JAERI-Tech
95-019

CONCEPTUAL DESIGN OF ITER SHIELDING BLANKET

March 1995

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編集兼発行　日本原子力研究所
印　　　刷　日立高速印刷株式会社

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(Received February 6, 1995)

The present report summarizes the design activities of the ITER first wall and shielding blanket conducted by the JA Home Team during this year(1994)in close contact with the JCT, and reported during the four Technical Meetings held at Garching ITER Co-center. These activities are based on the Task Agreement between the JCT and the JA Home Team.

In the present report, a layered configuration composed of separate first walls, modular-type blanket modules and separate back plates has been proposed to realize reliable assembly and maintenance

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This works is conducted as an ITER Technology R&D and this report corresponds to the 1994 ITER Comprehensive Task Agreement for Design Task(Task No. G16TD70, ID No.D66, Title : Blanket/Shield Development and Design).

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schemes as well as to realize reliable component designs under hign surface heat loads, high neutron wall loading and electromagnetic loads during disruptions. Outline of the structural design, consideration on fabricability and maintainability, and the results of thermal, mechanical and electromagnetic analyses are described.

Keywords : ITER, First Wall, Shielding Blanket,
Modular-type Blanket Modules, Back Plate, Assembly,
Maintenance, Fabricability, Thermal and Mechanical Analyses,
Electromagnetic Analysis

ITER遮蔽ブランケットの概念設計

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(1995年2月6日受理)

本レポートは，国際共同設計チームとの密接な協力の下に，1994年の1年間に日本ホームチームが行なった，ITER遮蔽ブランケット／第一壁の概念設計活動の成果を纏めたものである。本設計作業は，国際共同設計チームと日本ホームチームとの間で結ばれた作業契約に基づいてなされた。

高い表面熱流束，高い中性子壁負荷及びディスラプション時の電磁力の下で信頼性の高い遮蔽ブランケット／第一壁の設計を実現すると共に，信頼性の高い組立保守性を達成するために，本設計では，分離第一壁，モジュール構造を有する遮蔽ブランケット，分離後壁から成る層状構造の遮蔽ブランケットを提案した。本報告では，構造設計の概要，製作性や保守性の検討，及び熱機械，電磁構造解析の結果を報告する。

本作業は，国際熱核融合実験炉（International Thermonuclear Experimental Reactor）の工学設計活動として，1994年設計作業契約（Task No. G16TD70, ID No. D66）に基づいて実施した。

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1. Introduction

International Thermonuclear Experimental Reactor (ITER) is designed to generate a fusion power of 1.5 GW as a nominal value with a surface heal flux of 0.2 MW/m^2 and a neutron wall load of 1 MW/m^2 in average. Higher heat flux up to 0.5 MW/m^2 or more is anticipated at hot spot regions near X-point and ripple-loss regions. Shielding blanket made of austenitic stainless steel, mainly devoted to radiation shielding, is to be installed for the first decade of the ITER operation - Basic Performance Phase (BPP), while breeding blankets are to be installed instead of the shielding blanket during the last decade of the ITER operation - Extended Performance Phase (EPP). Operation parameters and design requirements for the shielding blanket are summarized in Table 1-1 and 1-2, respectively.

In this report, design activities on the ITER first wall and shielding blanket during the year of 1994 are described. These design activities have been conducted by the JA Home Team in close interaction with the JCT. For the design development, attention has been paid to a consistency of the design to meet the operation parameters and design requirements given by the JCT. In particular, design efforts have been placed not only on thermal, mechanical and electromagnetic (EM) performances of these components but also on integration issues such as maintainability and electrical connection of these components to form a current path in the toroidal direction.

In the course of the design development during this year, basic concept of the shielding blanket was drastically changed from "flexible" concept to "rigid" one. This report contains the outline of the design activities devoted to the latter concept, which is presently the main line of the JCT design. Also, Design Assessment Meeting was held in October of this year at San Diego ITER Co-center to assess the current status of the ITER design both by the JCT and by the four Home Teams, and many critical issues were clarified in this meeting. During the last quarter of this year, design efforts were concentrated on these critical issues pointed out during this meeting, in particular, on fabricability and maintainability of the "modular shielding blanket" concept, EM analysis and concept development of the electrical connection of the first wall, and transition scenario from BPP to EPP .

2. Configuration

2.1 Outline

Layered configuration composed of separate first walls, blanket modules and separate back plates has been proposed to realize reliable assembly and maintenance schemes as well as to realize reliable component designs under high surface heat loads up to 0.5 MW/m^2, neutron wall loading of 1 MW/m^2 and EM loads up to 1.5 MPa during disruptions [1]. A schematic and a bird's-eye views of the layered blanket configuration are shown in Figs. 2-1 and 2-2, respectively.

Modular shielding blankets with a common manifold and a structurally separated back plate, supported by the shelves extruding from the vacuum vessel, are being examined. The blanket modules have modular structures in

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Modular shielding blankets with a common manifold and a structurally separated back plate, supported by the shelves extruding from the vacuum vessel, are being examined. The blanket modules have modular structures in the toroidal and poloidal directions, and are welded to the back plates and to the common manifold. Other fixing options such as key-type attaching lock concept are also now being examined. Modular configuration is illustratively shown in Figs. 2-3 and 2-4.

Two design concepts of the separate first wall have been proposed; one is a separately cooled option mechanically integrated with the blanket module, and the other is a separately cooled and independently demountable option. The former option employs HIP bonded structure made of copper alloy and steel with rectangular channels embedded within the first wall. The latter option employs fail-safe quilting structures, made of steel and Cu-alloy, to assure highly reliable structure. It has a double-walled structure sandwiching mesh inserts for in-service inspection.

2.2 Back Plate

Current blanket design employs an idea of the strong back plate, 70 to 100 mm thick, welded together to form a rigid axisymmetric structure for supporting large EM loads on the blanket modules, for providing a path of eddy currents induced during disruptions and for de-coupling thermally the blanket module with the vacuum vessel. The thickness of the back plate is decided by the hoop stress due to the EM loads on the first wall and the back plate itself, and the thicknesses of 70 and 100 mm for the inboard and the outboard, respectively, are marginal from the viewpoints of membrane stress limit. Bolt-connected structure is not feasible for the back plate due to high membrane stress requirement.

In the case that conventional welding methods such as TIG are applied to the connection of the back plate, large welding deformation is expected and rigid fixture may be needed during the welding process to suppress an excessive deformation. Separate configuration from the blanket modules enables to provide enough space for the access of support fixtures within the vacuum vessel, and highly reliable welding of 70 - 100 mm thick back plates and good alignment can be assured.

Another option is an application of EBW, which has a number of attractive features such as much better accessibility from the plasma region, much smaller welding deformation and much higher welding speed, while weldability at overhead position and gap control between modules - typically less than 0.5 mm - are key issues to be examined by R&D. In this case blanket modules can be integrated with the back plate because of less requirement on access space and less welding deformation.

The back plate is a very reliable component made of bulky stainless steel, and is categorized, in the maintenance classification, as a class 3 (near-permanent) component. It must survive throughout the lifetime of the machine. Even in the case that the shielding blankets are replaced with the breeding blankets, the back plates are not replaced, leaving them as they are.

2.3 Blanket Module

The blanket has a modular box-type structure made of steel. The lateral and cross-sectional views of the blanket module are shown in Figs. 2-5 and 2-6, respectively. The blanket module is separated into 2-m-long modular units in the poloidal direction. Modular structure has advantages of improved thermo-mechanical performances and better fabricability. The first wall and the side wall are to be fabricated by HIP bonding method, and the size of the module is decided by the size of the HIP facility currently available in Japan.

Each blanket module is welded to and supported by the back plate through two connection "legs" located at the back of the module, as shown in Fig. 2-6. These legs must support the EM loads - both of the out-of-plane centering forces on the first wall and in-plane twisting forces on the side wall, if the electrical connection on the first wall is not provided. The thickness of the legs is dominated by the stress limit due to the latter EM loads, and the optimization is now under way. Detailed information is given in Sec. 5.

Instead of welding connection of the blanket module to the back plate, mechanical locking idea was proposed. Basic idea of the mechanical locking is shown in Figs. 2-7 to 2-9. This mechanism, composed of keys, screws and links/wedges, has many attractive features, such as rapid attaching/detaching due to elimination of welding and better accessibility from the plasma side. Further design studies and demonstration of this concept by a full scaled R&D are required during EDA to feed back to the blanket design.

Each module has four branch pipes - inlet/outlet for the first wall cooling line and inlet/outlet for the blanket cooling line as shown in Fig. 2-3, and individual branch pipes are connected to the respective manifolds. In order to allow minor adjustment during installation of the module and to assure precise adjustment for the laser welding, flexible joints such as U-shaped bellows are equipped for the branch pipes. A zoomed-up view of the branch pipe is shown in Fig. 2-10.

The blanket module is categorized, in the maintenance classification, as a class 2 (unscheduled maintenance) component. It can be removed and installed independently from the other components by an in-vessel transporter. In the case of maintenance of each module, two legs are welded/cut in-situ, and four branch pipes are also welded/cut by an internal-access pipe welding/ cutting machine. The weight of each module is limited to less than 5 tons so as to allow in-situ handling by the in-vessel transporter. The outboard blanket has a tapered side wall, as shown in Fig. 2-11, to allow radial motion in case of maintenance.

2.4 Separate First Wall

For the design of the first wall, two options have been examined. One is a separately cooled first wall integrated with the blanket modules. In this option, the first wall is composed of 2 to 5 mm beryllium layer, 5 to 10 mm Cu-alloy layer, rectangular cooling channels with 2 mm wall thickness and 10 mm rear layer, both of which are made of 316 SS, and integrated with the blanket module. HIP bonding is the proposed method for the fabrication of this first wall based on the trial fabrication experiences [2-6]. Cooling water is fed from the common manifold region, flows along the toroidal channels and returns back to the manifold. The cross-section of the first wall is illustrated in Fig. 2-12 (where old version of the blanket module is shown).

The other option is a separately cooled and independently demountable first wall panel, typically 2-m-long and 1-m-wide, with a fail-safe quilting configuration. A cross sectional view of the fail-safe first wall panel is shown in Fig. 2-13. It has a double-walled structure sandwiching a metallic mesh, which enables in-service inspection [7,8]. This idea was well developed for heat exchangers of fast breeder reactors. This type of separate first wall has attractive features such as possible in-service inspection, exclusion of in-vessel LOCA event, reduced amount of radwaste in case of maintenance, and relaxed thermo-mechanical performances. In particular, independently removable features maximize the advantages of the separate first wall concept in terms of maintainability, electrical connection and reduced amount of radwaste. A series of thermo-mechanical analyses of this panel were conducted under the surface heat flux of 0.3-1.0 MW/m^2 together with nuclear heating and coolant pressure. The maximum stress of the first wall panel is summarized in Fig. 2-14 as a function of surface heat flux, and the combination of Cu-alloy and SS316 has been proposed for the high surface heat load region of more than 0.5 MW/m^2.

3. Fabricability

Based on the manufacturing feasibility studies now under way by Japanese industries, the JA Home Team proposes to apply solid HIP bonding method to the first wall and side wall fabrication and to use conventional fabrication methods (TIG welding, EBW, etc.) for the internal components within the module box. Fabrication procedures of the shielding blanket integrated with the first wall is shown in Appendix 1, where the configuration of the blanket module is slightly different from the current reference design, but it can provide the information on step-by-step fabrication procedures of the reference shielding blanket.

Applicability of powder HIP bonding method was assessed by the domestic industries, and in conclusion, powder HIPping was not favored because of expected large deformation, difficult quality control and larger demand to material qualification. On the other hand, solid HIPping is a well experienced technology, and 1/2-scaled mock-up was already fabricated successfully with a dimensional error less than 2 mm, as shown in Fig. 3-1. Domestic HIP facilities have a capacity with a dimension of up to 1.1-m-dia. and 2.1-m-high.

As for the deformation due to the thick plate welding, industrial data base experienced in the fusion and the other fields were accumulated, and it was suggested welding deformation of the thick plate such as the back plate could be suppressed to within a reasonable range by selecting appropriate welding methods and supporting fixtures, though confirmation R&D is necessarily required.

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Initial assembly procedures were examined based on the modular blanket design. The following three extreme cases were compared,

(1) Pre-assembling of all of the blanket modules to the back plate at factory, sector installation from the top port, and back plate welding on site

(2) Back plate welding on site, and the blanket module welding to the back plate one-by-one on site

(3) Back plate welding on site, pre-assembling of the blanket modules per sector, and welding them to the back plate on-by-one on site,

and the comparison is summarized in Table 3-1 to 3-5. Among the above three cases, case (1) seems the most attractive because of shorter on-site construction period, less demand to the future R&D and possibly lower construction cost. The most critical point is to consider pre-assembling the components at factory as much as possible, which can minimize the construction period on site, minimize the number of the welding line on site, and minimize the welding deformation. From such a viewpoint, wider unit of the back plate with the blanket modules pre-welded at factory as much as possible should be considered. Above three cases are the extreme cases, and optimization of the initial assembly procedure seems possible by taking into consideration the assembly procedure of the vacuum vessel.

4. Maintainability

In the current JCT modular shielding blanket design, independent modular maintenance scheme is being proposed by utilizing the in-vessel transporter, in-situ welding/cutting of the "legs" connecting the blanket module with the back plate, and internal-access pipe cutting/welding.

Based on the experimental results obtained using a vehicle-type transporter with 1.2-tons payload capacity, a vehicle type transporter with 4~5 tons payload capability to cope with the reference blanket module handling can be designed and realized. Typical payload distribution by the 5-ton-class in-vessel transporter is illustrated in Fig. 4-1, and remote handling by this type of manipulator seems feasible, if the weight of the individual modules is limited to less than 5 tons. Since feasibility of the reference modular blanket design deeply depends on the feasibility of the maintainability, establishment of the maintainability of the modular blanket is one of the key issues to be demonstrated during EDA, and mock up test for class 1 and 2 components is necessarily to be conducted during EDA.

Development of the internal-access welding/cutting by using YAG laser system has been progressed and it was shown this technology is feasible and can be applied to the branch pipe connection/disconnection. Illustrative drawing of the internal-access pipe cutting/welding head with YAG laser is given in Fig. 4-2. Access of the internal-access pipe welding/cutting equipment from the top port was proposed, based on the pipe layout within the limit of minimum bend radius of 400 mm. Cooling pipe layout is decided by CAD analysis to avoid geometrical interfere with the other component and to allow pipe bending with the radius larger than 400 mm. Current solution is given in Figs. 4-3 to 4-5.

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Several candidate methods of the leg welding/cutting and possible access routes of these equipment were also examined. Candidate welding and cutting processes are summarized in Tables 4-1 to 4-4. Possible candidate methods for the support leg welding are narrow gap TIG welding and Iodine/ YAG laser, and those for the support leg cutting are Iodine/YAG laser. Access of the welding head to the leg is a critical issue, and several options shown in Figs. 4-6 to 4-9 are now under examination.

5. Aanlysis

5.1 Thermal and Mechanical performances

Two dimensional stress analysis of the blanket module was conducted under the load conditions of coolant pressure of 2 MPa and EM forces of 1.5 MPa. The maximum deformation and Tresca stress obtained are 9.1 mm and 263 MPa, respectively. Detailed information is summarized in Appendix 2.

Thermo-mechanical analysis of the first wall, also shown in Appendix 2, shows that the maximum temperature and Tresca stress are 293°C at the surface of beryllium layer and 290 MPa at the corner of the cooling channel, respectively, under the surface heat flux of 0.5 MW/m^2 and nuclear heating corresponding to the neutron wall loading of 1.2 MW/m^2.

5.2 EM Performances

Three dimensional EM and structural analysis of the reference modular blanket were conducted. The required thickness of the legs and the stress level of the legs and the back plate under the conditions of no electrical connection at the first wall were shown by a parametric survey of the leg thickness. The load conditions, FEM mesh data, and the results of the analyses are shown in Figs. 5-1 to 5-6, and more detailed information is given in Appendix 3. The optimum thickness of the leg is around 50 mm, and the stress level of the back plate is marginal. Further design optimization is needed to find out the structural solution.

The conceptual design of the electrical connection strip attached on to the first wall was developed. This concept is composed of multi-layered thin films made of Cu-alloy, bolt-connected on to the first wall, and is designed to react the surface and nuclear heating, EM loads and thermal expansion of the adjacent blanket modules. The optimized configuration is 6-mm-thick strips made of 50 layers of thin Cu-alloy films. Such a multi-layered connector is well experienced in the conventional kA-class circuit breaker.

6. BPP-to-EPP Transition Scenario

BPP-to-EPP transition scenario was briefly examined, based on full blanket change-out from shielding to breeding. Modular-type water-cooled solid breeder blanket was assumed because of its compatibility to the reference shielding blanket and basic device design. Critical issues associated with the transition from shielding to breeding blanket were briefly

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Several candidate methods of the leg welding/cutting and possible access routes of these equipment were also examined. Candidate welding and cutting processes are summarized in Tables 4-1 to 4-4. Possible candidate methods for the support leg welding are narrow gap TIG welding and Iodine/ YAG laser, and those for the support leg cutting are Iodine/YAG laser. Access of the welding head to the leg is a critical issue, and several options shown in Figs. 4-6 to 4-9 are now under examination.

5. Aanlysis

5.1 Thermal and Mechanical performances

Two dimensional stress analysis of the blanket module was conducted under the load conditions of coolant pressure of 2 MPa and EM forces of 1.5 MPa. The maximum deformation and Tresca stress obtained are 9.1 mm and 263 MPa, respectively. Detailed information is summarized in Appendix 2.

Thermo-mechanical analysis of the first wall, also shown in Appendix 2, shows that the maximum temperature and Tresca stress are 293°C at the surface of beryllium layer and 290 MPa at the corner of the cooling channel, respectively, under the surface heat flux of 0.5 MW/m^2 and nuclear heating corresponding to the neutron wall loading of 1.2 MW/m^2.

5.2 EM Performances

Three dimensional EM and structural analysis of the reference modular blanket were conducted. The required thickness of the legs and the stress level of the legs and the back plate under the conditions of no electrical connection at the first wall were shown by a parametric survey of the leg thickness. The load conditions, FEM mesh data, and the results of the analyses are shown in Figs. 5-1 to 5-6, and more detailed information is given in Appendix 3. The optimum thickness of the leg is around 50 mm, and the stress level of the back plate is marginal. Further design optimization is needed to find out the structural solution.

The conceptual design of the electrical connection strip attached on to the first wall was developed. This concept is composed of multi-layered thin films made of Cu-alloy, bolt-connected on to the first wall, and is designed to react the surface and nuclear heating, EM loads and thermal expansion of the adjacent blanket modules. The optimized configuration is 6-mm-thick strips made of 50 layers of thin Cu-alloy films. Such a multi-layered connector is well experienced in the conventional kA-class circuit breaker.

6. BPP-to-EPP Transition Scenario

BPP-to-EPP transition scenario was briefly examined, based on full blanket change-out from shielding to breeding. Modular-type water-cooled solid breeder blanket was assumed because of its compatibility to the reference shielding blanket and basic device design. Critical issues associated with the transition from shielding to breeding blanket were briefly

examined. One-dimensional neutronics analyses were conducted to compare the shielding capability of the two blankets - shielding and breeding. Typical result is shown in Fig. 6-1. Required additional thickness of the breeding blanket to achieve the same shielding capability with the shielding blanket is around 10 cm. Plasma operation scenario to achieve 0.9 MW/m^2 with the reduced plasma minor radius by 10 cm was examined, and possible scenario is shown in Figs. 6-2 and 6-3.

7. Conclusion

Activities on the ITER first wall, blanket and shield design conducted by the JA Home Team during the year of 1994 are reported. Layered configuration composed of separate first walls, modular-type shielding blanket modules and separate back plates has been proposed to realize reliable assembly and maintenance schemes as well as to realize reliable component designs. Proposed design is based on the technologies well experienced in the industries. And thermal, mechanical and EM analyses showed satisfactory performances of the proposed design under the design conditions, though further optimization and detailed design efforts are needed.

Acknowledgment

The authors would like to express their sincere appreciation to Drs. S. Shimamoto and S. Matsuda for their continuous guidance and encouragement. They also would like to acknowledge Kawasaki Heavy Industries Co. and all of other members who support this work.

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[2] S. Sato, et al.: "Fabrication of the Blanket Box Structure Integrated with First Wall for a Fusion Experimental Reactor," Proc. 15th Symp. on Fusion Eng., 259, Cape Cod (1993).

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Table 1 − 1 Design Parameters of the ITER First Wall and Shielding Blanket

- Nominal fusion power	1.5 GW
- Neutron wall loading	
- Average	1 MW/m^2
- Peak	1.2 MW/m^2
- Average neutron fluence	
- BPP	0.3 MWa/m^2
- EPP	3 MWa/m^2
- Nuclear heating at first wall	
- Beryllium	10 MW/m^3
- Cu alloy	23 MW/m^3
- SS 316	18 MW/m^3
- Surface heat flux	
- Average	0.2 MW/m^2
- Peak	0.5 MW/m^2
- Total number of cycles	100,000
- Structural material	SS316
- First wall protection material	Be
- Coolant	Water
- Coolant conditions	
- Inlet/outlet temperature	100/150°C
- Pressure	2 MPa
- EM force on first wall	
- Inboard	1.5 MPa
- Outboard	1.0 MPa
- EM force on first wall and back plate	
- Inboard	2 MPa*
- Outboard	1.5 MPa*

* need to be checked by detailed EM analysis

Table 1 − 2 Design Requirements on the ITER First Wall and Shielding Blanket

- Number of modules per sector	
- Inboard	2
- Outboard	4
- Service and manifold	Top port
- Electrical connection	First wall Back plate
- Self-supporting except	Dead weight Vertical EM force
- Baking temperature	
- First wall	350°C
- Blanket module	TBD
- Breeding capability	
- BPP	Not required
- EPP	Convertible Replaceable

Table 3 − 1 Abstract of the 1 − st case

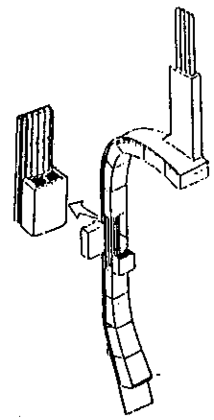
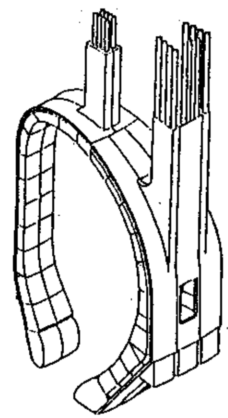
	Construction procedure		Note
Factory	① Fabricating blanket modules. ② Attaching blanket modules to a segment of back plate with piping. ③ Each segment of back plate and blanket with piping will be completed in factories.		
Site	① Assembling and fixing of all segments. ② Welding of back plates.		

Table 3 − 2 Abstract of the 2 − nd case

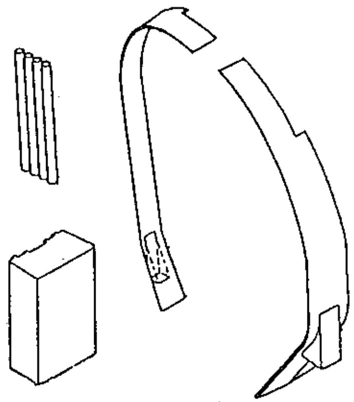
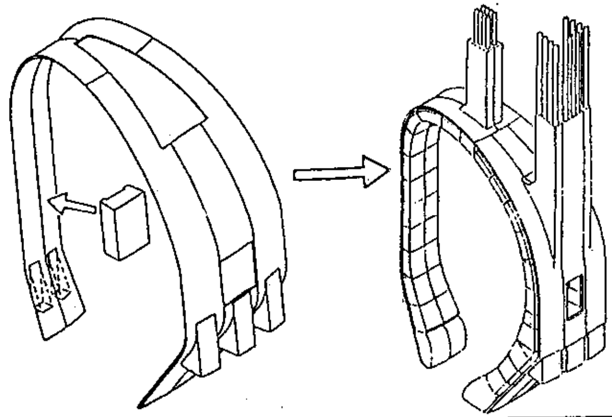
	Construction procedure		Note
Factory	① Fabricating back plates, blanket modules and piping, respectively. ② Each component will be completed in factories separately.		
Site	① Assembling and welding of only back plates at first. ② Attaching piping to back plates. ③ Attaching blanket modules to back plates one after another and connecting piping.		

Table 3 − 3 Abstract of the 3 − rd case

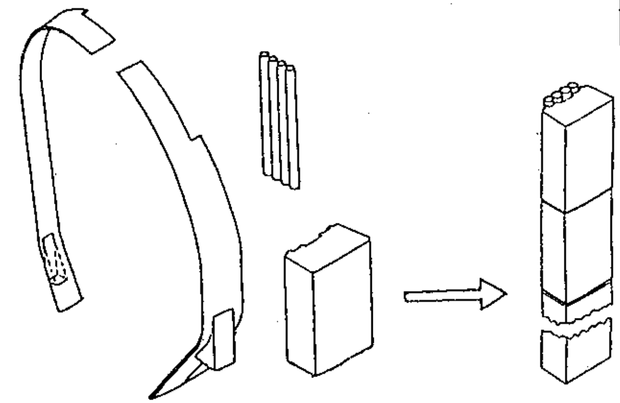
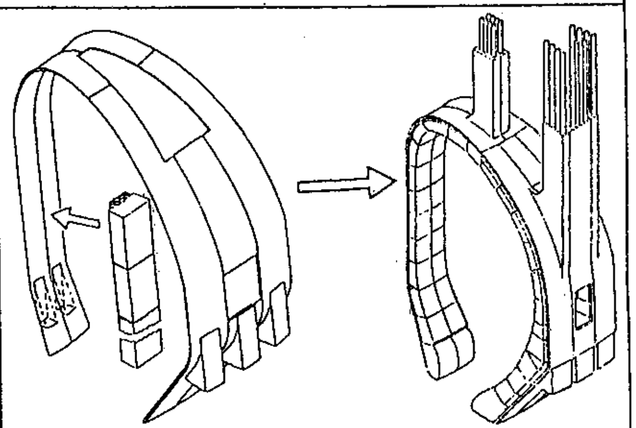
	Construction procedure		Note
Factory	① Fabricating back plates and blanket modules and piping, respectively. ② Fixing one segment of blankets on a fixture, temporarily.		
Site	① Assembling and welding of only back plates at first. ② Attaching blanket modules to back plates with the fixture for one segment.		

Table 3 − 4 Main technical subjects for three cases

		The 1-st case	The 2-nd case	The 3-rd case
New equipment and apparatus to be developed	factory	○Large scale HIP apparatus ○3-D NC-machine, remote control of welding apparatus ○Welding apparatus for the inside of 3-D bent pipe	○Large scale HIP apparatus ○3-D NC-machine, remote control of welding apparatus ○Welding apparatus for the inside of 3-D bent pipe	○Large scale HIP apparatus ○3-D NC-machine, remote control of welding apparatus ○Welding apparatus for the inside of 3-D bent pipe ○Temporary cramp jig
	site	○Remote control of welding apparatus ○NDT apparatus	○Blanket module fitting jig ○Remote control of welding apparatus ○Welding apparatus for the inside of 3-D bent pipe ○NDT apparatus	○Remote control of welding apparatus ○Welding apparatus for the inside of 3-D bent pipe ○NDT apparatus
Technical problems		○Deformation of blanket ◎Temporary fitting jig for B.P. welding ◎Welding method for B.P. in small area (TIG, EB or LASER) ◎Welding deformation of thick plates with blankets assembled on B.P. ○NDT in V.V. ○Joining of Be onto FW	○Deformation of blanket ○Temporary fitting jig for B.P. welding ◎Temporary fitting jig or fitting by remote handling equipment for blanket welding in V.V. ◎Welding method for blanket in small area (TIG or LASER) ○Welding deformation of thick plates ○NDT in V.V. ○Joining of Be onto FW	○Deformation of blanket ○Temporary fitting jig for B.P. welding ◎Temporary fitting jig for blanket welding in V.V. ◎Welding method for blanket in small area (TIG or LASER) ○Welding deformation of thick plates ○NDT in V.V. ○Joining of Be onto FW

Table 3 - 5 Comparison with characteristics of three cases

	The 1-st case	The 2-nd case	The 3-rd case
Merit	○Easier module assembly and QC ○Less jigs on site ○Shorter fabrication term on site	○Easier repair on site ○Easier transportation ○Easier B.P. fabrication and QC ○Shorter manufacturing term in the factory	○Less numbers of access into V.V. than the 2nd case ○Easier B.P. fabrication and QC
Demerit	○Longer manufacturing term in the factory ○Transportation of heavy products ○Fixture for welding of B.P.	○A lot of times to access into V.V. ○Increase of manufacturing steps in V.V. ○Longer fabrication term on site	○Need of temporary fixture for modules in the factory ○Prevension of deformation during transportation

Table 4 − 1 Comparison of Welding Process

Process	TIG Welding	MIG Welding	Electron Beam Welding (EBW)	Laser Beam Welding
Edge preparation	single U or H groove	single V, U or H groove	square groove with small gap	square groove with small gap
Maximum depth of penetration by flat position	> 100mm (build-up)	> 100mm (build-up)	150 mm/pass by 100kW EBW	25 mm/pass by 20kW CO_2 LB.
Weld time ratio (30mm penetration by vertical position)	100	15	1	2
Weldability by vertical position	feasible	feasible	feasible	feasible
Welding distortion	large, but reducible by narrow-gap welding	large, but reducible by narrow-gap welding	small	small
Features	- size of welding torch is smaller than MIG and EBW	-high welding speed - penetration/pass is larger than TIG	- high welding speed - small deformation	- high welding speed - small deformation
Key issues of process	- requires welding jigs to llimit welding distortion	- requires welding jigs to llimit welding distortion -elimination of excess metal	- weldability of overhead position - severe gap control - requires backing plate for protection	- weldability of thick plate by Iodine/YAG - severe gap control - requires backing plate for protection
Technical issues for the application to back plate welding	- position control of welding torch - space for welding jigs	- position control of welding torch - space for welding jigs	- local vacuum less than 0.1 Torr - development of compact EB gun - gap control - welding of backing plate	- weldability of thick plate - gap control

Table 4 − 2 Candidate Welding/cutting Process for Blanket supportleg

Process	**Welding process**		**Cutting process**
Candidate process	Narrow gap TIG welding	Iodine/YAG laser	Iodine/YAG laser
Advantage	- existing technology is almost directly applicable	- small welding distortion - high welding speed - high accessibility by flexible optical fiber and compact beam head, basic concept is shown in the figure	- existing technology is almost directly applicable - common head is available both welding/cutting
Weldability/cutting capacity of thick plate by vertical position	- feasible, basic concept is shown in the figure	- beam power is not sufficient to weld thick plate	- feasible but cutting speed depends on beam power
Disadvantage	- low welding speed	-	-
Technical issues of the process	- Welding distortion without welding jigs - positioning/gap controll	- Thick plate welding by increasing beam power - severe positioning and gap control	- reweldability of cutting surface without machining
Technical issuesto be solved by future R&D	- No problem	- same as above - remotization - weldability with filler metal	- same as above
Total Feasibility	- Feasible - Welding distortion can be manageable/ acceptable	Feasibility depend on gap controll and R&Ds	- No problem

Table 4 − 3 Candidate Welding Processes of Back Plate

Basic assembly scenario	**Case 1:** **Back plate welding on site without BM (sufficient space for welding jigs)**		**Case 2:** **1.Pre-assembling of blanket module to back plate** **2. Back plate welding on site**	
Candidate process	Narrow gap TIG welding	EB welding	Narrow gap TIG welding	EB welding
Advantage	- existing technology is almost directly applicable than EB welding	- existing technology directly applicable - small welding distortion - high welding speed	- existing technology is almost directly applicable than EB welding	- small welding distortion than narrow gap TIG - high welding speed
Weldability by overhead position	- feasible	- feasible up to 30 mm-thickness	- feasible	- feasible up to 30 mm-thickness
Disadvantage	- low welding speed	- requires local vacuum less than 0.1 Torr or evacuation of VV	- low welding speed	- requires local vacuum less than 0.1 Torr or evacuation of VV
Technical issues of the process	- Welding jigs to limit welding distortion - gap controll	- weldability of thick plate > 30 mm by overhead position - severe gap control - requires backing plate for protection	- Welding distortion without jigs - gap controll	- Feasibility of the beam injection through the gap between blanket modules (~ 20mm)
Technical issuesto be solved by future R&D	- No problem	- same as above	- same as above	- same as above
Feasibility of BP welding	- No problem - Welding distortion can be acceptable and manageable	Feasibility depend on gap controll and small R&D	- No problem in process - depends on positioning of BP	Feasibility depend on gap controll and R&Ds

Table 4 − 4 Comparison of Cutting Process

Process	Water jet (WJ) with abrasive grains	Laser beam (LB) cutting	Plasma cutting	Mechanical cutting
Cutting time ratio (SS316, 30mm^t)	5	2	1	50
Maximum plate thickness (Experience of industries and JAERI by flat position)	> 100 mm^t (Max. 300 mm^t)	~ 30 mm ^{t}(YAG) ~ 20 mm^t(CO_2) depends on beam type and beam power	> 100 mm^t (Max. 110 mm^t)	> 100 mm (Max. 30 mm^t)
Amount of disposal	large (water, chips and abrasive grains)	small (chips)	medium	large
Reweldability of cutting surface	reweldable	reweldable	not reweldable	not reweldable
Features	-no heat input	- small heat input	- high cutting speed	much experience
Key issues of process	-recovery of water, abrasive and chips - protection for penetration	- feasibility of thick plate cutting - protection for penetration	- recovery of disposal -	- recovery of disposal - life time of tools
Technical issues of application to the cutting of back plate	-recovery of water, abrasive and activated chips - protection for penetration	- feasibility of thick plate cutting - recovery of activated disposal - protection for penetration	- recovery of activated disposal - requires removal of heat affected zone for rewelding	- low possibility due to limited space to support reaction forces

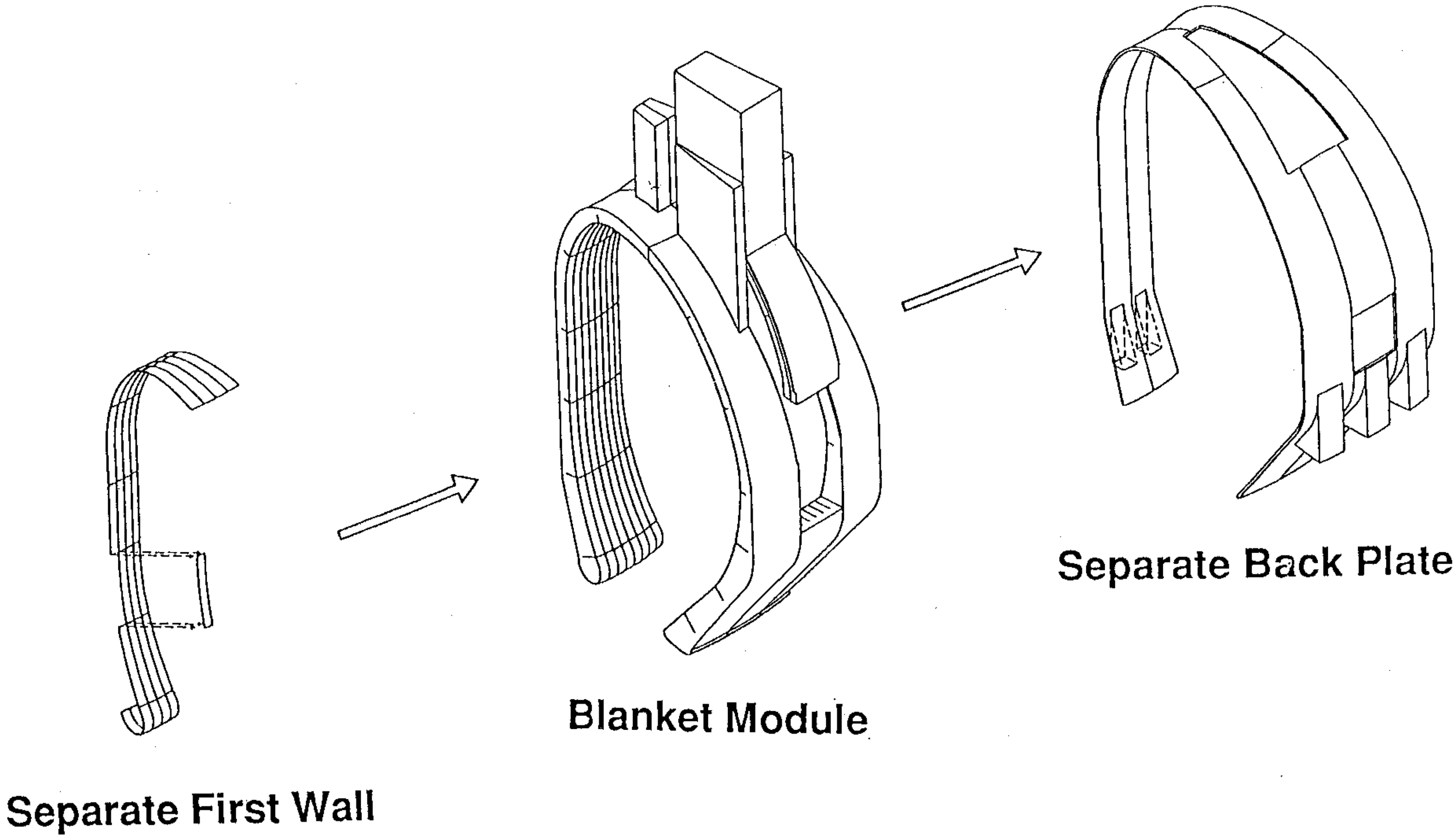


Fig.2 – 1 A schematic view of the layered blanket configuration composed of separate first walls, modular – type shielding blanket and separate back plates. Each component is cooled by individual Water line with the pressure of 2MPa and inlet／outlet temperatures of 150／200℃

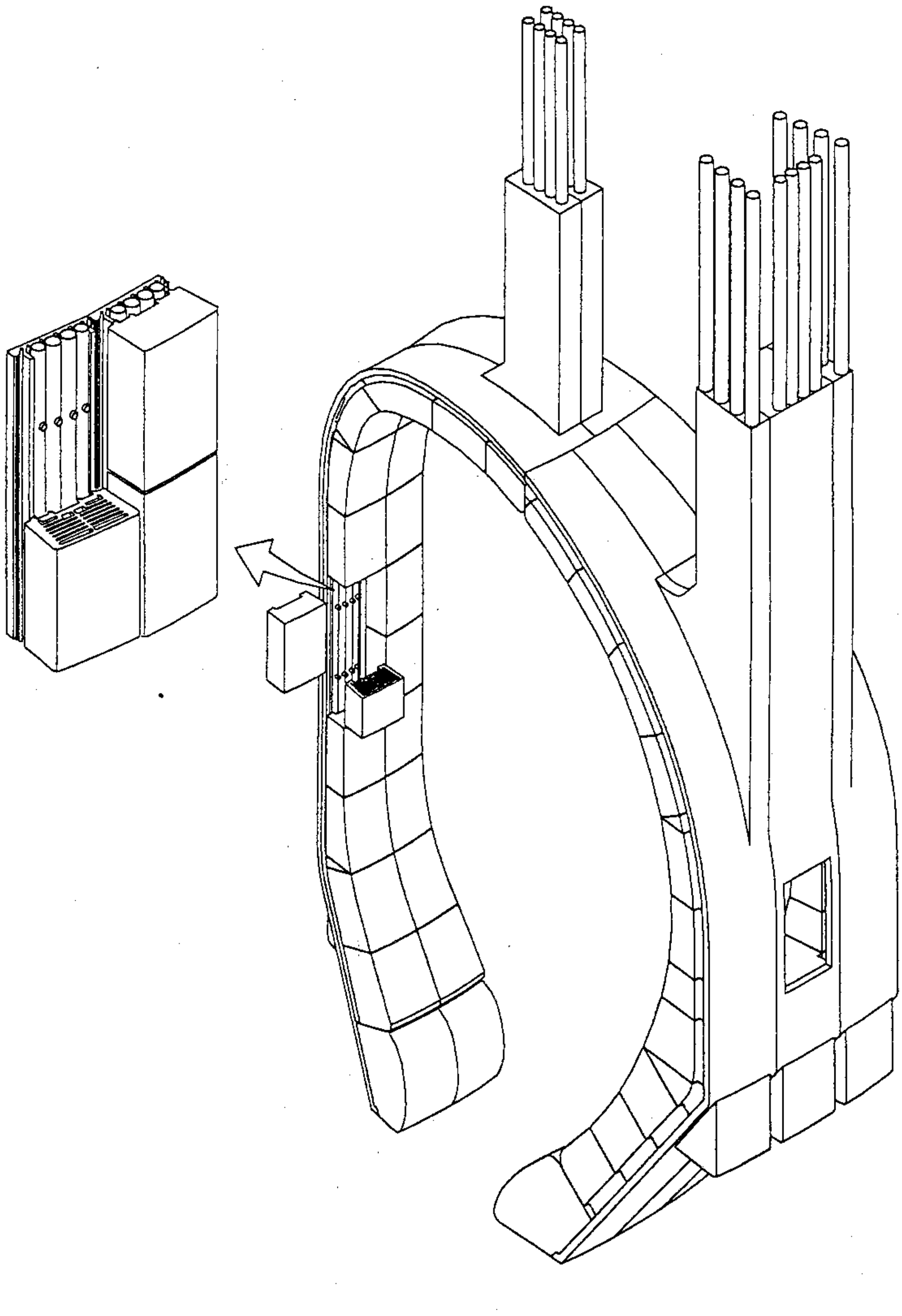


Fig.2 - 2 A bird's - eye view of the layered blanket sector
(two and three modules per sector for inboard and outboard, respectivety).

