Atlas thermal neutron, density, CBL, caliper, and temperature and Schlumberger's induction gamma ray, thermal neutron and CBL. Logs were run in the California well by GO Int'l., Schlumberger, N.L. McCullough (casing inspection) and Dresser Atlas. Plans called for 7 logs by all 4 companies. Numerous problems were encountered.

LOG COMPARISON FROM THE GEOTHERMAL CALIBRATION/TEST WELLS C/T-1 & T-2, Mathews, Mark; to be presented at the Society of Professional Well Logging Analysts, Tulsa Symposium, June 1979.

A NEW CASING CORROSION TOOL, Smith, G.S. (Schlumberger Well Services). SPE 7703, 1978.

Discussed using a multiple coil array and different frequencies to measure casing wall thickness with an improved electromagnetic tool that detects corrosion by in-situ inspection of oil-well casing. Presents principles and operating techniques of the device. Describes how the tool compensates for magnetic-permeability and casing inside-diameter variations.

PRODUCTION COST REDUCTION THROUGH CASING CORROSION MONITORING, Bradshaw, J.M. and Bohn, F.O., (Dresser Atlas), SPE 7704, 1978.

A corrosion test loop is recommended for most industrial waste disposal wells, where a bypass would allow frequent evaluation of test materials. If there is a change in injection fluid, the downhole mixture should be tested as connate fluids can alter the injected matter. Caliper surveys, spinner logs, and temperature logs are ways of monitoring an injection well.

VERTILOG: A DOWNHOLE CASING INSPECTION SERVICE, Bradshaw, J.M.,(Dresser Industries Inc.); Int. NACE Corrosion 76 Conf. Houston, 3/22-26/76 Preprint No. 44, 1976, 6 p.

The Vertilog is a casing inspection service designed to record anomalies in casing which is already in service. By interpreting the log recordings produced by the galvo readout system, the approximate range of nominal casing body-wall penetration can be determined. Also, it is possible to discriminate between internal and external damage and to evaluate whether the recorded anomaly is isolated or circumferential. All casing sizes, weights and grades from 4-1/2 in. OD through 8-5/8 in. OD (except 6-5/8 in OD) can be inspected with the Vertilog. Anomalies as small as 1/8 in. in diam. with as little as 20% penetration of the normal body wall of the casing can be detected, recorded and evaluated. Vertilog data will enable the customer to evaluate the condition of his casing in the well at the time of the survey. The Vertilog alone cannot evaluate the cause of an anomaly or the rate of progression of the anomaly caused by corrosion. If a base log is established on a given well, subsequent inspections can help evaluate the rate of progression if the anormalies are caused by corrosion. Other well logs available which will help to evaluate the conditions of a given well include the acoustic cement bond log, the cathodic potential profile, a sonic analysis survey and a differential temperature.

NEW CASING LOG DEFINES INTERNAL/EXTERNAL CORROSION, Bradshaw, James M., (Dresser Ind. Inc);Big Rapids, Michigan, World Oil vol. 183, p.53-55, Sept 4, 1976.

Discusses a casing-leak prevention program that uses corrosion monitoring devices to measure possible metal losses, need for cathodic protection, casing-string productive life. Reports how these measurements and estimates can help schedule and budget workovers before casing leaks develop.

RADIOGRAPHIC INSPECTIONS AT THE CALIPATRIA GEOTHERMAL TEST SITE, Durbin, P.F. (California Univ., Livermore USA.); Lawrence Livermore Lab. Contract W-7405-ENG-48, Mar. 1978, 9 p.

A report is given of radiographic inspections to estimate the extent of corrosion and scale buildup at the Geothermal Test Site in Calipatria, California. Radiation exposure techniques using ^{60}CO and ^{192}IR isotopes were developed. Radiography safety procedures were established. Five radiographic evaluations were made of the Geothermal Test Site from May 1976 to February 1977. Estimates of scale buildup from radiographs of operating plant pipes, valves, and tanks correlated closely with our actual scale measurements from used plant sections.

INFLUENCE OF SILT ZONES ON STEAM DRIVE PERFORMANCE UPPER CONGLOMERATE ZONE, YORBA LINDA FIELD, CALIFORNIA, Cook, D.L.; J. Pet.Tech. 1397-1404, Nov. 1977.

CATHODIC PROTECTION REQUIREMENTS FOR WELL CASINGS, Heinrichs, H.J., Ingram,W.O. and Schellenberger, B.G. (Amoco Canada Petroleum Co); 28th Annu. Petrol Soc. of Cim Tech. Mtg. (Edmonton, 5/30/77-6/3/77 Preprint 1977, 11 p.

Failures of well casings with and without cathodic protection in S. Swan Hills and Nipisi fields were investigated. Surveys which were conducted to determine the adequacy of the existing or the need for cathodic protection included casing potential profile (CPP) surveys, E log 1 tests, and remote off-wellhead potential surveys. The extent of the casing damage was confirmed with casing inspection logs, internal casing calipers, and visual inspection of recovered casing. The depths protected by past and present current levels, plus the depths that could be protected with additional current are discussed. Results from the CPP surveys, E log 1 tests, and remote off-wellhead potential survey are compared.

INJECTIVITY RESTORATION OF A HOT BRINE GEOTHERMAL INJECTION WELL, Messer, P.H., Pye, D.S., Gallus, J.P.; SPG Paper 6761 Oct. 1977, 7 p.

Well was caliper logged after conversion to injector. No scale, corrosion or wellbore restriction was found. After 16 mo. injection (775,000 BLI) well was surveyed to find cause of injection rate decrease. Uniform scale build-up was found w/caliper.

Well was mechanically scraped, brushed to TD and acid treated. Caliper survey indicated well cleaned to "original" conditions; only parts acid squeezed were open.

COMPUTER CALIPER, FINGER PRINTS OF THE HOLE FROM AUSTIN CHALK TO ELLENBURGER, Kading, H.W., 18th Annu. SPWLA Symp. (Houston, 6/5-8/77) Trans. (Paper No. P) 1977 12 p.

Every hole drilled has a different characteristic. A caliper that is linear, accurate and sensitive has many applications that can help the operator reach his objectives; determine cement volume, find a packer seat, determine a directional kick-off point and plug volume, find parted or collapsed casing, determine scale build-up, select perforating points, determine zones acidized in open hole, etc.

FUTURE WELL TESTING AND INJECTION AT THE EAST MESA FIELD, Mathias, K. G.;, Summary 2nd Geothermal Reservoir Engineering Symposium Stanford, p.98-188, 1976.

High corrosion rates noted on wireline equipment. Well logged with Schlumberger Casing thickness log (which detected no damage). They ran an injection test which also indicated no holes in the pipe.

TUBULAR GOODS RECLAMATION-A PROFITABLE VENTURE, F.G. Smith (Shell Oil Co); Int. Nace Corrosion 76 Conf. (Houston, 3/22-26/76) Preprint No. 45, 1976, 7 p.

A tubular goods reclamation program can return acceptable salvaged tubulars for use in lieu of new tubulars. Also, it can provide valuable corrosion data and permit improved corrosion control methods. To accomplish a reclamation program, tubing inspection methods should be evaluated and then standardized. Inspections results should provide corrosion data for monitoring corrosion and mechanical damage. These data can then be used to evaluate past and present corrosion control programs and to design future programs. During the first half of 1975, approx. 1.1 million ft of tubing and 0.2 million ft. of casing were recovered and inspected. Sixty percent of the tubing and 99% of the casing were reclaimed as useable. The estimated savings are $800,000 for the tubing and $1.7 million for the casing. The recovery rate for internal plastic-coated tubing was approximately 30% greater than for the bare tubing. About 40% of the rejected tubing was due to running and handling damage. This reclamation program has been effective in alleviating some of the current tubular goods shortage problems. The corrosion data obtained from the tubular inspections are useful in evaluating corrosion control programs.

CORROSION IN DISPOSAL WELLS, Owens, S.R.(Subsurface Disposal Corp); Water Sewage Works pp R10-R12, April 1975; Abstr. No. W76-05125, Selec. Water Resources Abstr. vol 9 No. 11 p 64 June 1, 1976

Industrial waste disposal wells are subject to corrosion problems such as stress-cracking, galvanic corrosion, and solvent action on elastomers. A typical disposal well contains a screen used to give uniform distribution of injection fluid. The screen is subject to stress-corrosion cracking, uniform corrosion, galvanic corrosion, and sinking. Excessive softening of the formation that supports the screen is another form of corrosion. Elastomers used in a packer must withstand the injection fluid and the injection zone liquid. They are subject to crevice and galvanic corrosion. Cement may fail if sulfur compounds are present, or if the effluent has a low pH.

PRESENT METHODS OF OPENING AND STARTING PRODUCTION IN WELLS AT CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO, Bernardo Dominguez A. Francisco; 2nd U. N. Symposium Development and use of Geothermal Resources, Javier Bermijo de La Mora, p. 1619-33, 1975.

Early failures believed to be a result of rapidly bringing wells on production. Current technique is to: (1) observe wells; (2) stimulate (if required); (3) slowly heat up well; (4) develop productive capacity; and (5) evaluate energy capacity.

Logging is an important evaluation technique. Open hole: Temp. Logs; G Logs; and Lithology Logs; After casing & flushing: multiple T-Logs, gamma ray collar; and multiple caliper.

Sand production usually decreases from 0.1% to .0003% (mass rate), Caliper logs of casing are run in a systematic cycle to check for corrosion, scale buildup, erosion, collapse or fracture of pipe. Anomalies are usually checked w/ lead impression blocks.

NEW CASING INSPECTION LOG, Cuthbert, J.F. and Johnson, W.M. Jr. (Schlumberger Well Serv.) Tx. Am. Gas Assoc. Oper. Sect. Proc. 1975 for Mtg., Los Angeles, Calif. and Bal Harbour, Fla., May 5-7 and May 19-21, 1975.

The new Pipe Analysis Log employs separate tests of the total casing wall and of the inner surface. Together, these two measurements permit detection, with a high degree of resolution, of small defects and corroded areas in the pipe, and also provide the ability to discriminate between defects on the inner and outer walls of a single string of casing. Example logs of the new casing-inspection tool, selected from an extensive test program and nine months of commercial application, are presented. Comparisons are made of the results from the new tool with defects observed in the pipe when out of the well. Data are shown graphically and tabularly. 5 refs.

USE OF GEOTHERMAL ENERGY AT TASMANN PULP AND PAPER COMPANY, LTD. N.Z., Wilson, R.D.; Multipurpose Use Geoth. Energy OIT Klamuth Falls, Ore., pp. 79-100, 1975.

Casing tends to scale up. Evaluation is with scale w/gage rings. Scale ($CaCO_3$) is reamed out & slots acidized, but each time the rate is down, liner is pulled & cleaned or new liner run.

AUTOMATIC NONDESTRUCTIVE TESTING OF OIL FIELD TUBULAR GOODS, Kahil, J.E., (PA Inc); 30th Annu. ASME Petrol. Div. Petrol Mech. Eng. Conf. Tulsa 9/21-25/75 Preprint No. 75, Pet 42, 8 pp 1975.

Deeper wells and increased offshore drilling are stressing the need for stringent quality control of oil-field development effort in nondestructive testing and a virtual explosion in the electronic field are leading to highly automated pipe inspection systems which are increasingly reliable, sensitive and accurate. The study is not a general review of nondestructive testing techniques. It focuses instead on pipe inspection methods which have proven to be fieldworthy. A discussion of the methods, which includes advantages and limitations, is followed by the description of a typical automatic pipe inspection system.

HERE'S HOW GETTY CONTROLS INJECTIVITY PROFILE IN VENTURA, Froning, S.P. and Birdwell, B.F.; Oil & Gas J., p. 60-65, Feb. 10, 1975.

CORROSION RATE MONITORING AT THE GEYSERS GEOTHERMAL POWER PLANT, Hanck, James A., Nekoksa, George; 2nd UN Symp. Dev. Use Geotherm. Res., p 1979-1984, 1975.

Corrosion monitoring system uses electrochemical, electro-resistance, and coupon techniques. Seems to work ok on surface euqipment.

CASING BUCKLING IN PRODUCING INTERVALS. Suman, G.O., Jr. (Completion Technology Co); Petrol Eng. vol 46, No 4 pp 36, 38, 40, 42, April 1974.

Extensive casing damage has been encountered within many of the production intervals of wells in the South Pass, Blocks 24 and 27 fields, located in the delta of the Mississippi River. The damage has been buckling (kinking) in or near the perforated intervals. Such damage has been found usually upon entering old wells for workover. The primary concern, when casing damage is encountered in a well, is to effect the workover objective in spite of the damage. The configuration of casing damage can be determined with the Sperry-Sun Kinkmeter and with Kinley caliper survey tools. This helps to ascertain the cause of the damage and to suggest means for repairing or passing the damaged zones. These downhole tools are described. Casing buckling in or near the perforated intervals is believed to be caused by axial loads induced in the casing as compaction of the depleting reservoirs takes place, usually combined with production of sand which has removed lateral restraining forces and enabled a deflection to occur. Experience has shown that unconsolidated formations are subject to substantial compaction. How workover jobs are effected is described.

IMPRESSION TOOL DEFINES DOWNHOLE EQUIPMENT PROBLEMS, Hutchinson, S. O., (Standard Oil Co. California); World Oil vol. 149, No 6, pp.74-80, 1974.

A new technique for evaluating the condition of downhole equipment with impression packers has been developed and field tested by Standard Oil Co. of California. Patents are pending on this technique and the impression method and variable length, inflatable packers used are being licensed by Chevron Research Co. The main components of the system are the inflatable packers which are covered with a new impressionable material that rapidly produces a reverse impression of the interior features of liners. For interpreting the impressions, field-proven methods have been developed for converting dimensions and extensions of extrusions in the recovered material to actual in situ conditions. With a true picture of well-bore conditions, decision-making can be speeded up and repair, remedial and/or stimulation operations can be more intelligently planned. This article describes information gained from 317 impression packer runs made in 136 different oil wells.

CASING POTENTIAL LOGGING RELATED TO VERTILOG CORROSION LOGGING, Lindsey, R.A. (AMF Tuboscope Inc) NACE Corrosion 74 Conf. (Chicago 3/4-8/74) Preprint No 66, 1974, 6 p.

In recent years, much development work has centered upon methods to detect and evaluate corrosion pitting damage to downhole well casings. One method which was introduced in 1968 and is now being employed extensively is a device called Vertilog. This tool is run as a service and enables the user to detect and evaluate corrosion pitting damage while casing is in position downhole. The basic technique employed by Vertilog is called electromagnetic flux leakage. One cause of corrosion pitting frequently found in downhole casing strings is an electric potential, with current usually leaving the pipe where corrosion damage is located. With this in mind, electric potential measuring devices have been developed for detecting and evaluating current flow in casing strings. One of these devices, known as Casing Potential Evaluator (CPE), is often run in conjunction with Vertilog corrosion survey service. Typical applications, together with log interpretation, are described.

NEW CASING INSPECTION LOG, Cuthbert, J.F. and Johnson, W.M. Jr. (Schlumberger Well Services); 49th Annu. Spe. of AIME Fall Mtg. Houston, 10/6-9/74 Preprint. No. SPE 5090, 1974, 12 p.

A new casing-inspection log in combination with other logs, provides for detailed evaluation of in-place well casing. The new Pipe Analysis Log employs separate tests of the total casing wall and of the inner surface. Together these 2 measurements permit detection, with a high

WELL MEASUREMENTS, Deuch, N.D., Geothermal Energy UNESCO, pp.86-96, 1973.

Regarding casing, Deuch recommends (1) deviation survey for direction and angle hole is off vertical; (2) calipers to check for corrosion or fractures; (3) ring gages to check on buildup of scale or sand or chemical deposition; (4) collar location (5) CBL and (6) perforating log.

Regarding cement, open hole caliper for cement volume calculations

THE PREDICTION AND CONTROL OF CASING WEAR, Bradley, Wm. B. and Fontenot, John E.; SPE ST22, 1973, 16 p.

Discusses techniques to predict and evaluate casing wear-especially in hot, deep, cracked holes. Utilizes caliper logging.

DETECTING LEAKS IN OILFIELD TUBULAR CONNECTIONS, Eaton, B. A. (Universal Drilling & Eng. Consult., Inc); World Oil v 177, No. 4, pp.48-50, 52, 54, Sept.1973.

An extensive research program has evaluated external pressure testing of tubular connections as a method for detecting damage and leaks. Laboratory testing methods, theoretical considerations, program results, and supporting field tests are shown. External testing, if properly done, is an excellent way to field test oil-field tubular connections. The primary reason is that most field connections are designed with relatively thin pin ends and thicker box ends to withstand more internal pressure than external pressure. Equations describing stress states involved when one cylinder is shrunk upon another also describe stresses in a tubular connection joined together. After a connection is made up and either internal or external pressure is applied, additional stresses caused by these pressures are described by thick-walled cylinder equations. All of these equations were programed for digital computer solution for various pipe sizes, make up stresses, pressure conditions.

degree of resolution of small defects and corroded areas in the pipe, and also provide the ability to discriminate between defects on the inner and outer walls of a single string of casing. This was not possible with just the wall-thickness information provided by the older low-frequency electro magnetic thickness tool. Using the data from the new log along with the older wall-thickness measurement, it is also possible to detect and locate severe corrosion or defects in the outer casing of a double string. Example logs of the new casing-inspection tool, selected from an extensive test program and 9 mo. of commercial application, are presented. Comparisons are made of the results from the new tool with defects observed in the pipe when out of the well.

APPLICATION OF RADIO-ACTIVE ISOTOPES IN SOLVING PRODUCTION PROBLEMS IN INDIAN OIL FIELD, Singh, L. and Mahada, N. (India Oil & Natural Gas Comm); U.N. ECAFE Mineral Resources Develop. Ser. No. 41 vol.2, pp. 135-142, 1973.

Radioactive logging and isotopes are becoming increasingly important in the development of oil and gas fields in India as methods to locate channeling and casing leaks and to determine the effectiveness of hydrofracturing. Some case histories of the work, performed by ONGC, are cited as examples. Future scope of this work for solving some of the current problems in the exploration/exploitation of Indian Oil and gas fields has been suggested. Reference is made to the use of radioisotopes in waterflood systems oil and gas injection profiles, fracture-sand tracing and secondary recovery operations. (12 refs)

USE OF THE TEMPERATURE LOG FOR DETERMINING FLOW RATES IN PROCUING WELLS, Curtis, M.R. and E.J. Witterholt (Schlumberger-Doll); 48th Annual Fall Mtg., Las Vegas, SPE-AIME, SPE 4637 Sep 30-Oct 3, 1973.

"Greatest usefulness of temperature logs (in flow determination) should be in conjunction with other flow rate information, in order to evaluate flow rates in casing annulus."

DRILLING THE DEEP WELL IN THE ROCKY MOUNTAINS, Maser, A.J, Dallas, D. E. and Myers, R. G., (Mountain Fuel Supply Co.); SPE of AIME Rocky Mt. Reg. Mtg. (Denver, 4/10-12/72) Preprint No. SPE-3831, 1972, 7 p.

There are many problems associated with deep well drilling. This study attempts to isolate these problems more common to the Rocky Mt. area: (1) the care of the drilling string and corrosion problems encountered and methods of damage prevention as employed by Mountain Fuel Supply Co.; (2) a discussion of chemicals used in conjunction w with the drilling mud system to control corrosion damage to casing and drill string; (3) the inspection methods and means of detecting the presence of corrosives; (4) a discussion of pressure control methods and equipment used; (5) the training methods and programs to assure proper procedures from drilling crews in case of blowout or high pressure formation kicks; and (6) results and values of training program observed during actual situations on the job.

EVALUATION AND DESIGN CONSIDERATIONS FOR CATHODIC PROTECTION OF WELL CASINGS, Kirklen, C.A. (Sun Oil Co); West Virginia Univ. Bull. Ser.73, No.6-1, pp.545-554, Dec. 1972.

The cathodic protection of oil well casings presents some special problems. At the present time there are 2 basic types of logging tools available to the industry that have proven through extensive use to be reasonably diagnostic in evaluating casing corrosion damage. These are the A-C Electromagnetic Casing Inspection Log and the D-C Electromagnetic Flux Leakage Detector. Each has specific capabilities that the other does not possess.

37 WAYS TO IMPROVE YOUR WELL COMPLETIONS, Desbrandes, R. (Inst. Francais du Petrole); World Oil v 174, No. 5, p. 71-74, April 1972.

