***FY 1996 Summary of
Hot Dry Rock Geothermal Power Project***

***Geothermal Energy Technology Department
New Energy and Industrial Technology Development Organization***

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1. Introduction

Since 1985, the New Energy and Industrial Technology Development Organization (NEDO) has enforced the "Hot Dry Rock Geothermal Power Project in Japan (Element Technology Development)" supplementary to the Sunshine Project and succeeding New Sunshine Project sponsored by the Ministry of International Trade and Industry's Agency of Industrial Science and Technology (AIST). The objective of this project is to identify the feasibility of a hot dry rock power generation system in Japan through the creation of artificial hot water systems and the development of fracture mapping/borehole measuring technologies as well as a system to extract heat by circulation. More specifically, element technologies including those for the creation of man-made reservoirs, promoted connection, logging, AE mapping, evaluation of inner reservoir flows, and prediction of extracted heat amount are under development while establishing a system to extract heat by circulation within a HDR on the test site installed in Hijiori, Okura-mura, Mogami-gun, Yamagata prefecture.

In Japan, R&D of hot dry rocks started in 1978 at the north-western foot of Mt. Yakedake, Gifu Pref. as part of AIST's Sunshine Project. For another thing, NEDO was a main body to participate in a 7-year period from 1981 through 1986 into the hot dry rock development program whose field experiments were made in Fenton Hill, USA as a joint research project pursued by three countries of Japan, the United States, and Germany under an IEA agreement. On the basis of experimental results at Yakedake and experiences in Fenton Hill, NEDO started field experiments in Hijiori in 1985.

This project is now in operation under the system illustrated below. We shall acknowledge the respectful guidance received from the New Sunshine Project Promotion Headquarters of AIST, MITI as well as the deliberate review of technical development implementation plans in detail by the Committee on HDR Program and 3 subcommittees established thereunder toward the realization of this project. We also appreciate the assistance given by AIST's National Institute for Resources and Environment (NIRE) in analyzing and evaluating experimental data. The Hijiori project has been conducted smoothly with the understanding of and cooperation rendered from local governments of Okura Village and Yamagata Prefecture.

2. Present State and Background of Hijiori Hot Dry Rock Test Site

The Hijiori hot dry rock test site is located on the southern edge of the two-kilometer diameter Hijiori caldera, which was formed about 10,000 years ago (Fig. 1). Topographic effects extend underground, and the prevalence of fracture groups has a strike in the east-west direction and a dip to the north side with high angle. The underground system of the Hijiori Hot Dry Rock Test Site includes a reservoir (shallow reservoir) at a depth of about 1,800 m, a reservoir (deep reservoir) at a depth of about 2,200 m, and four wells. History of the technical development at Hijiori test site is largely divided into two periods. One is ranging from fiscal 1985 to fiscal 1991, when the shallow reservoir was formed and various technological development works was carried out. The other is during and after fiscal 1992 when the study entered the deep reservoir development.

From fiscal 1985 to fiscal 1986, a seven-inch casing was installed in SKG-2, which had been drilled for developing the conventional hydrothermal resources, with a 14 m zone left uncased at the hole bottom. Hydraulic fracturing was conducted in the granodiorite basement as a depth of 1,500 m or more to create an artificial reservoir at about 1,800 m depth. In fiscal 1987, HDR-1 was drilled to a depth of 1,805 m toward the shallow reservoir formed in fiscal 1986, and communicated successfully to SKG-2 via the reservoir. During fiscal 1988, a circulation test for heat extraction was performed for two weeks using SKG-2 as the injection well and HDR-1 as the production well. In this test, hot water and steam at a maximum temperature of 180°C were produced. The test data, however, could not be used to determine the characteristics of the reservoirs because hot water and steam from HDR-1 blew out intermittently. After the circulation test, HDR-1 was deepened to 2,205 m to develop a deep reservoir in the future, and PBR casing liner was installed leaving the bottom 50 m of the hole open. In fiscal 1989, HDR-2 was drilled to a depth 1,910 m to confirm the location the hydraulic fracture and to perform a stable production. HDR-2 intersected the fracture closely to its expected location, thus confirming the effectiveness of the fracture mapping by acoustic emission (AE). After drilling HDR-2, an injection and circulation test was conducted to evaluate the upper reservoir at near 1,800 m depth using SKG-2 as the injection well and HDR-1 and HDR-2 as the production wells. The test for 29 days produced hot water and steam almost stably at a temperature range of from 160 to 170°C. Resultant thermal energy was calculated to be about 4.5 MW thermal. The recovery rate during the circulation test, however, remained at about 40%. In fiscal 1990, HDR-3 was drilled to a depth of 1,907 m to improve the productivity by constructing a multi-production well system. The target point of this drilling was set to the eastern side of SKG-2, where notable AEs were emitted in the circulation test for 29 days of fiscal 1989. A hydraulic Connection test after drilling indicated a good result between SKG-2 and HDR-3. In fiscal 1991, a circulation test for 90 days of the shallow reservoir was conducted using SKG-2 as the injection well and other three well as the production wells. The circulation with the multi-production well system is internationally unique in hot dry rock technical development. With the system, the circulation test on the whole wells and the production test for individual wells were carried out. The recovery rate of hot water and steam was 78% and the extracted heat energy was 8.5 MW thermal under a steady production condition. This proved the effectiveness of the multi-production well system.

In fiscal 1992, aiming at the creation of a larger scale and higher temperature reservoir, a hydraulic fracturing was performed at a depth of 2,151 to 2,205 m of HDR-1 using PBR. Creation of the reservoir was confirmed by AE monitoring. During fiscal 1993, HDR-3 was deepened to a depth of 2,303 m, and the Connection of HDR-3 with the deep reservoir was confirmed. In fiscal 1994, the shallow plug-back portion of HDR-1 well was repaired and then, HDR-2 well was deepened up to a depth of 2,300 m for connection to a deep reservoir. After deepening HDR-2 well, an injection test was executed to confirm that HDR-2 well connects with the deep reservoir. As the result of the past development, a Hijiori circulation system consisting of two layers was formed. In fiscal 1995, a preliminary circulation test was executed for a deep reservoir. In this test, river water injection started with HDR-1 well and continued for 25 days to produce steam and hot water from HDR-2 and HDR-3 wells. As a result, producing of steam and hot water at a temperature of about 180°C and a flow rate of about 14 to 15 t/h was obtained from each production well in the case of injection rate at 1 to 2 m³/min. However, the entire recovery was 40%. As the result of this test, it was confirmed that the impedance of HDR-3 well was higher than that of HDR-2 well. The necessity for improvement of the connection between HDR-1 well and HDR-3 well was clarified.

Fig. 1 Location of Hijiori HDR Test site:
 SKG-1 is an observation well, ST-1 through 11 are AE observation points

3. Technical Development Plan in fiscal 1996

In fiscal 1996, the following plans were set in accordance with the preliminary circulation test result in fiscal 1995 in order to improve the connectivity of HDR-3 well which was inferior to HDR-2a well in production characteristic.

- ① To improve the connection of a deep artificial reservoir, particularly to improve the HDR-3 well side, execute a flow enhancement test for about one month. Moreover, perform a conceptual design of a long-term circulation test.
- ② To evaluate chemical features of a deep reservoir, sample and analyze production and injection water.
- ③ Examine the geological features of ground surface and prepare an integrated geological-feature model.
- ④ Prepare a deep reservoir model by using various data values obtained through the circulation test.
- ⑤ Minutely analyze the AE data having been obtained so far and study the properties of a deep reservoir.
- ⑥ Perform the PTS logging during the flow enhancement test to quantitatively evaluate an output place.
- ⑦ To investigate environment, perform the micro-earthquake observation and sampling and analysis of river water and spring hot water.

4. Results of Technical Development in fiscal 1996

4.1 Flow enhancement test

In the flow enhancement test, tests for improving the productivity of HDR-3 well were executed.

