02

PNC TN9410 94-173

分置

Head Access Piping System Design

ヘッドアクセス型プラントの設計研究

１９９４年5月

動力炉・核燃料開発事業団
大洗工学センター

複製又はこの資料の入手については，下記にお問い合わせください。
〒311-13　茨城県東茨城郡大洗町成田町4002
動力炉・核燃料開発事業団
大洗工学センター　システム開発推進部・技術管理室

Enquires about copyright and reproduction should be addressed to: Technology Management Section O-arai Engineering Center, Power Reactor and Nuclear Fuel Development Corporation 4002 Narita-cho, O-arai-machi, Higashi-Ibaraki, Ibaraki-ken, 311-13, Japan

PNC TN9410 94-173
1994年6月

ヘッドアクセス型プラントの設計研究

中大路　道彦*、一宮　正和*
向坊　隆一*、前田　清彦**、永田　敬***

要旨

大洗工学センター技術開発部プラント工学室では、平成2年度から4年度にかけヘッドアクセス式ループ型プラントの設計研究を実施した。当初、プラントの出力を60万kWeとし、プラント概念を構築するとともに、プラントの簡素化·合理化のために新規概念を考案した。それらは、出入口配管接続ノズルを持たない単純な形状の原子炉容器、中間熱交換機に片持ち支持される逆L字型ホットレグ配管による短縮された一次系主配管、熱遮蔽板と液位制御を組み合せた簡素な炉壁保護構造、管内に一次側冷却材を流しコンパクト化を計った中間熱交換器などである。60万kWeプラントの設計研究で上記新概念の成立見通しおよびプラント合理化の可能性を得た。引き続き新概念の大型化への外挿性を130万kWe級プラントを対象として検討した結果、充分な可能性がある事が分かった。

本報告書は、フランスとの技術協力協定に基づきCEAに開示するために上記4年間のヘッドアクセス型プラントに関する設計研究の概要を纏めたものである。

---

*　:大洗工学センター技術開発部プラント工学室
**　:大洗工学センター安全工学部
***　:本社企画部

PNC TN9410 94-173
June, 1994

Head Access Piping System Design

M.Nakaoji*, M.Ichimiya*, R.Mukaibo*
K.Maeda**, T.Nagata***

Abstract

PNC made design studies on loop type FBR plants:a 600 MWe class in '91, and a 1300 MWe class in '93 both with the "head access"primary piping system.

This paper focuses on the features of the smaller plant at first and afterwards on the extension to the larger one. The contents of the paper consist of R/V wall protection mechanism, primary piping circuit, secondary piping circuit, plant layout and then, discusses the extension of the applicability of the wall protection mechanism, primary piping and equipment to the larger plant. Through these studies PNC reached the conclusion that the "head access"concept is applicable to all cases of FBRs from the demonstration to commercial phase.

---

* : Plant Eng'g Office, Technology Development Div., OEC, PNC.
** : Satety Eng'g Div., OEC, PNC.
*** : Policy Planning Div., Head Office, PNC.

CONTENTS

List of Tables

List of Figures

Head access piping system design

1. INTRODUCTION

The objectives of these design studies are to secure the integrity of a reactor vessel by simplifying the configuration of the vessel or by eliminating primary piping nozzles attached to the vessel wall, and both to contract the occupied floor area of equipment in cooling circuits and to reduce the material quantity by shortening the piping length.

Figure 1 shows a primary system named “head access” piping system. Design policies of the “head access” piping system are to realize the following. Firstly, simpler and plainer construction of a primary system : primary coolant streams in comparted and closed circuits, or it is contained in the piping and the equipment except the free liquid surface in a R/V ; a R/V wall near the normal sodium level is not protected with an engineered device, but with a passive one ; overflow columns in the circuits are replaced with an overflow mechanism built in pumps. Secondly, shortest primary piping : hot and cold legs have “head access ” or access to the core from the top of a reactor vessel ; hot leg pipes are supported in the form of a cantilever from IHX nozzles, and the other pipes are directly connected to nozzles of equipment. Thirdly, the elimination of a maintenance floor : a shielding plug doubles an operation floor and a roof deck. And lastly, removal of repair and maintenance work under the operation floor where nitrogen gas is usually filled to suppress spontaneous combustion of primary sodium in case of a coolant leakage accident.

2. PLANT CONFIGURATION

Figure 2 shows the comparison of reactor vessels, Monju R/V (280MWe) and '91 design R/V (approx. 600MWe). '91 design R/V has "head access" piping, while Monju R/V has piping directly connected to the wall. '91 design R/V dispenses with a rotating plug by adopting a refuelling system with a retractable upper internal structure, therefore its diameter is larger than that of Monju by only a half meter.

Figure 3 shows the basic design data of the 600 MWe class plant and relative elevations of the primary and secondary systems. Design data are as follows. The output of the plant is 1600MW thermal, and about 600MW electric. The number of loops is three. Primary sodium temperatures are 530°C at the outlet and 380°C at the inlet of the reactor vessel. Relative elevations are indicated on the basis of the nominal sodium level. The primary piping is placed under the operation floor (NsL+6.0m), and the secondary is positioned over this floor. Decay heat removal is made by an Intermediate Reactor Auxiliary Cooling System (IRACS), and the difference in the height of the center of heat exchanging surfaces between IHXs and air coolers of IRACSs is more than 20m to better the natural circulation of the coolant.

Figure 4 displays a cutaway view of the primary system. Heated sodium rises in a hot leg pipe and reaches an IHX, where heat is exchanged. Cooled sodium goes down in a middle leg pipe and is sucked up by a pump. Coolant is discharged from the pump gaining a head, and returns through a cold leg to the reactor vessel.

3. REACTOR WALL PROTECTION MECHANISM

The R/V wall near the NsL is protected from thermal stress by a simplified structure of thermal shielding plates. Figure 5 depicts the analytical conditions of a device and a modelled wall. Inside the reactor vessel, the vessel wall under the NsL is lined with thermal shielding laminae, and the wall over the NsL is directly exposed to Ar cover gas. Outside the R/V, the wall is also directly exposed to nitrogen gas. Parts of the wall exposed to gases are assumed to be adiabatic and the rest of wall immersed in sodium is conductive. The right side of the figure shows transients of the wall temperature for analysis. They occur at a normal start, a normal shutdown, and a manual reactor trip.

Figure 6 shows the transient thermal stress of R/V wall near the NsL. The vertical axis is the primary and secondary stress intensity range, and the horizontal axis is the rising and falling speed of wall temperature. The dotted line indicates a case where the sodium level varies in proportion to the expansion and shrinkage of sodium itself. The broken line shows a case where the sodium level is preserved constant. The double dotted line expresses a case where the liquid level is kept constant at the start and varies with a temperature change when the reactor is manually tripped. And the solid line shows a case where the liquid level is kept constant at the start and lowers with sodium shrinkage at the stop.

The last two cases satisfy the criterion, below 3Sm allowable stress intensity value for preventing ratchet strain. The simple wall protection device combined with sodium level regulation have proved analytically to be effective on thermal stress mitigation.

4. PIPING AND EQUIPMENT

4.1 PIPING ANALYSIS CRITERIA

The primary and secondary piping consists of hot legs, middle legs, and cold legs. Table 1 indicates the criteria of piping analysis on both the primary and secondary systems. Primary piping must meet a lower primary stress intensity than the limit for protection against buckling, and a lower thermal expansion stress intensity than 30kg/mm^2 for shake-down. Secondary piping must satisfy the criteria to have lower thermal expansion stress intensities than 25kg/mm^2 for the middle and cold legs, and 30kg/mm^2 for the hot leg, respectively.

Figure 7 gives the proposed floor responses in the horizontal direction at the R/V installation level at S1 and S2 earthquakes. S1 and S2 earthquakes are those that might strike a severe earthquake-prone zone in Japan once every 10 thousands years and 50 thousands years, respectively. The R/V and the primary and secondary piping are designed to have a higher natural frequency than 7Hz, for the acceleration of earthquakes increases drastically below a frequency of 7Hz.

4.2 PRIMARY CIRCUIT

- Primary piping

The shaded part of Figure 8 shows the analysed primary piping. The results of hot leg piping analysis are shown in

Figure 9. The hot leg is supported in the form of a cantilever at the IHX nozzle and with a hanger at the elbow, and the thermal deflection is not restricted. The increases in thickness and diameter of the hot leg pipe indicated in this figure have made the pipe meet the seismic criteria. Natural frequency of 1st mode is 7.2Hz. Max. primary stress intensities are 5.9kg/mm^2 at the elbow and 6.7kg/mm^2 at the end of a straight tube, respectively.

Figure 10 reveals analysis results on middle leg piping. It is rigidly supported at the nozzles of the IHX and the pump, and is restrained at the horizontal part between the two. When the piping is restrained at NsL−10.5 m, the first natural frequency is 7.91Hz, primary stress intensities by earthquake S2 are 5.9kg/mm^2 at the nozzle on the IHX and 12.3kg/mm^2 at the elbow on the pump side and thermal expansion stress intensities are below the limit : 21.8kg/mm^2 at the elbow on the pump side and 28.3kg/mm^2 at the elbow on the IHX side.

Figure 11 gives the results on the cold leg piping. The piping is rigidly supported at a pump nozzle and the core support structure, and is restrained at a check valve. The results are : the first natural frequency is 7.7Hz, max. primary stress intensity by earthquake S2 is 15.3kg/mm^2 and max. thermal expansion stress intensity is 19.7kg/mm^2 at the same upper elbow near the check valve. Stresses are well below the limit. The results expressed here have verified the prospect of head access piping structure.

- Intermediate heat exchanger (IHX)

The features of an IHX are the following. The inlet is at higher level to answer the elevation required for the “head access” piping. Primary coolant flows in the tubes and secondary coolant streams in the shell diagonally across the tubes to suppress temperature differences among tubes. A down-comer of secondary coolant is independent of the lower tubesheet, and no expansion bellows are needed at the top of the down-comer. Lastly, the shell is equipped with convexities or bellows at its lower part, and tubes are rigidly connected to the outer shell through the upper and lower tubesheets. The structure of the IHX measures 2.7m across and 15.6m long as shown in Figure 12.

4.3 SECONDARY CIRCUIT

Each of the three secondary circuits of this plant consists of a steam generator, a pump, an air cooler for IRACS, and piping without an expansion tank. The secondary piping and the steam generator are also explained here.

- Secondary piping

Piping, 711.2mm across, is rigidly supported at equipment nozzles. The thermal expansion is relieved by relative deflection of piping and seismic force is supported by snubbers. Thermal expansion analyses were carried out through the whole secondary piping. The thermal expansion analysis results on the hot leg piping are listed in Figure 13 according to SG support levels, and the selection was made from the viewpoints of both stress mitigation and stable erection of the SG. In the cases of support levels lower than NsL+10 m, calculated stresses satisfy the criteria of the limit. Seismic analyses were not performed for the reason that snubbers which resist seismic forces could be set at any places and produce higher natural frequencies than 7 Hz.

All of the other piping were analyzed and they proved to satisfy the analytical criteria.

