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AUTHOR(S): Roland A. Pettitt

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LOS ALAMOS SCIENTIFIC LABORATORY
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MONITORING AND REPAIRING GEOTHERMAL CASING CEMENT: A CASE HISTORY*

Roland A. Pettitt

Los Alamos Scientific Laboratory
Los Alamos, N.M. 87545

ABSTRACT

In the hot dry rock (HDR) concept of extracting geothermal energy, as developed by the Los Alamos Scientific Laboratory (LASL), a manmade geothermal reservoir has been created by drilling a deep hole into relatively impermeable hot rocks, creating a large surface area for heat transfer by hydraulic fracturing, then drilling a second hole to intersect the fracture to complete the closed circulation loop. A second generation system, presently being drilled, will entail creating multiple, parallel, vertical fractures between a pair of inclined boreholes.

The completion of HDR geothermal wells presents some very severe cementing problems. Current well depths are from 10,000 to 14,500 ft (3 to 4.4 km) with bottom hole temperatures up to 525°F (275°C). During investigation, development, and flowing of the reservoir, water injections may lower the temperature of the entire wellbore to 104°F (40°C). As a result, the casing string may be subjected to many temperature stress cycles representing differential temperatures of up to 455°F (235°C). The original completion of injection Hole EE-1, consisting of a conventional high-temperature formulation of Class B portland cement, stabilized with 40% silica sand, did not withstand these cyclic stresses, and rapid deterioration of casing-to-cement and cement-to-formation bonds occurred, which allowed significant flow in the resulting microannulus.

This paper will describe (a) the performance history of the casing cement for the existing HDR EE-1 injection well, (b) the subsequent remedial cementing program, (c) the cement bond logs, and (d) the radioactive isotope tracer injections tests, used to monitor the condition of the casing cement.

INTRODUCTION

To test the Los Alamos concept, a manmade geothermal reservoir was formed by drilling into a region of suitably hot rock and then creating a large vertical fracture, using conventional hydraulic fracturing techniques. After forming a circulation loop by drilling a second hole into the top of the fractured region, the heat contained in this reservoir is transported to the surface by circulation of water.

The first deep exploratory hole (GT-2) was completed in 1974 to a depth of 9610 ft in the granitic basement rocks of the Jemez Mountains of northern New Mexico at Fenton Hill. The bottomhole temperature was 388°F. A near-vertical hydraulic fracture with a radius of about 400 ft was created near the bottom of GT-2. Drilling of the second deep hole, EE-1, to intersect the fracture began in 1975, about 250 ft north of GT-2. It was completed at a depth of 10,053 ft and a bottomhole temperature of 400°F. EE-1 was cased to a depth of 9600 ft with 7-5/8-in. casing and now forms the injection well of the underground loop. The lower part of GT-2 was later directionally redrilled along a trajectory which created a greatly improved flow connection: now called GT-2B.

By October of 1978, this system had been successfully circulated for approximately 2800 h to determine temperature drawdown, permeation water losses, and flow characteristics of the pressurized reservoir. The pumping tests were terminated in October 1978 due to excessive water losses from failure of the cement behind the casing in EE-1. A remedial cementing program was instituted in January 1979 to correct the leakage up the EE-1 annulus.

Flow tests were again instituted in March of 1980, utilizing an increased downhole reservoir size, and are scheduled to continue until September. On April 24, 1980, the first electric power was produced at Fenton Hill with a 60 kw binary fluid generator.

As a result of the successes at Fenton Hill, LASL has been designated by DOE/DGE to be the lead agency in developing the nation's HDR resource. Investigations are currently underway, in other eastern and western states, to identify additional HDR sites with different geologic conditions as the next experimental HDR energy extraction locations. With this expansion of the HDR program, the problems of obtaining lasting casing cement jobs under different site parameters will also increase significantly.

