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DEVELOPMENT OF PRODUCTION TECHNOLOGY FOR DEEP-SEATED GEOTHERMAL RESOURCES

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ABSTRACT

NEDO has been conducting the "Development of Drilling and Production Technology for Deep-seated Geothermal Resources" project since 1994. The contents of the project can be divided into two categories: development of drilling technology and development of production technology. This paper outlines the progress of production technology development.

Some production technologies have reached the stage of field testing, and others are in the manufacturing stage after the completion of basic research. All of the production technologies being developed in this project are expected to be useful not only for deep-seated geothermal resources, but also for high-temperature shallow geothermal reservoirs.

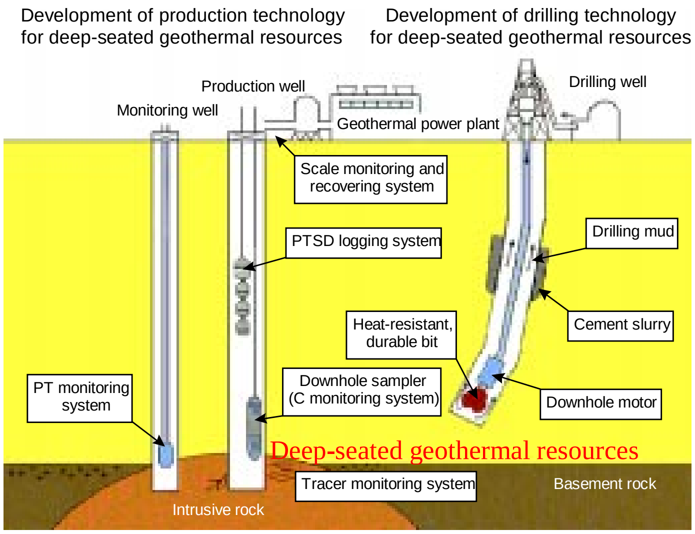

Fig.1. Conceptual diagram of development

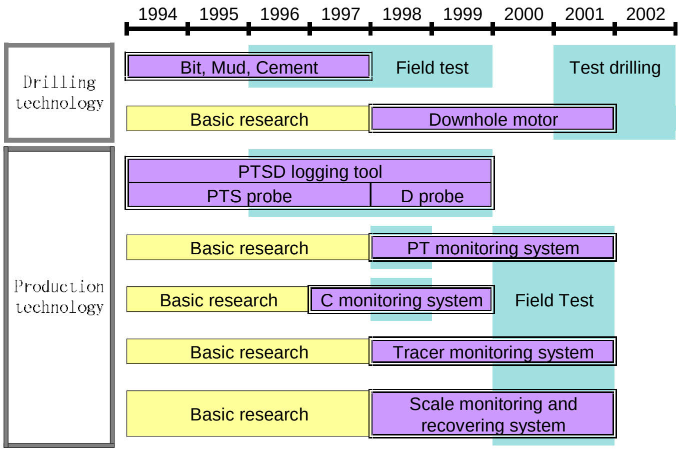

Fig.2. Plan for development

INTRODUCTION

Deep-seated geothermal resources located below already developed shallow reservoirs, if made exploitable, have the potential to supply a considerable amount of geothermal energy for power generation. NEDO is developing drilling and production technologies essential for outputting the steam expected to contribute to the increase of geothermal power generation capacity.

Figure 1 shows a conceptual diagram of this project. Deep-seated geothermal resources are located underneath shallower reservoirs at a depth of about 3,000-4,000m. The temperature and pressure of deep-seated geothermal resources are higher than those of shallow geothermal resources. To develop such resources safely and economically, we need to well understand reservoir performance, and we should recognize the difficulties that can be caused by scaling. However, present technologies are not adequate. Therefore we are developing such production technologies as the PTSD (Pressure, Temperature, Spinner flow meter and fluid Density) logging tool, PTC (Pressure, Temperature and Chemical sampler) monitoring system and tracer monitoring, scale monitoring and scale prevention systems. PTSD logging technology and PTC monitoring technology can be employed under temperature conditions of up to 400ºC, and tracer monitoring technology and scale monitoring technology under conditions of up to 350ºC.