- Steam generator

Steam generators are of once-through and helical coil type and produce super-heated steam, at a temperature of 483°C and a pressure of $154 kg/cm^2 g$. SGs are designed : sodium inlets and outlets are placed at the top of the SGs and distributor shoes are below the minimum sodium level in order to easily partition the sodium and the water circuit areas ; argon cover gas accommodates changes in sodium volume with vent piping connected to that of the secondary pump ; the SGs are supported at the middle of their shells to harmonize thermal stresses at the hot and middle leg pipes. The SG shown in Figure 14 measures 3.2m across and 27.5m long.

5. PLANT LAYOUT

Figure 15 shows the piping layout of the plants. The piping length is drastically shortened : the length of primary circuits is about a half and that of the secondary circuits is from about one-third to one-fourth of that of Monju. In Figure 16 are depicted reactor building sizes : the '91 design's is 73m long, 63m wide, and 76m high, while Monju plant's is 113m long, 98m wide, and 89m high. The reactor building area is reduced by 60%.

6. EXTENSION OF HEAD ACCESS PIPING CONCEPT TO A LARGER FBR

Being based on the '91 design study made according to the head access piping concept, a 1300 MWe FBR plant was designed to affirm the feasibility of the application of the concept explained earlier to a larger plant of commercial use. The following subjects which were thought to be key elements for the extension were mainly studied : validity of the wall protection mechanism to a larger reactor vessel, applicability of the hot leg piping concept to a larger construction, and potentialities of the enlargement of equipment in the primary circuit.

The expansion of a plant capacity from 600MWe to 1300 MWe depends upon the increase in the number of loops and in the capacity of equipment per loop , in concrete terms, the number of loops is changed from three to four and each loop has a greater capacity by 50% than that of '91 design.

- Validity of R/V wall protection mechanism

Thermal stress in the R/V wall near the nominal sodium level was analysed and evaluated during the plant thermal transients at reactor starts-up and shutdowns. Figure 17 shows the primary and secondary stress intensity range which are differences between stresses at a normal start and at a manual reactor trip with falling sodium level by shrinkage, and the thermal bending stress range and the thermal membrane stress at manual reactor trips. Figure 18 displays the relationship between the strain and the primary and secondary stress intensity range, and the limits of the two : 1 % for the strain and 35 kg / mm^2 for the range. Judging from the results of the satisfactory stress analysis, this wall protection mechanism for reactor vessels is effective to the thermal transients for the diameters of the reactor vessels from 8.4 m to 12 m.

- Application of the hot leg piping concept in a primary circuit to a 1300 MWe plant

Since hot leg piping of the "head access" style has an L shape structure which is fixed only on the IHX side and is free to thermally expand to the reactor side, expansion stress does not come theoretically, while the resistance of the piping to an earthquake is much more significant. According to the knowledge gained from the studies of the past, the piping must meet a requirement of a natural frequency higher than 7 Hz for the floor response where a reactor is installed. Scanning the piping design parameters such as diameters and thickness of the pipe, and horizontal levels at which the hot leg pipe runs, the structure of the pipe was designed and specified to satisfy the criteria at earthquakes. It was verified from the stress analysis that enlargement of piping structure is feasible. The structure of piping is shown in Figure 19.

- Potentialities of enlarging equipment in a primary circuit

An IHX and a primary pump were sized for a 1300 MWe plant capacity and were planned in drawings. Feasibilities of the concepts and of enlarging equipment were examined. PNC reached the judgment that these concepts of the equipment were feasible and the equipment itself could be scaled up in the light of results of design studies, structural analyses, and experiences on manufacture of similar equipment.

7. SUMMARY

The results of the studies summarized in this paper show the following. First of all, the feasibility of the “head access” piping system was verified and the system was applicable to 600MWe or larger FBR plants. Secondly, the basic structure of a passive reactor wall protection mechanism was designed and its effectiveness and enlargement were verified. Thirdly, the basic structures of an IHX and a steam generator were designed and their feasibility was assured. Finally, the piping layout of coolants in the reactor building was minimized to a fairly reasonable size.

Table.1 Criteria of Piping Analysis

Piping	Earthquake	Thermal Expansion	Supports
Primary Hot Leg Middle Leg Cold Leg	Natural frequency ≧ 7Hz Primary stress intensity at S2 earthquake (4.05G) ≦ Limit for protection against buckling	Thermal expansion stress ≦30kg/mm²	Nozzels, snubbers, and restraints
Secondary Hot Leg Middle Leg Cold Leg	No analysis for only minor stresses in prospect by fixed supports of snubber type	Thermal expansion stress ≦30kg/mm² Thermal expansion stress ≦25kg/mm²	Snubbers for earthquake, and relative motion for thermal expansion

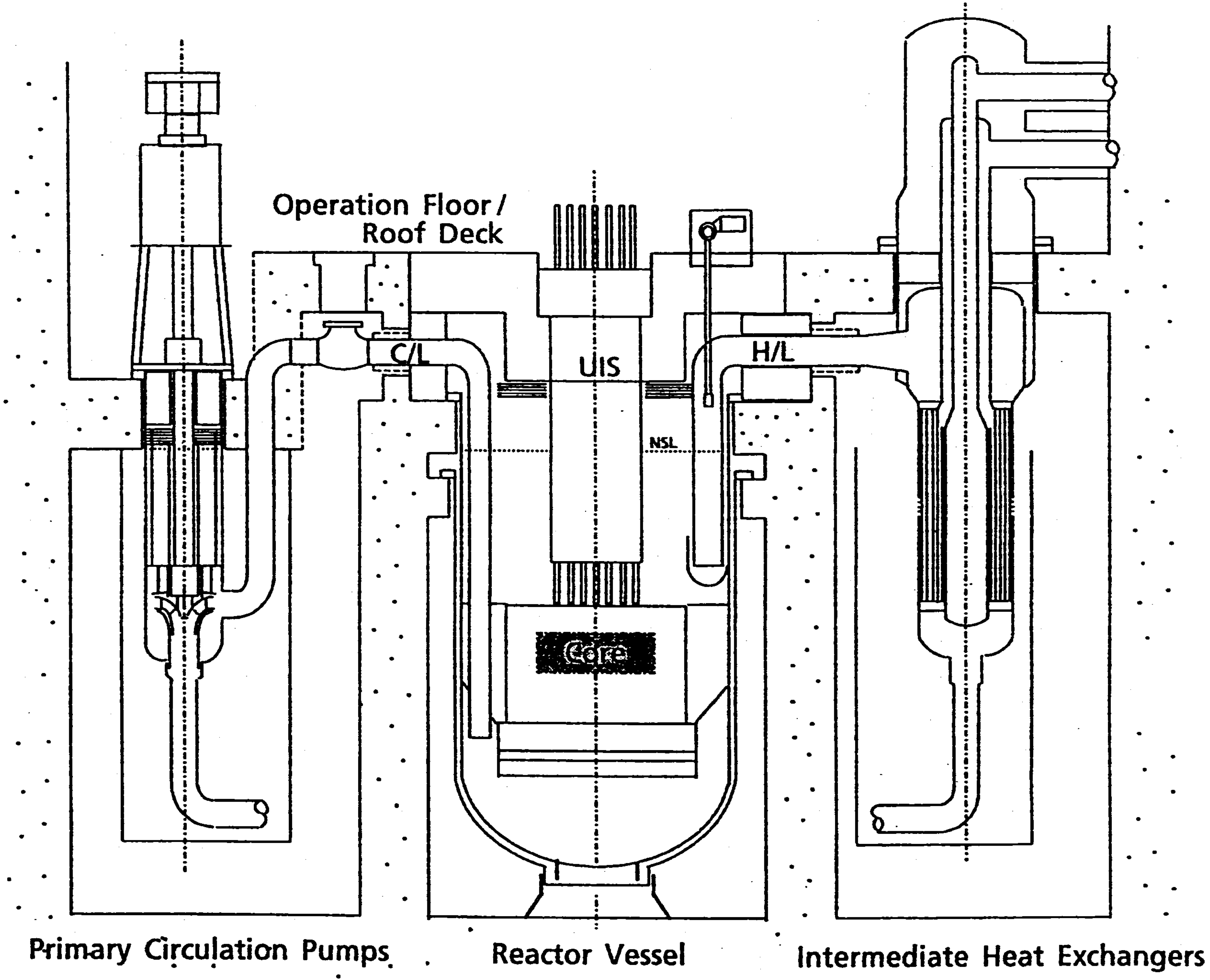
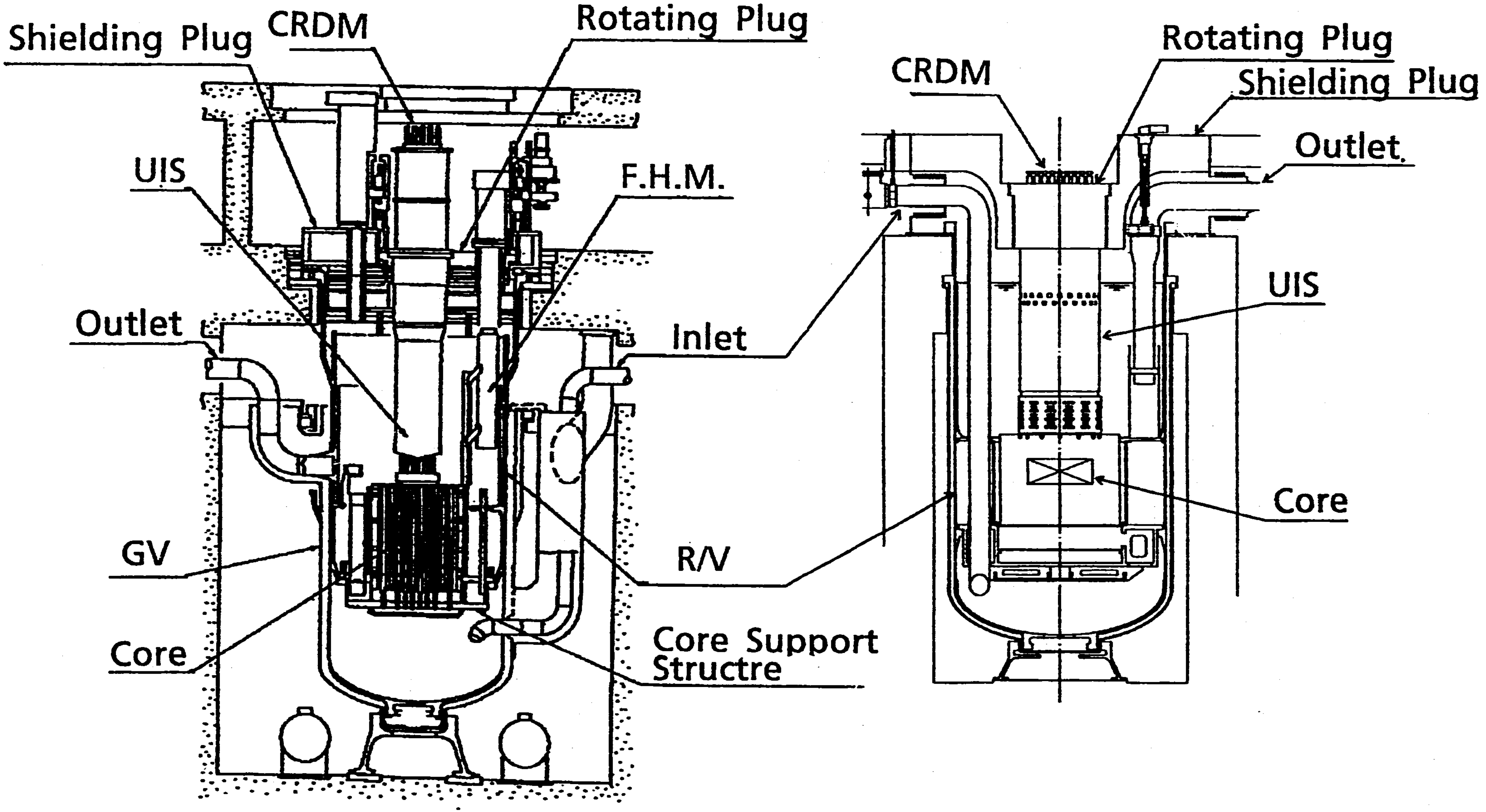