Combining practical operation know how with latest technology is providing some imaginative new approaches to petroleum production. Many wells are being economically completed today which would have condemned as dry, or too hazardous to work in, a few years ago. The 37 key developments discussed cover open-and cased-hole logging, production logging, perforating, general production tools and log interpretation. Examples of some outstanding production aids covered are: (1) logging methods controlling sand production; (2) techniques for evaluating elements such as carbon, aluminum, and silica in borehole rocks; (3) detection of casing tension failures in steam injection wells; (4) through-tubing formation logs and production tools; and (5) how to obtain cleaner, deeper perforations for higher well flow. Improved formation evaluation, more efficient perforating jobs and higher well productivities are resulting from recent advances in wireline tools. New engineering methods are now being applied in the field of solving some long standing problems associated with sand control, water injection, and workover planning.

THE ACOUSTIVIEWER--A NEW METHOD FOR INSPECTION OF DOWN-HOLE TUBULAR GOODS, Schaller, H. E., Kilpatrick, R. and Stratton, R. (Triangle Service Inc.); 47th Annu. Spe of AIME Fall Mtg. San Antonio, 10/8-11/72 Preprint No. SPE-4000, 1972 8 p.

Utilizing a down-hole acoustical scanning device, parted casing, split pipe, enlarged slots, holes and other abnormalities in pipe can be identified. The obvious importance of this information can be a controlling factor in remedial work. First, the precise location of the problem is identified in a relatively short time and recorded at the surface. Secondly, the scope of the problem is defined which enables the optimum planning for corrective action. To date, the field results with this tool have been limited to the Los Angeles Basin.

PROJECT RIO BLANCO DEFINITION PLAN; Volume III Reentry-Related Detailed Tasks., PNE-RB-18, February 28, 1972.(CER).

HOW TO FIND CASING LEAKS; Petrol Eng., vol43, No. 6, pp.76, 78, June 1971.

Casing leaks are a problem in producing and gas storage wells which are completed without tubing. Such leaks may cause blowouts or the charging of other sands. Also, loss of gas is expensive, particularly in storage wells where the gas has been purchased, compressed, and transported for injection. Routine testing methods for casing leaks require a rig, killing the well, running tubing and packer, testing with several packer settings and bringing the well back in.

This testing method is not only expensive, but there is the risk of damaging the reservoir with drilling fluid or excessive pressure. Cities Service Gas Co. personnel designed, built, and patented a special wire-line tool called a gas well testing packer. Major components of the tool are a hydraulically inflated packer, a reservoir containing hydraulic fluid, and a set of dogs which set in a casing joint recess. The latter are spring loaded and prevent the tool from going down, but permit upward movement. The dogs are released by jerking on the line when the tool is on bottom. When in position, the packer is inflated by reciprocating the wire line to trip a valve, allowing the fluid to discharge into the tool body. It can be set as many times and at as many depths as desired on a single run. All equipment including a small mast, a wire line winch, and a lubricator, is mounted on a small truck.

EXTERNAL TESTING FINDS HIDDEN CONNECTION LEAKS, Hasha, M.M., Snyder, R.E.; World Oil vol 172 n 2, p.27-30, Feb 1, 1971.

Operators will be expected to provide more reliable pollution-free completion systems. Managers will watch operating expenses more closely under the new total value approach which considers future savings from a positive testing program. Here are first published details of an external joint testing method that has evaluated 190,000 high pressure tubing and casing connections without a reported failure.

EVALUATION OF GAS STORAGE WELL COMPLETIONS WITH WELL LOGS, Smith, B. A., and Neal, M. (Schlumberger Well Services); 45th Annu. SPE of AIME Fall Mtg. Houston, 10/4-7/70 Preprint No. SPE 2965, 1970, 14 p.

Many of the problems connected with the underground storage of natural gas, in both aquifer and depleted reservoirs, can be solved by the proper application of modern wireline logging tools. Well logs are useful in gas storage wells for the location and inventory of gas-bearing zones, determination of levels where gas enters or is produced from the formation, determining well deliverability, and the location of casing leaks, as well as points where the pipe is defective due to corrosion. Logs run after the well is completed can help to evaluate the effectiveness of a stimulation process or the mechanical integrity of the completion. Logs run at intervals, as the storage well is produced, can define changes in gas saturation, movement of fluid contacts, and growth of the gas bubble, thus permitting a periodic inventory. Small diameter tools and pressure control systems are available with which most logging operations may be made in either tubing or casing without interrupting the well operation. Field examples from gas-storage projects in several different areas are used to illustrate the interpretation techniques.

RECENT TECHNOLOGY PREVIEWS NEW PRODUCTION TRENDS, Snyder, R.E.; World Oil vol 170, No. 3, pp. 82-85, Feb. 15, 1970

Information on 9 interesting developments in practical production technology is briefly described: (1) application of micellar fluids for increasing injectivity of injection wells improves permeability by removing residual oil and hydrocarbon contamination around the well bore; (2) flue gas injection operations in Crane County, Texas, for over 3 yr. reduced the use of natural gas in a 20-yr. old miscible injection program; (3) a 2-stage cementing method, using a 2% calcium chloride cement, was developed to displace into a thief zone to act as support for squeezing a larger stage; (4) special high speed, high-pressure centrifugal pumps were developed for a waterflood project in Cook Inlet, Alaska. (5) engineering and computer techniques were applied to reduce sucker rod failures and increase pumping efficiency in 8,000 ft wells located in Wyoming; (6) a new tool to investigate casing damage passes through casing doglegs of 3° per ft. in 7-in. casing, and in 22 wells indicated the principal cause of casing damage was buckling or lateral deflection within pay zones; (7) a new perforator design forces the sealing pad against the casing and isolates the new perforation from hydrostatic pressure in the well bore; (8) a new hydraulic fracturing technique uses a high viscous fracturing fluid; and (9) platform design with pollution control and safety devices was developed for wells in the Santa Barbara Channel.

MEASUREMENT OF CASING BUCKLING IN PRODUCING INTERVALS, Suman, G. O, Jr., Klementich, E. F., and Broussard, L.P.; J. Pet. Tech., 255-266, March 1970.

As part of a program to ascertain damage in some South Louisiana wells, a gyroscopic tool was designed for measuring lateral casing deflection over short intervals. It is found that the principal mode of damage is not collapse or shear, as previously supposed, but buckling in the producing interval. The tool, called a Kinkmeter, has been used to measure offsets adjacent to faults. Presented is information on the design and field use of the tool and results of surveys in a test well. Included is a method, used in conjunction with a computer program, for deriving the phantom axis of a pipe.

WELL LOG ODDITIES CALIPERS, Connolly, E.T.; Canadian Well Logging Society Journal, Vol. 2, Issue 1, p. 64, 1970.

WELL CASING CORROSION AND CATHODIC PROTECTION, Curry, E. L., (General Corrosion Services Corp.); SPE -AIME Rocky Mt. Reg. Mtg.. Casper, Wyoming, 6/8-9/70, Preprint No. SPE 2910 1970, 8 p.

One of the problems concerning the prevention of corrosion of oil and gas well casings is that of determining the current requirements for cathodic protection. The causes of corrosion on well casings are discussed, well completion practices that would minimize corrosion problems are suggested, and 2 methods for determining current requirements for cathodic protection are explained. Graphs and drawings are included to describe and substantiate both methods. The casing potential tool is the most used tool to locate and evaluate external casing corrosion. It also can be used to determine the current requirements for cathodic protection. The E-Log-1 survey (sometimes referred to as the log-current-potential method) cannot locate or evaluate external casing corrosion, but is a relatively inexpensive method for determining current requirements for cathodic protection.

APPLICATION OF MODERN WELL LOGGING METHODS TO SALT SOLUTION CAVITIES, Caldwell, J. W. and Strabala, J. M. (Seismograph Service Dorp); 3rd Northern Ohio Geol. Soc. Salt. Symp., Cleveland, 4/22-24/69 Proc. vol. 2, p. 341-352, 1970.

Two acoustical devices, the Seiscaliper and Seisviewer, have been introduced to the field recently and have applications in solution mined cavities. The Seiscaliper consists of a downhole acoustic scanner-transceiver unit run from standard logging cable with its associated surface control display. The system is designed to provide accurate mapping and orientation of solution-filled cavities. Additional detailed information of the roof and floor may be obtained by the use of multiple selected transducers. Profiles of the cavity, along magnetic bearings, are developed in addition to computerized calculations of volumes for the entire cavity. The Seisviewer produces a high resolution acoustic picture of the borehole or casing wall in any type of fluid. Acoustic pictures clearly define fractures, casing splits, pitting and perforations.

NEW PORTABLE TOOL TESTS GAS-WELL CASING FOR LEAKS QUICKLY, CHEAPLY; Oil and Gas J., vol. 68, No. 18, p. 132-134, May 4, 1970.

Cities Service Gas Co.'s new unique, gas-well casing tester saves time and money in the search for casing leaks. The small rig, which is easily operated by 2 men, can test 2 wells per day. Cost of testing a well with the new tools is estimated at 1/10 that of conventional methods, considering time, equipment, labor, and other expenses. A small mast, mounted on a pickup truck, is positioned over the well and a lubricator is bolted to the wellhead flange. The testing tool is located in the lubricator, and then lowered into the well when the master gate is opened. Catcher dogs on the test tool position themselves in recesses in casing collars and hold the tool in position. A small pump, operated by reciprocating a wire line, pumps oil into an inflatable packer at the base of the tool. With the packer inflated, the casing above it is sealed off from the producing formation and can be tested for leakage. A test is made to assure that the packer is seated properly and that no gas is entering the casing to replace that which might have been lost through a leak. At the conclusion of the test, the packer is easily retrieved from the well for use on the next test. The packer is deflated by pulling the wire line at the surface which opens a valve to return the inflating oil to its reservoir. The catcher dogs that hold the tool in position are designed to allow upward movement of the tool when extended so the tool is simply winched back into the lubricator.

A MAGNETIC DEVICE TO DETECT TENSION FAILURES IN OIL FIELD CASING, Patterson, M.M., Murphey, C.D.,Jr. and Sheffield, B.C. (Shell Development Co); 45th Annual SPE-AIMR Fall Mtg. Houston, 10/4-7/70, Preprint No. SPE 2958, 1970, 11 p.

A downhole television system was used to inspect the casing in several steam-injection wells. During these inspections, severe distortion of the surface television monitor was evident every time the subsurface camera passed a separation in the casing. Subsequent laboratory tests indicated that the distortion was caused by intense magnetic field of 30 gauss or more. The magnetic field at the casing separation is created because the separation allows opposite magnetic poles to be formed in the casing. The lines of flux once concentrated in the casing now form an external magnetic field about these new poles. A magnetic field of such magnitude can be located by search coil techniques. As a search coil traverses a magnetic field, a voltage is generated in the coil windings which is proportional to the strength of the field and the speed of the traverse of the coil. A search coil was designed using standard PGAC coil and a McCullough Mono-cable. This new instrument called the Magnetic Casing Logging Tool (MCLT) uses an x-y plotter as a readout device.

WELL CASING CORROSION AND CATHODIC PROTECTION, Curry, Elmer L., SPE 2910, June 1970, 8 p.

Discusses current potential logging techniques that help pinpoint areas where cathodic external corrosion is taking place.

MEASUREMENT OF CASING BUCKLING IN PRODUCING INTERVALS, Sunman, G. O., Klementick, G. F., Broussard, L.P.: SPE-2647, Oct.1969, 26 p.

Discusses use of "Kinkmeter", a sperry sun tool that provides accurate measurements of lateral casing deflection over short intervals. This provides information on failure mode-shear, collapse, offset, etc.

CALIPER LOGGING THEORY AND PRACTICE, Hilchie, D.W.; IX-1-3, The Log Analyst, Vol. IX, Issue 1, p. 3, 1968.

NEW ACOUSTICAL TOOL SCANS WELL BORE, Oil Gas J. vol 66, No. 49 pp 42-43, Dec. 2, 1968.

A new instrument, called the Borehole Televiewer, can make a minute examination of the borehole wall via television. Mobil Oil Corp. says the device can detect cracks or fractures in the hole wall as fine as 1/32 of an inch. The device uses a camera-like instrument that scans and photographs the inside of a well, even when it's filled with oil or mud. A 1/2-in. ceramic disk, the lens, sends and receives sound waves which detect imperfections in the wall of the hole. Wherever a fracture intersects the wall, the televiewer reveals its thickness, location, and its direction and angle. A picture of the wall is printed in thousands of fine lines, much as in a television picture. The picture is a permanent recording and resembles a geological electric log. A basic component of the tool is a transducer that slowly rotates in the hole. An audio signal of about 2 million Hz is bounced off the hole walls or casing. Any discontinuity in the wall's smoothness is detected in the reflected sound.

THE BOREHOLE TELEVIEWER-A NEW LOGGING CONCEPT FOR FRACTURE LOCATION AND OTHER TYPES OF BOREHOLE INSPECTION, Zemanek, J. (Mobil Res & Develop Corp); 43rd Ann SPE of AIME Fall Mtg Houston, 9/29/68-10/2/68 Preprint No. SPE 2402, 27 pp.

The Borehole Televiewer logging tool is an entirely new development for use in the field of formation evaluation and borehole inspection. The tool takes an acoustic picture in the form of a welling log of the inside of the well bore. The picture is oriented with respect to magnetic north. The log is run continuously. Both induced and natural fractures have been defined in remarkable detail with the tool. Well bores have been filled with either lease crude, water, or drilling mud. Logs have clearly revealed vuggy porosity, the size and distribution of perforations in casing and casing failures.

INDUCTION-TUNED METHOD TO DETERMINE CASING LENGTHS IN HYDROGEOLOGIC INVESTIGATIONS, Marsh, C.R. and Parizek, R.R., (Pennsvlvania State Univ); Ground Water vol 6, No.6, pp.11-17 Nov. Dec. 1968.

An induction-tuned device was designed and tested under a variety of well casing conditions. It can detect casing lengths to within 0.2 to 2.0 in. for casing ranging from 2 to 14 or more inches in diameter, which are made of either magnetic, or nonmagnetic metals. A casing separation as small as 1 in. is detectable for 12-in. diam. casing and a 4 in. or more separation is detectable for 4-in. ID casing. These values indicate the range in sensitivity to be expected when determining casing separations. The sensing element is a coil whose inductance is changed by varying its proximity to any metallic conductor. A coil and capacitor in parallel make a tuned circuit reasonant at 3 KC. The device includes a transistor in a phase shift oscillator, a second transistor which acts as a current amplifier, a 0 to 100 μa D-C meter driven through a bridge rectifer, capacitors, and other elements. Twelve to 14 v at 4 to 6 ma or less than 0.1 w is sufficient to power the device. All electrical elements are standard except the probe and all materials can be purchased for about $40.00 exclusive of the reel and cable assembly.

PROJECT MOHOLE, PHASE 2. ENGINEERING PLAN REPORT. VOLUME 3, Brown & Root, Inc., Staff; PB-178, 846, 717 pp 1967; Abstr. U.S. Gov. Res. Develop. Rep., vol 68 No. 18 p 97, 9/25/68

This report is one of a series summarizing development work in connection with the Mohole Project, prior to its cancellation. This volume covers drill pipe, riser casing system, riser buoy system, hole reentry, pipe inspection, drilling instrumentation, downhole drill, emergency fishing tools, test well drilling, initial sea drilling operations, and logistics.

CATHODIC PROTECTION OF OIL WELL CASINGS, Simmons, E. J., (Sun Oil Co); Okla. University Control Short Course (Norman, 9/16-18/68) Proc. p. F1-F15, 1968.

In recent years, cathodic protection has been used with increasing frequency throughout the oil and gas producing industry for protection of the external surfaces of well casings against corrosion. Economic projections based on lead repair costs vs. estimated costs of cathodic protection can indicate the economic feasibility of cathodic protection. Certain tools and techniques are available to help in assessing the economic feasibility as well as the physical feasibility. It is important early in the study to determine for certain if the leaks are due to external or internal corrosion, and these tools and techniques are useful here also. To obtain an idea of the extent of corrosion damage, the casing thickness logging tool is useful. The internal caliper is an auxiliary tool which can be run simultaneously with the casing thickness tool. From a study of the thickness and caliper logs, leak frequency curve prediction, leak repair cost, expected well life and other considerations, a decision can usually be made to justify, from the standpoint of economics, the feasibility of installing cathodic protection.

PIPE INSPECTION METHODS AND TECHNIQUES, Witten, R.J.(AMF Tuboscope Inc.); Petrol. Equip. Serv. vol. 31, No. 3, pp 37-40, May-June 1968

Electronic inspection has become an accepted method of determining service ability of new and used tubular goods. Many users now rely on some form of electronic inspection to aid them in reducing pipe failures. Pipe defects can generally be classified in 2 categories: 1) manufacturing origin; and 2) service-induced. As the name implies, manufacturing origin defects occur in pipe at the time of manufacture. Service-induced defects are created by handling, environment and other service conditions to which the pipe is subjected during its life. Reduction of pipe failures caused by defects can be achieved by inspection. To obtain optimum results in defect detection, a series of techniques must be employed. No single technique is capable of detecting all defects in the various orientations that can occur.

RADIOACTIVITY...SOME GAS INDUSTRY APPLICATIONS, Fishman, J.B. (Nucleonics Development Co.); GAS, vol 44 No. 5, pp 50-53, May 1968

There are several methods for the detection of radiation but only 4 have any practical applicability. All operate on the basis of radiation ionizing or exciting either a gas, solid, or liquid and the resulting energy being amplified and brought out as an electrical signal. Applications in the gas industry are divided into 3 areas: (1) uses in producing fields; (2) uses during transmission; and (3) laboratory studies. The well-logging methods briefly described are the gamma log, gamma-gamma logging, neutron-neutron logging, neutron-gamma logging, and neutron-activation logging. In all cases, the purpose is to estimate the porosity, gas-water interface, sleeve location, cement location, or chemical composition. A great deal of interpretation is required. Cementing of boreholes can be checked by labeling the cement. Cracking and fracturing of cementing can be determined by forcing radioactive material into boreholes and then checking residual activity of the fractures. Flow characteristics and leakage of gas or water can be easily traced by injection of radioactive materials. Some of the areas of use in transmission are to study pipe corrosion, engine and compressor wear, pipe leakage, pipe transmission properties, and to check the integrity of the pipe welds.

RADIOACTIVE TRACERS IN GEOPHYSICS, Alekseev, F.A. and Srebrodolskii, D.M. (USSR Nucl. Geophys. & Geochem. Inst); IAEA Radio-Isotope Tracers, Ind. & Geophys. Symp., Prague, 11/21-25/66, Proc., pp. 133-148, 1967; Rept. No. STI/PUB-142; Abstr. No. 14690, NUCL. SCI.ABSTR., vol.22, No. 8, p. 1516, April 30, 1968.

Radioactive tracers are widely used in geophysics for solving various problems of the oil industry. The main applications are: in injection wells, determining water formations and checking conditions in casings; in producing wells, determining annular circulation and checking casing conditions; and determining the level of the cement top when deep wells are encased in concrete, especially in regions of elevated temperature. To solve these problems, use is made of the isotopes Fe^{69}, Zr^{95}, Zn^{86} and I^{131}, in doses ranging from 0.5 to 1 mCi per cu M. of solution. Of late, increasing use is being made of tritium as a tracer, e.g., in determining the rate of water movement in 1 layer during the working of deposits, in techniques for pressure maintenance of fields, and in solving problems relating to the hydrodynamic relationships between individual layers and productive zones in massive oil fields. These problems are being solved by methods based on the use of radioactive tracers in aqueous form.

REVIEW OF RADIOTRACER APPLICATIONS IN GEOPYSICS IN THE UNITED STATES OF AMERICA, Mott, W.E. and Dempsey, J.C. (US Atomic Energy Comm); IAEA Radioisotope Tracers, Inc. & Geophys. Symp., Prague, 11/21-25/66, Proc. pp.111-130, 1967, Rept. No. STI/PUB-142; Abstr. No. 14689; NUCL. SCI ABSTR., vol. 22, No. 8, p. 1516, April 30, 1968.

