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High Temperature Engineering Test Reactor (HTTR) is the first graphite-moderated helium gas cooled reactor in Japan. The rise-to-power test of the HTTR started on September 28,1999 and thermal power of the HTTR reached its full power of 30 MW on December 7, 2001.

Vessel Cooling System (VCS) of the HTTR is the first Reactor Cavity Cooling System(RCCS) applied for High Temperature Gas Cooled Reactors. The VCS cools the core indirectly through the reactor pressure vessel to keep core integrity during the loss of core flow accidents such as depressurization accident. Minimum heat removal of the VCS to satisfy its safety requirement is 0.3MW at 30 MW power operation. Through the performance test of the VCS in the rise-to-power test of the HTTR, it was confirmed that the VCS heat removal at 30 MW power operation was higher than 0.3MW.

This paper shows outline of the VCS and test results on the VCS performance.

Keywords: HTTR, HTGR, Rise-to-power Test, VCS, RCCS

※ On loan to Secretariat of Nuclear Safety Commission.

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高温工学試験研究炉の炉容器冷却設備に関する試験データ

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(2002年12月13日受理)

高温工学試験研究炉(HTTR)は、日本で建設された最初の黒鉛減速ヘリウムガス冷却炉である。1999年9月28日から出力上昇試験を開始し、HTTRは2001年12月7日に定格出力30MWに到達した。

HTTRの炉容器冷却設備(VCS)は、高温ガス炉に実用化された最初のReactor Cavity Cooling System (RCCS)であり、炉心の強制冷却が喪失する減圧事故時に炉心の健全性を維持するために原子炉圧力容器を介して間接的に炉心を冷却する。そのために、定格出力時に0.3MW以上の除熱量を確保できるように設計されており、HTTRの出力上昇試験時に実施した性能試験によって、定格出力時に0.3MW以上の除熱量が確保されていることを確認した。

本報では、炉容器冷却設備の概要及び出力上昇試験時の試験結果について報告する。

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※ 内閣府 原子力安全委員会事務局出向中

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1. Introduction

A High Temperature Gas-cooled Reactors (HTGR), which is a graphite moderated and helium gas-cooled reactor, is attractive as one of the future energy options because of its capability of producing high temperature heat and its inherent safety characteristics. The modular HTGR with gas-turbine power generation system is well understood to have inherent safety features coupled with the modular concept to improve the economic competitiveness with the current fossil energy and light water reactor systems. The HTGRs will achieve a high degree of safety through reliance on inherent safety features. The high degree of safety is largely derived from the ability of the ceramic coated fuel particles to retain the fission products under normal and accident conditions, and the ability of the design of Reactor Cavity Cooling System (RCCS) to remove decay heat by natural heat transport mechanisms without excessive temperatures of the fuel and Reactor Pressure Vessel (RPV), and so on. Prior to licensing and commercial deployment of the HTGR, the methods used to predict the performance of the fuel and RPV should be validated with experimental data.

High Temperature Engineering Test Reactor (HTTR) is the first HTGR in Japan(1). The HTTR attained its thermal full power of 30MW on December 7, 2001 in the rise-to-power test which started on September 28, 1999(2). A Vessel Cooling System (VCS) is one of the safety engineered features of the HTTR and the first RCCS applied to the HTGR. The performance test of the VCS was carried out in the rise-to-power test to confirm that the VCS heat removal satisfies minimum requirement of 0.3MW at 30MW to keep the reactor safety during accident conditions. Test results showed that the VCS heat removal reached about 0.8MW. Experimental data on the VCS performance would contribute to the validation of prediction methods and codes for the RCCS performance.

This report shows outline of the VCS and experimental data on the VCS in the rise-to-power test.

2. Outline of Vessel Cooling System

2.1 Cooling System of HTTR

Reactor cooling system of the HTTR consists of the primary cooling system, secondary helium cooling system, pressurized water cooling system, auxiliary cooling system and VCS. A schematic diagram of the reactor cooling system is shown in Fig. 2.1.

The primary cooling system has two heat exchangers of a Primary Pressurized Water Cooler (PPWC) and an Intermediate Heat Exchanger (IHX). In the single loaded operation, only the PPWC is operated and maximum heat capacity of the PPWC is 30MW. In the parallel loaded operation, the PPWC and IHX are operated simultaneously and their maximum heat capacities are 20MW and 10MW, respectively. The RPV, PPWC and IHX are connected each other by the concentric hot gas duct. Primary coolant heated in the core flows from the RPV to the PPWC and IHX through inner side of the concentric hot gas duct and returns to the RPV through the outer side. The primary cooling system is also used to remove the residual heat in the reactor during normal shut down of the HTTR. Secondary helium cooling system is operated only in the parallel loaded operation. The pressurized water cooling system consists of air cooler, water pump and so on. The heat generated in the core is released to the atmosphere by the air cooler of the pressurized water cooling system.

The auxiliary cooling system is in standby during the normal operation and starts up automatically to cool the core directly after a reactor scram in the anticipated operation occurrences and the accidents such as reactivity insertion, pipe rupture in the secondary cooling system, and so on.

The VCS is operated during the reactor operation and shutdown. During normal operation, the VCS cools the concrete of primary side radiation shielding. At accidents such as depressurized accidents, when the core could not cooled by forced circulation of coolant, the core is cooled by VCS by natural convection and radiation from RPV.

2.2 Design requirement of VCS

The safety analysis for the depressurization accident showed that temperatures of the fuel and RPV did not exceed their limit temperatures of 1600°C and 550°C, respectively, to keep their structural integrity. In the safety analysis, the VCS heat removal of 0.3MW is used as the initial conditions. Therefore, the VCS is required to remove more than 0.3MW of heat at 30MW power operation.

On the other hand, the VCS is also designed that the VCS heat removal is less than 0.6MW to attain reactor outlet temperature of 950℃ at 30MW power operation during the high temperature test operation mode because the VCS heat removal during normal operation means heat loss from the reactor.

Also, the VCS is designed to cool the concrete of primary side radiation shielding below 65°C during the normal operation. The primary side radiation shielding made of concrete is surrounding the RPV. The concrete of the primary side radiation shielding should be keep below 65℃ to keep integrity.

2.3 Detail of VCS

The flow diagram of VCS is shown in Fig. 2.2. The VCS applies forced water cooling and is operated at constant flow rate through the normal and accident conditions. Table 2.1 shows major specification of the VCS.

The VCS consists of cooling panels, pumps, water coolers and so on. The cooling panels consist of upper, side and lower panels. Flow rate, inlet and outlet water temperature of each panel are measured individually as shown in Fig. 2.2. Water flowing in each panel is cooled by water cooler. The heat removed by the VCS is finally released to the atmosphere through cooling towers of an auxiliary component cooling water system.

The VCS has independent two sets of cooling system, the A and B systems, to satisfy minimum heat removal even if one of two sets loses its function. The upper, side and lower panels are installed on the inner surface of the radiation shielding made of concrete as shown in Fig.2.3. Water cooling tubes of the A and B systems are connected each other by the fin plates.

The upper panel is installed on the lower surface of the upper radiation shielding. The side panels are installed on the vertical surface of the primary side radiation shielding which is surrounding the RPV. The lower panels are installed at the vertical wall and bottom surface of lower cavity of the RPV.

The side and lower panels have thermal reflector plates. Primary coolant of about 400°C at 30MW flows along inner surface of the RPV during the normal operation. Therefore, the RPV surface temperature reaches about 400°C and radiation heat transfer is dominant to the heat transfer from the RPV to the VCS. The thermal reflector plates are located at the front of water cooling tubes to adjust the heat removal rate. Number of thermal reflector plates are shown in Table 2.2.

Moreover, there are heat removal adjustment panels at the side panel. The heat removal adjustment panel is water cooling panel located facing RPV wall. This panel is to be used when heat removal rate is expected lower than 0.3MW at full power operation. However, the heat removal adjustment panels are never used because the obtained heat removal of VCS is higher than 0.3MW at full power operation.

Flow diagram and cooling tube arrangement of the upper panel are shown in Fig. 2.4. The upper panel is composed of two systems, called A and B, which have 48 cooling tubes in a steel casing, respectively. Water is distributed to six inlet headers from the inlet ring header and flows to the outlet ring header through cooling tubes and outlet headers. Figure 2.4 also shows water flow direction of the A system. There are 31 holes for the standpipes of the RPV in the upper radiation shielding. Cooling tubes also pass the gap between holes to cool the upper radiation shielding made by concrete uniformly.

The side panel consists of twelve units because horizontal cross section of the reactor cavity is dodecagon. Figure 2.5 shows the schematics of panel arrangement of the side panel. Water flows into each unit through the lower ring header and goes out through the upper ring header. Figure 2.6 shows a reference unit of the side panel. An unit of side panel has 18 cooling tubes, 9 for the A system and 9 for the B system. Adjacent tubes are connected by steel plates.

From top to bottom of the side panel, there are two thermal reflector plates between cooling tubes and RPV. Between EL 19.025M and EL. 27.175M, there are two more thermal reflector panels as shown in Fig.2.6.

In the lower panel, circulating water flows into the lower panel (bottom) and returns to the water cooler after flows through the lower panel (side). Figure 2.7 shows the schematic flow diagram and cooling tube arrangement of lower panel(bottom) which is similar to the upper panel and its cooling tubes are installed between two plates. The lower panel (side) is similar to the side panel and consists of twelve units. Each unit has 16 cooling tubes, 8 for A system and 8 for B system, and two thermal reflectors as shown in Fig.2.8. Water is distributed to each unit from the inlet ring header. Then, water goes upward through 4 cooling tubes, and returns to the outlet ring header through the other 4 cooling tubes.

Table 2.1 Specification of VCS

Number of set	2 set (A & B systems)
Minimum requirement for heat removal	0.3MW
Nominal water flow rate	
Upper panel	6.5 ton/hour/each set
Side panel	72 ton/hour/each set
Lower panel	6.5 ton/hour/each set
Allowable temperature	90°C
Allowable pressure	0.98 MPaG
Number of cooling tube	
Upper panel	48/each set
Side panel	108/each set
Lower panel(side)	96/each set
Lower panel(bottom)	8 or 3/each set

Table 2.2 Thermal reflector plate

Panel	Numbers	Elevation
Side panel (See Fig.2.5)	3 (Carbon steel) 1(Stainless steel)	From EL.19.025M to EL.27.175M
	1 (Carbon steel) 1 (Stainless steel)	From EL.17.35M to EL.19.025M From EL.27.175M to EL.30.99M
Lower panel (side) (See Fig.2.6)	1 (Carbon steel) 1 (Stainless steel)	From EL.13.40M to EL.16.71M