Fig.1 '91 Head Access Piping Design Concept of Loop Type LMFBR



MONJU (280MWe)

'91 DESIGN (≃ 600MWe)

Fig.2 Comparison of Reactor Vessels

Design data

Output		1,600MWt ~600MWe
No. of loops		3
Primary Na temp.	Out	: 530°C
	In	: 380°C
Steam	483°C	154kg/cm^2
Core	Fuel	MOX
	Burnup	~90,000MWd/t
	Refueling Interval	12mon.
	Breeding ratio	1.20/1.05

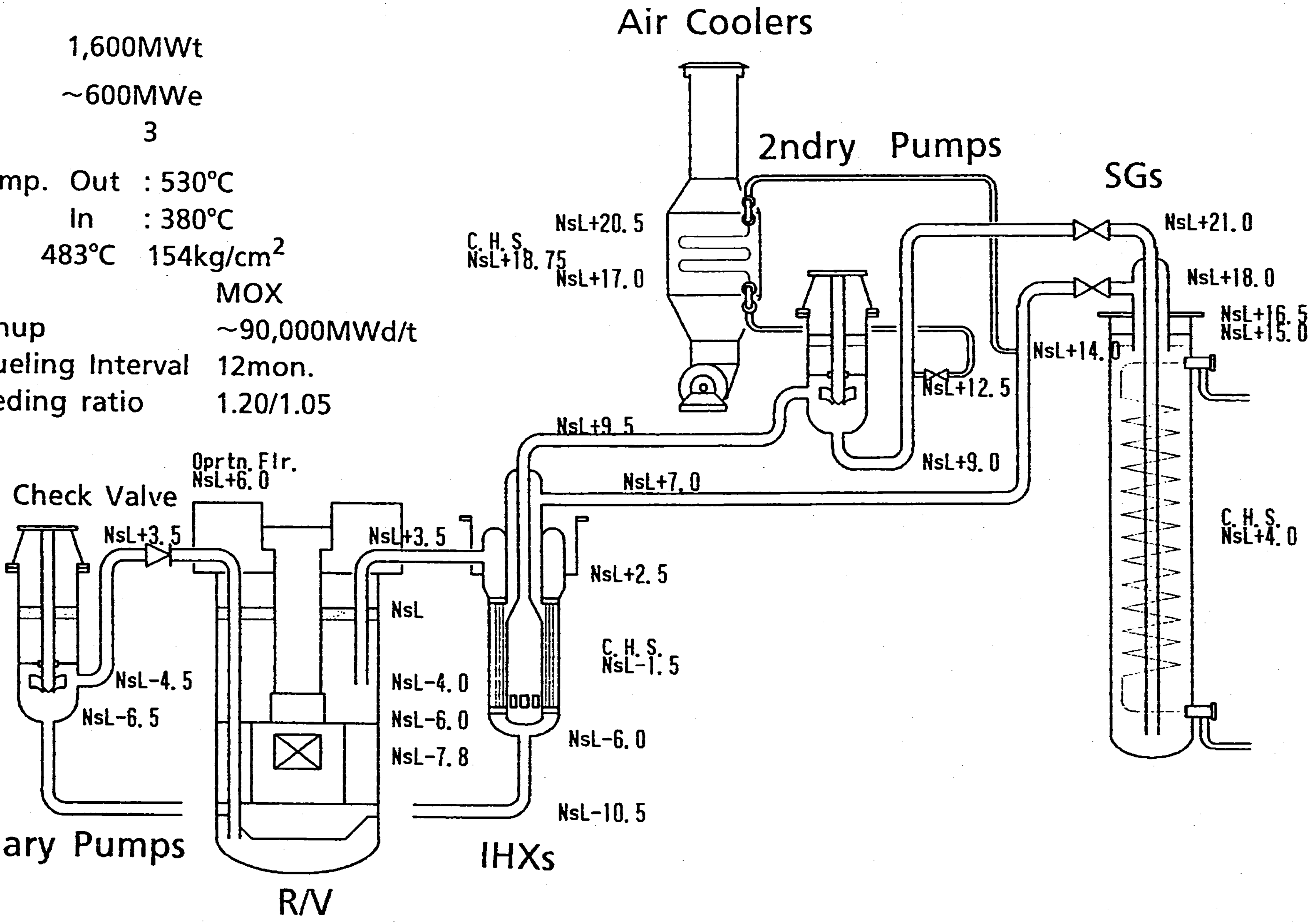


Fig.3 Coolant Circulation Diagram