Figure 2 shows the project plan. Research on the PTSD logging tool began in 1994. Now the PT-probe and S-probe have been already manufactured on a trial basis, and field tests were conducted in geothermal wells. Also, the D-probe has been manufactured on a trial basis and will be subsequently tested. Detailed design and laboratory tests have been conducted on the PT monitoring system. The C monitoring system has been already manufactured on a trial basis and will be field tested in geothermal wells this year. Regarding the tracer monitoring system, the basic thermal characteristics of aromatic acid and vapor tracers were studied. Next year we plan to develop a tracer simulator. Regarding a scale monitoring and prevention system, we have completed the basic research.

PTSD LOGGING TOOL

We measured temperature, pressure and fluid spinner (flow velocity) in both static and dynamic conditions in geothermal wells. The formation temperatures of deep-seated geothermal reservoirs have been estimated to be 300-400ºC. However, the logging cable widely used for PTS logging is a Teflon-coated type which is heat-resistant only up to 315ºC.

To solve this problem, we adopted a memory module to record data. While logging, the borehole data and time are recorded in the memory module inserted in the tool, and at the same time tool depth and time are recorded on a surface encoder. After retrieving the tools, the borehole data are combined with surface data.

Table 1 shows the specifications of the PTSD logging tool. The PTSD logging tool is composed of a PT-probe, an S-probe and a D-probe. These probes can be combined into one unit which can be used under temperature conditions of 400ºC for 6 hours.

PT-probe

The PT-probe measures borehole pressure and temperature data in both dynamic and static conditions. These data are extremely important in analyzing geothermal wells.

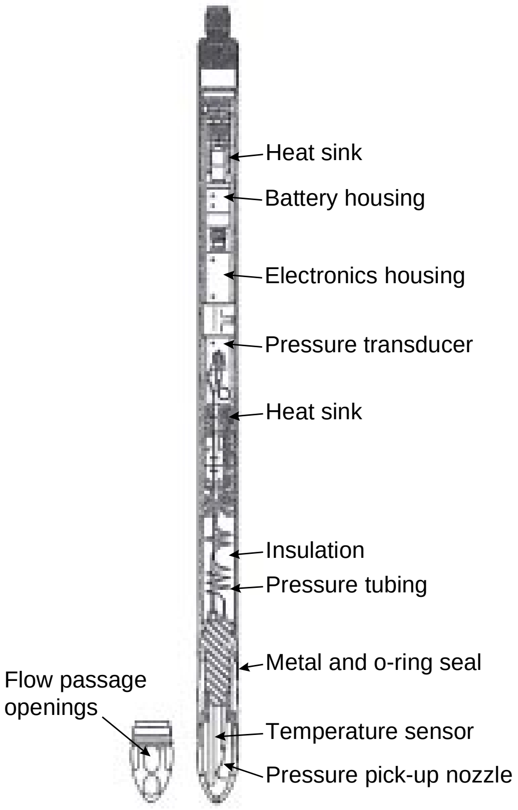

Fig.3. Main components of the advanced PT-probe logging tool

Table 1. Specification of PTSD logging tool

Probe	PT	S	D
Development	Finished	Finished	Under development
Diameter / Length / Weight	54mm / 2625mm / 26kg	56mm / 3210mm / 35kg	56mm / 3000mm (plan)
Heat resistance / Press. durability	400deg.C / 490kg/cm^2	400deg. C / 490kg/cm^2	400deg. C / 490kg/cm^2 (plan)
Max. time	6 hours	6 hours	6 hours (plan)
Labo. test / Field test	Finished	Finished	1998 / 1999
Others	Pressure accuracy : 0.2kg/cm^2, Temperature accuracy : 0.6deg. C	Not detected a direction of rotation	Density accuracy : 0.01g/cm^3 (plan), measuring time : 5 min.

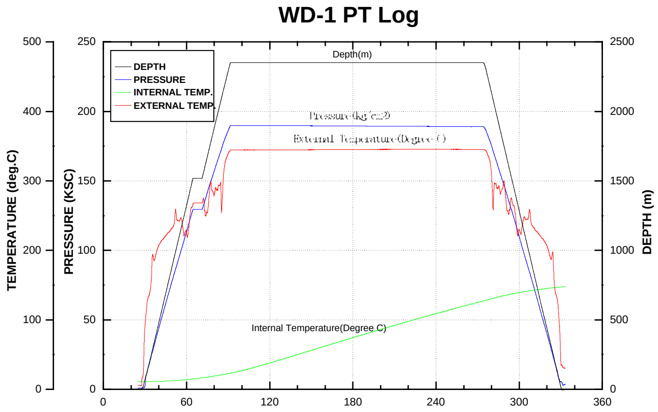

Fig.4. Results of PT logging (1996/3/14)

