Development of Hot Dry Rock Technology at Hijiori Test Site
- Program for a Long Term Circulation Test -

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ABSTRACT

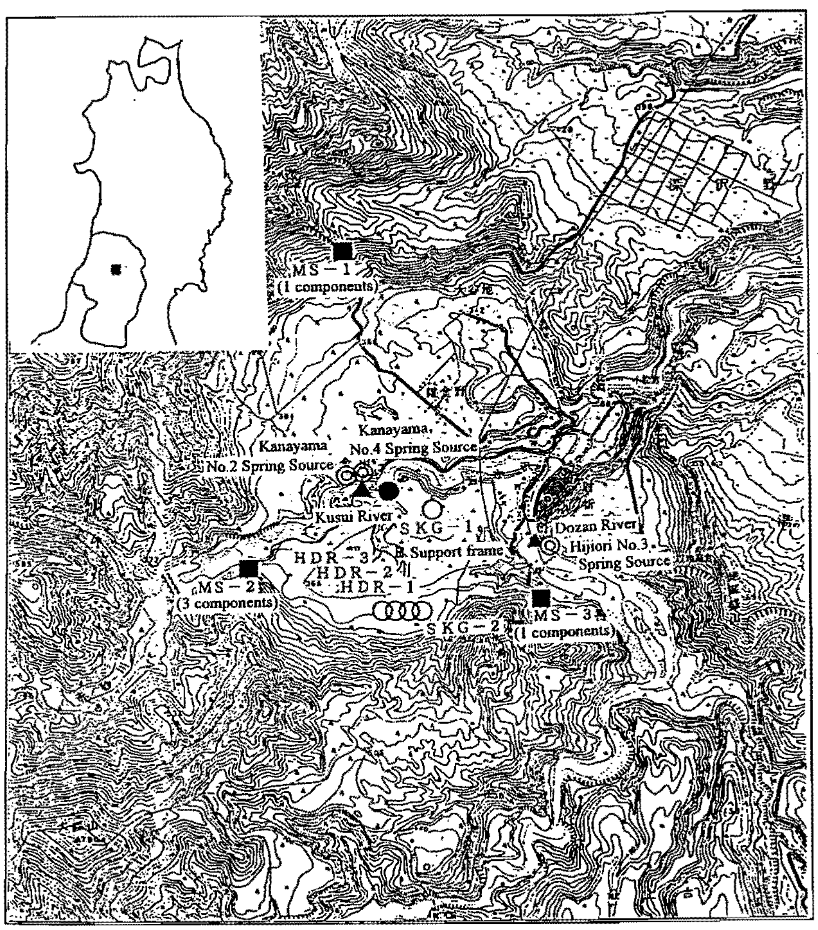
Since 1985, the New Energy and Industrial Technology Development Organization (NEDO) has continued the development of Hot Dry Rock power generation in Hijiori Hot Dry Rock test site, Yamagata prefecture, Japan, as part of the Sunshine Project and succeeding New Sunshine Project sponsored by Agency of Industrial Science and Technology (AIST), a branch of the Ministry of International Trade and Industry(MITI). The objective of this project is to identify the feasibility of a Hot Dry Rock power generation system in Japan. Thus, the research and development being undertaken at Hijiori HDR test site is aiming to establish hot rock drilling technology, logging borehole technology for evaluating the state of the rock around the well, hydraulic fracturing technology for creating artificial fractures in rock, fracture mapping technology for surveying the reservoir area, and reservoir evaluation technology for predicting reservoir longevity.

INTRODUCTION

The Hijiori HDR test site is located on the southern edge of the 2 km diameter Hijiori caldera, which was formed about 10,000 years ago (Fig.1). Topographic effect 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.

As noted in Fig.2, the technical development being carried out the Hijiori HDR test site is largely divided into two phases. The first phase was conducted from 1985 to 1991, when a shallower reservoir was formed and various technological development works were carried out. The second phase started from fiscal 1992, when the study entered a deeper reservoir development.