Radiotracers are extensively used in the drilling, completion, and treatment of oil wells and in secondary recovery operations. They have proved particularly effective for following the movements of fluids in, adjacent to, and between well bores and for following and pinpointing the stopping-place of materials introduced into well bores. Specific applications include: the determination of production profiles; the determination of injectivity profiles and the rate and path of travel between injection and production wells; the location of cement tops; thief zones, channels, and casing leaks, the control of the placement of plugging materials; and, the determination of the number, type and extent of fractures following stimulation. The application of radio-tracers to geophysical problems in the U.S.A. is reviewed. An aim is to evaluate the present position of the radio tracer technique with emphasis on extent of use, practical limitations, and competition from alternative techniques.

CATHODIC PROTECTION OF OIL WELL CASINGS, Simmons, E.J. (Sun Oil Co); 15th Ann. SW. Petrol. Short Course Lubbock 4/18-19/68, Proc. pp 245-255, 1968.

To obtain an idea of the extent of corrosion damage, the casing thickness logging tool is useful. This tool consists of a downhole instrument connected to a surface recorder. The tool is pulled up the hole, giving a continuous indication of metal mass surrounding the coils. The electronic internal caliper log is available as an auxiliary tool which can be run simultaneously with the casing thickness tool. From a study of the thickness and caliper logs, leak frequency curve predictions, leak repair costs, expected well life, and other considerations, a decision can usually be made to justify, from the standpoint of economics, the feasibility of installing cathodic protection. If the leaks are fairly shallow, normally it can be assumed that protection can be obtained with a modest outlay for equipment and labor. The deeper the leak zone, the more necessary it is to determine feasibility. Certain tools and techniques are available to determine whether applied current can be made to reach the depth required.

NEW TEMPERATURE LOG PINPOINTS WATER LOSS INJECTION WELLS, Riley, E. A., (Mitchell, (G) & Assocs); World Oil, vol 164, No 1, pp. 69-72, Jan. 1967.

A new, extremely accurate differential temperature survey technique has been used successfully by Anadarko Production Co. to precisely locate a downhole water loss in a waterflood injection well which was previously undetectable by any other means. The differential temperature log accurately measures fractional temperature anomalies associated with fluid movements downhole. Besides being used to detect fluid communication downhole in water injection wells, the technique is applicable for finding tubing-casing leaks, gas communication, productive zones, lost circulation zones, production profiles and gas-oil-water contacts. This article discusses use of the differential temperature survey as a diagnostic, injection profile tool.

INJECTION PROFILES DURING STEAM INJECTION, Bookout, D.E., Glenn, J.J.,Jr. and Schaller, H.E.; API Spring Mtg., Pacific Coast District, Division of Production, May 2-4, 1967. (Triangel Services, Inc.)

STEROSCOPIC DEEP WELL PHOTOGRAPHY IN OPAQUE FLUIDS, Mullins, J.E.; Paper N, SPWLA Symposium,1966.

LOGGING EQUIPMENT. PT. 17. HOW TO MAKE FLUID-INTERFACE SURVEYS, Helander, D.P.(Tulsa University); Oil & Gas Equip.,vol 12, No. 10, pp 6-7, Aug. 1966.

Two techniques are possible for obtaining fluid-interface profiles, moving-interface and static-interface. The moving-interface technique consists of injecting one of the dissimilar fluids into a well at a constant rate and then following their interface as it moves down the wellbore. As long as the wellbore is uniform, a constant rate of fall occurs. But when the survey is conducted in non-uniform wellbores, such as in open holes, variations in hole size cause corresponding changes in fluid velocity. This effect can be accounted for by running a caliper survey or by running a variation of the moving interface technique. When conducting and non-conducting fluids are used as the dissimilar fluids, a detection tool measuring the electrical conductivity of the fluids is used. A gamma-ray logging tool is used when tracking the interface form between radioactivity and non-radioactivity fluids The interface may be formed between a clear and an opaque fluid, for which a dye-photo tool is a detector. The location of casing leaks can also be determined with a dye-photo tool.

USE OF CATHODIC PROTECTION FOR EXTERNAL CASING CORROSION CONTROL, Simmons, E.J. (Sun Oil Co); Okla. Univ. Corrosion Control Short Course Norman, 9/22-24/65 , Proc., pp. 1-E-28E, 1966.

The use of cathodic protection for controlling corrosion on the external surface of casing when only the upper and inside portions are accessible. This inaccessibility hampers the corrosion engineer in 3 ways--makes corrosion detection more difficult, limits the control techniques to only cathodic protection, and eliminates may of the techniques normally used in planning and designing a control system. The use of 2 tools, the casing thickness log of Welex and McCollough and Lane-Wells casing voltage profile tool, to determine the point at which corrosion is occurring in a casing string, have helped to solve this problem.

NEW ELECTRONIC CASING CALIPER LOG INTRODUCED FOR CORROSION DETECTION, Edwards, J.M. & Stroud, S.G. SPE 1327, 36th Regional Fall Mtg., SPE-AIME, Bakersfield, Nov. 4-5, 1965.

McCullough's electronic casing caliper measures ID of pipe. Run with casing inspection tool, it determines whether metal loss or damage has occurred internally or externally. Rated to 350°F in 1965.

TECHNIQUE AND EQUIPMENT DEMONSTRATIONS OF TUBULAR GOODS INSPECTION, Demecs, R.C. (AMF Tuboscope Inc.), PB-175, 338, 10/16/65, 304 p.

Techniques applicable to the non-destructive inspection of tubular goods to be used during the drilling phase of Project Mohole are described. Primarily, modified basic techniques of improved sensitivity were demonstrated, although in certain instances, new methods were devised. Actual hardware was assembled to demonstrate most of the techniques under conditions similar to those known to exist in drilling operations. The report covers 4 main areas of interest: (1) platform drill pipe inspection, (2) platform riser casing inspection, (3) platform thread inspection; and (4) receiving inspection. These, in turn, are divided into subsections, each describing a means of detecting specific flaws and variations in pipe parameters. Recommendations are also made based on past experience and knowledge gained during the contract tenure.

SCIENCE SECTION, PROJECT MOHOLE PROGRESS REPORT, AUGUST 15, 1965, Brown & Root, Inc., Staff; PB-175, 309, August 31, 1965, 17 p.

A bottom-profile design study was made to determine whether the various acoustic systems and associated equipment to be installed on the drilling platform can be used for bottom profile work while the platform is under way. The acoustic systems studied were: the long baseline sonar subsystem,; the time difference sonar subsystem; the phase comparison subsystem, and the shallow water echo depth sounder. The study revealed that in order to use either the long-baseline sonar subsystem or the time-difference sonar subsystem, circuits would have to be modified and transducers added or changed. The present concept in the use of the long-baseline sonar vessel-positioning system involves the placement of the interrogation and receiver transducer on a cable hung over the stern of the vessel. Testing of the drill pipe and casing materials continued. The dynamic stress analysis of the drill pipe has been developed to include the circulation of the drilling fluid, the pipe area changes for a tapered drill-string design, and the wave propagation in the fluid. More work is continued on the riser system stress analysis. The design of a wire-line retractable diamond core bit adaptable for coring the Mohole has been made.

MANAGEMENT IN RELATION TO MEASUREMENTS AND BORE MAINTENANCE OF AN OPERATING GEOTHERMAL STEAM FIELD, Innes. I.A.; Pros. New ources of Energy, Vol. 3, Rome 7/21-31/61, pp.208-214, 1964.

Some measurements that impact on study are: 1) temperature and well head height (monthly) (This measures effective cement bond on pipe) (2) caliper of casing (semiannual) measures corrosion or hole collapse, etc. (Also measurements of groundwater elevation (pressure) and temperature to check on leakage (monthly). Check on leaks by injecting cold water and running temperature profile. $CaCO_3$ & SO_2 are principal mineral deposits. Various size gage-rings or go-devils run to check scale build-up. Scale buildup is removed on about a yearly basis.

A REPORT ON FIELD RESULTS OF THE ELECTROMAGNETIC CASING INSPECTION LOG, SPE 664, 38th Fall Mtg., SPE-AIME, New Orleans, Oct. 6-9, 1963.

McCullough's Casing Inspection log 16 years ago was utilizing an exciter and pickup coil for creation and measurement of a magnetic field which is shifted in phase and attenuated by: 1) casing wall thickness, 2) frequency; 3) magnetic permeability; and 4) metal resistivity. A reference joint is used to overcome problems of magnetic permeability and metal resistivity uncertainties; small corroded areas are detected by a differential pickup coil. A number of field cases are cited in which the log was successfully utilized.

THERMAL SURVEYS APPLIED TO OIL FIELD PROBLEMS, Abadie, H.G.; Petrol. Eng. vol 18 n.9, p. 47-48, 1947.

The possibility of locating leaks in casing or tubing in an oil well was demonstrated by the detection of a leak in a water string. The well had a protective string of casing cemented at 5,533 feet, a water string cemented at 7,029 feet, a liner, and tubing; in preparation for the survey, the well was gas-lifted with a compressor for 18 hours to ensure equilibrium conditions and a thermal log was made on a high temperature photographic film over the interval from 4,700 feet. The curve showed a thermal anomaly of 13 degrees F, at 5,535 feet. Subsequent tests by water circulation under pressure revealed a leak between depths of 5,538 and 5,540. Detection by geothermal logging of points of lost circulation necessary in the drilling of 10,000-foot wells was successful on several occasions. In the case described the casing had been set at 6,286 feet in a Templor section and circulation was lost during the drilling at 9,319 feet in Kreyenhagen shale. Before the logging operation, considerable mud was pumped into the well to establish a pronounced thermal anomaly at the point of loss and an anomalous change of 52 degrees F was recorded at 6,500 feet, effectively locating the point of circulation loss. V.S.---from Geophys. Abs. 132, U.S. Geol. Survey Bull. 959-A, p. 56-57, N. 9876.

ANNOTATED BIBLIOGRAPHY OF PATENTS

CASING INTEGRITY TESTING

APPENDIX C2

WELL CASING CORROSION METER--U.S. 3,999,121, c. 12/21/76, f. 8/11/75, (Appl. 603,845); Taylor, J.M., Jr., asr. (Standard Oil Co., Indiana;

An apparatus is described for making a surface measurement of well casing external corrosion current. The instrument has a voltmeter, a variable current source, a reference electrode, and a ground electrode. Current is coupled to the well casing to ground circuit by the ground electrode to cause-preselected, small potential change in the well casing relative to the reference electrode. The voltmeter is used to measure the applied current level which is, for a fixed casing potential change, proportional to well casing corrosion current. (9 claims)

METHOD FOR MEASURING THE THERMAL CONDUCTIVITY OF WELL CASING AND THE LIKE--U.S. 3,981,187, c. 9/21/76, f. 7/7/75 (Appl. 593,282); Howell, E.P., asr. (Atlantic Richfield Co.);

A method is described for measuring the thermal conductivity of well casing in situ. The instrument consists of a probe several feet in length lowered into a well and decentralized so that it maintains contact with the casing wall. Two temperature sensors situated adjacent opposite ends of the probe are thermally insulated from an electrically heated intervening portion of the probe body. The probe is moved from one depth to another at a constant predetermined velocity, and the sensors continuously measure the temperature of the casing wall before and after passage of the heated probe portion. The effective thermal conductivity of the casing is directly proportional to the temperature change as the heater passes a point along the casing. (2 claims) (Continuation-in-part of U.S. Appl. 454,754 f. 3/25/74)

WIRELINE OPERATED TUBING DETECTOR--U.S. 3,905,227, c. 9/16/75, f. 2/1/74 (Appl. 438,739) Kinley, M.M.;

A wire-line operated tool is described for obtaining the impression of the inside wall of a well tubing in order to determine the location and extent of damage or defects in well tubing. The tool employs a tubular support housing adapted for movement within a well tubing on a wire line. A yieldable memory in the form of an inflatable sleeve having a yieldable external surface is mounted with the tubular support housing. A double piston assembly expands the impression sleeve well tubing. A wire line attached to the double piston activates the piston to expand the inflatable sleeve into engagement with the inside wall of the well tubing. Such expansion occurs by inflating the inflatable sleeve to a first lower pressure and then a second higher pressure, in order to cause the yieldable external surface of the sleeve to effectively engage the inside wall of the well tubing and to penetrate any defects or damaged areas in the well tubing wall. (16 claims)

IMPRESSION PACKER--U.S. 3,855,854, c. 12/24/74, f. 6/25/73 (Appl. 373,341); Hutchinson, S.O., Anderson, G.W. and Newby, G. L., asrs., (Chevron Research Co.);.

An impression packer is described for obtaining impressions in wells. The packer has an impression sleeve formed of a mixture of partially cured synthetic nitrile rubber ~~and natural~~ rubber processing oil. The expandable and retractable packer sleeve will form and retain an impression of irregularities in a downhole surface. The partial cure of the synthetic nitrile rubber is done by heating nitrile rubber containing less than full curing amounts of the curing chemicals. A particularly desirable impression sleeve has resulted when the mixture contains by weight 70-75% partially cured synthetic nitrile rubber including the cure chemicals, 14 to 16% natural rubber smoked sheet, 7.5 to 8.5% silica powder, and 3.5 to 4.5% rubber processing oil. (3 claims)

IMPRESSION PACKER--U.S. 3,855,856, c. 12/24/74, f. 6/25/73 (Appl. 373,343), Hutchinson,S.O, Anderson,G.W. and Newby, G. L., asrs., (Chevron Research Co.);

An impression packer for use in obtaining impressions in wells has an impression sleeve formed of a mixture of natural rubber smoked sheet, silica powder, and rubber processing oil. The expandable and retractable packer sleeve will form and retain an impression or irregularities in a downhole surface. A mixture containing,by weight 50 to 75% of natural rubber smoked sheet, 10 to 30% of hydrated amorphous silica powder, and 3 to 15% of rubber processing oil has been found satisfactory. A particularly desirable impression sleeve has resulted when the mixture consists of about 57.2% by wt.of natural rubber smoked sheet, about 28.4% silica powder, and about 14.4% rubber processing oil. (2 claims)

HIGH-RESOLUTION MAGNETIC ANOMALY DETECTOR FOR WELL BORE PIPING--U.S. 3,845,381, c. 10/29/74, f. 4/12/73 (Appl. 350,551), Hart, H. J., asr., (Schlumberger Tech. Corp);

An apparatus for detecting magnetic anomalies in the metallic casing which lines a well bore is described. More particularly, the apparatus is suitable for detecting the joint between 2 sections of flush-joint casing. A center core member located between the permanent magnet is shaped such that the flux generated by each permanent magnet travels along 2 paths from the detector to the casing. A pair of series-opposed windings is wound at longitudinally spaced intervals around the core member such that a change in the proportion of flux traveling along each path will be detected by the windings. A pair of magnetic flux focusing rings is interposed in one of the 2 paths of each flux field for concentrating the flux in that path, thereby providing a detector having improved resolution. (13 claims)

PROFILOGRAPH FOR EXAMINING PIPES IN OIL WELLS--U.S. 3,727,126 c. 4/10/73, f. 9/11/70 (Appl. 71,608), Kisselman, M.L. Shots, M.B., and Larin,V.P., asrs., (USSR Agency);

A device for determining the wear of casing pipes in wells consists of an exploration unit having housing in which is mounted a pickup transformer fed from an

A-C source and connected to a recorder. At the place of the pickup location, the housing of the exploration unit has in its central part a channel let through the drilling mud, while one pickup device measures the pipe wall thickness, the ovality thereof, and the shape of wear in the pipe so as to provide measurement of the residual strength of the pipe. (4 claims)

LOCATING HOLES IN TUBING--U.S. 3,696,660, c. 10/10/72, f. 3/2/70 (Appl. 15,572), Hubbard, G.O.;

Leaks in underground conduit, such as in vertical drill pipe in wells or underground pipelines, are located by closing one end of a segment of the conduit and then pumping a plug into the pipeline. As long as fluid is escaping from the conduit through the leak, the plug will move, but when the plug passes the leak, the plug will no longer move because of the fluid trapped between the plug and the closure. Then the plug can be located by a wire line attached to the plug. If the plug is to be retrieved by pulling the plug, a passageway through the plug is opened to prevent swabbing the conduit when retrieving the plug. (6 claims)

DEFORMATION LOGGING APPARATUS AND METHOD--U.S. 3,641,678 c. 2/15/72, f. 12/20/68 (Appl. 785,569), Murphey, C.E.,Jr. and Sheffield, B.C.,asrs., (Shell Oil Co.);

It is frequently necessary to determine where and to what extent the internal configuration of a tubing has departed from that of a right cylinder. Such deformations may involve a smooth curving along the axis of the tubing or a smooth oval shaping of the wall of the tubing. Such smooth deformations are difficult or impossible to detect by procedures that have been previously used for inspecting the internal configurations of tubing. Such deformations are apt to occur in the early stages of a production-well-casing-failure problem that will ultimately shorten the productive life of the well. A method and apparatus for inspecting the internal configuration of a circular opening are described, wherein a scanning probe device having a feeler arm is extended into the opening, and the arm is pivoted into engagement with the inner wall of the opening. The feeler arm pivots about its pivoting axis while the pivoting axis is revolved about an axis of resolution within the opening. The degree of variation between the angle of the feeler arm and the axis of revolution indicates the internal contour of the opening. (4 claims)

CASING INSPECTION METHODS AND APPARATUS--U.S. 3,654,251, c. 2/16/71, f. 3/4/68 (Appl. 710,303), Youmans,A.H., asr., (Dresser Industries Inc);

Methods and apparatus for the inspection of casing, pipelines, tanks, or the like are described. The internal surface is canned with an X-ray beam. The intensity of the resulting scattered X-rays is measured, displayed, and recorded in correlation with the scan as a measure of the condition of the surface or the thickness of the scanned material. (12 claims)

CAMERA DEVICE FOR INTERNAL INSPECTION OF PIPE--U.S. 3,557,674 c. 1/26/71, f. 2/5/68 (Appl. 703,152), Carney, R. F.,Jr., asr. (Seminole Pollut.Equip Corp.);

A photographic device is described for inspecting the interiors of pipes, such as water mains, sewer lines, oil wells, and the like. The device is of the kind arranged to provide a signal at a remote location indicating its proper operation. A single frame 35-mm camera is mounted in a generally cylinderical capsule with a strobe light, an electric drive motor, and a battery. The system is self-contained except for a remote annunciator arrangement and control switch connected to the capsule by a single pair of electric leads. The strobe light is fired by the discharge of a capacitor, which immediately thereafter starts to charge. The annunciator includes a buzzer shunted by a gas-filled diade lamp. The buzzer sounds during charging of the capacitor, and shuts off when the diode fires, which occurs when the capacitor becomes approx. fully charged (2 claims)

METHOD FOR MAGNETICALLY MEASURING WALL THICKNESS OF METAL PIPES AND PLATE STRUCTURES--U.S. 3,532,969, c. 10/6/70, f. 2/20/68 (Appl. 706,818); McCullough, I.J., and Stroud, S.G. asrs., (National Lead Co);

Means and method are described for magnetically measuring metal thickness, such as plate structures and wall thickness of pipes which are accessible from the inside, but not necessarily from the outside. In the case of a pipe, a primary coil and secondary coil are positioned in inductively coupled spaced relation within the pipe, with means for attenuating the magnetic field from the energized primary coil which is within the pipe. The attenuating means consists of a short-circuited turn or ring of current conducting material such as copper or aluminum positioned between the coils and acting to inductively generate a magnetic field in opposition to the magnetic field coupling in the path lying within the pipe between the coil. Laminated rings positioned at the ends of the primary coil and secondary coil further act to concentrate the magnetic field, so that it forms a coupling path outside of the pipe and in addition concentrates the magnetic flux at the position where the flux passes through the pipe wall. (4 claims)

MAGNETOMETER INSPECTION APPARATUS FOR FERROMAGNETIC OBJECTS--U.S. 3,443,211, c. 5/6/69, f. 4/1/65 (Appl. 444,739); Wood, F.M. and Walters, W.T., asrs., (American Mach & Foundry Co);

Equipment is described for magnetic inspection of ferromagnetic members, such as well pipe for surface anomalies, which may be caused by such things as corrosion, wear or the like. A noncontacting caliper, having no movable parts, may be pulled along the surface of an inspected member for detecting the presence of these anomalies and identifying other characteristics, such as depth, width, and location of these anomalies. The apparatus uses magnetometers on one pole of a magnetizer core which has a larger pole. The magnetizer may be a permanent magnet or include an A-C source. A shield may be provided for the magnetometers. (19 claims)