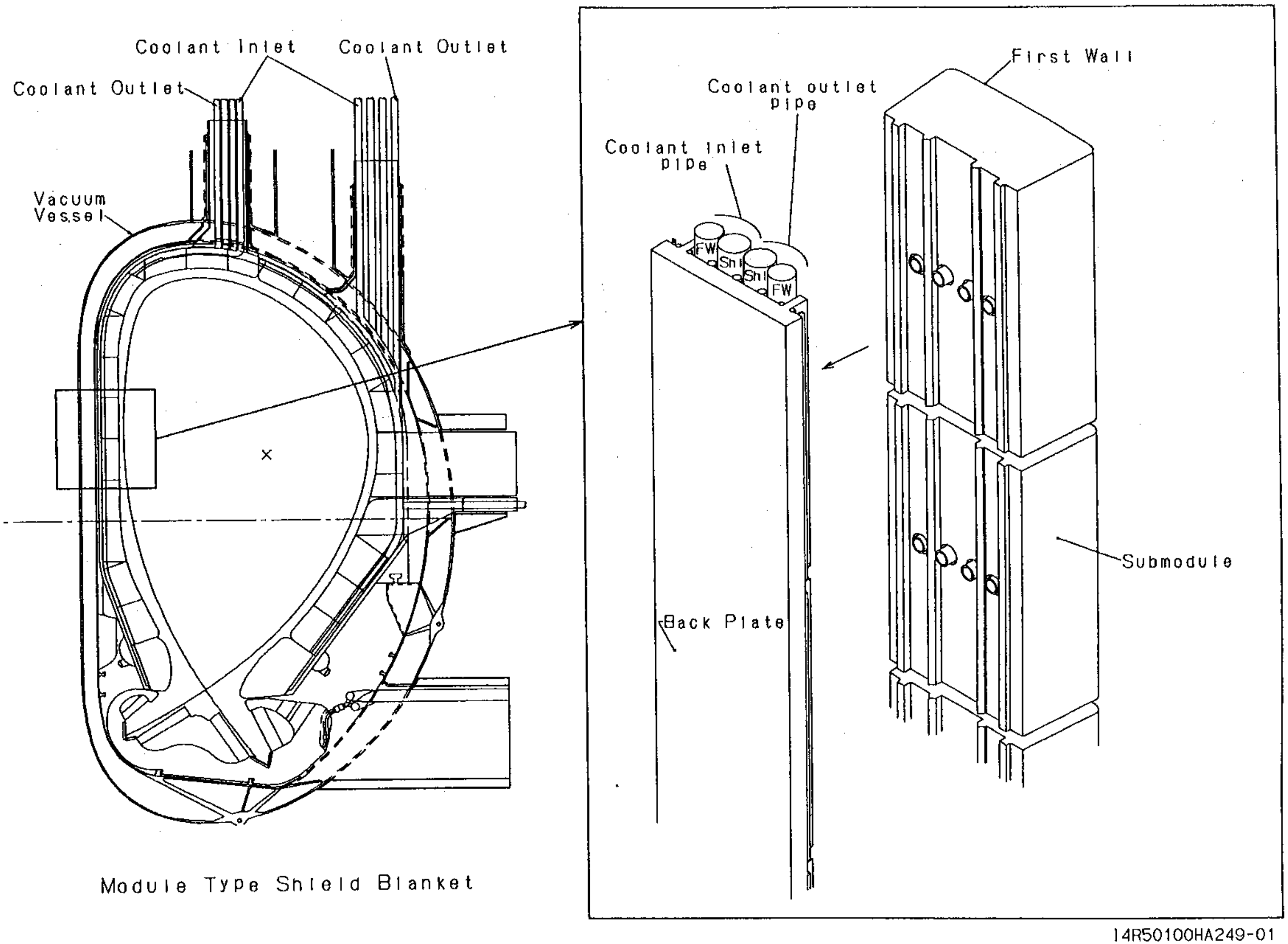


Fig.2－3 A sctematic view of the blanket module showing each component composing the blanket module.

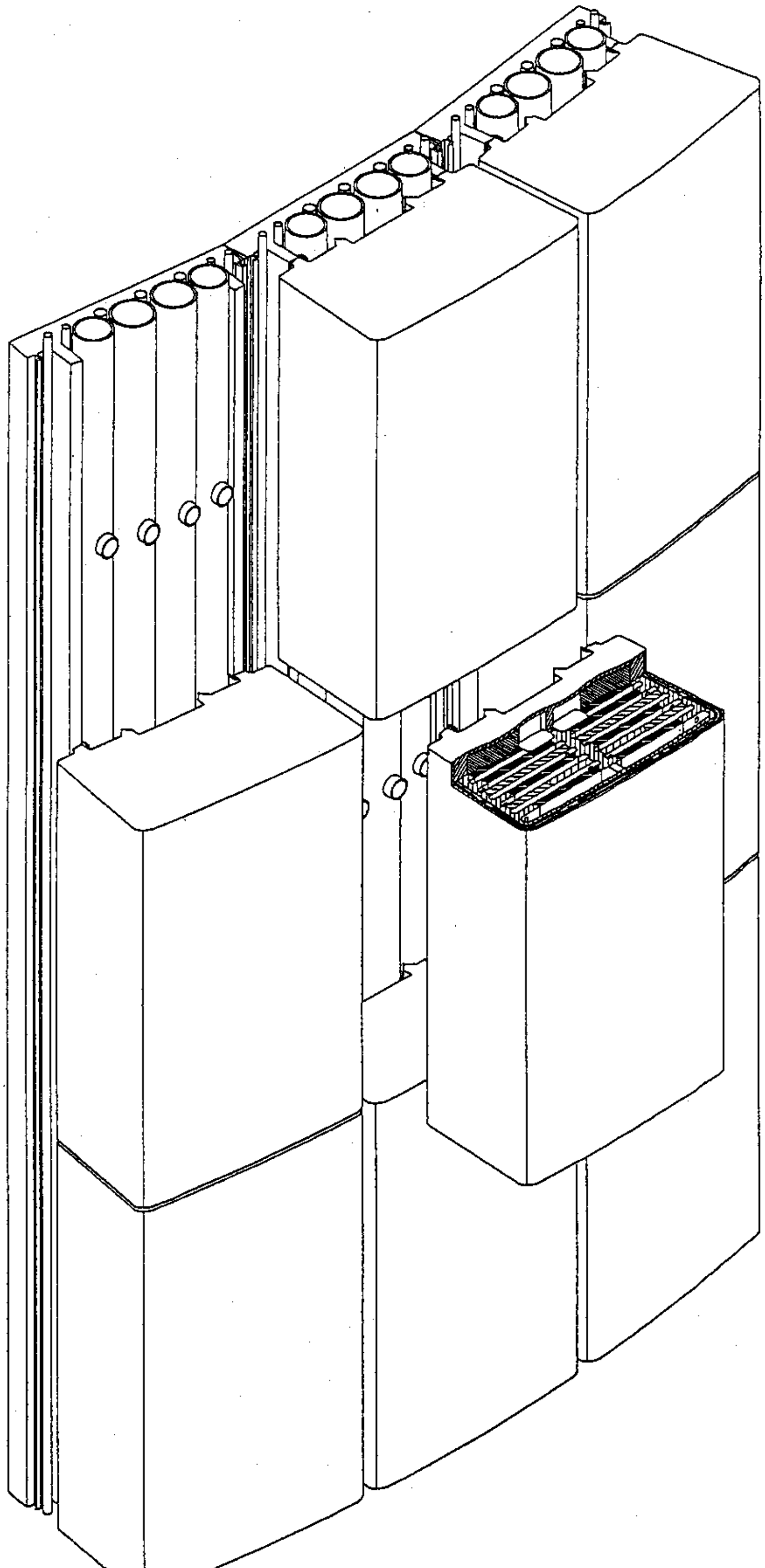


Fig.2 − 4 A zoomed − up view of a modular shieding blanket.

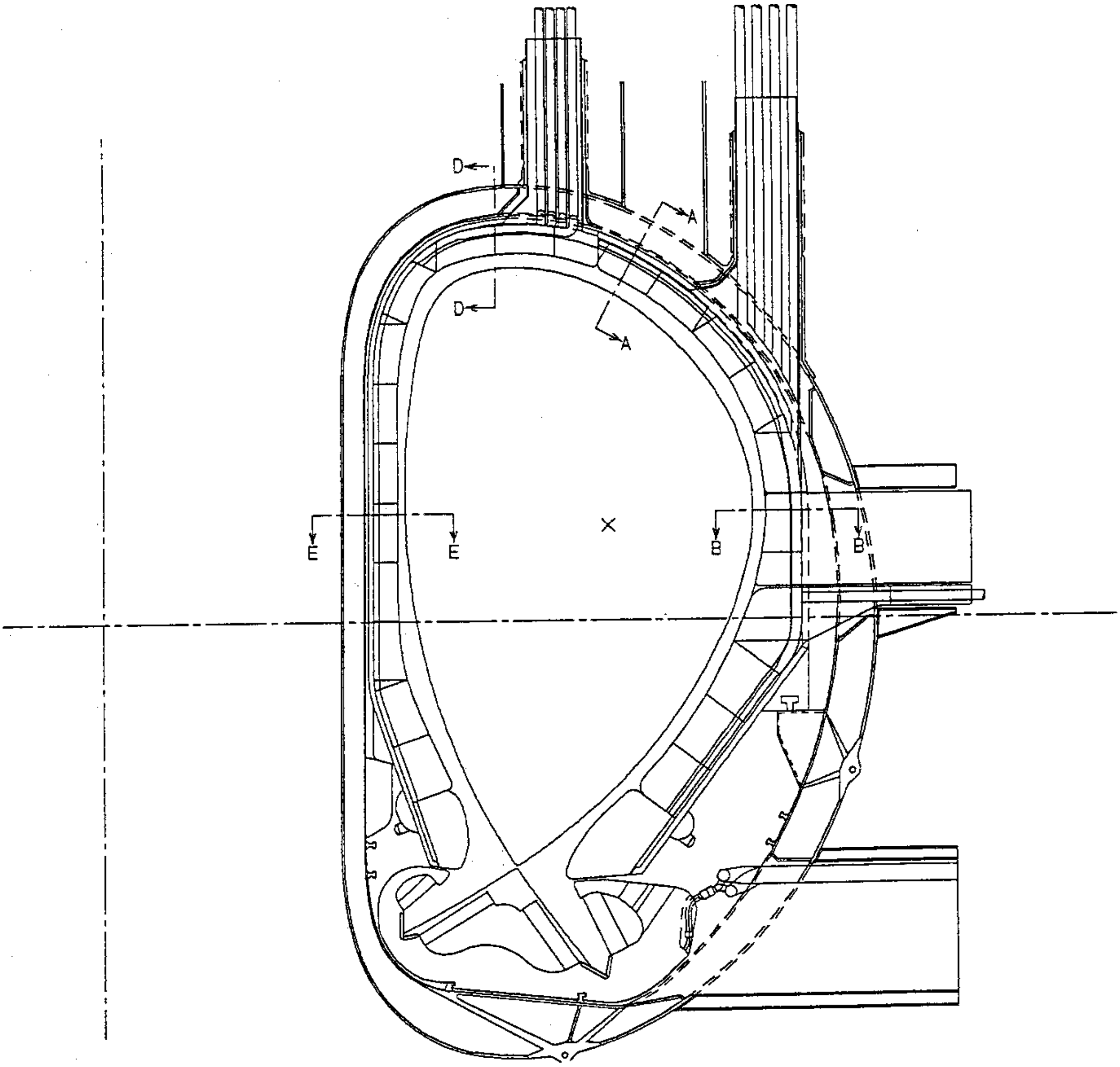


Fig.2 − 5 A lateral view of the shielding blanket. The blanket module is supported by the shelves extruding from the vacuum vessel.

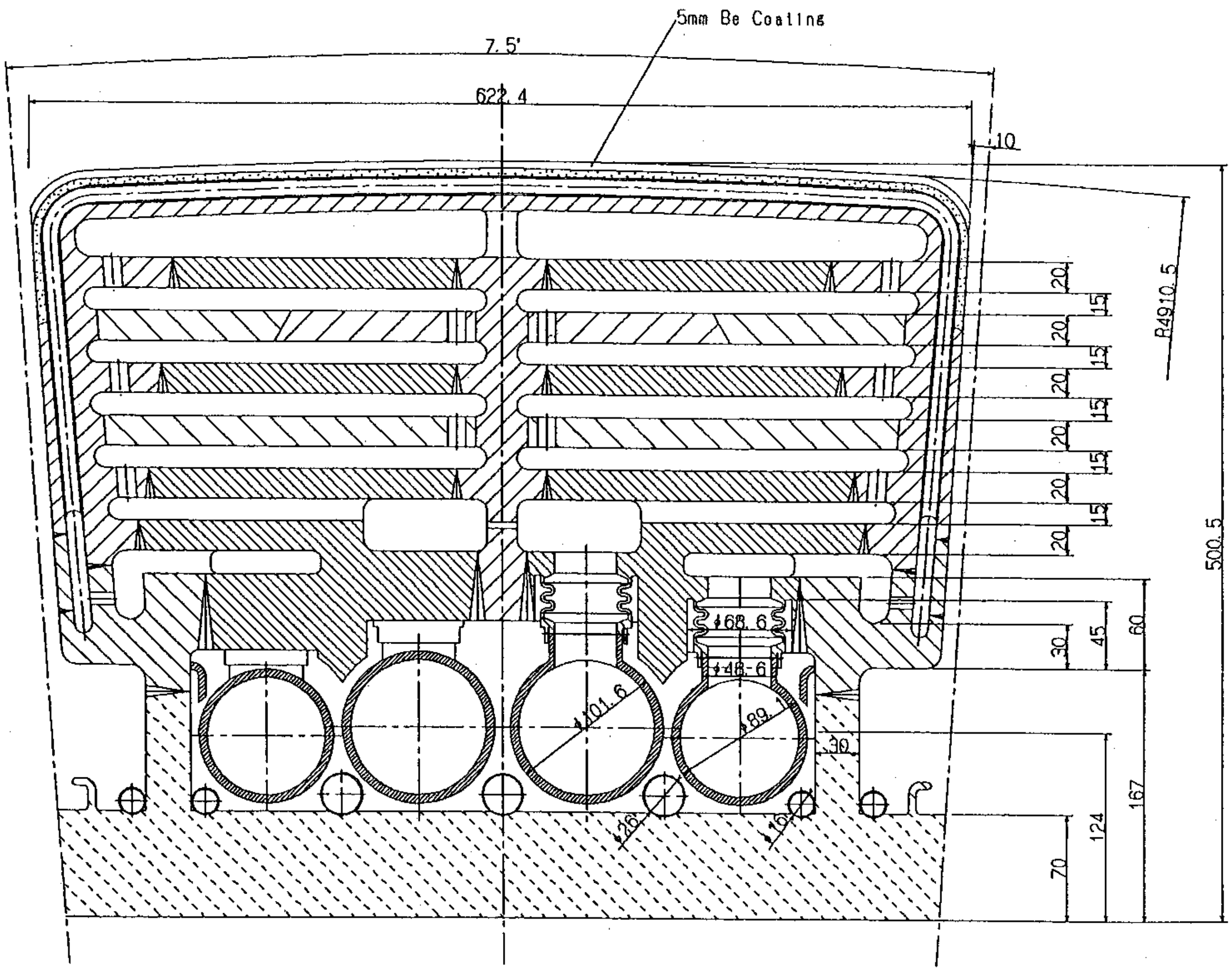


Fig.2－6 A cross sectional view of the blanket module. The blanket module is welded to the back plate by two legs. Four coolant manifolds are located between the back plate and the blanket module.

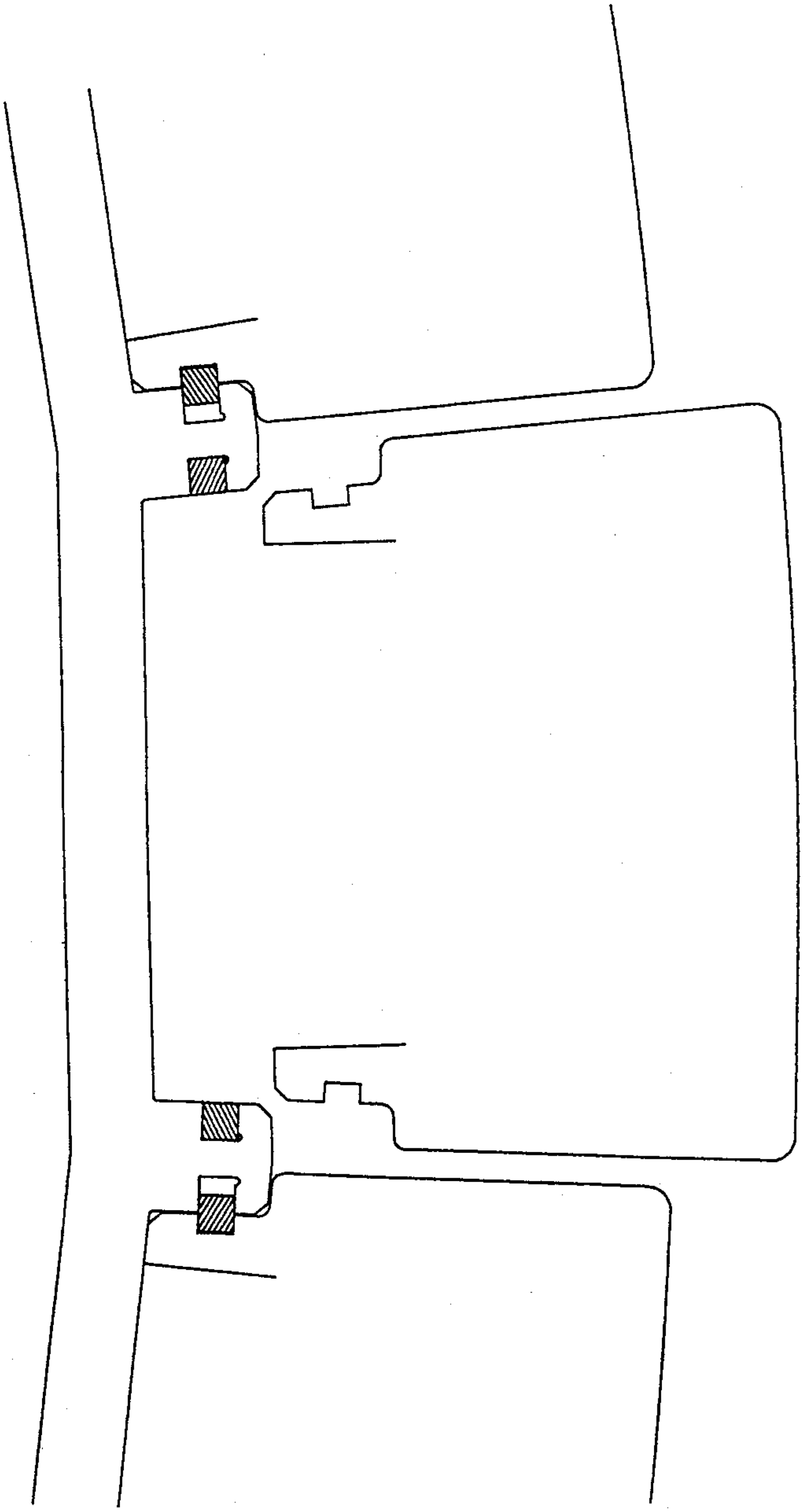


Fig.2－7 A schematic view showing the concept of mechanical locking of the blanket module by using keys.

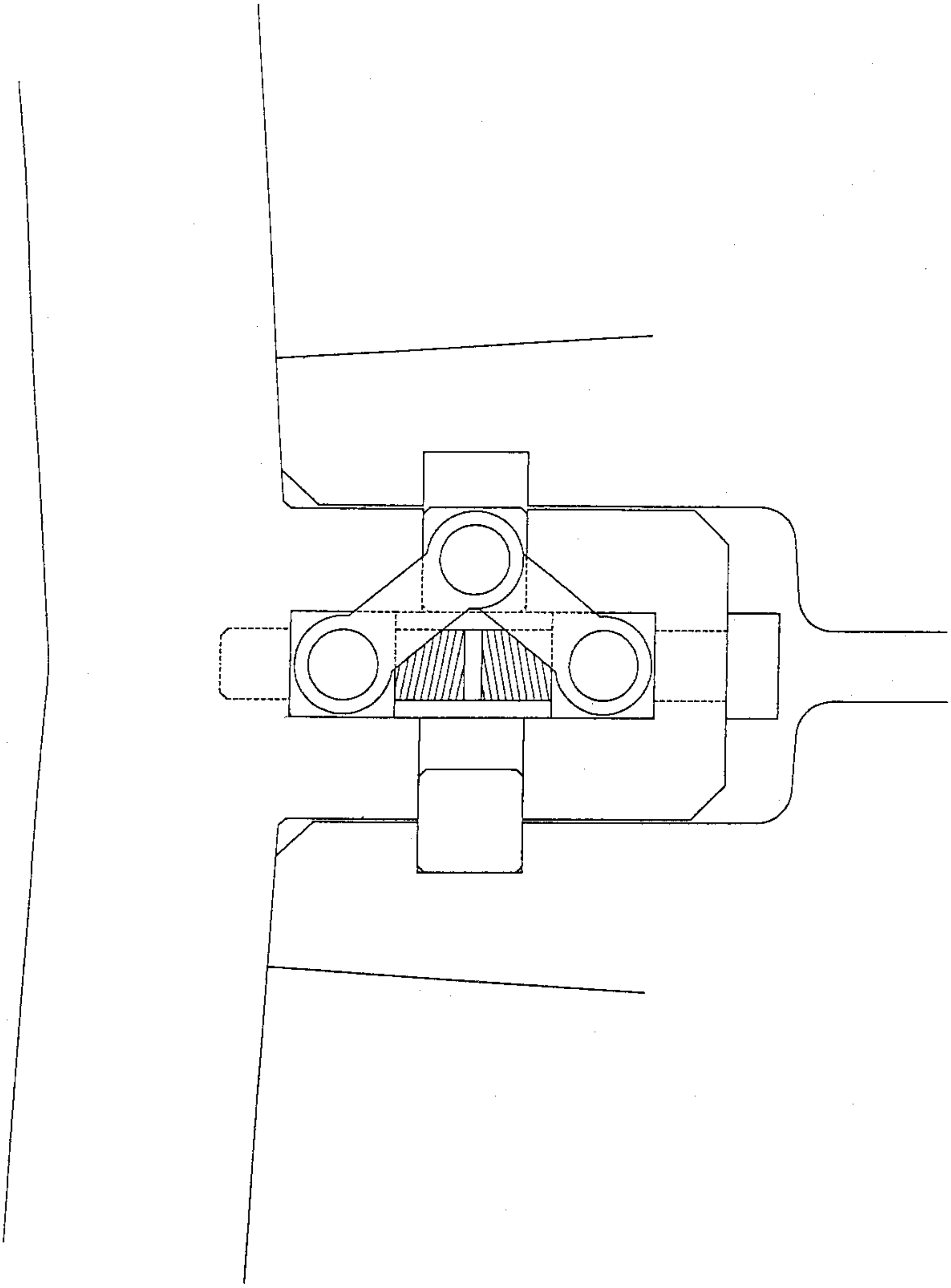


Fig.2－8 A zoomed up view of the key attaching lock and its driving mechanism composed of screw and links.

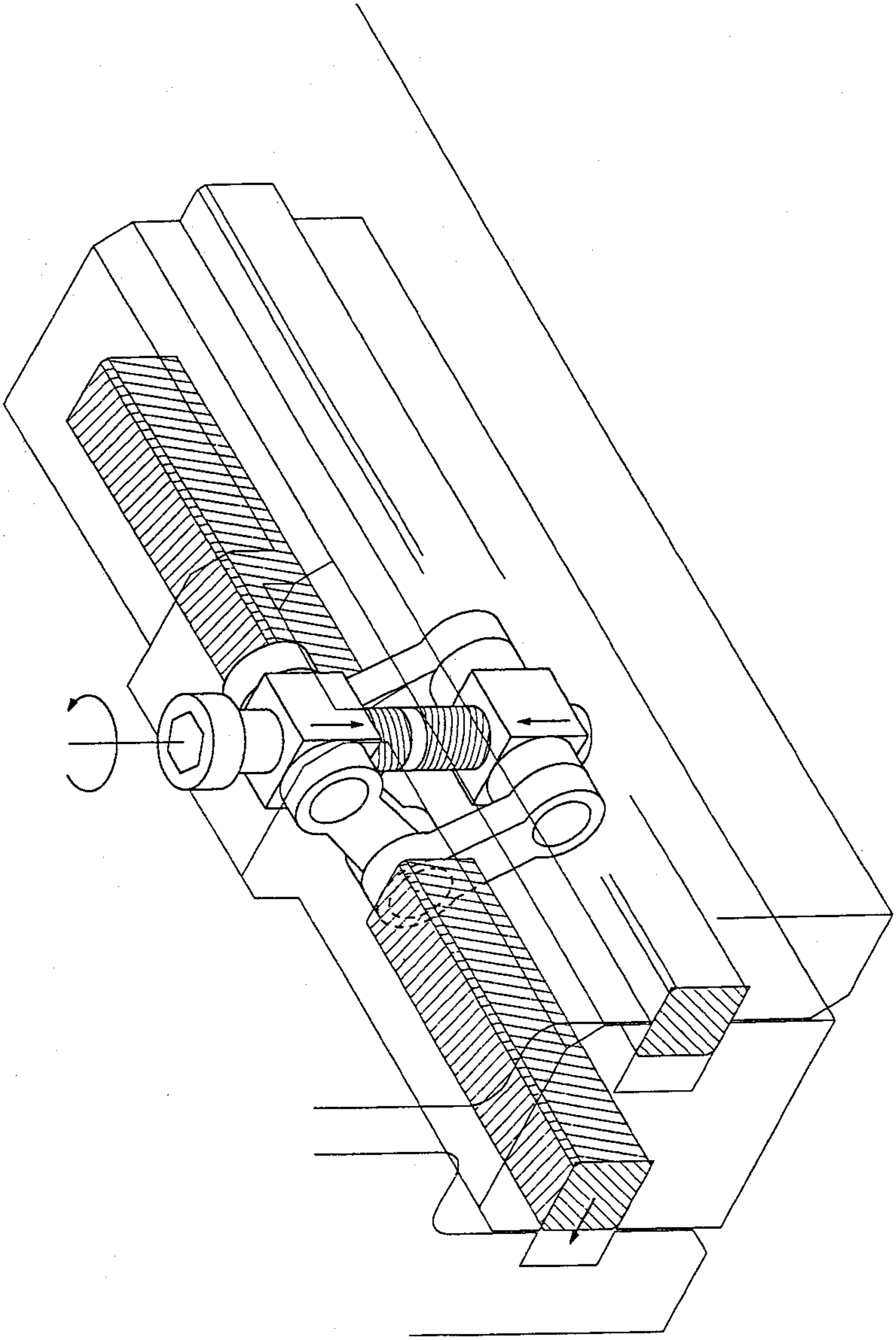


Fig.2 − 9 A three − dimensional view of the key driving mechanism, which can be driven by front access through the gap between two modules.

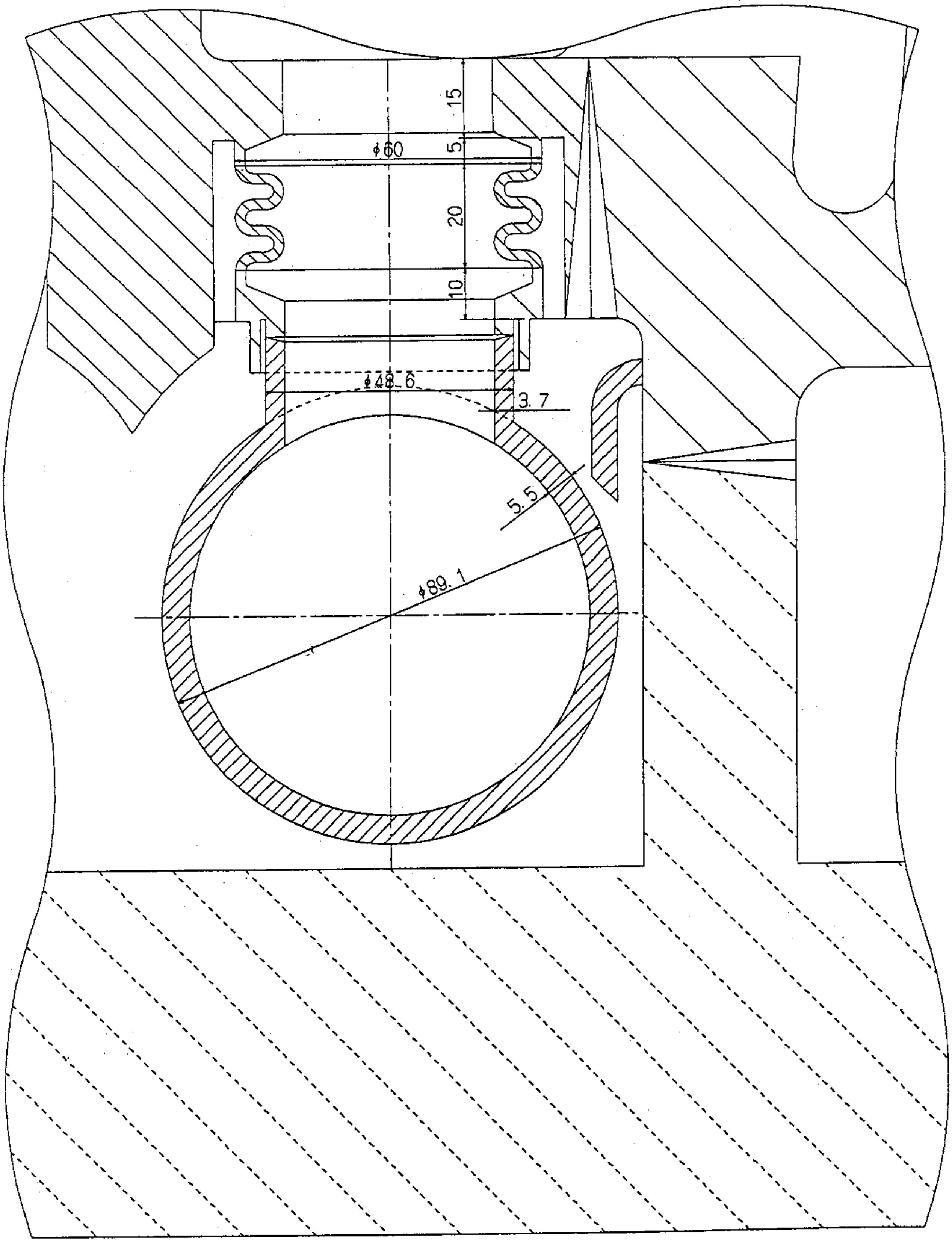


Fig.2 − 10 A zoomed up view of the cooling pipe connection. A flexible joint is provided at the branch pipe connecting the blanket module and the manifold, which can absorb the minor mis − alignment of the module.

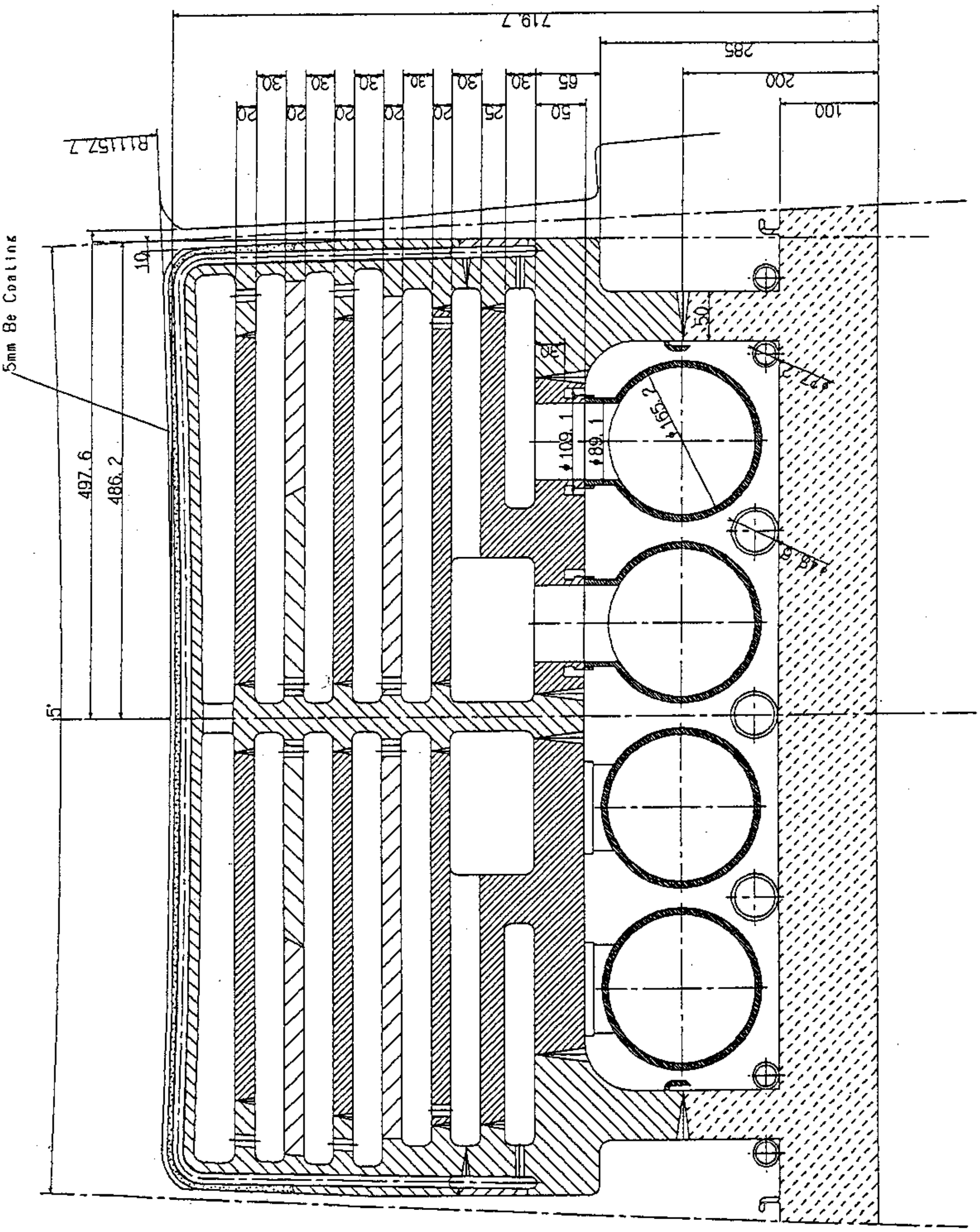
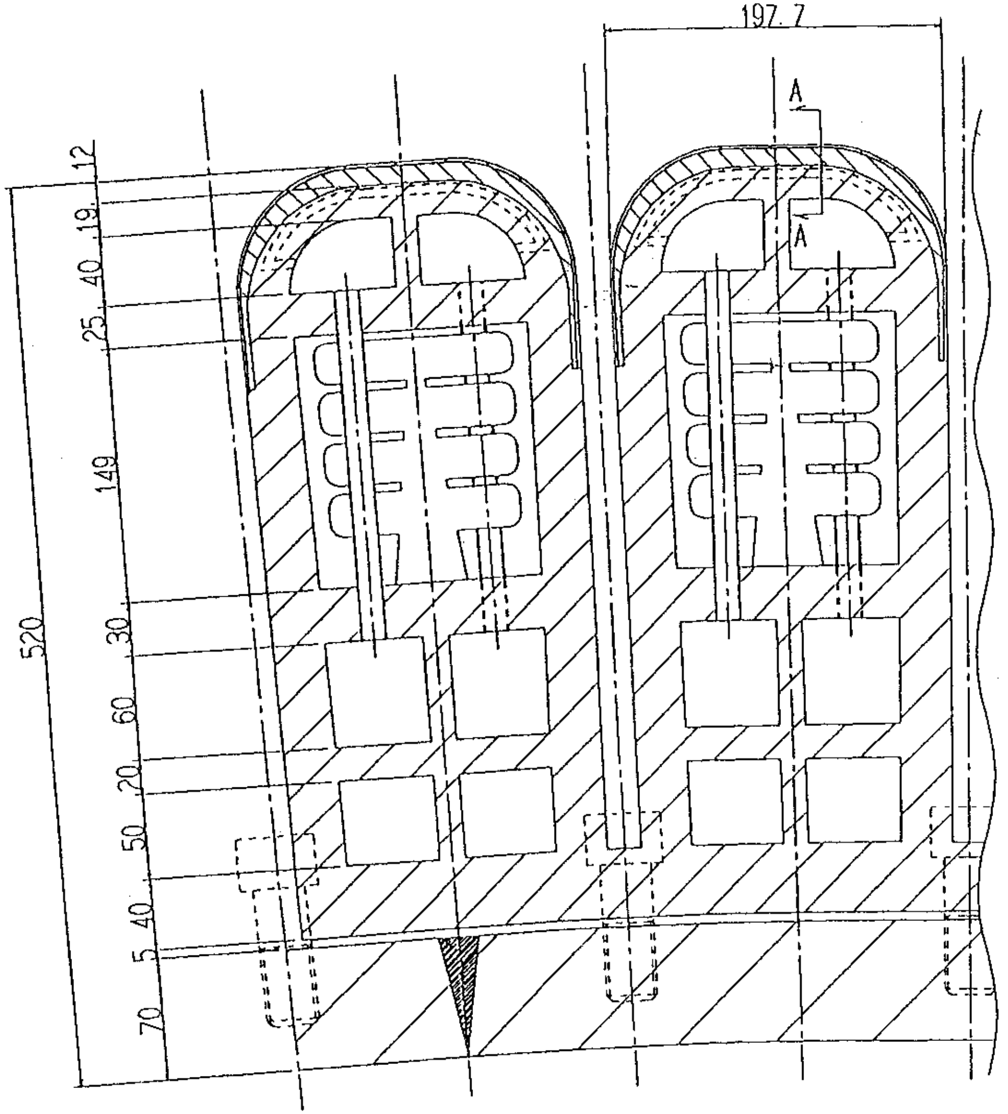
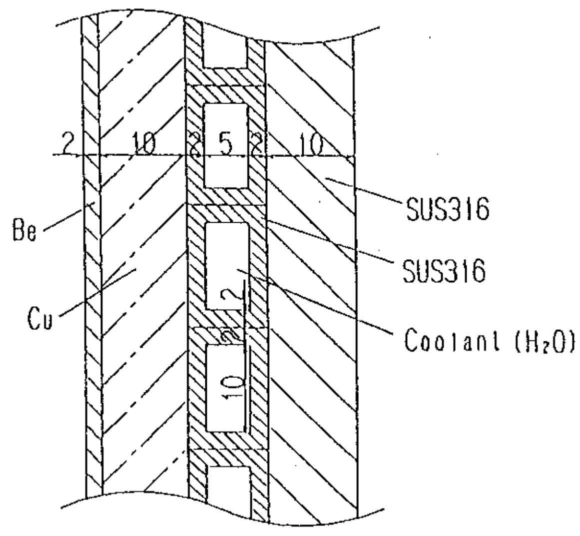


Fig.2 – 11 A cross sectional view of the outboard blanket module, showing a tepered side wall to allow radial motion in case of installation and maintenance.



Blanket Module fixed to Saparate Back Plate



Cross Section of First Wall (A-A)

Fig.2 − 12 A cross sectional view of the separately - cooled first wall integrated with the blanket module (where old version of the blanket module is shown).