The well, SKG-2 (depth 1802 m, the bottom hole temperature 254 ℃) was drilled to explore a geothermal reservoir. At first, the shallower reservoir was created by hydraulic stimulation at about 1800 m deep in 1986. The amount of injected water was 1080m^3. HDR-1(depth 2206 m), HDR-2(depth 1910 m)



■ : Micro-seismometer installation
◎ : Hot spring water sampling
▲ : River water sampling
● : Micro-earthquake recorder installation
○ : Well

1 : 25,000 Hijiori
500m 0 500 1000 1500m

Fig. 1 Location of Hijiori HDR test site

	FY86	FY87	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	FY96
1,800-m-deep reservoir depth ; ± 1,800 m temperature ± 250℃	Hydraulic fracturing created a man-made reservoir	Drilled HDR - 1 to 1,805 m communica -ted to the SKG - 2	Circulation test for 2 weeks Deepen HDR - 1 to 2,205 m Set PBR	Drilled HDR - 2 to 1,910 m Circulation test for 29 days 40 % 4.5 MW thermal	Drilled HDR - 3 to 1,907 m communica -ted to the SKG - 2	Circulation test for 90 days 78 % 8.5 MW thermal					
2,200-m-deep reservoir depth ; ± 2,200 m temperature ± 270℃							Hydraulic fracturing created a man-made reservoir	Deepen HDR - 3 to 2,303 m communica -ted to the HDR - 1	Sidetracked & Deepen HDR - 2 communica ted to the HDR - 1	Preliminaly circulation test for 25 days 40% 8~9 MW thermal	Circulation for reduce the flow impedance

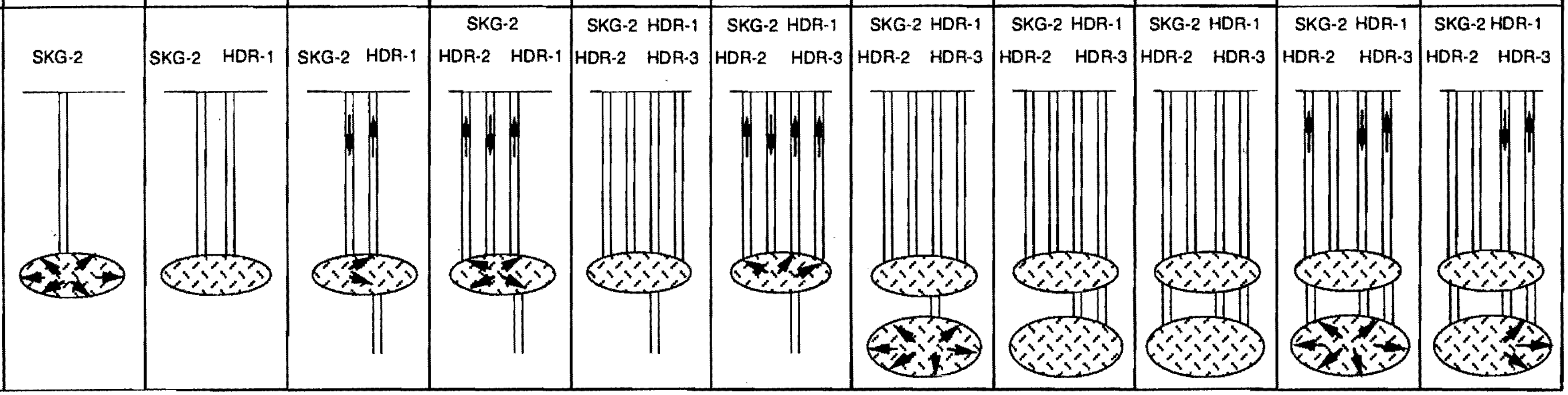


Fig. 2 History of the Hijiori HDR test site

and HDR-3(depth 1907 m) were drilled to construct a circulation system in 1987, 1989 and 1990. Three circulation tests were performed to estimate the shallower reservoir characteristics using these wells until 1991. During a 90-day circulation test using four wells in 1991, the amount of hot water and steam produced from three production wells was about 80 % of the total injected water(Yamaguchi et al., 1992).