LEAK TESTER FOR FLOW CONDUCTORS--U.S. 3,420,095 c. 1/7/69 f. 9/12/66 (Appl. 578,572), Brown, N.V., Tamplen, J.W. and Meaux, D.J., asrs., (Otis Engineering Corp);

A pipe and joint tester having packer means sealing off the joint or coupling between 1 coupled lengths of pipe separately from a packer means sealing between one length of pipe and the tester are described. The coupling or joint may be tested with gas and the remainder of one length of pipe tested with liquid, for pressure leaks. Testing may be done simultaneously with the 2 types of fluids, or the testing may be done by gas alone or liquid alone, if desired. Releasable anchor means are provided for supporting the tester in the pipe while additional lengths of pipe are connected. (35 claims)

WELL PACKER AND METHOD OF MANIPULATING SAME IN A WELL BORE--U.S. 3,412,790 c. 11/26/68, f. 12/16/65 (Appl. 514,211), Brown, C.C.;

A well packer is described and a method of using it in a well casing to detect casing leaks is given. The method includes the steps of lowering the well packer into the casing on a tubing string, rendering the well packer active, setting and releasing the well packer at different levels in the well casing responsive to longitudinal movement of the tubing string, and pressure testing the casing for leakage with the well packet set at each level. The well packer includes an operative connection with an active position and an inactive position together with means for preventing inadvertent movement between the active and inactive positions. (5 claims)

METHOD FOR LOCATING TESNION FAILURES IN OIL WELL CASINGS--U.S. 3,393,732, c. 7/23/68, f. 5/21/65 (Appl. 457,606), Murphey, C.E. Jr., Patterson, M.M. and Sheffield, B.C., asrs. (Shell Oil Co);

A method is described for locating tension failures in the casing of a well in which the casing was heated and cooled, for example, the casing of a well used in a thermal recovery process. The tension failures are located by logging the well with a tool that is selectively responsive to a magnetic field strength. (3 claims)

METHODS OF AND APPARATUS FOR PRODUCING A VISUAL RECORD OF PHYSICAL CONDITIONS OF MATERIALS TRAVERSED BY A BOREHOLE--U.S. 3,369,626, c. 2/20/68, f. 10/23/65 (Appl. 507,630), Zemanek, J, Jr., asr. (Mobil Oil Corp);

An acoustic logging system is described for producing visual records of the physical conditions of wall structure traversed by a borehole. A beam of pulsed acoustic, high-frequency energy is swept across the face of the wall structure through 360°. Reflected energy is detected and sent uphole to the cathode ray oscilloscope. The sweep of the cathode ray beam is initiated by a geographical sensing device in the downhole tool so as to correlate the rotational position of the beam with the received data. The cathode ray beam is moved as a function of depth relative to a recording medium to produce a picture of the wall structure. (36 claims)

ELECTRICAL CONDUCTIVITY PROBE-- Can. 755,249, c. 3/21/67, f. 3/24/65 (pr. U.S. 4/13/64, Appl. 359,192), Nathan, C.C., Kilnar, J.J. and Pittman, R.W., asrs. (Texaco Development Corp); Can. Pat. Office Rec., vol. 95. No. 12. p.2551, 3/21/67;

A probe is described for use in measuring electrical properties of interior coating on electrically conductive pipe located below the surface in a deep well. The probe consists of an elongated body of electrically conductive material having an electrically-conductive wiper on it for establishing a conductive path to the pipe through the interior coating. An electrically-conductive line is connected to the body for completing a circuit from the body to the surface. A first electrically insulated coating means is used for covering the line to prevent any leakage path for current flow between the line and the pipe. A second electrically-insulated coating means is used for covering substantially all of the exposed surface of the body except that covered by the wiper. An electrically-insulating wiper means is spaced ahead of the conductive wiper for cleaning any conductive film off the surface of the interior coating. (11 claims)

APPARATUS FOR THE LOCATION OF AXIAL AND RADIAL DISCONTINUITIES IN TUBING USING A ROTATING DETECTOR INCLINED TO THE TUBING AXIS - U.S. 3,302,104, c. 1/31/67, f. 11/18/63 (Appl. 324,474) Copland, G.V., asr. (Halliburton Co);

An apparatus is described for locating axial and radial discontinuities in tubing. The device comprises a magnetic source arranged to be rotated about an axis that is inclined to the axis of the tubing. This permits detection of discontinuities in the pipe when the tool is moved at a relatively slow rate of speed or even when the tool is stationary. The output signal of the assembly is well adapted for transmission to the surface by conventional systems. (5 claims)

APPARATUS FOR INSPECTING INTERIORS OF APPARATUSES AND THE LIKE--U.S. 3,279,085, c. 10/18/66 f. 3/11/63 (Appl. 264,383); Reihart, T.R., asr. (Shell Oil Co);

This is a scanning system for an optical viewing device that permits the scanning of a large area of a cylinder or borehole wall. A spherical convex mirror is located on the optical axis of the optical viewing device to provide a scanning device that yields a 360° view of the interior of a tubular opening. The spherical distortion of non-paraxial rays of the device is utilized to obtain near equal resolution for features in perpendicular directions on the cylinder or borehole wall. Small characters or numbers may be etched on the surface of the mirror and, since the mirror is identical with respect to any angular direction, it may be rotated about any one of 3 axes without changing its optical qualities. The coordinates of these 3 axes may be etched into the surface of the mirror without seriously affecting the view of the borehole wall. A reticule in the optical device may be used as an index to measure the angular position of the mirror. (2 claims)

WELL TOOL-U.S. 3,173,290, c. 3/16/65, f. 6/2/60, Conover,G.E. asr. (Lynes, Inc) ;

This is a tool for testing tubing or casing for leaks or for packing-off individual productive strata. It is inserted into the pipe to be tested and has a pair of spaced inflatable packers to seal portions of the pipe string. A control head at the top of the tool has a horizontal opening into which a plug can slide. This plug and head have passages through which fluid can pass to inflate the packers. These packers can be inflated separately, there being a pressure compensator located above the lower packer to prevent its expanding due to pressure of fluid thereabove in the tool. An additional passage in the plug, head and body of the tool, allows fluid to pass through ports between the packers to test the portion of pipe between the packers or to permit the production of formation fluids from strata packed off between the packers. The tool can be run on tubing or on a cable. Flexible hoses from the surface connect to the plug whereby fluid is available for expanding the packers and testing the pipe. (12 claims)

METHOD AND APPARATUS FOR TESTING WELL PIPE SUCH AS CASING OR FLOW TUBING--U.S. 3,165,919, c. 1/19/65, f. 2/8/62, Loomis, G.L.;

This is an improved method and apparatus for testing well tubing or pipe by applying hydraulic pressure to the interior of the pipe between spaced, sealed-off packers. The 2 packers are not set or expanded simultaneously to form fluid barriers. The testing tool is positioned in the well with the 2 packers located, respectively, below and above the ends of the portion of length of well pipe to be tested. The lowest packer is first set and the well pipe is filled with testing fluid, water, upward past the unset upper packer to completely evacuate the testing area of air or other fluids. The upper packer is then set, thereby trapping a column of testing liquid between the 2 packers. A pre-determined pressure is applied to the testing liquid. If no pressure drop occurs, the test is complete and the packers are released, thereby allowing the test liquid to fall by gravity within the well pipe past the lower packer. (16 claims)

TESTING TOOL FOR WELL PIPE OR THE LIKE--U.S. 3,165,918 c. 1/19/65 f. 2/2/62, Loomis, G.L.;

This is a well-tool, testing device which can be run into well pipe to test the pipe for leaks by the application of a fluid under pressure. The device has a long body made up of several sections. Near each end of the tool are resilient packers together with their setting pistons. A bore extends almost through the tool vertically and is open at the top to receive hydraulic fluid under pressure. The lower end is closed. This bore is increased in size near the packers to hold valves which operate under hydrostatic pressure to force the pistons to set the packers. A section of the tool about midway between the packers contains a valve which permits the flow of hydraulic fluid under pressure to the sealed off section between the packers after the packers have been set. Usually the tester is used to test pipe and joints at the surface but it can also be used to test for leaks down the well pipe. (19 claims)

APPENDIX D

ANNOTATED BIBLIOGRAPHY

CASING AND CEMENT FAILURES

DRILLING AND PRODUCING WET STEAM WELLS AT CERRO PRIETO, MEXICO, Rehm, William A; Petroleum Engineer International, pp. 78-90, April 1979.

Comingling of produced waters from different zones of of temperature causes major scaling problems. Problems are mainly related to casing collapse and inadequate cementing.

Casing collapse is attributed to well being heated too quickly (one month is used to bring a well up to temperature). Cooling during shut-in causes casing parting. Cold ground water near surface can also cause parting. Heavy weight, low strength casing is used as well as a separate production string.

High temperatures and low wellbore frac. pressures result in poor cement jobs. Cement bond and temperature logs are not useful because of the cement setting slowly in upper part of the hole and formation temperature masking the cement temperatures. Lead impressions are used as a guide to remedial action.

Cementing process must isolate casing from cooler non-produced formation waters. Lost circulation and viscous cements hamper achieving this goal. Results are hard to check because of lack of bonding.

PERFORMANCE OF OIL WELL CEMENT COMPOSITIONS IN GEOTHERMAL WELLS, Gallus, J.P., Pyle, D.E., Watters, L.T.; SPE Paper #7591 53rd Annual Fall Technical Conference of SPE-AIME Houston. TX. Oct. 1-3, 1978.

Several cementing systems have been found to remain competent under geothermal well conditions for periods to one year. Leveling of compressive strength and perm. curves at about 6 mo. indicate that these systems should maintain integrity for well life. API Class G cement apparently can be rendered as effective for geothermal brine well applications as API class J cement by adding 40 to 80% silicon to facilitate formation of desirable truscottite.

Discusses failure mode of cement in two wells with different salinity hot brines in Imperial Valley.

CATHODIC PROTECTION REQUIREMENTS FOR WELL CASINGS, Heindricks, H.J., Ingram, W.O., Schellenberger, B.G., 28th Ann. Pet. Soc. of CIM Technical Mtg. Edmonton, June 1977

Failures of casings in S. Swan Hills and Nipisi fields were investigated to determine cathodic protection adequacy and/or needs.

IN-SITU COMBUSTION IN THE TULARE FORMATION, SOUTH BELRIDGE FIELD, KERN COUNTY, CALIF. Gates, C.F., Jung, K.D., Surface, R.S, SPE6556 47th Regional SPE Mtg., Bakersfield, CA, April 13-15, 1977.

Four injection wells have failed. Two failed because of collapsed casing, one after 1½ yrs. and the other after 4½ yrs. Their replacements failed because of holes in the casing, above the perfs, one after 5 yrs. and the other after 9½ yrs.

PROBLEMS OCCUR IN HIGH H_2S FIELDS--Oilweek vol. 28, No. 2 pp 16-17, Feb. 21, 1977.

Commercial development of gas fields containing up to 50% H_2S has been a feature of Alberta operations since the first sour gas field went on production 25 yrs. ago. Speaking on problems of corrosion and mechanical failure in production and processing of wet sour gas, A. Kowalchuk of Gulf Oil Canada Ltd. noted 4 major fields with high H_2S: Waterton. IV. - 32%; Olds, -18%, Waterton III- 14%; and Pincher Creek, 10.6%. The Bearberry field, with 90.6%, cannot be produced with present technology. These fields also tend to be heavy on C_1-propane but fields with lower H_2S tend to have high CO_2 content, up to 5%. Many tubing failures have occurred due to hydrogen stress corrosion cracking in early development stages. They have continued, but solutions have been found. A prevalent cause has been H_2S saturation of drilling mud or during drillstem testing. Cracked casing collars were frequent early failures. Use of API 5AC grade C75 material has resulted in better control with J55 casing and tubular material failures rare now and usually due to mill problems with quenching, heat treatment or manganese segregation.

CASING FAILURE IN STEAM STIMULATED WELLS, Bissoondatt, J.C.; Petroleum Expo and Conf.Pap.San Fernando, Trinidad, sponsored by AIME, Soc. of Pet. Eng., Trinidad and Tobago Sect. Paper SPE-5951, p.72-78, 1976.

Casing failure in production wells stimulated with steam presents economic and technical limitations in the application of the method. Completion of a steam injection well must be designed so that saturated steam can be injected into an oil reservoir at the desired rate, pressure or temperature and heat content. During the injection of steam, heat is lost to the surrounding well bore, equipment and the earth due to the high temperature of the steam. It is therefore desirable to design the completion so that heat loss is minimized and the casing temperature is kept low enough to prevent casing damage while insuring that most of the steam goes into the productive formation. This paper outlines some of the procedures adopted and problems encountered during the thermal exploitation of the Guapo Field in Trinidad.

COLLAPSE PRESSURE STRENGTH OF CASING REDUCED BY WEAR, Murphey, C. E., (Shell Development Co); Oil Gas J. vol.74, No. 45 pp 206-208, 213, 216, November 8, 1976.

The remaining collapse strength of worn casing may be estimated if the degree of wear is known. Collapse tests were performed on steel tubes with flats milled on the exterior to simulate worn casing. External pressure and axial load were applied to the tubes having differing ranges of wall thickness, yield strength, and degree of wear. Empirical correlation of the data and comparison with elastic collapse calculations indicate the percentage reduction in collapse pressure due to wear. This reduction is predictable within upper and lower bounds. The upper bound is at least six-tenths of the percentage reduction in minimum wall thickness. The lower bound is no greater than the percentage reduction in minimum wall thickness, provided that one-fourth of the original wall remains. It should be noted that for wear with a very wide distribution, approaching a uniform reduction of wall thickness, a greater reduction in collapse pressure with minimum wall thickness can be expected. For wear over a narrow region, such as wire-line cutting, less reduction in collapse pressure should occur. The test program is described, and tabular data show the results of collapse tests.

CORROSION CONTROL IN THE WELL BORE, EnDean, E.J.; Petrol Eng. vol.48,No:10,pp.50, 52,59-60, 62, Aug. 1976.

The most frequent cause of equipment failures in the well bore is the corrosivity of produced fluids, which can increase markedly as water production increases. Unless changes are quickly detected, corrosion-induced failures can occur before an effective inhibition program can be developed. When the well bore and surface equipment are in an oil-wet condition, the production system is protected as long as oil remains in the external phase of the produced liquids. The phase relationship between the oil and water generally will invert between a cut of 25 to 35%, at which time the well-bore equipment changes to a water-wet condition. The time required for equipment to become water-wet depends on the tenacity and thickness of the oil film. An illustration represents a stepwise procedure that can be followed in evaluating the corrosive possibilities in a well. When a study or equipment failure has established that corrosion is occuring, corrosion inhibition should be evaluated with the aim of reducing well-equipment repair costs while maintaining maximum allowable production. An example illustrates one approach.

CASING COLLAPSE PERFORMANCE. Mendizadeh, P. Journal of Engineering Ind. Trans ASME vol.98, Ser.8,n.3, Paper No. 75-Pet-41, pp1112-1119, August 1976.

CORROSION IN DISPOSAL WELLS-Owens, S.R.,(Sub-surface Disposal Corp); Water Sewage Works pp R10-R12 April 1975; Abstr. No. W76-05125 Selec. Water Resources Abstr., vol.9,No.11, p.64. 6/1/76,June 1, 1976.

Industrial waste disposal wells are subject to corrosion problems such as stress-cracking, galvanic corrosion, and solvent action on elastomers. A typical disposal well contains a screen used to give uniform distribution of injection fluid. The screen is subject to stress-corrosion cracking, uniform corrosion, galvanic corrosion, and sinking. Excessive softening of the formation that supports the screen is another form of corrosion. Elastomers used in a packer must withstand the injection fluid and the injection zone liquid. They are subject to crevice and galvanic corrosion. Cement may fail if sulfur compounds are present, or if the effluent has a low pH. The tubing itself (carbon steel, stainless, or FRP) is subject to many forms of corrosion such as differential oxygen-concentration cell corrosion, crevice corrosion in joints, and uniform corrosion due to acids. A corrosion test loop is recommended for most industrial waste disposal wells, where a bypass would allow frequent evaluation of test materials. If there is a change in injection fluid, the downhole mixture should be tested as connate fluids can alter the injected matter. Caliper surveys, spinner logs, and temperature logs are ways of monitoring an injection well.

BLOWOUT OF A GEOTHERMAL WELL. Bacon, C.F. Calif. Geol. vol.29, no. 1, pp.13-17, Jan. 1976. BBBBBBB

On the evening of March 31, 1975 at approx. 6:45 P.M. the Union Oil Co. geothermal well G.D.C. 65-28 blew out. The well, which has been on standby since its completion Sept 7 1968, is located in a remote area of the Mayacmas Mt., 4 miles southeast of the main Geysers geothermal area; the blowout apparently was not witnessed. The well, like over 50% of the wells drilled at The Geysers, was sited on a Quaternary landslide. Since the blowout, a great deal of time, money, and effort has been spent to regain control of the well and to try to determine whether or not the well blew out as a result of renewed movements on the old slide. How the well was controlled is described. The well was finally killed or quenched by pumping in large volumes of cold water and a cement plug was installed below 160 ft. The cause, geometry, and location of the casing failure were investigated. The data indicated slippage of materials in the old slide mass--probably moving along a plane similar to those exposed higher up in the excavation walls.

OBSERVATION OF THE EFFECT OF A THREE-YEAR SHUTDOWN AT BROADLANDS GEOTHERMAL FIELD N.Z. Hitchcock, Geoffrey,W., Bixley, Paul F.. 2nd U.N. Symposium on Development and Use of Geothermal Resources, p 1657-61, 1975.

Failure was reported in master valve in Well No. 25.

UTILIZATION OF GEOTHERMAL ENERGY IN KLAMUTH FALLS, Lund, John W. Culver, G.Gene, Svanevik, Larsen S., Multi-purpose Use of Geothermal Energy, Oregon Institute of Technology Kalmuth Falls, Ore., pp. 146-178, 1975.

Early casing lasted less than 15 yrs. (average). Heat exchanger coil lasted less than 10 years. Current practice anticipate casing lives of about 50 years and coil lives of about 14 years (corrosion ususally occurs at the water/air interface)

UTILIZATION OF INTERMEDIATE TEMPERATURE GEOTHERMAL WATER IN KLAMUTH FALLS, OREGON, Lund, John W., Culver, G. Gene, Svanenik, Larsen S., 2nd U.N. Symposium on Development and Use of Geothermal Resources, pp2147-2154, 1975.

Early wells were cased to only about 10 m and with 3 mm wall thickness pipe. Life is usually less than 15 years. The "heating coil" (black iron pipe) usually lasts less than 14 yr.

Currently a 8" casing has 6-8 mm wall thickness and is perforated at bottom. It contains a packer and is grouted from packer to surface. Expected life is up to 50 yrs in artesian wells and the casing life is about 32 years.

This area has used geothermal heating for approximately 70 years.

GEOTHERMAL HEATING OF GOVERNMENT BUILDINGS IN ROTORNA (N.Z.), Shannon, Robert, J. 2nd U.N. Symposium on Development and Use of Geothermal Resources, p. 2165-2172, 1975.

External corrosion of casing is more severe than internal. External corrosion is usually associated with cold acid groundwater.

ENVIRONMENTAL IMPACT OF DEVELOPMENT IN THE GEYSERS GEOTHERMAL FIELD USA, Reed, Marshal J., Campbell, Glen E., 2nd U.N. Symposium on Development & Use of Geothermal Resources, pp. 1399-1410, 1975.

One drilling well has failed. Thermal #4 is still blowing 80,000 kg/hr of steam.

Two producers have failed, thermal #5 & Happy Jack #7, #5 was controlled and plugged in 5 days. #7 blew from Jan. 73 to Nov. 74 before being plugged and abandoned.

RECENT STUDIES OF THE AHUACHAPIN GEOTHERMAL FIELD, Vides, Alberto, 2ndSymposium on Development and Use of Geothermal Resources, pp.1834- 1835, 1975.

Failure casing collapse was reported for 2 wells No. 8 & 15. No details on casing, etc.

RESULTS AND IMPROVEMENT OF WATER TREATMENT IN THE COOLING WATER SYSTEM OF OTAKE GEOTHERMAL POWER PLANT, Yesntake, Hideo, Hirashima, Mizuki; 2nd U.N. Symposium on Development & Use of Geothermal Resources, pp1871-1877, 1975.

Suggests periodic inspections to evaluate corrosion-scale, etc. They have had failures.