EE-1 CEMENTING HISTORY

The casing in EE-1 (Fig. 1) was run in and cemented after the well had been drilled to the total depth of 10,053 ft. At that time, a connection had been made with the fracture at the bottom of the companion well, GT-2. In order to prevent cement from entering the fracture system while the EE-1 casing was being cemented, GT-2 was kept pressurized. (In retrospect, shutting in GT-2 would have been the better plan to follow). As a result of the pressure from the GT-2 side, a small water flow was present in the EE-1 casing-rock annulus, which displaced the cement slurry upward from the bottom of the casing—creating the same effect as overdisplacement of the slurry.

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It was planned to cement only the bottom 1000 ft of the casing, from 9600 to 8600 ft. A Class B cement slurry with 40% silica flour was used. Immediately after cementing, the bond logs of October 27, 1975, indicated that the bottom 600 ft was 30 to 50% cemented, with 1100 ft of good bond above (Fig. 3).

With continued intermittent flow between EE-1 and GT-2 during the testing and fracturing, the well was subjected to cyclic temperature changes ranging from 104°F to nearly 400°F. As a result of these temperature fluctuations, the casing-cement bond progressively deteriorated upward. A fracture was later opened at about the 9000 ft depth behind the casing, through which most of the water was circulated for an extended flow experiment (Fig. 2).

During the pumping experiment, near the end of September 1978, a 0.2 gal/min leak to the ground surface was observed and monitored, up the EE-1 casing annulus. The leak continued at that rate until the end of the pumping sequence on October 16, 1978. EE-1 was shut in for a week, but when pumping was resumed on October 23, a flow of about 20 gal/min developed up the annulus to the surface, with total downhole water losses amounting to 40 gal/min (Fig. 4). Pumping was terminated on October 27, as downhole water losses could no longer be accurately determined, and it was feared that significant quantities of water could be entering porous zones and/or aquifers in the upper section of EE-1.

REMEDIAL CEMENTING

In January 1979, the EE-1 casing was recemented using a mixture of Class H cement and 80% silica flour. This design was based on the investigations performed by Gallus, Pyle, and Watters. The volume of cement injected was designed to fill the large open annulus behind the casing below the 9000 ft depth, to allow some to enter the fracture at that depth and also to allow some to travel up the microannulus above the fracture.

The bottom of the 9-7/8-in. open hole was filled with 80 cu ft of 10 to 20 mesh sand, followed by 130 cu ft of 20 to 40 mesh sand. The sand was washed out with the workover rig tubing string to a depth of 9620 ft (20 ft below the 7-5/8-in. casing shoe). A Halliburton drillable cement retainer packer was run in and set at a depth of 9542 ft, and the annulus between the workover tubing and the casing was pressurized to 1700 psi. An initial pumping rate was established at 5 bbls/min at 1300 psi with the companion well GT-2 open. Ten bbls of water were pumped ahead of the cement at a rate of 4 bbls/min. Cementing began at 5 bbls/min and 1500 psi. The cement mixture consisted of 180 cu ft of slurry, Class H cement, 40% fine silica sand, 40% silica flour, 1% CFR-2, 1.2% HR-12, 5.73 gal water/sack. Displacement started at 3 bbls/min and 300 psi. After 8 minutes, the pressure rose to about 600 psi and the rate was decreased to 2 bbls/min until displacement was completed. A total displacement of 54 bbls of water was pumped, with the pressure at 1210 psi. A calculated 1 bbl of slurry remained in the tubing. The hole was shut in and the pressure declined to 600 psi, but remained at 500 psi for 5 min. GT-2 was shut in at a pressure of 125 psi.

When drilling of the retainer and cement began the next day, it was found that the retainer had actually been set at a depth of 9577 ft, about 35 ft (1 joint) deeper than had been intended.