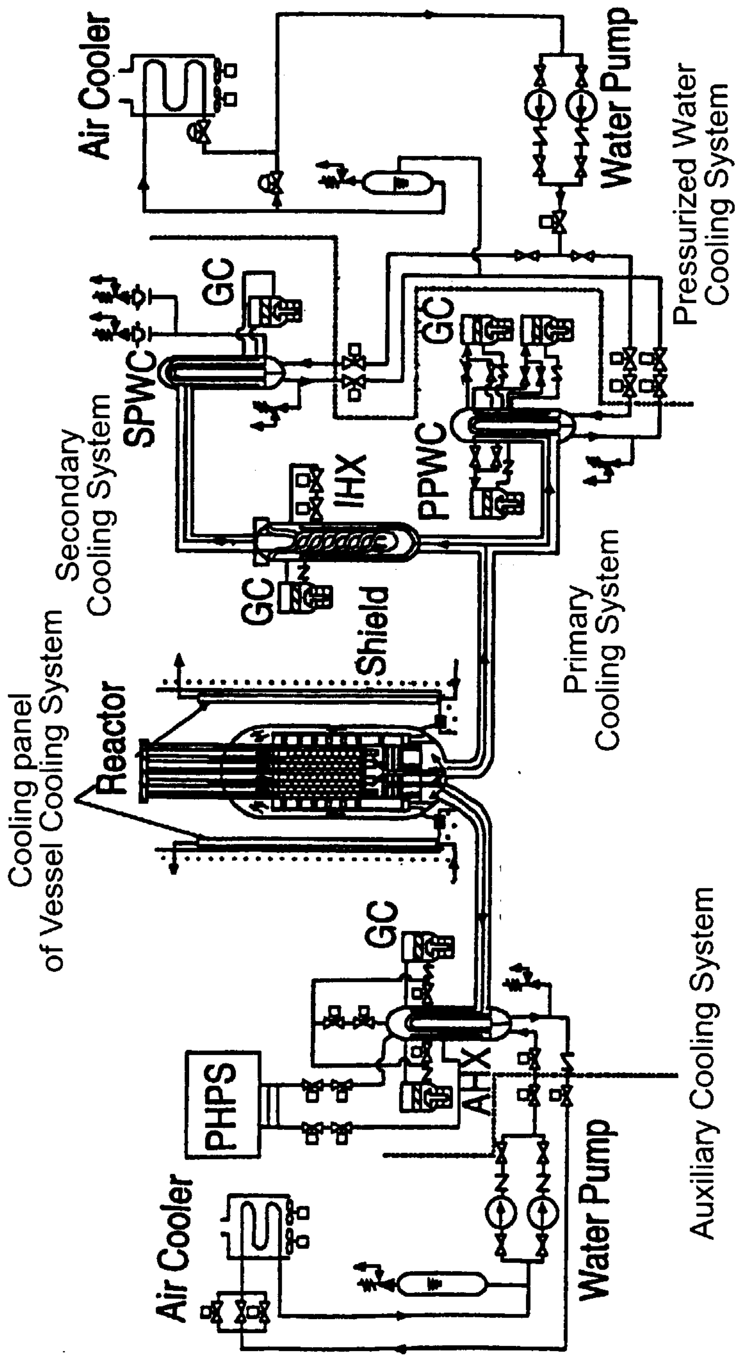

Fig.2.1 Schematic drawing of cooling system

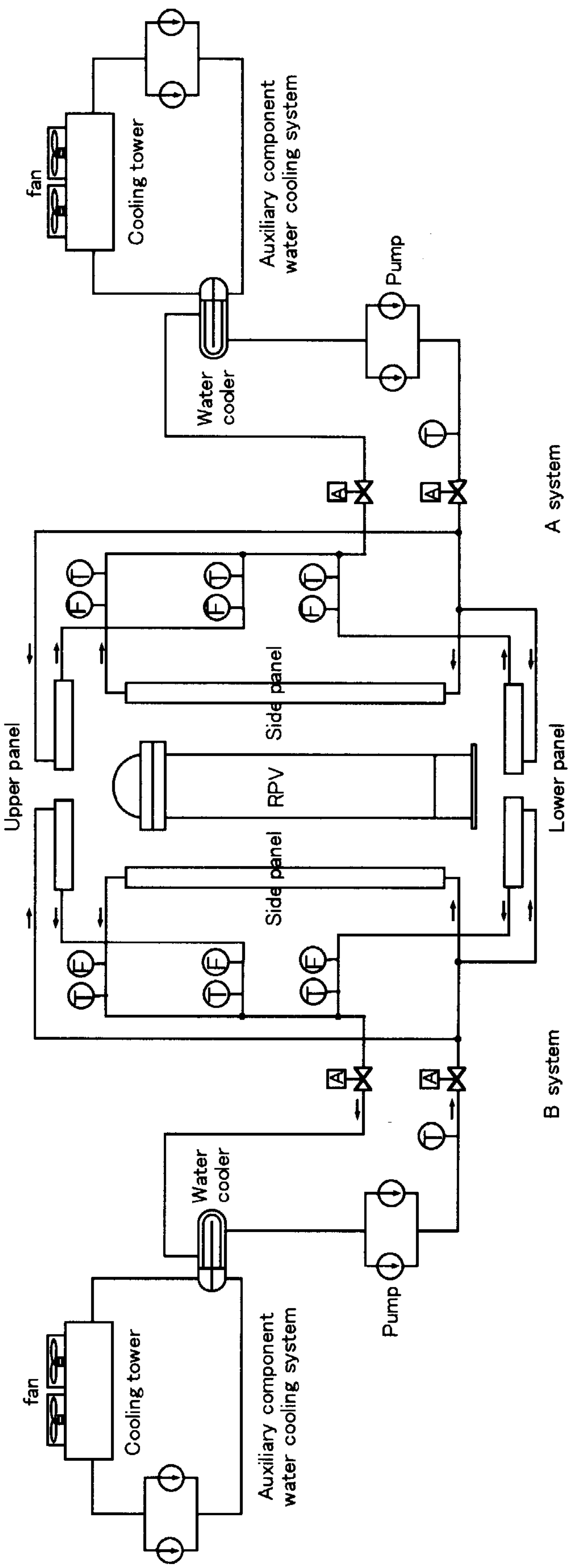

Fig.2.2 Schematic drawing of VCS

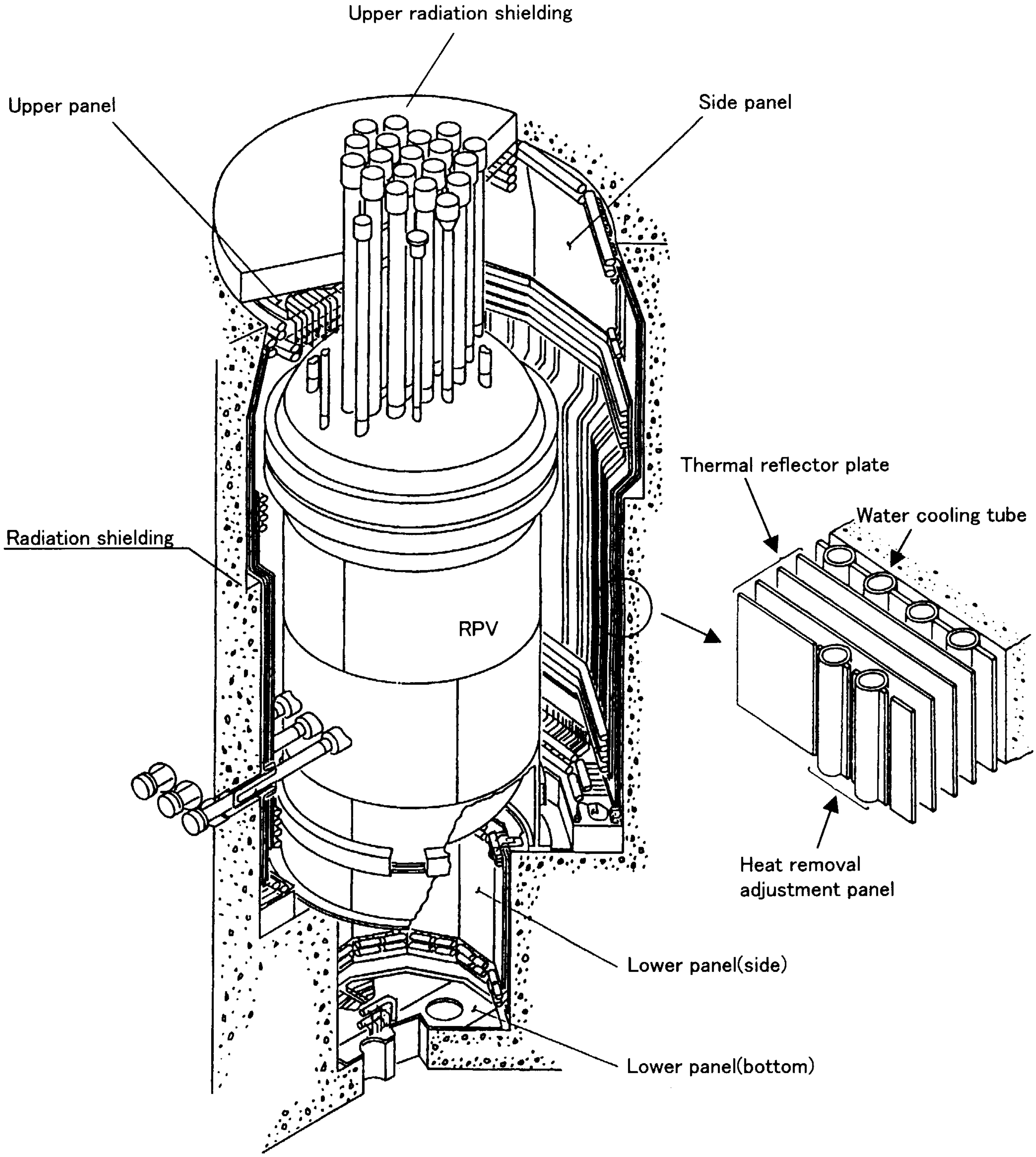

Fig.2.3 Cooling panels of VCS and RPV

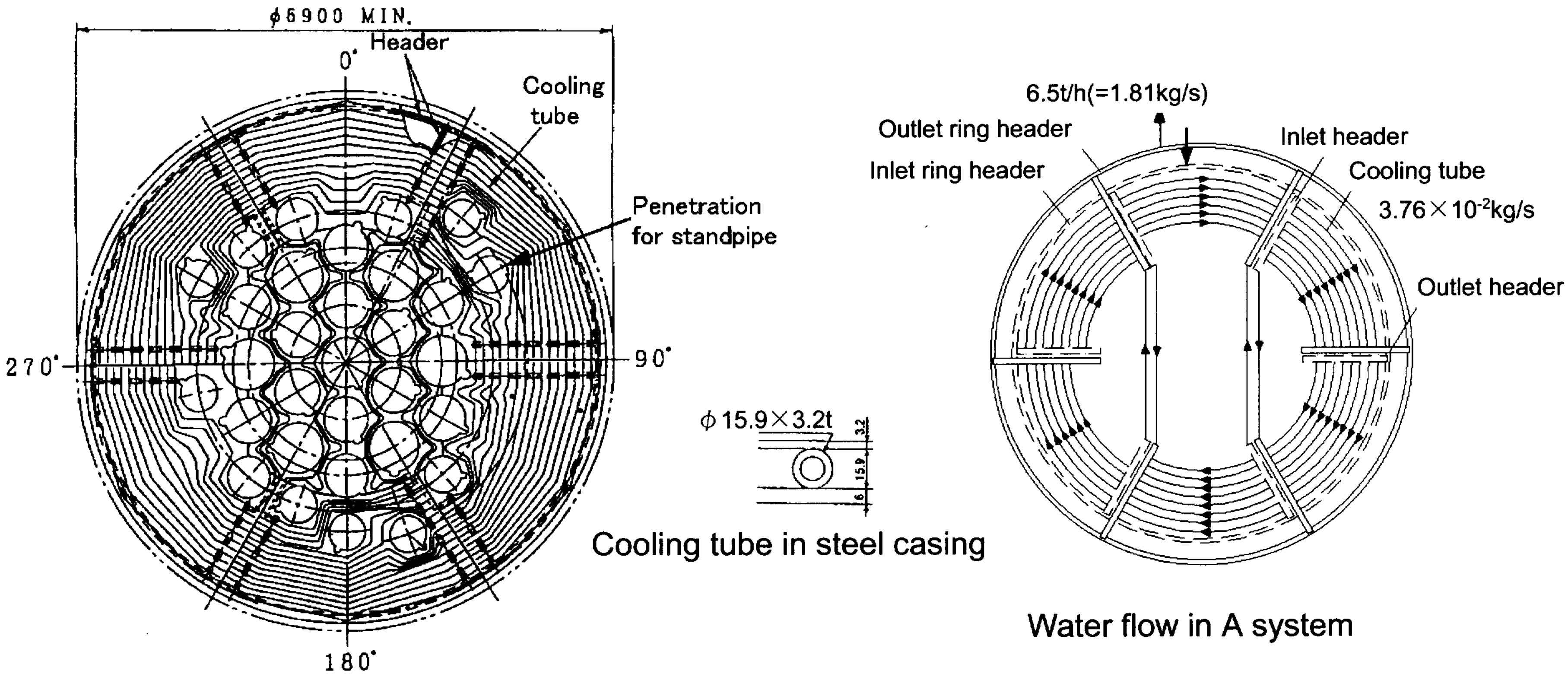

Fig.2.4 Flow diagram and cooling tube arrangement of upper panel

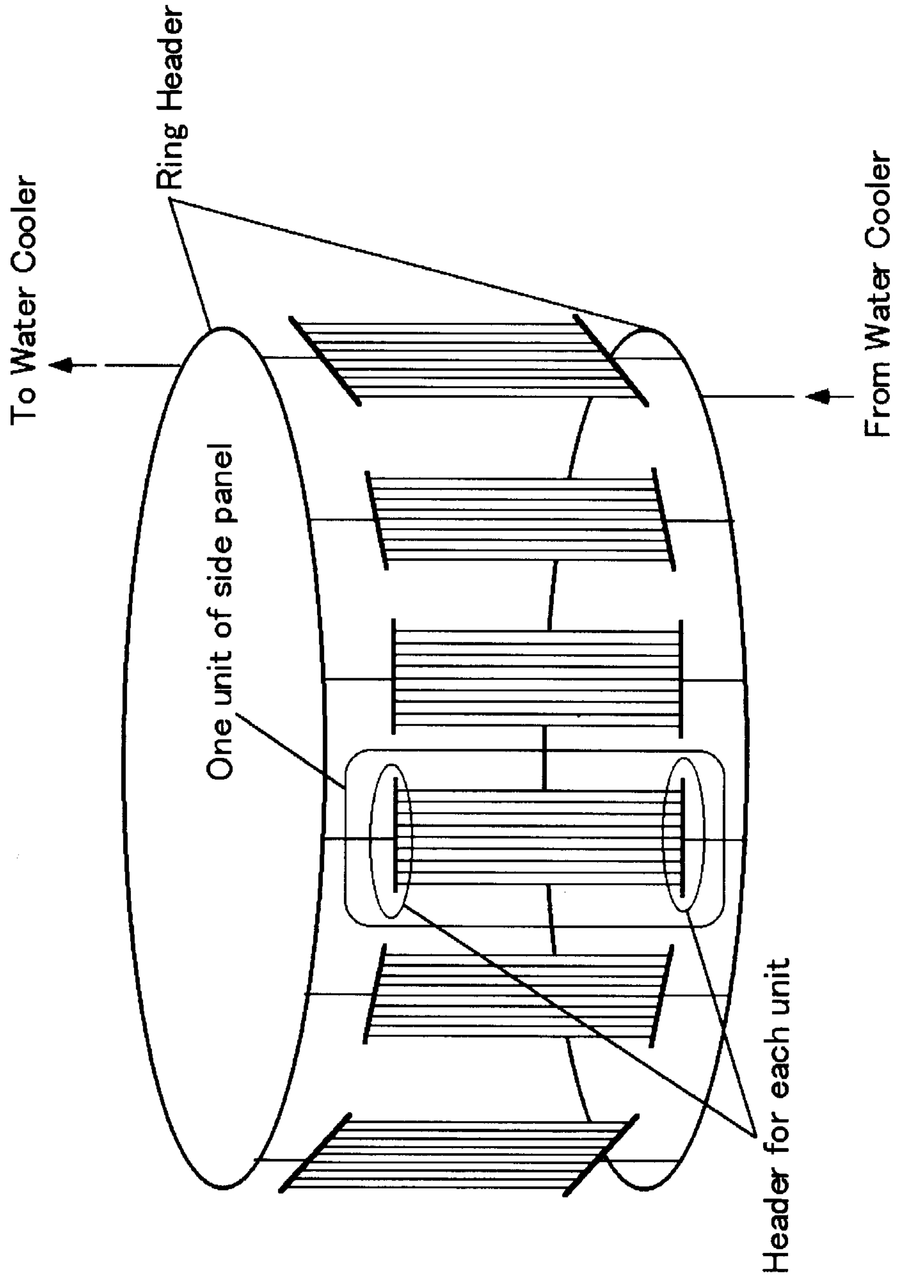