ADVANCEMENT IN CEMENTATION TECHNIQUES IN THE ITALIAN GEOTHERMAL WELLS, Cigni, Ugo, Fabbru, Fulvio, Giovannoni, Anselmo, 2nd U .N. Symposium on Development & Use of Geothermal Resources pp.1471-81, 1975.

Failures came generally in lower part of string when variations in temperature occurred. They were usually associated with bad cement jobs, channeling, bad cement, and dog legs (off center pipe). Failures have decreased as cementing practices have improved. When good cement/pipe/formation - bond occurs, thermal stresses are resisted.

Current casing designs use buttress threads and (thicker-than-required) J-55 for corrosion resistance. Current cementing practices use complete fill, helped by centering pipe, and over-displacing mud contaminated cement and use of additives. Most problems-failures, etc. result from cycling temperatures in the casing-especially after an appreciable time at high temperature.

PRESENT METHODS OF OPENING AND STARTING PRODUCTION IN WELLS AT CERRO PRIETO GEOTHERMAL FIELD, BAJA CALIFORNIA, MEXICO. Dominguez, Bernardo, Francisco.A. Javier Bermejo de La Mora; 2nd U.N. Symposium on Developmental Use of Geothermal Resources, pp1619-33, 1975.

Early failures believed to be a result of rapidly bringing wells on production. Current technique is to: (1) observe well; (2) stimulate (if required) (3) slowly heat up well; (4) develop productive capacity; and (5) evaluate energy capacity.

Logging is an important evaluation technique. Openhole - temperature logs E logs and lithology logs. After casing & flushing - multiple t logs, gamma ray collar, and multiple calipers.

Sand production usually decreases from 0.1% to .0003% (mass rate).

Caliper logs of casing are run in a systematic cycle to check for corrosion, scale buildup, erosion, collapse or fracture of pipe. Anomalies are usually checked with lead impression blocks.

CERRO PRIETO GEOTHERMOELECTRIC PROJECT: POLLUTION AND BASIC PROTECTION, Sergio, Mercado G.; Second U.N. Symposium on Development & Use of Geothermal Resources, pp. 1394-98, 1975.

Casing failures are attributed to external corrosion of highly saline fluids in formation behind pipe that were not isolated by annuler cement. Cathodic protection is being considered to reduce this type of corrosion.

Wells are electrically-insulated from collection system to lessen galvanic corrosion.

REPAIR AND CONTROL OF GEOTHERMAL WELLS AT CERRO PRIETO, BAJA CALIFORNIA, MEXICO, Dominguez, Bernardo, Francisco, A. (Comision Federal de Electricidad, Baja California, Mexico) Proceedings of the second United Nations symposium on the development and use of geothermal resources. Vol. 2. (In Spanish and English), pp 1483-1495, 1975.

To maintain the steam production required for the operation of Units 1 and 2 at the Cerro Prieto geothermal power plant, a maintenance and repair program of wells was undertaken. Fractures and collapses were found primarily between the ground surface and a depth of 600 M. Only two of the damaged wells were abandoned due to lack of adequate safety for putting them back into operation. The repair and maintenance activity began with caliper logs, lead impressions, and electrical logs. Based on the information obtained, new well casings were installed and adequate cementing operations were performed. Related to these problems is the loss of control of Well M-13 which was found to have a fracture at a depth of 200 M. It has been controlled and properly repaired. Conclusion: future wells should be provided with casings of higher strength to withstand the thermal expansion stresses. Also, the opening and development of wells should be carefully controlled.

EFFECT OF CASING WEAR ON THE BURST STRENGTH OF CASING-STATISTICAL BURST STRENGTH OF WORN AND UNWORN CASING STRINGS, Bradley, W.B.; ASME Meeting, Sept. 21-25, 1975, 9 p.

A theoretical analysis has been performed to determine the effects of wear on the burst strength of casing. Burst occurs either by a leakage at the casing joint or by a rupturing if the casing wall. The statistical nature of rupturing of casing is presented in this paper; joint leakage is discussed in a companion paper. A method is presented in this paper that calculates the probable burst strength and confidence limits given the statistical distribution of casing properties; this method may be used for both worn and unworn casing.

HERE'S HOW CASING WEAR AFFECTS JOINT LEAKAGE. Bradley, W.B.; Oil Gas J. vol 73 n. 52, pp170-173, Dec. 29, 1975.

The results of a theoretical analysis performed to determine the effects of wear on the burst strength of casing show that, for practical purposes, joint leakage under internal pressure is affected by casing wear. Failure of casing under internal pressure (burst) will occur either by rupturing of the wall or by leakage at the joints. Either failure can cause serious problems during drilling and subsequent completion and production. This paper describes the effects of casing wear on leakage of casing joints under pressure and casing failure by thread jump-out.

MATERIAL PROBLEMS ASSOCIATED WITH THE DEVELOPMENT OF GEOTHERMAL ENERGY RESOURCES, (BuMines) Hall, Beverly A. OFR 82-86, May 1975.

Scaling studies in Imperial Valley geothermal brines indicate there are "hard and soft scales" formations. Hard scale forms at 1/8"/yr. and soft scale at 1"/wk. in some cases. Continuous determination of in situ chemistry is required. Overall salinity of brine reservations within the Salton-Mexicali trough varies from 0.3 to 32 per cent.

The technological base of the metals industry needs to be brought to bear on corrosion and scaling problems.

FIELD OPERATING EXPERIENCE IN LOCATING AND RECOVERING LAND-SLIDE-DAMAGED OIL WELLS , Johnson, R.J. (Getty Oil Co.) 44th Annu. Spe of AIME Calif. Reg. Mtg. San Francisco 4/4-5/74 Preprint No. SPE 4895, 1974, 8 p.

Landslides have damaged 65 oil wells on Getty Oil Company's leases in the Ventura Avenue field. During a landslide, some wells may remain connected to the surface while other wells may be buried. Well damage ranges from slight bending to complete severing of all casing strings and depth of damage varies from 15 to 120 ft. Two major problems have been encountered when repair work is planned for a landslide damaged well. The first problem is to locate the undamaged well casing below the landslide. The second problem is to recover the well and replace the damaged casing. Some methods used by Getty Oil Co. to locate the undamaged portion of a well are conventional surveys, dipneedle surveys, magnetometer surveys, kinkmeter surveys, and test holes. Three methods have been used to recover landslide damaged wells in the Ventura Avenue field. The simplest method is an open excavation made with standard earthmoving equipment. This method is limited to shallow depths and locations where the landslide would not be reactivated. To reach greater depths, special methods such as hand-dug or machine-dug shafts must be used. All 3 methods have been used successfully by Getty Oil Co.

MODEL FOR EVENTS OCCURRING AT RANDOM POINTS IN TIME AND IN EXAMPLE APPLICATION TO CASING FAILURES IN CEDAR CREEK ANTICLINE WELLS. Chestnut, Dwayne A., Goldberg, Bernard; Soc. Pet. Eng. AIME J., vol. 14, n.5, pp 482-490, Oct. 1974.

The economic decision of preventive maintenance vs waiting for failure before making repairs can be readily quantified from small data sets of past failures and costs. The history of casing failures caused by salt-flow loading is described here by the Polisson Pure Death Process. The economic analysis then finds the optimal time to take preventive action and the net loss or gain while waiting for failure before making repairs.

EXPERIMENTAL MEASUREMENT OF CASING WEAR DUE TO RECIPROCATING DRILL PIPE AND WIRELINE. Fontenot, J.E., McEver, J.W.; ASME Paper #74-Pet-50, Sept. 15-18, 1974.

An experimental investigation was undertaken to explore the effects of various factors on casing wear due to tripping drill pipe and running wireline. Wear tests were run using full-size samples of casing, drill pipe, and wireline. Tests were run at various contact loads in water, a gel mud containing sand, and in a 14-lb/gal water base mud containing various quantities of simulated drill solids. The drill pipe wear results were compared with field data. The major conclusions reached are: tripping drill pipe is generally not a major cause of casing wear, and the presence of abrasive solids in the mud greatly accelerates wear due to running wireline.

IMPROPERLY CEMENTED SURFACE PIPE CAUSES PROBLEMS LATER, Ani, T.A.(Iraq National Oil Co); World Oil, vol.179, No. 4, pp 91-93, Sept. 1974.

If surface pipe is not cemented properly, wellhead movement may result and could lead to a catastrophic failure. Wellhead movement occurred in several wells completed in the Zubair reservoir in the N. portion of Rumaila Field, Iraq., when wells were shut in after flowing or were produced after being shut in. After studying 2 wells, the Iraqi National Oil Co. (INOC) found that improper surface cement jobs caused the problems. To avoid this problem, an excessive amount of cement should be used and circulated to surface to insure a good cement job. If necessary, a duplex cement shoe could be used when cementing surface pipe.

CASING BUCKLING IN PRODUCING INTERVALS, Suman, G.O. (Completion Technology Co); Petrol Eng., vol 46 n. 4, pp 36, 38, 40, 42, April 1974.

Extensive casing damage has been encountered within many of the production intervals of wells in the South Pass Blocks 24 and 27 fields located in the delta of the Mississippi River. The damage has been buckling (kinking) in or near the perforated intervals. Such damage has been found usually upon entering old wells for workover. The primary concern, when casing damage is encountered in a well, is to affect the workover objective in spite of the damage. The configuration of casing damage can be determined with the Sperry-Sun Kinkmeter and with Kinley caliper survey tools. This helps to ascertain the cause of the damaged zones. These downhole tools are described. Casing buckling in or near the perforated interval is believed to be caused by axial loads induced in the casing as compaction of the depleting reservoirs takes place, usually combined with production of sand which has removed lateral restraining forces and enabled a deflection to occur. Experience has shown that unconsolidated formations are subject to substantial compaction. How workover jobs are effected is described.

PREVENTING INSTABILITY IN PARTIALLY-CEMENTED INTERMEDIATE CASING STRINGS, Dellinger, Thomas B. & McLean, J.C. SPE 4606 Oct. 1973 7 p

Describes factors leading to loss of two hot, deep wells (19,000'& 21,000') due to instability factors in intermediate casing. A computer program was developed to analyze conditions leading to instabilities. No casing failures were reported in next 22 wells drilled using this program.

HOW TO SEAL TUBING COLLAR LEAKS; Petrol Eng.vol.45, No. 6, pp. 66, June 1973.

A gas well in Bee County, Texas, developed a leak in a 2-in. tubing collar at 448 ft. The tubing pressure was 4,150 psi and casing pressure was 2,000 psi. The problem was to seal off the leak and permit the well to produce without a workover. The solution a 10-ft long steel liner with wall thickness of .035 in and 1.865 in ID was set in 5 hr. This was adequate to pass plugs and chokes and to maintain full production. A line drawing illustrates the manner in which the liner was fitted and swaged out to the proper diameter.

WELL CASING CATHODIC PROTECTION EFFECTIVENESS--AN ANALYSIS IN RETROSPECT, Kirklen, Chas. A. ; SPE 4682, 1973 .

Discusses leak protection experience with cathodic protection, especially opposite some shallow zones containing corrosive waters. Effectiveness ranged from 71-100%. Median effectiveness was 85%.

COLLECTION AND TRANSMISSION OF GEOTHERMAL FLUIDS, Smith, J. H., Geothermal Energy, UNESCO, pp. 97-106, 1973 .

Maximum velocities for saturated steam are 6000-12,000 ft./min, with lower velocities in smaller pipe. Hot water (200°C) is more "explosive" than steam (x 12). Therefore, more surveys are needed in hot water pipe than steam. Changes in velocity and pressure in these pipes can cause cavitation and rapid wear. Welds are examined by radiography.

PLANNING WORKOVERS IN WELLS WITH FAULT DAMAGED CASING, SOUTH PASS BLOCK 27 FIELD, McCauley, T.V. (Shell Oil Co), 48th Annu. Spe of AIME Fall Mtg. Las Vegas, 9/30/73-10/3/73), Preprint No. SPE 4607, 1973. 12 pp.

This study summarizes Shell's workover experience through casing damage resulting from formation movement along active fault planes in the South Pass Block 27 field. This study was based on 165 workovers on fault-cut wells. Damage was encountered in 54 wells, resulting in 21 abandonments. Up to the time of this study, no damage was found in wells which were not cemented through the fault zone. Methods for determining the probability of encountering damage or losing any well cemented through active faults were developed based on age of the well, depth of the fault, type of well (single or dual), year of workover, and years on gas lift. It was determined that successful completions can be made below damaged casing after milling or swaging to repair damage. However, a successful completion had not been made in cases where an interval longer than 9 ft. required more than 8 hr. to mill. Also, if additional milling was required after the casing had once been restored to full gage, the well was lost. As a result of this study, damage is evaluated early in a workover, and workovers on marginal profit wells with high damage risk are avoided.

CONVERSION OF STEAM INJECTION TO WATERFLOOD, EAST COALINGA FIELD, B.I. Afoeju; SPE 4502, 1973.

23 of 60 steam injectors had casing failures. These were repaired by cementing to surface a smaller casing string inside original producing string.

DRILLING FOR GEOTHERMAL STEAM & HOT WATER, Matsuo, Keiji, Geothermal Energy, Unesco, pp. 73-84, 1973.

Casing is fully cemented. Slotted liner is used where necessary (max. OD possible). I.D. should be large enough so steam flow is below sonic velocity. Suggest using internal flush joint and select metallurgy to resist corrosion of stream. Regarding cementing: clean up mud cake; centralize pipe, turbulent flow, avoid water pockets, stage if lost circulation is suspected; and use proper cement composition.

Types of failures are casing collapse by water pocket, tensile or compressive failure of pipe and corrosion. Some repairs were successful when failure was near well head. (Run tubing below holes and produce through tubing. Weld or otherwise patch holes. These techniques are used at Matsukawa field, Japan) Useful well surveys include temperatures, electric spinner, inclinometer pressure BH sampler, CBL.

Optimum producing conditions can frequently be obtained by installing tubing down holes where rate is below expectations and casing was sized too large.

In one instance, a shallow corrosive zone was corroding liner. Liner was milled off and a smaller casing was landed inside liner and cemented inside producing string, shutting off upper corrosive zone.

METHODS OF CASING REPAIR IN KANSAS, Cross, R.R. (Halliburton Services); Heart of Amer. Kansas Oil Lifting Short Course Great Bend, Kans., 3/8-9/72 Selec. Pap, 1972 4 pp.

Highly corrosive water from the Dakota Formation is the cause of a major number of increasing failures in this area. Casing leaks below the cement top can be repaired by one of 2 methods: (1) a stressed steel liner may be positioned over the leaking interval with a string of tubing and a liner expanding tool. Applied hydraulic pressure causes the expanding cylinder to move upward through the steel liner sleeve; and (2) using a retrievable bridge plug and a retrievable squeeze packer, the leak can be squeezed with cement. Leaks above the top of the cement are indicated by a high chloride content of the water entering the well caused by the Dakota water flowing by the salt section. There are a number of methods used in repairing these leaks. Also, there are methods of producing the well without repairing the casing leak. Since it is often necessary to further test the wells before making the decision to repair the casing, the methods of temporarily shutting off the water are included so that a complete test can be accomplished. Where the leak is above the cement, the most obvious method of repair is to back off the casing below the leak and replace the damage joints. The most used method of casing repair is squeeze cementing. This procedure is described.

OIL WELL CASING EVIDENCE OF THE SENSITIVITY TO RAPID RAILURE IN AN H_2S ENVIRONMENT. Hill, M., Kawasaki, E. P. Kronback, G. E.; Material Protection Performance, vol.11, n.1, p 19-22, Jan. 1972.

Specification of a specific hardness or strength level will not necessarily assure good resistance to attack by aqueous hydrogen sulfide. At a given hardness level, the sulfide resistance will depend upon the microstructure of the steel.

UTILIZATION OF GEOTHERMAL ENERGY IN ROTORNA, N.Z., Burrows, William, Multipurpose Use of Geothermal Energy, Oregon Inst. of Technology, Klamath Falls, Ore., pp.43-59, 1971.

Penetration (corrosion) of casing from outside acid shallow water is common. Two cases of shear failure were probably caused by subsidence.

Gas flow around production string could not be prevented, so a 4" well was drilled 4' from producer. It was used to circulate and vent between holes, thus cementing producer.

Corrosion destroyed First Forest Research Institute well with medium thick, galvanized single casing. Second well with double casing cemented between black iron pipe has held up. Calcite deposition in formation occurred at low summer flow rates.

COMBATING WELL CASING CORROSION - McGaleb, A.C.(Diamond Shamrock Corp); ASME Petrol. Mech. Eng. Underwater Technol. Conf. Houston 9/19-23/71) Preprint No. 71-Pet-16, 1971 8 p.

Well casings are difficult to protect properly from corrosion because of their inaccessibility for test. Understanding the causes of well-casing corrosion can lead to prevention methods to stop or greatly reduce this corrosion. The author gives his interpretation of the corrosion process on well casings and the methods he uses to reduce well casing failures caused by external corrosion. The purpose of this study is to briefly cover the causes of well-casing corrosion and ways to effecitvely combat it through cathodic protection.

METALLURGICAL MICROSTRUCTURE OF OIL WELL CASING: EVIDENCE OF THE SENSITIVITY TO RAPID FAILURE IN A HYDROGEN SULFIDE ENVIRONMENT Hill,M.,Kawasaki,E.P. and Kronback, G. E., (Republic Steel Corp); Int. Nace Corrosion Forum Chicago, 3/22-26/71),Preprint No. 10, 1971 14p.

The pressence of hydrogen sulfide in deep high pressure oil wells often results in rapid failure of the incorporated high strength tubular products. The increasing weight of evidence indicates that hydrogen embrittlement is the major contributory factor. Absorption of H_2S on the metal surface impedes recombination of nascent hydrogen atoms which, instead, diffuse into the pipe, concentrate at points of high stress and lead to its ultimate failure. The results of research show that hardness or ultimate tensile strength, taken alone, does not adequately describe the resistance of a steel to cracking, when exposed to aqueous hydrogen sulfide. It has been found that by applying certain heat-treating practices, at least to steel laboratory specimens, a high degree of sulfide cracking resistance can be imparted to steels with a hardness of R^c28 and an ultimate tensile strength of 130 ksi. This is attributed to a high degree of resistance to the microstructure of the steel. Preliminary research has indicated the existence of a relationship between microstructure and sulfide cracking resistance which is consistent with Snape's finding that a specialized heat treatment would raise the resistance of AISI 4340 steel appreciably.

NEW INTERPRETATIONS OF VOLUME AND PRESSURE VARIATIONS NOTED AT THE WELLHEAD AS A RESULT OF CHANGING THERMAL REGIMES INSIDE THE WELL Bantea,I andStan, Al, Chem. Oil Gas Rom. vol. 6 No 2, pp 139-150, 1970..

It has been noticed from experience at the well site, that in addition to gas leaks in the threaded connections of the casing, another phenomenon bringing about changes in the casing strings in the well is the change of mean temperatures of fluids. The most frequency cases measured at the wellhead are the following: (1) where penetrating a layer with increasing temperature while drilling is in progress; (2) in casing cementing; (3) in substituting fluids in the column with cooler fluids for casing testing or during production testing; and (4) when injecting hot or cold fluids into the system. Generally, the modification of pressure as measured at the wellhead is explained by gas penetration under pressure, the thermal expansion of fluids enclosed being neglected. A theoretical substantiation of the problem is carried out by means of mathematical analysis. Some aspects measured were conducted on a case history well 4,600 M deep. The evaluation of pressure changes inside the casing column by means of the procedures laid down in the work allows for a more comprehensive understanding of the phenomena occurring in practice.

CASING FAILURE STUDY - CEDAR CREEK ANTICLINE--J.D. Clegg (Shell Oil Co); 45th Annu Spe of AIME Fall Mtg Houston 10/4-7/70, Preprint No. SPE 3036, 1970. 12 p.

Casing failures, due to salt flow on the Cedar Creek Anticline, have been a major problem. Some 37 wells were lost and an additional 31 have casing deformation. This report discusses the success of various completion, and remedial programs to deter casing failures during the last 18 yr. Experience indicates that the chance of failure is low: (1) if a sufficient collapse strength casing (about 0.8 of overburden) is used and (2) if the casing is properly cemented. Cemented liners and internal pressure have proved beneficial in preventing casing failures in wells completed with relatively low collapse strength casing.

