APPENDIX B

PUNA GEOTHERMAL VENTURE
PROGRAM FOR MECHANICAL INTEGRITY TESTING AND MONITORING OF INJECTION WELLS
July 29, 1996

1. INTRODUCTION

1.1 Background

Pursuant to Underground Injection Control (UIC) Permit No. HI596002, the U.S. Environmental Protection Agency requires that Puna Geothermal Venture (PGV) comply with this Testing and Monitoring Program (TMP) for injection wells. Monitoring and testing provisions in this TMP are similar in most respects to those in the "Casing Monitoring Program," April 26, 1993 version, which is referenced by title in PGV's current UIC Permit No. UH-1529. **(The Casing Monitoring Program related to Hawaii UIC Permit No. UH-1529 was originally dated 11/21/1991 and amended later dated 4/26/1993.)** It is anticipated that this same TMP will be approved and adopted by the Hawaii Department of Health as a replacement for the 1993 "Casing Monitoring Program." Revisions to testing and monitoring provisions in the 1993 "Casing Monitoring Program" have been made as a result of a joint review of PGV's injection well monitoring and testing involving EPA, BLM (as advisor to EPA), HDOH and PGV. The purpose of these revisions is to better accomplish the goal of protecting the groundwater aquifer under the PGV project site, which is considered to be a USDW. The principle changes in the monitoring and testing procedures are as follows:

- As described in Section 3.1 of this TMP for wells in injection service, the annulus nitrogen pressure will be maintained to keep the nitrogen/water interface at a depth of at least 2000 ft.

The 1993 CMP requires that the nitrogen/water interface be maintained "more than half way down the annulus." Based on a nominal casing depth of 4000 ft., the two criteria are effectively the same.

- In accordance with Section 3.2.1, the annual casing pressure test of each well will be done by depressing the water level to 3000 ft. with nitrogen while the well is on injection. Annulus pressure drop exceeding 10% in five hours will be considered indicative of a leak requiring diagnosis and repair.

  The 1993 CMP specifies that the pressure test be done by depressing the water level to the shoe of the 9-5/8-inch casing with nitrogen (while, by practical necessity, the well is shut in.). An annulus pressure drop exceeding 8% in 30 minutes was considered indicative of a leak requiring diagnosis and repair. The principle difference is the increase in length of the test period from 30 minutes to five hours, which makes the nitrogen pressure test equivalent to a 30-minute test with water.

1.2 Purpose

The purpose of this TMP is to specify the observations, tests, drilling operations and , if necessary, remedial actions required to insure that the mechanical integrity of injection well casing and cement is maintained through the drilling, testing and operation of PGV wells. The cemented and hung casing strings that are used in the PGV wells are designed to prevent contamination of any underground source of drinking water (USDW) by injected fluids. Contamination of the USDW's might occur if the casing strings are breached due to corrosion or mechanical failure or if there is a failure of the cement to seal the casing/borehole annulus between the casing shoe and the lowermost USDW. The testing and monitoring program described below is designed to detect and diagnose a loss of mechanical integrity in the casing or cement.

Remedial actions required to restore mechanical integrity are also described.

1.3 Scope

This TMP covers all injection wells on the 500-acre PGV site.

2. TESTING DURING DRILLING AND COMPLETION

2.1 Pressure Testing During Drilling

Each injection well is completed with three casing strings (not including the 30-inch conductor pipe) cemented to the surface (Figure 1). Upon completion of cementing each casing string and prior to drilling out the cement shoe, the casing well be pressure tested. The DLNR will be notified at least 24 hours before each test for the opportunity to witness it. The test will consist of pressurizing the casing with water or drilling mud to a specified test pressure and monitoring the pressure for 30 minutes with the well shut-in. The minimum casing test pressure shall be approximately one-third of the internal yield pressure rating, provided that the test pressure shall not be less than 600 psig nor greater than 2500 psig. In cases where combination strings or liners are involved, the above test pressures shall apply to the lowest pressure-rated casing. The pressure drop during the 30-minute period shall not exceed 10% of the test pressure.

In the event of a pressure loss exceeding the above criterion, one or more of the following diagnostic methods will be used to locate the leak:

- Temperature log while injecting
- Shut-in temperature survey
- Casing inspection logs with multi-arm caliper and/or magnetic inspection tools
- Pressure testing with a packer(s) on drillpipe
- Other applicable methods

After identification of the point of leakage, a cement squeeze job will be performed and the casing retested.