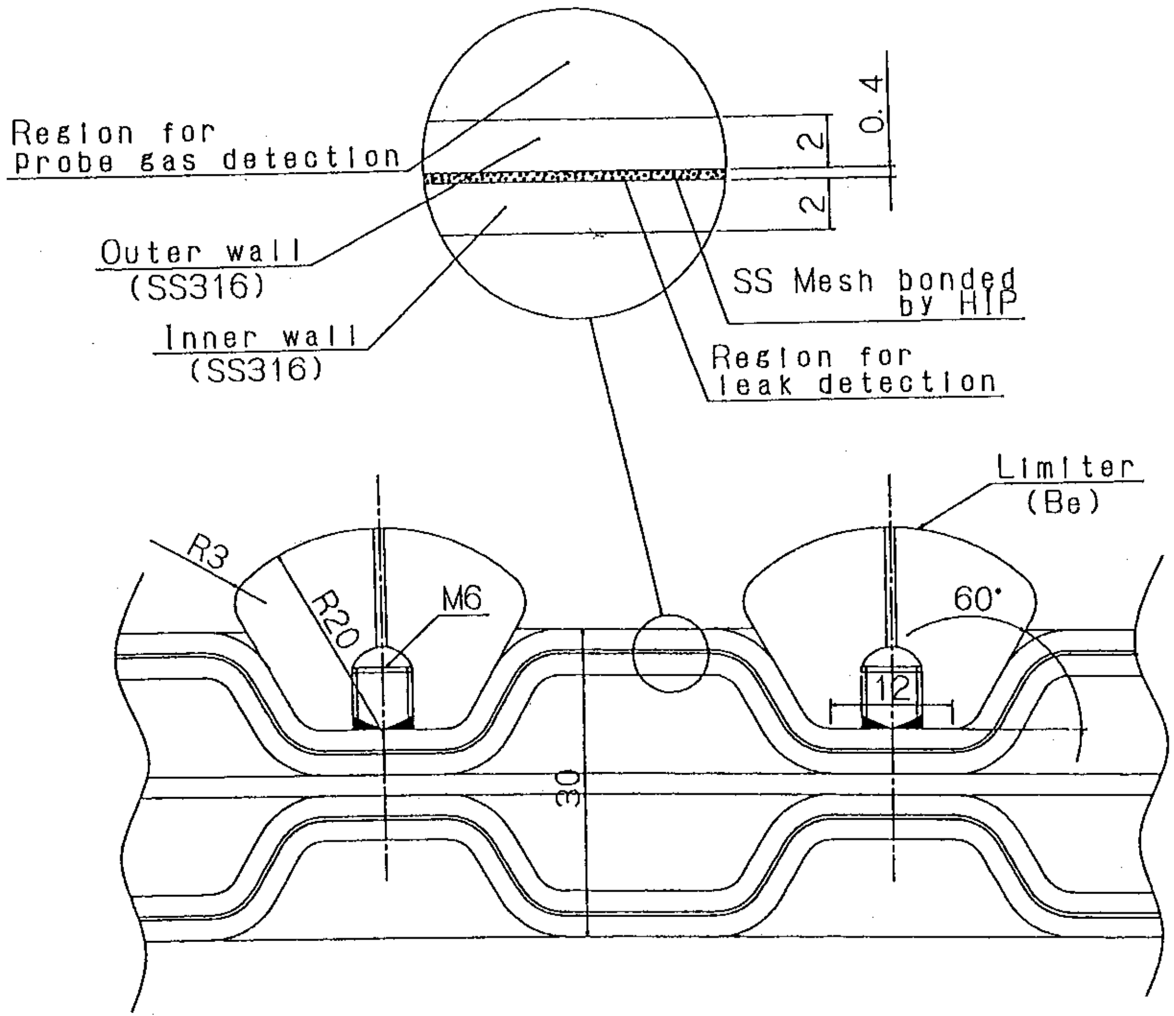


Fig.2 - 13 A cross sectional view of separately cooled and independently demountable first wall panel made of double - walled fail - safe quilting structure. Double - walled structure sandwiching a metallic mesh enables in - service inspection, resulting no water leakage as well as fracture of the first wall. Quilting panel structure can withstand high heat load and large EM loads, and it is bolt connected to the blanket module.

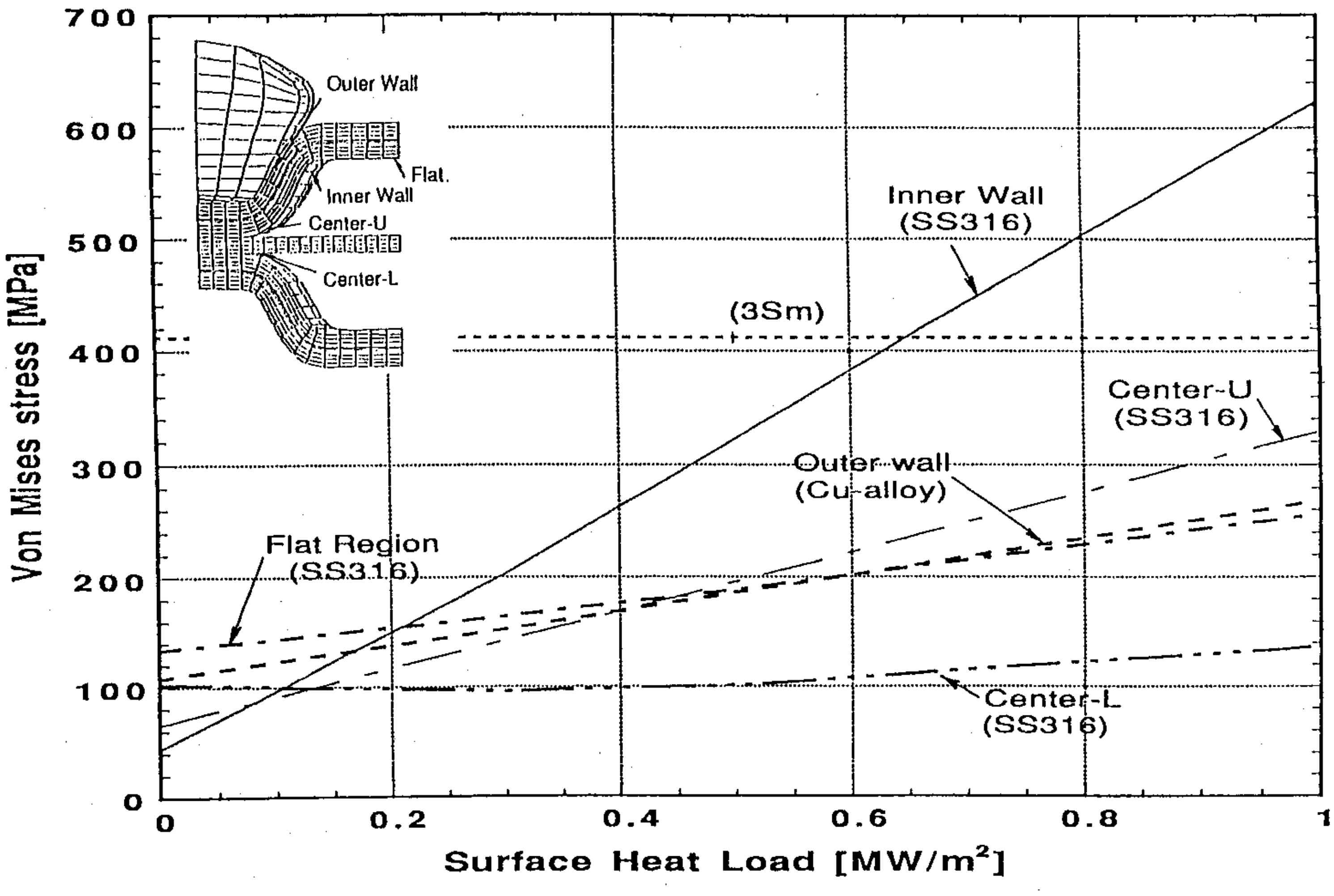


Fig.2 − 14 Von Mises stress in double − walled separate first wall of Cu − alloy and SS316 as a function of surface heat load (inner pressure : 2MPa).

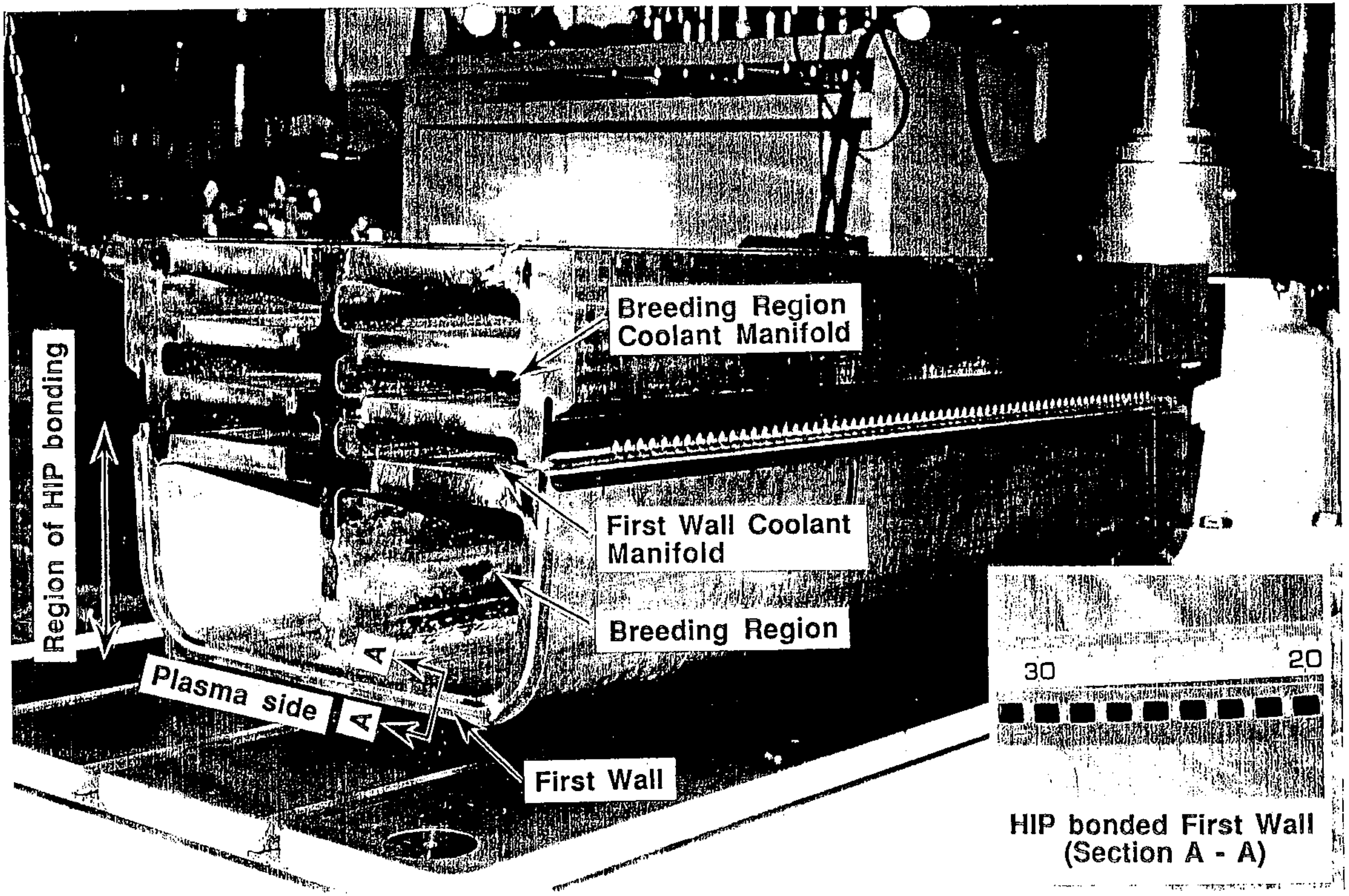


Fig.3－1 A 1／2－scaled mockup of the blanket box structure fabricated by HIP bonding.

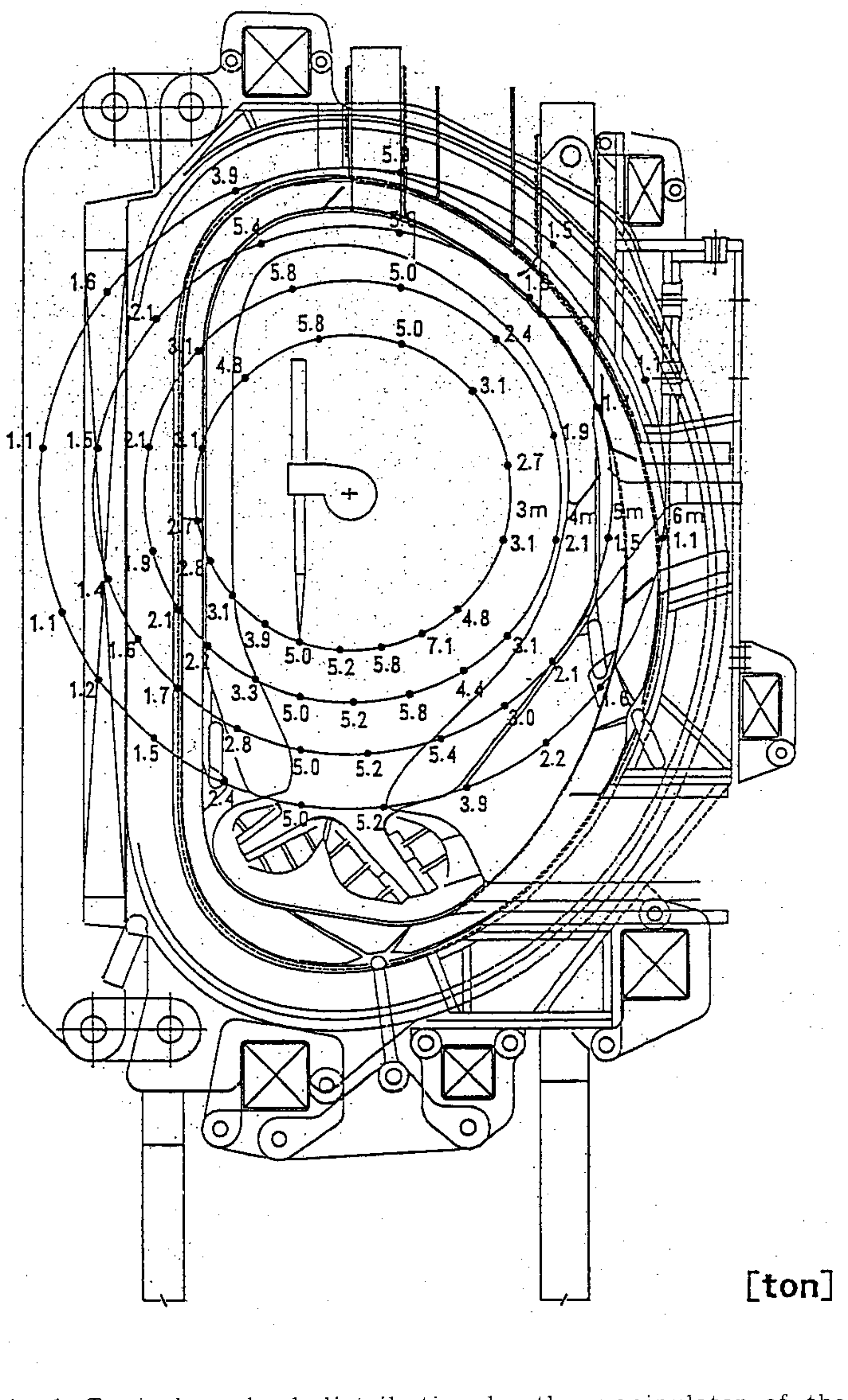


Fig.4 − 1 Typical payload distribution by the manipulator of the 5 − ton − class in − vessel transporter.

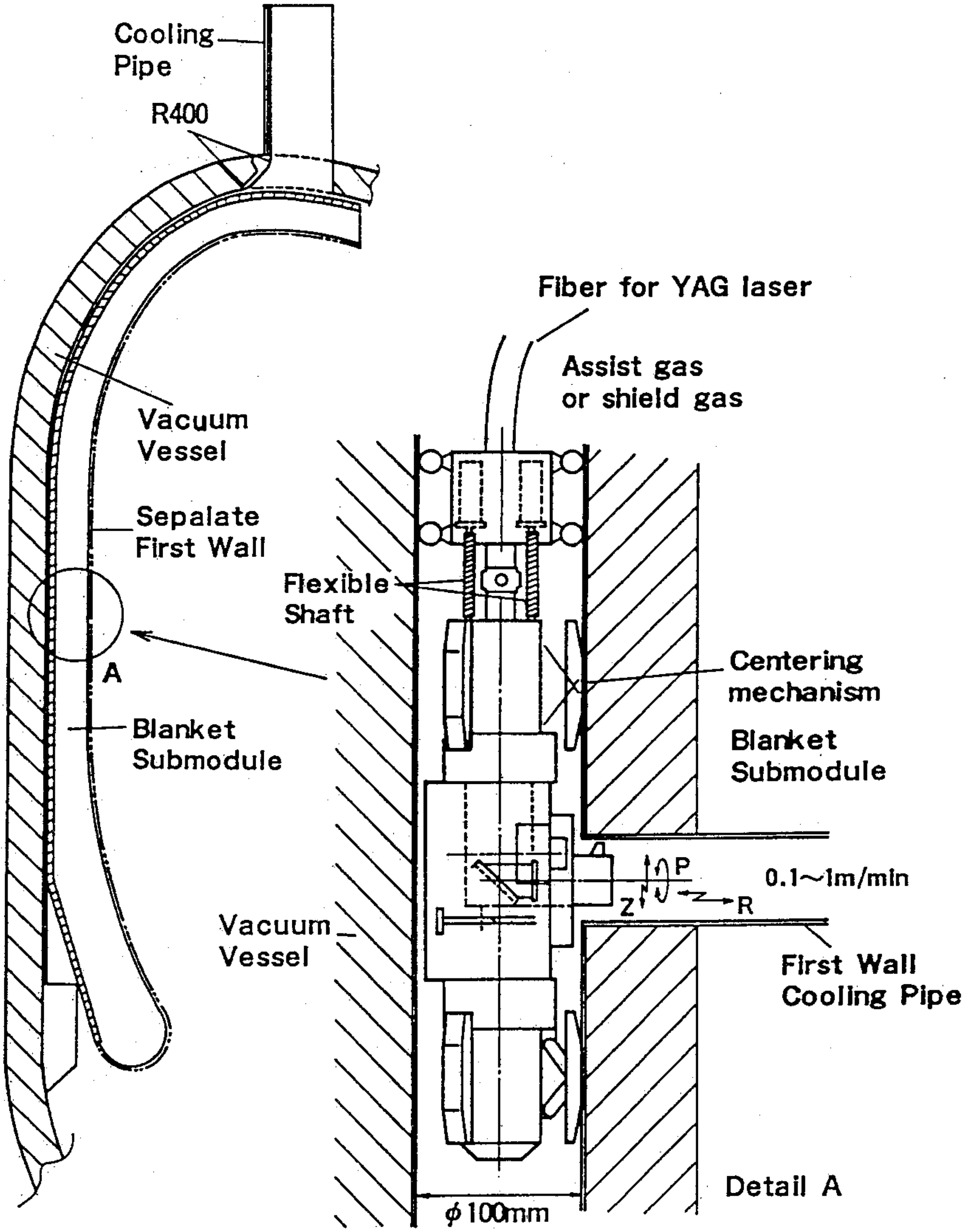


Fig.4－2 Concept of processing head of YAG laser internal－access pipe cutting／welding equipment.

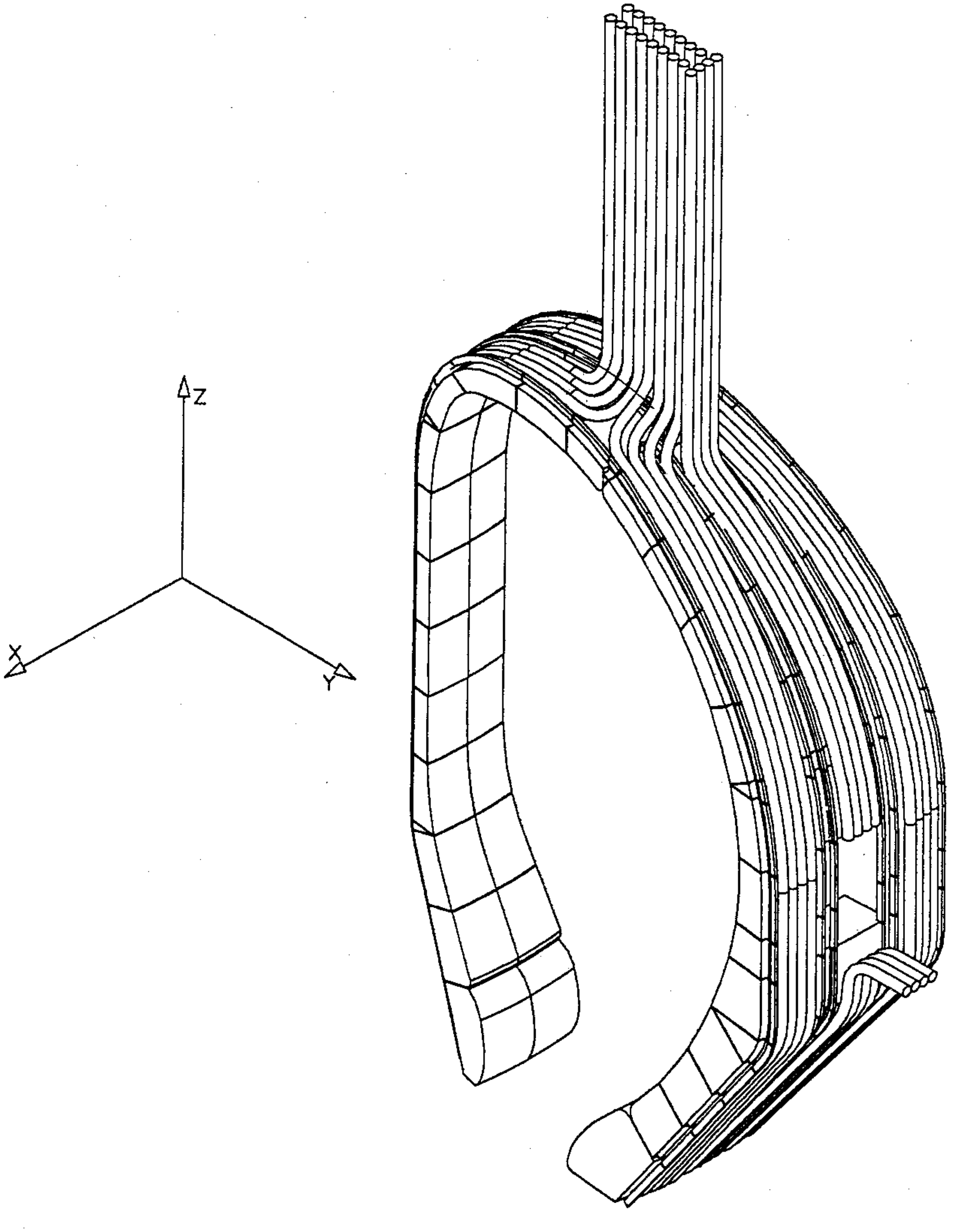


Fig.4 − 3 Three dimensional piping layout for the blanket module.
Piping route is fixed with the bending radius larger than 400mm.

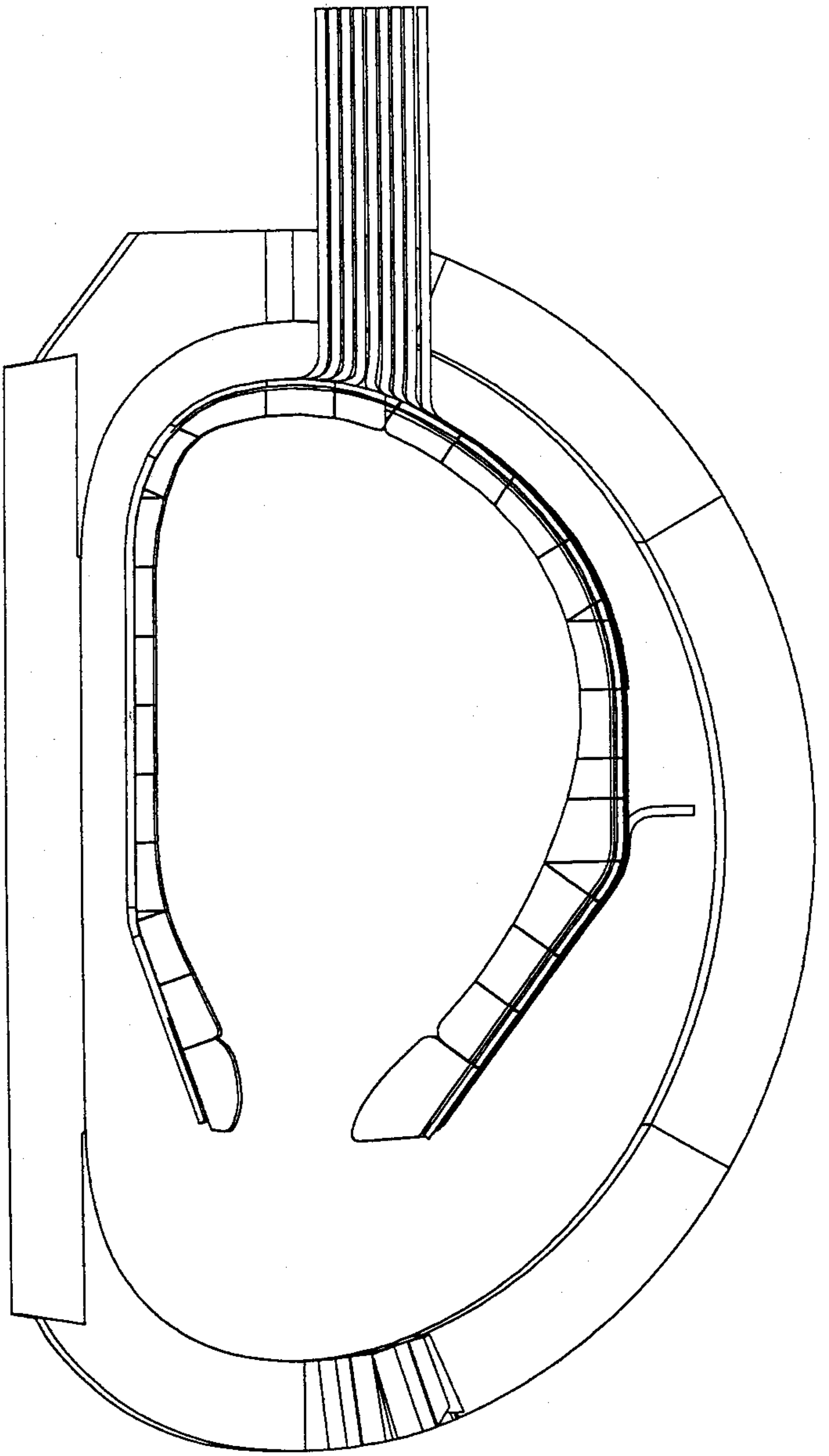


Fig.4 − 4 Lateral view of piping layout for the blanket module.

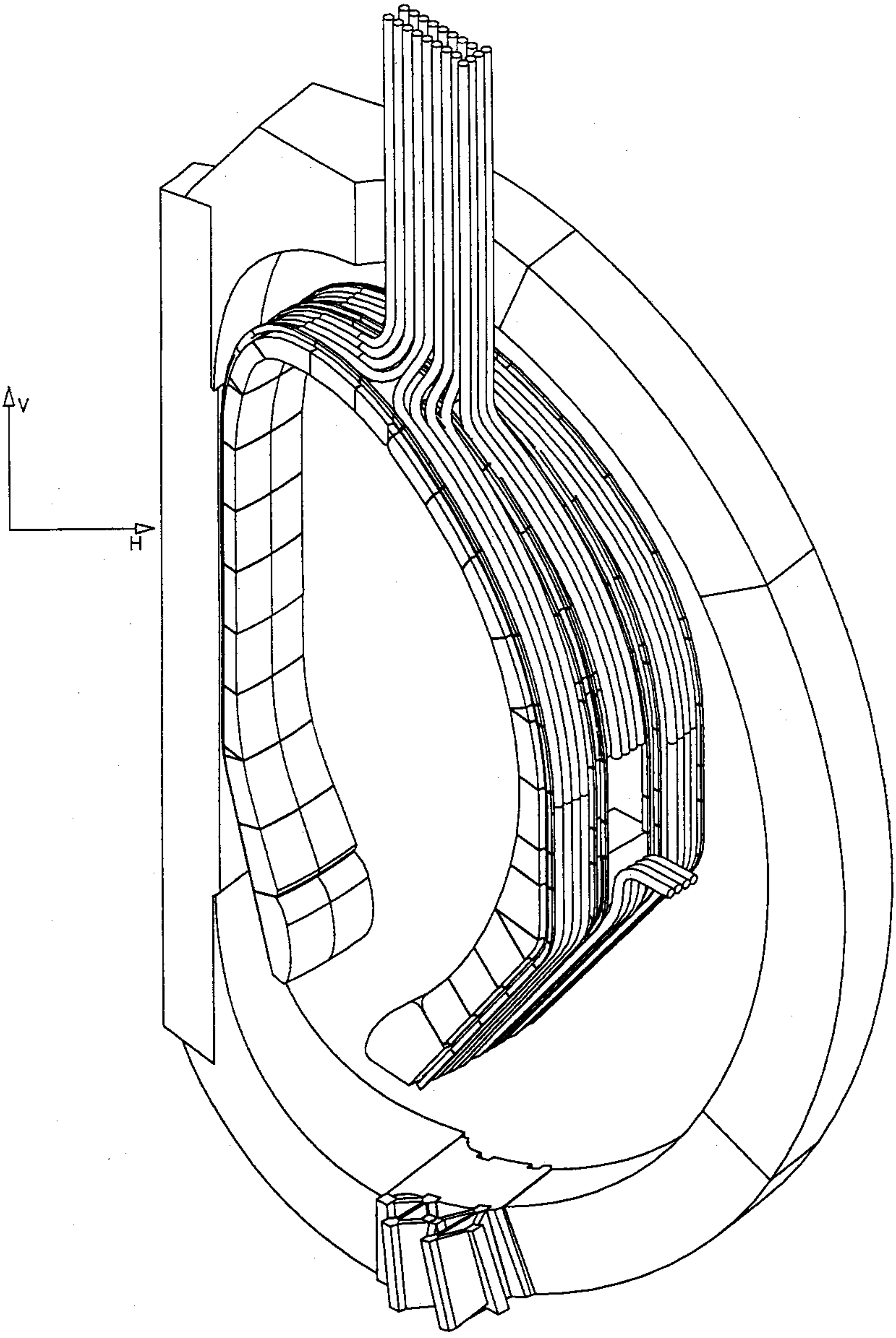


Fig.4 − 5 Relationship between piping route of the blanket module and the toroidal field coils.

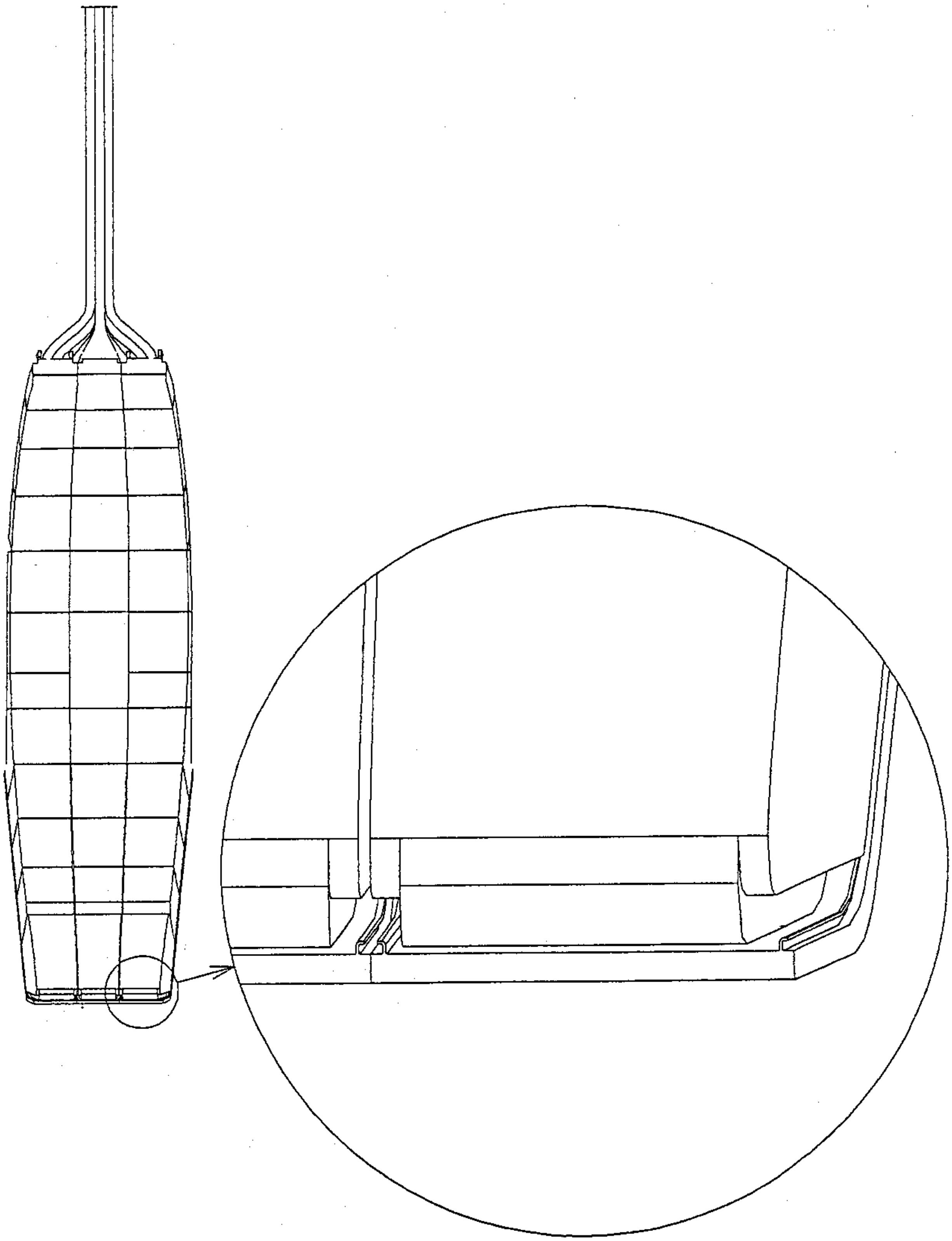


Fig.4 − 6 One possible solution for the access route of the on − site cutting／welding machine head for the blanket module legs ; from the bottom of the blanket.

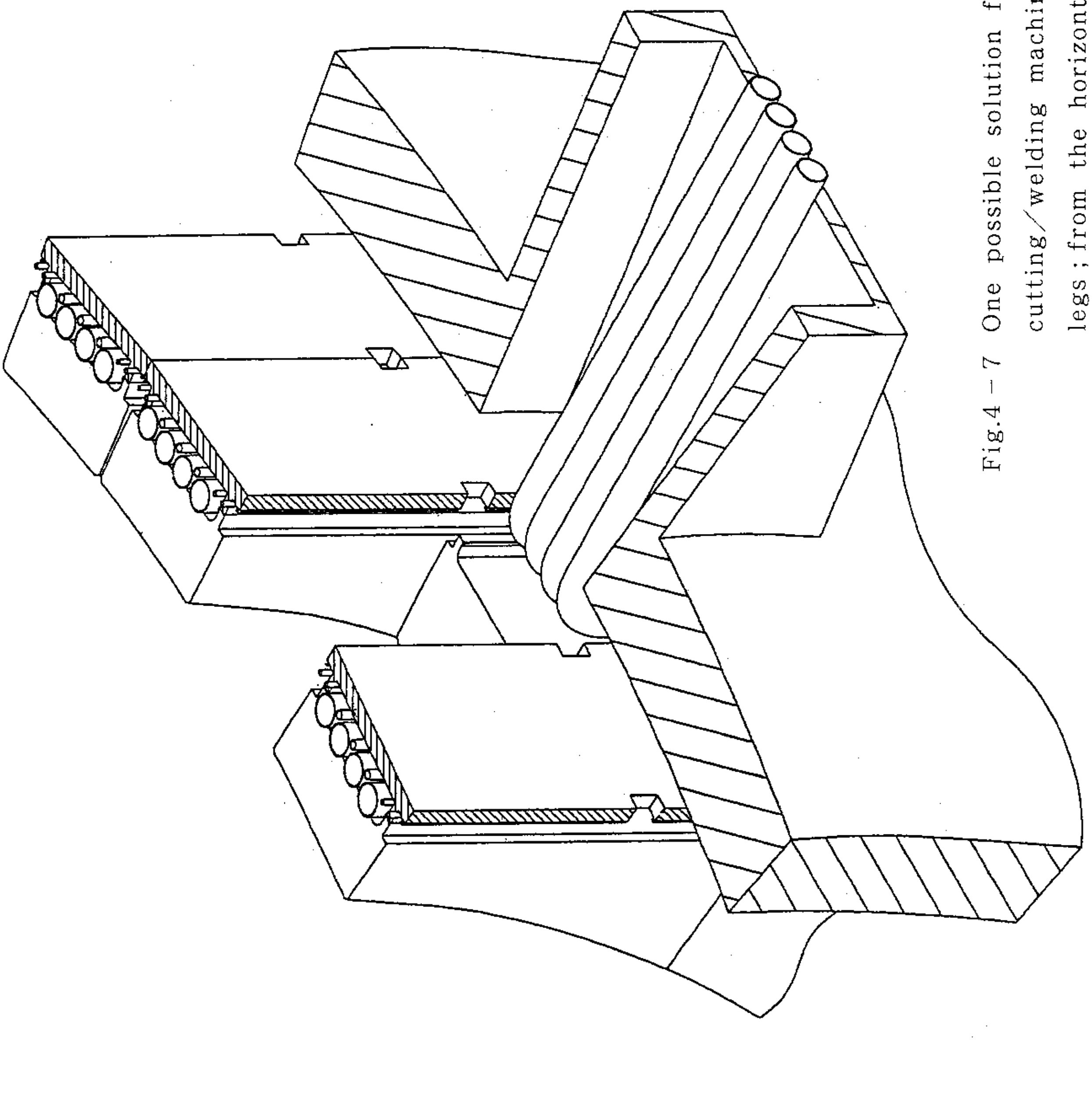


Fig.4 - 7 One possible solution for the access route of the on - site cutting/welding machine head for the blanket module legs ; from the horizontal port.

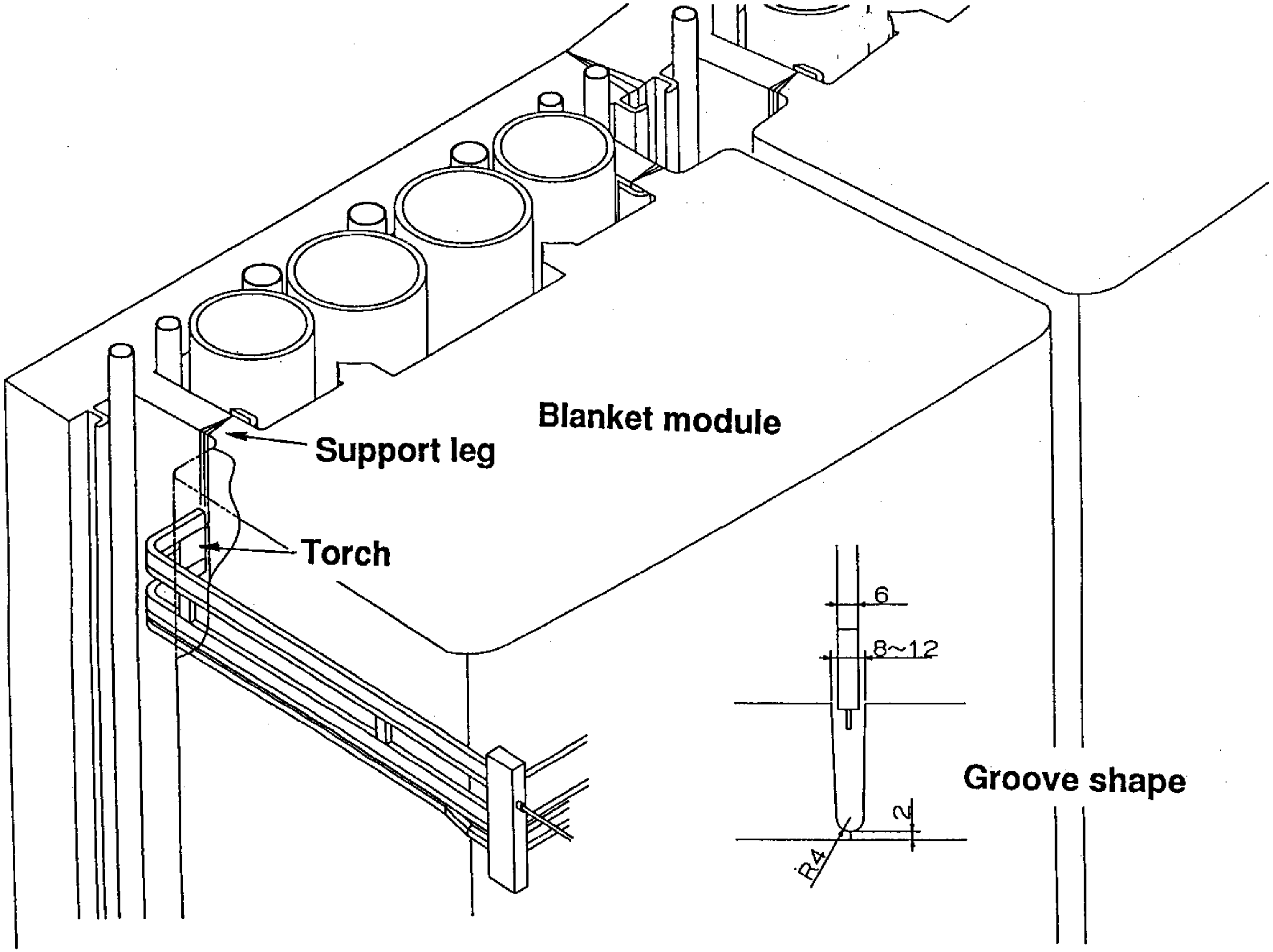


Fig.4 - 8 Basic concept of narrow gap TIG welding of the support leg of the blanket module.