THE TM-SAND STEAM STIMULATION PROJECT, HUNTINGTON BEACH OFFSHORE FIELD- A REMARKABLE EXAMPLE OF A HEAVY OIL RESERVOIR RESPONDING TO CYCLIC STEAM INJECTION PROCESS, Yoelin, Sherwin D.; SPE 3104, 1970 .

They had 4 non-gravel pack injectors. Two failed during 1st cycle. Failure occurred in the liners and long cemented sections of pipe where movement was restricted.

Four other wells have been redrilled because of casing failures. There were early wells not designed for steam injection. One was a high temperature design.

Total wells steamed were 9 existing wells (6 failed)
26 new wells (1 failed)
Typical well life is 8-10 yrs.

CEMENT SHEATH TEMPERATURES AROUND STEAM INJECTION WELLS Bateman, B. L., (Southwestern Louisiana Univ) and Crawford, P. B., (Texas A & M Univ); 25th ASME Petrol. Mech. Eng. Anniv. Conf. Denver 9/13-17/70 , Preprint No. 70 Pet. 24 1970, 9 p

The early stimulation of wells by steam injection resulted in many failures due to the interaction of the pipe, cement, cementing bond, and rock response to the sudden increase in temperature.

PRESENT STATE OF DRILLING AND REPAIRING OF GEOTHERMAL WELLS IN JAPAN, ~~Matsuo~~, K; U.N. Symposium on Geothermal Development and Use, Pisa Geothermics Special Issue 2, p 1467, 1970.

In Matsukawa, Iwate Prefecture (Japan) well, the cementing was incomplete. A water pocket expanded and collapsed the casing.

CATHODIC PROTECTION ON WELL CASINGS NEEDS CONSTANT SURVEILLANCE, Woeter, R.F.; Oil & Gas Journal v 68 46, Nov. 16, 1970.

External corrosion caused casing failures in several of Mobile W. Texas wells. Cathodic protection was installed.

COMBUSTION-A PRIMARY RECOVERY PROCESS, MOCO ZONE RESERVIOIR-MIDWAY SUNSET FIELD, KERN COUNTY, CALIFORNIA. SPE 3059 45th Fall Mtg. SPE-AIME, Houston, TX, Oct 4-7, 1970

Temperature in producer is held below 500°F by injecting cooling water into the tubing/casing annulus. The most practicable solution to the injection well damage problem has been completion with cemented and perforated lines of API grade J 55 pipe. Also, temperature is controlled so failure does not occur.

METHOD FOR ELIMINATING WEAR FAILURES OF WELL CASING, Stuart C. A., U.S. 3,682,256 c. 8/8/72 f. 5/15/70, (Appl. 37,901),

Casing wear is a serious problem in the drilling of well boreholes. A casing-wear hole may develop in less than 25 days or may not occur in a year. When casing wear is not quantified, casing-wear failures, unnecessary installation of inner strings, and unnecessary suspension of drilling can result. A blowout which includes a shallow casing-wear hole is one of the most dangerous situations encountered in a well. A method is described for eliminating wear failures of the casing of a well borehole extending into a subterranean earth formation, by determining where casing wear takes place, quantifying casing wear continuously, designing the casing for wear, reducing the amount of wear, and replacing casing worn to the tolerable limit.

CATHODIC PROTECTION OF OIL WELL CASINGS- Bradley, B.W. and Bates, R.D (Shell Oil Co); Material Protection v. 5 No. 7, pp 33-35, July 1966.

At Bisti Field in New Mexico, failures due to leaks in Shell Oil Co's oil well casings had become a serious problem. External corrosion was theorized as the cause of the failures and cathodic protection was installed to reduce the problem. The reasons why cathodic protection was chosen are discussed, the unique design of this particular system described, and the problems encountered in its operation listed. Field tests indicated that 20-amp rectifiers should be installed. The rectifiers were equipped with a warning light that was to go out when rectifier output dropped below 10 amp., making it easier to insure proper rectifier operation. Some of the operating problems include failure of cable splices and high circuit resistance caused by drying anode beds. A schematic shows the anode installation, as well as the revised 50-ft. anode bed design.

THE CASING FAILURE PROBLEM IN STEAM INJECTION WELLS, CAT CANYON OIL FIELD, SANTA BARBARA COUNTY, CALIFORNIA, Dietrich, W.K. Willhite.G.P..(Continental Oil Co); 21st Ann. ASME Petr. Mech. Eng. Conf. New Orleans, 9/18-21/66. Paper No. 66-Pet. 38: Abstr. Mech. Eng., v 88, No 11, p 82, Nov. 1966.

Casing failure as a result of a standard 8-round coupling disengagement in J-55 grade casing has been a problem after the casing has been subjected to elevated temperatures. Cyclic steam injection at high temperatures can stress the casing above its yield point and create a permanent deformation. This deformation experienced in compression will result in large tensile stresses upon cooling, and these tensile stresses can exceed the tensile strength of J-55 grade standard couplings. In-well modifications to reduce the casing temperature have been used in an attempt to stimulate these wells without failure. The radiation shield and the high-pressure-gas annuli have been used in numerous stimulations at Cat Canyon. New well alterations include upgrading the well casing grade and coupling strength to accept these high stresses, prestressing the initial well completion, or allowing the well casing to elongate freely, thereby avoiding stress concentration.

FAILURES IN THE BOTTOM JOINTS OF SURFACE AND INTERMEDIATE CASING STRINGS, Schuh, F.K..(Atlantic Richfield Co.); 42nd Ann. Spe. of AIME Fall Mtg. Houston 10/1-4/67, Preprint No. SPE-1845, 1967, 10 p.

The drilling industry has long been plagued by failures in the bottom few joints of surface and intermediate casing strings. This paper presents an analysis of the various possible causes of failure and concludes that failures are caused by short-lived, high energy torque impluses delivered from the drill string through the bit while drilling out the cementing plugs, cement and floating equipment. The magnitude of these torque impluses is shown to be a function of the rotational momentum of the drill string and a method of calculating the magnitude of these impulses is derived. The available methods of strengthening the bottom joints are reviewed. It is concluded that while present methods are ineffective, a combination of improved procedures for strengthening and minor restrictions on drill-out practices will prevent failures.

HIGH TEMPERATURE TENSILE PROPERTIES OF CASING AND TUBING; Thomas, P. D., (Asiatic Petroleum Corp); API Petrol. Div. Mech. Properties Pipe Symp. San Francisco, 6/12/67 Proc. No. SS 2-3, v SS-2, 1967, 28p.

The advent of fire flooding, steam production, and steam flooding has increased the importance of high-temperature properties of steel in casing and tubing. Steam flooding, which has been plagued by a series of casing failures, forms the predominant background for this paper. It was found that 4 American pipe manufacturers had privately and independently made a number of high-temperature tensile tests on API casings and tubing grades. These test results are tabulated and shown in graphical form in this paper. The combined test results do not represent a sufficient volume of data to permit establishment of minimum stress values or establish average values. However, they can be considered typical and they do show how temperatures up to 1,000°F reduce the mechanical properties and the modulus of the elasticity of steels used for casing and tubing. Also included at the end of the paper are comments by B.B. Grainger, F.M. Rouget and J. Duret, H.G. Thurston, and author's reply.

CASING FAILURES IN IRRIGATION WELLS IN AN AREA OF LAND SUBSIDENCE, CALIFORNIA- Wilson, W.E. (US Geological Survey); Abstr. Ann. Geol. Soc. Amer. & Ass. Soc. Mtg Mexico D.F. 11/11-13/68 Program, p 324, 1968.

Sediment compaction in California commonly results in shortening and rupture of well casings. During 1950-1961, approx. 1,200 casing failures were reported in 275 irrigation wells in a part of the

Los Banos-Kettleman City land-subsidence area. These effects of compaction contrast to the Mexico City area, where casings protrude above the subsiding surface, Failures are known throughout the thickness of water-bearing deposits penetrated by wells, and over a depth range of nearly 2,000 ft. Of 603 failures plotted on geologic sections, 72% occur in a zone from 300 ft. above to 400 ft below the principal confining bed, the Corcoran Clay member of the Tulare Formation. The failure density of Diablan alluvial deposits averages 4.6 f/twf (failures per thousand well feet surveyed), but varies systematically with depth, steadily increasing to a maximum of 14.0 f/twf at 100 to 200 ft. below the Corcoran, and then decreasing with greater depths. Failure density of these deposits is directly related to unit compaction, and the depth distribution of failure density, therefore, reflects in detail the relative distribution of unit compaction.

CATHODIC PROTECTION OF OIL WELL CASINGS, Simmons, E.J. (Sun Oil Co.); Okla. Univ. Corrosion Control Short Course Norman 9/16-18/68 Proc., pp F-1-F-15, 1968.

In recent years, cathodic protection has been used with increasing frequency throughout the oil and gas producing industry for protection of the external surfaces of well casings against corrosion. Economic projections based on repair costs vs. estimated costs of cathodic protection can indicate the economic feasibility of cathodic protection. Certain tools and techniques are available to help in assessing the economic feasibility as well as the physical feasibility. It is important early in the study to determine for certain if the leaks are due to external or internal corrosion, and which tools and techniques are useful. To obtain an idea of the extent of corrosion damage, the casing thickness logging tool is useful. The internal caliper is an auxiliary tool which can be run simultaneously with the casing thickness tool. From a study of the thickness and caliper logs, leak frequency curve prediction, leak repair cost, expected well life and other considerations, a decision can usually be made to justify, from the standpoint of economics, the feasibility of installing cathodic protection.

CONTROL OF WELL CASING CORROSION IN THE STEELMAN OIL FIELD, Motyka, D.R. Oilweek v 19 #2, p 30. Feb. 26, 1968.

Corrosion caused 11 casing failures in 1961-1962. Cathodic protection was installed and was successful.

GUIDELINES TO PROBLEM WELL DIAGNOSIS, Allen, T.O., Roberts, A. P., (Oil & Gas Consult Internat); Petrol. Eng., v 40, No. 13, pp 43-46, Dec. 1968.

Mechanical failures center around primary cement failures, casing and tubing leaks, well-bore communication in multiple completions, and other downhole mechanical failures.

A METHOD OF OBTAINING LEAKPROOF API THREADED CONNECTIONS IN HIGH PRESSURE GAS SERVICE, Weiner, P.D. and True, M.E.; API Southern Dist. Prod. Div. Spring Mtg., Shreveport, 1969.

API Survey showed that 86% casing failures, 55% tubing failures occured in connections. Field leakage tests showed 60% of tubing or casing strings had at least one leaking connection.

CYCLIC STEAM INJECTION OPERATIONS, GUADALUPE FIELD, CA. Stracke, K.J., Mason, D.C., Altman, R.G.; Amer. Petrol Inst. Div. Prod. Drilling Prod. Pract. Pap., p 35-9, 1969.

This paper describes some of the problems encountered in cyclic steam injection in the Guadalupe Field, San Luis Obispo County, Calif. Traditional problems inherent to steam stimulation such as casing failure, sand control, and adaption of existing facilities to greater volumes of high-temperature production were encountered; innovations in methods and equipment used to implement cost reductions are discussed.

CALCULATION OF ALLOWABLE MAXIMUM CASING TEMPERATURE TO PREVENT TENSION FAILURE OF THERMAL WELLS, Holliday, G.H.; ASME Pet. Mech. Eng. Conf. Tulsa, Sept 1969.

STEAM DISTILLATION DRIVE BREA FIELD, CALIFORNIA, Volek, C.W. and Pryor, J.A, SPE Paper 3441, Oct. 1971, 8 p.

Steam injection was started into well where CBL showed poor cement in 2 upper stages. Steam went down tubing through packer seat above injection interval. Packer and casing failed after 2 months of injection.

Pressure tests, impression blocks, caliper, downhole TV used to identify modes of failure. They were in casing body and API 8 round and buttress coupling. Tension resulted in break at last engaged thread and jump-out, compression closed coupling standoff.

Failure mechanism was studied in 200' test well.

Insulated tubing was attempted next. This failed after 31 mo. due to buckling. Second well also failed by tubing buckling after 12 mo.

Last technique was prestressed insulated tubing hung from well head, with gas annulus.

BHT in steam wells was in excess of 625°F.

DELAYED FRACTURE OF GEOTHERMAL BORE CASING STEELS, Marshall, and Tombs, A.; Australasian Corrosion Eng., v 13 n 9, p 7-14, Sept. 1969.

Field tests using constant- load, notched and plain tensile specimens have shown that conventional bore casing steels and some proprietary "sulfide- resistant" casing steels exhibit delayed fracture when exposed to geothermal steam condensate. Test results suggest that the delayed fracture involves both stress corrosion and hydrogen cracking mechanisms. The implications of this behavior to the service performance of geothermal bore casings are discussed briefly.

SOME CORROSION PROBLEMS IN THE PETROLEUM INDUSTRY, Clark, P., (Metlab X-Ray Ply Ltd.); Australian Chem. Process. Eng. v 22 No. 4, pp 27-30, April 1969.

Pure hydrocarbons are not corrosive to normal construction materials. However, crude oil contains varying quantities of impurities which cause the corrosion. Sulfur-and chloride-bearing compounds are the 2 greatest sources of corrosion. Internal corrosion in typical oil and gas wells originates from hydrogen sulfide, carbon dioxide, organic acids and chlorides present in the produced fluids; oxygen is normally absent. All surfaces in contact with the fluids are liable to be attacked. Downhole rates of corrosion are influenced by the higher temperature and pressure conditions found there. Internal corrosion of producing equipment is normally referred to as being sour or sweet depending on the presence or absence of H_2S. Methods of treating internal corrosion of wells are varied. Organic inhibitors can be employed, but due to the produced waters varying greatly in composition and in proportion to the quantity of produced fluids, it is not surprising that there is no one inhibitor of universal application. External corrosion of well casings is a major problem, due to the high repair costs involved. The most common causes of causing corrosion are given.

CASING BUCKLING DETERMINED BY STRESS DIAGRAM, Holmquist, D., Petrol Eng. v. 41 No 13, pp.74, 76, Dec. 1969.

Buckling characteristics of casing can be seen at a glance on a stress diagram prepared on rectangular arithmatic coordinates. The diagram can be prepared using only conventional oil-field engineering materials, instruments and data. An illustration shows the buckling characteristics of a hypothetical combination string at any depth in the unsupported interval. The basic considerations for the construction and interpretation of this type diagram are given by a formula which is derived for stresses up to and including the proportional limit. The diagram reveals that the string is not subject to buckling action in any of the 3 phases investigated. The stress diagram method may also have practical application to other operations, such as stimulation where pressures and/or temperatures are changed.

UNUSUAL FISHING JOB SAVES A TEXAS WELL, Leissner, E.L.(Midwest Oil Corp); Oil Gas J., v. 65, No. 2, pp.117-119, Jan. 9, 1967

How an operator got a fish out of the hole on a difficult workover job is narrated. A parted wire line on a routine pressure survey, parted tubing and severe corrosion were some of the problems encountered. The corrosion was so severe that the Christmas tree was considered to be unsafe at the existing wellhead pressure of 1200 psig. The tubing was found to be parted at approximately 1,885 ft. and the fish was located at 1,949 ft. After several hours of trying to remove the fish from the well, it was decided that the pressure bomb had lodged in the annulus. The top section of the fish was cut and the pressure bomb retrieved before progressing further. The fish was finally removed in a total of 6 pieces. It was then necessary to plug a leak in the casing that resulted from the unusual activity of the fishing operating. A small portion of the fish was left in the open-hole producing zone and a test was made. Results of the test were good and the well has proved to be as good a producer as before.

THE DEVELOPMENT OF CASING FOR GEOTHERMAL BOREHOLES AT WAIRAKEI, N.Z. Fooks, A.C.L., Proc. New Sources of Energy, Rome 7/21-31/61, U.N. Vol. 3, pp. 170-185, 1964.

Casing is carefully cemented through mineralized zones. Casing is run with more collapse resistance on inner string than burst on outer string. Casing has collapsed where water was trapped between two sections of cement. Casings are centralized at joints to prevent offsets. Heating and cooling is done slowly to prevent thermal shock.

No casing failures due to corrosion have been reported (6 year experience). Cathodic protection has been considered.

CASING FAILURES IN GEOTHERMAL BORES AT WAIRAKEI, John We. Smith; Proceedings of New Sources of Energy, Conf. Rome Vol. 3, U.N., pp. 254-263, 1964.

Most failures are due to: (1) erosion; and (2) thermal effects. Thermal failures looked like expanding water was trapped by cemented sections that are inside conductor pipe. When coupling failure occurs, it appeared to be in areas without cement behind pipe. Failures haven't occurred with completely cemented wells. Thermal failures seemd to occur with temperatures above 120°C. which caused stresses in excess of both compressive and tensile limits.

A STUDY OF FATIGUE AND OTHER RELATED PROBLEMS ASSOCIATED WITH DRILL PIPE AND CASING MATERIALS FOR PROJECT MOHOLE. Battelle Memorial Institute. Scientific and Technical Progress for the Period Ending 15 May 1964.

Progress is reported on a study of fatigue and other related problems associated with drill pipe and casing meterials for Project Mohole.

RECONDITIONING OF STEAM BORES AT KAWERAN, N.Z., Dench, N.D., N.Z. Engineering, Vol. 17, No. ID, 1962.

Journal not available but may contain useful information.

APPENDIX E

ANNOTATED BIBLIOGRAPHY

SPECIAL COMPLETION AND PROTECTIVE TREATMENT TECHNIQUES

A CURRENT APPRAISAL OF THERMAL RECOVERY, Prats, M.: J. Pet Tech, p 1129-1136, Aug 1978.

A number of thermal recovery processes are described, and the areas of interest for thermal operations in North America are indicated. A number of the operators of thermal recovery projects are identified. California production accounted for 60% of U. S. thermal production (18% of total California production), 38% of world wide thermal production and 35% of world wide enhanced oil production.

CONSIDERATION OF CASING-LAYOUT AND CEMENTATION TECHNIQUES IN VERY DEEP WELLS IN THE VIENNA BASIN, L. Riedl and F. Baldauf; SPE of AIME Europe Spring Mtg. Amsterdam 5/29-30/74 Preprint No. SPE-4838, 1974; 11 p.

Deep drilling in Austria is restricted to the Vienna Basin where at present time depths of 6,000 m are attained. The slightly-overpressured gas pay zone lies in the Triassic Hauptdolpmit at depths between 4,800 to 6,000 m. After having drilled several deep wells, it was concluded that the following casing layout is sufficient: 18-5/8 in.-100m, 13-3/8 in.-3,600m, 7 in. liner - 5,600 m, 5 in. liner - 6,000m. H_2S environment requires careful selection of the casing grades. High temperatures cause a considerable reduction of yield strength and excessive landing loads. The support of the cement sheath is neglected. Burst in casing design for intermediate casing strings is based on blowout conditions assuming that gas has displaced the drilling fluid in the lowest third section of the hole. To keep the casing load at the casing head within a reasonable range, the first intermediate casing string is cemented to the surface and the cement top of the casing strings to follow should be at the depth of approx. 1,200 M Close attention is given to the design of the cementing slurries and their proper displacement based on rheological calculations.

PERFORMANCE OF OIL WELL CEMENTING COMPOSITIONS IN GEOTHERMAL WELLS, Gallus, J.P., D.E. Pyle, L.T. Watters; SPE Paper #7591 53rd Annual Fall Technical Conference of SPE-AIME, Houston, TX, Oct 1-3, 1978.

Several cementing systems have been found to remain competent under geothermal well conditions for periods to one year. Leveling of compressive strength and permeability curves at about 6 mo. indicate that these systems should maintain integrity for the well life. API Class G cement apparently can be rendered as effective for geothermal brine well applications as API Class J cement by adding 40 to 80% silicon to facilitate formation of desirable Truscottite.

INHIBITION OF STEEL CORROSION IN SOUR GAS WELL ENVIRONMENTS CONTAINING SULFUR AND ETHYLAMINE, F. F. Lyle, Jr. (Southwest Research Inst), S. Lechler and J. Brandt (Mobil Oil AC) and F.E. Blount and E.S. Snavely (Mobil Res. & Develop Corp); Mater.Performance v 17 No 1, pp 24-31, Jan. 1978.