Figure 3 shows the main components of the advanced PT-probe. The PT-probe is composed of a memory module, battery module, pressure sensor and temperature sensor. The pressure is measured by an absolute pressure strain gauge transducer, and the temperature is measured by a platinum resistance thermometer. The seal mechanism is composed of a

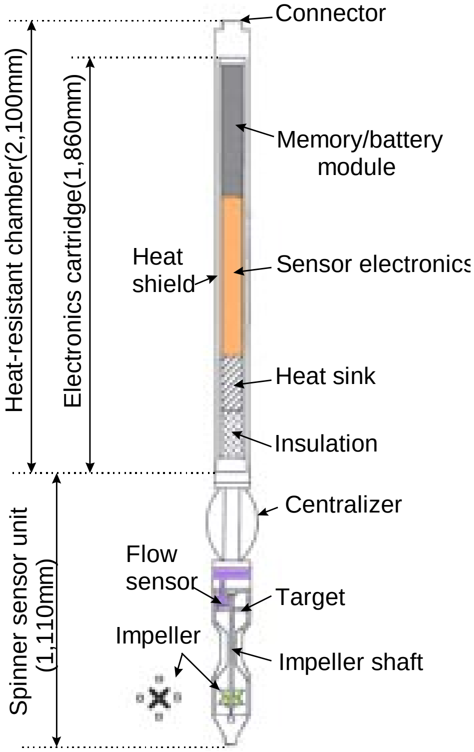

Fig.5. Main components of the advanced S-probe logging tool

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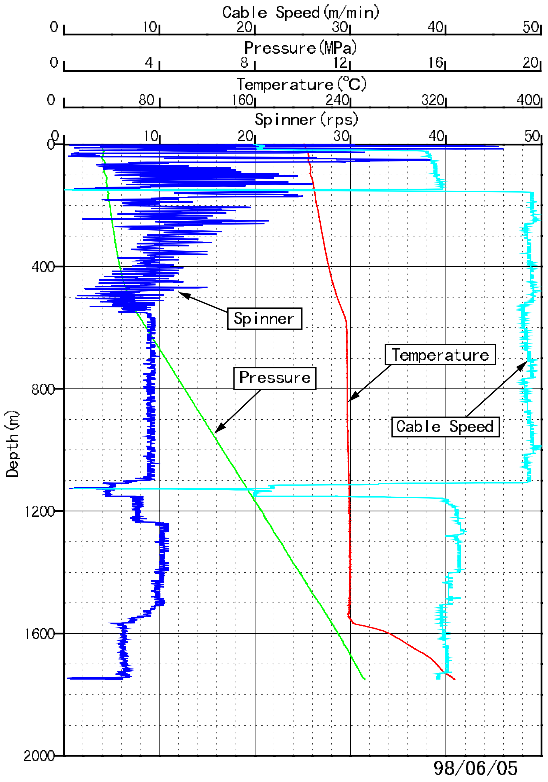
Figure 4 shows the result of the PT logging tool field test carried out in the WD-1 well (Uchida et al., 1997). The result proved that this tool worked successfully under 350ºC conditions. We see from Figure 4 that the internal temperature increased up to 75ºC, though the external temperature had increased up to 350ºC. The internal electronic parts are designed to operate at a maximum of 150ºC.

S-probe

The S-probe measures flow velocity in geothermal wells in both dynamic and static conditions. Feedpoints, injection points and boiling point are obtained through this logging.

As shown in Figure 3, this probe includes a memory/battery module, sensor electronics, a heat sink, insulation and a spinner sensor unit. The spinner sensor unit is composed of an impeller and target, flow sensor, etc. The impeller and target rotate according to flow velocity. The flow sensor is an eddy current type and



converts the rotation into electric signals.

Fig.6. Well temperature, pressure and frequency of the spinner plotted against depth

Figure 6 shows well temperature, pressure and revolutions of the spinner plotted against depth. This field test was conducted at a temperature of over 320ºC. The maximum logging temperature with a conventional cable is 315ºC, making a survey impossible.