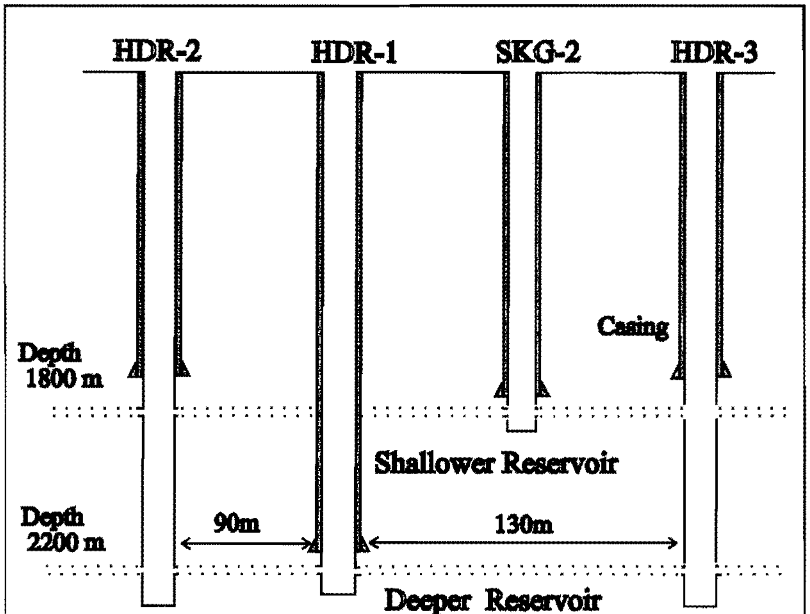


Fig. 3 Concept of a Hijiori HDR system
(Black zone of well show casing, and white zone is openhole)

As a result of the success, it was proposed to carry out a larger scale and higher temperature development of the deeper reservoir. In 1992, hydraulic stimulation with about 2000 m^3 water was conducted at a depth between 2151 and 2205 m in HDR-1 to create the deeper reservoir. In 1993 and 1994, HDR-3 and HDR-2 were deepened to a depth of 2303 m and 2302 m to intersect the deeper reservoir, and a three-wells system was established. The distance from HDR-1 to HDR-3 was about 130 m at the depth of reservoir and from HDR-1 to HDR-2 was about 90 m. The Hijiori HDR system has two reservoirs(the shallower reservoir and the deeper reservoir) and four wells (SKG-2, HDR-1, HDR-2 and HDR-3) as shown in Fig. 3.

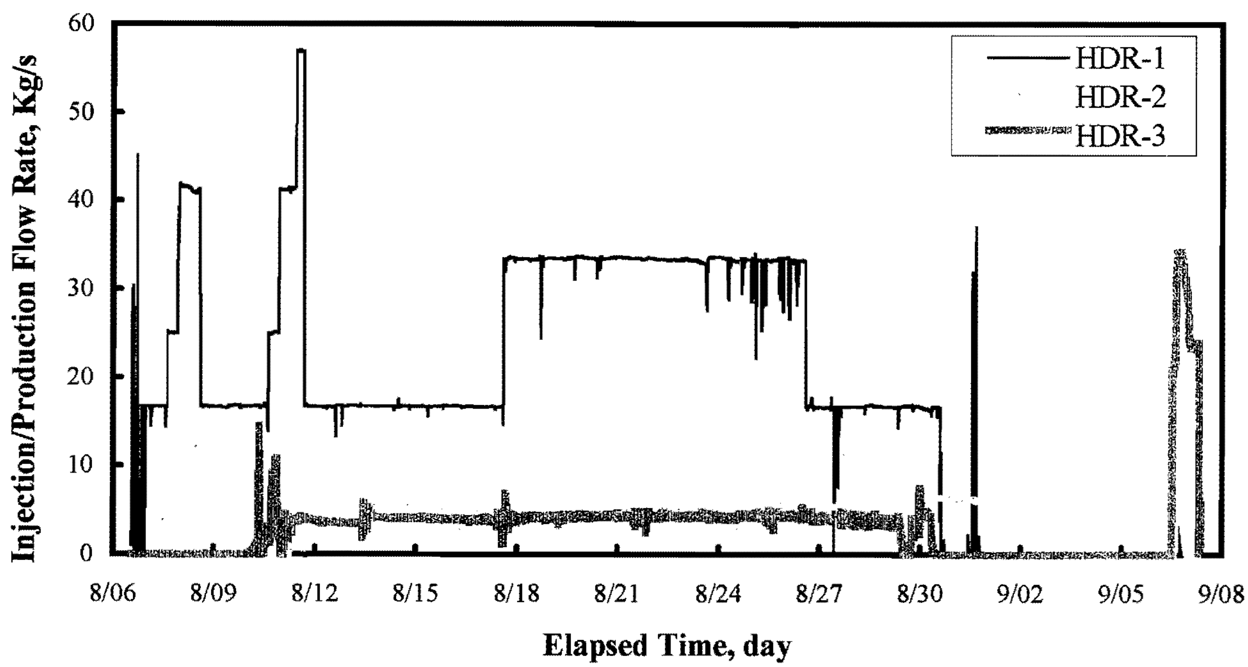


Fig. 4 Records of flow rate obtained during a preliminary circulation test in 1995
(The injection well was HDR-1 and production wells were HDR-2 and HDR-3)

TWO CIRCULATION TEST FOR THE DEEPER RESERVOIR

In 1995, a preliminary circulation test was conducted with an injection well HDR-1, and two production wells HDR-2 and HDR-3(Sato et al., 1995). The purpose of the test was to evaluate the deeper reservoir characteristic for the long term circulation test and to improve the connectivity of the deeper reservoir between the injection well and production wells. The period of the test was from August 6 to 30. The injection and production flow rate are shown in Fig. 4.