Fig.2.5 Flow diagram and arrangement of side panel

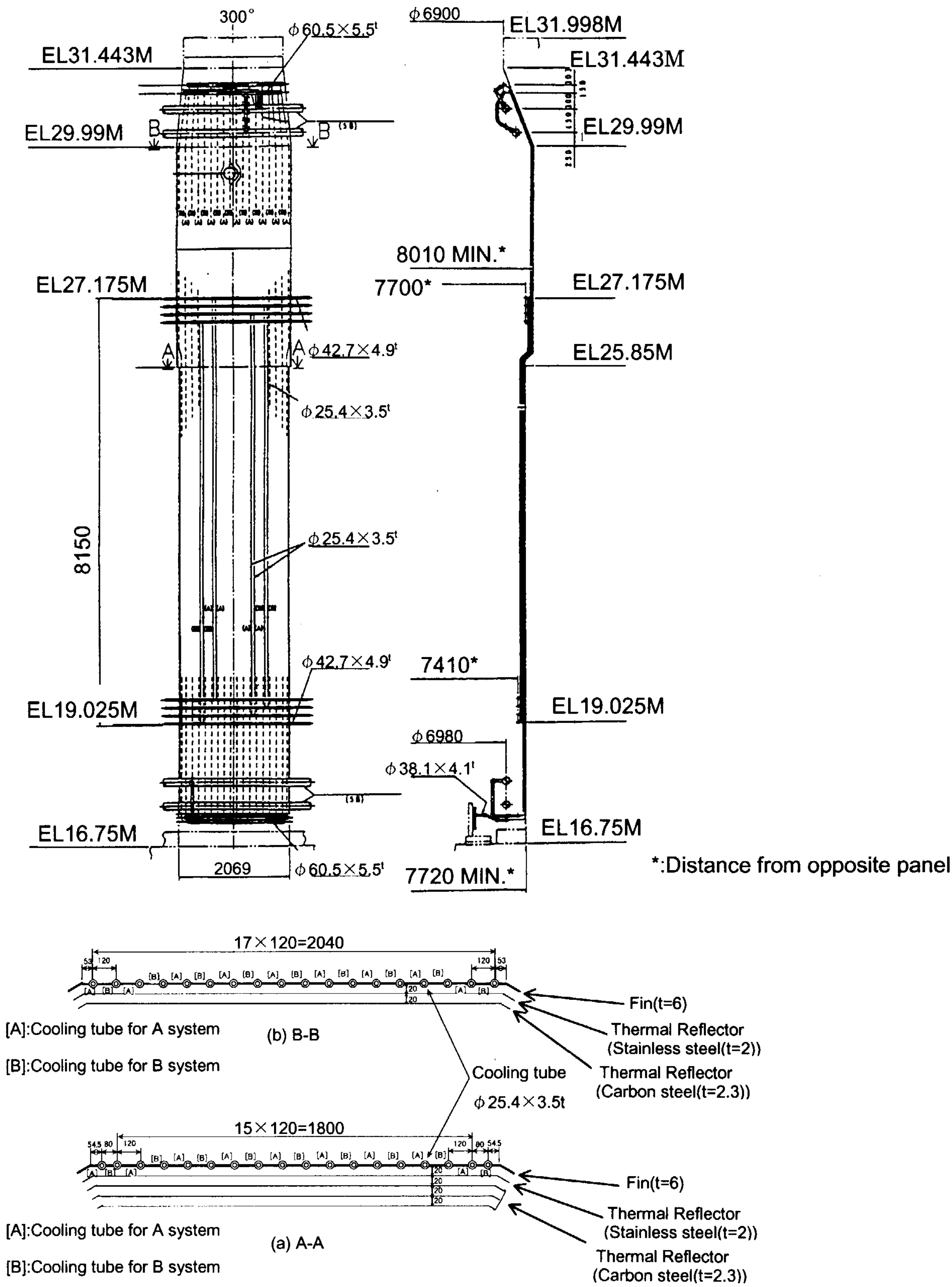

Fig.2.6 Detail of side panel

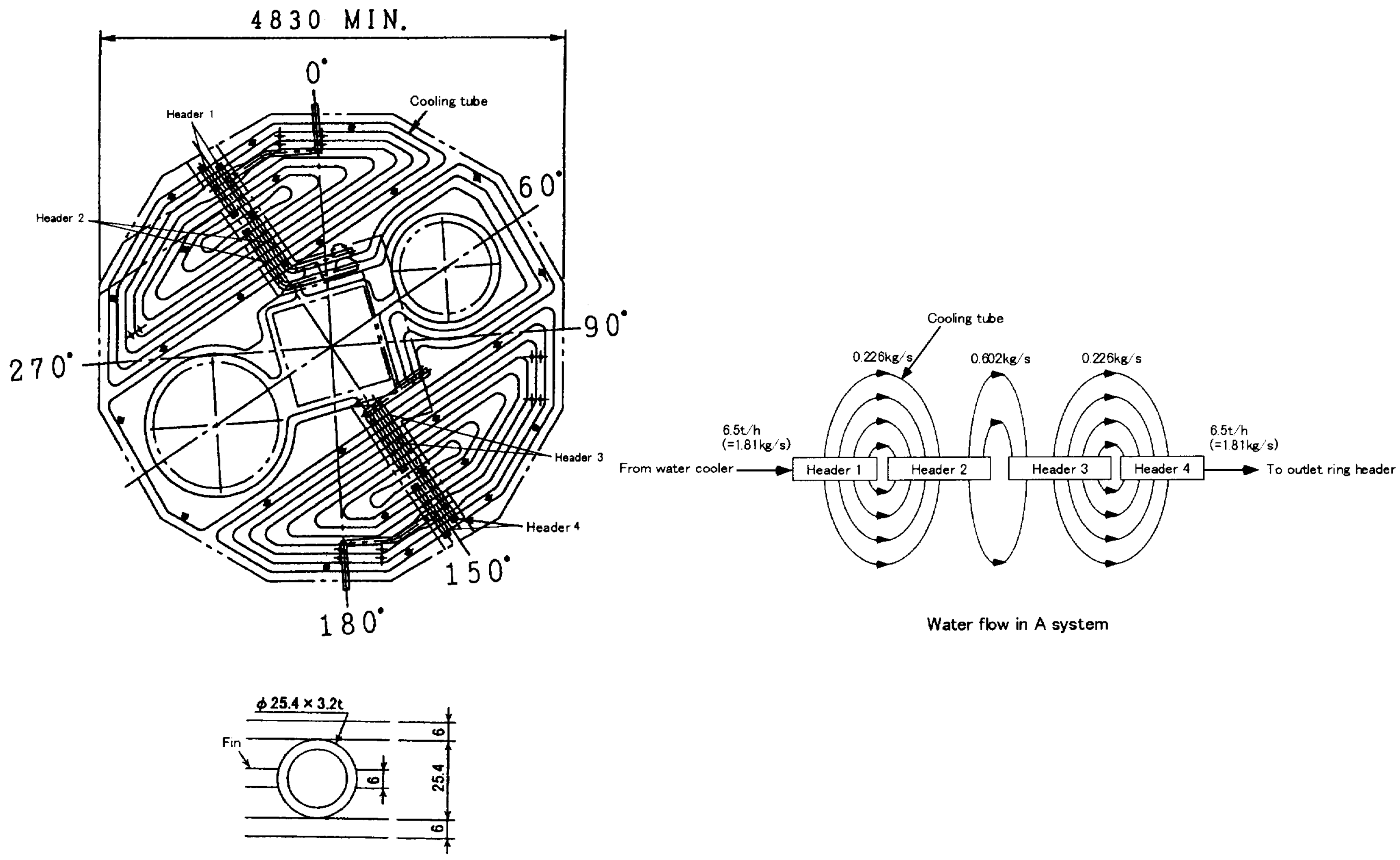

Fig.2.7 Flow diagram and cooling tube arrangement of lower panel(bottom)

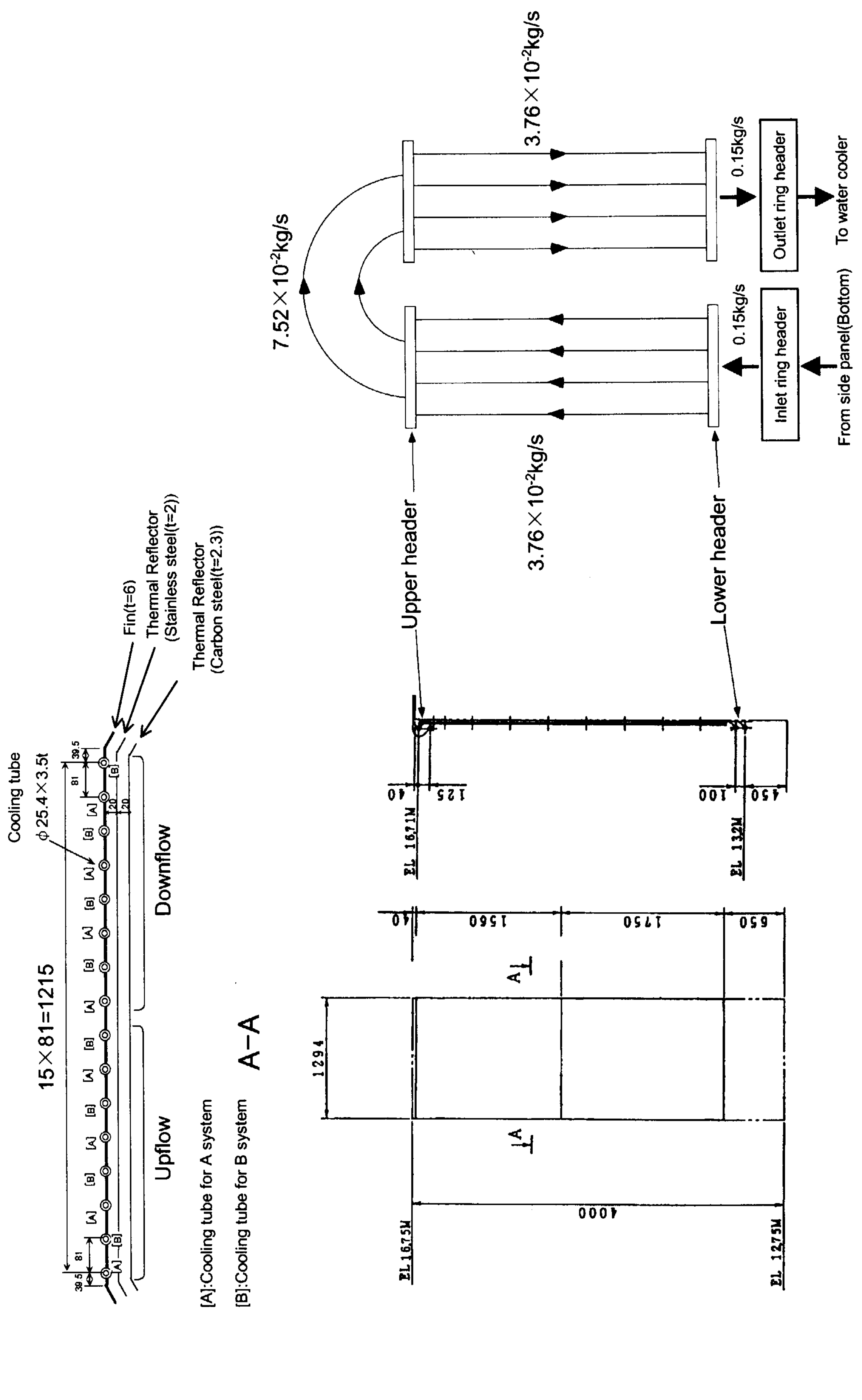

Fig.2.8 Flow diagram and cooling tube arrangement of lower panel (side)