D-probe

The D-probe measures fluid density in geothermal wells usually under dynamic conditions. The data are used to analyze the ratio of steam and hot water in two-phase flow.

As shown in Figure 7, this probe is composed of a memory/battery module, sensor electronics, a heat sink, insulation, collimators, a detector and Cs-137. Cs-137 is a radioactive isotope. Gamma rays radiated by Cs-137 pass through the flow pass, and the intensity of the gamma rays vary based on the average density of the flow. The intensity of the gamma rays is measured by the detector.

This probe is being manufactured now and will be laboratory tested by the end of FY1998(march 31, 1999). A field test will be conducted the following year.

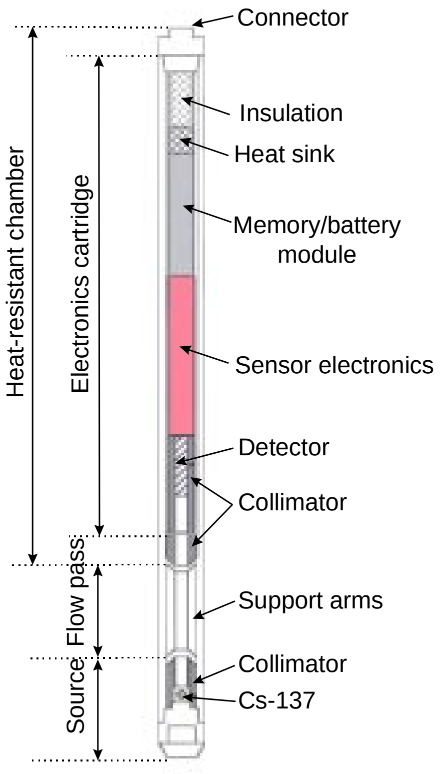


Fig.7. Main components of the advanced D-probe logging tool

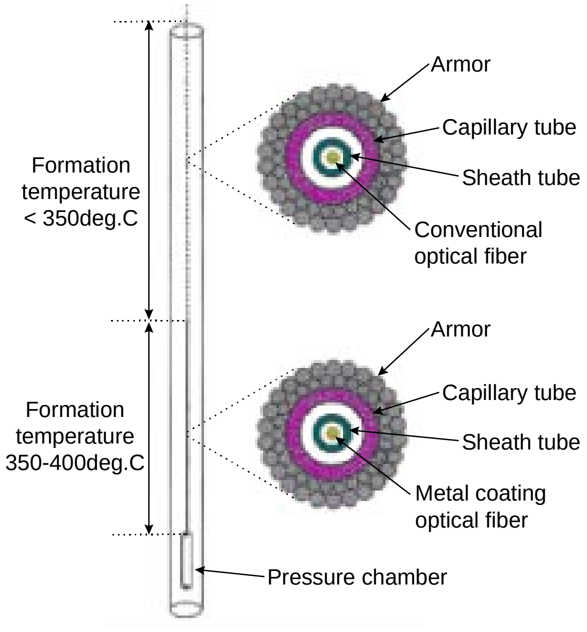


Fig.8. Outline of the PT monitoring system

PT MONITORING SYSTEM

The PT monitoring system measures the pressure and temperature in geothermal wells over a long interval. By monitoring them, the productivity of the well can be predicted. The system is still in the design stage and is composed of metal capillary tubing and uses optical fiber methods (Osato et al., 1997). However, there are problems with using a conventional system in deep geothermal wells; the capillary tubing has low tensile strength and the optical fiber is heat-resistant only up to about 300ºC.

The specifications of the PT monitoring system are as follows:

a)	Max. temperature	400ºC
b)	Max. pressure	490kg/cm^2
c)	Maximum depth	4,000m
d)	pH condition	pH3 (assumed)

Figure 8 shows a cross-section of the capillary tubing and optical fiber. Metal coated optical fiber was selected for its resistance to heat, and armored cable for its tensile.

C MONITORING SYSTEM

It is important to know the chemical components of deep geothermal fluid. Such knowledge enables the prediction and evaluation of scaling as well as estimation of the life span of the reservoir.