Primary System

- R/V Wall Protection
- Primary Piping
- Intermediate Heat Exchanger

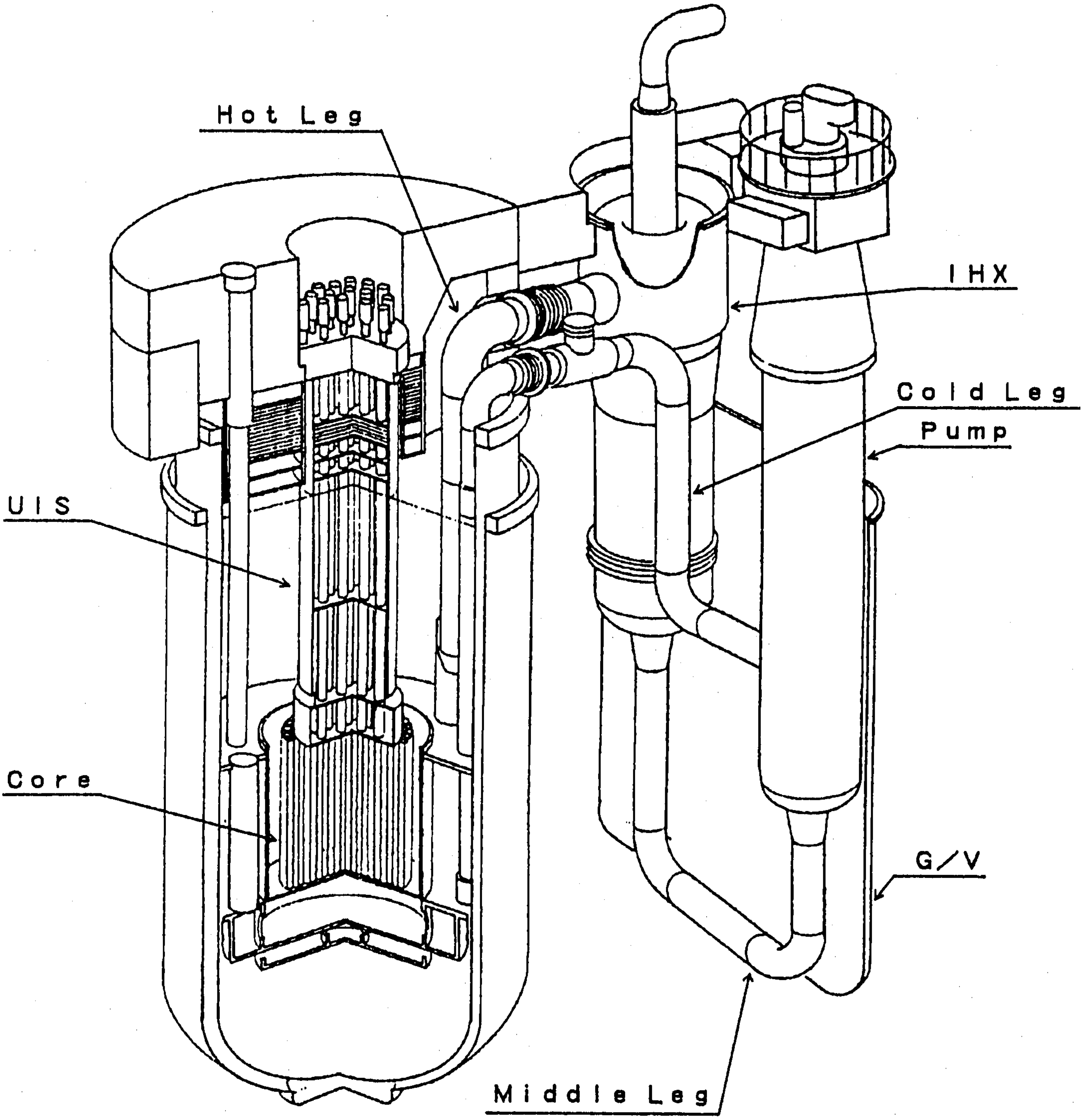


Fig.4 Cutaway View of Primary System

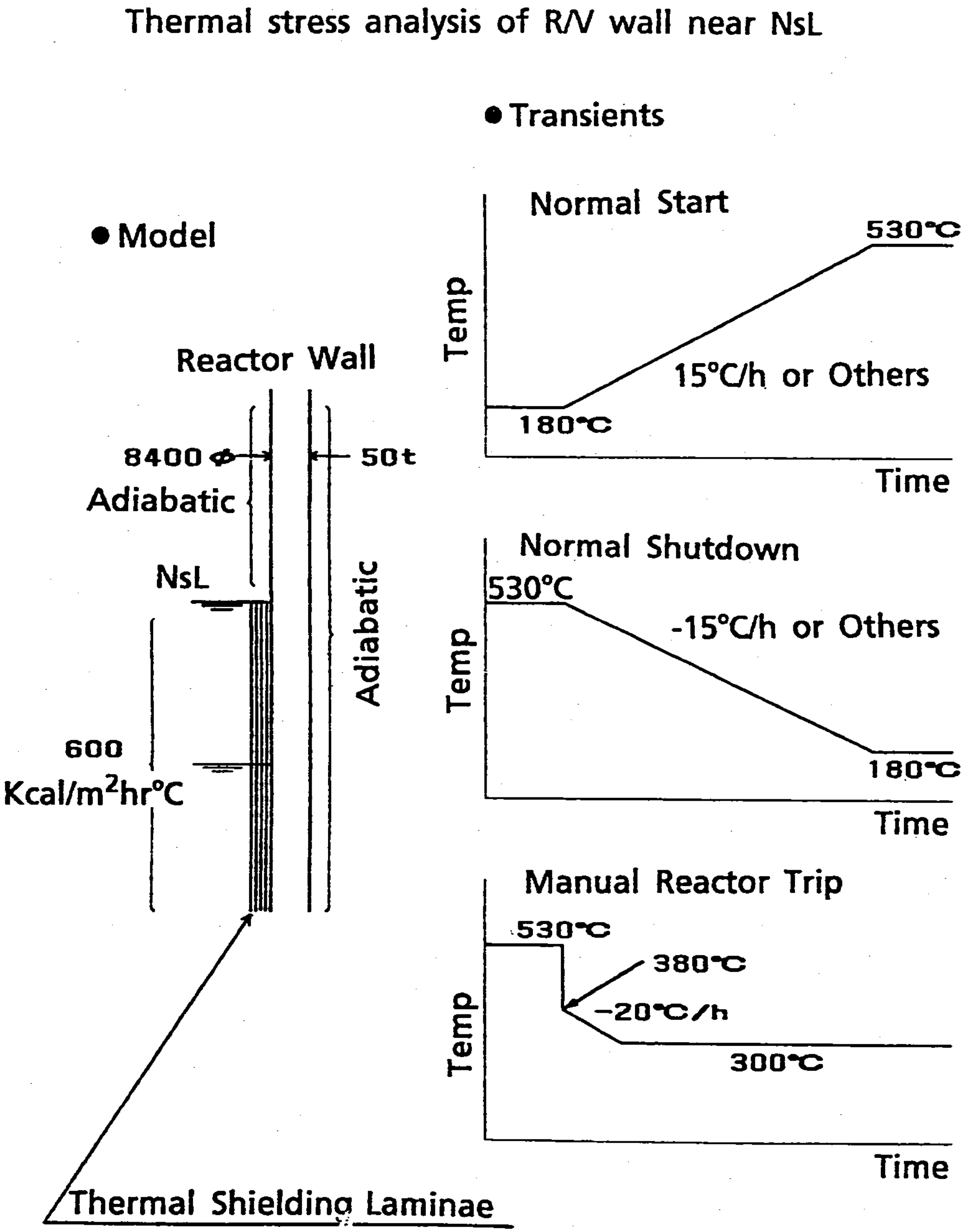


Fig.5 Conditions of R/V wall Analyses

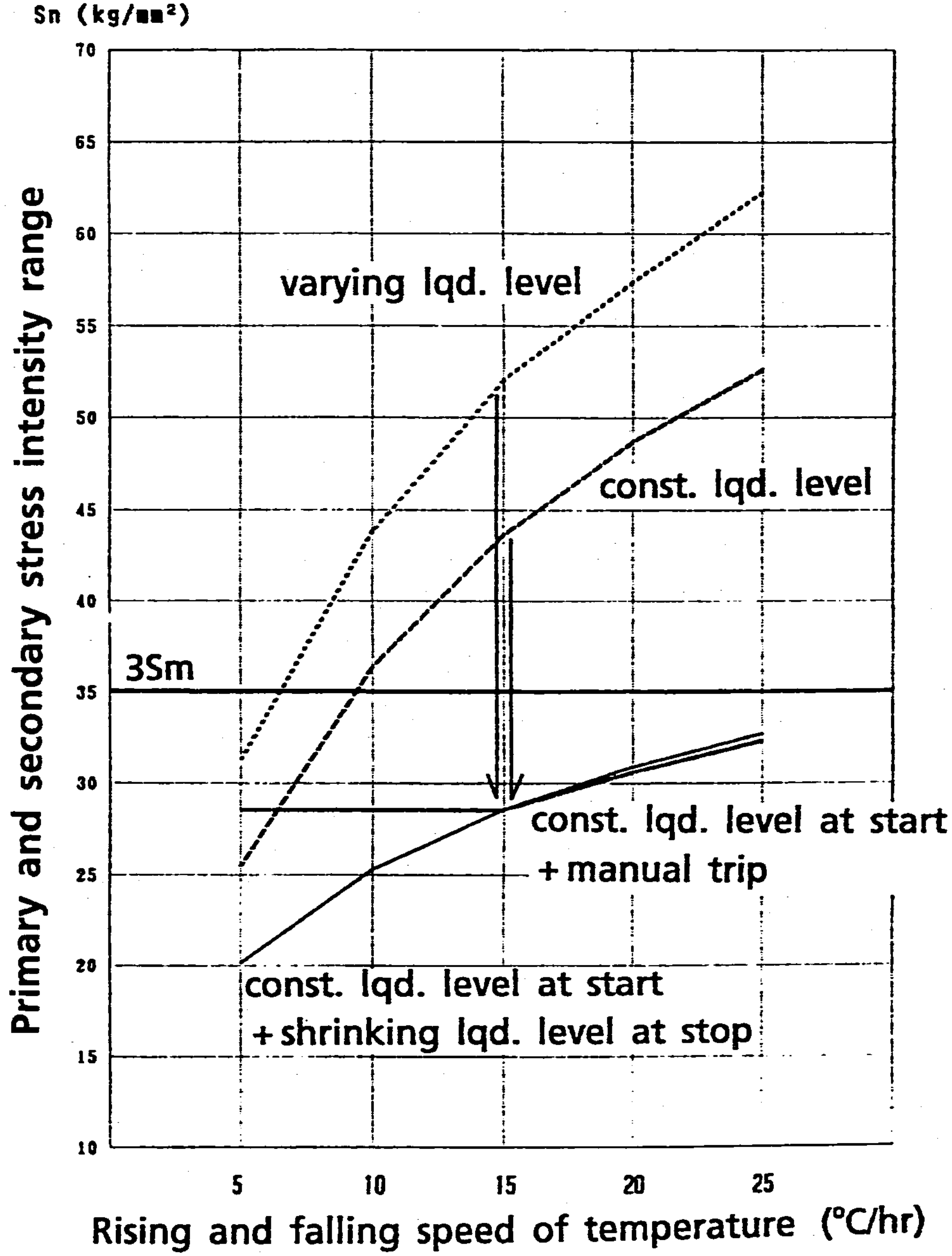


Fig.6 Thermal stress intensity range of R/V wall near NsL at transients

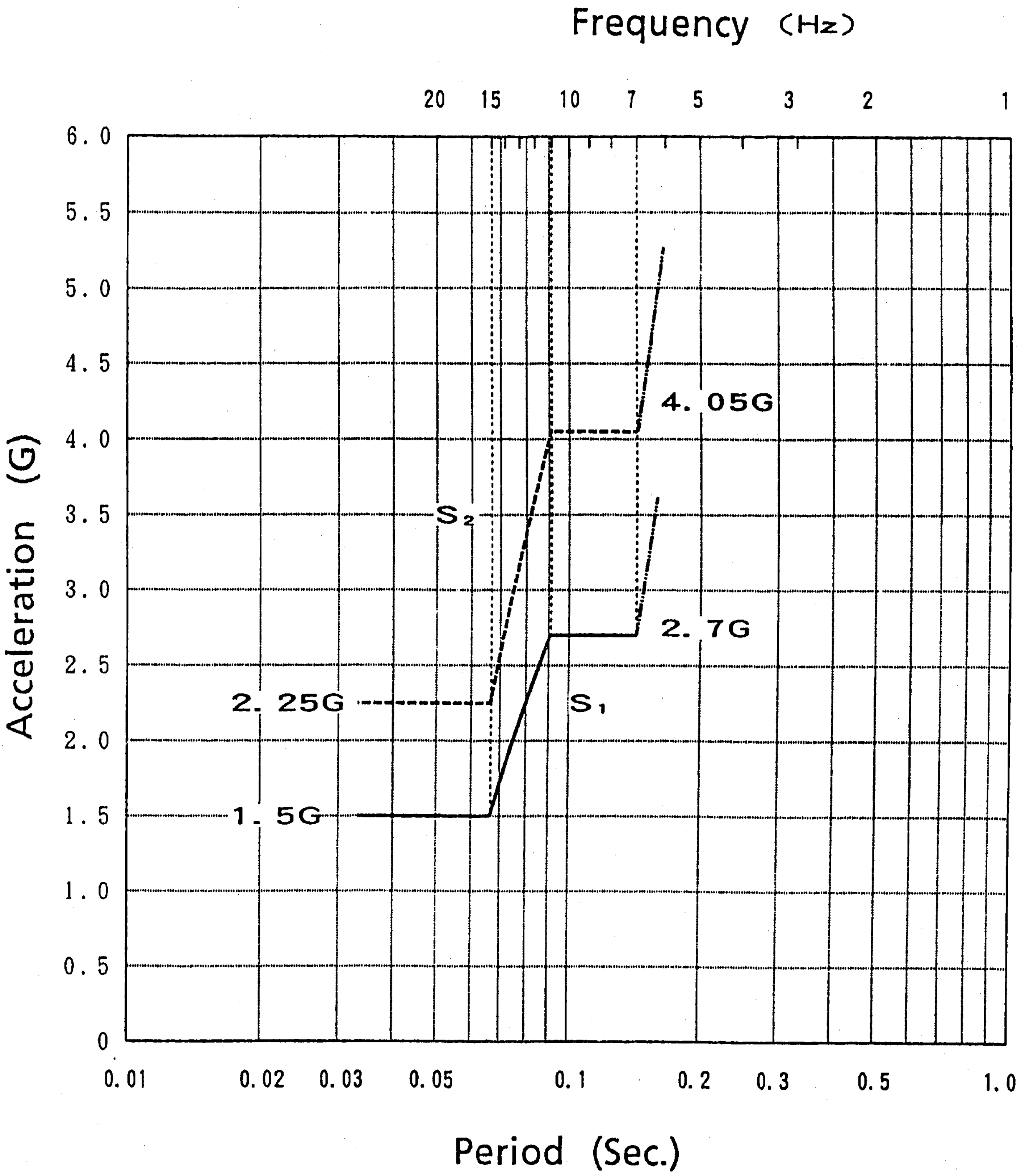