3. Test results

The rise-to-power test of the HTTR for the rated power operation was carried out since September 28, 1999 to confirm the performance of the HTTR such as control system, radiation shielding, heat exchangers, VCS and so on. The VCS performance test was carried out to confirm that the VCS heat removal at 30MW power operation was more than 0.3MW and the primary side radiation shielding temperatures did not exceed temperature limit of 65°C. The VCS heat removal was calculated from flow rate, inlet and outlet temperatures of the upper, side and side panels.

3.1 Results of heat removal rate

Table 3.1 shows reactor data at 30MW for the single and parallel loaded operations. Flow rate, inlet and outlet temperatures, and calculated VCS heat removal at 30MW are shown in Table 3.2. VCS heat removal is a sum of heat removal of upper, side and lower panels. Heat removal of each panel is calculated by flow rate, inlet and outlet temperature of each panel.

VCS heat removal at 30MW reached about 0.81MW in the single loaded operation. Heat removal of the upper, side and lower panels are 0.12MW, 0.62MW and 0.07MW, respectively. Ratios of heat removal of the upper, side and lower panels to total heat removal were about 15%, 76% and 9%, respectively.

In the parallel loaded operation, total heat removal and heat removal of the upper, side and lower panels at 30MW were about 0.82MW, 0.13MW, 0.62MW and 0.07MW, respectively. The ratios of heat removal of the upper, side and lower panels to total heat removal in the parallel loaded operation were about 15%, 76% and 9%, respectively.

The test results of the single and parallel loaded operations showed no difference in the VCS heat removal. The measurement error of the VCS heat removal was estimated to be about 30% at the rated power operation of 30MW.

3.2 Transient behavior at operation

(1) Single loaded operation

Transient behaviors of VCS heat removal, reactor power, reactor inlet and outlet temperatures for the single loaded operation are shown in Fig.3.1. Reactor operation was started on October 25, 2001. Reactor power was increased step by step. Reactor power was kept about 84% to 93% from November 6 to December 6 to reduce impurity in the primary coolant. Then, Reactor power was risen to about 100%. Manual scram test was carried out on December 14, 2001 and reactor power decreased to 0%. VCS heat removal, reactor inlet and outlet temperatures showed similar transient behavior to the reactor power transient.

VCS heat removal showed fluctuation with the range between 0.77MW and 0.85 MW at 30MW operation. This fluctuation was due to change in water temperature at the cooling tower. Figure 3.2 shows transient behaviors of water temperature at the cooling tower, inlet and outlet temperatures of the upper panel of the A system during the single loaded operation. Also, transients of the B system are shown in Fig. 3.3. Water temperature of the cooling tower is controlled manually within set temperature range by on-off control of the cooling tower fans. The set temperature range is changed during operation. Therefore, temperature range of water temperature showed different variation at operation period. For example, from December 1 to December 14, water temperature of the A systems at 30MW was controlled in the range between 19°C and 23°C. For the B system, water temperature also was controlled between 17°C and 23°C. As a result, the panel inlet temperature changes according to the transient of the water temperatures at the cooling towers, Therefore, VCS heat removal changes as shown in Fig.3.1.

Figure 3.4 shows VCS heat removal and reactor inlet temperature versus reactor power during the single loaded operation. The VCS heat removal was about 0.1MW before the reactor operation. Primary coolant was heated up to about 120°C, then RPV was also heated up about 120°C before the reactor operation. Therefore, VCS shows about 0.1MW of heat removal.

The VCS heat removal increased with increase in reactor power. The VCS heat removal increased nonlinearly because radiation heat transfer contributed mainly to heat transfer from the RPV to the cooling panels. Reactor power was controlled by the reactor power control system from 30% to 100%. Reactor inlet temperature was also controlled from 180°C at 30% to 395°C at 100% according to change in the reactor power.

Figure 3.5 shows ratios of heat removal of the upper, lower and side panels to total heat removal through the single loaded operation. The ratios were fairly constant from low power to 30MW and are about 15%, 9% and 76% for the upper, lower and side panels, respectively. However, ratio of lower panel was slightly increased with increase in reactor power.

(2) Parallel loaded operation

Figures 3.6-3.10 show experimental results at parallel loaded operation. They showed similarity to the results of the single loaded operation. Reactor operation was started on January 25, 2002. Reactor power was increased step by step. The reactor power was changed from 67% to 77% to conduct the experiment to obtain data of decay and production behavior of xenon. Loss of off-site electric power simulation test was carried out on March 6, 2002 and the reactor power decreased to 0 %.[(3)]

VCS heat removal was changed corresponding to the change in reactor power and reactor inlet temperature. Also, VCS heat removal shows fluctuation similar to that of the single loaded operation. This fluctuation was due to the change in water temperature of water cooler. In the parallel loaded operation, water temperature at cooling tower was controlled between 23°C to 17°C for the A system, 23°C to 19°C for the B system at 30MW operation. Then inlet and outlet temperature of panel were changed corresponding to the water temperature change. Therefore, VCS heat removal rate showed fluctuation as shown in Fig. 3.6.

3.3 Temperature profile on RPV and side panel

Several thermocouples were set on the outer surface of the RPV and inner surface of the side panel. Temperature profiles of RPV wall and side panel at 30 MW are shown in Table 3, Figs.3.11 and 3.12 for the single and parallel loaded operation. Both cases show similar results. Helium of about 400°C flows upward along the inner wall of RPV. Therefore, the middle part of RPV surface showed flat temperature profile. The RPV surface (elevation range between 19M and 26M) showed about 10°C of temperature change. However, surface temperature of side pane face to the RPV showed about 80°C of temperature change at lower part. This change in temperature difference were shown in both cases.

3.4 Results of concrete temperature at primary side radiation shielding

There were six thermocouples in the concrete of primary side radiation shielding. These thermocouples were located in three different height. Results of different height are shown in Fig. 3.13. Concrete temperatures increased with increase in reactor inlet temperature. Higher position showed higher temperature. It was considered that temperature at higher position in reactor cavity showed higher temperature because of natural convection in the cavity. Therefore, concrete temperature at higher position became higher temperature.

Maximum temperature of primary radiation shielding temperature at 30MW of the single and parallel loaded operation reached 56.5°C and 58°C, respectively. Test results showed that measured temperatures satisfied limit temperature of 65°C.

Table 3.1 Operation data of reactor at 30 MW

	Single loaded operation	Parallel loaded operation
Reactor		
Reactor inlet temperature	392°C	392°C
Reactor outlet temperature	844°C	828°C
Pressure	4.0MPaG	4.0MPaG
Coolant flow rate	12.3kg/s	12.4kg/s

Table 3.2 Operation data and heat removal of VCS at 30 MW

	Single loaded operation	Parallel loaded operation
VCS (A system)		
Inlet temperature	32.1°C	32.2°C
Upper panel		
Outlet temperature	39.7°C	38.5°C
Flow rate	7.3t/h	9.0t/h
Side panel		
Outlet temperature	35.6°C	36.0°C
Flow rate	79.7t/h	73.6t/h
Lower panel		
Outlet temperature	37.5°C	37.2°C
Flow rate	7.3t/h	8.1t/h
VCS (B system)		
Inlet temperature	34.2°C	34.8°C
Upper panel		
Outlet temperature	41.5°C	40.8°C
Flow rate	7.0t/h	8.7t/h
Side panel		
Outlet temperature	37.4°C	38.2°C
Flow rate	77.7t/h	74.8t/h
Lower panel		
Outlet temperature	37.6°C	37.6°C
Flow rate	6.9t/h	8.2t/h
VCS heat removal		
Total	0.81MW (100%)	0.82MW (100%)
Upper panel	0.12MW (15%)	0.13MW (15%)
Side panel	0.62MW (76%)	0.62MW (76%)
Lower panel	0.07MW (9%)	0.07MW (9%)

Table 3.3 Surface temperatures of RPV and VCS panel at 30MW

	Elevation (m)	Single loaded operation (°C)	Parallel loaded operation (°C)
RPV Temperature	29.6	314.2	314.0
	29.4	307.3	306.9
	28.8	291.7	290.8
	27.7	327.8	327.0
	27.0	342.9	342.1
	25.9	362.0	361.2
	23.6	360.7	360.0
	22.7	358.9	358.1
	19.2	349.3	347.7
	18.48	291.4	289.6
VCS Panel Temperature	29.05	205.2	204.2
	26.5	312.9	312.1
	25.9	317.1	316.4
	24.5	313.3	312.4
	23.6	314.5	313.4
	22.7	303.8	302.4
	21.5	291.2	290.1
	20.45	263.2	262.7
	19.86	236.7	235.3

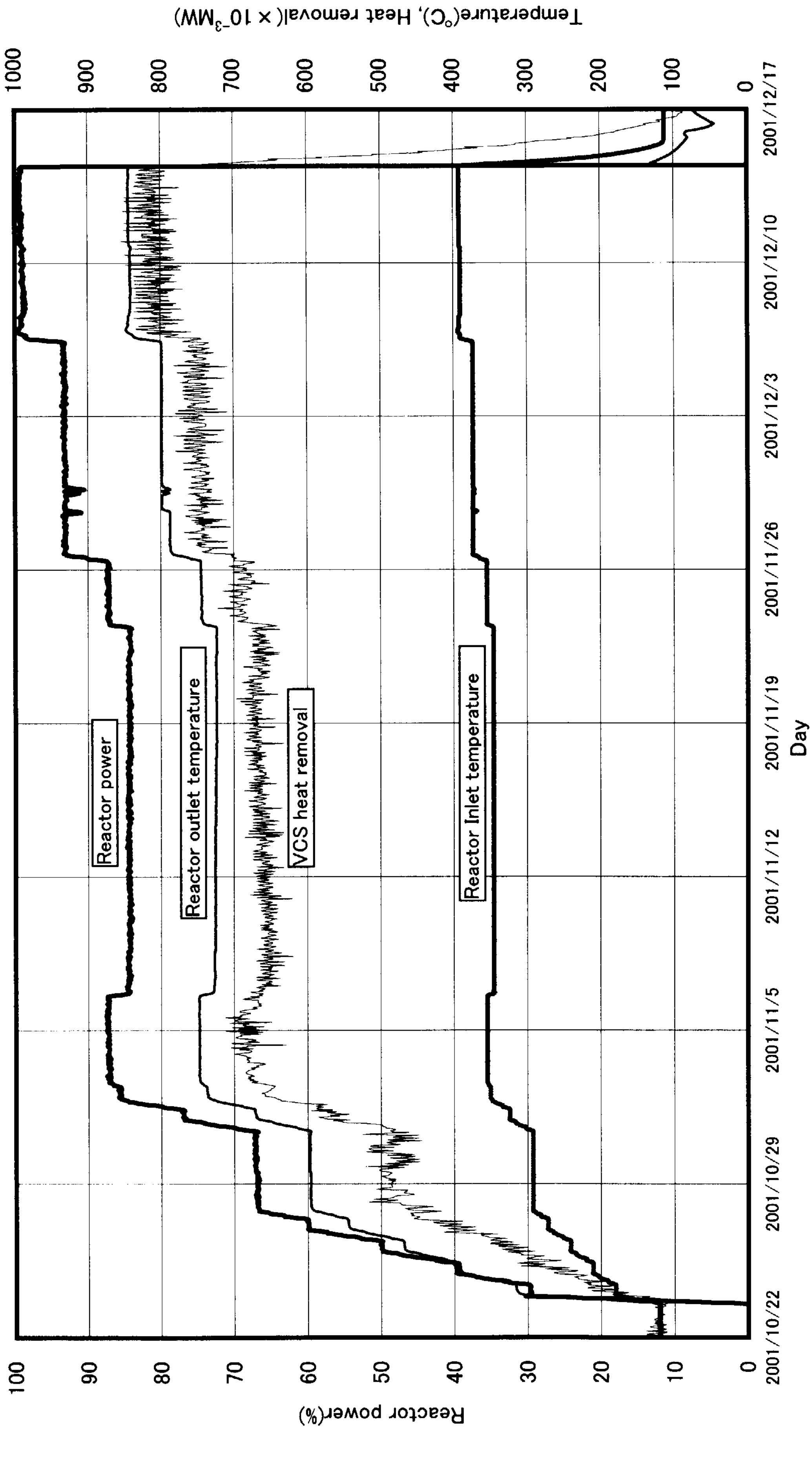

Fig.3.1 Transient behaviours of VCS heat removal, reactor power, reactor inlet and outlet temperatures (Single loaded operation)