At the beginning of the test, water was injected under high pressure to improve the connectivity at the maximum flow rate of about 60 kg/s. After initial high flow rate injection, the productivity of the deeper reservoir was evaluated using around 16.7 kg/s or 33.4 kg/s during the test. The summary of the test is shown in Table 1. A total recovery rate of the test was about 40 %. And a recovery rate of hot water and steam was about 55% - 60% during the constant flow rate at 16.7 kg/s. The amount of hot water and steam from HDR-2 was larger than that from HDR-3.

Table 1 Summary of the preliminary circulation test in 1995

Circulation test period	25 days	Aug. 6 - 30, 1995
HDR-1 total injection	51500 m^3	Total recovery : 39.0 %
HDR-2 total production	13200 m^3	Recovery of HDR-2 : 25.6 %
HDR-3 total production	6900 m^3	Recovery of HDR-3 : 13.4 %
Constant flow circulation test recovery (Aug. 11 - 17)	About 55 %	Flow: 16.7 kg/s Valve opening: 40 %
Constant flow circulation test recovery (Aug. 17 - 26)	About 30 %	Flow: 33.4 kg/s Valve opening: 40 %
Constant flow circulation test recovery (Aug. 26 - 30)	About 50 %	Flow: 16.7 kg/s Valve opening: 40 %
Wellhead temperature during HDR-2 production	About 180 °C	Heat output: about 4.5 MW
Wellhead pressure during HDR-2 production	About 10 kgf/cm^2	
Wellhead temperature during HDR-3 production	About 180 °C	Heat output: about 4.0 MW
Wellhead pressure during HDR-3 production	About 10 kgf/cm^2	

AE was measured to evaluate extension of the deeper reservoir during the test. As noted in Fig. 5, AE sources were mostly distributed in the east-west direction around HDR-1, and ranged from 1500 m to 2700 m deep. The circle show a location of AE, and the size indicate the magnitude of AE. AE events during the test were extensively distributed around AE of the hydraulic fracturing in 1992.

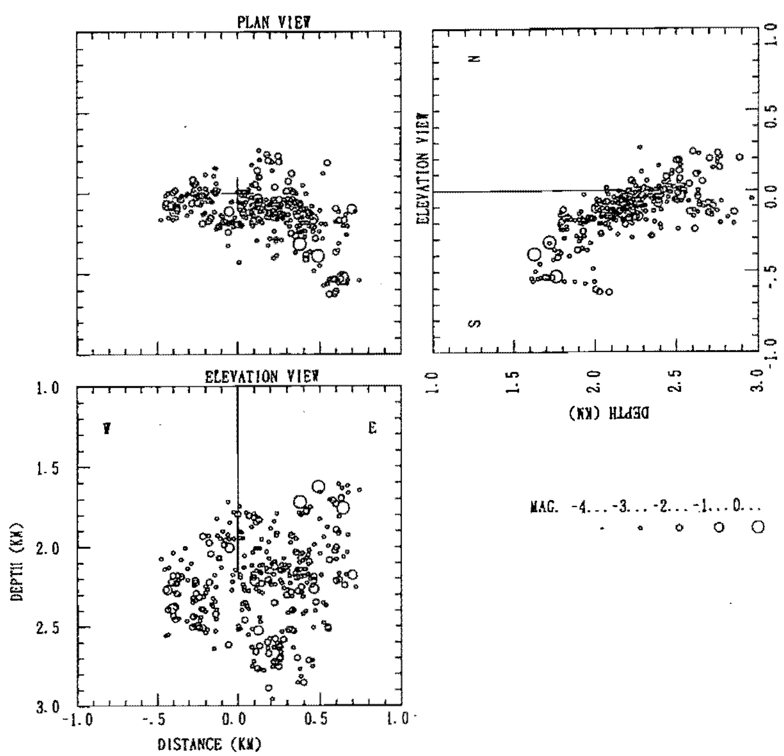


Fig. 5 Seismic source distribution of AE during preliminary circulation test in 1995

PTS logging was periodically carried out in the two production wells during the test. The pressure, temperature and flow rate were measured along each production well. As shown in Fig. 6, the number of outlet points where hot water flowed into the production wells was ten in HDR-2 and nine in HDR-3. In total, nineteen outlet points were recognized in production wells from these data. The mark of "F**-1" to "F**-5" indicate outlet points of the shallower reservoir, and other show outlet points of the deeper reservoir.