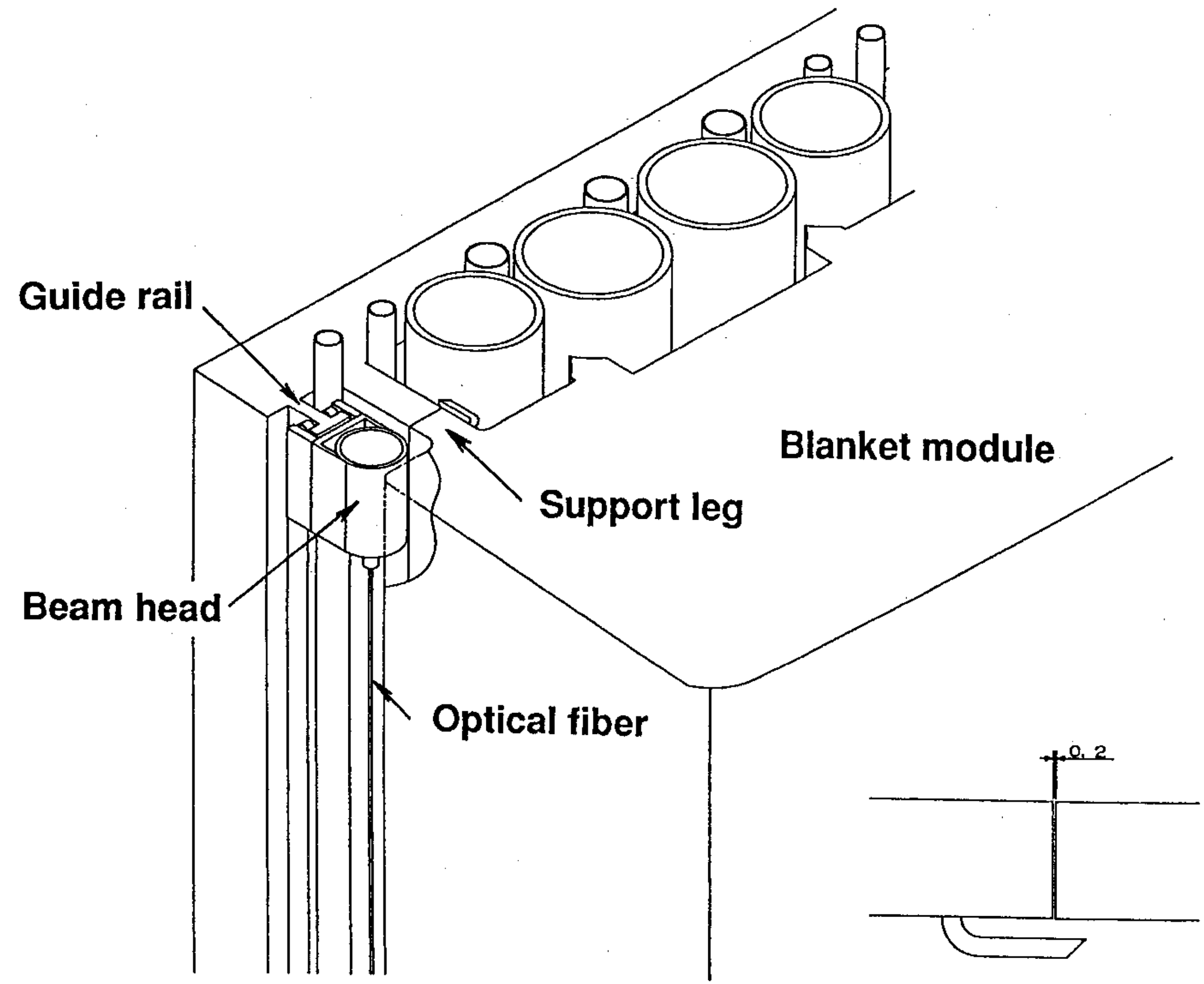


Fig.4 - 9 Basic concept of Iodine/YAG laser beam welding/cutting of the support leg of the blanket module.

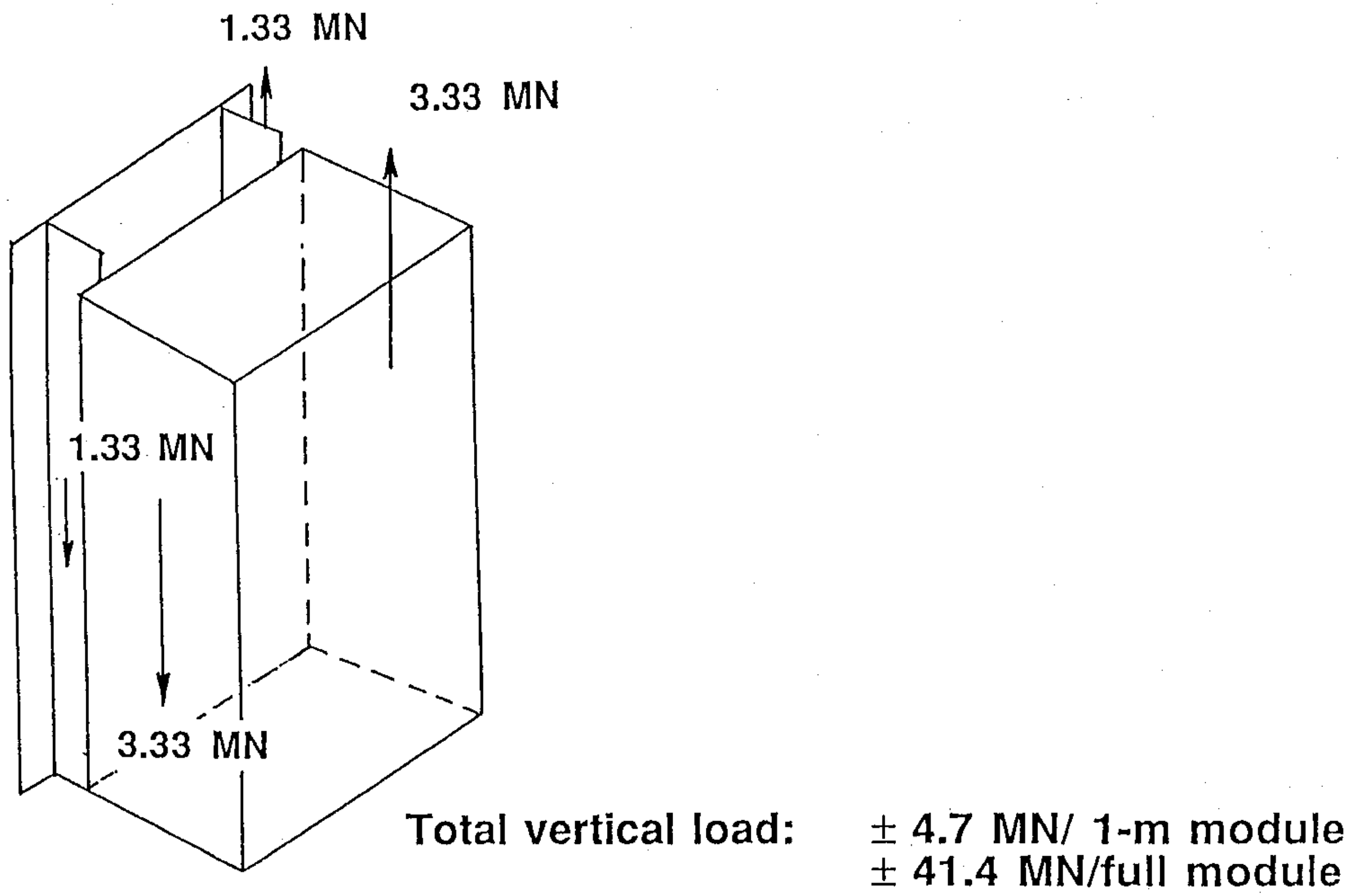


Fig.5 - 1 EM load of the inboard blanket module due to 10ms centered plasma disruption.

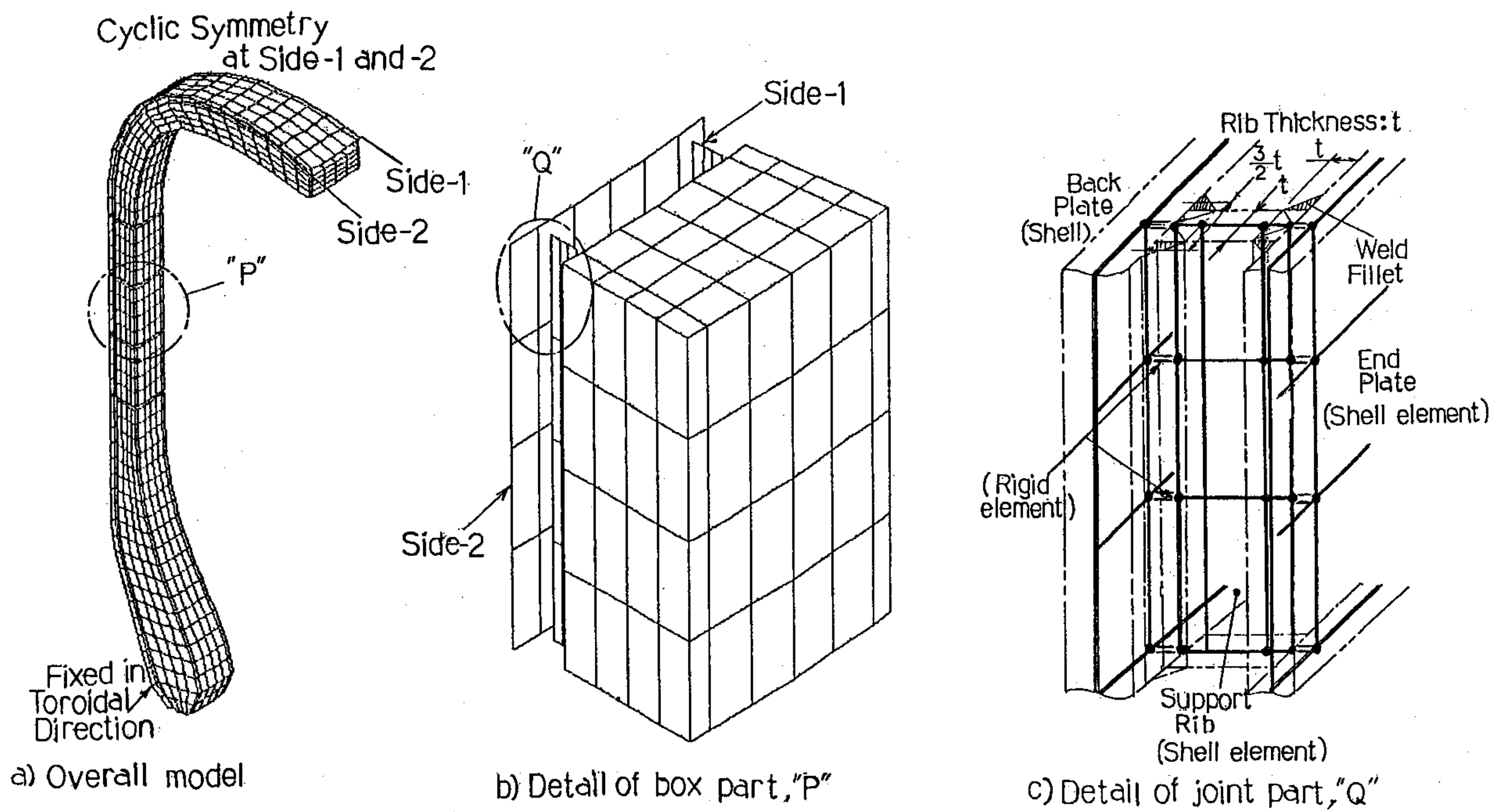


Fig.5 − 2 FEM model for the stress analysis of the inboard blanket.

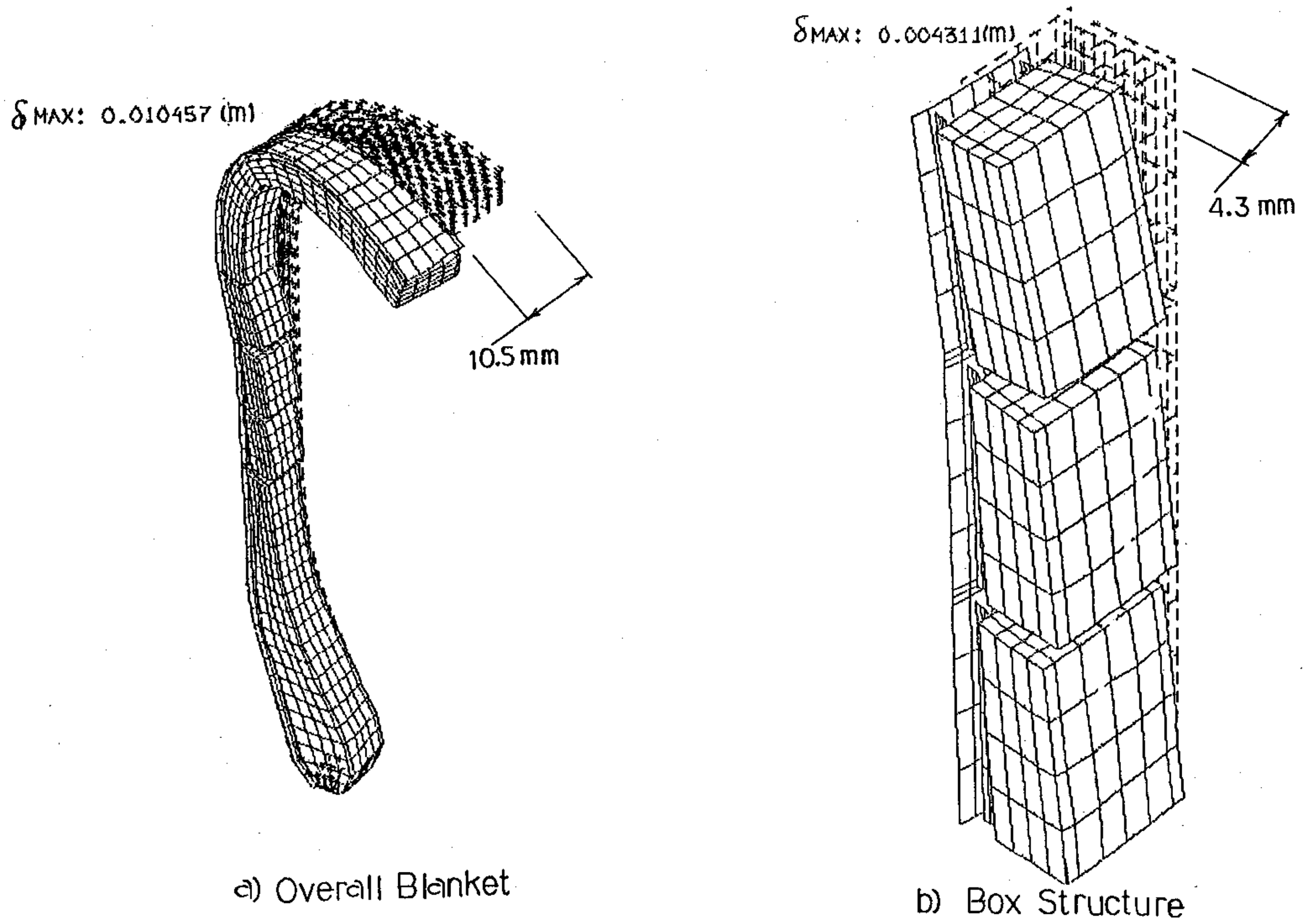


Fig.5 − 3 Deformation of modular − type inboard blanket due to centered plasma disruption for the leg thickness of 50mm.

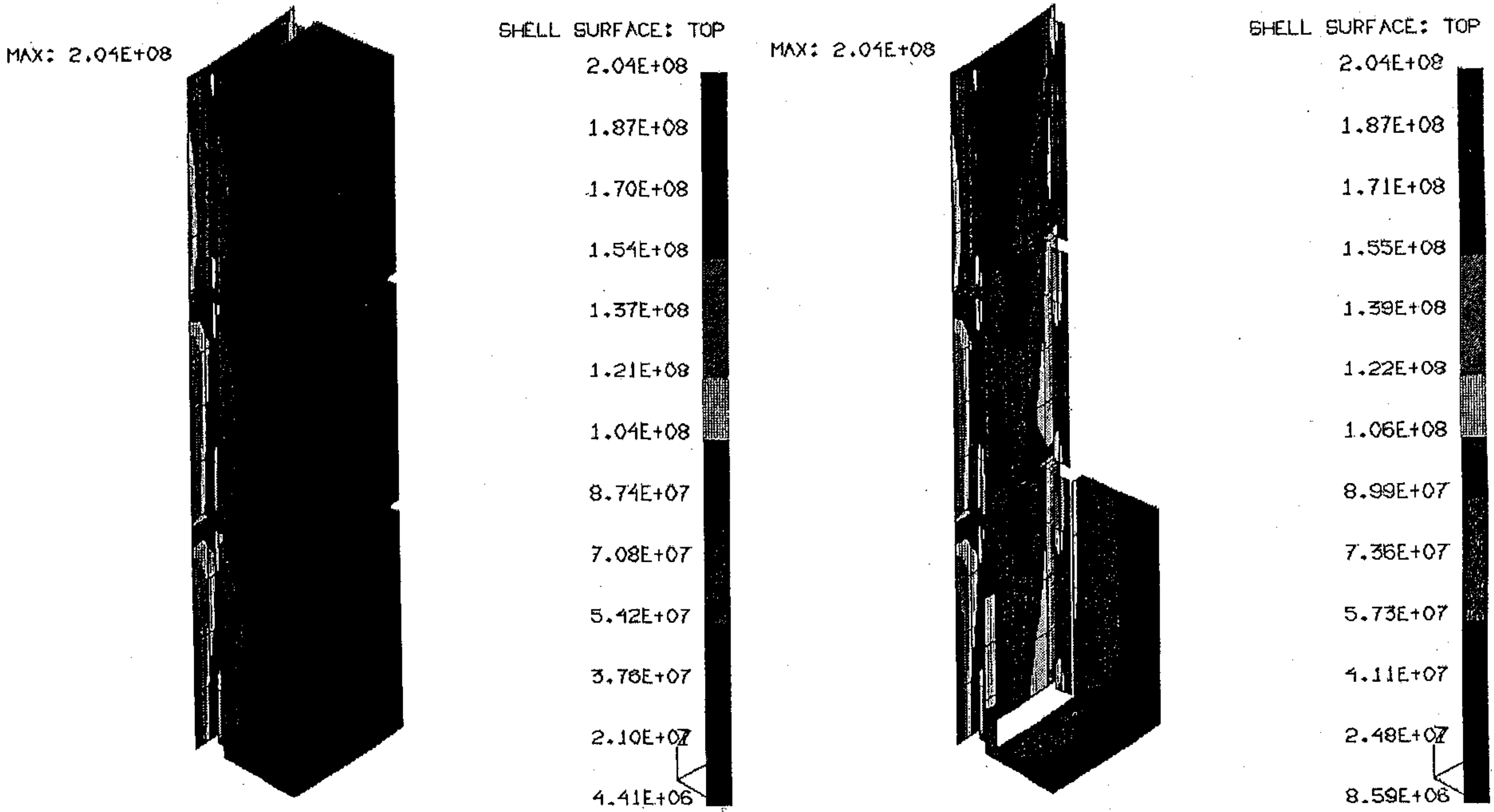


Fig.5 – 4 Distribution of Von Mises stress in the modular – type inboard blanket for the leg thickness of 50mm.

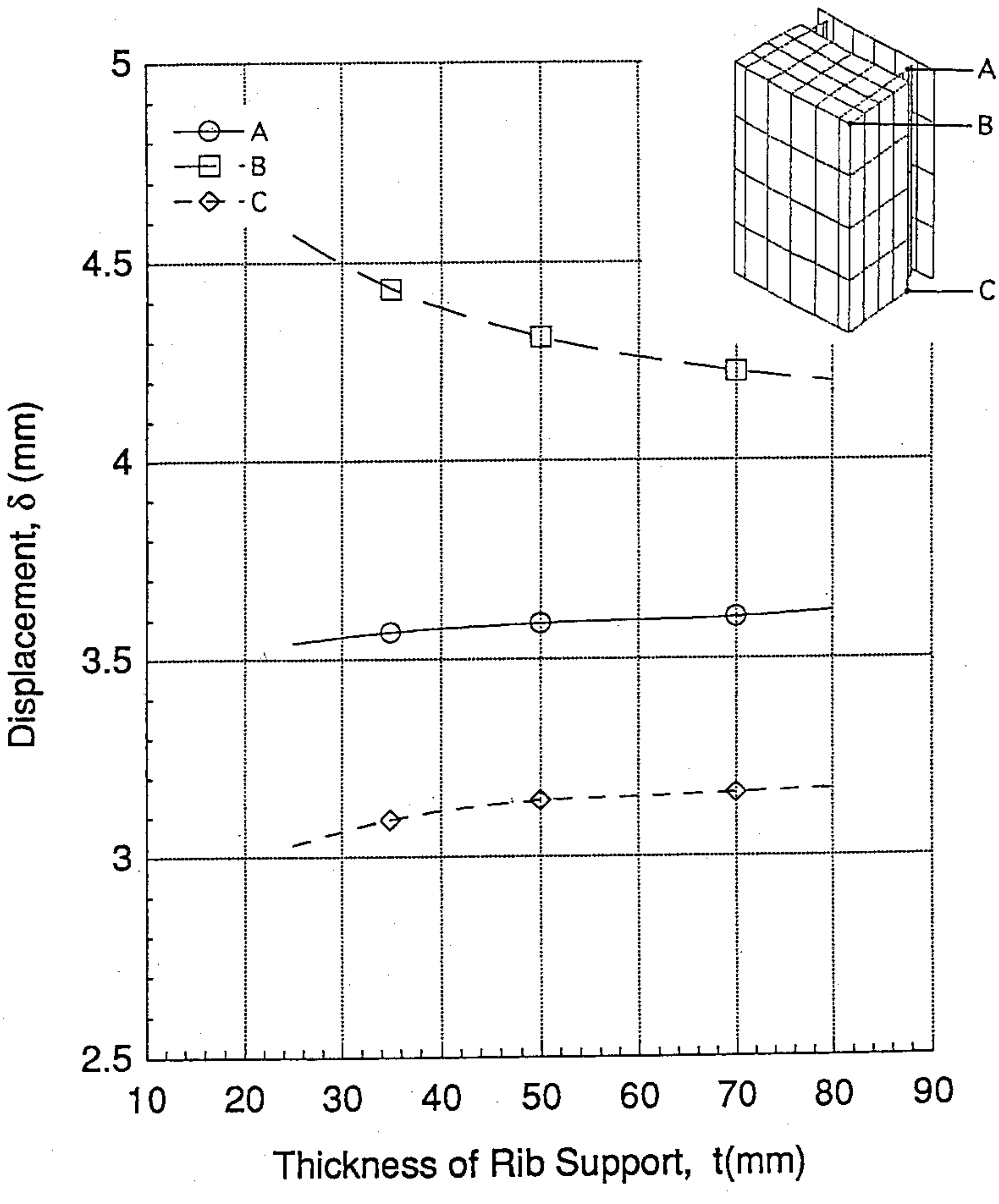


Fig.5 – 5 Relationship between the displacement of the blanket module and the thickness of the support leg.

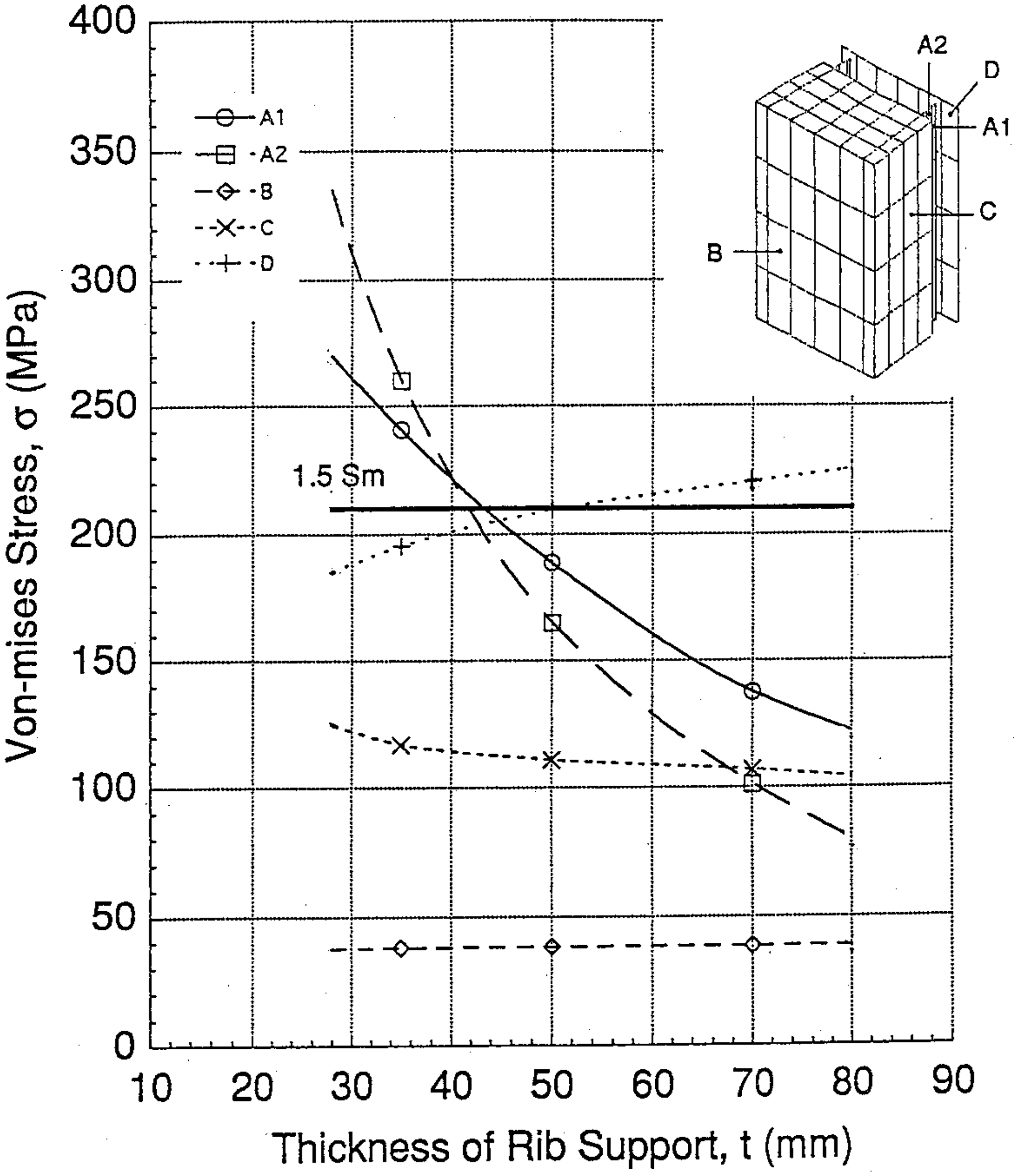


Fig.5 − 6 Relationship between Von Mises stress of the blanket module and the thickness of the support leg.

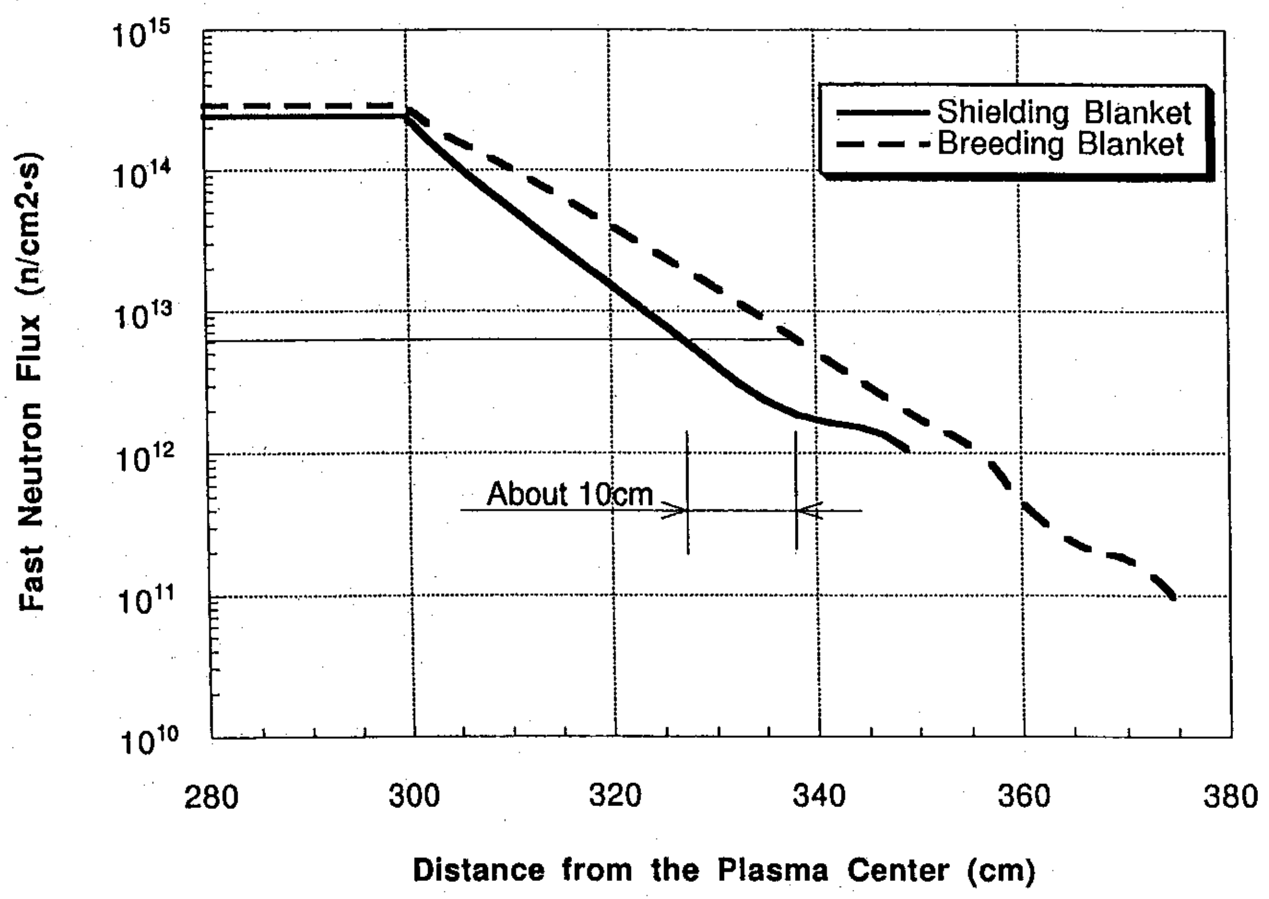


Fig.6 − 1 Comparison of shielding Performance between shielding and breeding blankets. Additional thickness of 10cm is needed for the breeding blanket to obtain the same shielding performance as the shielding blanket.

Main plasma parameters:

Major radius	8.1 m
Minor radius	2.89 m (0.11m smaller than OD)
Elongation(95%)	1.55
Plasma current	24 MA
Fusion power	1.45 GW (0.05MW smaller than OD)
Average temperature	12 keV
NBI beam energy	1.3 MeV
NBI injection radius	6.2 m (24 TFC version)
Beryllium fraction (N_{Be}/N_e)	2.0 %
Helium confinement time(τ_{He}/τ_E)	12.0

Computed results:

Wall neutron load	0.915 MW/m^2
H factor	ITER 89 power law
Divertor peak heat load	Harrison - Kukushkin model

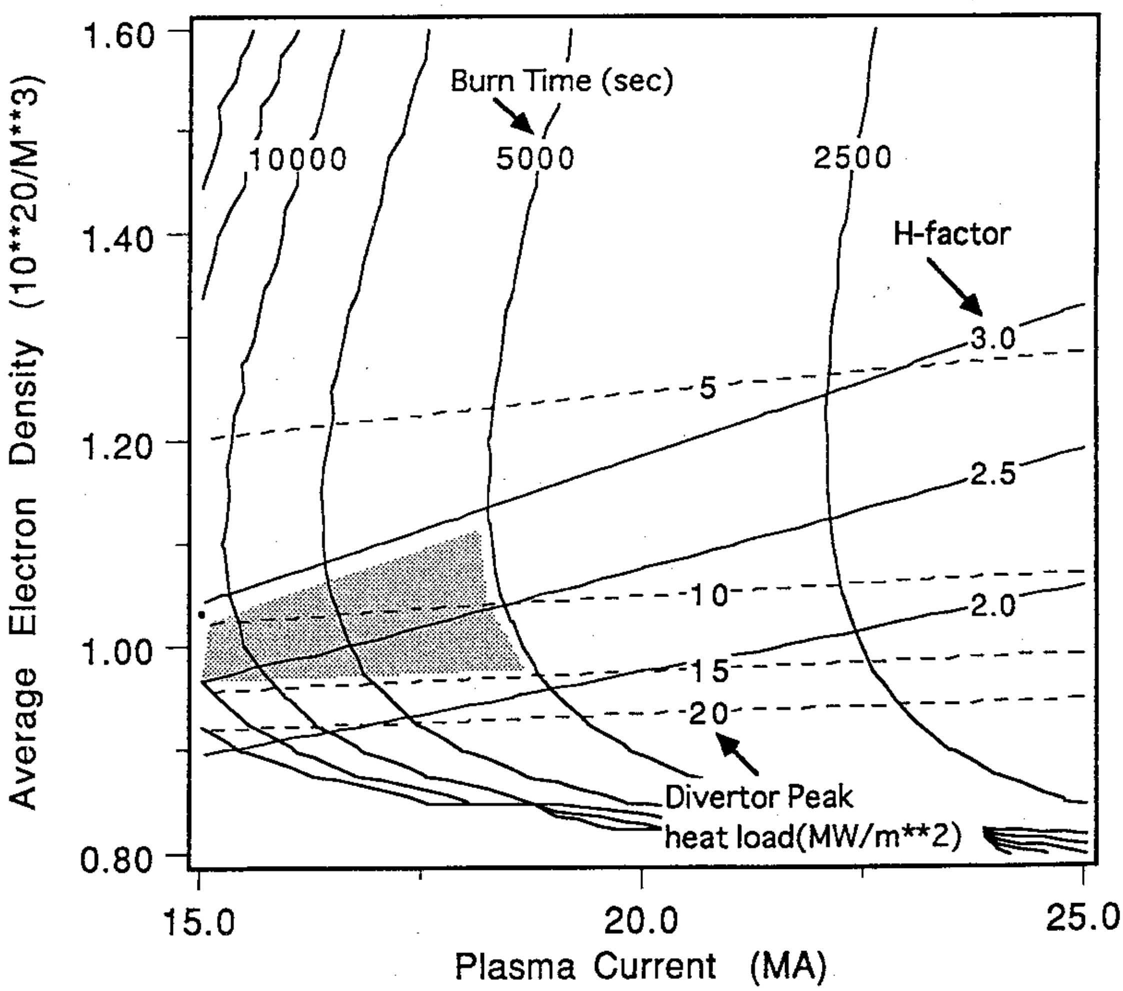


Fig.6 − 2 Long − burn operation scenario with the smaller minor radius by 10cm.

Main plasma parameters:

Major radius	8.1 m
Minor radius	3.0 m
Elongation(95%)	1.55
Plasma current	24 MA
Fusion power	1.5 GW
Average temperature	12 keV
NBI beam energy	1.3 MeV
NBI injection radius	6.2 m (24 TFC version)
Beryllium fraction (N_{Be}/N_e)	2.0 %
Helium confinement time(τ_{He}/τ_E)	12.0

Computed results:

Wall neutron load	0.915 MW/m^2
H factor	ITER 89 power law
Divertor peak heat load	Harrison - Kukushkin model

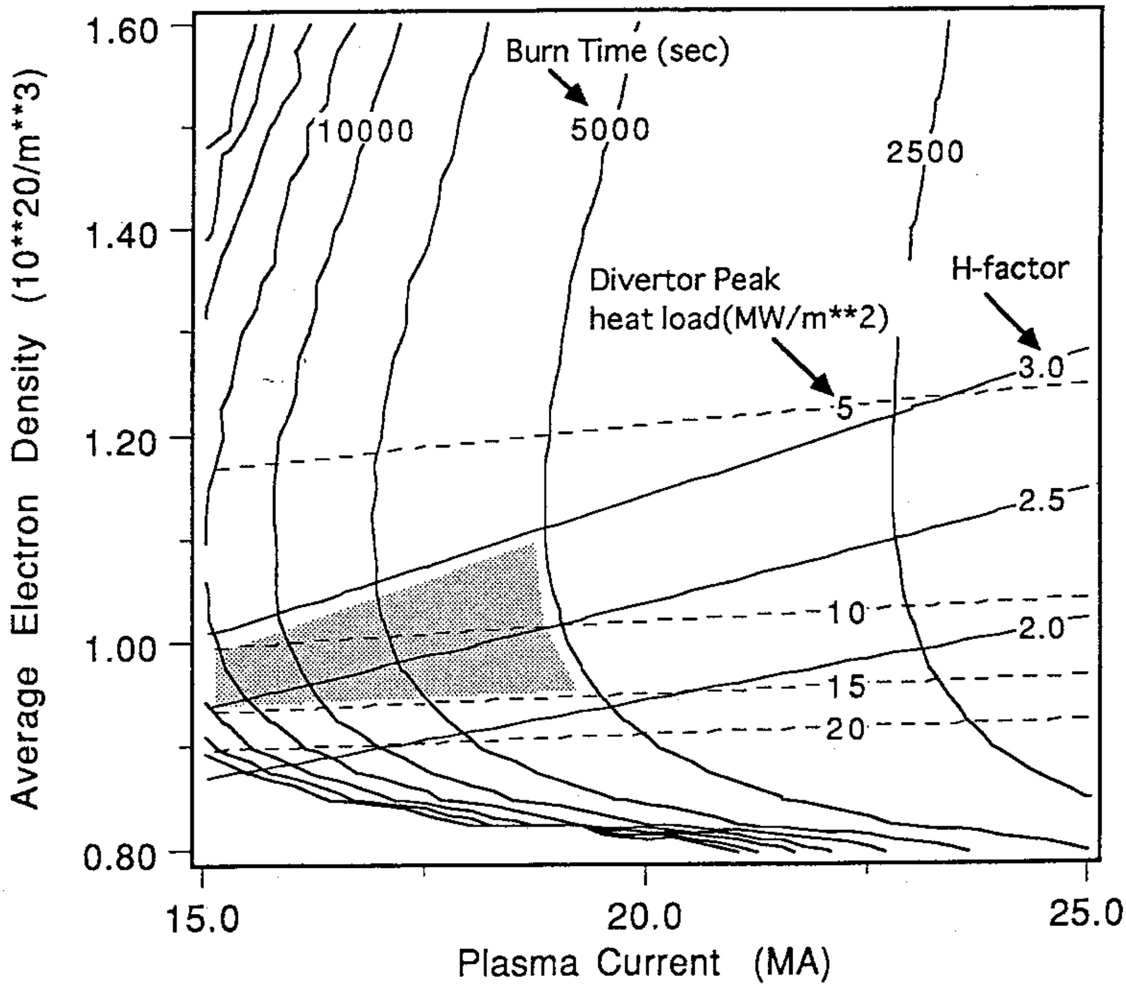


Fig.6 – 3 Long – burn operation scenario for the nominal minor radius.

Appendix 1

Fabrication Procedure of Shielding Blanket Integrated with the First Wall

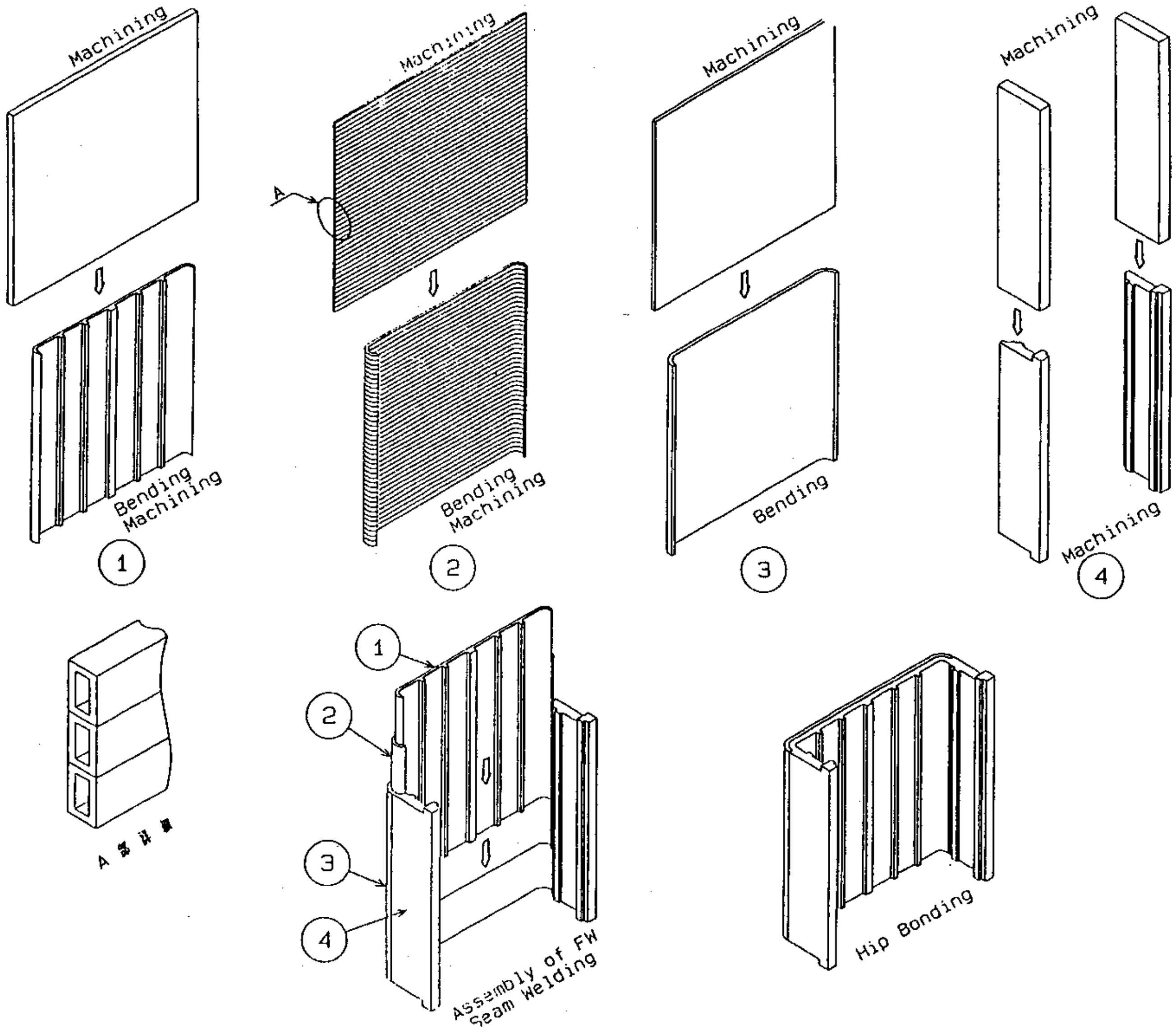


Fig.A − 1 − 1 Fabrication procedure of the first wall with the front part of the side wall.