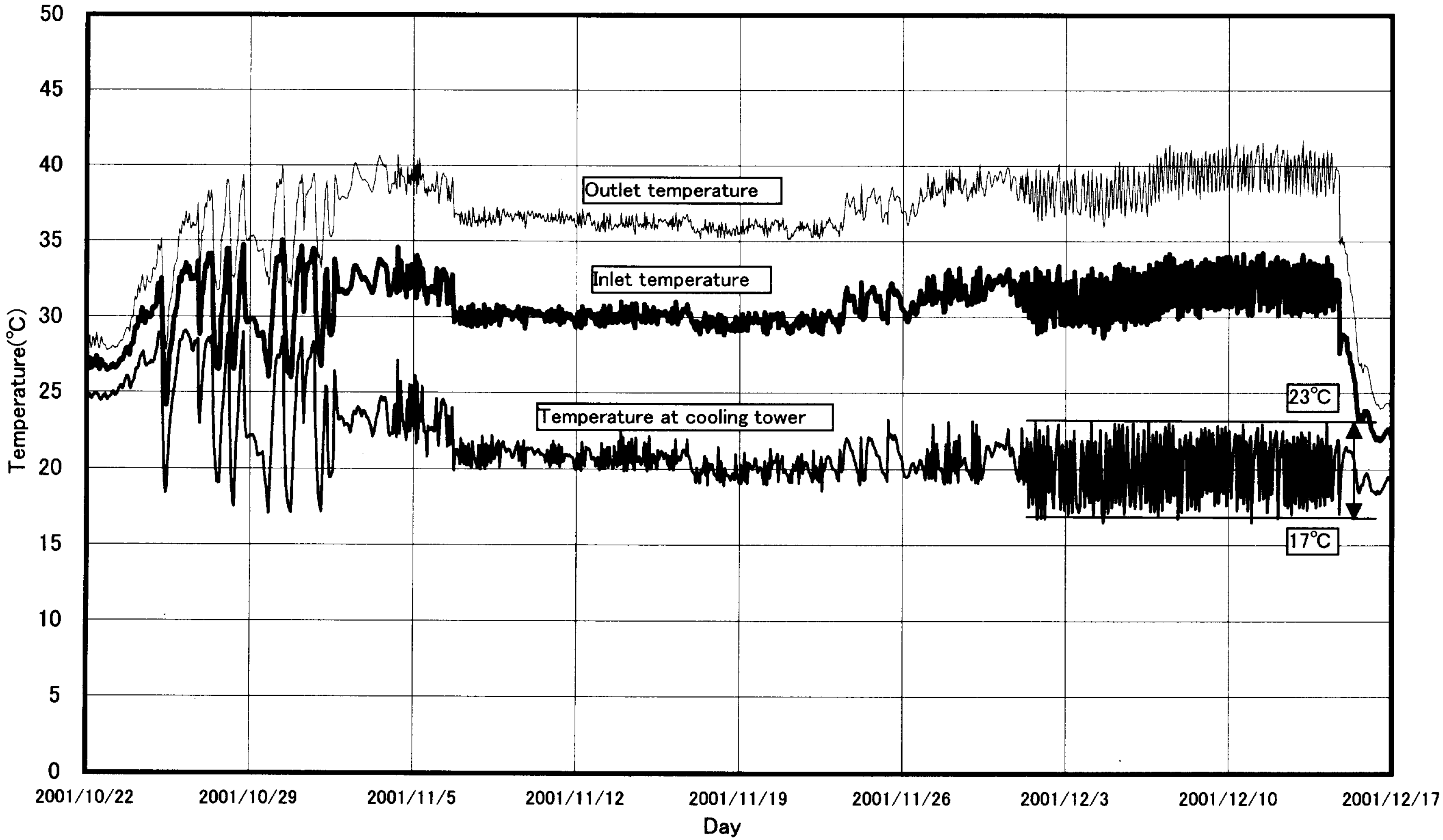

Fig.3.2 Transient behaviours of water temperature at cooling tower, inlet and outlet temperatures of upper panel (A system)
(Single loaded operation)

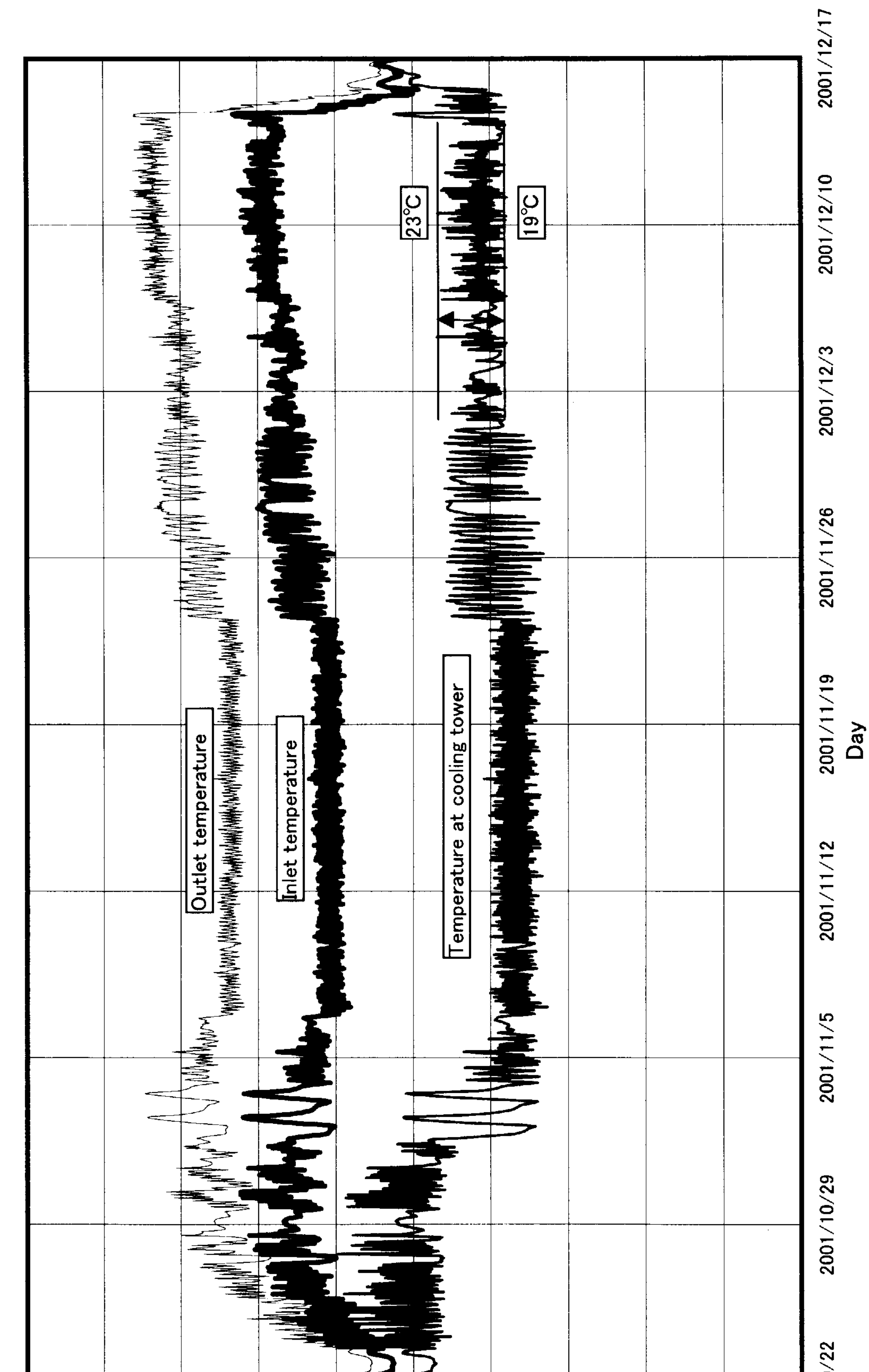

Fig.3.3 Transient behaviours of water temperature at cooling tower, inlet and outlet temperatures of upper panel (B system)
(Single loaded operation)

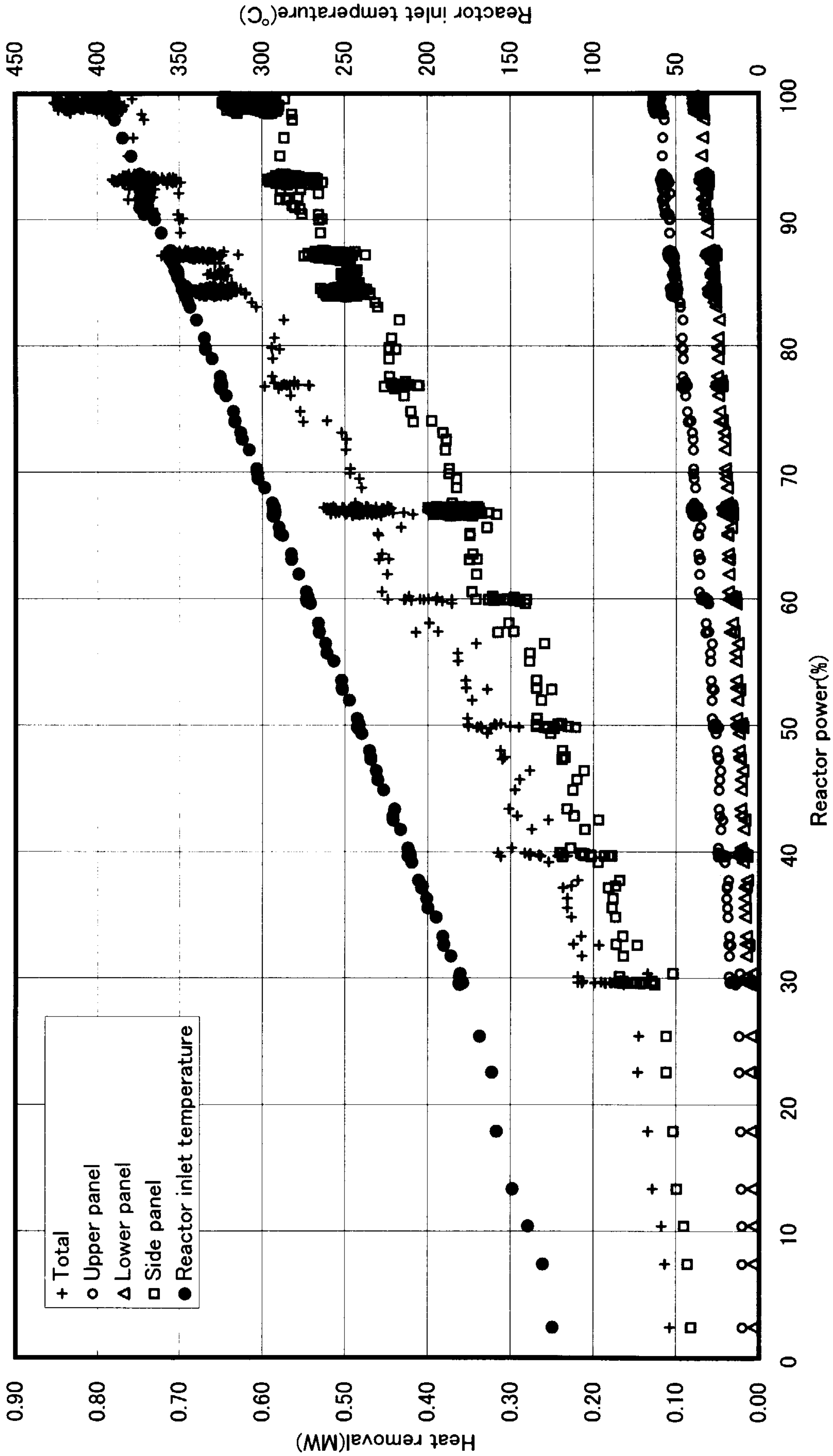

Fig.3.4 Heat removal and reactor inlet temperature vs. reactor power
(Single loaded operation)