- ① To increase the pressure applied to a deep reservoir as much as possible so as to decrease the impedance nearby a deep reservoir at the connection depth with HDR-1 well, execute the circulation test by decreasing a valve opening (valve opening of 20 to 40%).
- ② Particularly, it is expected that a thermal stress develops and enlarges a crack of connection by the fact that a lower temperature than a reservoir temperature fluid flows. To progress the effect, increase the valve opening so as to increase the flow rate of the fluid (valve opening of 40 to 100%).
- ③ To evaluate the result of each test for improving connection, compare test results by performing stable circulation at 40% before and after.
- ④ Moreover, to evaluate the connection improvement in this fiscal year and obtain the data for future long-term circulation test, production from both wells at the opening (40%) same as that in the last fiscal year and execute the productive characteristic test (characteristic test between 40 and 100%) under the exhalation state of the both wells and study an optimum circulation system.

It was scheduled that injection and circulation shown in Fig. 2 were executed after the PTS logging in the stationary state before starting the flow enhancement test on four wells (HDR-1, HDR-2a, HDR-3, and SKG-2). The flow enhancement test was executed for 31 days between August 10 and September 9 and the test period including the monitoring executed up to September 11 was 33 days. Table 1 and Table 2 show the outline of results of the flow enhancement test.

Table 1 Outline of results of flow enhancement test in FY 1996 (Excluding step rate test)

Period	Flow Enhancement Test in 1996		Total
	August 10 - September 1	September 2 - September 9	
	One-production-well test (HDR-2a)	Two-production-well test (HDR-2a & HDR-3)	
HDR-1 injection	32200 m ³	8700 m ³	40900 m ³
HDR-2a production		3650 m ³ (41.2 %)	3650 m ³ (9.0%)
HDR-3 production	6340 m ³ (19.7 %)	2720 m ³ (31.3 %)	9060 m ³ (22.2 %)
Temperature and pressure of wellhead during production by HDR-2a		Pressure; about 1 MPa Temperature: about 180 °C	
Temperature and pressure of wellhead during production by HDR-3		Pressure; about 1 MPa Temperature: about 180 °C	

Fig. 3 - Fig. 11 show the above test results. From Fig. 4, it is found that the injection pressure of HDR-1 well lowered by about 15kg/cm² in the test period (90--> 75.5 kg/cm²). It is estimated that this is because thermal cracks were caused by the fact that the impedance nearby the injected-fluid outgoing place of HDR-1 well was decreased due to continuous forced injection for about one month and by continuously flowing a low-temperature fluid through high-temperature rocks.

From Fig. 5, it is found that the wellhead pressure of HDR-3 well under independent production is 8 to 9 kg/cm² and the temperature at the wellhead is about 175°C. In the test, production of well stopped by adjusting the valve opening to improve the connection of HDR-3 well. Moreover, production became unstable while a PTS logging unit lowered in the inside well.

As shown in Fig. 6, in the case of production of HDR-2a well performed at the latter half of the test, the wellhead pressure is about 9.5 kg/cm² and the temperature at the wellhead is about 180°C. Moreover, in the case of the state in the well of HDR-2a well at the time of independent production of HDR-3 well, an internal flow was observed from the PTS logging result, in which a fluid came in from a deep reservoir (about 2,150 m), rose

Fig. 2 Plan of a flow enhancement test in FY 1996

Table 2 Progress of the flow enhancement test in Fiscal year 1996(1)

Test item	Date	Injection rate (m ³ /min)	Injection pressure (kg/cm ²)	Remarks
Step rate test before circulation	8/10 10:00 - 8/10 11:50 11:50 - 13:00 13:00 - 13:15 13:15 - 13:36 13:36 - 13:52 13:52 - 14:09 14:09 - 14:29 14:29 - 14:53 14:53 - 16:53	1.0 0 0.25 0.5 0.75 1.0 1.5 1.8 0	89 89→1 18 52 74 83 93 102 102→5	10:00-10:50 PTS fixed-point observation (1500m), 10:50-11:50 Outgoing specifying, Injection rate 110m ³ Shut-in Injection rate of 120 m ³ PTS fixed-point observation (1500m) Shut-in
Test 1 (constant circulation at HDR-3 well); Valve opening of 40%	8/10 - 8/16 9:00	1.0	89	① 8/10 16:53; Start of continuous injection at 1.0 m ³ /min ② 8/11 8:50; Arrival at HDR-2a-well water-level wellhead (Full opening of secondary valve) ③ 8/11 20:30; Arrival at HDR-3-well water-level wellhead (HDR-2a-well wellhead pressure of 1.5 kg/cm ²) ④ 8/12 10:00; Start of intermittent exhalation (15:00 The opening was set to 25% for improvement of intermittent state.) ⑤ 8/12 20:00; Start of continuous production (HDR-1; Wellhead pressure of 91 kg/cm ² , HDR-2a; Wellhead pressure of 1.4 kg/cm ²), ⑥ 8/13 8:50-11:20; Adjustment of wellhead opening of HDR-3 well (From 25% to 40%) ⑦ 8/13 19:15; First-time tracer test (Total volume of 1 m ³ including uranine, potassium iodide, and tungsten) ⑧ 8/14 8:50-14:20; PTS logging of HDR-2a well ⑨ 8/15 8:00; HDR-1; Wellhead pressure of 89kg/cm ² , HDR-2a; Water level of 4.4 m, HDR-3; Wellhead opening of 40%, WHT:176°C, Steam flow rate: 4 t/h, Hot water flow rate: 14 t/h (Recovery of 30%) ⑩ 8/15 8:50-20:00; PTS logging of HDR-3 well, 18:30; Temporary stop of production (Recovered at 22:00)
Test 2 (Back pressure stimulation of HDR-3 well); Valve opening of 25%	8/16 9:00 - 8/22 8:45	1.0	83.5	① 8/16 9:00-11:30; Adjustment of wellhead opening of HDR-3 well (From 40% to 25%) ② 8/16 11:30; Temporary stop of production during adjustment of wellhead opening of HDR-3 well (Recovered at 13:00) ③ 8/16 11:30; Second-time tracer test (Total volume of 1 m ³ including uranine and potassium bromide) ④ 8/20 8:45-13:30; PTS logging of HDR-2a well ⑤ 8/21 8:00; HDR-1; Wellhead pressure of 83.5 kg/cm ² , HDR-2a; Wellhead pressure of 5.0 kg/cm ² , HDR-3; Wellhead opening: 25%, WHP:9.7kg/cm ² , WHT:177.5°C, Steam flow rate: 1.5 t/h, Hot water flow rate: 7 t/h (Recovery of 15%) ⑥ 8/21 9:15-19:20; PTS logging of HDR-3 well

Table 2 Progress of the flow enhancement test in Fiscal year 1996(2)