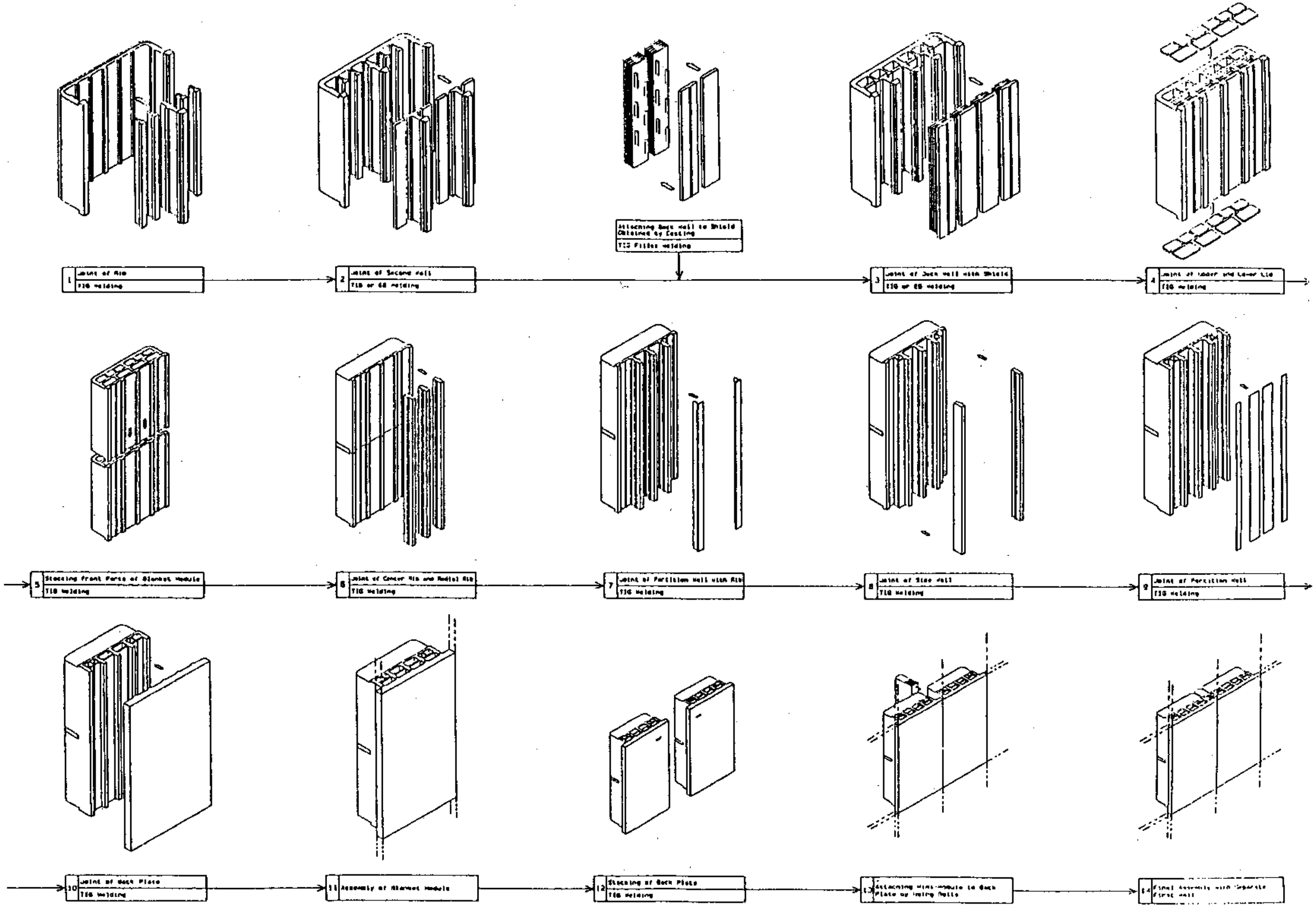
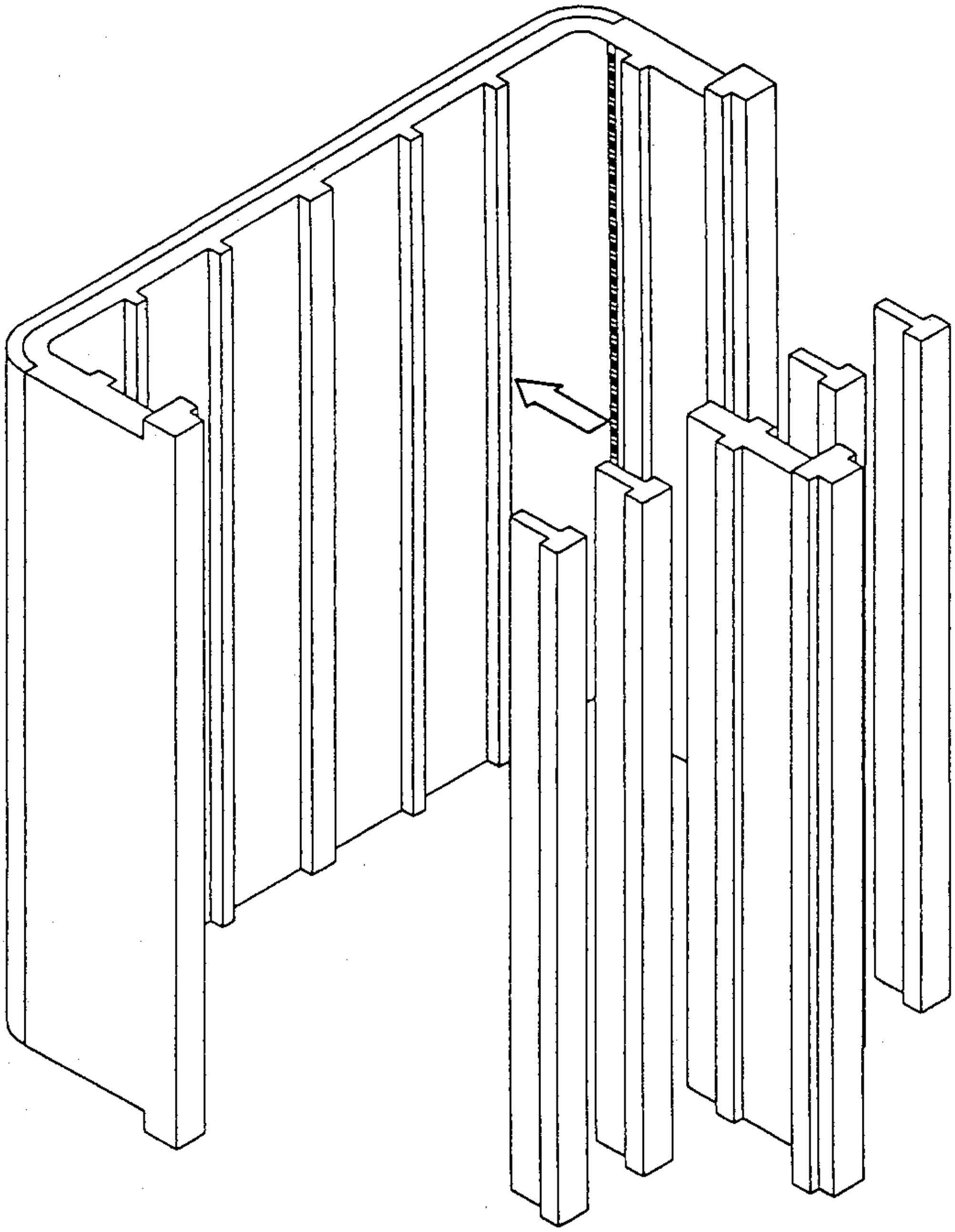
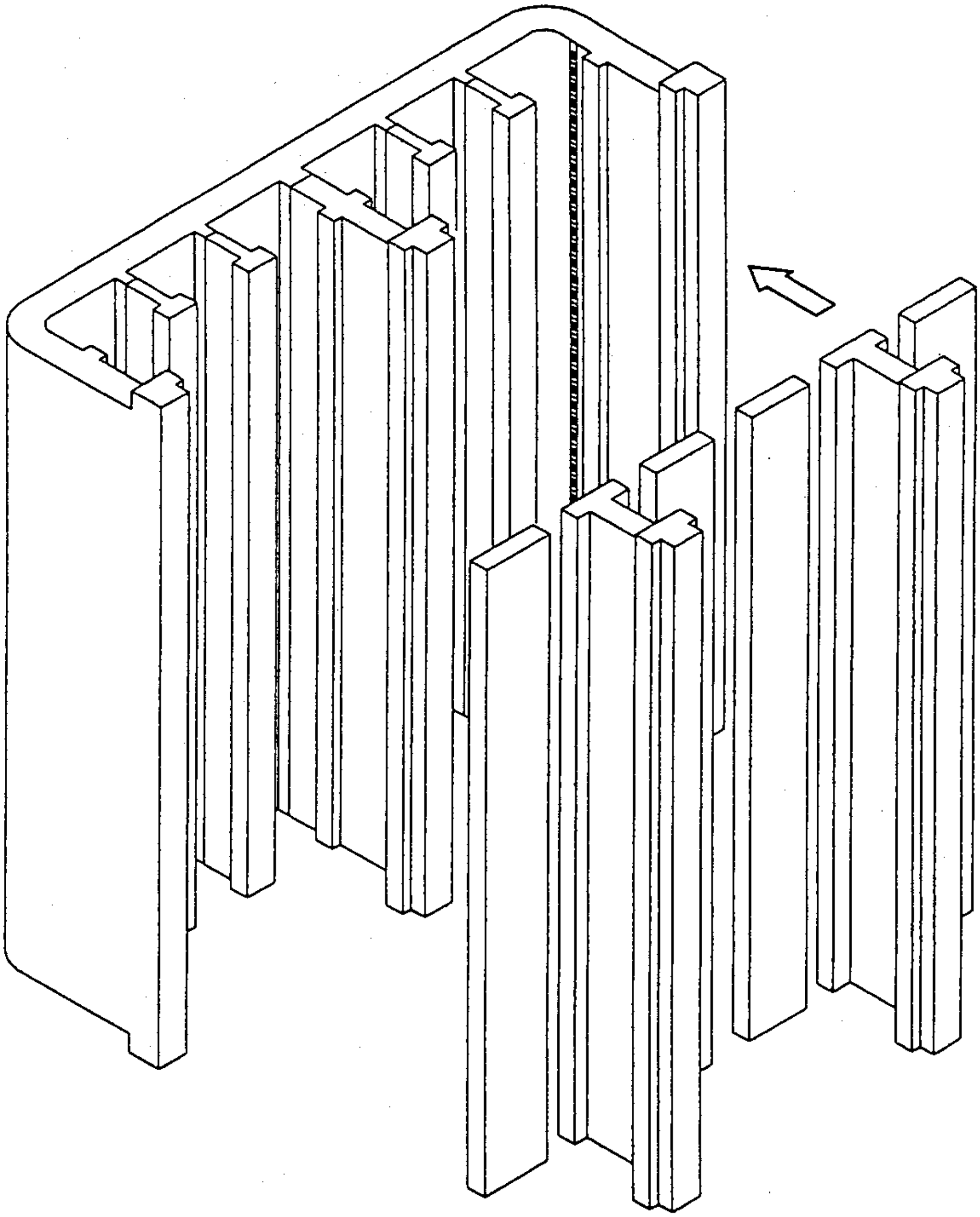


Fig.A - 1 - 2 Fabrication procedure after fabricating of the first wall.



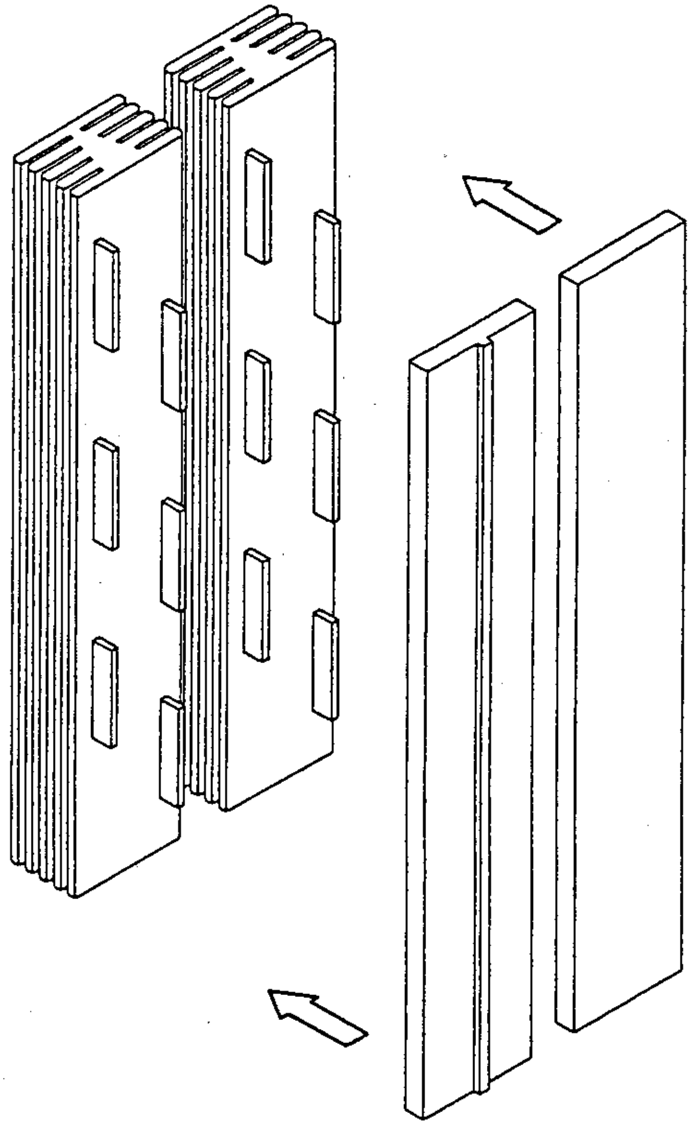
1	Joint of Rib
	TIG Welding

Fig.A - 1 - 3 Jointing the rib to the first wall by TIG welding.



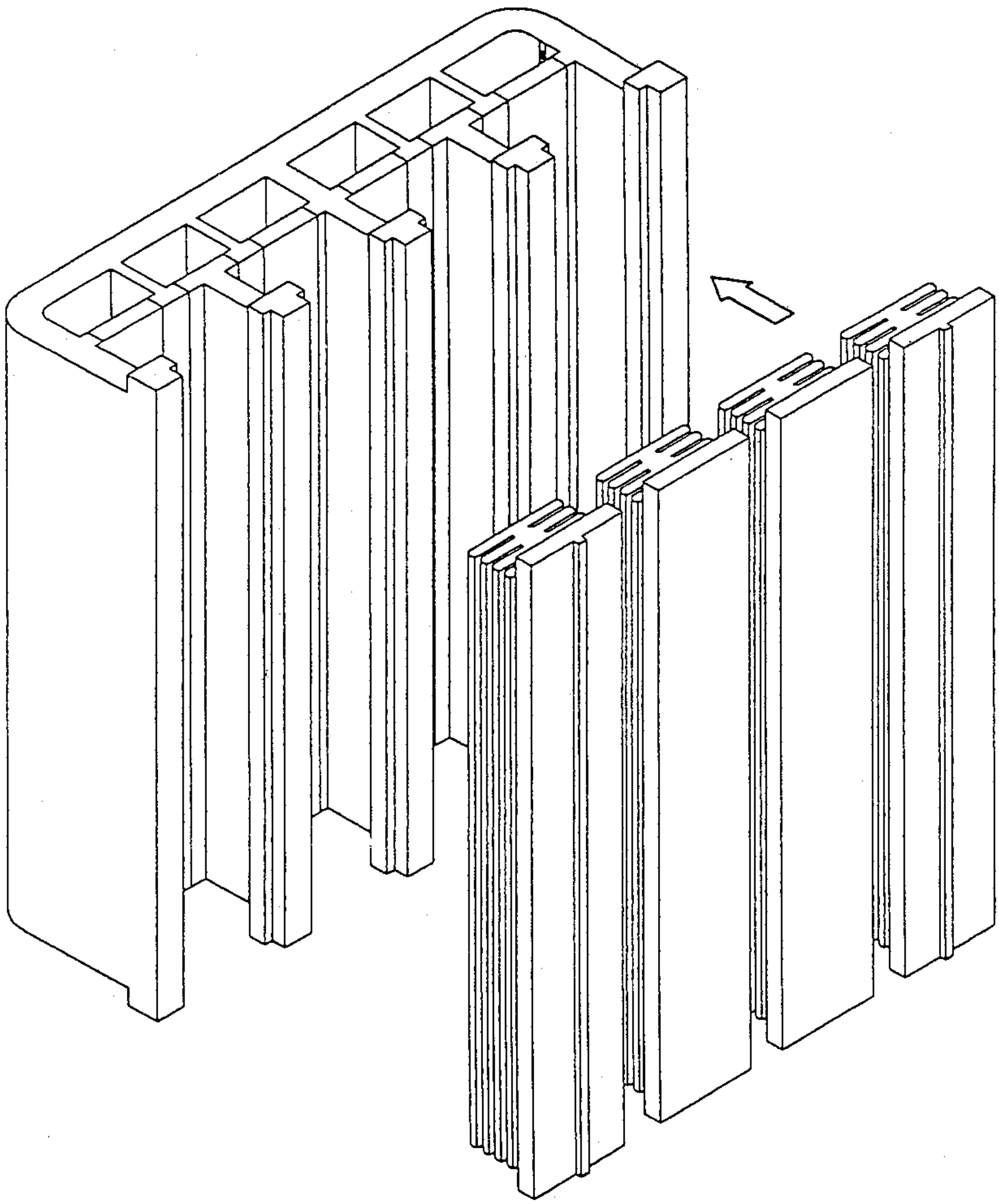
2	Joint of Second Wall
	TIG or EB Welding

Fig.A - 1 - 4 Jointing the second wall to the rib and the front part of the side wall by TIG or EB welding.



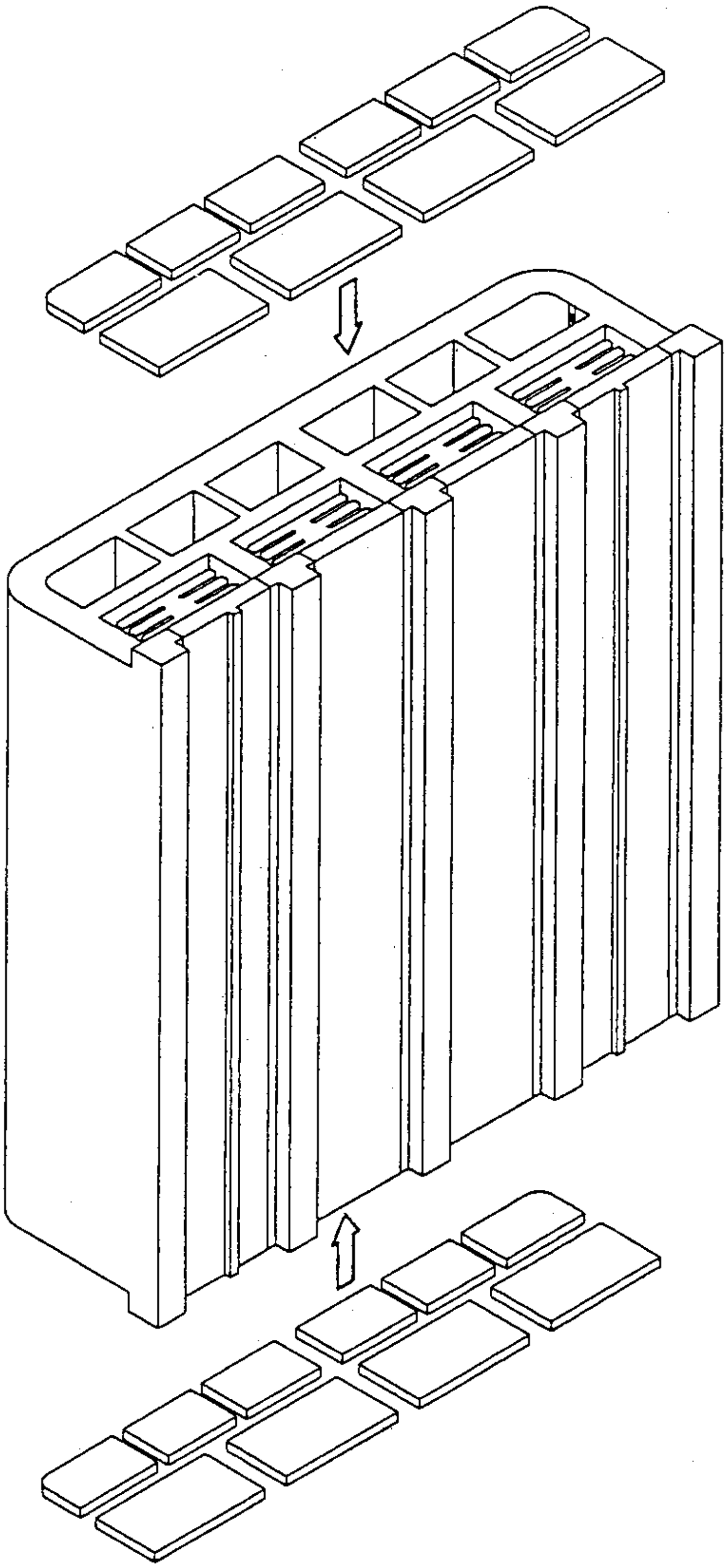
Attaching Back Wall to Shield Obtained by Casting
TIG Fillet Welding

Fig.A − 1 − 5 Attaching the back wall to the shield structure by TIG fillet welding. The shield structure are fabricated by casting.



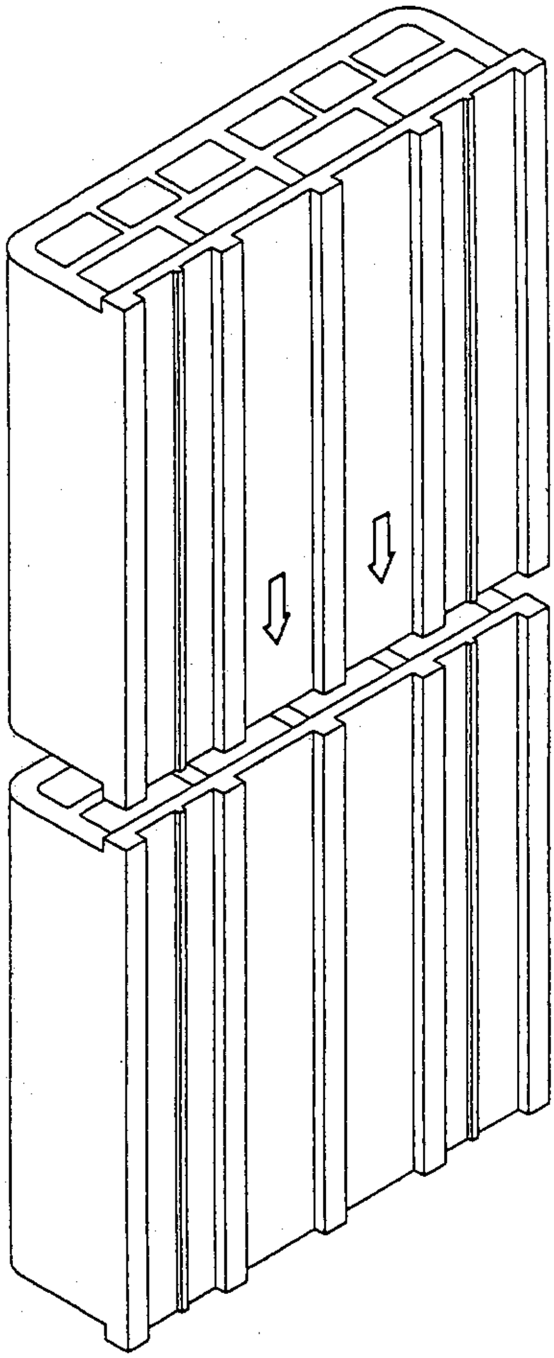
3	Joint of Back Wall with Shield
	TIG or EB Welding

Fig.A − 1 − 6 Jointing the back wall with the shield structure to the rib and the front part of the side wall by TIG or EB weding.



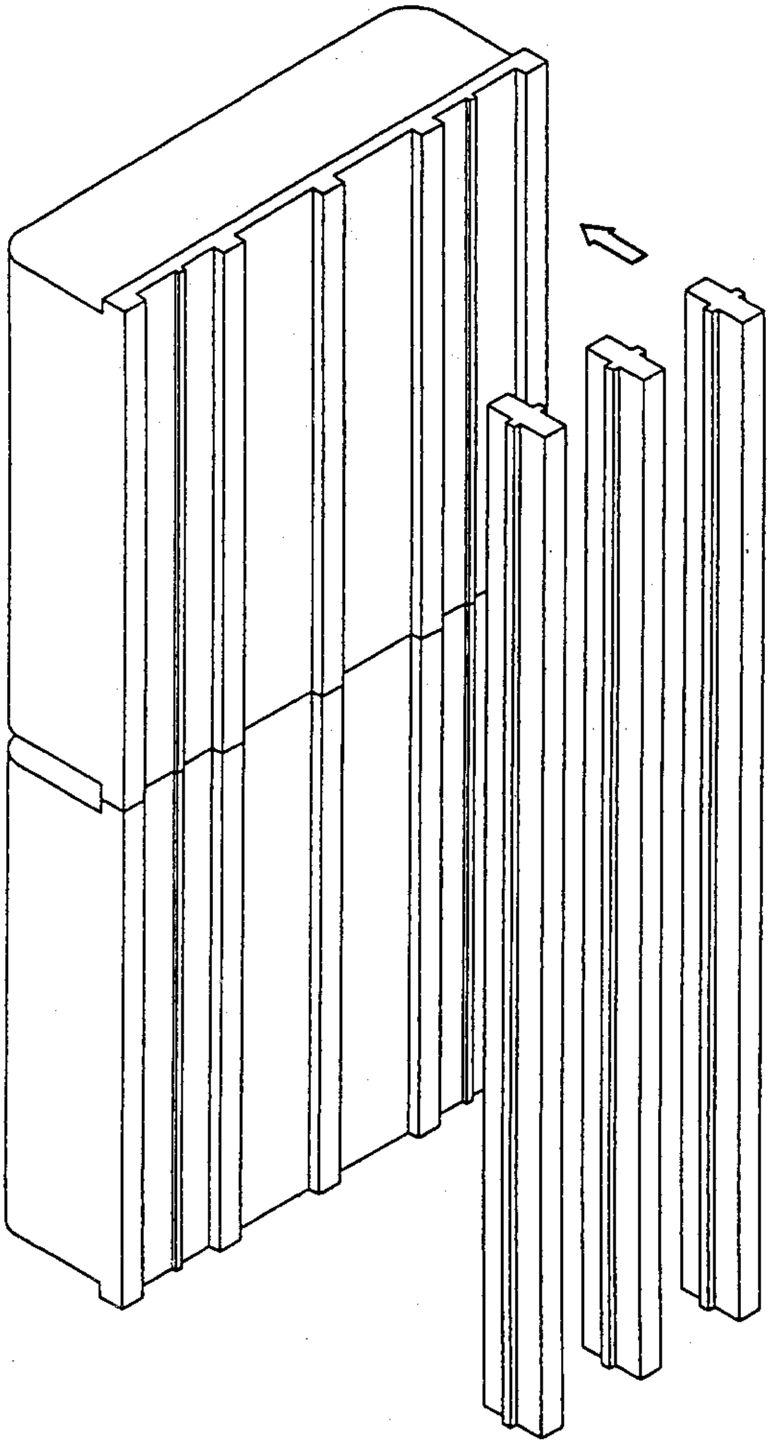
4	Joint of Upper and Lower Lid
	TIG Welding

Fig.A − 1 − 7 Joint of the upper and the lower lid TIG welding.



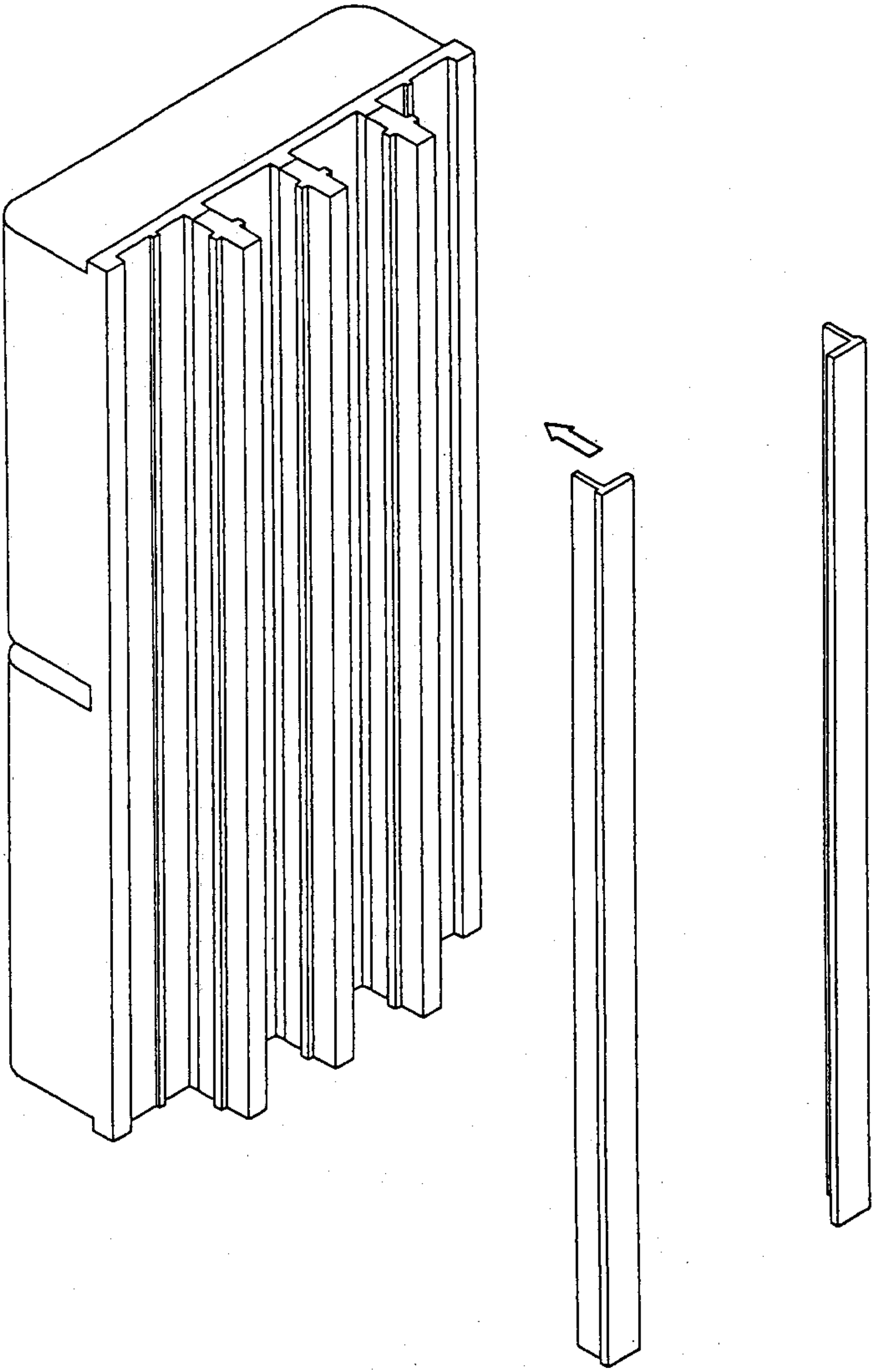
5	Stacking Front Parts of Blanket Module
	TIG Welding

Fig.A－1－8 Stack of the front parts of the blanket module by TIG welding.



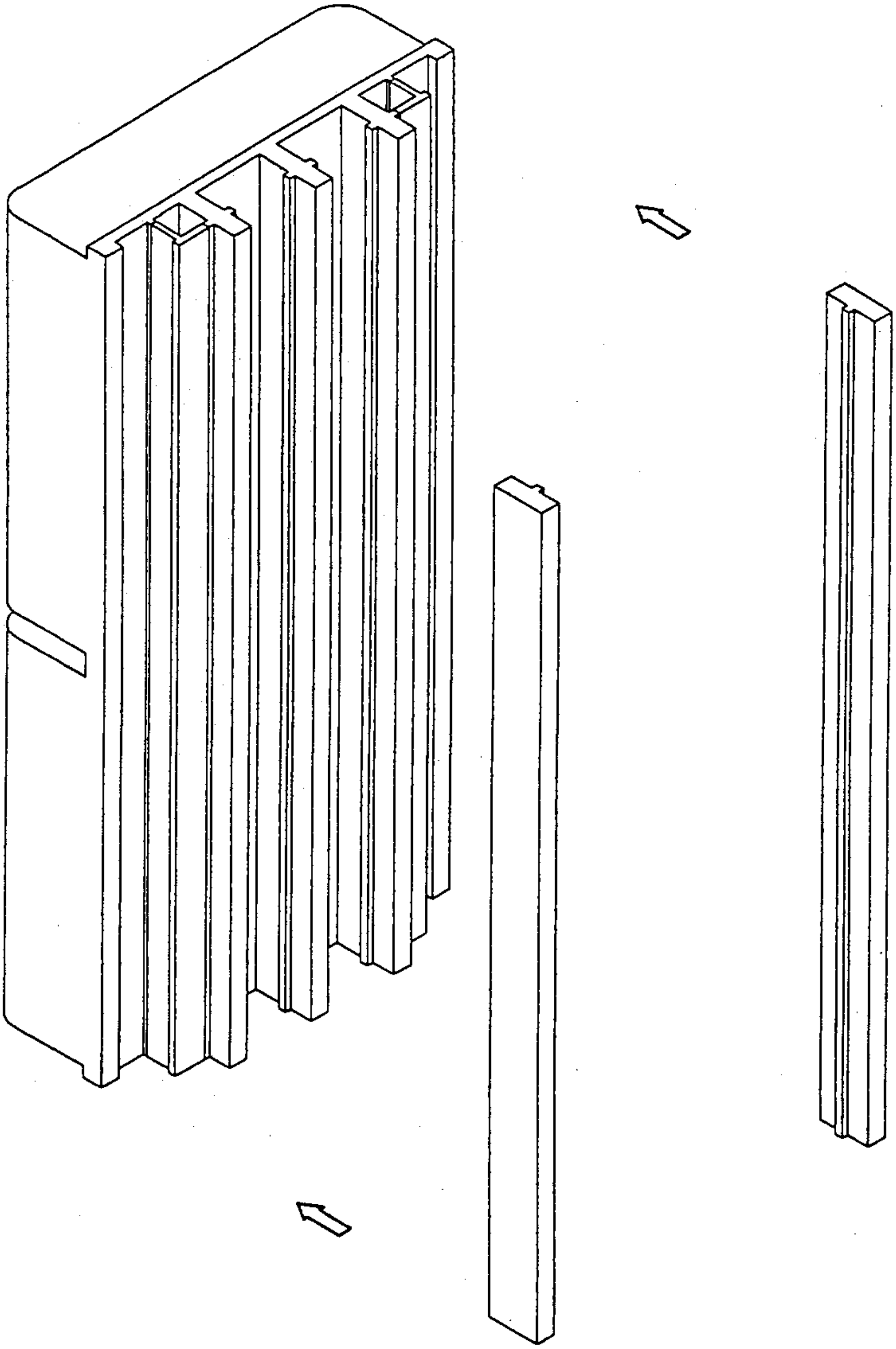
6	Joint of Center Rib and Radial Rib
	TIG Welding

Fig.A－1－9 Joint of the center and the radial rib by TIG welding.



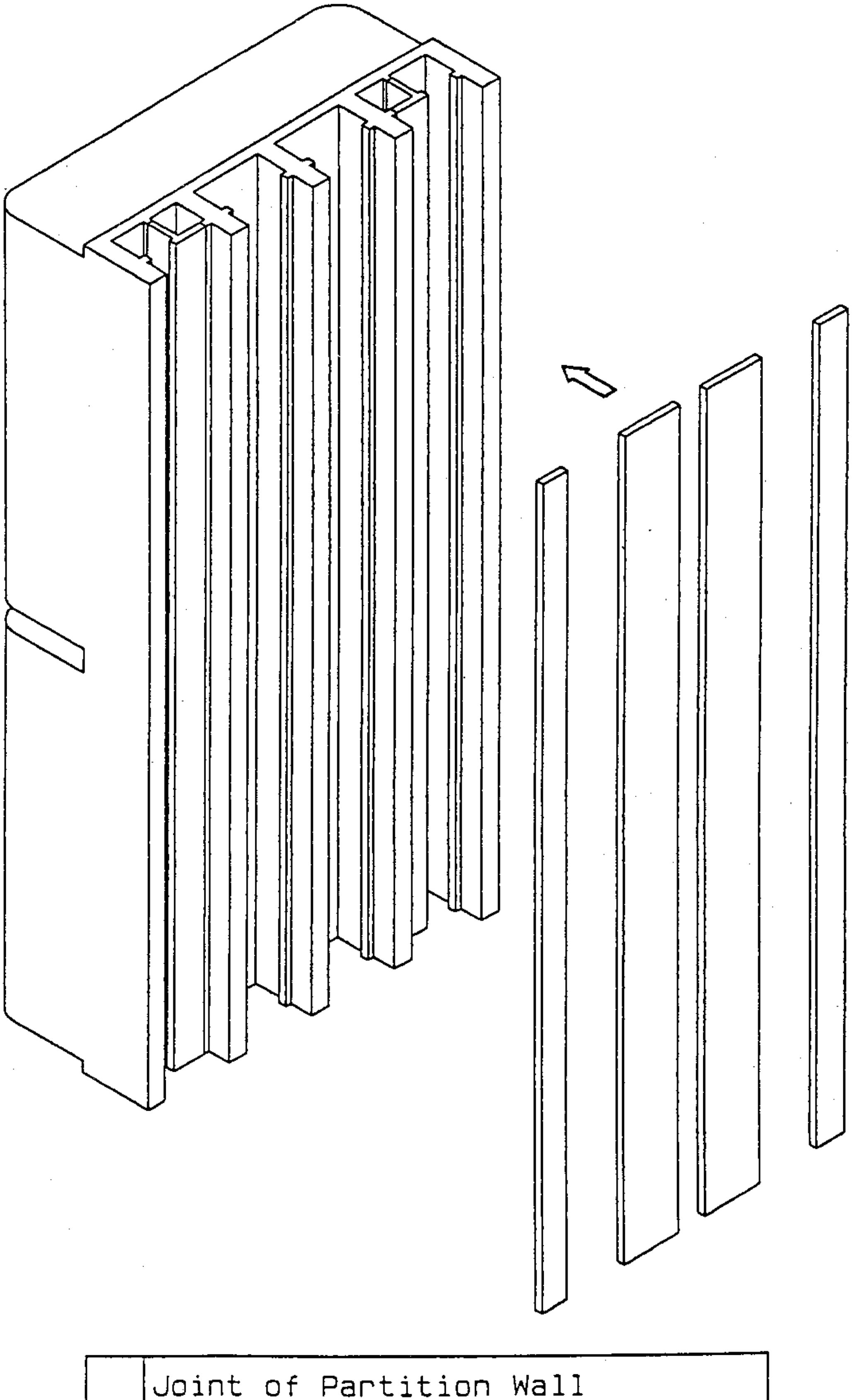
7	Joint of Partition Wall with Rib
	TIG Welding

Fig.A－1－10 Joint of the partition wall with the rib by TIG welding.