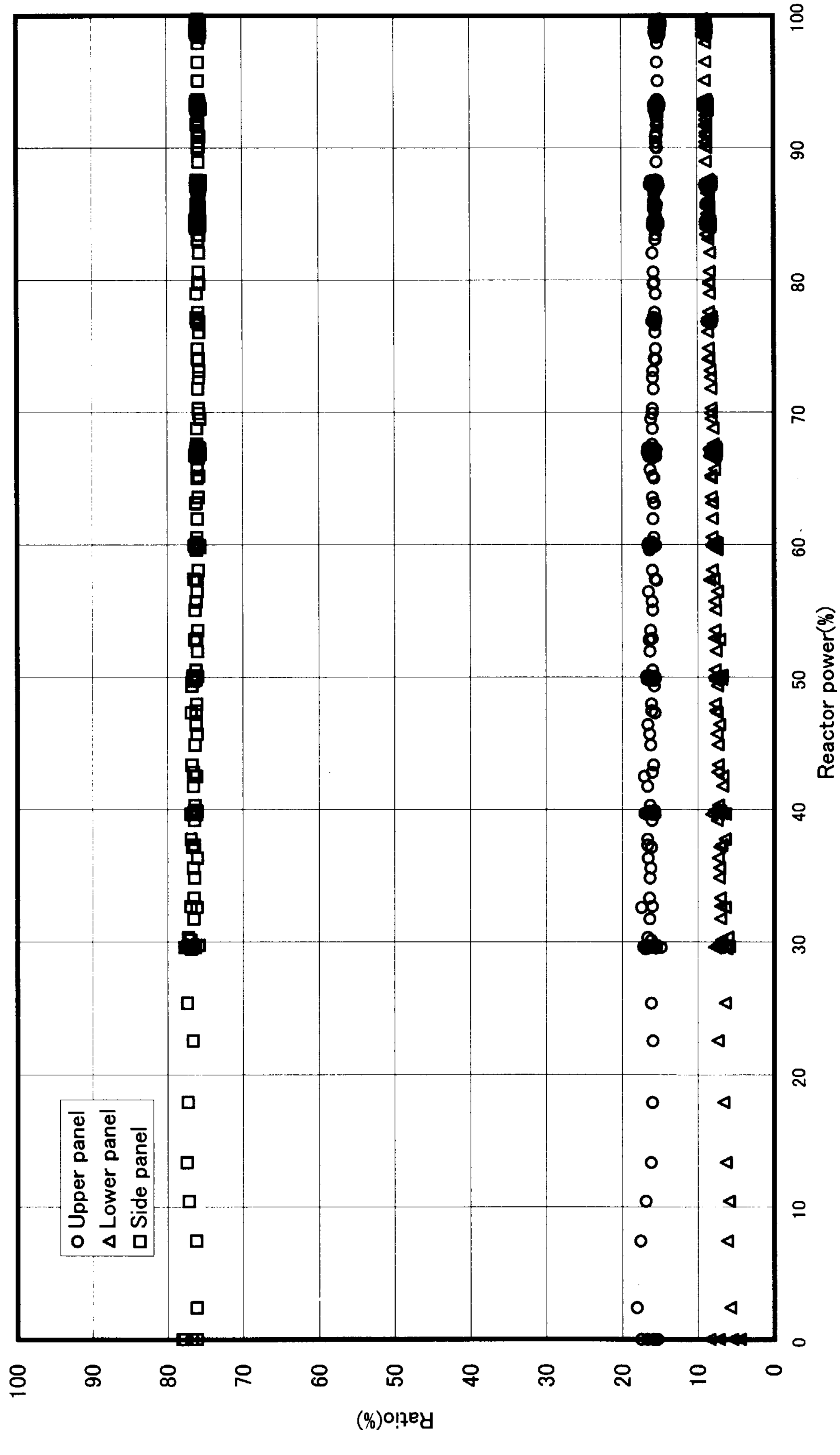

Fig.3.5 Heat removal ratio of each panel to total heat removal vs. reactor power
(Single loaded operation)

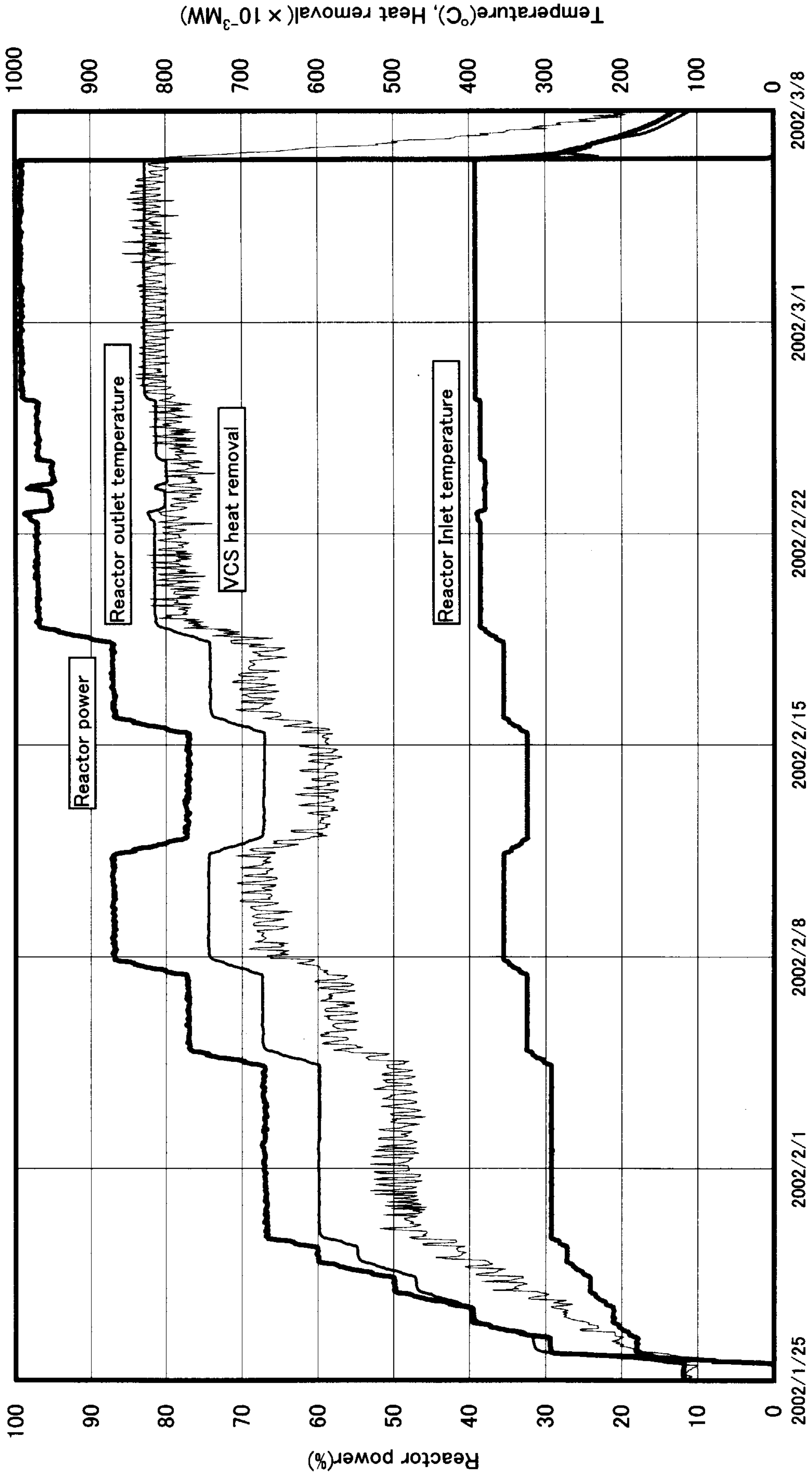

Fig.3.6 Transient behaviours of VCS heat removal, reactor power, reactor inlet and outlet temperatures (Parallel loaded operation)

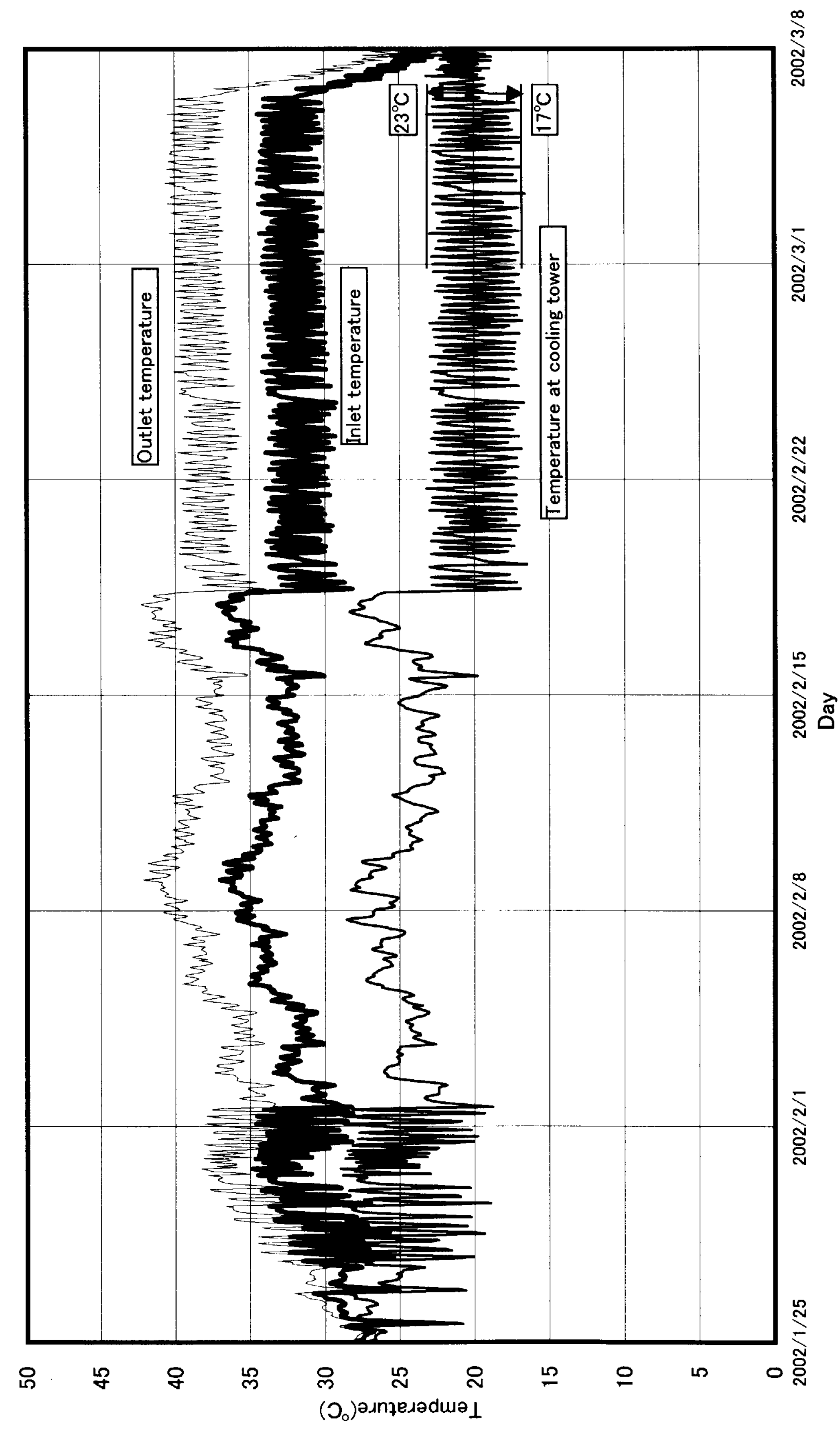

Fig.3.7 Transient behaviours of water temperature at cooling tower, inlet and outlet temperatures of upper panel (A system)
(Parallel loaded operation)