In 1996, a one-month circulation test was carried out with HDR-1 as an injection well and HDR-3 as production well. The purpose of this test was to improve a connectivity of fractures between HDR-1 as the injection well and HDR-3 as the production well, because performance of both HDR-2 and HDR-3 were difference. The injection flow rate was constantly 16.7 kg/s during this test. A single production well test for HDR-3 was conducted from August 10 to September 1. After the single production well test, hot water and steam were produced from two production wells until September 9. The summary of this test is shown in Table 2. A recovery rate was 70 % during two production wells test.

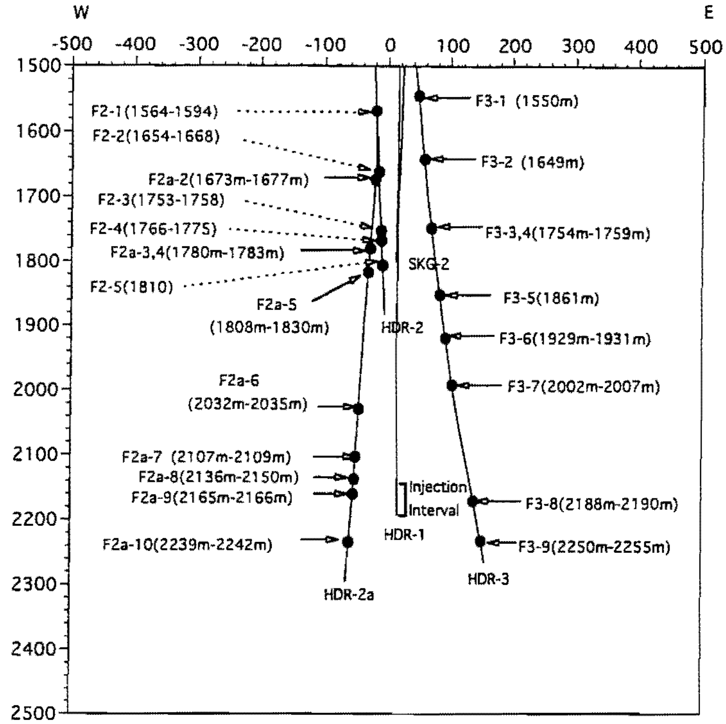


Fig. 6 Trajectories of injection and production wells and the location of outlet points at Hijiori HDR test site (Elevation view in E-W direction)

Table 2 Summary of the one-month circulation test in 1996

	Circulation Test in 1996		Total
Period	August 10 - September 1	September 2 - September 9	
	Single production test	Two production test	
HDR-1 injection	32200 m^3	8700 m^3	40900 m^3
HDR-2 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 %)

FUTURE PLAN

Two circulation tests were conducted to estimate the deeper reservoir characteristic for the long term circulation test in 1995 and 1996. We got some data to evaluate the behavior of the deeper reservoir from tests. Thus, NEDO continue the Hijiori HDR project as shown in Table 3. NEDO will be making a program for the long term circulation test from 1997 to 1999. In this preparatory period, we are going to discuss data measured during the long term circulation test.

As the Hijiori HDR test site is located in a heavy snow fall area, a surface pipe system must be protected from freezing during the long term circulation test. And, NEDO make design and construction of facilities for a long term circulation test in Hijiori HDR test site from 1997 to 1999.

NEDO is going to make a 3D graphic system of Hijiori HDR test site from 1997 to 1999. For example, the geological data, temperature logging data, BHTV data (dip, azimuth, depth, etc) and AE measured by some tests are put in this system.

NEDO have a plan of a long-term circulation test of the Hijiori HDR system to confirm the feasibility of Hot Dry Rock power generation from the autumn in 2000 till the autumn in 2002. Objective of the long term circulation test is to estimate life and volume of the deeper reservoir. As noted in Fig. 3, the characteristic of Hijiori HDR system is one reservoir with one injection well (the shallower reservoir with SKG-2 and the deeper reservoir with HDR-1). Then, NEDO is thinking an attempt that water is injected in SKG-2 and HDR-1 to estimate the multi-reservoir of Hijiori HDR system during a particular period of the long term circulation test.

Table 3 Schedule of Hijiori HDR project until a long term circulation test

	Preparation (1997 to 1999)	Test (2000 to 2002)
Task of Hijiori HDR project	● make a program for a long term circulation test ● design and construction of facilities ● make a 3D graphic system of Hijiori HDR test site	A Long Term Circulation Test

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