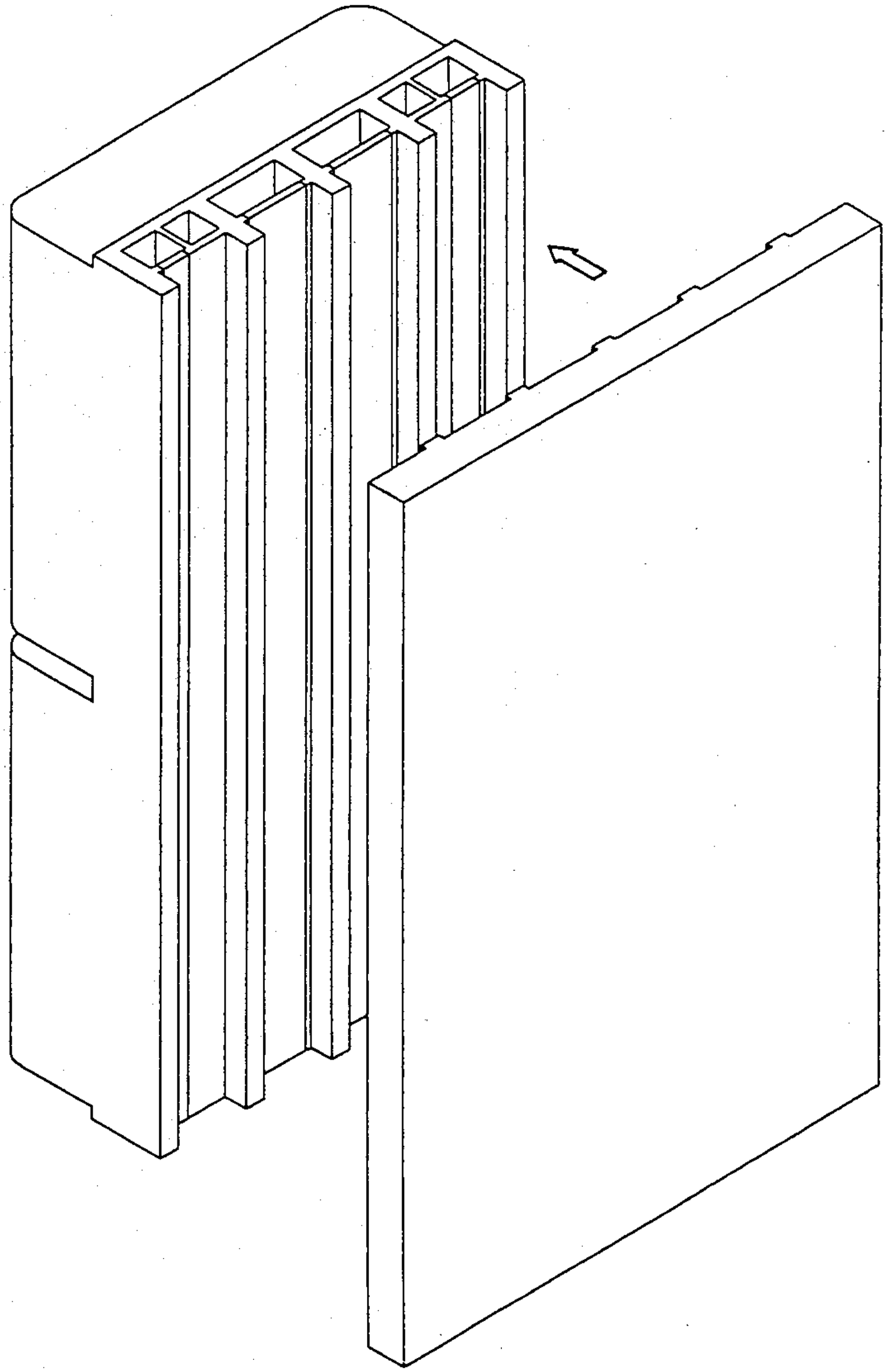
8	Joint of Side Wall
	TIG Welding

Fig.A − 1 − 11 Joint of the rear parts of the side wall by TIG welding.



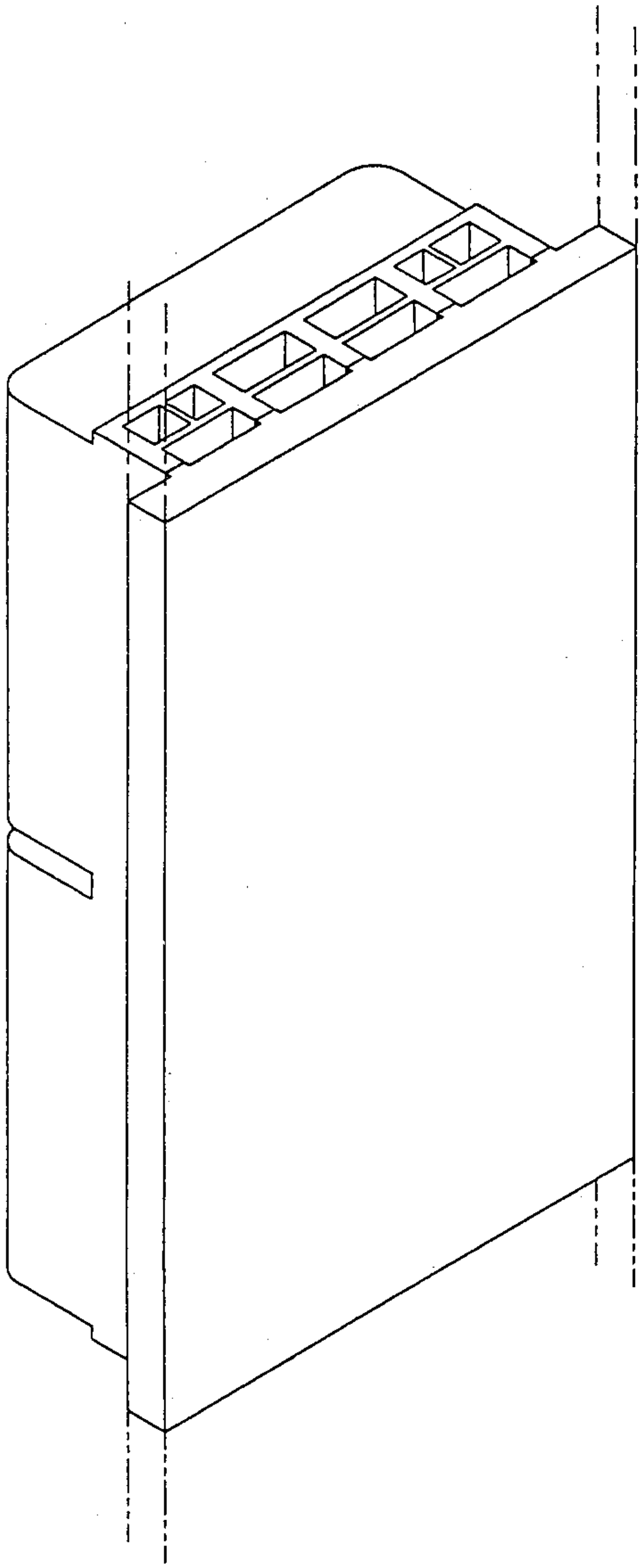
9	Joint of Partition Wall
	TIG Welding

Fig.A − 1 − 12 Joint of the partition wall by TIG welding.



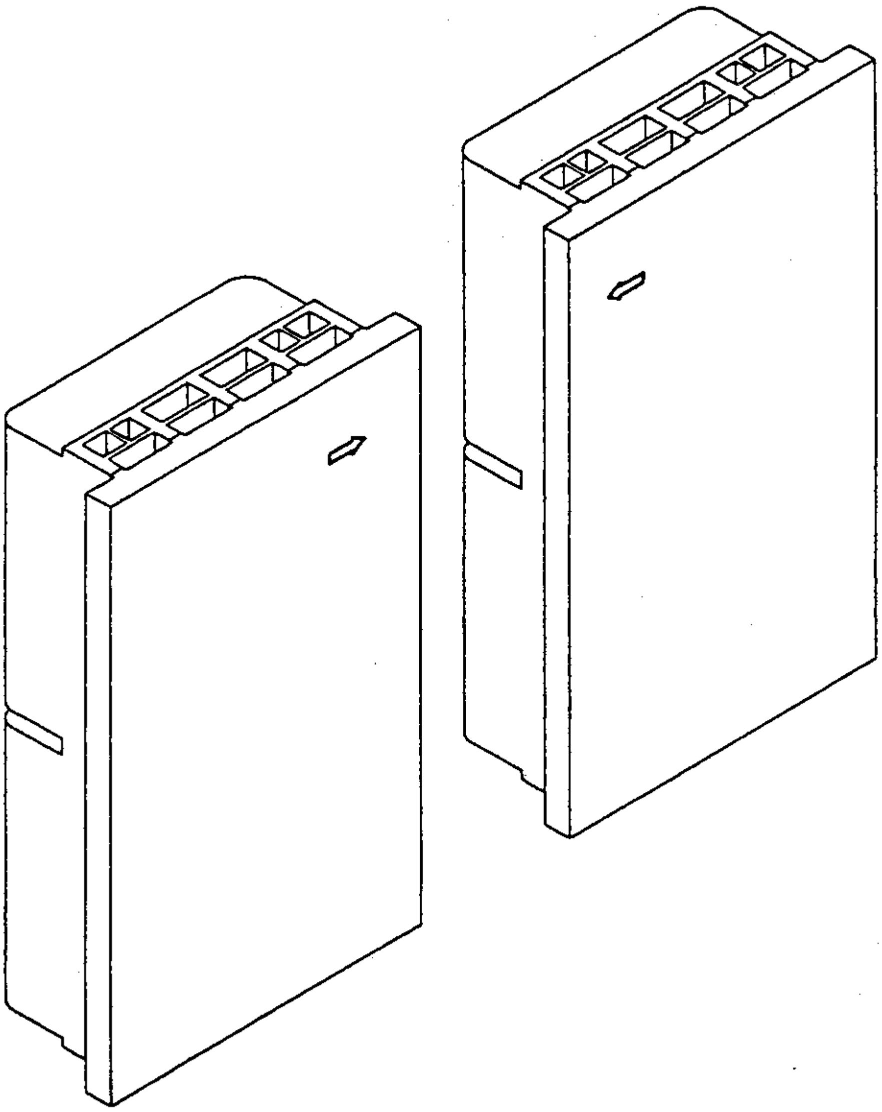
10	Joint of Back Plate
	TIG Welding

Fig.A－1－13 Joint of the back plate by TIG welding.



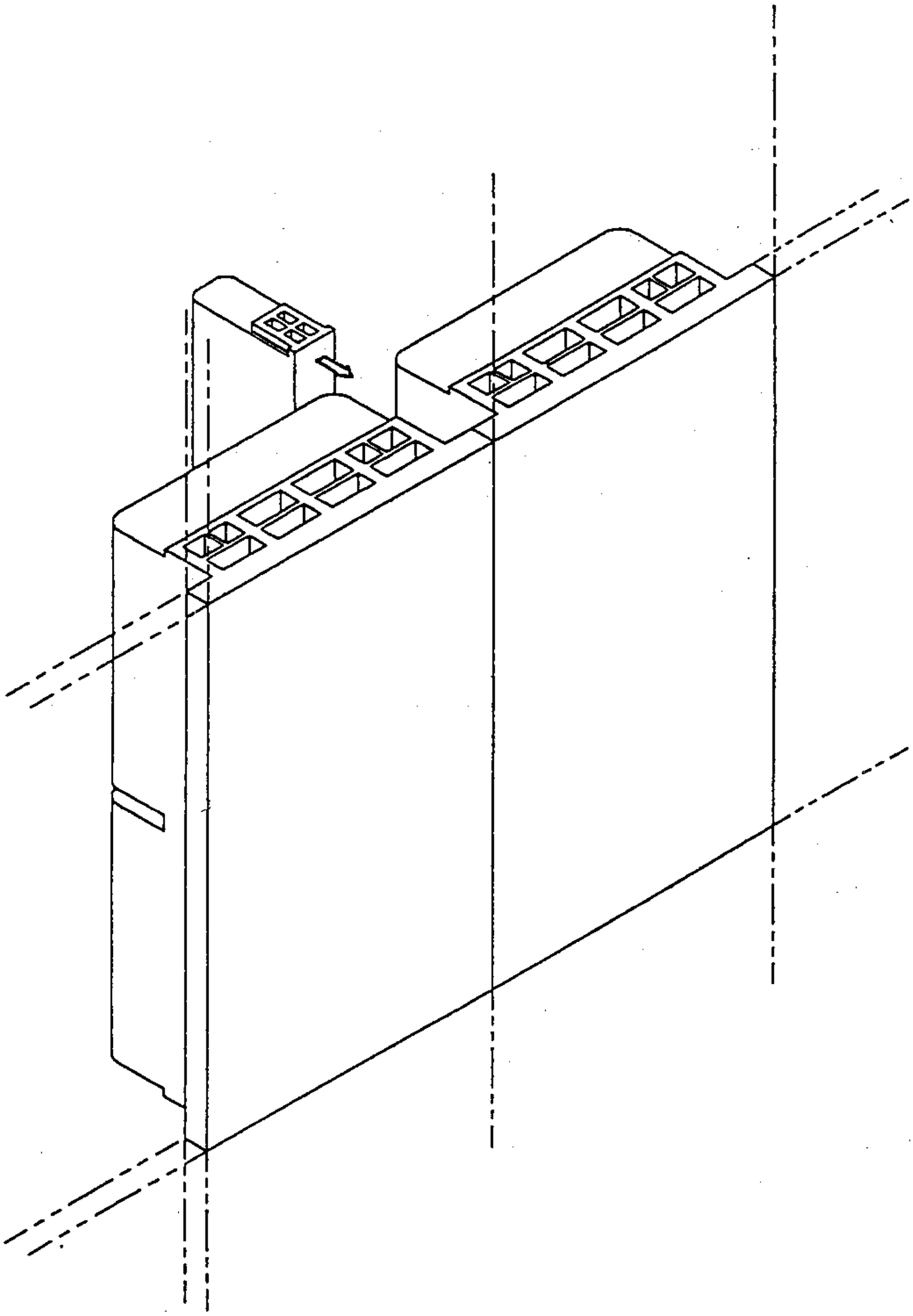
11	Assembly of Blanket Module

Fig.A − 1 − 14 Assembly of the blanket module.



12	Stacking of Back Plate
	TIG Welding

Fig.A－1－15 Stack of the back plate by TIG welding.



13	Attaching Mini-Module to Back Plate by Using Bolts

Fig.A－1－16 Attaching the mini－module to the back plate by using bolts.

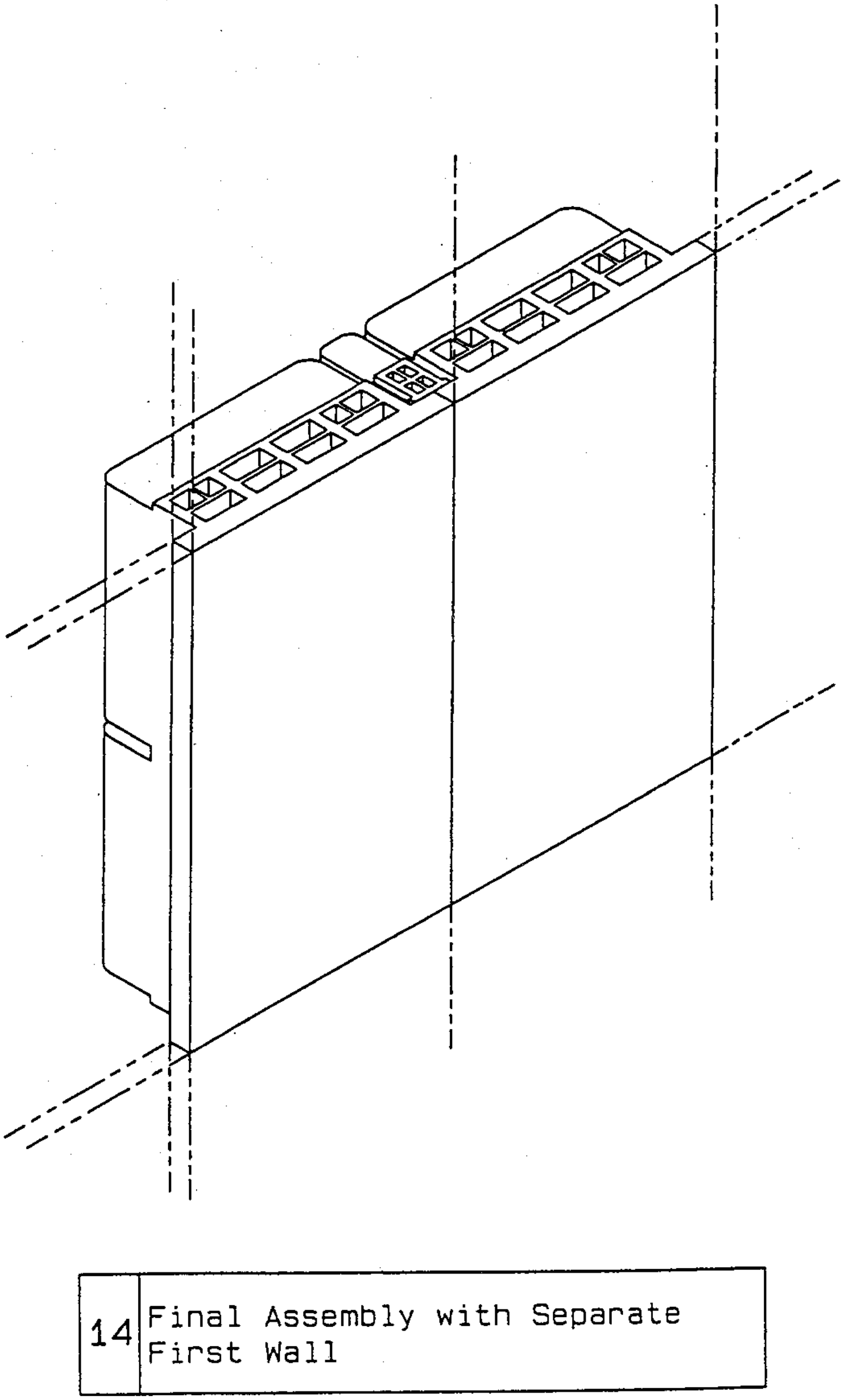


Fig.A - 1 - 17 Final assembly with the separste first wall.

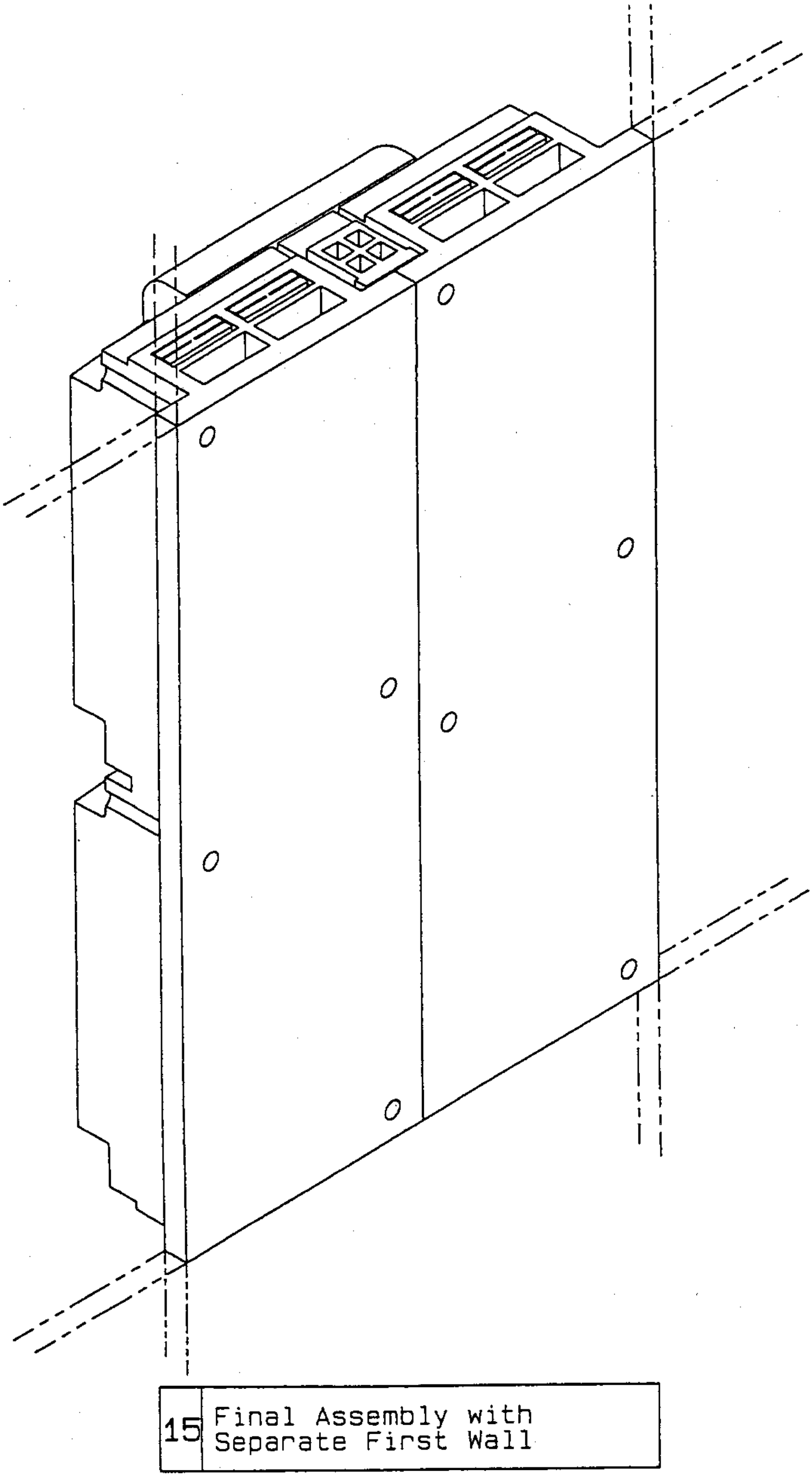


Fig.A − 1 − 18 Final assembly with the separate first wall.

Appendix 2

Thermal and Mechanical Analyses of the ITER Blanket/First Wall

Thermo-mechanical Analysis of Blanket Module

- Conditions	
- Surface heat flux	0.5 MW/m^2
- Nuclear heating	
- Beryllium	10 MW/m^3
- Cu alloy	23 MW/m^3
- SS 316	18 MW/m^3
- Coolant temperature	150°C
- Heat transfer coeff.	
- Rectangular channel	15 kW/m^2K
- Rear plate	10 kW/m^2K

- Analysis Model	
- Local first wall model	
- Be coating	2 mm
- Cu plate	5 mm
- SS Cooling channel	5 x 10 mm^2 2 mm thick
- SS rear plate	10 mm
- 2-D generalized plane strain model	

Fig.A－2－1 FEM model for the thermo－mechanical analysis of the first wall of the blanket module.

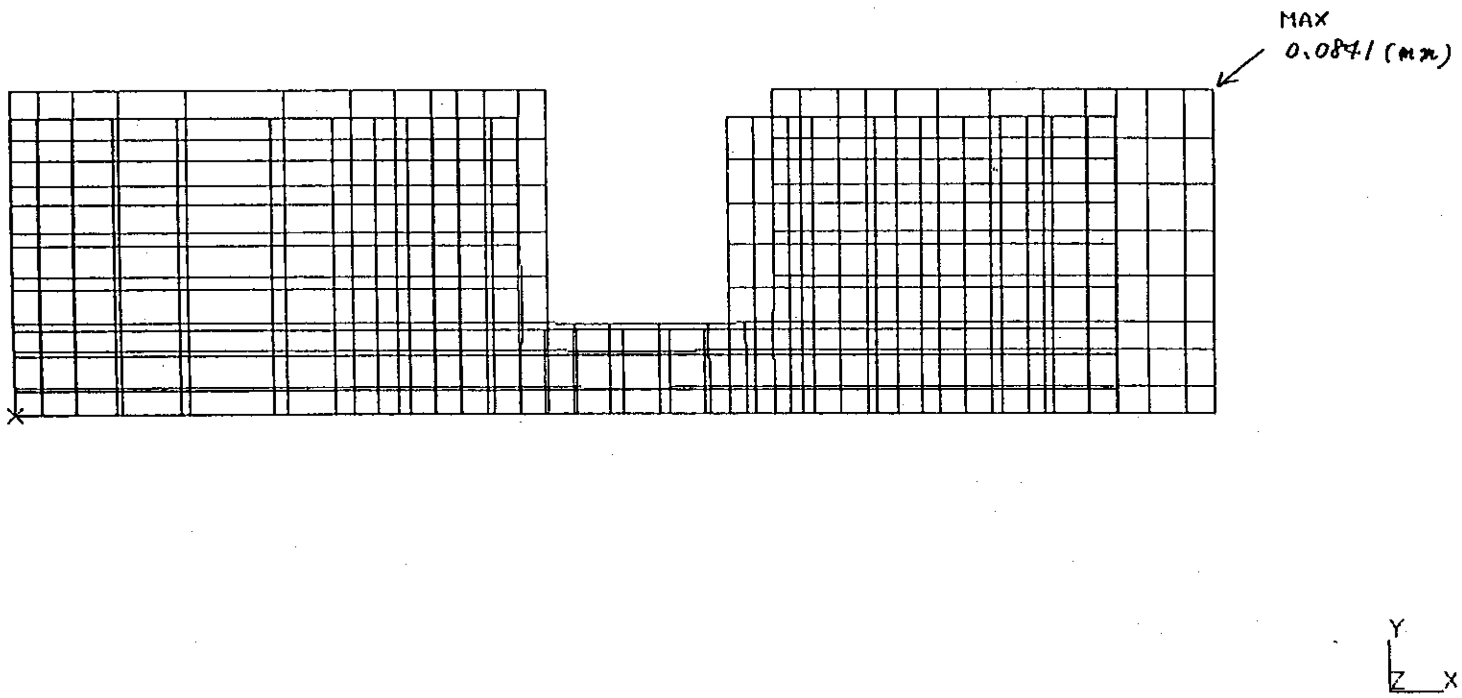


Fig.A - 2 - 2 Displacement of the cross section of the first wall.

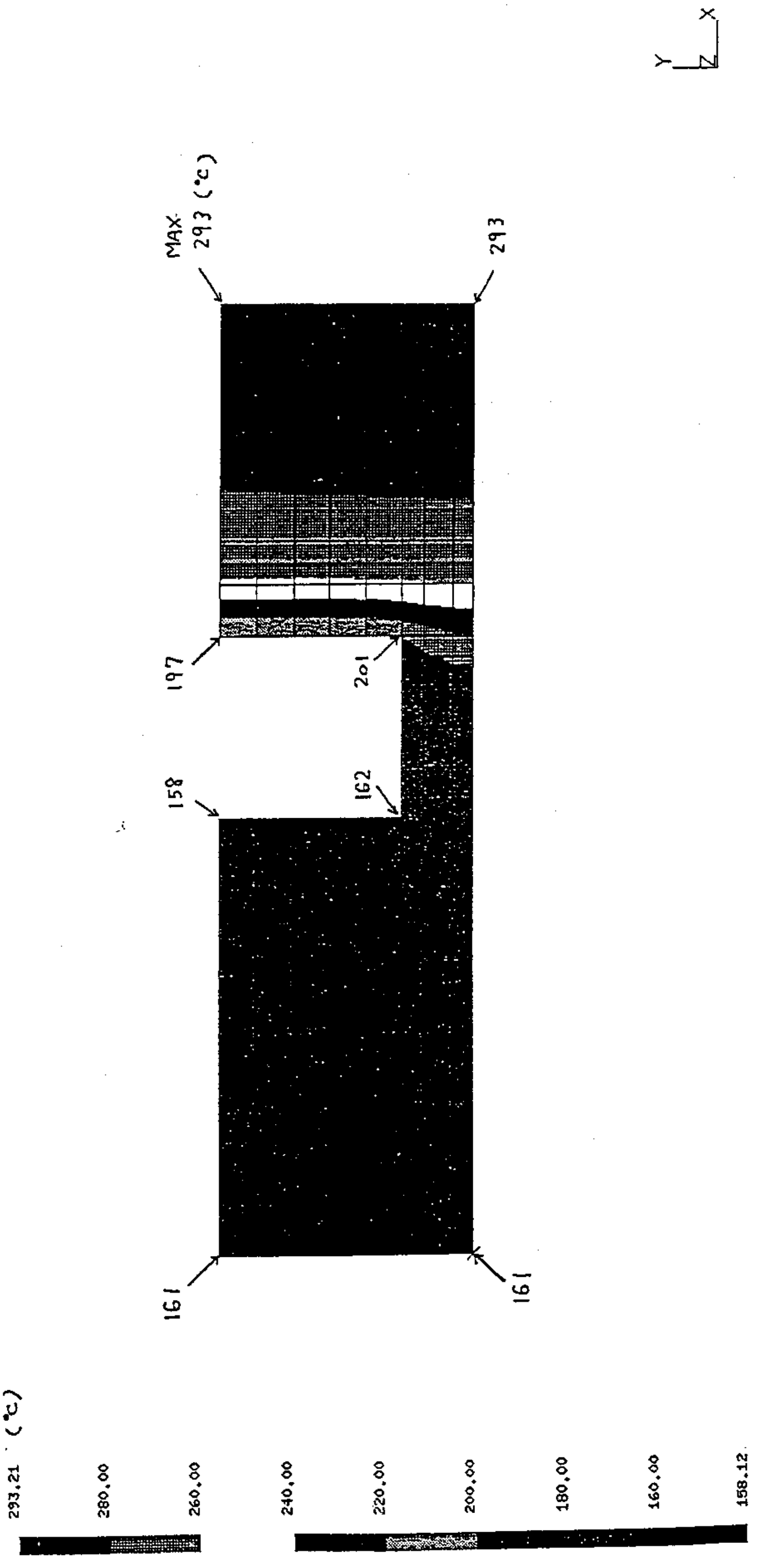


Fig.A - 2 - 3 Temperature distribution of the cross section of the first wall.

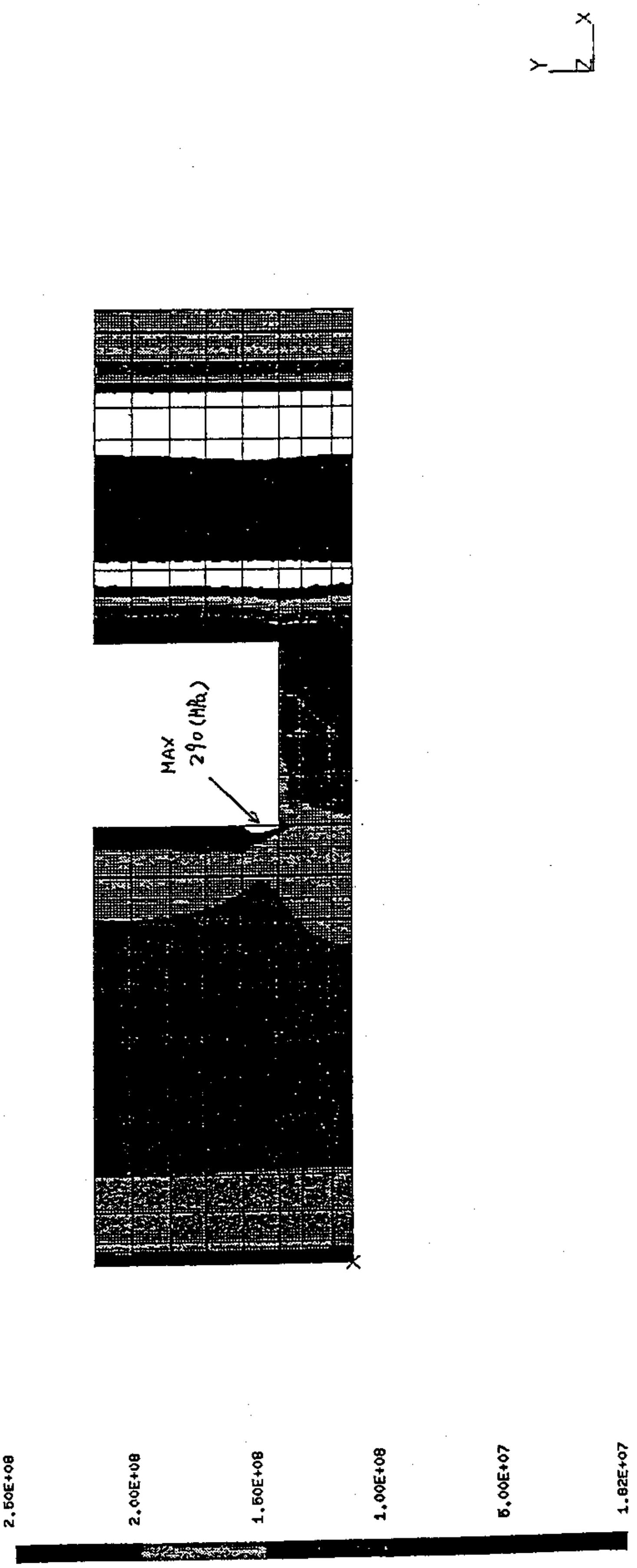


Fig.A－2－4 Tresca stress distribution of the cross section of the first wall.

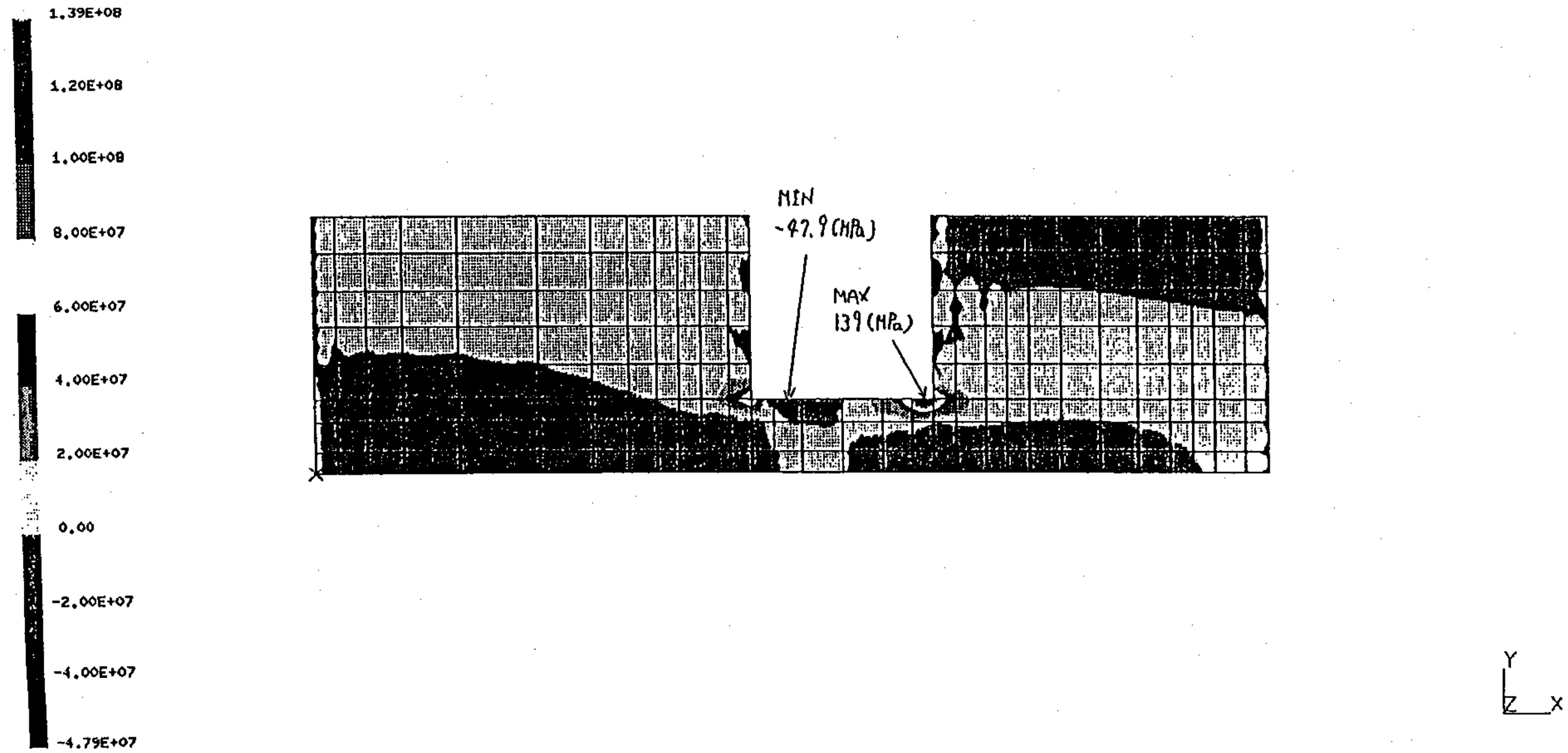


Fig.A − 2 − 5 Normal stress distribution of the radial direction of the cross section of the first wall.

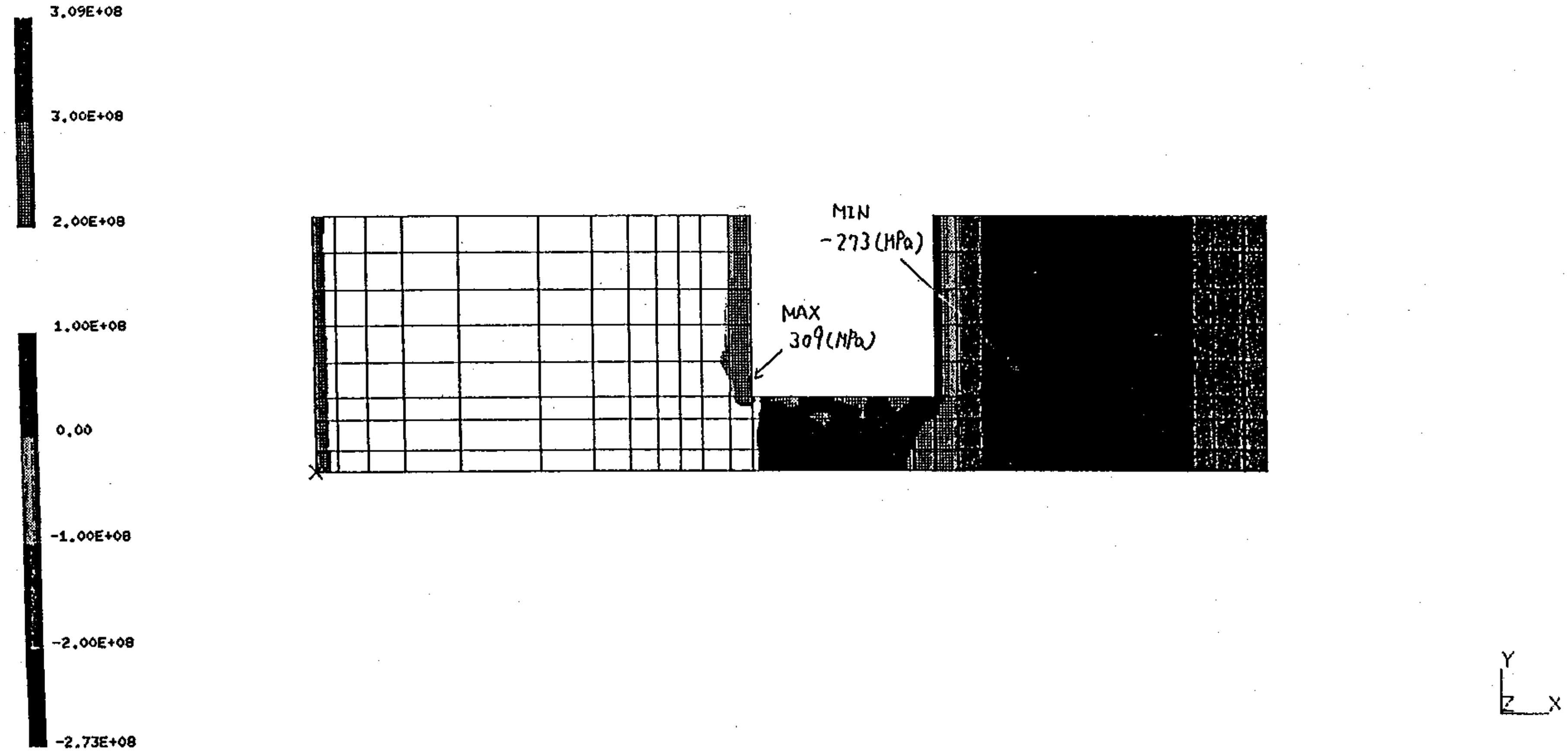


Fig.A − 2 − 6 Normal stress distribution of the toroidal direction of the cross section of the first wall.