The main specifications of the sampler are as follows:

a)	temperature	6 hours-400ºC
b)	pressure	70MPa-400ºC
c)	diameter	82mm
d)	length	10m max.
e)	volume	1 liter
f)	cable	Slick line

The C monitoring system is comprises a downhole fluid sampler and a surface tool. Figure 9 is a conceptual diagram of the downhole fluid sampler. This tool is a vacuum-type sampler. In this system the sampler chamber is isolated by a piston whose position is controlled by a working fluid. When the inlet valve is opened, high-pressure fluid enters the sample chamber. The speed of the piston is controlled to avoid flushing. The inlet valve is closed by a spring and internal pressure after sampling. The surface tool plays an important role in analyzing the chemical components.

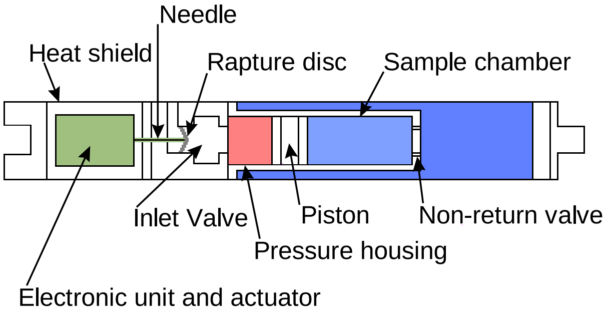


Fig.9. Conceptual diagram of the downhole sampler

TRACER MONITORING SYSTEM

To predict and evaluate the life span of a geothermal reservoir, the permeability between production and reinjection wells must be understood. Tracer monitoring has been conducted for this purpose.

Table 2. The principal tracer materials (materials in gray cells studied in this project)

Group		Tracer		Field
General		I	idoine	East Mesa(Adams,1985)
		Br	bromine	Ohnuma(Kubota and Matsubaya,1987)
		Cl	chlorine	Mori(Kasai and Sarudate,1986)
		NH_3	ammonia	Larderello(D'amore et al.,1987)
Radioactive	stable	δD	heavy hydrogen	Larderello(D'amore et al.,1987)
		$\delta^{18}O$	heavy oxygen	Geysers(Beall et al.,1989; Gambill,1991)
	unstable	^{3}H	hydrogen	Geysers(Gulati et al.,1978)
		^{131}l	idoine	Wairakei(Fox and Horne,1988)
		U	uranium	Broadlands(Barry et al.,1982)
		Th	tritium	East Mesa(Whittier et al.,1985)
Aromatic acid		Benzenesulfonic acid		Dixie Valley(Adams et al.,1992)
		4 methyl benzenesulfonic acid		
		4 ethyl benzenesulfonic acid		
		2,5 dimethyl benzenesulfonic acid		
		Paratoluenesulfonic acid		Fenton Hill
Freon		CCl_2F_2	R-12	Geysers(Moore et al.,1991)
		$CClF_3$	R-13	
		CF_4	R-14	
		C_2HF_5	R-125	
		$CHCIF_2$	R-22	
		CHF3	R-23	
		SF6	sulfur hexafluoride	Wairakei(Bixley et al.,1995)
Fluorescent		Rhodamine		Dixie Valley etc.
		Fluorescence		
Others		Molybdenum		Hijiori(Matsunaga et al.,1990)
		Tungsten etc.		
		Ester group		
		Alcohol group		Yellow Stone
		Bromobenzene(derivatives)		Fenton Hill

Conventional tracer materials can be used at maximum temperatures of 200-300ºC. Technologies to analyze flows between deep and shallow zones have not yet been established. Tracer materials for high temperatures and tracer flow analysis technology are therefore being developed.

Table 2 shows the conventional tracer materials. Many of these materials were tested in our research. Our objective is to select suitable materials for fluid tracer, two-phase tracer, and gas tracer. We tested the thermal stability of the tracers in gray cells shown in Table 2. The conditions were as follows :

a)	Temperature (°C)	250 or 300
b)	Period (week)	1 or 2
c)	Initial pH	4 or 6.6
d)	with / without rock	

SCALE MONITORING AND PREVENTION SYSTEM

Dissolved materials and the depositing conditions of deep geothermal fluids have not yet been determined. Scaling which occurs during production must be better understood. Such an understanding will contribute to safe, stable power generation.

Table 3 shows the scales often found in production wells, surface equipment, injection wells and the reservoir (after injection). We have had problems with scaling in the development shallow geothermal resources, and more difficult problem will be encountered in the development of deep-seated geothermal resources. Also, according to the type of scaling caused by the mixing of shallow and deep geothermal fluids must be investigated. There are many possible chemical reactions between shallow and deep geothermal fluids. We anticipate that developing technology for solving or preventing SiO_2, cray minerals and $CaSO_4$ scaling will be necessary for successful deep geothermal resource development.