Within two days, the retainer was completely drilled out and the cement drilled to 10 ft below the bottom of the casing. The hole was pressure tested at 1000 psi surface pressure; the rate of decline was about 120 psi in 10 min. Drilling out of the cement then continued. The top of the sand was encountered at 9677 ft. This lower depth (by 57 feet) for the top of the sand could be attributed to two causes: 1) miscount of tubing string (considered unlikely as the same number of joints were in the rack as when the sand was washed down to 9620 ft), or 2) the sand was displaced into the fracture system by jetting action of the cementing operation. A cement plug on top of the sand would have eliminated this uncertainty.

CEMENT CONDITION MONITORING

Two methods were used to monitor the condition of the cement behind the casing. Both methods proved to be useful in detecting and assessing the deterioration of the cement bond.

Cement Bond Logs

A number of cement bond logs were run in the lower part of the cased hole. The progressive deterioration of the bond behind the casing through 1977 is shown in Fig. 3. Bonding that was rated at 30% to 50% in 1975 decreased to zero by 1977; and some of the upper bonding rated at a minimum of 95% in 1975 decreased to 10% to 60% in the same period.

Cement bond logs run after the recementing indicate a greatly improved condition: partial cementing from 9600 ft to 9450 ft, good bond from 9450 to 9080 ft, and improved bond from 9080 to 8850 ft (Fig. 4). Shortly after the recementing, the well was subjected to a severe thermal shock by a 16 bbl/min pumping operation to create another hydraulic fracture below the casing shoe at 9600 ft. Another bond log was run on October 18, 1979 to determine what damage had been done to the bond by this shock, and to set a baseline for evaluation of the bond during a prolonged pumping/flow test scheduled for the spring of 1980 (Fig. 5). This log showed deterioration from the condition immediately after recementing.

In order to provide consistent and comparable results, all cement bond logging was performed by the Schlumberger Well Surveying Office in Farmington, New Mexico. The same high-temperature wireline and the same high-temperature logging tool was used whenever possible to further reduce any calibration/measurement discrepancies.

Radioactive Tracer Logs

The use of radioactive tracers to chart the downhole movement of fluid is a powerful tool, not only for understanding the complex nature of the fracture system between the two holes, but also for charting the deterioration of the cement bond behind the casing. In August, 1978, a pulse of the isotope I^{131} was injected into EE-1. This isotope, with a half-life of 8 days, emits strong gamma rays and was followed downhole by Geiger-Mueller detectors as it traversed and left the EE-1 casing, passed upward behind the casing to finally exit into the main fracture at 9000 ft into the GT-2B open hole. Figure 6 shows the movement of the tracer.

In May, 1980, during the prolonged pumping test, another radioactive tracer log was conducted. This time an improved tracer isotope, Br^{82} with a half-life of 36 hours was used. Most of the isotope exited the EE-1 borehole through the new fracture below the casing shoe, but a small amount did enter the microannulus behind the casing and travel upward to about 9500 ft. There it remained until it decayed and did not move higher. This seemed to corroborate the cement bond log of October 18, 1979 that damage had occurred to the cement around the lower part of the casing, but that the cement higher in the hole was still in good condition.