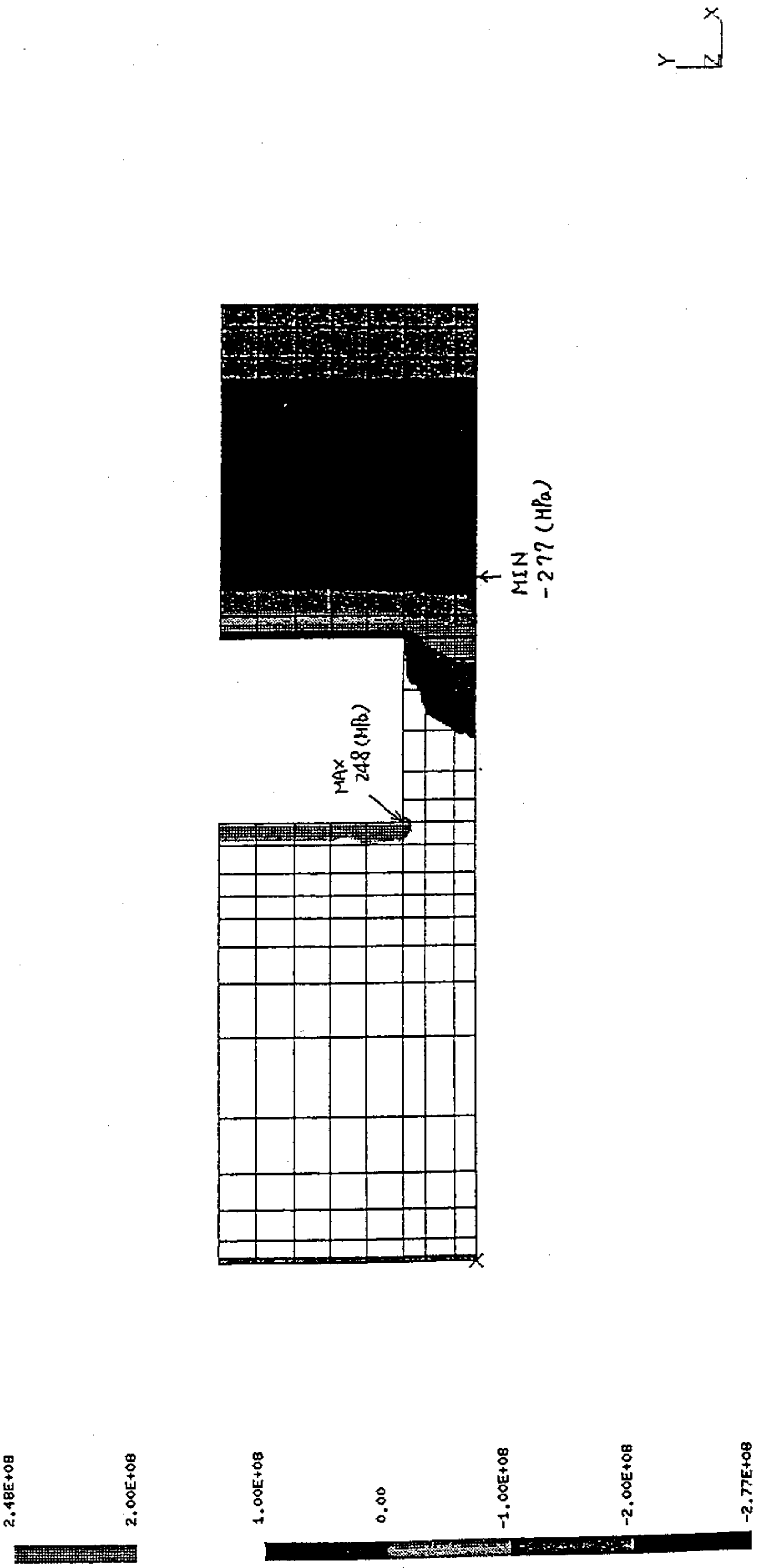


Fig.A－2－7 Normal stress distribution of the poloidal direction of the cross section of the first wall.

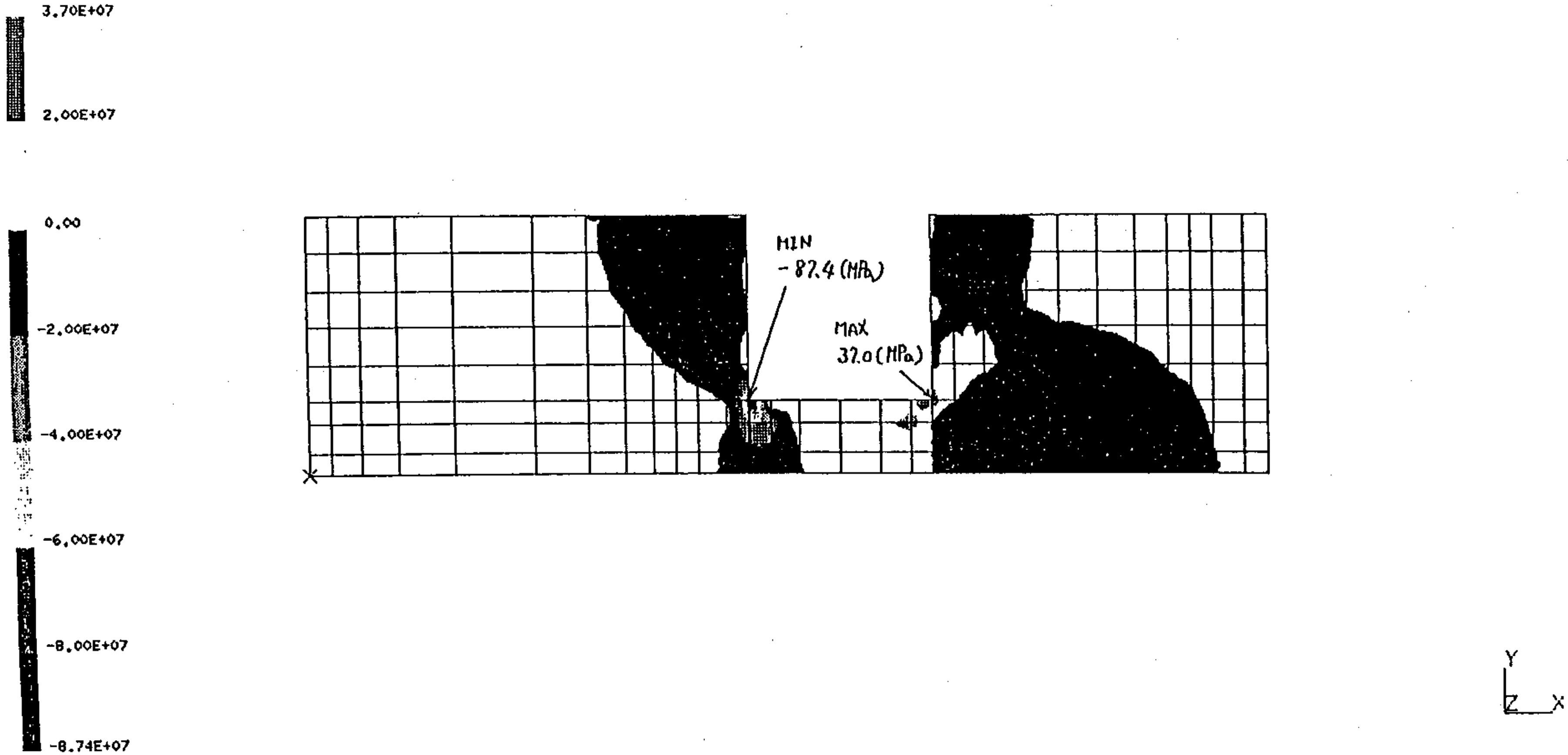


Fig.A − 2 − 8 Shear stress distribution of the cross section of the first wall.

Mechanical Analysis of Blanket Module

- Conditions
  - Coolant pressure 2 MPa
  - EM force on first wall 1.5 MPa

- Analysis Model
  - Outboard midplane
    - First wall (Be+Cu+SS) 2+10+19 mm
    - Side wall 30 mm
    - Back plate 100 mm
  - 2-D generalized plane strain model

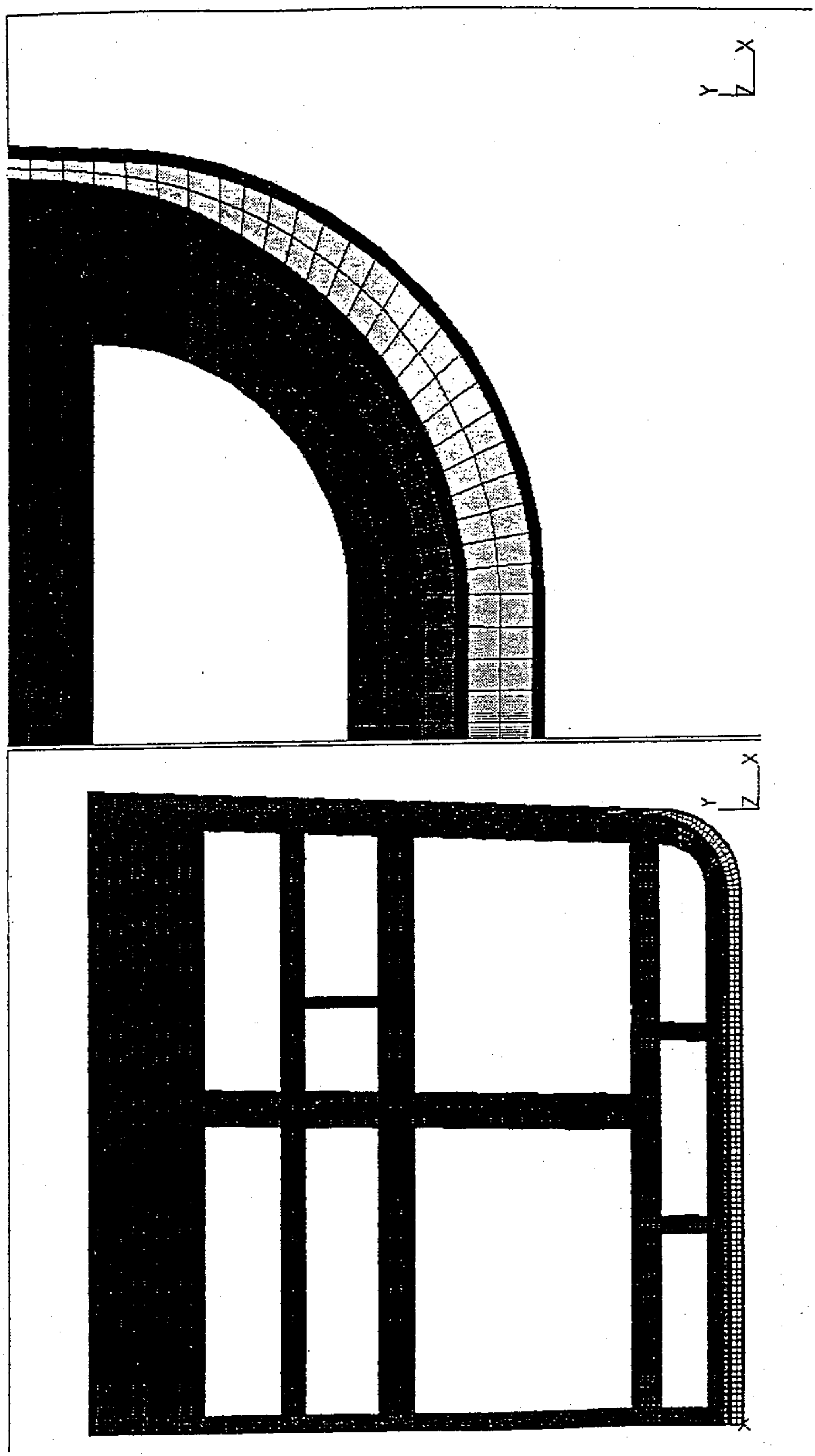
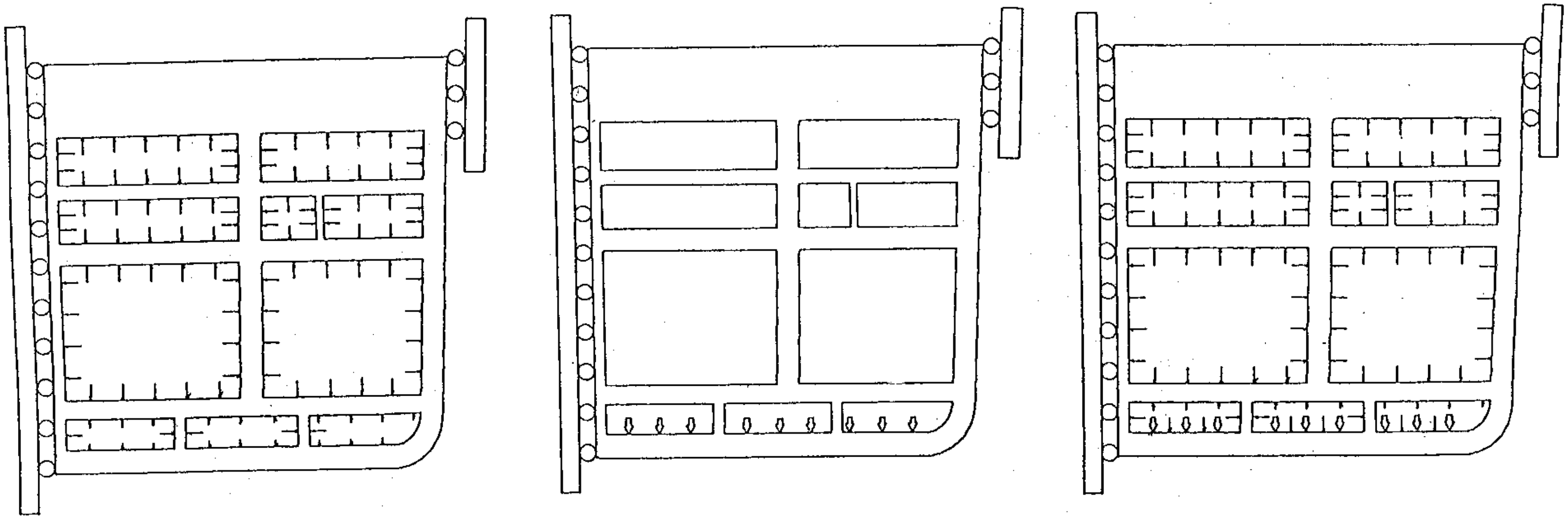


Fig.A－2－9 FEM model for the mechanical analysis of the blanket module.



Load Condition

1. Coolant Pressure 2. 0 (MPa)

Load Condition

1. EM Force 1. 5 (MPa)

Load Condition

1. Coolant Pressure 2. 0 (MPa)
2. EM Force 1. 5 (MPa)

Fig.A − 2 − 10 Boundary condition of FEM model for the mechanical analysis of the blanket module.

Load Condition

1. Coolant Pressure 2.0 (MPa)
2. EM Force 1.5 (MPa)

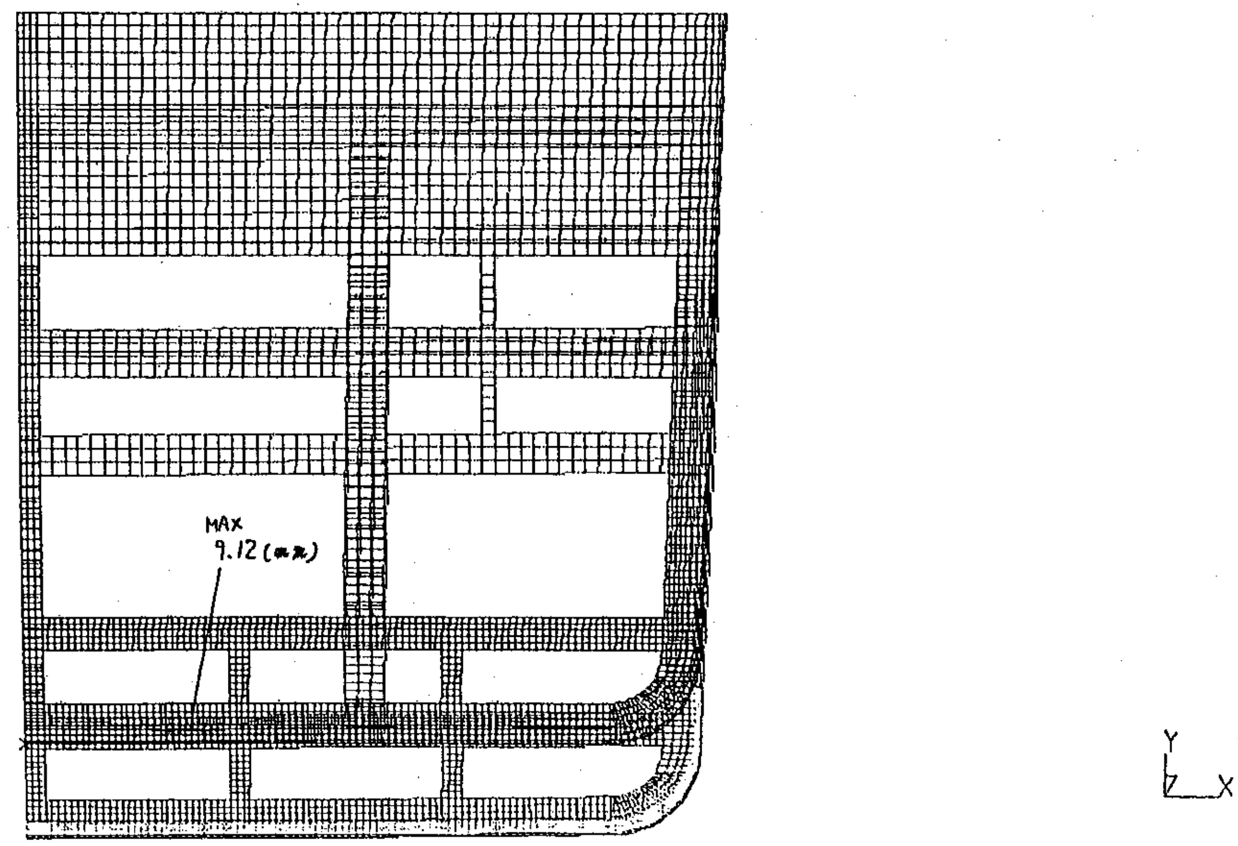


Fig.A − 2 − 11 Displacement of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2. 0 (MPa)
2. EM Force 1. 5 (MPa)

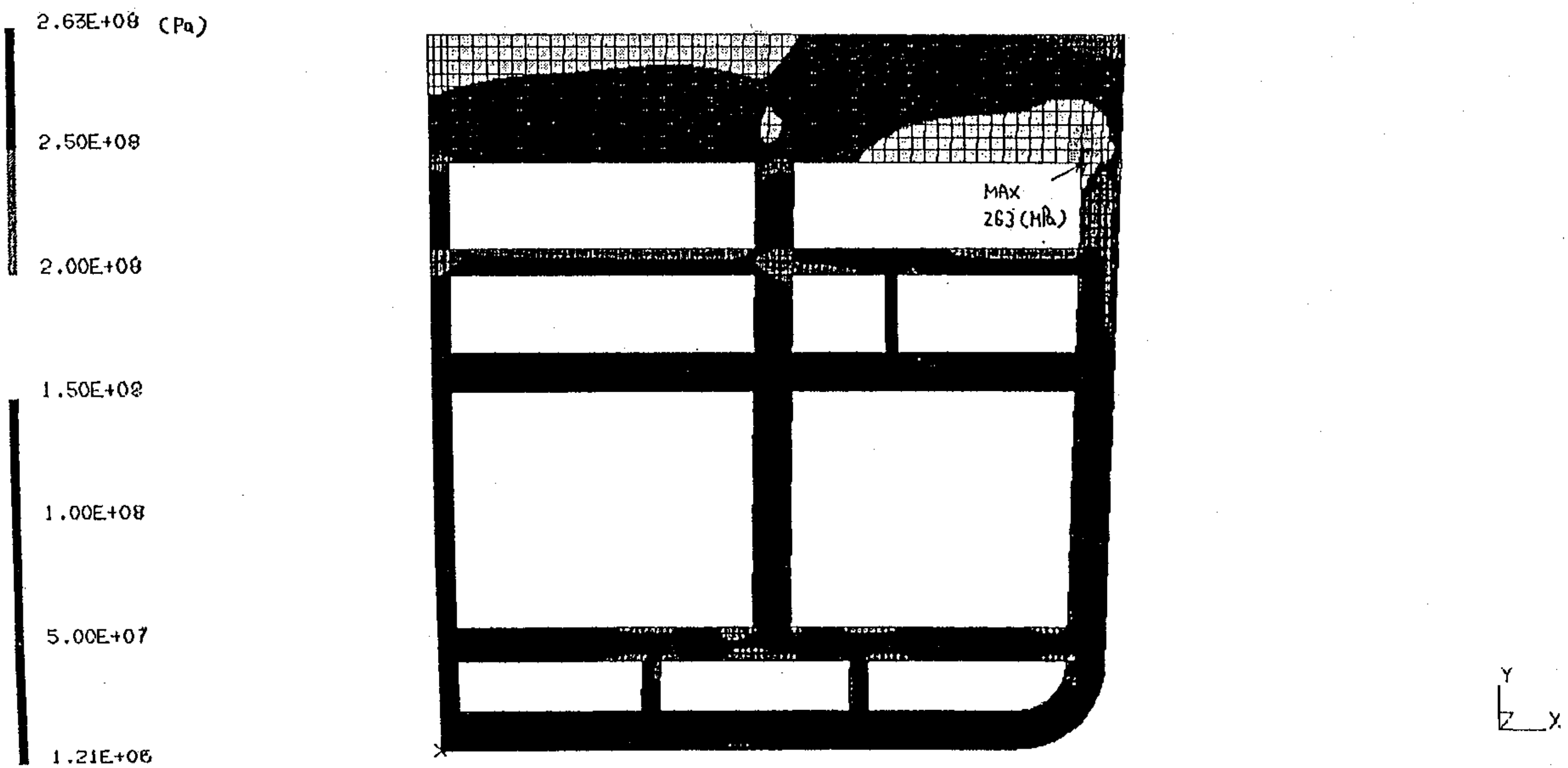


Fig.A − 2 − 12 Tresca stress distribution of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2.0 (MPa)
2. EM Force 1.5 (MPa)

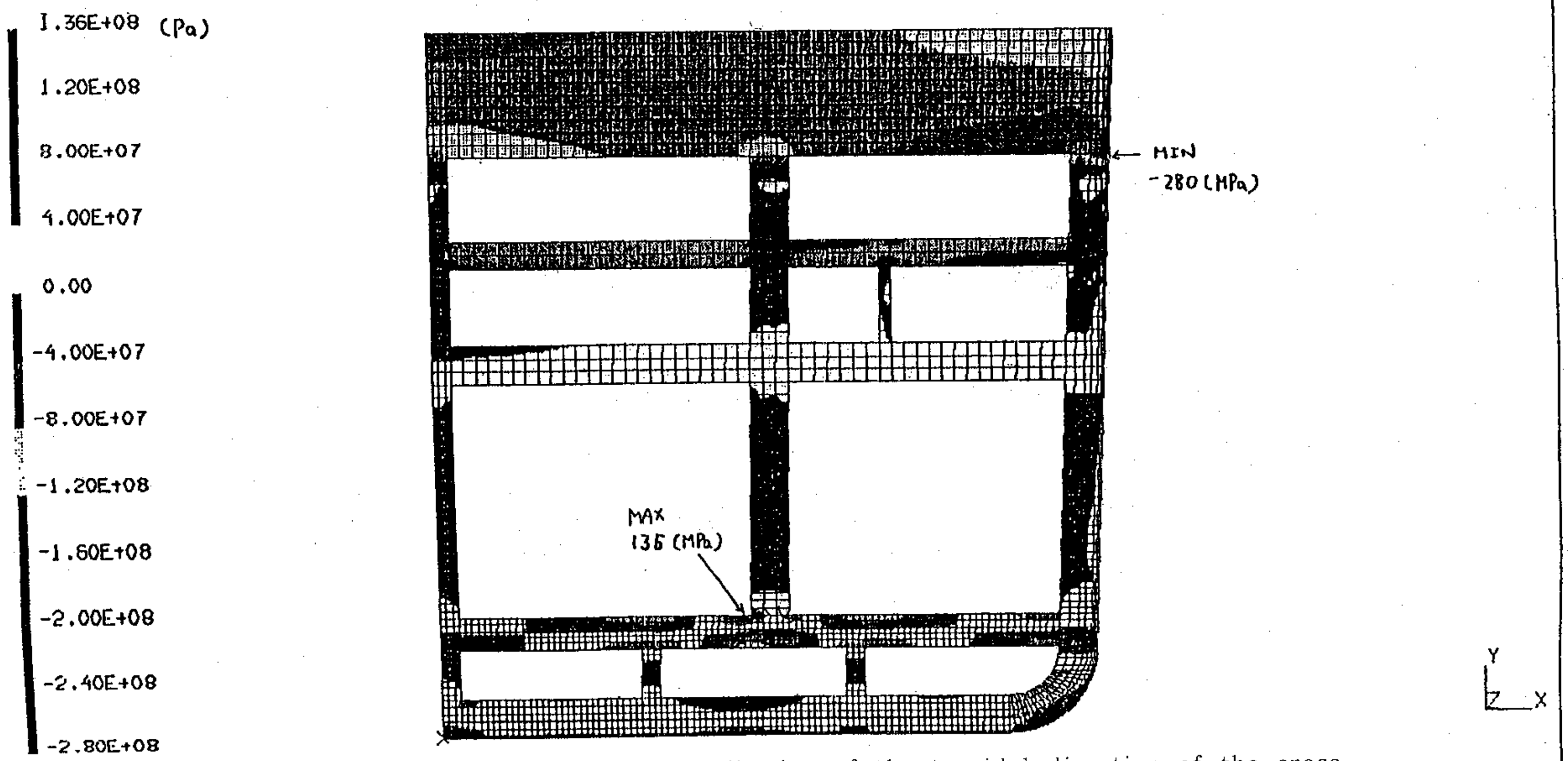


Fig.A − 2 − 13 Normal stress distribution of the toroidal direction of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2.0 (MPa)
2. EM Force 1.5 (MPa)

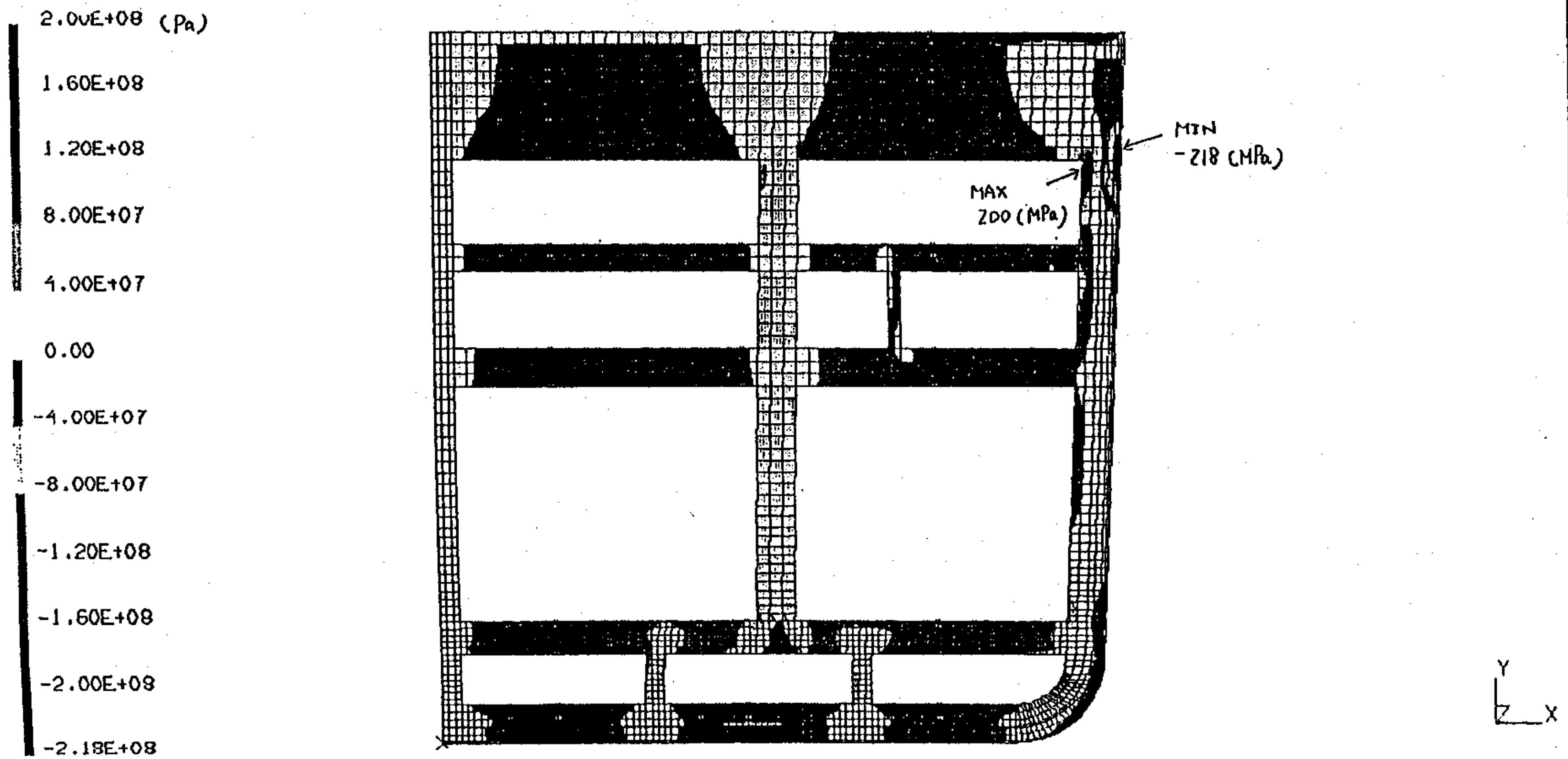


Fig.A－2－14 Normal stress distribution of the radial direction of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2. 0 (MPa)
2. EM Force 1. 5 (MPa)

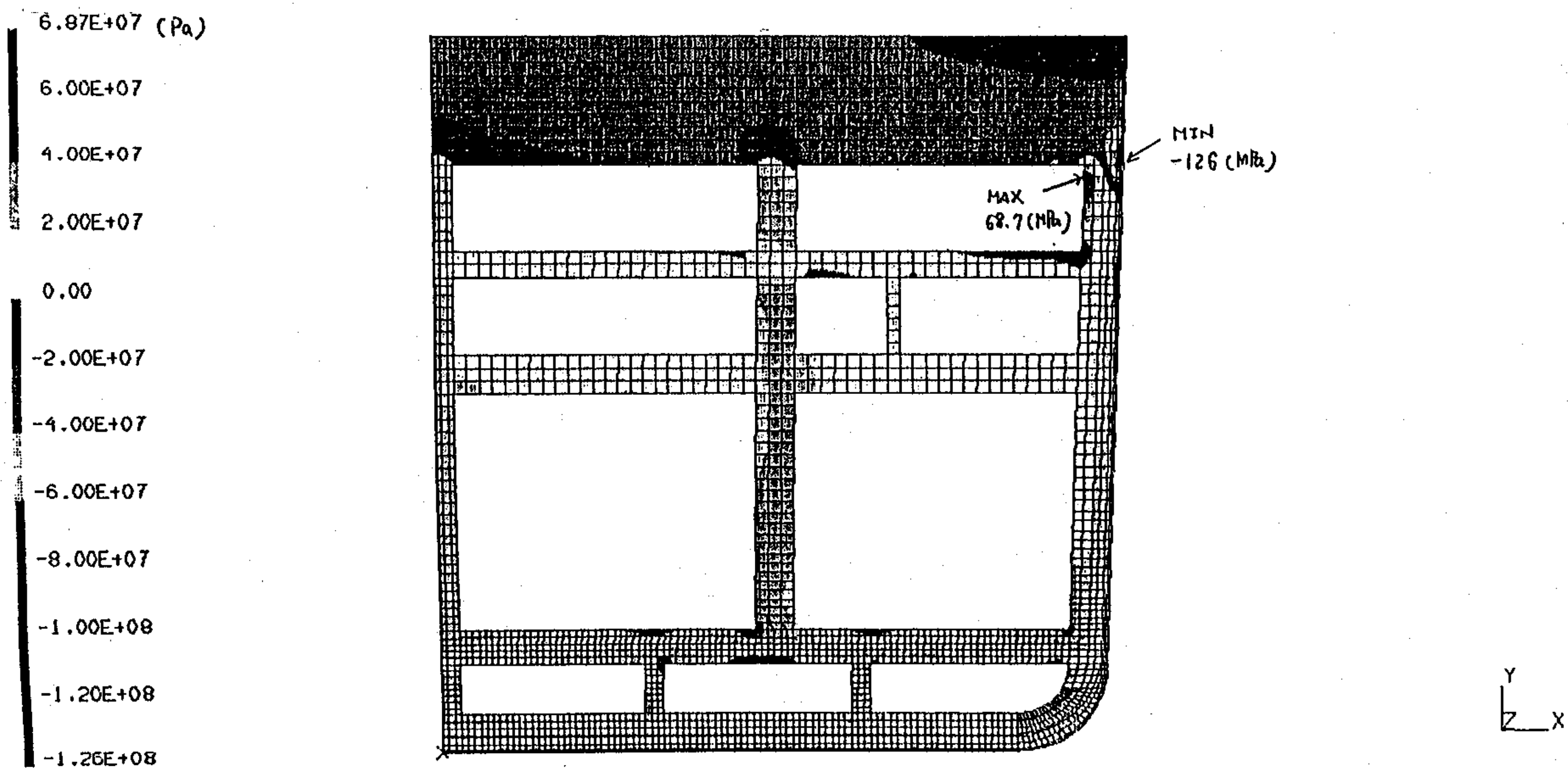


Fig.A − 2 − 15 Normal stress distribution of the poloidal direction of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2.0 (MPa)
2. EM Force 1.5 (MPa)

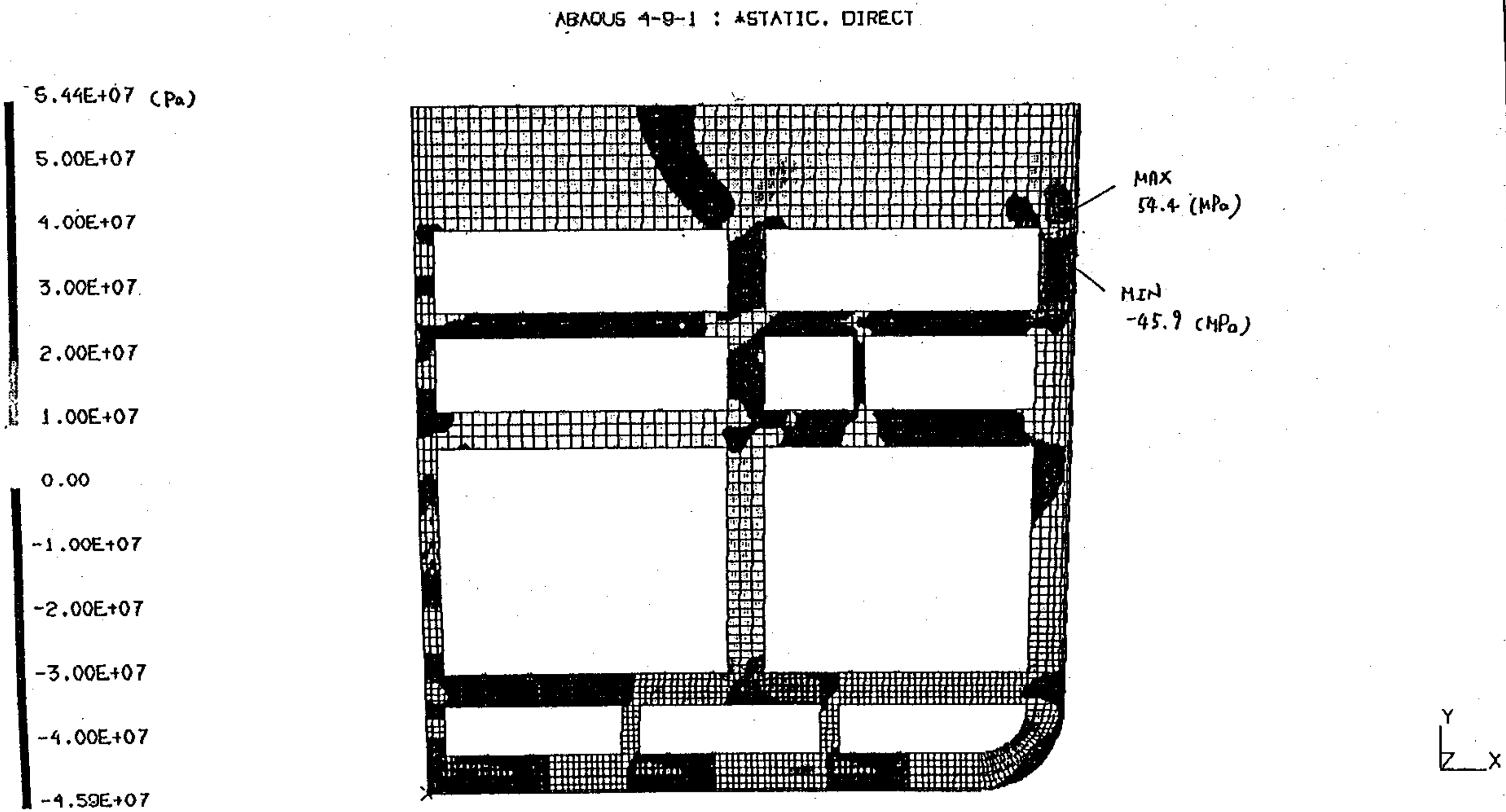


Fig.A − 2 − 16 Shear stress distribution of the cross section of the blanket module due to coolant pressure of 2.0MPa and EM force of 1.5MPa.