Test item	Date	Injection rate (m ³ /min)	Injection pressure (kg/cm ²)	Remarks
Test 3 (Comparative production of HDR-3 well); Valve opening of 40%,	8/22 8:45 - 8/25 9:00	1.0	82	① 8/22 8:45-11:15; Adjustment of wellhead opening of HDR-3 well (From 25% to 40%) ② 8/24 8:00; HDR-1; Wellhead pressure of 82 kg/cm ² , HDR-2a: Wellhead pressure of 4.3 kg/cm ² , HDR-3; Wellhead opening: 40%, WHP:9.5kg/cm ² ,WHT:179°C, Steam flow rate:3.5 t/h, Hot water flow rate: 10 t/h (Recovery of 22.5%) ③ 8/24 8:40-19:30; PTS logging of HDR-3 well
Test 4 (Open of HDR-3 well); Valve opening of 46%	8/25 9:00 - 8/30 10:20	1.0	77.4	① 8/25 9:00-15:35; Adjustment of wellhead opening of HDR-3 well (From 40% to 60%) ② 8/26 8:00; HDR-1; Wellhead pressure of 81 kg/cm ² , HDR-2a; Wellhead pressure of 3.5 kg/cm ² , HDR-3; Wellhead opening: 60%, WHP:6.3kg/cm ² ,WHT:164°C, Steam flow rate: 5.6 t/h, Hot water flow rate: 19 t/h (Very moderate pulsation, Recover of 41%) ③ 8/26 9:00-11:00; Adjustment of wellhead opening of HDR-3 well (From 60% to 65%), 23:30;Stop of production of HDR-3 well (Change to intermittent state) ④ 8/26 23:56 Adjustment of wellhead opening(65%→60%) ⑤ 8/27 3:40;Restart of production 7:00;Stop of production 8:00;Adjustment of wellhead opening(60%→50%) 9:20; Restart of production 14:20; Stop of production and adjustment of wellhead opening(50%→40%) 16:30; Restart of production ⑥ 8/28 9:00-15:20; Adjustment of wellhead opening of HDR-3(40%→46%) ⑦ 8/30 8:00; HDR-1; Wellhead pressure of 77.4 kg/cm ² , HDR-2a;Wellhead pressure of 3.8 kg/cm ² , HDR-3; Wellhead opening:46%, WHP:7.5kg/cm ² ,WHT:172°C, Steam flow rate: 4.5 t/h, Hot water flow rate: 11t/h (Recovery of 25.8%) ⑧ 8/29 11:15-8/30 4:45; PTS logging of HDR-2a well ⑨ 8/30 8:40-8/30 10:00; PTS logging of HDR-3 well, (Tending to stop production under logging), 10:20;Stop of production
Test 5 (Comparative production of HDR-3 well); Valve opening of 40%	8/30 10:20 - 9/2 9:00	1.0	76.6	① 8/30 10:20;Adjustment of wellhead opening of HDR-3 (46%→40%) ② 8/30 12:30;Restart of production ③ 8/30 24:00;Third-time tracer test (Total volume of 1 m ³ including potassium iodide, uranine, and amino G acid) ④ 9/1 8:00; HDR-1; Wellhead pressure of 76.6 kg/cm ² , HDR-2a; Wellhead pressure of 5.2 kg/cm ² , HDR-3; Wellhead opening: 40%, WHP:8.3kg/cm ² ,WHT:173°C,Steam flow rate: 3.3 t/h, Hot water flow rate: 10.2 t/h (Recovery of 22.5%) ⑤ 9/1 8:40-14:30; PTS logging of HDR-3 well (10:00 Stop of production under logging)

Table 2 Progress of the flow enhancement test in Fiscal year 1996(3)

Test item	Date	Injection rate (m ³ /min)	Injection pressure (kg/cm ²)	Remarks
Test 6 (Confirmation of connection improvement effect), Start of production of HDR-2a, Valve opening of 40%	9/2 9:00 - 9/6 11:40	1.0	75.5	① 9/2 9:00- 9:30; Adjustment of wellhead opening of HDR-3 well(40%→36%) ② 9/2 13:10-21:10; Adjustment of wellhead opening of HDR-2a well (0%→40% ; Start of production) ③ 9/2 21:50; Adjustment of wellhead opening of HDR-3 (36%→38%) ④ 9/3 8:40-9:00; Adjustment of wellhead opening of HDR-3 (38%→40%) ⑤ 9/3 18:30; Fourth-time tracer test (Total volume of 1 m ³ including fluorescent dye and potassium bromide) ⑥ 9/4 9:00-14:30; PTS logging of HDR-2a well ⑦ 9/5 9:00-14:30; PTS logging of HDR-3 well 11:40; HDR-2a well was fully opened because production of HDR-3 well stopped under logging 13:30; Restart of production of HDR-3 well 16:20 Restart of production of HDR-2a well ⑧ 9/6 8:00; HDR-1; Wellhead pressure of 75.5 kg/cm ² HDR-2a; Wellhead opening: 40%, WHP:9.6kg/cm ² , WHT:179°C, Steam flow rate: 5.2 t/h, Hot water flow rate: 16.3 t/h (Recovery of 35.8%) HDR-3; Wellhead opening: 40%, WHP:10.1kg/cm ² , WHT:180°C, Steam flow rate: 4.9 t/h, Hot water flow rate: 9.5 t/h (Recovery of 24.0%)
Test 7 (Well characteristic test); HDR-2a and HDR-3 production characteristics	9/6 11:40 - 9/8 9:00	1.0	75.5	① 9/6 11:40; HDR-2a valve opening of 40 to 43% 13:10; 43%→46% 13:40; 46%→50% ② 9/7 8:50; HDR-2a valve opening of 50 to 45% 17:00; 45%→40% ③ 9/8 8:00; HDR-1; Wellhead pressure of 75.5 kg/cm ² , HDR-2a; Wellhead opening: 40%, WHP:9.2kg/cm ² , WHT:176°C, Steam flow rate: 4.8 t/h, Hot water flow rate; 13.0 t/h (Recovery of 29.7%) HDR-3; Wellhead opening:40%, WHP:8.7kg/cm ² , WHT:176°C, Steam flow rate: 4.2 t/h, Hot water flow rate:11.1 t/h (Recovery of 25.5%)
Test 8 (Shut-in test)	9/8 9:00 - 9/9 9:45	0	75.5→12	① 9/8 9:00; Stop of injection to HDR-1 well (Wellhead pressure of 75.5 kg/cm ²) ② 9/9 9:45; 12.1kg/cm ²

Table 2 Progress of the flow enhancement test in Fiscal year 1996(4)

Test item	Date	Injection rate (m ³ /min)	Injection pressure (kg/cm ²)	Remarks
Step rate test after circulation	9/9 9:45 - 9/9 11:25	1.0	54	<p>9:45-10:30 PTS fixed-point observation (1500m). 10:30-11:25 Outgoing specifying, Injection rate 100m³</p> <p>Shut-in</p> <p>Injection rate of 120 m³</p> <p>PTS fixed-point observation (1993m)</p> <p>End of injection(Shut-in)</p> <p>① 16:00; Opening of wellhead of HDR-1 well for recovery of PTS logging unit (Wellhead pressure of 20 kg/cm²)</p> <p>② 18:00; Wellhead pressure of 0 kg/cm²</p>
	11:25- 12:35	0	54→16	
	12:35- 12:50	0.25	21	
	12:50- 13:05	0.5	32	
	13:05- 13:20	0.75	42	
	13:20- 13:35	1.0	50	
	13:35- 13:55	1.5	64	
	13:55- 14:20	1.8	75	
	9/9 14:20	0		
Test 9 (monitoring test)	9/9 14:20 - 9/11 17:30			<p>① 9/10 10:30; Stop of production of HDR-2a well under logging</p> <p>② 9/11 17:30; Stop of production of HDR-3 well (Full opening of secondary valve)</p> <p>③ 9/12; Temperature logging of HDR-1 well</p>
SKG-2 well pressure monitoring	8/10 - 9/25			<p>Observation depth of 1,400 m</p> <p>(Continuous measurement using capillary tube system)</p>

HDR-3 VALVE OPENING (1996)

Test name (Date)

- ①HDR-1:WHP
- ②HDR-2a:WIP
- ③HDR-3:Valve Open
- ④HDR-3:WHP
- ⑤HDR-3:WHT
- ⑥HDR-3:Water
- ⑦HDR-3:Steam
- ⑧HDR-3:Recovery
- ⑨Flash Depth

Test 1 (8/15)
①89kg/cm²
②-4.4m
③40%
④8.8kg/cm²
⑤176°C
⑥14t/h
⑦4t/h
⑧30%
⑨1240m

Test 2 (8/21)
①83.5kg/cm²
②5kg/cm²
③25%
④9.7kg/cm²
⑤177.5°C
⑥7t/h
⑦1.5t/h
⑧15%
⑨600m

Test 3 (8/24)
①82kg/cm²
②4.3kg/cm²
③40%
④9.5kg/cm²
⑤179°C
⑥10.0t/h
⑦3.5t/h
⑧22.5%
⑨990m

Test 4 (8/26)
①81kg/cm²
②3.5kg/cm²
③60%
④6.5kg/cm²
⑤164°C
⑥19t/h
⑦5.6t/h
⑧41.0%
⑨なし

Test 4 (8/30)
①77.4kg/cm²
②3.8kg/cm²
③46%
④7.5kg/cm²
⑤172°C
⑥11t/h
⑦4.5t/h
⑧25.8%
⑨なし 1170m

Test 5 (9/1)
①76.6kg/cm²
②5.2kg/cm²
③40%
④8.3kg/cm²
⑤173°C
⑥10.2t/h
⑦3.3t/h
⑧22.5%
⑨915m