After a successful pressure test of each casing string, drilling will proceed to a point at least one foot below the casing shoe, and a pressure leak-off test will be performed to test the integrity of the annular cement. Each test will be performed at a pressure approaching the fracturing pressure of the exposed formation. If there is excessive leak-off, a squeeze cement job will be performed, the cement will be drilled out and the test will be repeated. Drilling will not proceed until an effective cement seal is established in the casing/borehole annulus above the casing shoe. In some situations, such as the case where there is natural formation permeability immediately below the casing shoe, it may not be practical to prove cement integrity with the pressure test described above. As an alternative, a standard water shutoff test (WSO) may be done above the shoe, or shut-in temperature surveys may be run.

2.2 Logs and Surveys During Injection Testing

Upon completion of drilling and prior to installation of the hangdown liner, a water injection test may be performed, if needed, to obtain a preliminary evaluation of the well. During such a test, one or more of the following logs or surveys may be run:

- TPS or T/P logs through the open hole and cased intervals with the well on injection; or

- Shut-in temperature survey(s) before and/or after injection.

If any of these logs or surveys indicates a loss of mechanical integrity, the problem will be diagnosed, and repair procedures will be performed in accordance with Section 2.3.

2.3 Casing Repair

Once a loss of mechanical integrity is identified and approximately located, casing repair procedures will be initiated. These procedures may include any or all of the following activities:

2.3.1 Shut in well and run magnetic and multi-arm casing inspection logging tools to locate the leak and to evaluate the casing condition.

2.3.2 Rig up workover rig on well. Run packer(s) on drillpipe and pressure test to confirm suspected leaking interval.

2.3.3 Execute cement squeeze job to seal casing leak or stop interzonal flows behind casing.

2.3.4 Perform casing pressure test and other diagnostic tests as necessary to confirm success of the remedial work. If good, move rig off well and return well to injection service.

2.3.5 In the event of major casing failure, a cemented liner may be installed through the damaged interval.

2.3.6 Prior to drilling out the liner shoe, the liner will be pressure tested as described in Section 2.1.

2.3.7 If mechanical integrity cannot be restored satisfactorily, the well will be plugged and abandoned.

3. MONITORING AND TESTING AFTER WELL IS PLACED IN SERVICE

3.1 Continuous Monitoring During Routine Injection Operations

During routine injection well operations, including brief periods when well(s) may be temporarily out of service, the following conditions will be maintained:

3.1.1 A continuous recording of the following parameters will be maintained for each well:

* Injection wellhead pressure,
* Annulus (nitrogen) pressure, and
* Injection flow rate.

These parameters shall be recorded on a graphical chart which shows their relationship to elapsed time. Plant operators will take daily readings at each well.

3.1.2 The annular space between the hangdown liner and cemented casing will be pressurized with nitrogen, and the pressure will be monitored and recorded in accordance with Section 3..1. above. The annulus will be repressurized with nitrogen as necessary to maintain the nitrogen/water interface at a depth of 2000 ft KB (1975 ft below ground level) or deeper. some loss of nitrogen pressure is normal, and occasional repressurization will be required. If the rate of nitrogen pressure decline is such that it is impractical to maintain the required minimum pressure, it will be considered indicative of a leak requiring diagnosis and repair.

3.2 Annual Testing

Once annually, tests and surveys will be conducted to verify mechanical integrity of the hangdown liner. The casing and hangdown liner will be tested for leaks by one of the following procedures, or a combination thereof.

3.2.1 Perform a pump-down test on the annulus between the hangdown liner and the cemented casing. The test will be done with the well on injection at normal operating flow rate and wellhead pressure, or higher.

<u>or</u>

3.2.2 If the hangdown liner is pulled, the casing may be pressure tested above a bridge plug or packer set near the shoe following the basic procedure outlined in Section 2.1. Integrity of the hangdown liner may be verified by inspection on the surface, by a pressure test (with nitrogen) after it is run in the hole, or by a TPS log with the well on injection.

Integrity of the cement (external mechanical integrity) will be checked during each workover by one or more of the following procedures:

3.2.3 One or more shut-in static temperature surveys will be run. Shut-in time will be at least 12 hours, or longer if necessary to obtain meaningful results.

<u>or</u>

3.2.4 Other logs or surveys may be run, at the discretion of PGV, if static temperature surveys are not definitive.

3.3 Restoration of Mechanical Integrity or Abandonment

In the event that the diagnostic procedures indicate a loss of mechanical integrity, remedial or abandonment procedures will be carried out as specified in Section 2.3.