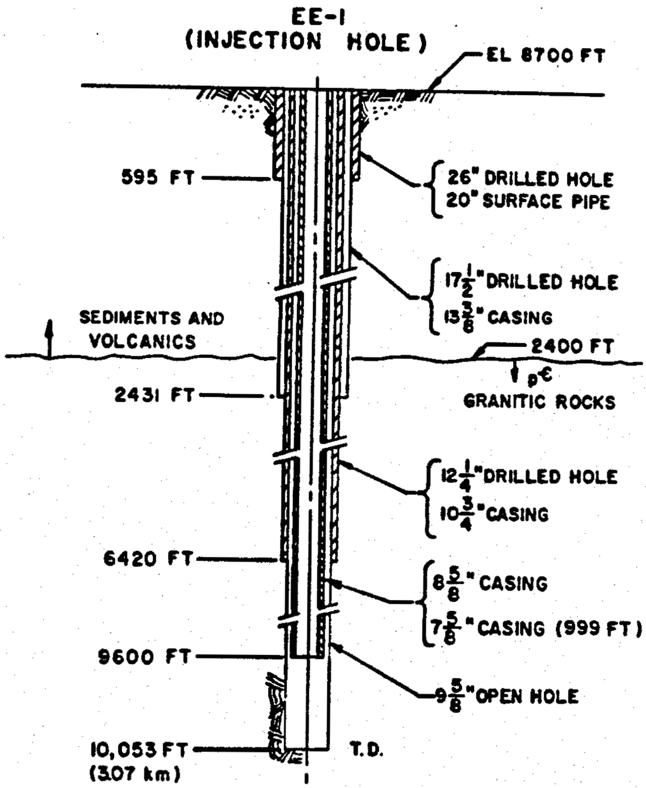

Fig. 1 Casing diagram for Well EE-1.

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Reference to a specific company, product name, or service does not imply approval or recommendations of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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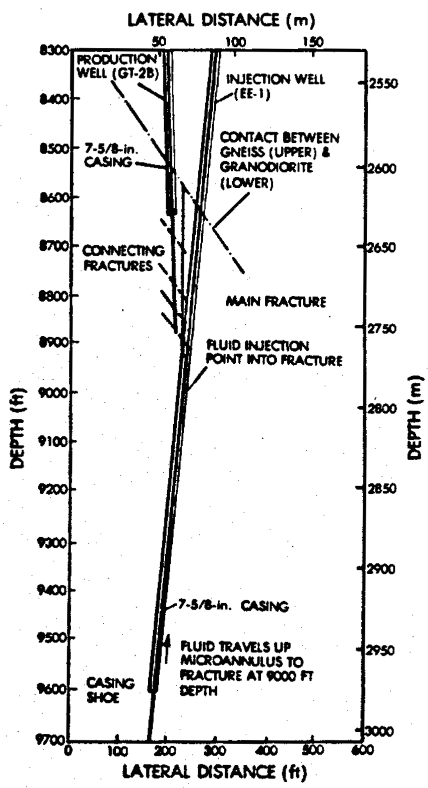

Fig. 2 Elevation view schematic of the GT-2B/EE-1 fracture and wellbore system.

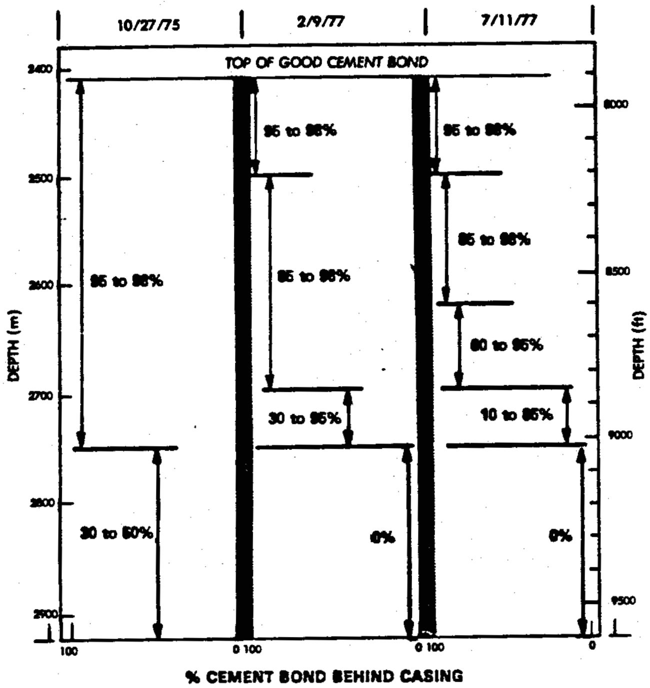

Fig. 3 Cement bond log chart for EE-1, 1975 to 1977.