Test 6 (9/6)
①75.5kg/cm²
②9.6kg/cm²
③40%
④10.1kg/cm²
⑤180°C
⑥9.5t/h
⑦4.9t/h
⑧24.0%
⑨なし 1140m

Test 7 (9/8)
①75.5kg/cm²
②9.2kg/cm²
③40%
④8.7kg/cm²
⑤176°C
⑥11.1t/h
⑦4.2t/h
⑧25.5%
⑨None

Fig. 3 Outline of flow enhancement test

HDR-1 INJECTION

Fig. 4 Records of Injection rate and Pressure in HDR-1 well

HDR-3 PRODUCTION

Fig.5 Records of Injection rate, Temperature and Pressure in HDR-3 well

HDR-2a PRODUCTION

Fig.6 Records of Injection rate, Temperature and Pressure in HDR-2a well

Fig. 7 Records of downhole Pressure in SKG-2 well

STEP RATE TEST (1996)

BEFORE CIRCULATION

Fig. 8 Results of step rate test before circulation

AFTER CIRCULATION

Fig. 9 Results of step rate test after circulation

Fig. 10 History of wellhead pressure-injection rate
(preliminary circulation test and flow enhancement test)

Fig. 11 Production well characteristic curve

Table 3 Analysis results of injection test in Hijiori HDR test site (1989 to 1996)

EXPERIMENT DATE	TRANSMISSIVITY m ² /Pa.sec	STORATIVITY m/Pa	EXPERIMENT METHOD	ANALYSIS METHOD	OTHERS
1989 10/18	2.97 × 10 ⁻⁹	1.25 × 10 ⁻⁸	SKG-2 ~ HDR-1 interference	pressure matching	shallow reservoir
	1.25 × 10 ⁻⁹	8.19 × 10 ⁻⁹	SKG-2 ~ HDR-2 interference	pressure matching	shallow reservoir
1990 8/3	3.72 × 10 ⁻⁹	0.967 × 10 ⁻⁸	SKG-2 ~ HDR-1 interference	pressure matching	shallow reservoir
	3.67 × 10 ⁻⁹	1.12 × 10 ⁻⁹	SKG-2 ~ HDR-2 interference	pressure matching	shallow reservoir
10/27~28	1.42 × 10 ⁻⁹	5.58 × 10 ⁻⁸	SKG-2 ~ HDR-1 interference	pressure matching	shallow reservoir
	1.50 × 10 ⁻⁹	2.10 × 10 ⁻⁹	SKG-2 ~ HDR-2 interference	pressure matching	shallow reservoir
	1.35 × 10 ⁻⁹	3.44 × 10 ⁻⁹	SKG-2 ~ HDR-3 interference	pressure matching	shallow reservoir
1992 7/19	5.61 × 10 ⁻¹⁵	3.01 × 10 ⁻¹⁷	HDR-1 build up & fall off	pressure matching	HDR-1 before fracturing
	~	~			deep reservoir
7/24	1.86 × 10 ⁻¹¹	0.45 × 10 ⁻¹⁶			
	6.76 × 10 ⁻¹⁰	1.09 × 10 ⁻¹⁰	HDR-1 build up & fall off	pressure matching	HDR-1 after fracturing
8/7					deep reservoir
	3.89 × 10 ⁻⁹	1.82 × 10 ⁻⁹	HDR-1 build up	pressure matching	HDR-1 after plug back
					deep & shallow reservoir ?
1993 8/30~31	1.97 × 10 ⁻⁹	3.98 × 10 ⁻⁹	HDR-1 ~ HDR-3 interference	pressure matching	deep & shallow reservoir ?
8/31	9.82 × 10 ⁻¹⁰	1.02 × 10 ⁻⁹	HDR-1 build up	pressure matching	deep & shallow reservoir ?
	~	~			
8/31	1.16 × 10 ⁻⁹	2.91 × 10 ⁻⁹			
	2.14 × 10 ⁻¹⁰	~	HDR-1 fall off	homer plot	deep & shallow reservoir ?
9/2	1.23 × 10 ⁻⁹	~	HDR-3 fall off	homer plot	deep & shallow reservoir ?
1994 9/22	1.66 × 10 ⁻⁸	6.74 × 10 ⁻⁹	HDR-1 ~ SKG-2 interference	pressure matching	deep & shallow reservoir
	9.44 × 10 ⁻⁹	6.58 × 10 ⁻⁹	HDR-1 ~ SKG-2 interference	pressure matching	deep & shallow reservoir
	8.21 × 10 ⁻⁹	4.21 × 10 ⁻⁹	HDR-1 ~ HDR-2 interference	pressure matching	deep & shallow reservoir
	6.17 × 10 ⁻⁹	6.75 × 10 ⁻⁹	HDR-1 ~ HDR-3 interference	pressure matching	deep & shallow reservoir
9/23	1.48 × 10 ⁻¹⁰	2.60 × 10 ⁻¹⁰	HDR-1 build up	pressure matching	deep & shallow reservoir
	~	~			
	5.41 × 10 ⁻¹⁰	6.60 × 10 ⁻⁸			
1995 8/6	4.9 × 10 ⁻¹⁰	1.6 × 10 ⁻¹⁰	HDR-1 build up	pressure matching	deep reservoir before circulation
	~	~			
8/31	2.4 × 10 ⁻⁹	1.4 × 10 ⁻⁹			
	3.5 × 10 ⁻⁹	1.2 × 10 ⁻⁹	HDR-1 build up	pressure matching	deep reservoir after circulation
1996 8/10	2.9 × 10 ⁻¹⁰	1.3 × 10 ⁻⁹	HDR-1 build up	pressure matching	deep reservoir before circulation
	~	~			
9/9	2.4 × 10 ⁻⁹	2.9 × 10 ⁻⁸			
	2.5 × 10 ⁻⁹	1.6 × 10 ⁻⁹	HDR-1 build up	pressure matching	deep reservoir after circulation

along the well, and thereafter went out to a shallow reservoir (about 1,800 m). It is estimated that some of the fluid flown to the reservoir from a shallow portion of HDR-2a is also produced from HDR-3 well through the shallow reservoir.

Referring Fig.7 and based on the continuous measurement records of inside well pressure in SKG-2 well only connected to the shallow reservoir, it is estimated that the pressure rise in the well at the beginning of the test raises the shallow-reservoir pressure because an internal flow occurs in which an object incoming from a deep portion of HDR-2a well goes out to the shallow reservoir. Thereafter, a well pressure change is observed in SKG-2 well in accordance with the fluctuation in well pressure due to the adjustment of valve opening of HDR-3 well. However, it is found that the fluctuation is smaller compared to the pressure change in the well at the time of production by two wells due to start of production of HDR-2a well.

From the injection characteristic curves of HDR-1 well obtained before and after the flow enhancement test and through the preliminary circulation test in the last fiscal year in Fig. 10, it was observed that an injection pressure was slowly lowered by intermittently performing a circulation test. However, in the latter period of the test in this fiscal year, it is observed that the injection pressure is stabilized at about 75 kg/cm².

Fig. 11 shows well characteristic curves of HDR-2a and HDR-3 wells obtained from preliminary circulation tests of a deep reservoir executed in the last fiscal year and this fiscal year. In the case of these curves, points where injection flow rates and injection pressures differ are also plotted. Therefore, though it is difficult to obtain a conclusion from the viewpoint of flow rate, it is found from the results that HDR-2a well is superior to HDR-3 well in production characteristic. By using the results of step rate tests executed before and after the preliminary circulation test, the permeability of a reservoir was studied. Table 3 shows the injection test analysis results up to this fiscal year in Hijiori.

Moreover, as a part of the study of a hot dry rock system, the technical basic study when performing power generation on the basis of the past data was performed by using the binary power generation system as a power generation system. Basic conditions are shown below. Moreover, results are shown in Table 5.

- ① Use steam and hot water of HDR-2a and HDR-3 wells.
- ② Use the existing system for the power generation equipment side.
- ③ Typical values of the results of preliminary circulation tests executed in fiscal 1995 are used as the conditions of hot water flow rate and temperature (see Table 4).