We have been studying monitoring and prevention technology for scaling. For monitoring technology we are attempting to predict the composition of deep geothermal fluid and there by predict scaling for prevention technology, we intend to study the conditions when scaling doesn’t occur, and carry tests in the laboratory and the field.

CONCLUSION

In implementing the "Development of Drilling and Production Technology for Deep-seated Geothermal Resources" project, we have had difficulties as follows:

Table 3. Various scales in a geothermal plant system

	Shallow fluid	Deep fluid	Mixing shallow and deep fluid
Production well	▓ $CaCO_3$	▓ $CaCO_3$	▓ $CaCO_3$
		SiO_2	░ SiO_2
	$CaSO_4$	$CaSO_4$	$CaSO_4$
	Fe-S-O Group	Fe-S-O Group	Fe-S-O Group
	Cray minerals		░ Cray minerals
		Fe-Si Group	
		Fe-Mg-Si Group	Fe-Mg-Si Group
Surface plant	▒ SiO_2	░ SiO_2	░ SiO_2
	Fe-S-O Group	Fe-S-O Group	Fe-S-O Group
	Cray minerals	Cray minerals	Cray minerals
		Fe-Mg-Si Group	Fe-Mg-Si Group
Injection well	▒ SiO_2	░ SiO_2	░ SiO_2
		Fe-S-O Group	Fe-S-O Group
	Cray minerals	Cray minerals	Cray minerals
Reservoir (after injection)	▒ SiO_2	░ SiO_2	░ SiO_2
	$CaSO_4$	$CaSO_4$	░ $CaSO_4$
			░ Cray minerals

▓	We have solutions such as using an inhibitor.
▒	We have some difficulties.
░	We have many difficulties but we expect that successful deep geothermal resource development will require solutions.

a) There are few deep geothermal wells which can be used for the test.
b) Materials applicable to deep geothermal wells are very expensive.

However, as this large energy source in the near future, the technology to exploit it is indispensable. It is hoped that the results of this project contribute to the further development of needed technology.

Our aim is to create technology which can be applied practically. For this purpose, we will continue to test and improve development technology as much as possible.

ACKNOWLEDGEMENT

Figure 10 shows the structure of this project. The authors are grateful for the support and cooperation of the parties listed below. We would also like to express our deepest thanks to Tokyo Electric Power Co. Ltd. and Japex Geothermal Kyushu Co. Ltd. for their cooperation.

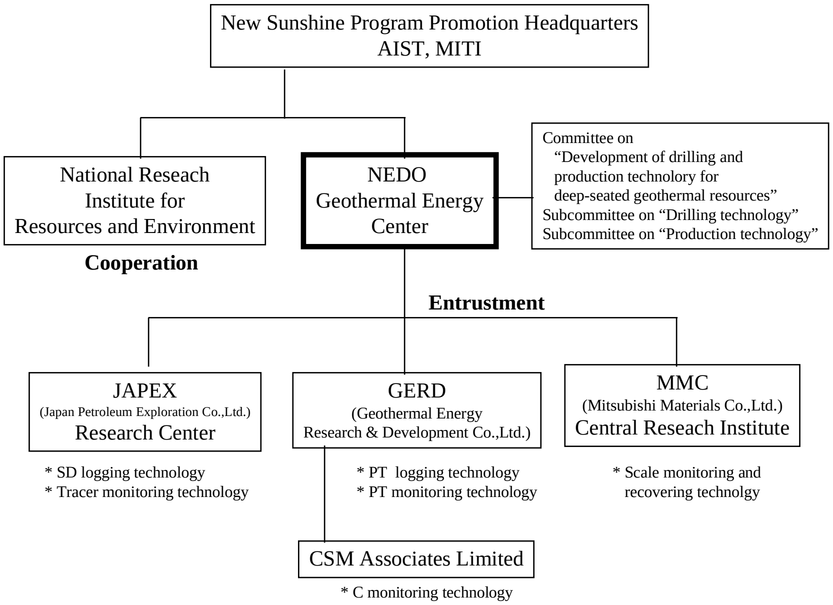


Figure 10: Structure of the project

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