Fig.7 R/V Installation Floor Response

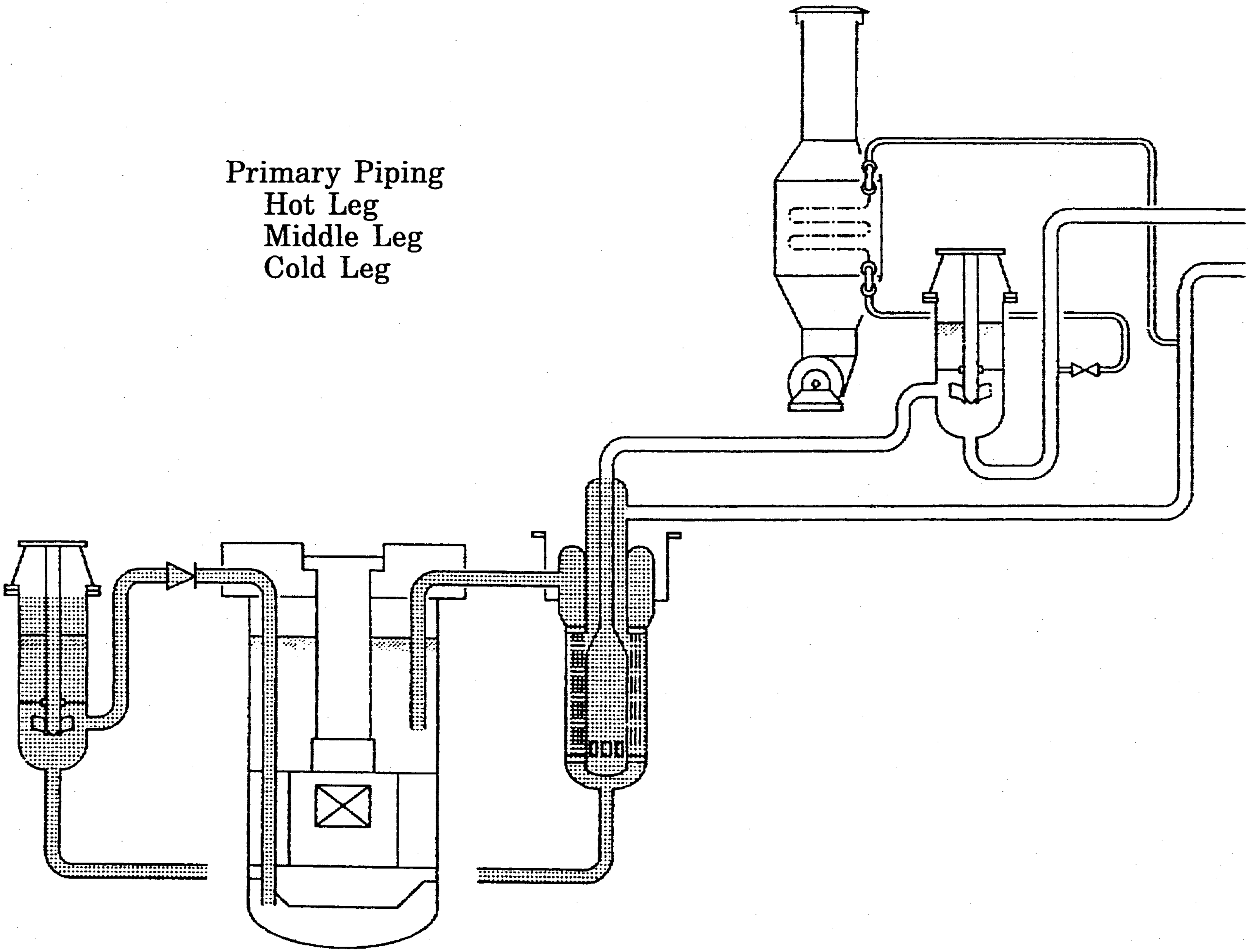
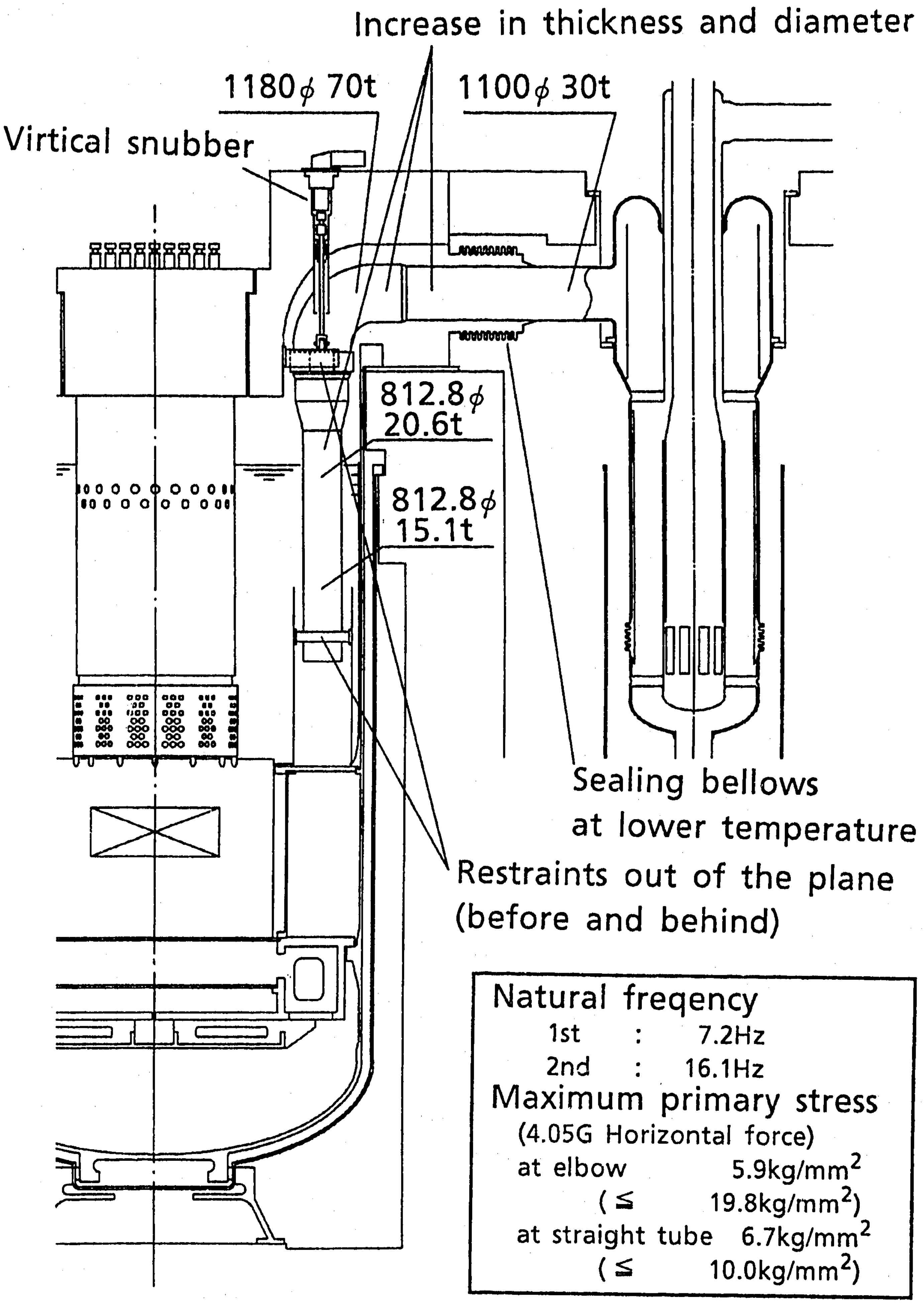


Fig.8 Primary Piping



Natural freqency
1st : 7.2Hz
2nd : 16.1Hz
Maximum primary stress
(4.05G Horizontal force)
at elbow 5.9kg/mm^2
(≦ 19.8kg/mm^2)
at straight tube 6.7kg/mm^2
(≦ 10.0kg/mm^2)

Fig.9 Results of Hot Leg Piping Analysis

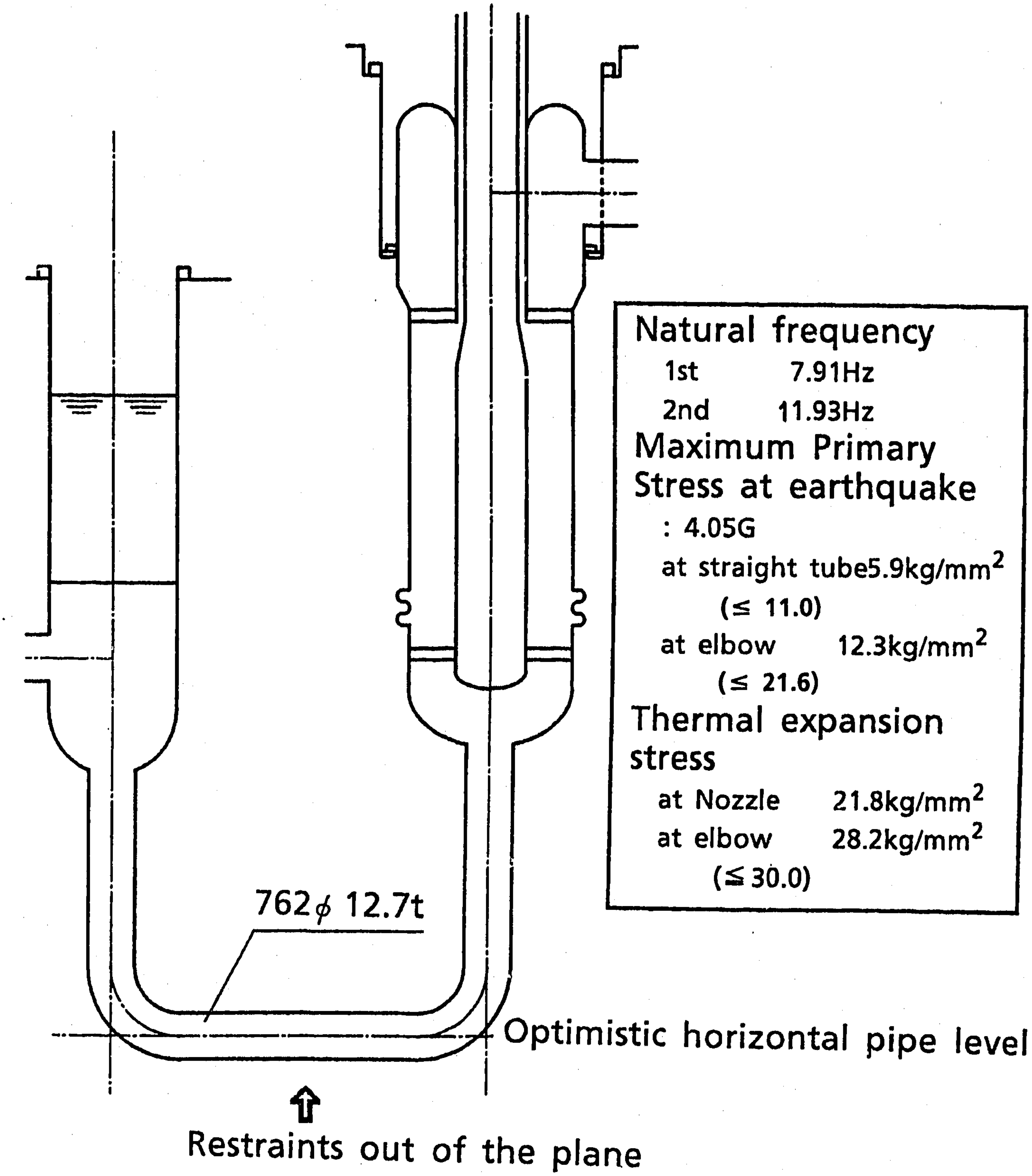
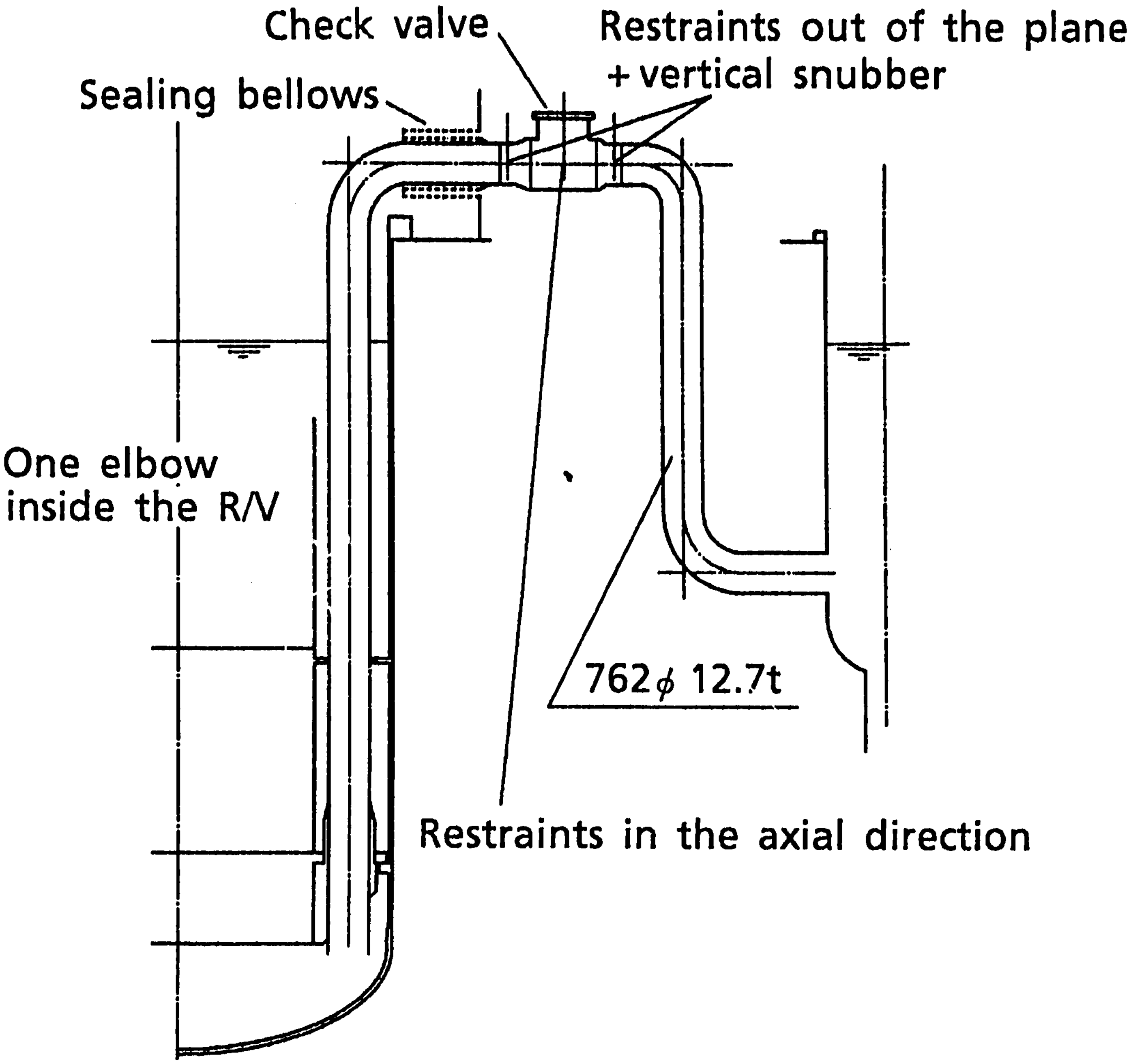