Table 4 Steam and hot-water conditions

HDR-2a	Wellhead pressure	1.1 MPa
	Wellhead temperature	185 °C
	Flow rate	17 t/h
	after gas-liquid separation (at 0.1 MPa)	Steam 4 t/h Hot water 13 t/h
HDR-3	Wellhead pressure	0.8 MPa
	Wellhead temperature	178 °C
	Flow rate	12 t/h
	after gas-liquid separation (at 0.1 MPa)	Steam 4 t/h Hot water 8 t/h

Table 5 Generated power output

HDR-2a	Generated power output GROSS	310kw
	NET	250kw
	Discharged hot-water temperature	50°C
HDR-3	Generated power output GROSS	300kw
	NET	240kw
	Discharged hot-water temperature	50°C

4.2 Geochemical survey

When the flow enhancement test was performed, injected water and produced water were sampled at temporal intervals and chemically analyzed in order to contribute to estimation of properties of a reservoir and behavior of geothermal fluid. In this case, 33 samples were sampled from HDR-2a well and 127 samples were sampled from HDR-3 well to measure the electric conductivity and PH of the samples. Moreover, 23 samples of injected water were sampled to measure the electric conductivity and pH of the samples. The chemical analysis was performed for the analysis items of Na, K, Ca, Mg, Al, SO_4 , Cl, HCO_3 , B, SiO_2 , and CO_3 on 5 samples of injected water and 35 samples of produced water. Fig. 12 shows the change of injected water with time. In the case of the change of chemical components of produced water of HDR-3 well with time shown in Fig. 13, Na, K, Cl, and B show almost the same behavior, and they show a high concentration at the beginning of circulation and then the concentration is lowered and stabilized, but the concentration is increased again in the latter period of circulation (around September 6).

SO_4 shows the same behavior as Cl at the beginning of circulation and it is suggested that addition of these components including SO_4 is greatly controlled by the mixture of bed water with a high concentration (water originally present in a gap such as an underground crack) and injected water. The subsequent behavior is different from that of Cl. Particularly, the concentration rises due to direct injection of river water at the beginning of September, that is, lowering of temperature of injected water and thereafter, concentration lowers in accordance with the temperature rise of the injected water (because river water was not supplied into a pit after end of circulation). This coincides with the fact that the solubility of anhydride (CaSO_4) present in a crack of substrate has a negative dependency to temperature.

Fig. 14 shows a Na-Cl diagram. From Fig. 14, it is found that each produced water is almost linearly distributed in the mixture line between the component at the bottom left end (injected water) and the component at the top right end (bed water), that is, the behavior of these components is controlled by mixture. By obtaining the equivalent ratio of Na:Cl of the bed water serving as an end component from the gradient of the regression line, the following values are obtained: 0.49:0.51 for the produced water of HDR-2a well and 0.48:0.52 for the produced water of HDR-3 well. As the result of performing the same study on the produced water when the preliminary circulation test was executed in fiscal 1995, the produced waters of the both wells show the same values in equivalent ratio and y-intercept and therefore, it is found that the both produced waters showed almost the same behavior in both fiscal years.

Fig. 12 Records of concentration of injection water

Fig. 13 Records of concentration of production water

Fig. 14 Na-Cl diagram (Up:1995, Low:1996)

4.3 AE measurement

By rereading the AE data obtained from the hydraulic-fracturing and circulation tests executed in 1988, 1989, 1992, and 1995 among various experiments having been executed so far in the Hijiori HDR test site, AE sources were redetermined by adding data for P wave and S wave. Moreover, the hypocenter was redetermined by using not only the existing method of obtaining each AE hypocenter but also a method of obtaining many AE hypocenters and observation-point correction values at the same time.

Hypocenter determination was performed by using two methods such as Single event determination (hereafter referred to as SED method) and Joint hypocenter determination (hereafter referred to as JHD method). The SED method is a hypocenter determining method having been used so far, which a hypocenter factor minimizing the sum of squares of the travel-time residue of the initial motion of a P wave observed on each AE is obtained through successive approximation by using the least square. The JHD method is a method of solving an observation equation consisting of many AE hypocenter factors and observation-point correction values, which was developed in 1970's. This time, analysis was performed by using a data set consisting of the initial motion data for P and S waves.

Fig. 15 and Fig. 16 show AE distributions obtained by the SED method. Fig. 15 shows a case of using only P-wave initial motion data and Fig. 16 shows a case of using the initial motion data for P and S waves. As the result of comparing the both, any extreme difference is not found between epicenter distributions depending on presence or absence of S-wave data. However, in the case of the depth direction, hypocenter fluctuation is small and hypocenters are further concentrically distributed when a hypocenter is determined by also adding S-wave data compared to the case of determining a hypocenter by using P-wave data. Therefore, it is judged that a hypocenter is more accurately determined.

Fig. 17 shows the result of redetermining a hypocenter by using the JHD method. In the case of the SED method, a hypocenter is determined by using P-wave initial-motion data at four observation points or more. In the case of the JHD method, however, solutions are not well converged when the unknown are almost equal to the number of observation points. Therefore, a hypocenter was redetermined by adding the initial-motion read value of an S wave to AEs from which P-wave initial motion is read at seven observation points or more. As a result, the determined number of AEs capable of determining a hypocenter was 50 to 90% in the case of the SED method. As the result of comparing Fig. 17 (JHD method) with Fig. 16 (SED method), a hypocenter obtained by the JHD method tends to be shallowly determined compared to the case of the SED method but any remarkable difference is not found between epicenter distributions.

Hydraulic fracturing of the deep reservoir in 1992 and the AE for the preliminary circulation test in 1995 were reanalyzed in order to improve the hypocenter-position orienting accuracy. In this case, AE doublet analysis, surface-data combined analysis, and analytical technique such as orthogonal projection were used to improve the accuracy. The AE doublet analysis is a method for improving the accuracy of the relative positional relation between similar events and the surface-data combined analysis and the orthogonal projection are methods for improving the absolute position accuracy of a group. As an example, Fig. 18 shows surface observation points recorded through AE measurement when the deep-portion preliminary circulation test was performed in 1995 and AE waveforms of a three-axis double-sonde system.

The hydraulic fracturing distribution in 1992 and the AE hypocenter distribution following the preliminary circulation test in 1995 show a trend of extending in the direction of N110E. Therefore, the both distributions are compared on a cross sections projected in the direction and the direction perpendicular to the former direction. Fig. 19 compares the hypocenter distribution diagrams of the both experiments. The both diagrams are obtained as doublet-analysis results. However, the result of the preliminary circulation test is a doublet analysis result obtained by performing the calibration according to orthogonal projection in accordance with the result of the combination analysis.

The most characteristic difference between the both distribution lies in the fact that hypocenters are distributed along a monolithic structure dipping to the north side with high angle in the case of the hydraulic fracturing distribution but two clusters are recognized in the result of the preliminary circulation test. Two clusters show

almost parallel tilt angles dipping to the north side with high angle, in which the upper cluster has a relatively large fluctuation but the lower cluster is very concentrated. As the result of comparing these clusters with the monolithic structure at the time of hydraulic fracturing, it is found that the upper cluster is distributed at the position corresponding to the monolithic structure. However, it is found that no AE is distributed in the region where the lower cluster is distributed at the time of hydraulic fracturing. The lower cluster is a group which mainly shows brisk activities from the former half of a circulation test. However, activities of the groups forming the upper cluster are slow and most of them show brisk activities after increasing the flow rate up to 57 kg/s in the second-time well stimulation period. From the above mentioned, it is understood that the upper cluster reflects a reservoir in which a cracked zone activated due to hydraulic fracturing is reactivated and enlarged through the preliminary circulation test and the lower cluster reflects a cracked zone newly activated through the preliminary circulation test.