Solid sulfur that plugs tubing in sour gas wells produced by Mobil Oil AG in Deutchland is removed by circulation of 40% ethylamine solution. However, the ethylamine causes severe corrosion of lower portions of tubing and casing. A research program to solve the corrosion problem found that, under bottomhole conditions, concentration of sulfur ethylamine is a dominant factor in the corrosion reaction. Catastrophic corrosion rates of steel (1,000 to 2,000 m/yr) occur with evolution of hydrogen in low sulfur concentration while higher sulfur concentrations inhibit corrosion by formation of a protective FeS_2 film, and hydrogen is not produced. Pitting that occurred where the protective FeS_2 was mechanically damaged was prevented by adding one percent by weight of a proprietary amine-phosphate inhibitor. Acceptable inhibition was not obtained in the absence of sulfur by any of the organic and inorganic compounds that were investigated. Exposure of test solutions to air increased corrosion rates even with the best inhibitor-sulfur formulation and increased the amount of inhibitor required for protection.

STEAM DRIVE AS A SUPPLEMENTAL RECOVERY PROCESS IN AN INTERMEDIATE VISCOSITY RESERVOIR, MOUNT POSO FIELD, CALIFORNIA, Stokes, D.D., Brew, J.R., Whitten, D.G. and Wooden, L.W.; J. Pet. Tech. p 125-131 Jan. 1978.

Well problems were generally associated with lost liner seals or sand production. Sand is being controlled by gravel packs or chemical consolidation of sand. No problems were reported for steam injector wells.

CATHODIC PROTECTION REQUIREMENTS FOR WELL CASINGS, H.J. Heinrichs, W.O. Ingram and B.G. Schellenberger (Amoco Canada Petroleum Co); 28th Annu. Petrol Soc. of Cim Tech. Mtg. Edmonton, 5/30/77-6/3/77 Preprint 1977., 11 p.

Failures of well casings with and without cathodic protection in S.Swan Hills and Nipisi fields were investigated. Surveys which were conducted to determine the adequacy of the existing or the need for cathodic protection included casing potential profile (CPP) surveys, E logs, injection tests, and remote off-wellhead potential surveys. The extent of the casing damage was confirmed with casing inspection logs, internal casing calipers, and visual inspection of recovered casing. The depths protected by past and present current levels, plus the depths that could be protected with additional current are discussed. Results from the CPP surveys, E logs, and remote off-wellhead potential surveys are compared.

DRILLING AND COMPLETION PLANS, W.E. Boyd, Proc. 3rd Geopressured Geothermal Energy Conference, 1977.

4000 deep wells have been drilled in the Gulf Coast Area. These wells have encountered temp. from 275-350^{o}F. CBL Logs are scheduled for the Brazoria County test and it is anticipated that these logs will function well enough to evaluate quality of cement behind the pipe. Cement gaps and channels will be squeeze cemented to insure a good bond between the pipe and the wall of the hole.

Regarding casing/tubing, since pressures as high as 12,000 psi are anticipated, care will be taken to get "bubble tight" joints by thread lubricants/seals and specific torque will be used to tighten joints.

REVIEW OF PRACTICAL METHOD OF CASING DESIGN FOR DEEP WELLS, K.R. DeLuish and L.E. Jayne (Hydril Co); SPE of AIME Practical Aspects of Drilling and Prod. Oper. Reg. Mtg. Oklahoma City, 2/20-22/77) Proc. , SPE-6475 , pp 111-117, 1977 .

The design of casing and liner strings grows more critical as well depths and bottom hole pressure increase. Service conditions, economics, material properties and stress-inducing parameters must all be considered to arrive at an optimum casing or liner design. A practical approach for the consideration of the 3 basic load conditions, i.e., internal pressure, collapse pressure, and tension, and how they affect casing string design decisions, is presented. Safety factors that have wide industry acceptance and use are discussed. Actual practice is reviewed by comparing the ideal to the practical. In addition, other considerations and their impact on the final design are examined.

STATUS OF THE SECTION 26C STEAMFLOOD, MIDWAY-SUNSET FIELD, CALIFORNIA, Duerksen, J.H., and Gomaa, E.E.; SPE-6748, Fall Meeting, Denver, October 1977 .

Well temperatures were in range of 400-480^{o}F. Temperatures were measured with an iron-constantine thermocouple on an insulated and shielded thermocouple cable which was tensioned with a sinker bar assembly. Scale buildup was a problem that was mitigated by using high abrasion resistance equipment.

CEMENTING OIL AND GAS WELLS...INCLUDING CASING HANDLING PROCEDURES, PT. 1, G.O. Suman, Jr. and R.C. Ellis (Completion Technol Co); World Oil v 184, No,4, pp 43-51, March 1977 .

This study discusses basic cement properties in relation to ability to support casing loads and prevent damage to joint loss. Discussions are presented of:(1) the function of the cement sheath in supporting the formation and protecting the casing from various kinds of damage such as fault shear, perforating deformation, and joint loss while drilling; (2) drilling fluid selection and conditioning to improve cement displacement efficiency and prevent differential pipe sticking during cementing; and (3) common causes of casing failure that can adversely affect the cement job as well as future operations, including mill defects appearing in new pipe. Discussions are illustrated by schematic drawings, curves, tabular data and photographs.

CONTROL OF EXTERNAL CASING CORROSION WITH CATHODIC PROTECTION, D.R. Warr(Armor Supply Corp); Oklahoma Univ. Corrosion Contr. Course, Norman, Okla., 9/8-10/75 Proc., pp. 27/1-27/8, 1976.

Casing should protect the well for its entire life; therefore, corrosion which might cause failure of the casing must be prevented or curtailed if costly repair jobs are to be prevented. Internal corrosion problems usually can be controlled with chemical inhibitors, but external corrosion usually must be controlled with cathodic protection. Over the past 25 yr., cathodic protection has been used with increasing frequency to protect well casings, particularly in secondary recovery projects where the desired life of the producing wells has been extended beyond the original estimated life. The use of cathodic protection is becoming even more common today due to increasing costs of repairing casing failures and of drilling new wells to replace wells lost from corrosion failures. The following categories are discussed: 1) detection of external casing corrosion; (2) current requirements for casing protection; and (3) application of cathodic protection. Cathodic protection is a very effective method of preventing external well casing corrosion. One survey by an NACE task group showed an effectiveness of 98%. The protection systems should be examined periodically for malfunctions.

REPAIR AND CONTROL OF GEOTHERMAL WELLS AT CERRO PRIETO, BAJA CALIFORNIA, MEXICO, Bernardo Dominguez, A., Francisco, Vital B. (Commission Federal de Electricidad, Baja California, Mexico). Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, Vol. 2., Berkeley, CA, Univ. of California, pp 1483-1495, 1976.

To maintain the steam production required for the operation of Units 1 and 2 at the Cerro Prieto geothermal power plant, a maintenance and repair program of the wells was undertaken, fractures and collapses were found primarily between the ground surface and a depth of 600 Only two of the damaged wells were abandoned due to lack of adequate safety for putting them back into operation. The repair and maintenance activity began with caliper logs, lead impressions, and electrical logs. Based on the information obtained, new well casings were installed and adequate cementing operations were performed. Related to these problems is the loss of control of Well M-13 which was found to have a fracture at a depth of 200 M. It has been controlled and properly repaired. Conclusion: future wells should be provided with casings of higher strength to withstand the thermal expansion stresses. Also, the opening and development of wells should be carefully controlled.

REVIEW OF SOUTH FLORIDA OPERATIONS, J.R. Gordon and F.W. Broussard (Sun Oil Co); 51st Annu. SPE of AIME Fall Mtg. (New Orleans, 10/3-6/76; Preprint No. SPE 6145, 1976. 8 pp.

This study discusses the techniques and equipment employed by Sun Oil Co. to successfully operate in the highly corrosive environment in S. Florida. Deep, low pressure, undersaturated reservoirs can be economically produced even in the presence of severe corrosion. Primary emphasis is placed on producing problems caused by internal corrosion from hydrogen sulfide and carbon dioxide, and external corrosion from sulfate-reducing bacteria.

CERRO PRIETO GEOTHERMOELECTRIC PROJECT: POLLUTION AND BASIC PROTECTION, Sergio, Mercado G.; Second UN Symposium on Development & Use of Geothermal Resources, pp 1394-98 , 1975.

Casing failures are attributed to external corrosion of highly saline fluids in formation behind pipe that were not isolated by annular cement. Cathodic protection is being considered to reduce this type of corrosion.

Wells are electrically insulated from collection system to lessen galvanic corrosion.

OFFSHORE CORROSION CONTROL PROGRAM FOR PLATFORMS, PIPELINE AND PRODUCTION EQUIPMENT, M.M. Lewellen and J.M. Council (Exxon Co); 7th Annu. SPE of AIME Offshore Technol. Conf. Houston, 5/5-8/75, Preprint No. OTC 2377, pp 443-452, 1975 v 3.

Exxon uses a 4-part Corrosion Control Program, as an effective means of monitoring and controlling corrosion of 89 offshore platforms, 90 offshore pipelines and 80 oil and gas wells in the Gulf of Mexico. The program consists of Pt. 1--internal pipeline corrosion control; Pt. 2-- external underwater platform and pipeline corrosion control; Pt. 3--external corrosion control of production equipment, piping and platforms above mean Gulf level; and Pt. 4 -- subsurface well equipment corrosion control. Exxon's experience indicates that a comprehensive corrosion control program can minimize corrosion damage to platforms, pipelines, and production equipment. Corrosion inspections of platforms, pipelines and equipment provide data for evaluating the effectiveness of different mitigation techniques.

GEOTHERMAL WELL TECHNOLOGY AND POTENTIAL APPLICATIONS OF SUBTERRENE DEVICES - A STATUS REPORT, John H. Altseimer; 2nd UN Symp on Dev & Use of Geothermal Res., pp 1453-1470, 1975.

This article reports requirements for heavy casing walls and special metallurgy in addition to wear caused by drill pipe without protectors (Rubber protectors broke down in hot wells) in geothermal wells. Squeeze cementing was frequently required where channels were noted. (50% Geysers wells required squeeze jobs)

PROJECT RIO BLANCO ALTERNATE REENTRY WELL RB-AR-2 HOLE HISTORY* PNE-RB-75 ; (NVO-38-33).

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* Summary included in Section V.

PROGRAM IS DESIGNED TO ANALYZE CASING BUCKLING IN THERMAL RECOVERY, Nelson, C.G.; Oil Gas J. v 73 n 49, p 79-82, Dec. 8, 1975

A casing-failure problem in newer producing wells in a field under steam displacement has prompted a program to analyze the probably cause and propose remedies. Suggested solutions to the problem in lieu of sand control are: (1) liner-type completion, (2) limiting the interval perforated for production, and (3) the use of larger diameter casing.

THE TEN-PATTERN STEAMFLOOD, KERN RIVER FIELD, CALIFORNIA, Blevins, T.R. and Billingsley, R.M. J. Pet. Tech. p 1505-1514, Dec. 1975

Wells were cemented to surface. The only problems reported were sand production and intrusion through the jet perforations.

OIL RECOVERY BY COMBINATION, THERMAL DRIVE -Husky Oil Co. Staff; U.S. Energy Res. Develop. Adm. Progr. Rev. No. 4 (BERC-75/4), pp 43-47, Nov. 1975.

The objective of the project is to demonstrate the technical efficiency and economics of producing petroleum from a formerly low-productivity petroleum reservoir using the combination thermal drive (in situ combustion utilizing controlled water injection) in conjunction with short-term thermal stimulation of production wells. The work will be conducted in 4 phases: (1) reservoir and geological evaluation; (2) complete preparation for full field test; (3) full field project operations; and (4) heat scavenging and evaluation. A summary of technical progress indicates that during this quarter the 9 wells completed to date in the field have been produced by pumping. Results indicate that very little crude oil was produced by primary production methods. Steam was injected in wells 3-2, 2-3, and 6-3. Remedial work was required in Well 1-2.

DEFINITION PLAN: ALTERNATE REENTRY AND TESTING, PROJECT RIO BLANCO. PNE-RB-57 Rev. 1 September 1975 (NV) (NVO-145 Rev. 1) *

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* Summary included in Section V.

PERFORMANCE OF STEAM DISPLACEMENT IN THE KERN RIVER FIELD, Bursell, C.G. and Pittman, G.M.; J. Pet. Tech. p 997-1004 August, 1975.

There are 668 steam injection wells and more than 1000 producers in Kern River Field thermal operations area. Steam temperatures are rather low, about 250°F, thus many normal steam flood high-temperature-associated problems were not encountered.

EXPERIENCE WITH HIGH STRENGTH STEEL OIL FIELD TUBULAR GOODS USED IN SOUR SERVICE--T.M. Swanson and J.P. Tralmer (Shell Development Co); Int. NACE Corrosion 75 Conf. Toronto 4/14-18/75 Preprint No. 101, 1975, 5p.

The determination of the relationship between sulfide corrosion cracking resistance and hardness has permitted Shell to write specifications based on hardness measurements for high strength casing and tubing for its sour wells. The upper hardness limit of the specification is determined by the material's resistance to sulfide corrosion cracking while the lower hardness limit is controlled by the required minimum yield strenghth. Since the hardness specification range is rather narrow, extremely rigorous pipe mill controls, particularly in the quenching and tempering operations, are required. Extensive hardness inspection is required to prevent possible failures in the field. Current test results and field performance experience indicate satisfactory sulfide cracking resistant pipe can be manufactured with minimum strength to 90,000 psi. By continuous cooperative effort between the oil and steel industries, it is hoped that higher strength tubulars resistant to sulfide corrosion cracking can be developed in order that pipe will be available for exploitation of sour gas wells at depths greater than 25,000 ft.

STEAM INJECTION INTO THE D AND E ZONE, TULARE FORMATION, SOUTH BELRIDGE FIELD, KERN COUNTY, CALIFORNIA, Gates C.F. and Brewer, S.W.; J. Pet. Tech. p 343-348, March 1975.

Fifteen of the 40 initial wells failed in the first 9 years of steaming, and all but 2 failed during the first 12 year. One-third of the failures were caused by casing collapse or holes in the casing.

In addition high water cuts in some of the wells prior to casing or liner failure indicated a failure of the cement used to shut off upper water zones.

New ells were drilled using scratchers, centralizers and pipe reciprocation during cementing. Only 1 out of 17 new wells has failed.

OPTIMUM MEANS OF PROTECTING CASING AND DRILLPIPE TOOL JOINTS AGAINST WEAR--M.E. True (Exxon Co) and P.D. Weiner (Texas A&M Univ); 49th Annu. Spe of AIME Fall Mtg. Houston 10/6-9/74 Preprint No. SPE 5162,

The drilling of deeper wells and use of directional wells have increased the frequency of casing failures caused by drill pipe and tool joint wear. This paper discusses the results of an investigation conducted by the Texas A & M Research Foundation under contract to Exxon Co., U.S.A., to determine from laboratory tests (1) the amount of casing and tool joint wear caused by rotating tool joints with and without various hardfacings in different grades of casing in various typical drilling fluids; (2) to permit the selection of the optimum tool joint hardfacing materials for protecting casing and drill pipe tool joints against wear; and (3) the effectiveness of drill pipe and casing protectors in several typical drilling fluids. The results of this project showed that (1) rough hardfacing produced extreme casing wear in all types of drilling fluids (2) plain tool joints, when rotated in all types of drilling fluids except water produced very little casing wear, but tool joint wear was relatively high; (3) smooth ground tungsten carbide can be used as a hardfacing on tool joints to protect casing and tool joints against excessive wear, and (4) drill pipe and casing protector rubbers cause very little casing wear.

FORMULAS FOR CANISTER AND PIPE DESIGN IN UNDERGROUND NUCLEAR EMPLACEMENT--A. Blake (Calif Univ Livermore); J. PRESSURE VESSEL TECHNOL. v 96 Ser J No 2, pp 65-72, May 1974

Pressure vessel theory and practice are applied to the analysis and design of long emplacement strings and canister hardware used in a complex environment of underground nuclear tests. Design formulas are given for the collapse pressure of canisters and piping under external soil pressure and for the axial response of gussetted flanges, supported by the theoretical and experimental results. The paper is intended primarily as a practical treatment of a complex problem of structural response with the aid of the user-oriented, closed-form solutions.

RECOVERY OF OIL BY STEAM INJECTION IN THE SMACKOVER FIELD, ARKANSAS, Smith, R.V., Bertuzzi, A.F., Templeton, E.E. and Clamplitt, R.L.; J. Pet. Tech. p 883-889, Aug. 1973

Wells were completed by cementing N-80 Hydril casing to bottom of surface casing with Class A cement containing 20% "Diacel D". A second long string was cemented to the level of the surface casing with Class G containing 30% silica flour. No thermal well failures were reported.

WELL CASING CATHODIC PROTECTION EFFECTIVENESS--AN ANALYSIS IN RETROSPECT, C.A. Kirklen (Sun Oil Co.); 48th Annu. SPE of AIME Fall Mtg. Las Vegas 9/30/73-10/3/73 Preprint No. SPE 4682 1973. 8 p

This study analyzes the effectiveness of cathodic protection as a means of alleviating external corrosion on well casings. The 943 wells included in this study are divided into 7 groups located in S. Texas, W. Texas, and the Oklahoma Panhandle area. A serious corrosion problem as evidenced by numerous leaks of external origin was known to exist among each of the 7 groups prior to the time that cathodic protection systems were installed. This study analyzes the leak history in each of the groups following 4 to 10 yr. of cathodic current application in comparison to the leak frequency that existed prior to the time that cathodic protection was applied. Leak prevention effectiveness attributable to the application of cathodic protection and flowline insulating devices for the 7 well groups in this study ranged from zero to 100% with an average effectiveness of 71% and a median effectiveness of 85%.

PROJECT RULISON MANAGER'S REPORT. PNE-R-63 April 1973*
(NV) (NVO-71)

* Summary included in Section V.

OPERATION AND PERFORMANCE OF THE SLOCUM THERMAL RECOVERY PROJECT, Hall, A. L. and Bowman, R. W., J. Pet. Tech., p 402-408, April 1973

Injection wells use K 55 heavy wall pipe cemented with Class H containing silica flour. Perlitem and $CaCl_2$, with injection through a liner secured with a down hole packer or a patented friction ring assembly. Producers are completed in a similar manner.

The production from hot wells is frequently above 250^{o}F and contains H_2S. No well failures were reported although heat and H_2S caused production problems.

GEOTHERMAL DRILLING IN CALIFORNIA, Cromling, John; J.P.T., pp 1033-38, Sept 1973 .

Discusses drilling-cementing-completion problems in several different geothermal areas in California.

PLANNING AND OPERATIONS DIRECTIVE - PROJECT RIO BLANCO, PNE-RB-35, (NV) (NVO-125), February 1973. *

PROJECT RIO BLANCO DEFINITION PLAN, VOLUME I - PROJECT DESCRIPTION, PNE-RB-16 (Rev. 1) (CER) ,January 24, 1973.

PROJECT RULISON FINAL REPORT--PHASE II. PNE-R-60 (CER) * December 28, 1972 .

THE EL DORADO STEAM DRIVE - A PILOT TERTIARY RECOVERY TEST, Hearn, C.L.; J.Pet. Tech. p 1377-1384, Nov. 1972 .

Injection wells were completed with 4½" heavy wall J-55 cemented in a 10" hole. The casing was sand blasted, centralized, and lugs were welded on in the upper part of the holes. The threads were treated with a teflon lub and the cement was Class A with 40% silica flour.

Injection was at 650 psig and 480^{o}F. No new well failures were reported. One old well casing leak was reported.

TECHNICAL STUDIES REPORT NUMBER TWO-PROJECT WAGON WHEEL. * PNE-WW-13 , October 1, 1972 • (EPNG)

* Summary included in Section V.

SHELL MAKES A SUCCESS OF STEAMFLOOD AT YORBA LINDA, Stokes, D.D. and Doscher, T.M.; Oil & Gas J. p 71-78 Sept 2, 1972

METHOD FOR ELIMINATING WEAR FAILURES OF WELL CASING--U.S. 3.682,256 c 8/8/72 f 5/15/70 (Appl 37,901), C.A. Stuart.

Casing wear is a serious problem in the drilling of well boreholes. A casing-wear hole may develop in less than 25 days or may not occur in a year. When casing wear is not quantified, casing-wear failures, unnecessary installation of inner strings, and unnecessary suspension of drilling can result. A blowout which includes a shallow casing-wear hole is one of the most dangerous situations encountered in a well. A method is described for eliminating wear failures of the casing of a well borehole extending into a subterranean earth formation by determining where casing wear takes place, quantifying casing wear continuously designing the casing for wear, reducing the amount of wear, and replacing casing worn to the tolerable limit.