Fig.10 Results of Middle Leg Piping Analysis



Natural frequency

1st : 7.7Hz

2nd : 8.4Hz

Max. primary stress at earthquake

(4.05G Horizontal force)

at elbow : 15.3kg/mm^2 (≦21.6)

at straight tube : 5.0kg/mm^2 (≦11.0)

Thermal expansion stress (at rated operation)

at elbow : 19.7kg/mm^2 (≦30.0)

at Nozzle : 2.8kg/mm^2 (≦30.0)

Fig.11 Results of Cold Leg Piping Analysis

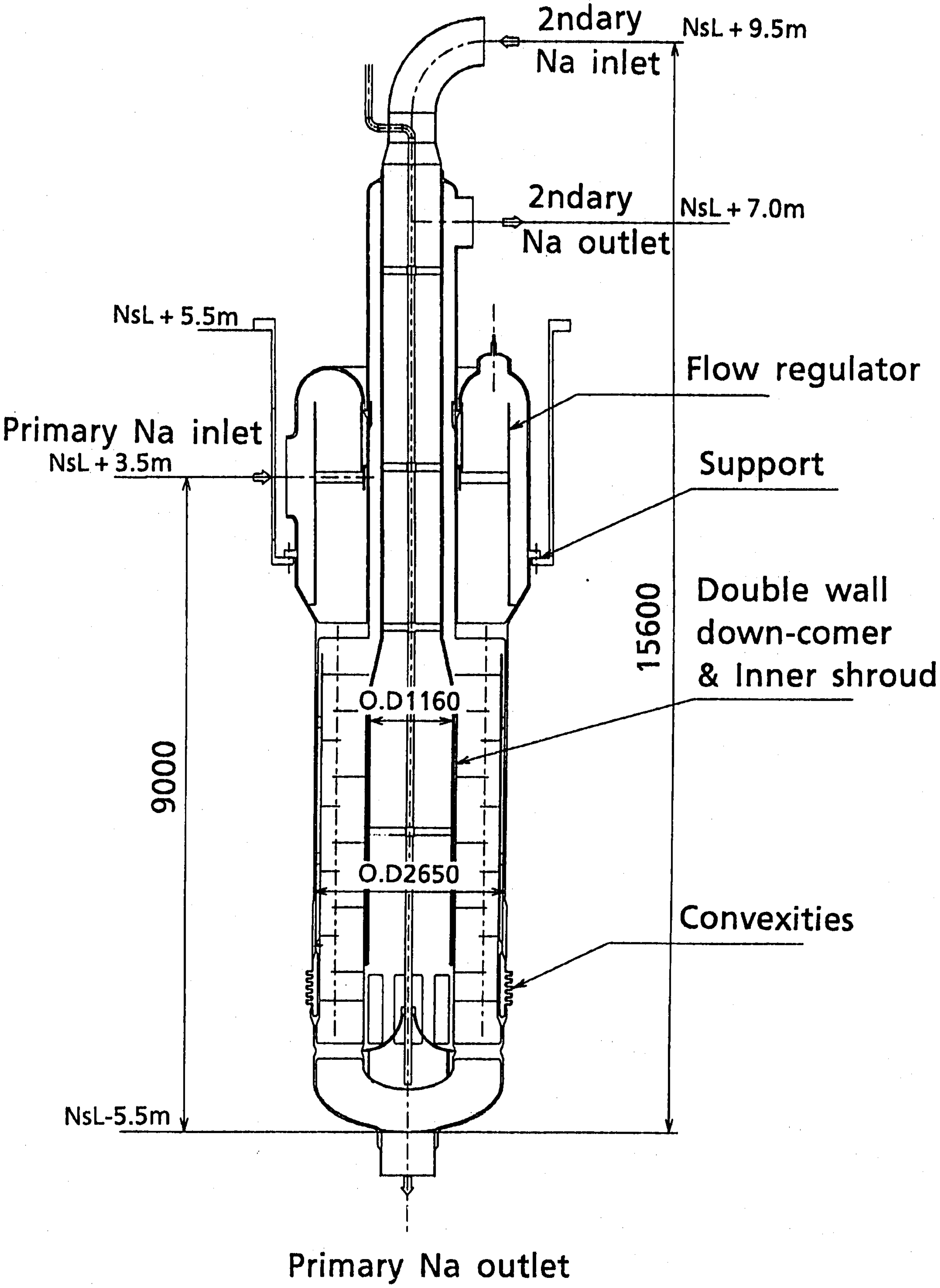
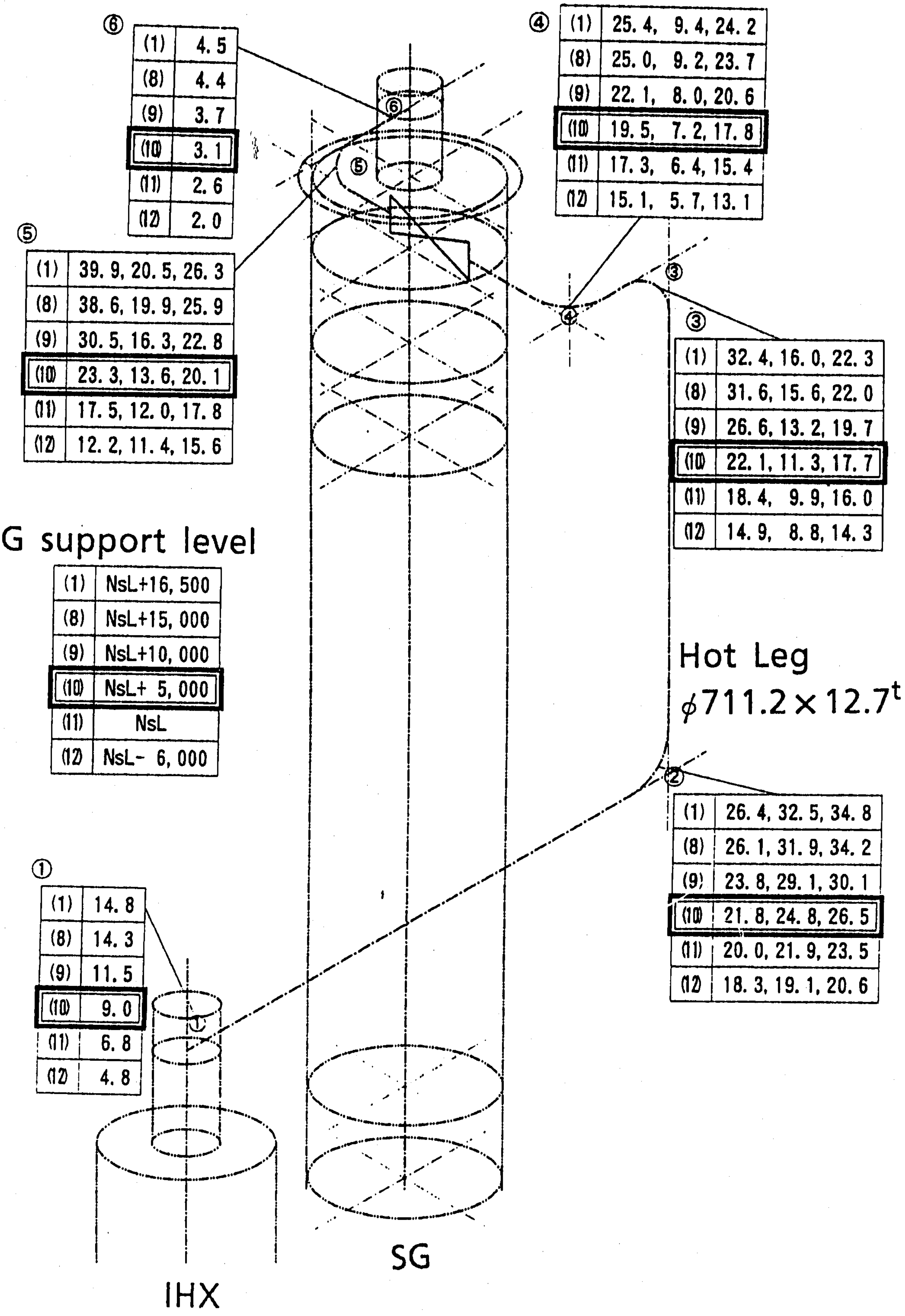


Fig.12 Structure Concept of Intermediate Heat Exchanger



⑥

(1)	4.5
(8)	4.4
(9)	3.7
(10)	3.1
(11)	2.6
(12)	2.0

④

(1)	25.4, 9.4, 24.2
(8)	25.0, 9.2, 23.7
(9)	22.1, 8.0, 20.6
(10)	19.5, 7.2, 17.8
(11)	17.3, 6.4, 15.4
(12)	15.1, 5.7, 13.1