These states are clarified by the b-b' cross section. From the a-a' cross section, however, it is found that a newly activated lower cluster is distributed at the HDR-3 well side. Moreover, though many AE were concentrated nearby the pit bottom of HDR-1 well at the time of hydraulic fracturing, the number of AE decreased at the time of the preliminary circulation test. The trend in which the number of AE at the HDR-2a well side is less than the number of AE at the HDR-3 well side is observed in the both experiments. Fig. 20 shows a hypocenter distribution chart obtained by superimposing the both experiment results each other. From Fig. 20, it is found that the monolithic structure at the time of hydraulic fracturing is superimposed on the upper cluster at the time of the preliminary circulation test and two structure are shown as a whole.

Symbol ■ in Fig. 20 denotes a production zone detected through PTS logging under the preliminary circulation test of a deep reservoir. As the result of comparing the AE cluster with the production zone confirmed through the PTS logging, a preferable relation is recognized between them. Particularly, from the b-b' cross section, a state can be observed in which a plane formed by a cluster crosses a well. Main cluster in the upper cluster penetrates the production zone of HDR-3 well (third zone from the top) and that of HDR-2a well (second zone from the top). The small cluster slightly lower than the main cluster crosses the production zone of HDR-3 well (fourth zone from the top) and production zones of HDR-2a well (third and fourth zones from the top) are present on the extension line of the production zone of HDR-3 well. The lower cluster formed through the preliminary circulation test is located immediately under the pit bottom of HDR-3 well and its extension line crosses the production zone at the bottom of HDR-2a well. As described above, the plane structure formed by the AE hypocenter distribution well corresponds to the production zone confirmed through PTS logging and reflects the position of connection crack.

Fig. 15 AE distribution from 1989 to 1995

A case is shown in which determination is made by the SED method by using P-wave initial data. Fig. 15 shows hypocenter distributions produced due to the hydraulic fracturing in 1988, circulation test in 1989, hydraulic fracturing in 1992, and circulation test in 1995 in order from the top and moreover shows the epicenter distribution, east-west sectional view, and north-south sectional view in order from the left.

Fig. 16 AE distribution from 1989 to 1995

A case is shown in which determination is made by the SED method by using P- and S-wave initial data.

Fig. 16 shows hypocenter distributions produced due to the hydraulic fracturing in 1988, circulation test in 1989, hydraulic fracturing in 1992, and circulation test in 1995 in order from the top and moreover shows the epicenter distribution, east-west sectional view, and north-south sectional view in order from the left.

Fig. 17 AE distribution from 1989 to 1995

A case is shown in which determination is made by the JHD method by using P- and S-wave initial data.

Fig. 17 shows hypocenter distributions produced due to the hydraulic fracturing in 1988, circulation test in 1989, hydraulic fracturing in 1992, and circulation test in 1995 in order from the top and moreover shows the epicenter distribution, east-west sectional view, and north-south sectional view in order from the left.

Fig. 18 An example of AE waveforms recorded at observation points in well and surface observation points
 All are vertical motion components.
 Symbols ▲ and ▼ denote P-wave initial-motion arrival times.

Fig. 19 Comparison between AE cluster distributions following hydraulic fracturing and preliminary circulation test
Left: Hydraulic fracturing (1992), Right: Preliminary circulation test (1995)

doublet92+95.hyp

Fig. 20 AE distributions following hydraulic fracturing and preliminary circulation test
 Results of orienting hypocenter position through AE doublet analysis using three-axis double
 sonde method
 Symbol ■ denotes a production zone confirmed through PTS logging under preliminary
 circulation test.

4.4 Borehole measurement

To quantitatively evaluate connection places of HDR-1, HDR-2a, and HDR-3 wells under a flow enhancement test, temperature measurement under a stationary state and PTS logging were performed.

Fig. 21 - Fig. 24 show results of temperature measurement under a stationary state executed before the flow enhancement test (between 8/7 - 8/9). Influence of the shallow-portion circulation test in FY 1991 is observed on all wells and particularly, it is remarkably observed on HDR-2a and SKG-2 wells.

Table 6 shows the results of PTS logging of HDR-1 well. Table 6 also shows all results of PTS logging performed from FY 1992 to FY 1996. From these results, a trend is observed in which main fluid-outgoing places move to upper portions between the initial period and latter period of the circulation test. This trend was also observed at the time of the deep-portion preliminary circulation test in FY 1995.

In the case of HDR-2a well, measurement was performed while all wellheads were closed except the measurement on 9/4 at the final stage of the test. Under the above state, the fluid incoming from a deep reservoir (1,900 to 2,300 m) goes to the outside of wells between depths of 1,550 and 1,830 m which is the connection place between shallow reservoirs (depths of 1,500 to 1,900 m). Fig. 25 shows typical flow-rate analysis results while wells were opened and closed together with the change of temperature profile with time. The main fluid incoming place is F2a-3 in the case of the shallow reservoir and F2a-9 in the case of the deep reservoir and this is the same as the case in fiscal 1995. While HDR-2a is closed, hot water is produced only from the deep reservoir and discharged to the shallow reservoir. Even when hot water is produced from a shallow portion by opening wells, the production of hot water at a deep portion is not remarkably changed. As shown in Fig. 27(b), the temperature of water incoming from F2a-9 which is a main fracture at a deep portion is lowered similarly to the case of the last year. Though the temperature was 250°C at the beginning of circulation, it was lowered up to about 220°C after three weeks.

HDR-3 well has an unstable production and it frequently stops just by PTS logging descending in well. Therefore, it is difficult to perform stable measurement. Fig. 26 shows the change of the temperature profile of HDR-3 well with time and the flow rate analysis result under a relatively stable state. In the case of HDR-3 well, a remarkable connection place observed for HDR-2a well was not observed similarly to the case of the last year. The shallow reservoir is relatively stably changed in a range of 230°C to 240°C and the deep reservoir is also relatively stably changed in a range of 250°C to 270°C. However, no remarkable temperature drop was observed similarly to the case of the last year.

Fig. 29 is obtained by plotting the results of the flow enhancement test of this fiscal year for the relation between the production of the shallow reservoir obtained in the last fiscal year and the pressure in the pit of the geothermal fluid production well. Moreover, Fig. 30 shows the relation between the differential pressure in the pits of the injection well and the geothermal fluid production well at the same level (1,900 m TVD) and the flow rate produced from the deep reservoir.

In the case of the deep reservoir, the results of the last fiscal year and this fiscal year are on the same line but no change is observed in the flowing impedance of the deep reservoir. Moreover, even if circulation is made under a closed state or production from a shallow portion is stopped, the results are on the same line. Therefore, it is found that the production from the deep reservoir is univocally controlled in accordance with the differential pressure between the injection well and the geothermal fluid production well independently of these conditions.

Moreover, results of the shallow reservoir of this fiscal year are plotted at the right of the flow rate-pressure line obtained in the last fiscal year. This is probably because the pressure of the shallow reservoir is kept higher than that in the last fiscal year due to the closure of HDR-2a well since hot water incoming from a deep portion of HDR-2a well goes out to the shallow reservoir through a well.

Table 6 Rate of outlet point from HDR-1 well to deep reservoir

Outlet point	FY1992	FY1993	FY1994	FY 1995		FY 1996	
				8/6	8/27	8/10	9/9
2165m-2167m	18%	22%	10%	5%	35%	10%	45%
2174m-2176m	2%	-	5%	-	10%	-	15%
2182m-2184m	30%	30%	20%	30%	20%	50%	25%
2188m-2189m	-	-	-	-	10%	0%	0%
2193m-2195m	20%	3%	10%	20%	10%	25%	10%
2202m-2204m	30%	45%	55%	45%	15%	15%	5%

**Fig. 23 Results of temperature logging of HDR-2 and HDR-2a well
(1991,1992,1995,1996)
(Left track) HDR-2 well, (Right track) HDR-2a well**

Fig. 25 Results of temperature and flow rate analysis of HDR-2a well and connection fracture (Left track) Flow rate analysis results, (Right track) Temperature measurement

Fig. 27 (a) HDR Well trajectories and production points (plan)

Fig. 27 (b) Change of production rate (Up: HDR-2a well, Low: HDR-3 well)

**Fig.28 Change of water temperature of outlet point during flow enhancement test
(Right: HDR-3 well, Left;HDR-2a well)**

Fig. 29 Plotting of production flow rate and pressure of shallow reservoir in FY 1995 and 1996

Fig. 30 Plotting of production flow rate and pressure of deep reservoir in FY 1995 and 1996

4.5 Geological survey

To contribute to construction of a Hijiori HDR geological fracture system model, a synthetic analysis stressing the survey of the surface geology of Hijiori caldera structure was executed to prepare a Hijiori area geological map and sectional diagram around caldera and estimate the geological origin of the existing natural fracture system related to a connection fracture.