PROJECT GASBUGGY HOLE HISTORIES GB-E; GB-E-R; GB-1; GB 2R * & 2 RS; GB-D; GB-10-36, nd (F&S) PNE-G-71

16th ANNUAL APPALACHIAN UNDERGROUND CORROSION SHORT COURSE - W. VA. Univ. Bull. Ser. 72 No. 6-4, Dec. 1971 659 p.

This course was organized to provide both technical and nontechnical presentations of practical and theoretical abstracts of the causes of corrosion, instrumentation, corrosion surveys, cathodic protection, pipe coatings, and miscellaneous methods of corrosion control.

DIFFERENTIAL PRESSURE TOOLS FOR PLUGGING HOLES IN WELL PIPE--U.S. 3, 614,988 c. 10/26/71 f. 7/30/69 (Appl 846,203), L.K. Moore.

There are many situations in which holes, cracks or other openings occur either intentionally or accidentally, in well casing or other well pipe.

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* Summary included in Section V.

For example, the hole may occur because of an intentional perforation using conventional perforating apparatus, or the hole, crack or other opening may occur because of corrosion, a defect in the pipe or an unintentional puncturing of the pipe. With this apparatus, a fluid pressure differential between the inside and the outside of the pipe to be sealed is utilized for locating a part of the apparatus in contact with the well pipe adjacent to the opening and closure material is introduced through the opening for forming a plug or closure. (15 claims)

PROJECT RIO BLANCO-LLL TECHNICAL STUDIES. PNE-RB-6 August* 2, 1971. (CER)

PRESENT STATE OF DRILLING AND REPAIRING OF GEOTHERMAL WELLS IN JAPAN, Matsuo, K.; U.N. Sumposium on Geo. Dev. & Use (Geothermics, sp.Issue 2) p.1467, 1970.

Suggests use of internal flush joints or special buttress coupling and taper couplings between pipes of different I.D. Corrosion problems are FeS_2 formation or stress corrosion because of high temperature. . . is mixed with cement to counteract cement degradation.

CASING STRING DESIGN FOR GEOTHERMAL WELLS,-N.D. Dench; Geother. Mics. Spec. Issue 2,v. 2,Pt. 2,pp 1485-1496, 1970.

Drilling to depths exceeding 1,600 ft (500) has been conducted by the Ministry of Works in 10 geothermal fields in the North Island of New Zealand. Measurements in the wells have established the pattern of temperatures and pressures which occur throughout their depth and life, and which are used in calculating the various loads imposed on the casings. Changes of temperature caused by drilling operations result in severe casing stresses, and sometimes in failure, particularly in axial compression. The ability of several types of casing joints to resist this loading has been measured in laboratory tests, and enough results have been obtained to allow the designer to estimate

* Summary included in Section V.

actual failure strengths for some joints, and to make the best choice for any particular service. By relating design loads to casing strengths, for various conditions of stressing, a set of design factors has proved useful in assessing the adequacy of casing strings proposed for geothermal service. Data are given on down-hole conditions and joint testing, together with examples of casing designs, and are checked against their field success or failure.

CATHODIC PROTECTION ON WELL CASINGS NEEDS CONSTANT SURVEILLANCE. R.F. Weeter (Mobil Oil Corp); Oil Gas J. v. 68, No. 46, pp 173, 175, 179, 181, November 16, 1970.

Mobil Oil Corp.'s experience with cathodic-protection systems on well-casings points out some of the sound operating procedures needed to make the installation effective. Several casing failures attributed to external corrosion occurred in a group of wells under study in W. Texas. Some 300 wells in the area were drilled between 1949 and 1954, and produced from 7 different horizons. Depths of the various zones are shown by a typical well profile. External casing corrosion was learned to be the cause of failure through use of downhole logs. Cathodic protection equipment was installed in 1965-1966 on both production and injection wells, but 11 more failures occurred by the end of 1967. An evaluation was made to determine the causes of the frequent rectifier and related equipment failures and of the high incidence of casing failures. As a result of the findings, metallic conduit has been replaced by plastic conduit in all field installations, green insulated-type TW cable is used for grounding wire, butt wrap is no longer used in pit areas, and poles are not placed in the pits if another location is practical. Care is taken to avoid bypassing of insulation, and insulation is placed as close to the wellhead as practical. A position of cathodic-protection technician has been created with responsibility for cathodic protection.

DESCRIPTION AND SPECIFICATIONS OF THE RULISON CHRISTMAS TREE* INSTALLED ON THE R-EX Well. PNE-R-38 (Austral Oil Co.Inc.), July 1970.

* Summary included in Section V.

PROCESS USES HYDRAULICS TO PRESTRESS CASING D.E. Holmquist; Oil Gas J., v 68 , No. 20, pp 138, 142, Mar. 18, 1970.

A new process prestresses casing hydraulically, increasing its temperature tolerance for use in thermal-recovery projects. The temperature tolerance of J-55 casing is increased about 35°F and N-80 by 50°F, by merely applying something less than burst pressure to the casing after bumping the cement plug and maintaining this pressure until the casing is secured at the top and bottom. Casing-to-cement bond may be weakened as a result of casing contraction when pressure is released, but the cement-to-formation bond should not be affected. The bonding strength of the casing attachments should remain considerable. A prestressed string is less subject to buckling than a conventional string. Hydraulic prestressing may be used to provide a greater margin of safety or to raise the temperature limit with the same margin of safety. An axial stress vs. depth diagram of hydraulically prestressed casing in a hypothetical well drilled for steam injection is presented.

PROJECT WAGON WHEEL-INTERIM REPORT OF WAGON WHEEL NO. 1 AT * CASING POINT DEPTH OF 12,106 feet. PNE-WW-15, April 1970 (EPNG)

PROJECT RIO BLANCO DATA REPORT-PRODUCTION TESTING ALTERNATE * REENTRY HOLE RB-AR-2 (NVO-154) PNE-RB-69

EMPLACEMENT AND CEMENTING OF HOLE 25-95A (EMPLACEMENT HOLE)* HAYWARD WELL IN GARFIELD COUNTY, COLORADO (Austral Oil Co., Ind.) 1969

CYCLIC STEAM INJECTION-GUADALUPE FIELD, CALIFORNIA*; K.J. Stracke, D.C. Mason and R. G. Altman (Union Oil Co. California); API Prod. Div. Pacific Coast Dist. Spring Mtg. Los Angeles, 5/13-15/69 , Preprint No. 801-45L, pp. 135-145, 1969.

* Summary included in Section V

A case history is presented of cyclic steam injection, the related problems, and how they were solved. There are 4 basic approaches to the solution of a casing failure problem for wells which are to be subjected to cyclic elevated temperature. These are as follows: (1) permit free expansion of the casing to avoid compression stresses;(2) prestress the casing string in tension to reduce compressive loads when expansion occurs, (3) select casing grade of sufficient strength to withstand stresses from the anticipated temperatures; and (4) limit the maximum temperature to which the casing is subjected to maintain stresses below the yield strength for the particular grade of casing used. The average initial primary production rate per well in Guadalupe field is 45 to 50 bopd. The average initial production rate after first cycle steaming is 250 bopd and the average first cycle oil recovery is 30,000 to 33,000 bbl. The production decline rate per steam cycle varies, but averages between 10 to 12% per yr. Most of the wells are steamed once every 11 to 12 mo.

ANSWERS TO QUESTIONS POSED BY THE COLORADO COMMITTEE FOR ENVIRONMENTAL INFORMATION RELATING TO THE FORTHCOMING RULISON UNDERGROUND NUCLEAR EXPLOSION IN WESTERN COLORADO. PNE-G-48 August 27, 1969. (NV) *

COST OF RISK ANALYSIS OF WELL REPAIRS PAYS OFF FOR SHELL, C.A. Morris (Shell Oil Co.); Oil Gas J., v 67, No. 50, pp, 70-73. December 15, 1969.

Casing collapse caused by flowing salt sections has been a problem since the first well was drilled on the Cedar Creek Anticline in SE. Montana in the early 1950's. It is estimated that more than $8 million has been spent by Shell in attempting to solve this problem. In mid-1964, the company selected a program for future wells which requires: (1) high-strength casing opposite the salt section; (2) use of salt-base drilling mud with a salt concentration above 150,000 ppm; and (3) two-stage cementing with the DV collar located just below the salt section. The knowledge gained from a testing program initiated in 1967 was the basis of the casing remedial program. A cost/risk analysis was completed for each well which considered each alternative (do nothing; load the annulus; install a scab liner; install a full liner; extend an existing liner; or install high-strength tubing). In each of the remedial alternatives, it was necessary to assign a probability of failure.

* Summary included in Section V

A computer program was written to correlate failure probability with time. Some of the example curves resulting are shown. An example of the analysis also is given.

PERSPECTIVE ON CASING DESIGN FACTORS, G. Crosby; Petrol Eng. v 41, No. 9, pp 49-52, Aug. 1969.

At least one major company and one service company are getting away from safety factors and considering API rated strengths of body and joint plus 50,000 to 75,000 lb. for pullout on protection and production pipe, respectively. The wide variance of safety factors indicates that satisfactory results are being obtained at all levels. In running of all casing strings, various dynamic conditions are the cause of most casing failures (included is running into dog legs or bridges too hard, which could be avoided by proper hole preparation). If such conditions cannot be economically avoided, careful running of the casing is very important. More expensive pipe is seldom the solution. A basic parameter in casing design is the maximum condition which could be expected. Each operator must consider various factors in the area in which he is drilling. These would include proportionate success of cement jobs as indicated by bond logs. Burst is another important aspect as drilling proceeds into abnormally pressured areas. Another reason design factors remain high is corrosion. At the present time, however, no one knows what is the proper safety factor.

A METHOD OF OBTAINING LEAKPROOF API THREADED CONNECTIONS IN HIGH-PRESSURE GAS SERVICE P.D. Weiner (Texas A & M Univ) and M.E. True (Humble Oil & Refining Co); API Southern Dist. Prod. Div. Spring Mtg. Shreveport. LA., 3/5-7/69 Preprint No. 926-14-M, 1969 18 p.

The search by the Petroleum Industry for oil and gas at greater depths imposes increased demands on tubular goods. The average depth of exploratory gas wells increased from 4,962 ft. in 1950 to 7,478 ft. in 1967. Along with this increase in depth, pressures as high as 15,000 psi are being experienced. These conditions have increased the threat of tubular connection leaks. An API survey of tubular string failures indicated that 86%

of the reported casing failures and 55% of the tubing failures occurred in connections. These failures cost the operators a minimum of $75,000 each. Results of field leakage tests show that approximately 60% of the tubing or casing strings had at least one leaking connection when made up in accordance with current accepted techniques. A theoretical and experimental program has been undertaken to determine what conditions must be satisfied to assure that API pipe joints are made up to insure joint integrity. Based on the results of this study, it has been concluded that to assure leakproof API connections, the joints must be made up to both a minimum torque and minimum turns with a limit on maximum turns.

SOME PRACTICAL CONSIDERATIONS IN THE DESIGN OF STEAM INJECTION WELLS, R.C. Earlougher Jr., J. Pet. Tech. pp 79-86, Jan. 1969.

Stress and strain on hot well casing can be calculated with relationships presented in this paper. Frequently prestressing or other measures such as heavier wall pipe, etc. must be used to keep stresses well below yield point of pipe and couplings.

PROJECT GASBUGGY OPERATIONAL EXPERIENCES. PNE-G-28 January * 10, 1969. (UCRL) (UCRL-71356)

AVOIDING CASING DAMAGE DURING DIRECT STEAM DRIVE OIL PRODUCTION-- U.S. 3,420,298 c. 1/7/69, f. 8/4/67 (Appl. 658,315); A.J. Cornelius, asr. (Phillips Petroleum Co);

Oil is produced from an oil stratum by a steam drive from an injection well to one or more offset production wells by periodically substantially-reducing the rate of steam injection during a soak period to allow heat transfer to the stratum oil. The steam rate is reduced to merely maintain established casing temperature during the primary injection phase. This avoids contraction and expansion of the casing in the injection well with attendant cratering or collapsing. (8 claims)

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* Summary included in Section V

PROTECTING THE CASING OF A HOT FLUID INJECTION WELL WITH VAPORIZABLE LIQUID--U.S. 3,533,472 c. 10/13/70, f. 5/31/68 (Appl. 733,510); A.J. Cornelius asr. (Phillips Petroleum Co);

To protect a casing against failure during injection of a heated fluid, such as steam, there is passed into the annulus between the conduit and casing a liquid, such as ammonia, whose boiling point is less than the annulus temperature at reservoir injection pressure, thus causing formation of a gas or vapor to protect the casing against the heat from the hot fluid in the injection conduit. The liquid to be injected into the annulus is chosen so that its boiling point falls below the upper limit of about 400°F at reservoir injection pressure. A surfactant and a nonboiling fluid may be injected with the vaporizable liquid to form a foam-filled annulus. (10 claims)

CONTROL OF WELL CASING CORROSION IN THE STEELMAN OIL FIELD--D.R. Motyka (British American Oil Co. Ltd); NACE Can. Reg. Western Div. Conf., Calgary, 2/14-16/68 Pap.; Abstr., Oilweek, v. 19, No. 2, p.30, Feb. 26, 1968.

Cathodic protection in the Steelman oil field, Canada, has resulted in a marked reduction in the rate of oil well casing failures. Vertical graphite anodes and rectifier ground beds were installed late in 1962. Initial casing failure had occurred in Dec. 1959 in a 4 in. casing string 3.4 yr. old. Another 11 casing failures were detected in 1961 and 1962 during conversion to water injection. Attempting to repair by cutting off and installing new casing with an overshot cost $78,000 in one case and $35,000 each in 2 more. Pronounced areas of patchy corrosion were found, as well as great numbers of isolated shallow pits. There was preferential attack on the electric resistance weld (ERW) seam area but casing was otherwise generally in good shape. It is believed that use of starch-gyp drilling mud was a major factor in the damage. Facilities installed cost $800 per protected well or $680,000 capital cost. Operating cost is $25 per year/per well. A casing failure repair could easily exceed $10,000 but in operation the cathodic protection system would have made a break, even if each projected leak cost only $2,000.

SPECIFICATIONS FOR POST-SHOT DRILLING AND RE-ENTRY, GB-2; * PROJECT GASBUGGY. PNE-G-39 , May 1968 , (F&S).

PROJECT RULISON-WELL PLUGGING AND SITE ABANDONMENT PLAN * PNE-R-67-1 (NVO-174 Rev. 1)

DESIGN CRITERIA FOR COMPLETION OF STEAM INJECTION WELLS, Willhite, G.P., and Dietrich, W.K.; J. Pet. Tech.,p 15-17,

Casing failures have been reported in California and Texas to Wyoming in thermal wells (about 500°F). Most frequent failure location is in joints.

Wells should be handled in such a way as to keep pipe/joint combination below yeild point at all times.

FAILURES IN THE BOTTOM JOINTS OF SURFACE AND INTERMEDIATE CASING STRINGS, F.J. Schuh (Atlantic Richfield Co); 42nd Ann. Spe. of AIME Fall Mtg. Houston 10/1-4/67, Preprint No. SPE 1845, 1967 10 p..

The drilling industry has long been plagued by failures in the bottom few joints of surface and intermediate casing strings. This paper presents an analysis of the various possible causes of failure and concludes that failures are caused by short-lived, high energy torque impulses delivered from the drill string through the bit while drilling out the cementing plugs, cement and floating equipment. The magnitude of these torque impulses is shown to be a function of the rotational momentum of the drill string and a method of calculating the magnitude of these impulses is derived. The available methods of strengthening the bottom joints are reviewed. It is concluded that while present methods are ineffective, a combination of improved procedures for strengthening and minor restrictions on drill out practices will prevent failures.

SPECIFICATIONS FOR DRILLING, EMPLACEMENT, AND INSTRUMENTATION: * PROJECT GASBUGGY, PNE-G-40 (F&S), July 1967.

SPECIFICATIONS FOR CEMENTING SERVICES: PROJECT GASBUGGY. * PNE-G-36 ,July 1967.

* Summary included in Section V

ENGINEERING AND PLANNING A DEEP ABNORMALLY PRESSURED WELL-H.B. Owens, Jr. and D.E.Boone (Amerada Petroleum Corp); 42nd Annu. SPE of AIME Fall Mtg., Houston 10/1-4/67, Preprint No. SPE-1844, 1967 7 p.

The problems encountered in drilling deep abnormally pressured wells were studied. Conclusions from this study were applied to design a deep well drilling program. More significant parts of the program are presented. Portions of the program discussed include initial engineering and planning, conductor pipe installation, drilling surface and intermediate hole, setting surface and immediate casing, pipe handling and trips, and liner completions, in addition to pipe inspection and corrosion control. Application of this program to a well in S. Louisiana is also considered.

USE OF CATHODIC PROTECTION FOR EXTERNAL CASING CORROSION CONTROL, E.J. Simmons (Sun Oil Co); Okla. Univ. Corrosion Control Short Course, Norman, 9/22-24/65, Proc., pp. 1-E-28-E, 1966.

The use of cathodic protection for controlling corrosion on the external surface of casing is limited by its inaccessibility. The problem is better understood when it is recognized that in using such a corrosion control method an attempt is being made to protect the outside surface of casing when only the upper and inside portions are accessible. This inaccessibility hampers the corrosion engineer in 3 ways--makes corrosion detection more difficult, limits the control techniques to only cathodic protection and eliminates many of the techniques normally used in planning and designing a control system. The use of 2 tools--the casing thickness log of Welex and McCollough; and Lane-Wells* casing voltage profile tool--to determine the point at which corrosion is occurring in a casing string have helped to solve this problem.

A STUDY OF FATIGUE AND OTHER RELATED PROBLEMS ASSOCIATED WITH DRILL PIPE AND CASING MATERIALS FOR PROJECT MOHOLE, Schuetz, Arnold E., Hyler, Walter S., Jackson Lloyd R., Boyd, Walter K.: (Battelle Memorial Institute); Feb. 28, 1964.

The results of a preliminary study to evaluate materials for the drill string to be used in

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Project Mohole are presented in this report. Most of the evaluation was made on high-strength S-135 heat-treated drill pipe; but some comparative testing also was made on the more common Grade E steel pipe. Studies were carried out concerned with fatigue strength in air, corrosion fatigue in sea water, stress-corrosion cracking at high temperature and pressure, and with impact strength. The fatigue strength of S-135 steel was generally higher than that of Grade E steel; however, with the higher notch sensitivity of the S-135 steel, its notched alternating stress limit was the same as that for the Grade E steel. As expected, fatigue strengths of the steels were reduced in the sea water environment. Thus, a critical problem exists in controlling corrosion fatigue of the drill string. Fortunately, no susceptibility to stress-corrosion cracking in sea water at 2200-psi pressure at 650°F was found for either steel. Impact strength of the S-135 steel appears to be marginal and to require improvement. Possibilities of combating the two critical conditions--corrosion fatigue and fracture toughness--are discussed.

GEOTHERMAL DRILLING PRACTICES AT WAIRAKEI, N.Z., S.B. Craig, Proc. New Sources of Energy, Rome, 7/21-31/61, UN.N Vol. 3, pp 121-133, 1964.

Current practice is to completely cement all strings and grout the surface to about 60" diameter and 100' deep, use 8" production casing with 6 5/8" slotted liner, one centralizer per 100' and grout casing from top if no returns are obtained. Centralizers are welded on all (collars) joints to prevent offset. Most failures are in couplers and special buttress threads are currently being used (in 8" pipe). Directional drilling has been successful when specialized personnel and equipment were used.

THE DEVELOPMENT OF CASING FOR GEOTHERMAL BOREHOLES AT WAIRAKEI, N.Z., A. CL. Fooks; Proc. New Sources of Energy, Rome 7/21-31/61, U.N. Vol. 3, pp. 170-185, 1964.

Casing is carefully cemented through mineralized zones. Casing is run with more collapse resistance on inner string than burst on outer string. Collapse has occurred where water was trapped between two sections of cement. Casings are centralized at joints to prevent offsets. Heating and cooling is done slowly to prevent thermal shock.

No casing failures due to corrosion has been reported (6 year experience). Cathodic protection has been considered.

APPENDIX F

COMPOSITE LISTING OF REFERENCES

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