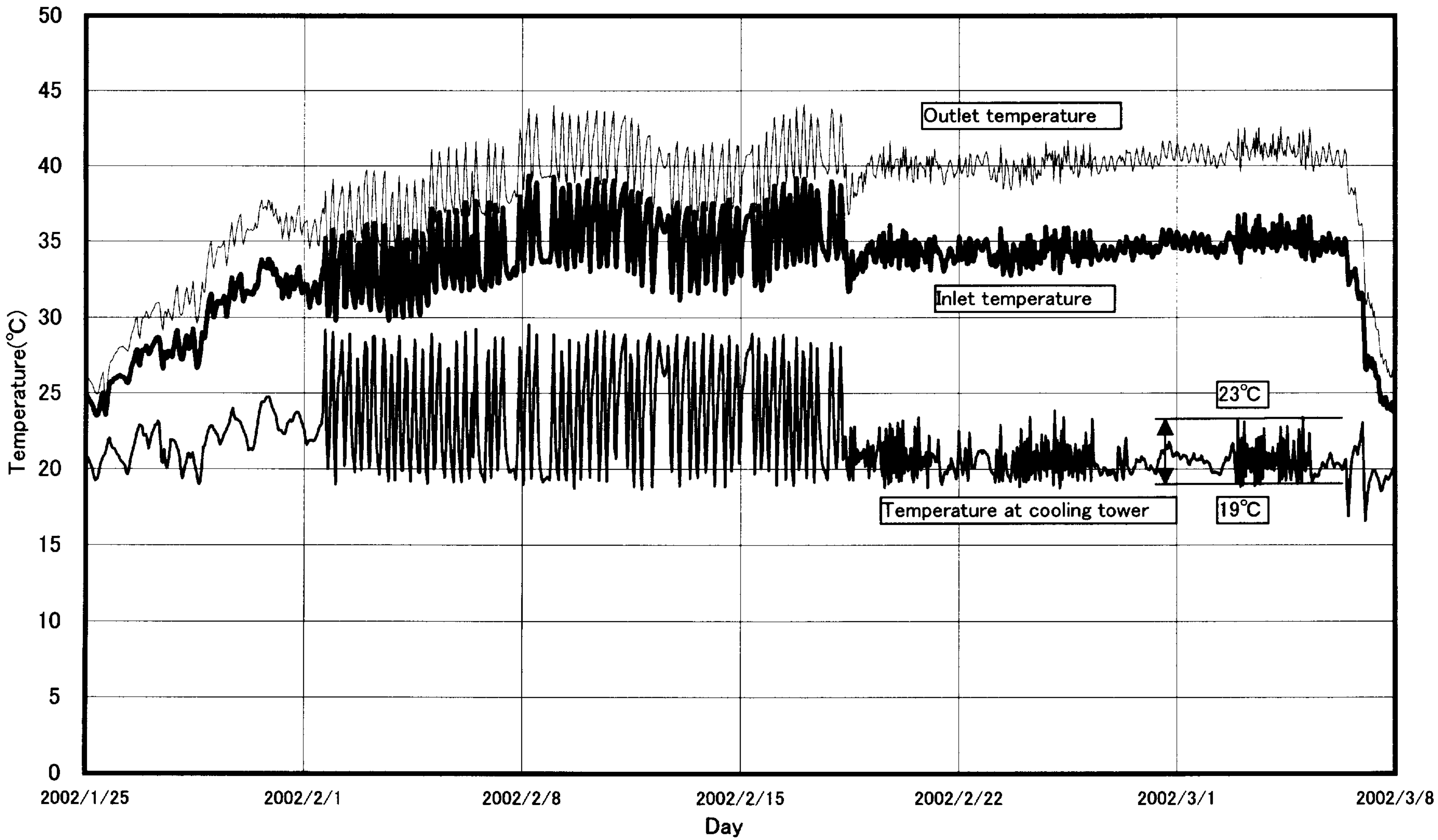

Fig.3.8 Transient behaviours of water temperature at cooling tower, inlet and outlet temperatures of upper panel (B system)
(Parallel loaded operation)

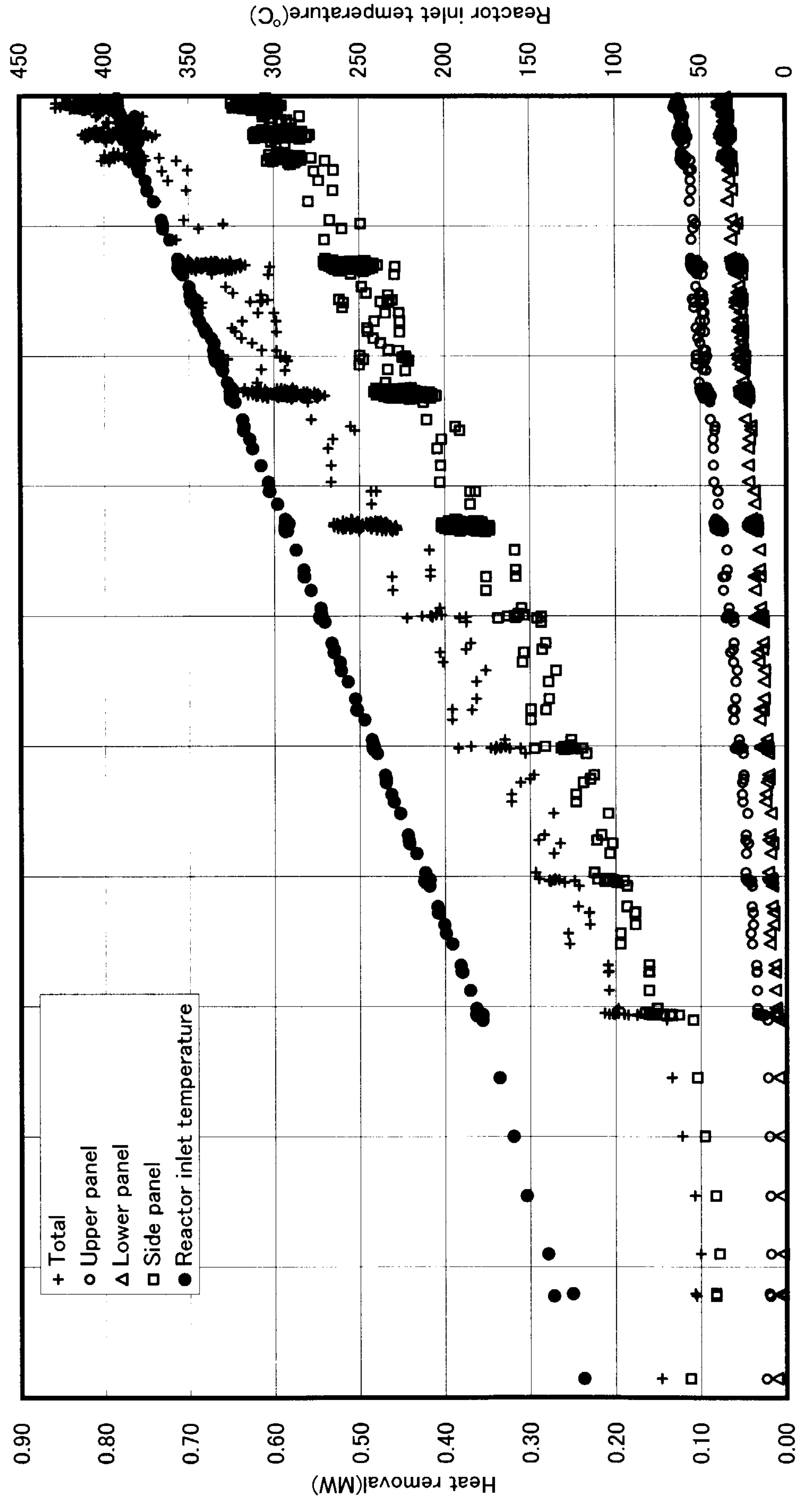

Fig.3.9 Heat removal and reactor inlet temperaure vs. reactor power
(Parallel loaded operation)

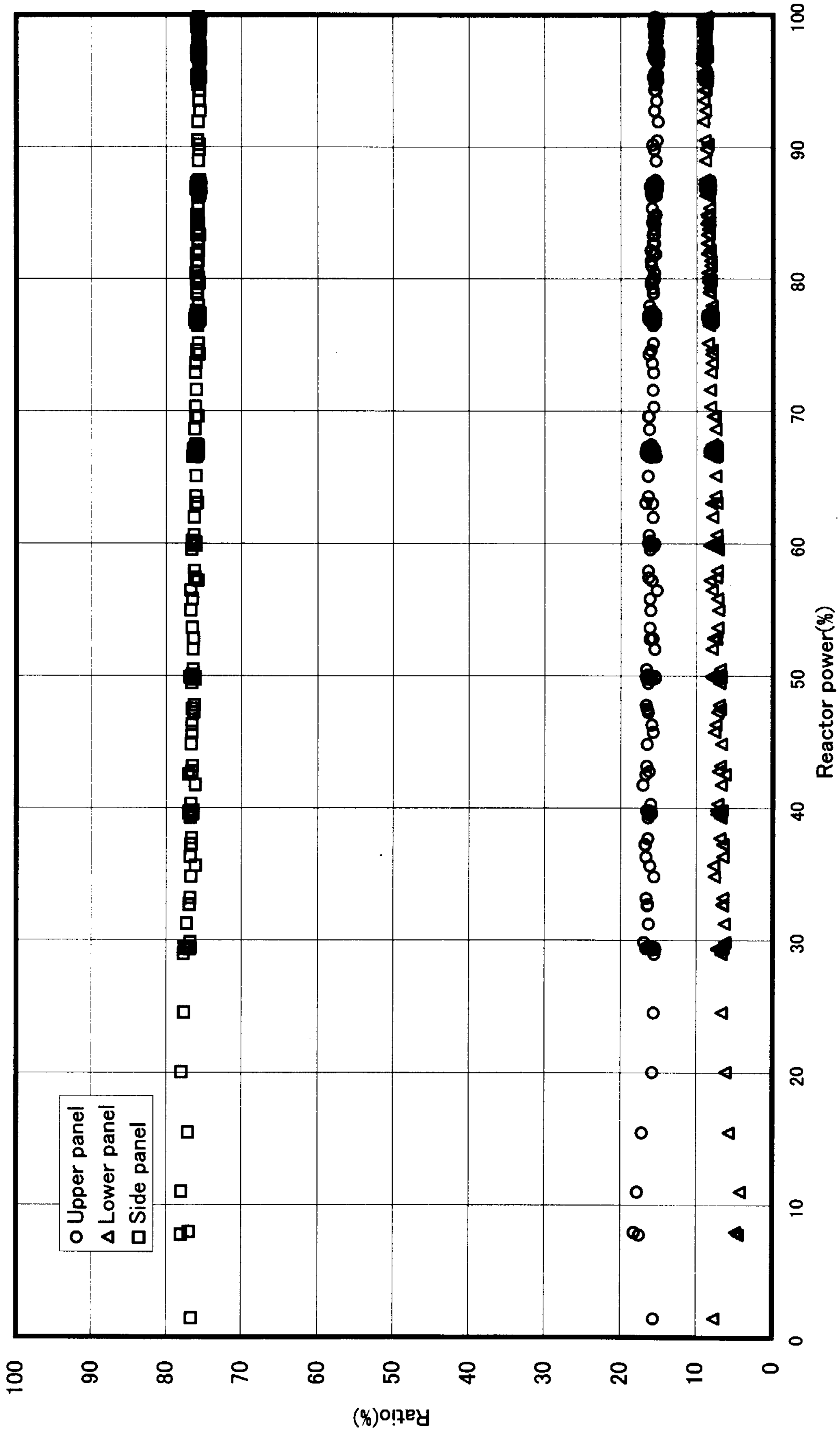

Fig.3.10 Heat removal ratio of each panel to total heat removal vs. reactor power
(Parallel loaded operation)