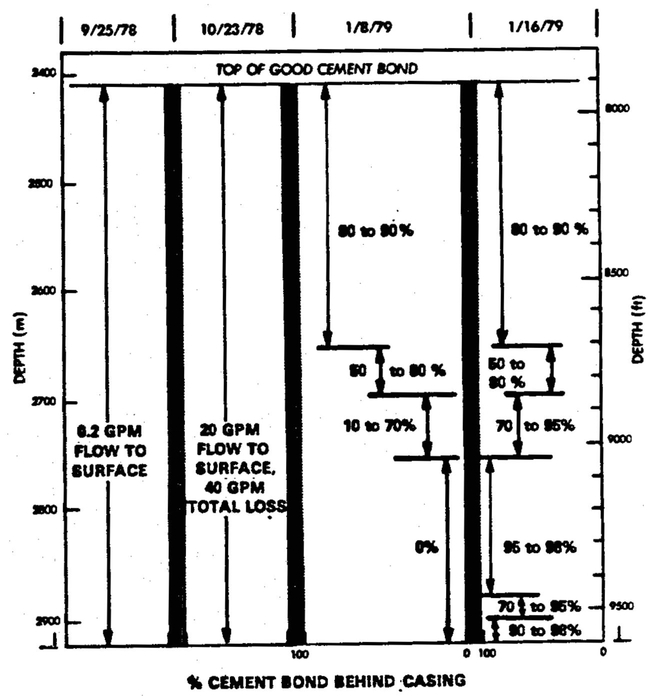

Fig. 4 Cement bond log chart for EE-1, 1978 to 1979.

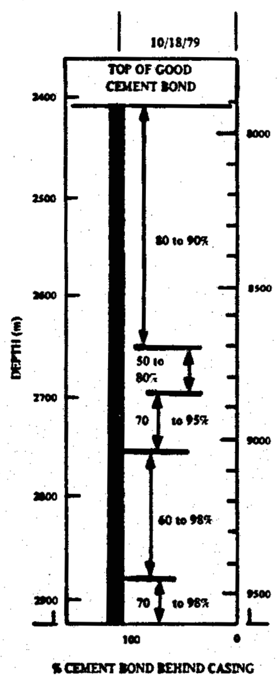

Fig. 5 Cement bond log chart for EE-1, October 1979.

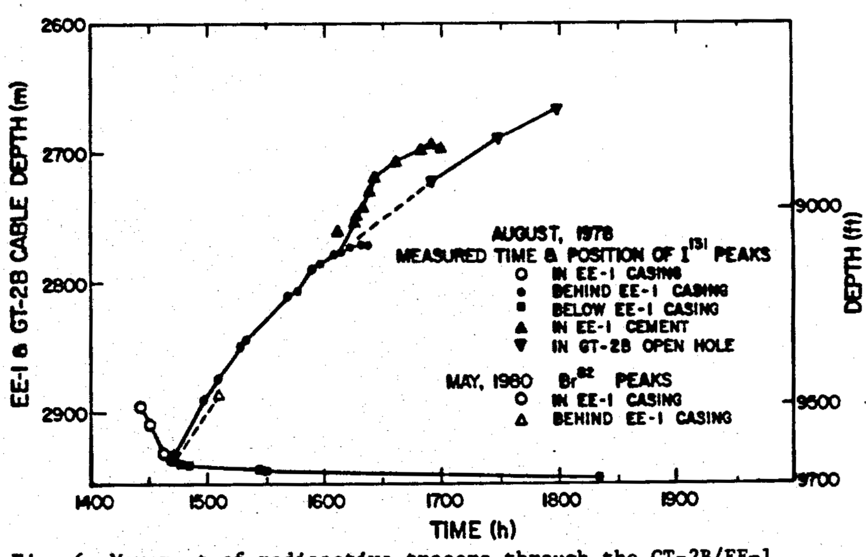

Fig. 6 Movement of radioactive tracers through the GT-2B/EE-1 borehole fracture system.