⑤

(1)	39.9, 20.5, 26.3
(8)	38.6, 19.9, 25.9
(9)	30.5, 16.3, 22.8
(10)	23.3, 13.6, 20.1
(11)	17.5, 12.0, 17.8
(12)	12.2, 11.4, 15.6

③

(1)	32.4, 16.0, 22.3
(8)	31.6, 15.6, 22.0
(9)	26.6, 13.2, 19.7
(10)	22.1, 11.3, 17.7
(11)	18.4, 9.9, 16.0
(12)	14.9, 8.8, 14.3

SG support level

(1)	NsL+16,500
(8)	NsL+15,000
(9)	NsL+10,000
(10)	NsL+ 5,000
(11)	NsL
(12)	NsL- 6,000

②

(1)	26.4, 32.5, 34.8
(8)	26.1, 31.9, 34.2
(9)	23.8, 29.1, 30.1
(10)	21.8, 24.8, 26.5
(11)	20.0, 21.9, 23.5
(12)	18.3, 19.1, 20.6

①

(1)	14.8
(8)	14.3
(9)	11.5
(10)	9.0
(11)	6.8
(12)	4.8

Fig.13 Results of Thermal Expansion Analysis of Secondary Circuit

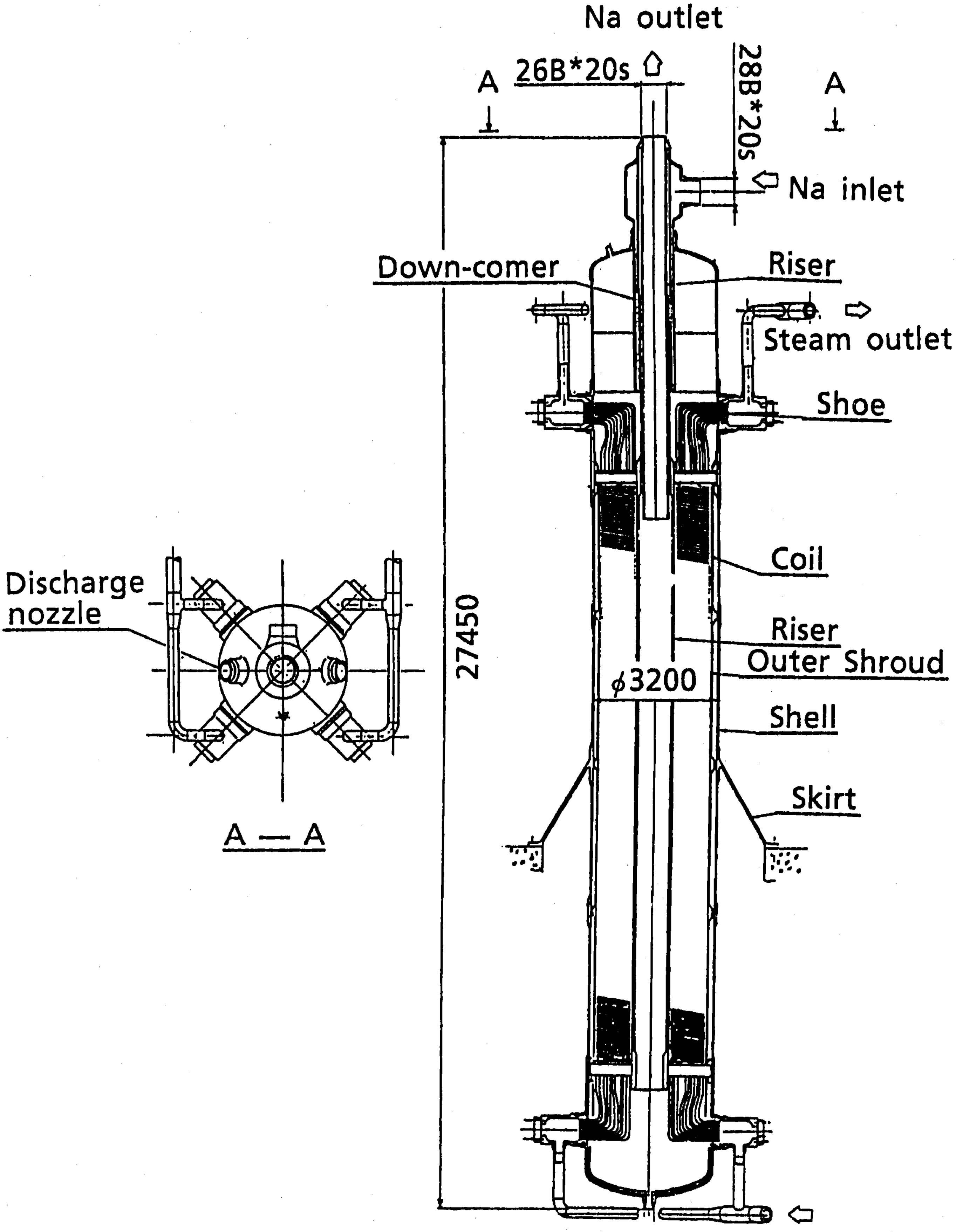
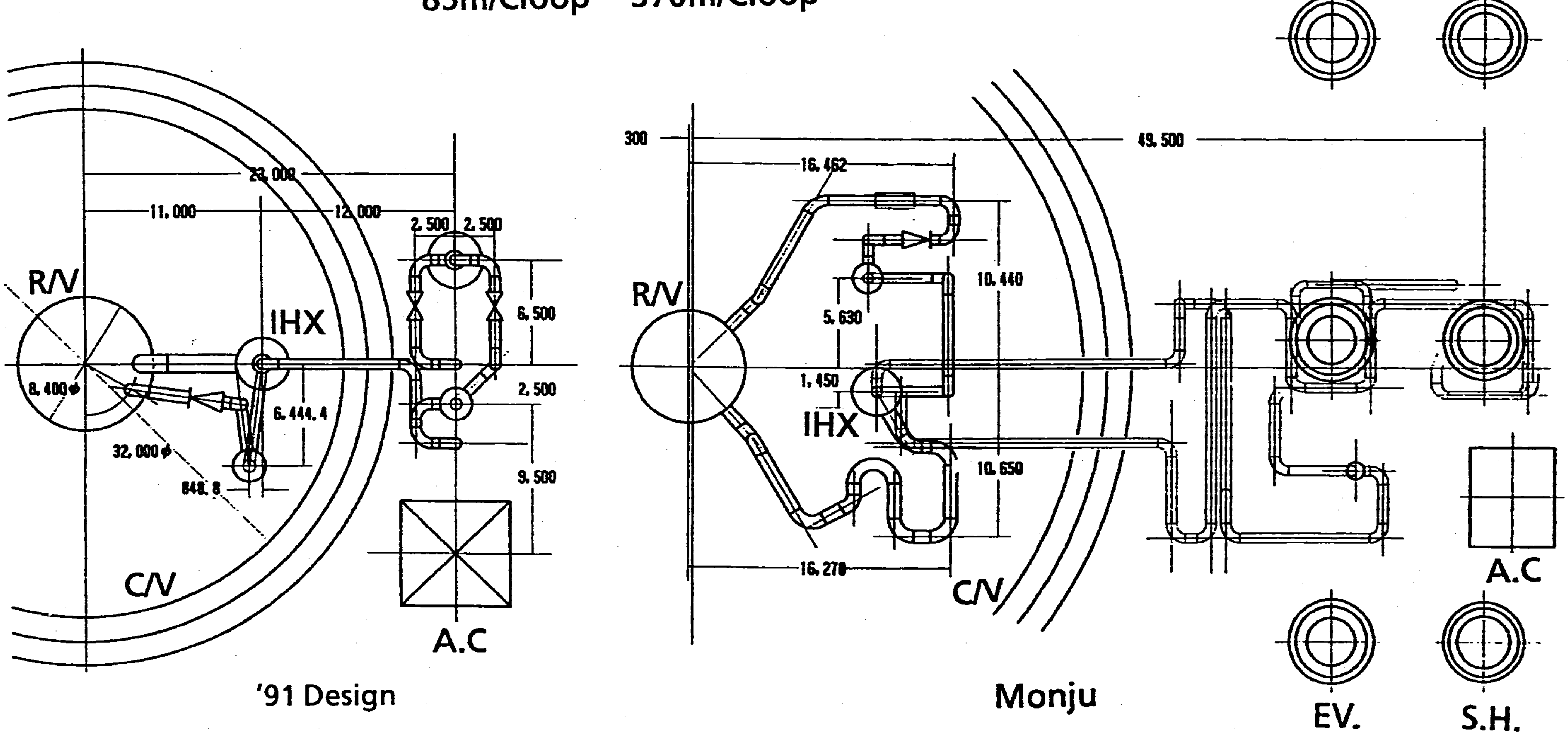


Fig.14 Structure Concept of Steam Generator

	'91 Design	Monju
Primary Circuit	58m/loop	102m/loop
Secondary Circuit	85m/Aloop	363m/Aloop
	83m/Bloop	234m/Bloop
	85m/Cloop	370m/Cloop