Table 7 shows the fracture system of the south block including Hijiori area. The major connection fracture system of Hijiori HDR reservoir is a part of DF-1 group because it dips to the north side with high angle with an E-W strike and it is confirmed that the fracture system is recognized as SF-13 group also on the surface as shown in Table 8 and moreover conjugates with SF-2 group dipping to the south side with high angle with an E-W strike.

Table 8 Comparison between deep oriented core and surface fracture system (South block)

	Oriented core	Surface (South block)	Remarks
Fracture system	A part of DF-1	SF-13	Conjugated with major connection fracture SF-2
	A part of DF-1	SF-3	
	A part of DF-1	SF-1	Conjugated with erupted fracture SF-13 in Ishidaki spa
	DF-12	SF-2	
	DF-2	SF-6	
	DF-3	SF-8	
	DF-5	SF-14	

Table 9 Major connection fractures observed through oriented core

Classification		No.	Strike	Dip	Remarks	Fracture system
FY 1993	No.2 core of HDR-3 well 2183.0m - 2183.4m Connection indicating fracture Occurrence of water level change(HDR-1)	580	N64°E	74°N	Left lateral displacement fault	DF-8
		581	N63°W	67°N	Left lateral displacement fault	
		582	N61°W	72°N	Normal fault	DF-1
		583	N55°W	74°N	Normal fault (Maximum opening)	
FY 1994	HDR-2a	Excellent fracture group		N68°-90°W	60°-85°N	DF-1 DF-7
		Opened fracture	46	N47°W	67°N	DF-7
			47	N48°W	75°N	
			56	N69°W	67°N	

It is estimated that major connection fracture forming a shallow reservoir is a fracture plane with a strike of N77° E and an inclination of 70° N judging from the data for AE mapping, BHTV, and core fracture. The connection fracture system forming the shallow reservoir is classified into DF-1 and it is estimated that DF-1 corresponds to SF-3 or SF-13 of the surface fracture system and it relates to F-5 fault probably forming the south margin of Hijiori caldera. The connection fracture forming the shallow reservoir corresponds to the fracture system DF-1 having a NW-SE strike judging from the result of classifying fracture systems according to core (see Table 9). Similarly, the surface fracture system corresponds to SF-1, which is the most excellent fracture system in the south and west blocks around Hijiori caldera. Moreover, the surface fracture system is a fracture system related to the fault scarp forming a lineament and a triangular end face and F-4 fault estimated as the south-west margin of the caldera.

Thus, it is estimated that the major connection fracture forming the shallow and deep reservoirs of the artificial hot water system established by Hijiori SKG-2, HDR-1, HDR-2, HDR-2a, and HDR-3 relates to the existing bidirectional natural fracture systems (SF-3, SF-13, and SF-1) distributed from the south margin of Hijiori caldera up to the southwest margin of the caldera and the south and west blocks.

Table 7 Comprehensive table of fracture systems (South block)

Classification	Strike and inclination	Solidification	Displacement sense	Older fracture system	Conjugation	Remarks
SF-1	NW32W-58W · SN high angle 73N<>68S	Not solidified-solidified	Left lateral displacement, reverse-fault S-up	SF-7	SF-13	Erupted fracture in Ishidaki spa
SF-2	EW62E-62W · S33-88S	Solidified	Normal right lateral-displacement component	SF-3,-7		Iron, spring, carbonate, and segregated vein
SF-3	EW82E-89E · SN high angle 82N<>77S	Not solidified	Reverse S-up right lateral displacement component	SF-4,-12		Iron spring
SF-4	NW41W-64W · S high angle 61-83S	-	Normal fault component, right lateral displacement	SF-3,-9b		Cold mineral spring and limonite
SF-5	WNW74-78W · N high angle 71-82N	-	Reverse fault, right lateral displacement component	SF-12		
SF-6	NW-WNW56-84W · N middle angle 33-61N	Solidified	Normal fault component	SF-2		Segregated vein
SF-7	NNW3-28W · S middle high angle 53-88S	-	Left lateral displacement component	SF-3		Neighborhood of caldera is unclear
SF-8	NNW-NW21-39W · N high angle 58-85N	-	Normal, right lateral displacement component	SF-12		Iron cold mineral spring
SF-9a	NE-N36E-OE · W middle low angle 31-42W	-	Normal fault component	SF-4		Neighborhood of caldera is unclear
SF-9b	N-NW0E-46W · W middle low angle 31-42W	-	Normal fault component	SF-2,-3, -4,-7		
SF-10	NNE6-18E · EW high angle 81E<>68S	-	Left lateral displacement, normal fault component			
SF-11	NNE3-34E · S high angle 53-82S	-	Reverse, left lateral displacement component	SF-2,-3	F-2	Segregated vein
SF-12	NE42-68E · SN high angle 68N<>72S	Demi-solidified	Right lateral displacement component	SF-1,-2,-6		Limonite
SF-13	EW75E<>86W · N middle high angle 61-73N	-	Normal fault component	SF-9a,-11,-2		Major fracture of shallow reservoir
SF-14	NE48-66E · S middle high angle 48-82 S	Solidified	Left lateral displacement			Fresh water
SF-15	NE14E · S middle angle 56 S		Normal fault component			

4.6 Preparation for fracture model

Through the hydraulic fracturing experiment and circulation test repeated several times in Hijiori experiment site, a lot of fracture information is accumulated including AE data, PTS logging data, BHTV data, various logging data and now, it is desired to model a hot dry rock reservoir model based on these pieces of information. Therefore, the operation of preparing a fracture model of Hijiori experiment site by arranging and unifying the various pieces of information having been obtained so far is started in this fiscal year.

To further understand the knowledge about the fracture system of the hot dry rock reservoir, it is effective to unify various pieces of information and capture an underground structure as a three-dimensional image. A hot dry rock underground information visualizing and interpreting system purposes to visualize underground information and provide an input model for a reservoir simulator. It consists of "three-dimensional visualizing software", "fracture model preparing and analyzing software" and a hardware system serving as an operational environment of these software (see Fig. 31).

In this fiscal year, to construct the foundation of the hot dry rock underground information visualizing and interpreting system, the information for the basic functions of the three-dimensional visualizing software is collected. It is decided to introduce the above software and a work station by judging that Earth Vision based on a silicon graphics work station (SGI) is the most suitable as a software and hardware system considered to be the most suitable.

Fig. 31 Block diagram of HDR underground information visualizing and interpreting system

4.7 Reservoir analysis

In this fiscal year, a crack due to a plane factor and the crack expression method according to the Smeared method are added to the fissile reservoir behavior simulator developed by the last fiscal year. Moreover, the Hijiori reservoir model is improved by using the data for the circulation test executed in this fiscal year.

In the case of a Smeared crack model, the mesh of a rock body is divided without being conscious of a cracked plane. The cracked plane has an advantage that it can be separately defined as a collection of planes. From the viewpoint of calculation, it is detected which cracked plane a three-dimensional solid factor automatically defining a rock body in a program and thereby, the solid factor is expressed as an anisotropic model including the flow characteristic of the cracked plane.

The entire factor model used for simulation is a rectangular having lengths of 2,000 m in the east-west direction, 1,000 m in the north-south direction, and 2,000 m in the depth direction as shown in Fig. 32 and has 2,662 calculated nodes. In the case of the number of fractures, it is assumed that one shallow reservoir is used and three deep reservoirs are used in accordance with the data for AE, BHTV, and PTS because it is the main purpose to model a deep reservoir this time. Fig. 32 also shows these fractures. These fractures show that the strike runs in the east-west direction and the dipping to the north side is about 70°. Among these fractures, the fluid-circulation fracture which is the main fracture is estimated as the fracture in <3> in accordance with the data for PTS. This time, matching is performed by stressing the behavior of the main fracture.