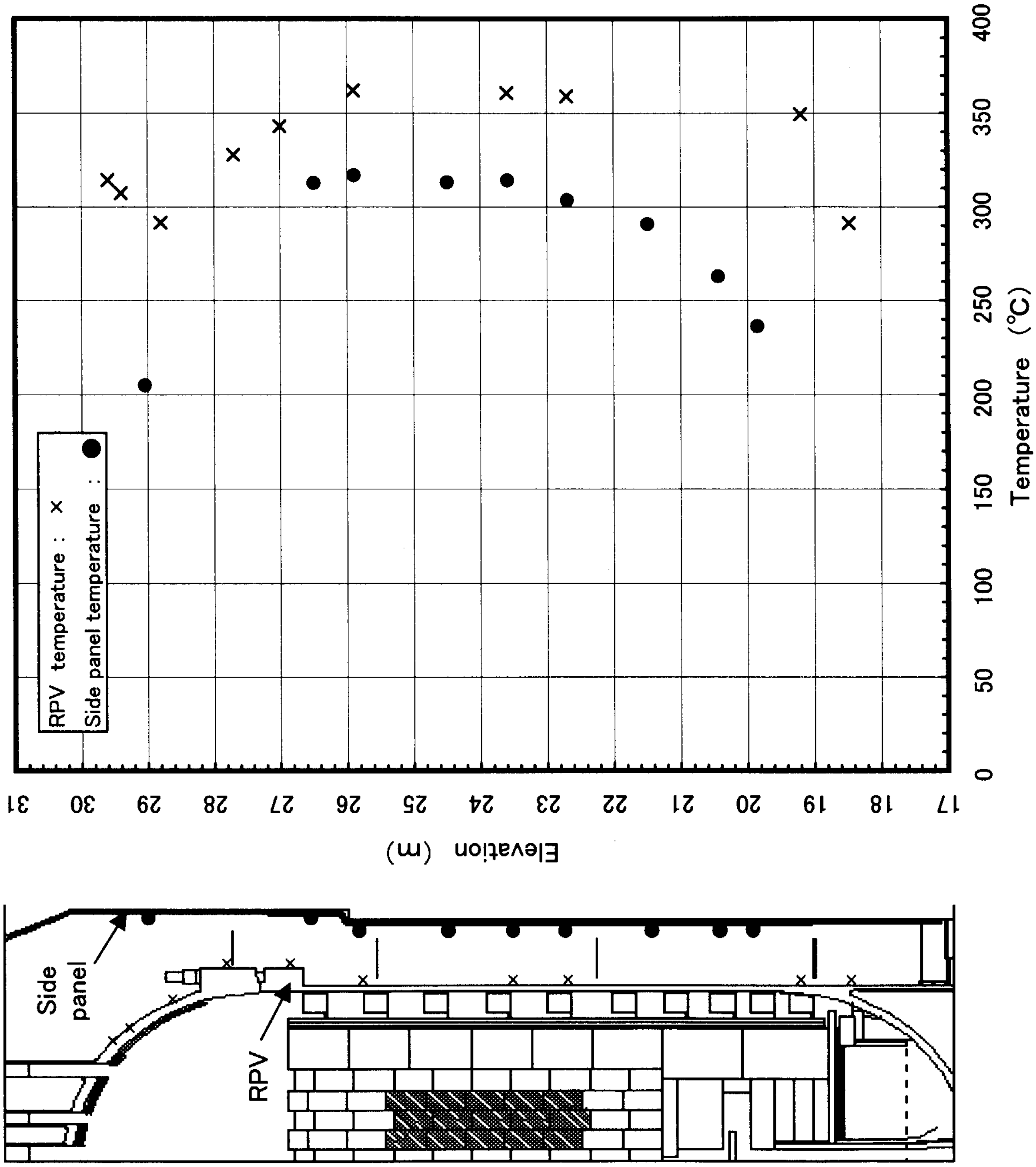

Fig.3.11. Temperature profile on RPV and side panel
(Single loaded operation)

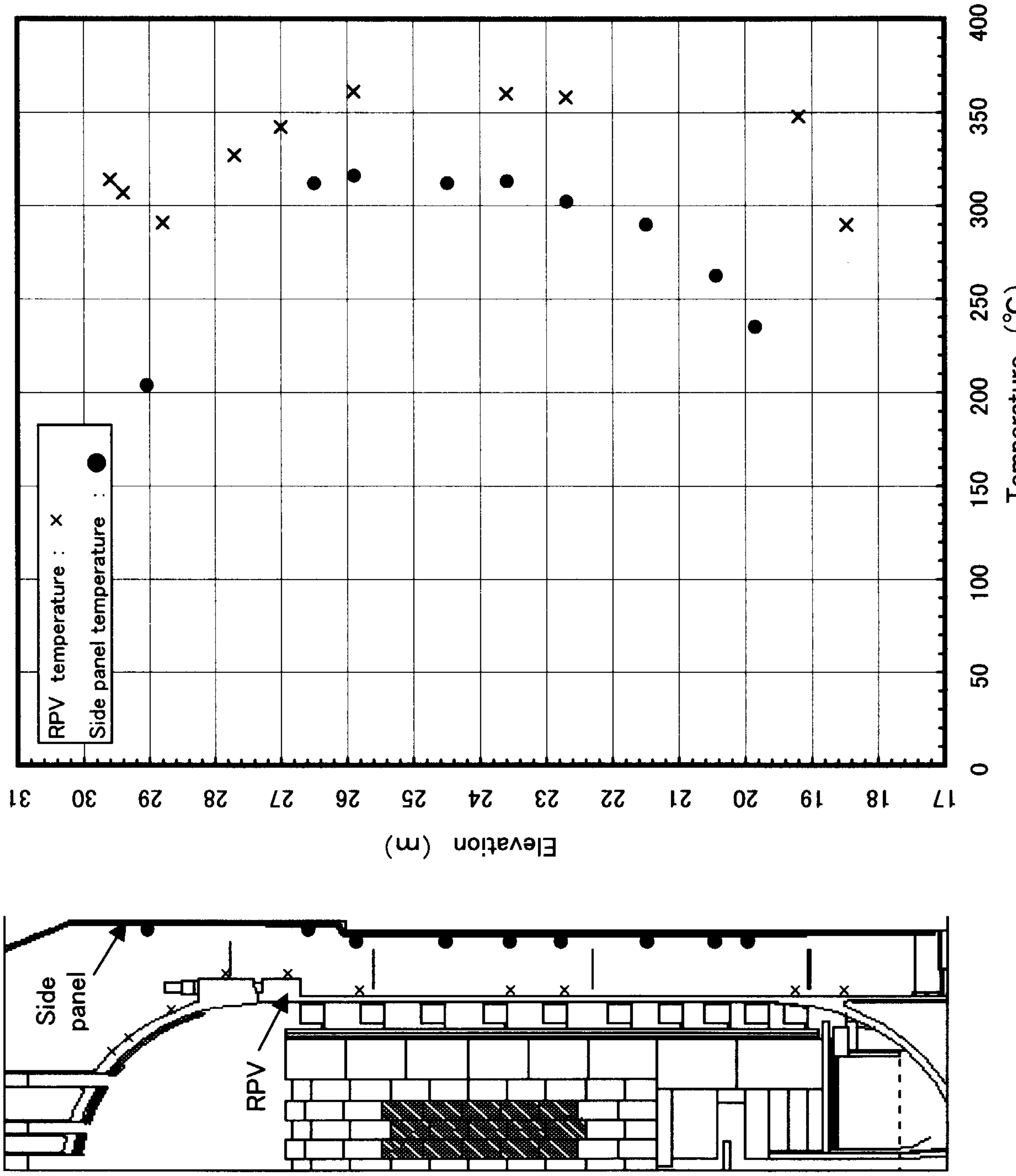

Fig.3.12. Temperature profile on RPV and side panel
(Parallel loaded operation)

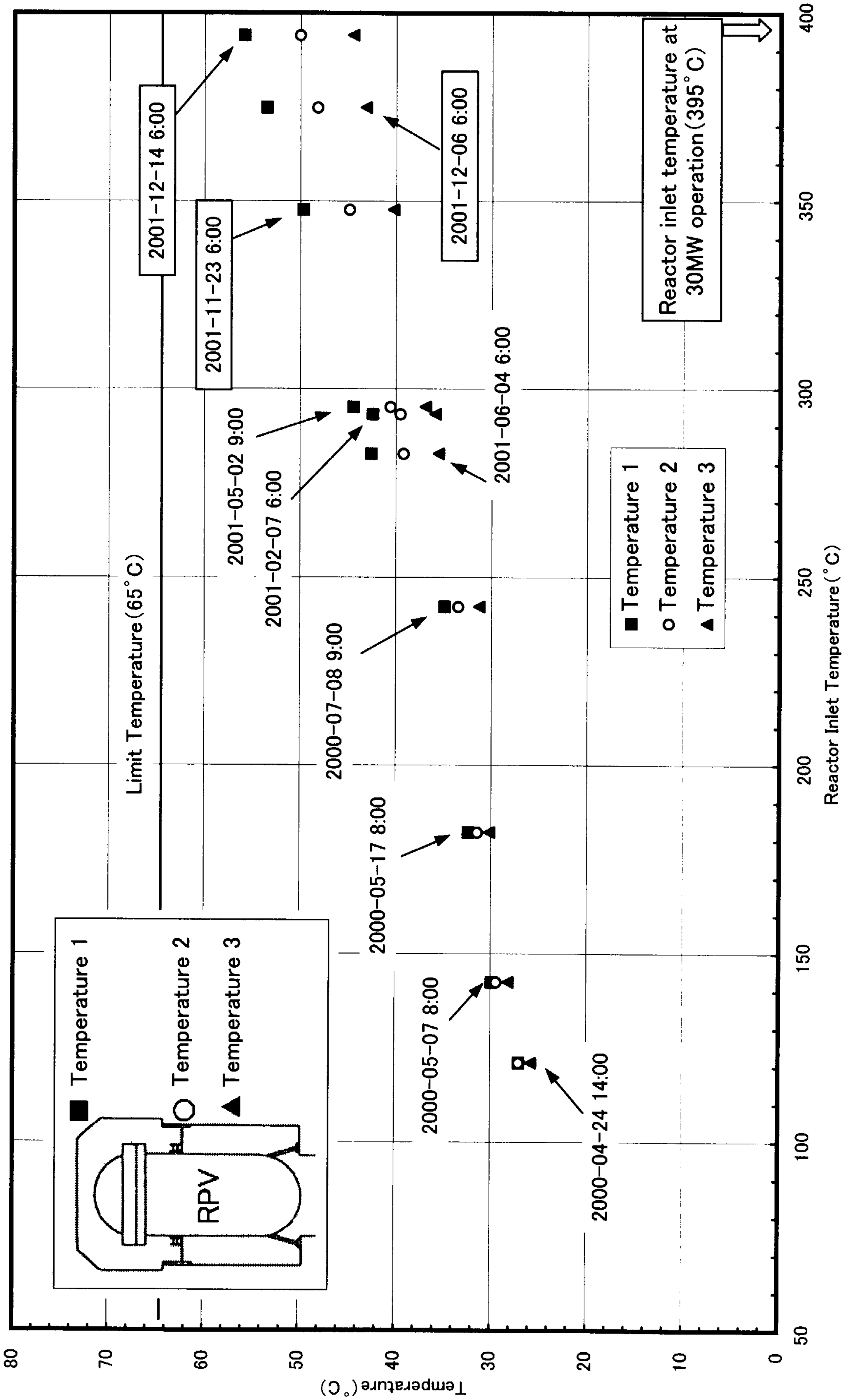

Fig.3.13　Primary radiation shielding temperature vs. reactor inlet temperature

4.Conclusion

The VCS which is an engineered safety features of the HTTR, is designed to cool the core by the cooling panels during the loss of forced core cooling such as the depressurization accident. Test results in the rise to power test of the HTTR showed that VCS heat removal at 30 MW power operation was about 0.8 MW and was higher than minimum heat removal of 0.3MW to secure the core safety. However, it was higher than the design requirement to achieve 950°C at 30MW power operation. It is necessary to further consideration to achieve outlet coolant temperature 950°C at high temperature test operation.

Primary radiation shielding temperature also satisfied its limit temperature of 65°C.

Data obtained in the tests will be utilized to verify analysis codes of reactor cavity cooling systems.

References

(1) Saito S, et al., "Design of High Temperature Engineering Test Reactor", JAERI-1332, Japan Atomic Energy Research Institute, (1994).

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(3) Takeda T, et al., "Data on Loss of Off-site Electric Power Simulation Tests of the High Temperature Engineering Test Reactor", JAERI-Data/Code 2002-015 ,(2002).

国際単位系(SI)と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表2　SIと併用される単位

名　称	記　号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m \cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ Å = 0.1\ nm = 10^{-10}\ m$

$1\ b = 100\ fm^2 = 10^{-28}\ m^2$

$1\ bar = 0.1\ MPa = 10^5\ Pa$

$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

$1\ rad = 1\ cGy = 10^{-2}\ Gy$

$1\ rem = 1\ cSv = 10^{-2}\ Sv$

(注)

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および1 uの値はCODATAの1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　$1\ Pa \cdot s (N \cdot s/m^2) = 10\ P$(ポアズ)(g/(cm·s))

動粘度　$1\ m^2/s = 10^4\ St$(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf・m	kW・h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J (計量法)
　　= 4.184 J　(熱化学)
　　= 4.1855 J　(15 °C)
　　= 4.1868 J (国際蒸気表)

仕事率　1 PS (仏馬力)
　　= 75 kgf・m/s
　　= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

(86年12月26日現在)

Data on Test Results of Vessel Cooling System of High Temperature Engineering Test Reactor