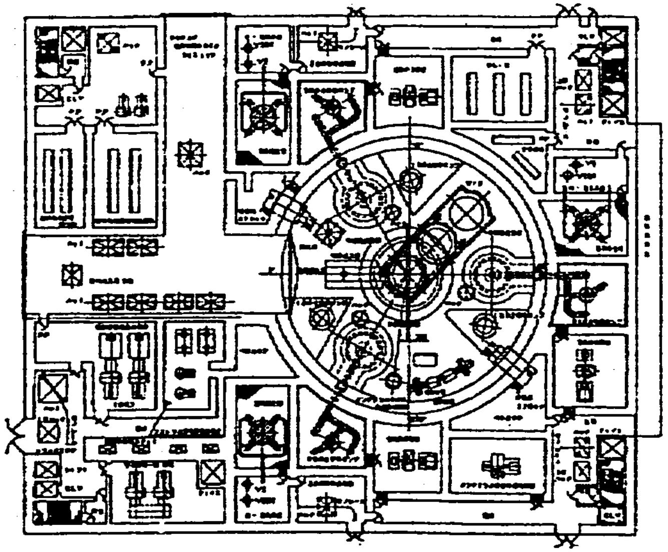
'91 Design

Monju

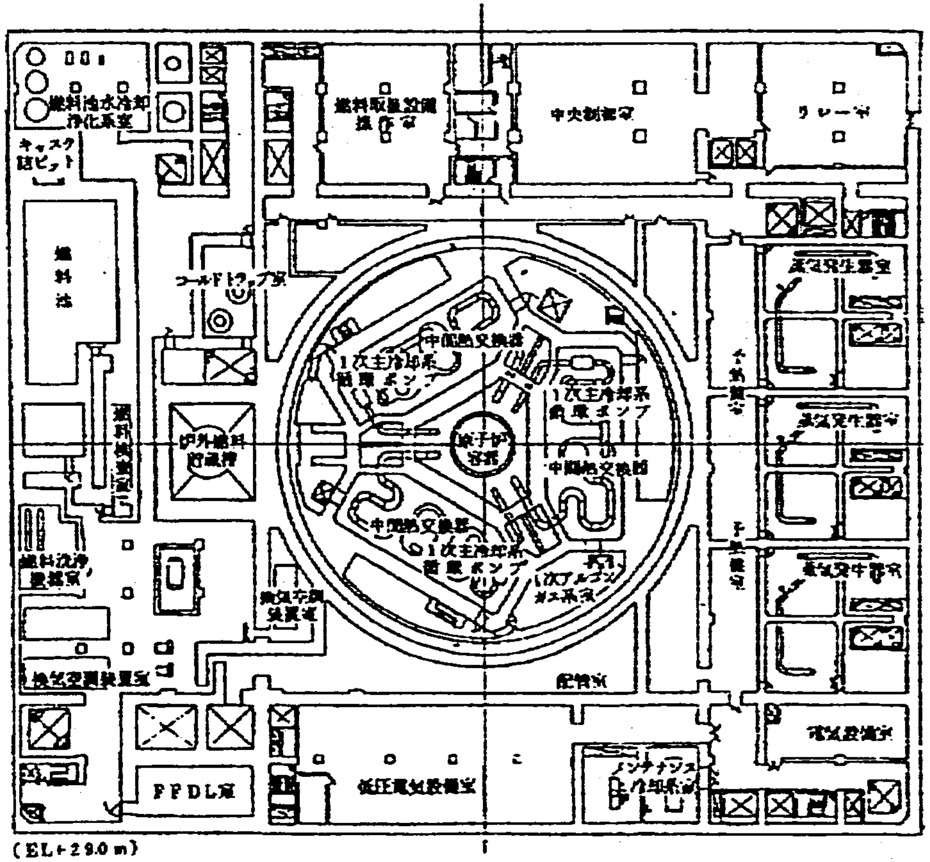
Fig.15 Piping Layout

’91 Design　73m^L×63m^W×76m^H

Monju　113m^L×98m^W×89m^H



’91 Design



Monju

Fig.16　Reactor Building Size

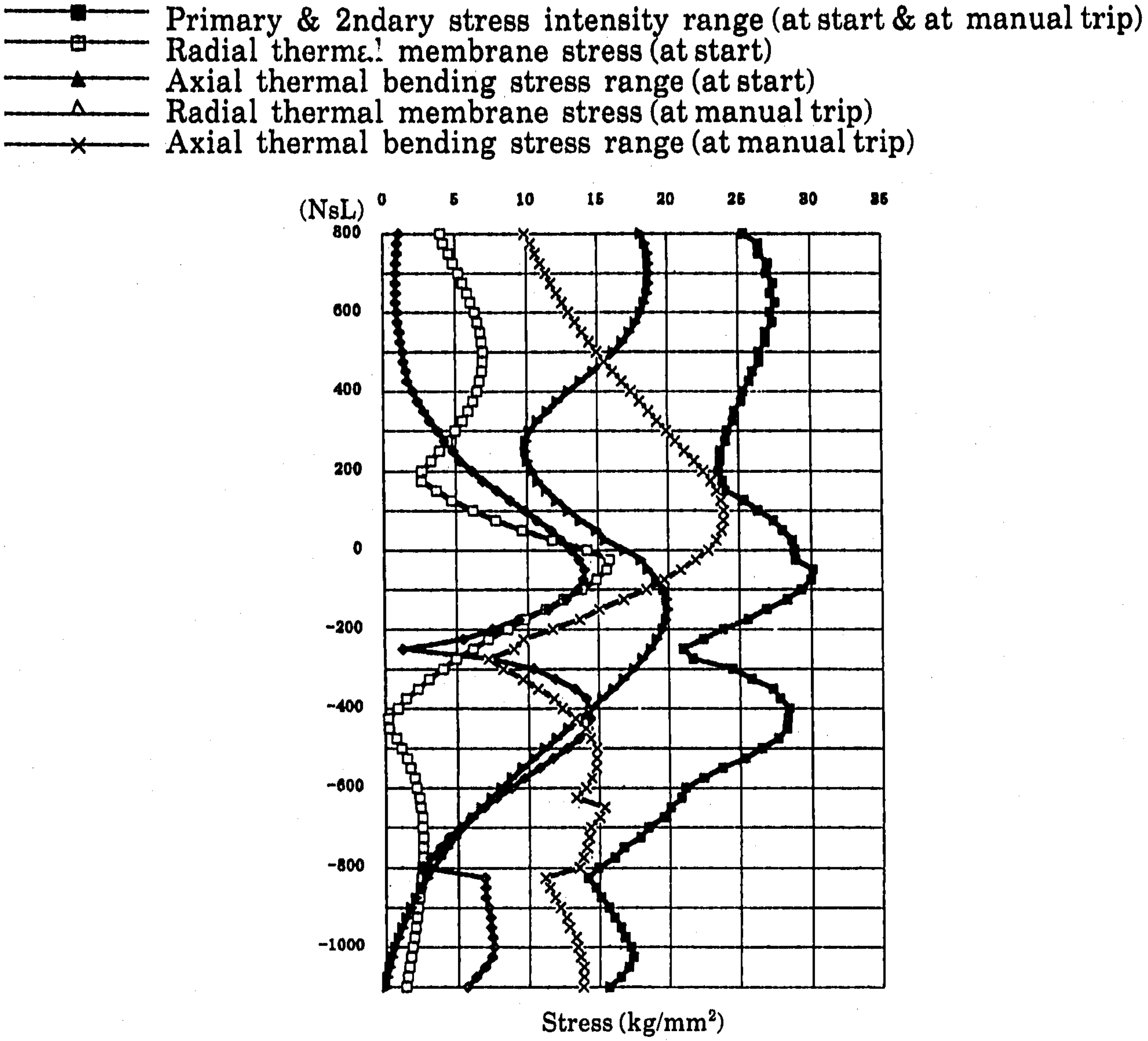


Fig.17 Stresses along RV elevation (RV dia. : 9.6m)

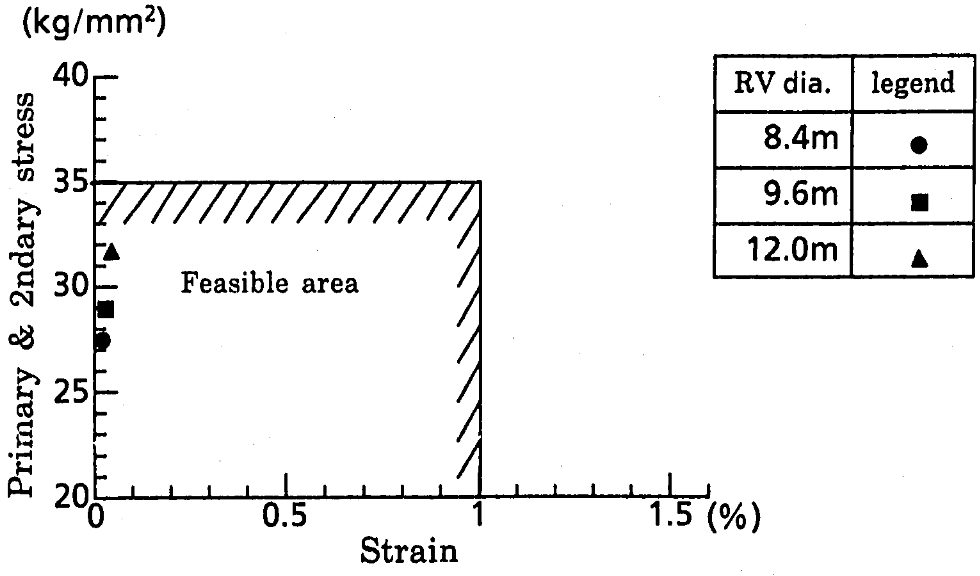


Fig.18 Primary & 2ndary stress intensity range and strain

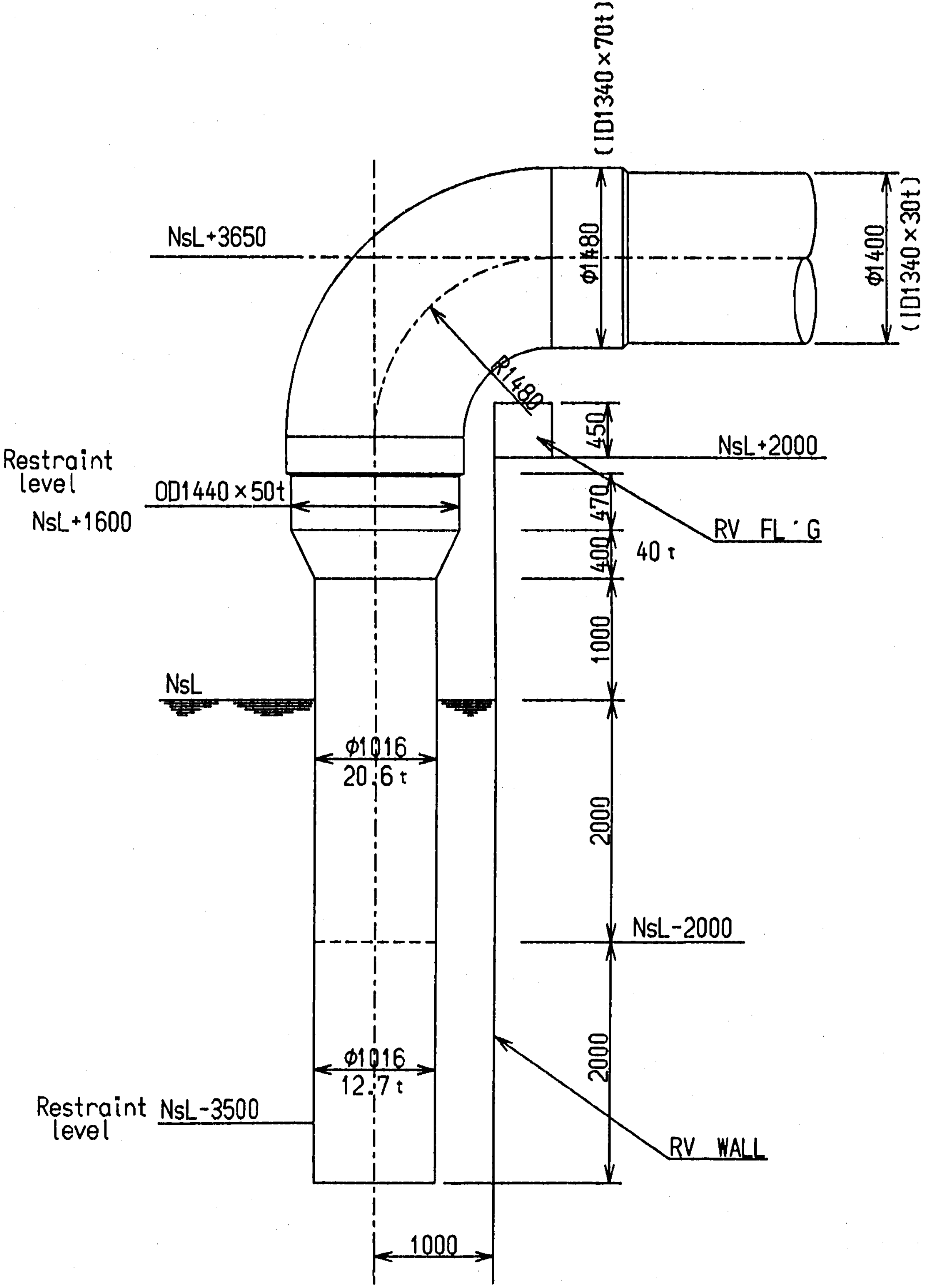


FIG.19 HOT LEG PIPE FOR 1300MWe PLANT