Fig. 33 shows the comparison between the measured temperature of the main incoming point (F2a-9) of HDR-2a well and the simulation temperature in which values of the parameter km_f for equivalent heat conduction are changed. From Fig. 33, it is found that the measured temperature at the preliminary circulation test in the last fiscal year shows a value close to the simulation temperature curve having a km_f value of 1.0 and the measured temperature at the flow enhancement test in this fiscal year shows a value close to the curve having a km_f value of 100.0. " km_f " is a value related to a fracture area (contact area between a rock matrix and a fluid) and the above values show that fracture areas may differ due to the influences of the circulation tests in fiscal 1995.

Fig. 34 shows the comparison between the injection pressure measured value of HDR-1 well and the simulation pressure and Fig. 35 shows the comparison between the pressure measured value of SKG-2 well and the simulation pressure. Matching between these pressures is not always preferable and therefore, it is necessary to perform a simulation considering the influence of fracture open.

Fig. 32 Hijiori reservoir model

Fig. 33 Comparison between calculated temperature and measured temperature at main outlet point (F2a-9) of HDR-2a well

Fig. 34 Comparison between calculated pressure and measured pressure in HDR-1 well

Fig. 35 Comparison between calculated pressure and measured pressure in SKG-2 well

4.8 Environmental survey

(1) Micro-earthquake observation

The total number of earthquakes acquired between April 1, 1996 through March 31, 1997 reaches 543 times and therefore, it is found that many earthquakes occur compared to the number of earthquakes in an ordinary year. However, the number of earthquakes which may have occurred relatively nearby Hijiori is almost equal to the number of earthquakes in an ordinary year and the number of earthquakes confirmed in a 30-km square around SKG-1 well at a depth of 20 km or less was 13 times.

(2) Survey on river water and spring water

Survey of river water was performed at Kusui River and Harai River (Dozen River) one place each and survey on spring water was performed a total of 15 times at two places such as Kanayama No. 2 Spring and Hijiori No. 3 Spring. From the sample analysis results up to March, 1997, any influence on environment is not recognized.

5. Summary of the Study in FY 1996

(1) Flow enhancement test

According to the results of the preliminary circulation test in fiscal 1995, the production characteristic of HDR-3 well was not preferable compared to that of HDR-2a well. Therefore, to improve the production capacity of HDR-3 well, circulation was performed only between HDR-1 well and HDR-3 well under a back-pressure stimulation state and an open stimulation state by closing the wellhead of HDR-2a and changing the valve opening of the wellhead of HDR-3 well in several steps. Thereafter for six days, the characteristics of Hijiori deep reservoir were confirmed for a long-term circulation test by the production from the both wells of HDR-2a and HDR-3.

Moreover, to confirm the circulation characteristic of the reservoir, a step rate test for changing injection flow rates stepwise was performed before and after the circulation test. Under the flow enhancement test, the wellhead pressure, flow rate, and temperature of each well were measured and PTS logging, AE measurement, and fluid geochemical survey were executed.

As the test schedule, the independent well test only between HDR-1 well and HDR-3 well was performed between August 10 through September 1. In this period, the valve opening of HDR-3 well was set to 40% between August 10 through August 15, between August 22 through August 24, and between August 30 through September 1, 25% between August 16 through August 21 due to back pressure stimulation, and 46 to 60% between August 25 and August 29 for fluid-flow acceleration according to open stimulation. In the two well test between September 2 through September 9, a recovery of about 70% was obtained at a wellhead temperature of about 180°C and a production wellhead pressure of 1 MPa. The step rate test was performed before and after (August 10 and September 9) the flow enhancement test and the injection into HDR-1 well was stopped to monitor until September 11.

(2) Geochemical survey

Similarly to the last year, the injection water into HDR-1 well and production water from HDR-2a well and HDR-3 well were chemically analyzed during the flow enhancement test.

As the result of studying the contribution of the rock-water reaction to the production water containing Na component, a value almost equal to that of the production water at the preliminary circulation test in the previous year was obtained in the case of HDR-2a well and HDR-3 well.

(3) AE measurement

Hypocenters were redetermined by rereading the AE data obtained from hydraulic-fracturing and circulation tests performed in 1988, 1989, 1992, and 1995 among the various tests executed so far and using not only P-wave data but also S-wave data. As the result of comparing the hypocenter distribution using only P-wave initial-motion data with the hypocenter distribution when using not only the P-wave initial-motion data but also S-wave initial-motion data, any remarkable difference is not observed between the distributions depending on the presence or absence of S-wave data about the epicenter distribution. About the depth direction, however, hypocenters have less fluctuation and are more concentrically distributed when determining the hypocenters by also using S-wave data compared to the case of determining them by using only P-wave data and it is clarified that the hypocenters are obtained at a higher accuracy.

For AE following the deep reservoir establishment hydraulic fracturing and the preliminary circulation test, the accuracy is improved by introducing the AE doublet analysis, surface data combined analysis, and analysis technique such as orthogonal production analysis. The AE doublet analysis is a method for improving the accuracy of the relative positional relation between similar events and the surface data combined analysis and the orthogonal production are methods for improving the absolute positional accuracy.

Two roughly divided AE clusters were formed in the deep reservoir through the hydraulic fracturing experiment and the preliminary circulation test. Among these clusters, the upper cluster was formed mainly by the hydraulic fracturing experiment and further activated through the later preliminary circulation test. The lower

cluster was newly formed by the preliminary circulation test (particularly in the first-time well stimulation period) and the both clusters have a plane structure dipping to the north side with high angle.

A preferable corresponding relation is recognized between the production zone and the AE cluster distribution. The upper cluster penetrates HDR-2a well and HDR-3 well, and the lower cluster is located immediately under the pit bottom and its extension line crosses the production zone at the bottom of HDR-2a well.

(4) Borehole measurement

To quantitatively evaluate the connection places of HDR-1, HDR-2a and HDR-3 wells under the flow enhancement test, temperature measurement was executed under a stationary state and PTS logging was executed during the circulation test. In the case of the inlet points of HDR-1 which is an injection well, the trend in which main inlet point moved upward was observed from the initial period to the latter period of circulation similarly to the preliminary circulation test period.

In the case of HDR-2a well, similarly to the case of the preliminary circulation test, main outlet points was F2a-3 for the shallow reservoir and F2a-9 for the deep reservoir. In the case of HDR-3 well, however, any remarkable connection place was not observed similarly to the last year.

Then, the relation between the production flow rate and the pressure of the shall and deep reservoirs was studied. From the relation between the differential pressure of pressures in pits of the injection well and geothermal fluid production well at the same level (1,900 mTVD) and the production flow rate from the deep reservoir, it was found that the results in the last fiscal year and this fiscal year were on the same line, no change in the flow impedance from the deep reservoir was observed, and the production from the deep reservoir was univocally controlled in accordance with the differential pressure between the injection well and the geothermal fluid production well.

(5) Geological survey

The geological structure cross section of Hijiori area was made by performing synthetic analysis including other well data in Hijiori area. Moreover, a fracture system related to the artificial reservoir in Hijiori experiment site was estimated by performing fracture analysis.

(6) Preparation for fracture model

To construct the foundation of the hot dry rock underground information visualizing and interpreting system, Earth Vision was introduced as the most suitable software by collecting the information for the basic functions of a three-dimensional visualization software. Moreover, a silicon graphics work station (SGI) was used as the hardware system.

(7) Reservoir analysis

A crack according to a plane factor and a crack expression method according to the Smeared method were newly added to a fissile reservoir simulator as a crack model. In the case of the crack model according to the Smeared method, it is unnecessary to accurately mesh-divide a cracked surface and a complex crack expression can be easily made. Moreover, by using the crack model according to the Smeared method, behavior simulation of Hijiori reservoir was executed in the flow enhancement test to make and study a reservoir model.

(8) Environmental survey

To survey the influence of the flow enhancement test executed in this fiscal year on the environment, micro-earthquakes were always observed and river water and spring water were sampled and analyzed. From the results of observing micro-earthquakes and results of analyzing river water and spring water, any influence of the flow enhancement test on the environment is not recognized.