Load Condition

1. Coolant Pressure 2.0 (MPa)

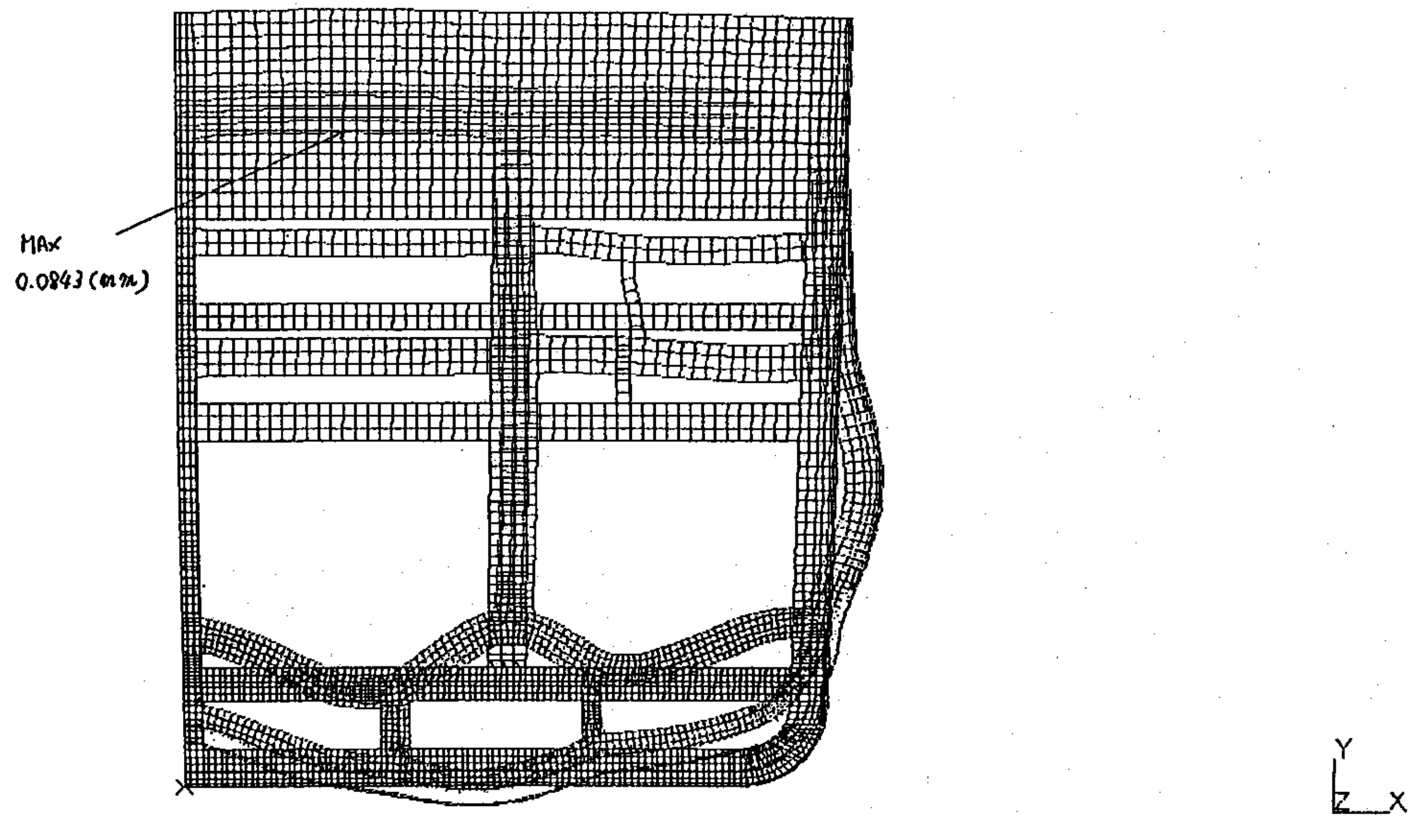


Fig.A − 2 − 17 Displacement of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition

1. Coolant Pressure 2. 0 (MPa)

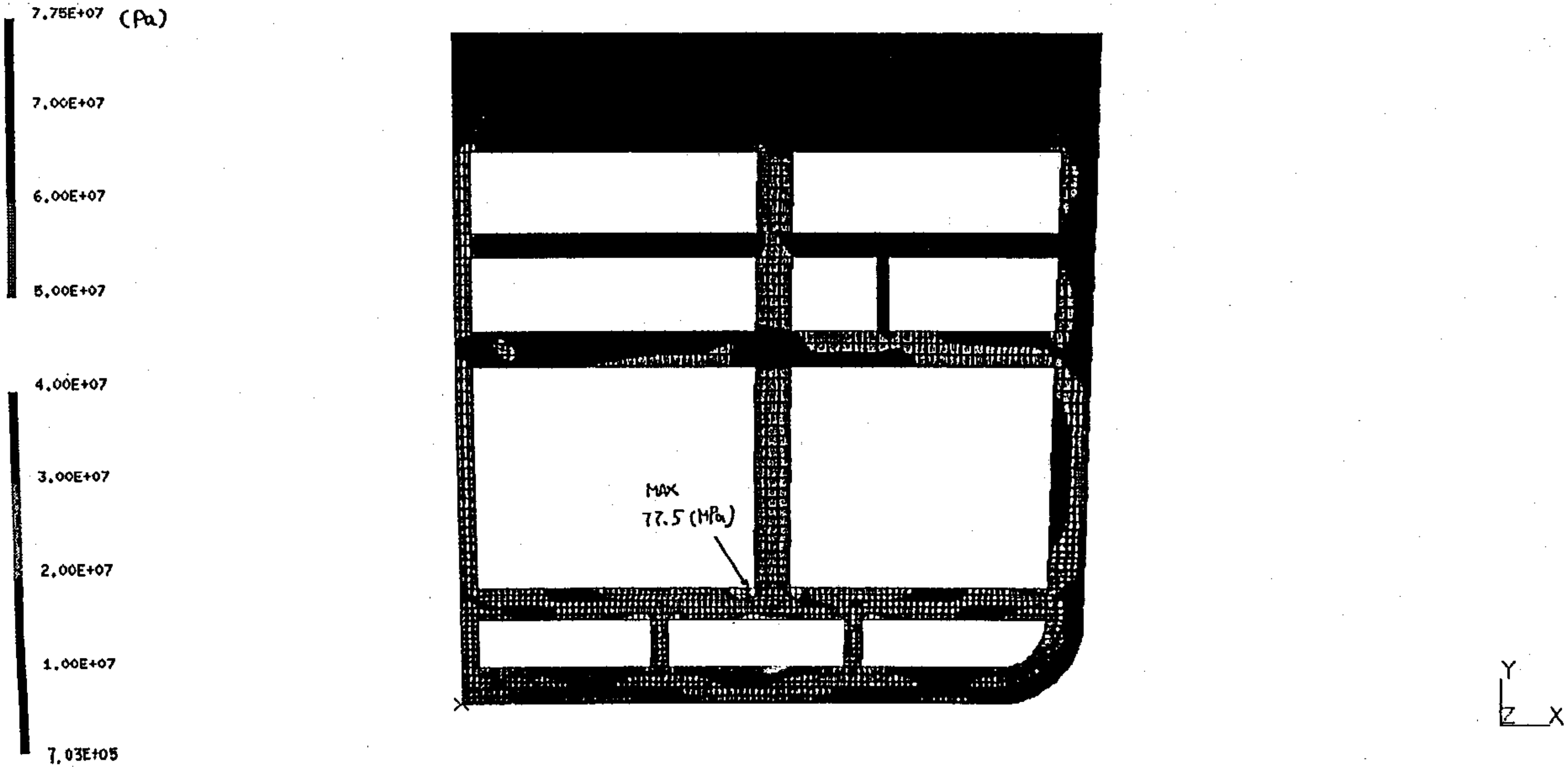


Fig.A－2－18 Tresca stress distribution of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition

1. Coolant Pressure 2. 0 (MPa)

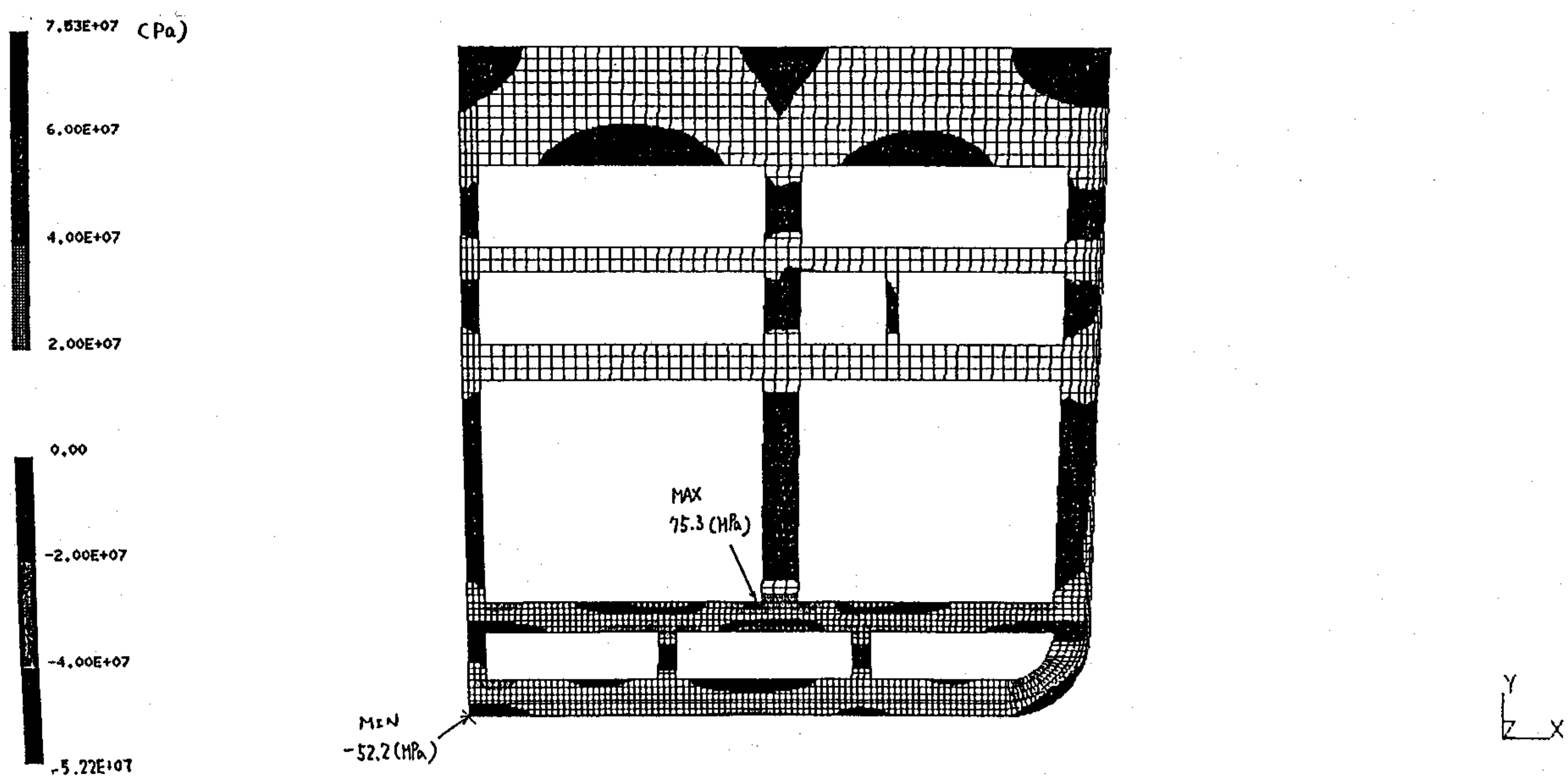


Fig.A － 2 － 19 Normal stress distribution of the toroidal direction of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition.

1. Coolant Pressure 2. 0 (MPa)

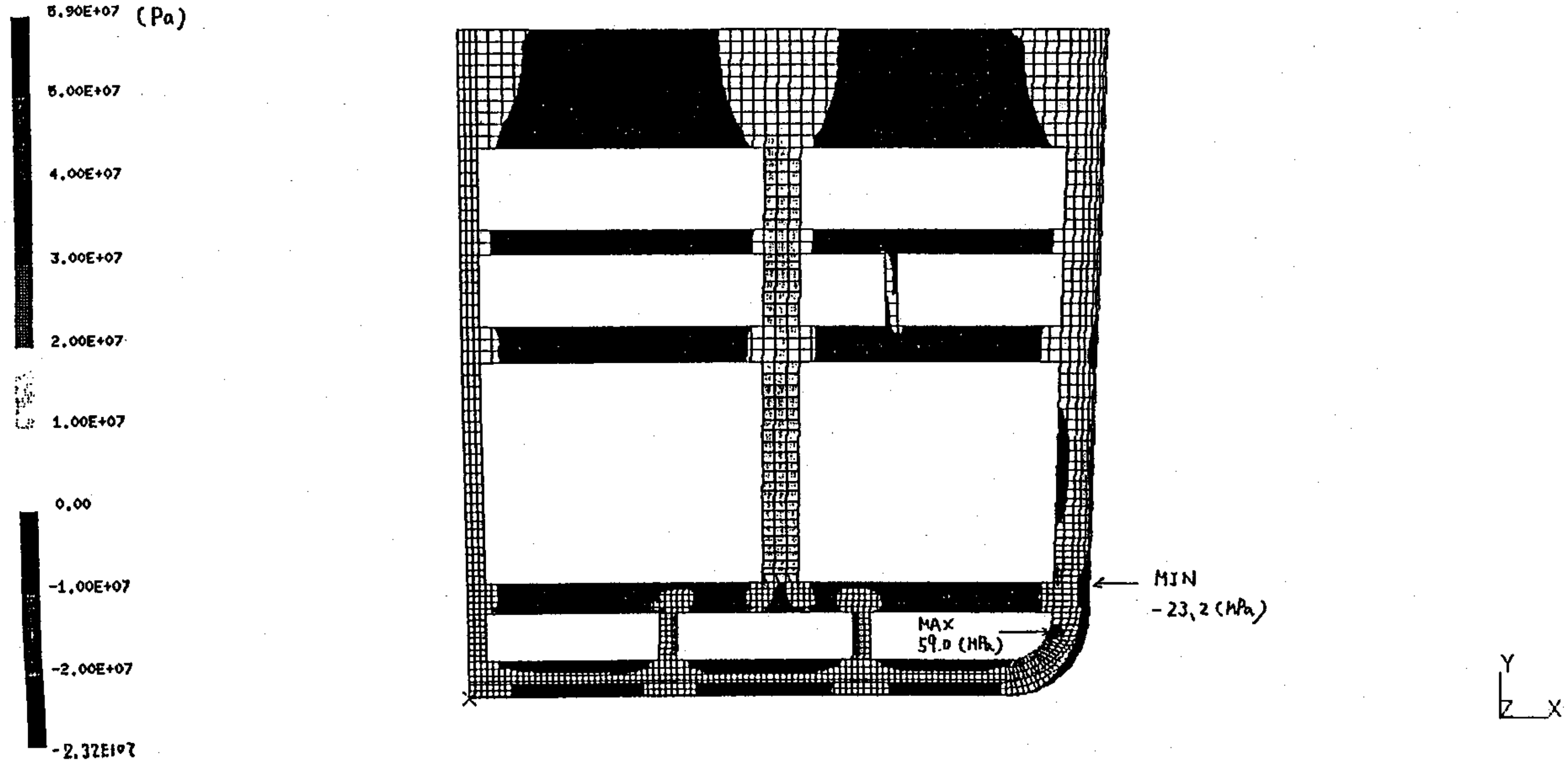


Fig.A - 2 - 20 Normal stress distribution of the radial directaion of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition

1. Coolant Pressure 2.0 (MPa)

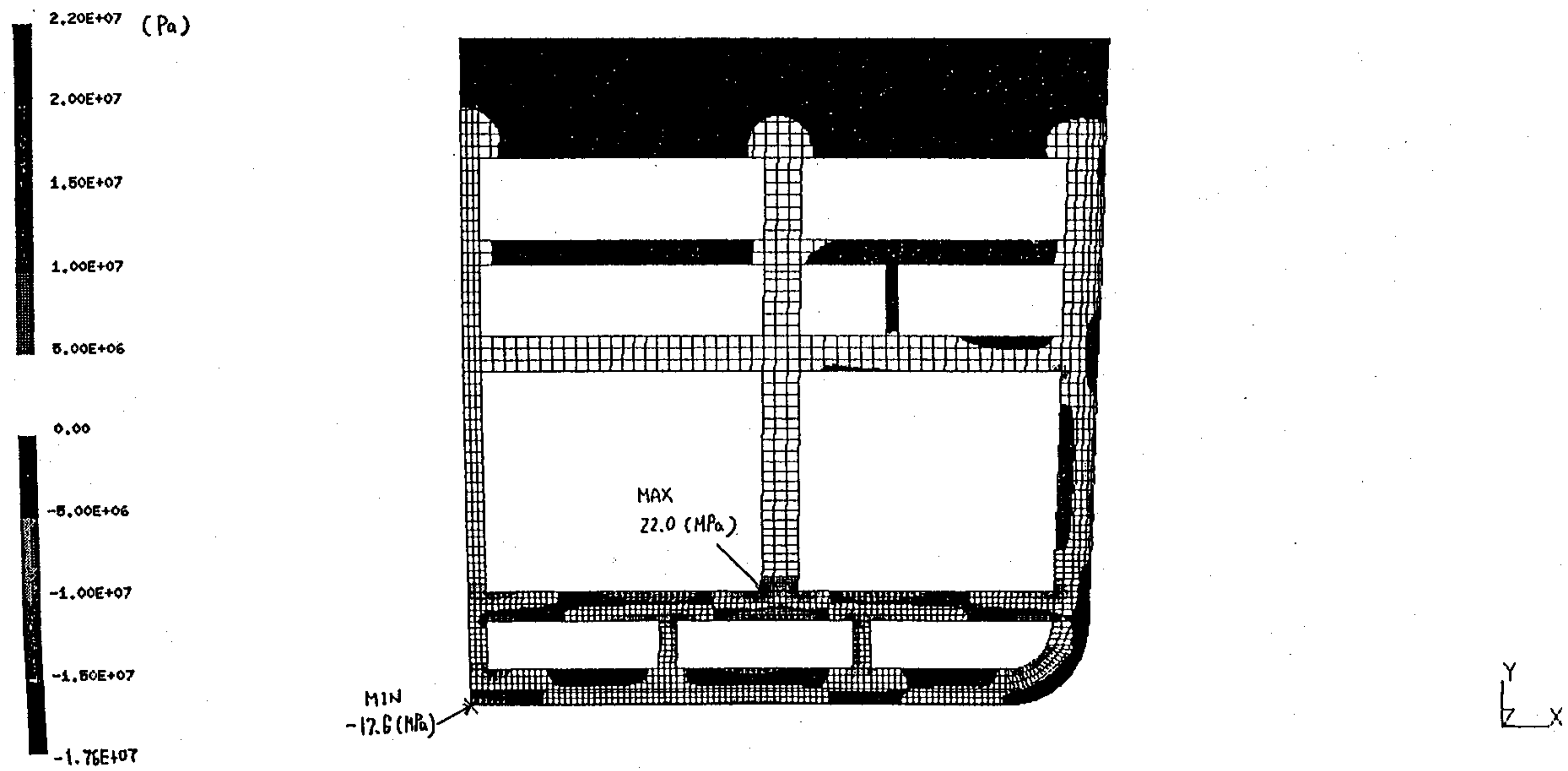


Fig.A − 2 − 21 Normal stress distribution of the poloidal direction of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition

1.. Coolant Pressure 2. 0 (MPa)

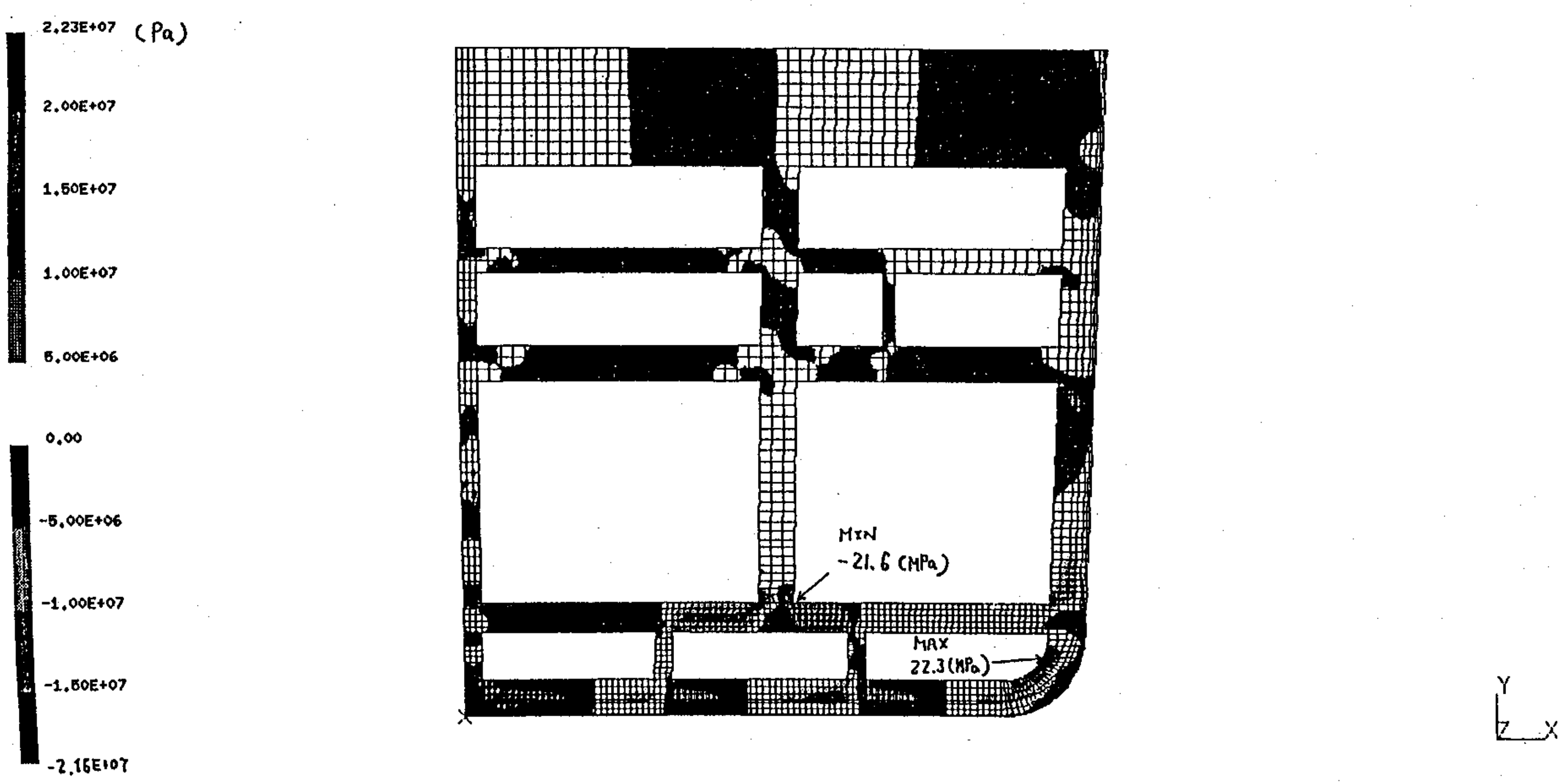


Fig.A - 2 - 22 Shear stress distribution of the cross section of the blanket module due to coolant pressure of 2.0MPa.

Load Condition

1. EM Force 1. 5 (MPa)

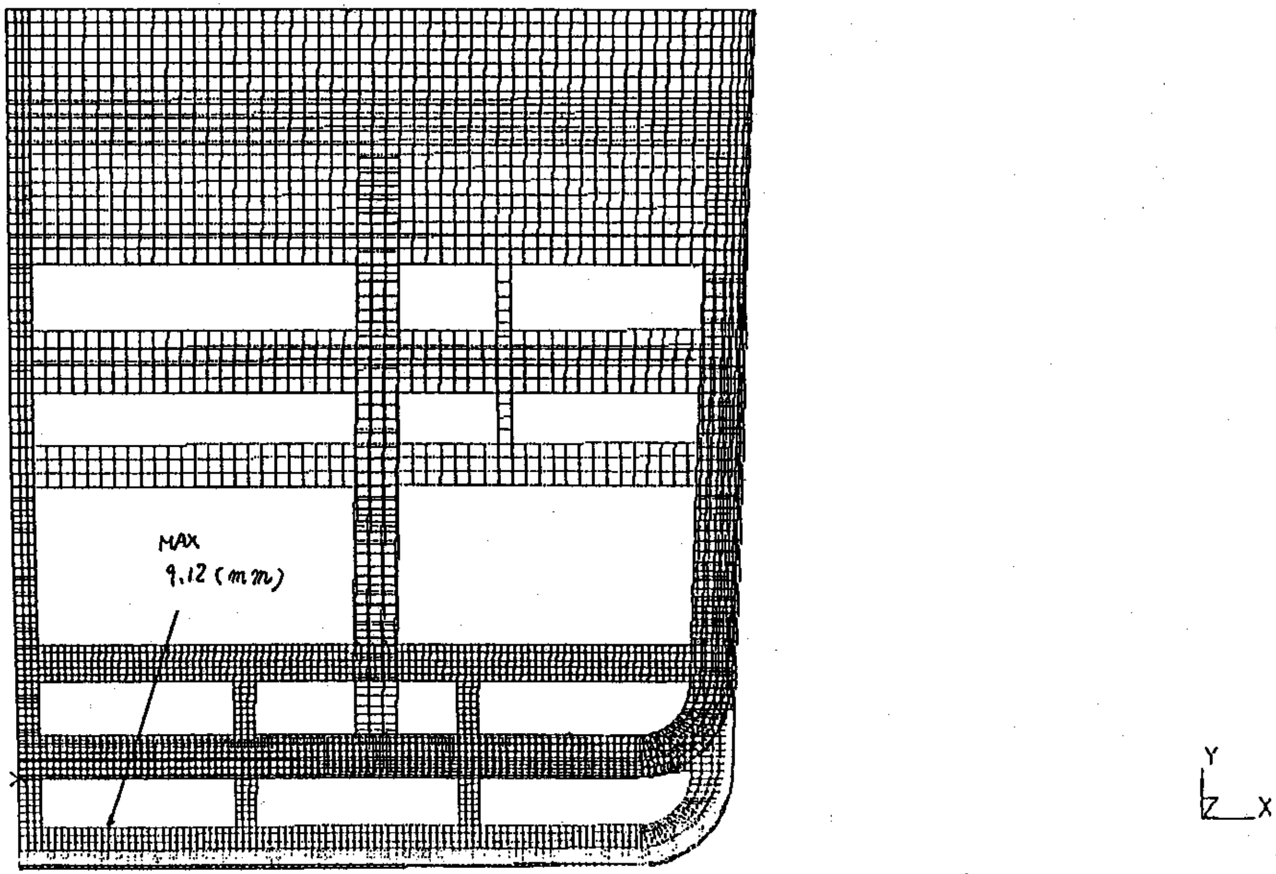


Fig.A − 2 − 23 Displacement of the cross section of the blanket module due to EM force of 1.5MPa.

Load Condition

1. EM Force 1. 5 (MPa)

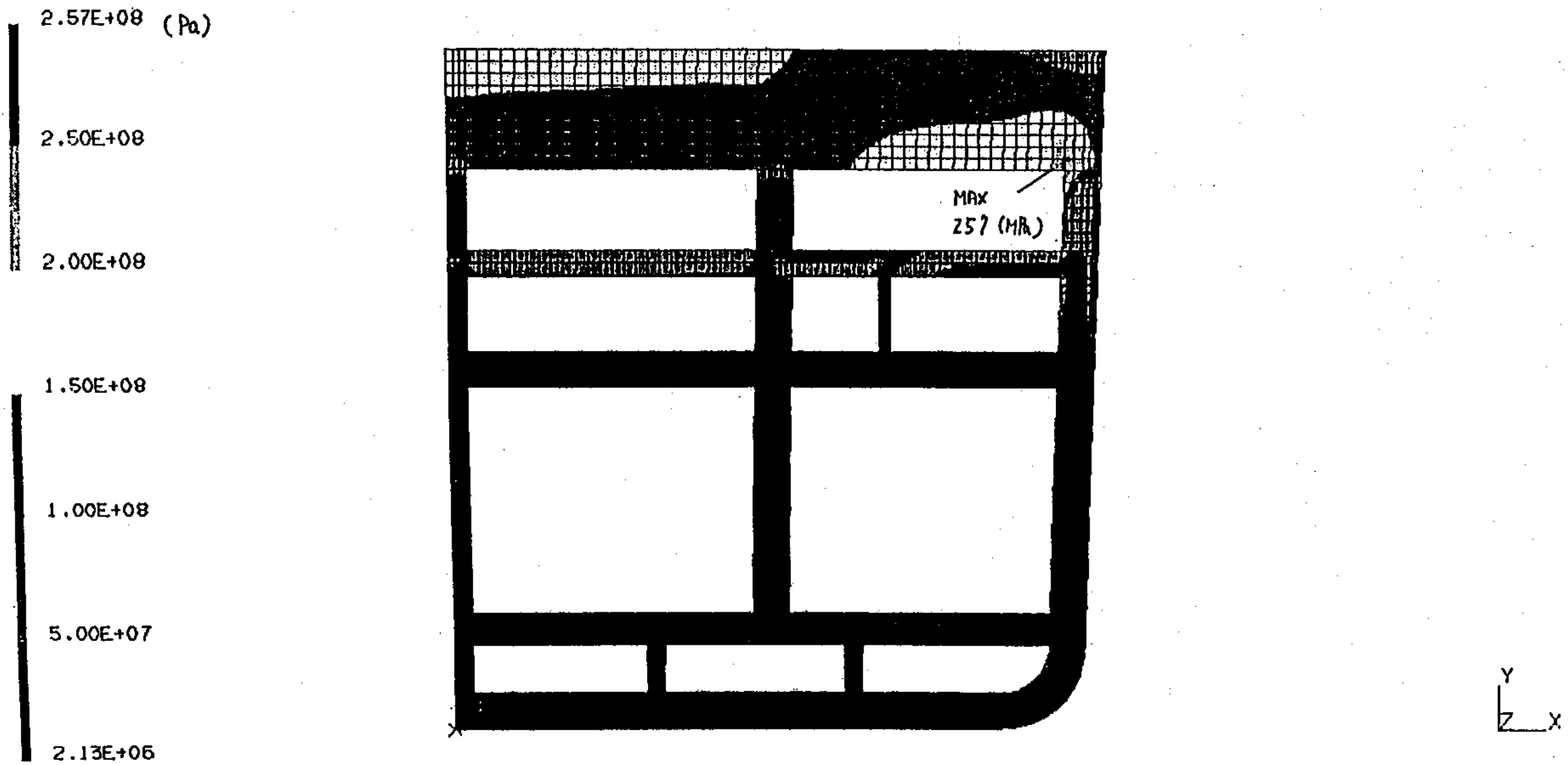


Fig.A - 2 - 24 Tresce stress distribution of the cross section of the blanket mobule due to EM force of 1.5MPa.

Load Condition

1. EM Force 1.5 (MPa)

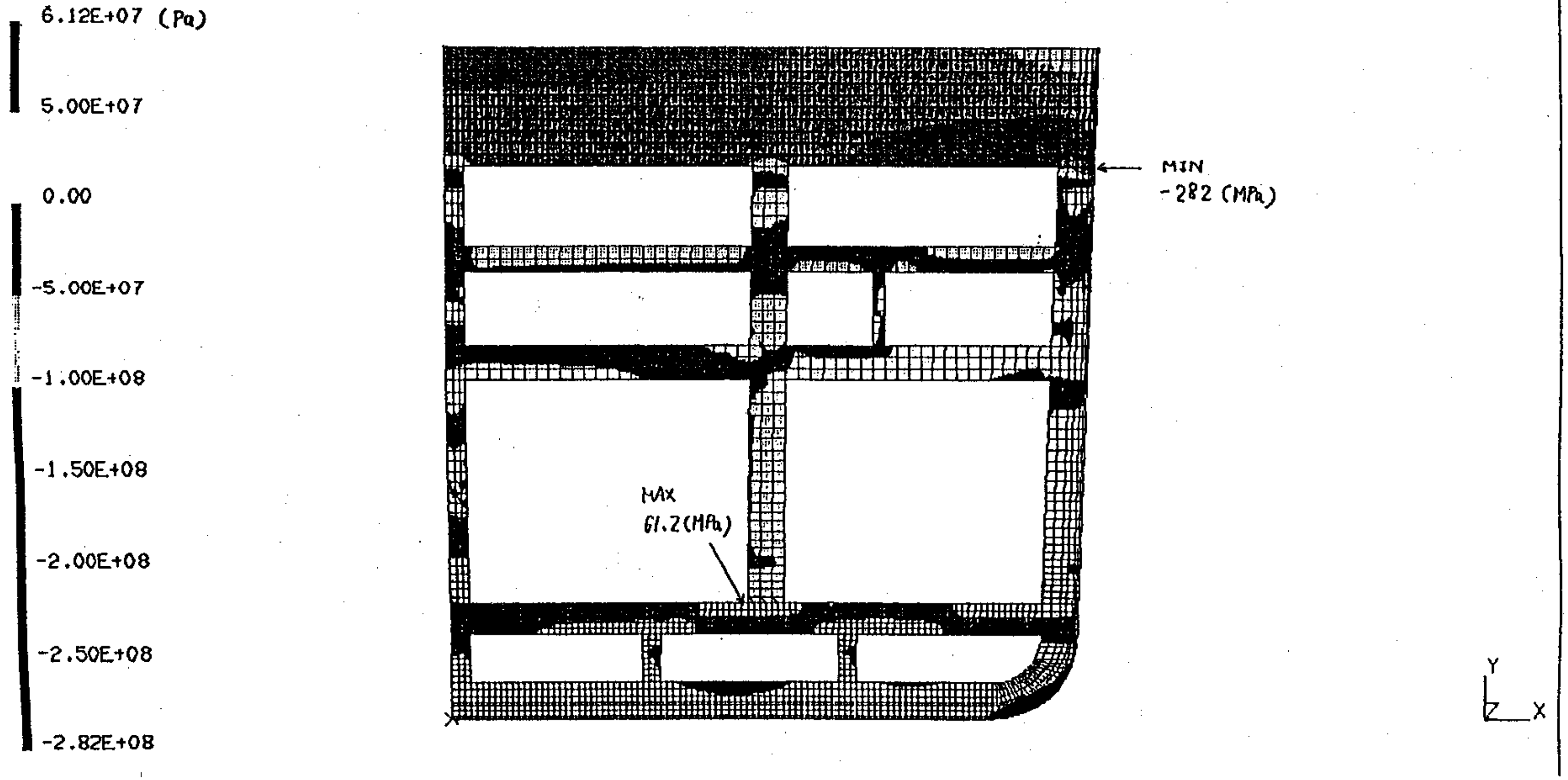


Fig.A - 2 - 25 Normal stress distribution of the toroidal direction of the cross section of the blanket module due to EM force of 1.5MPa.

Load Condition

1. EM Force 1. 5 (MPa)

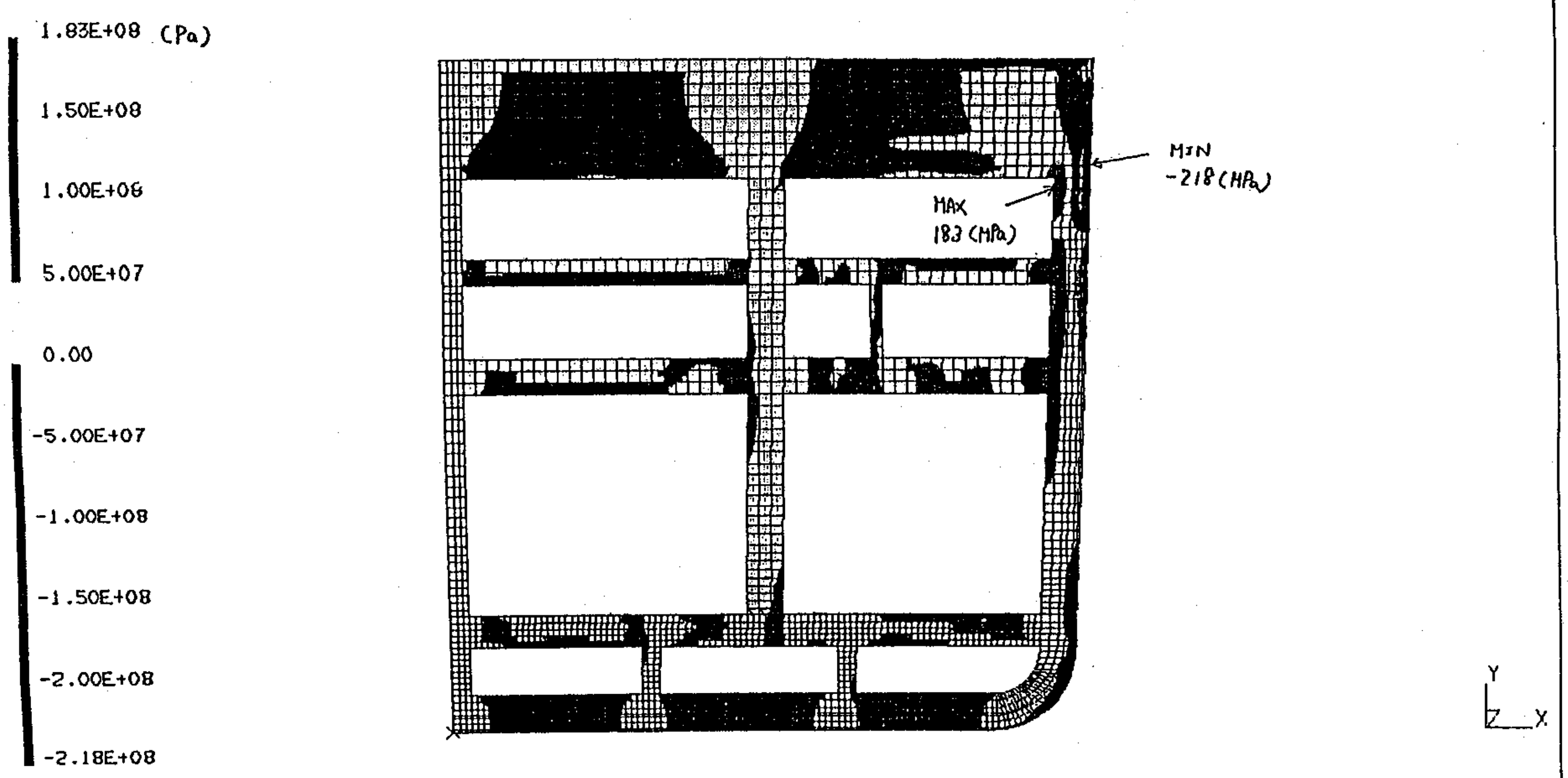


Fig.A − 2 − 26 Normal stress distribution of the radial direction of the cross section of the blanket module due to EM force of 1.5MPa.

Load Condition

1. EM Force 1. 5 (MPa)

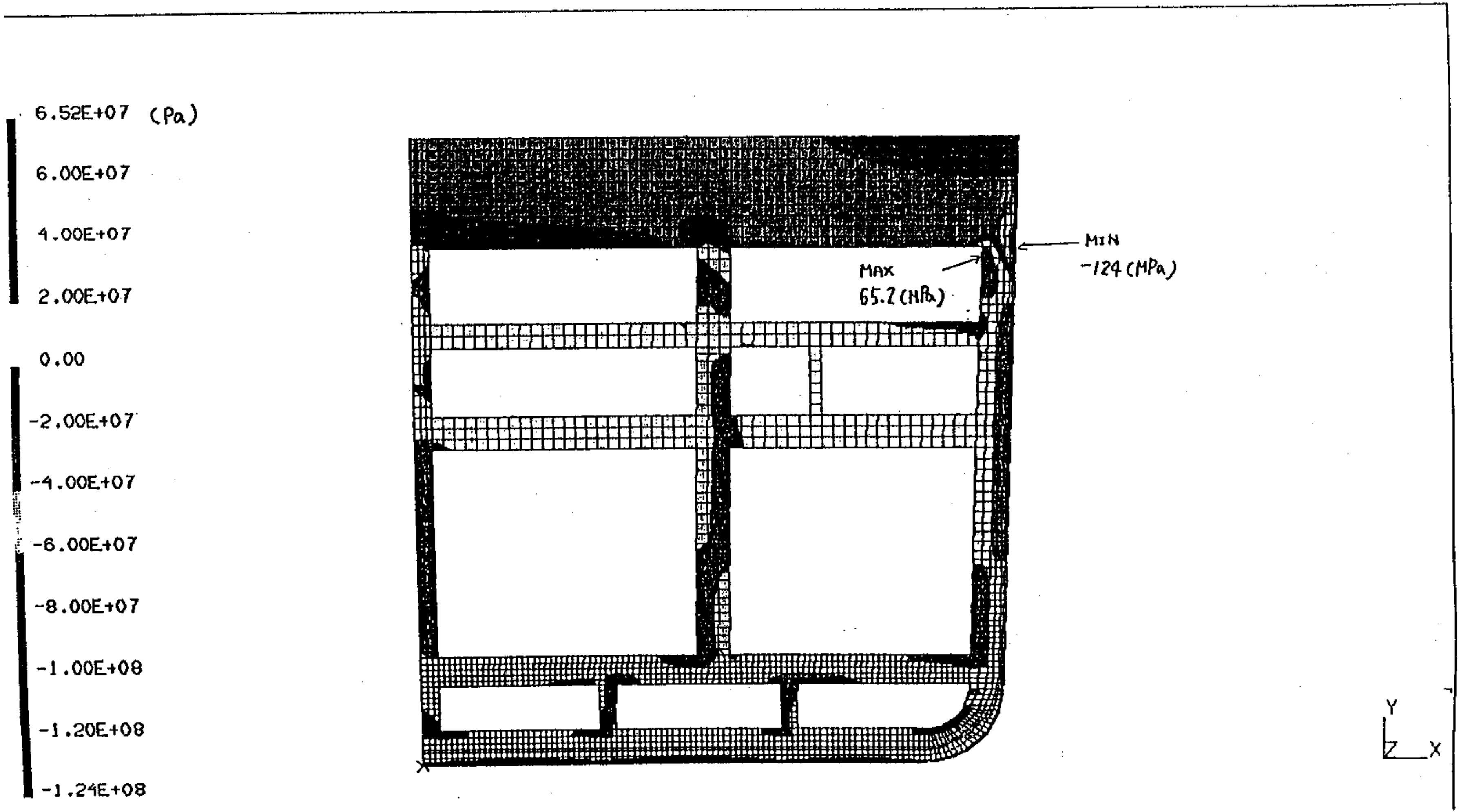


FIg.A − 2 − 27 Normal stress distribution of the poloidal direction of the cross section of the blanket module due to EM force of 1.5MPa.

Load Condition

1. EM Force 1.5 (MPa)

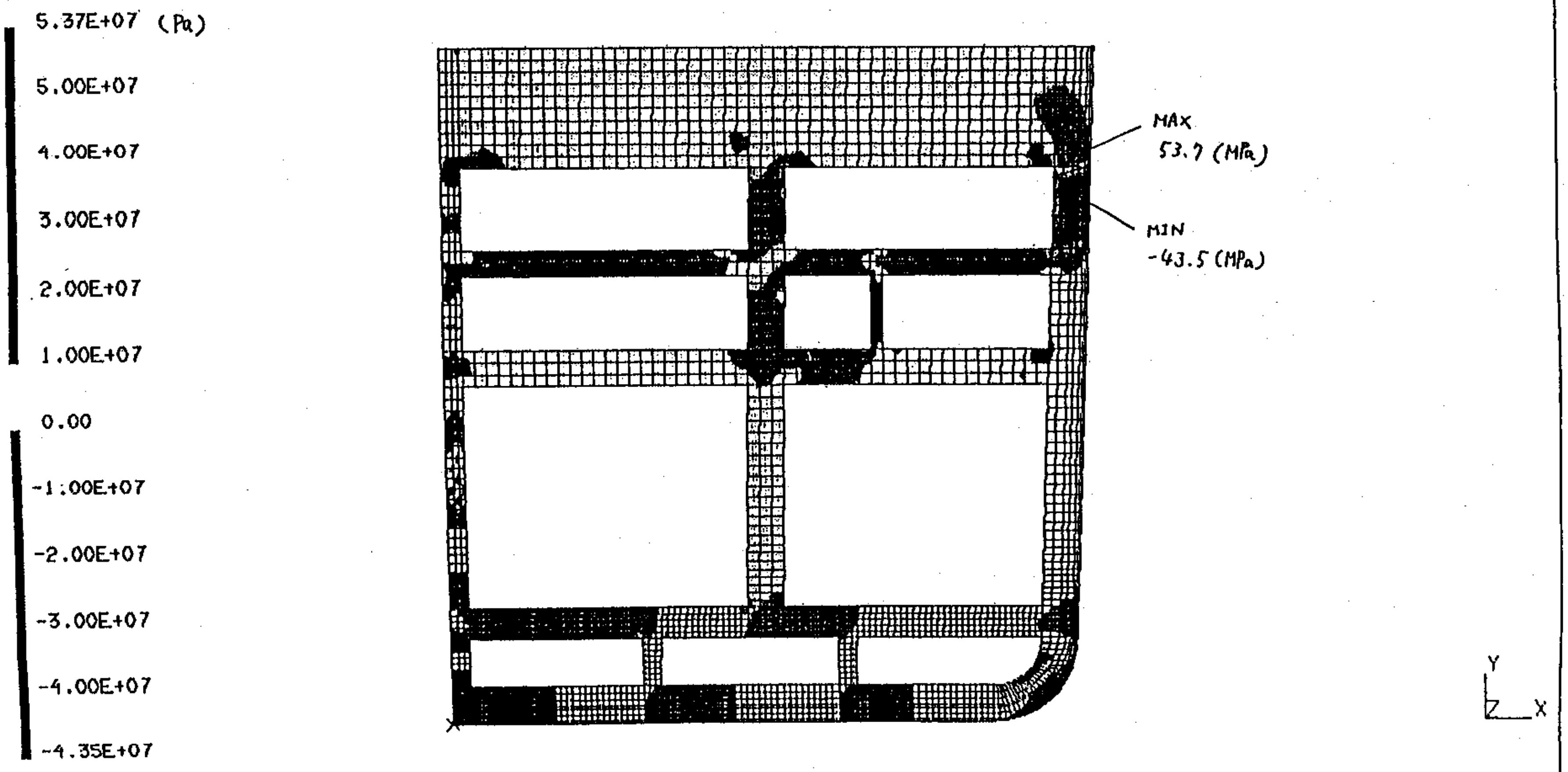


Fig.A − 2 − 28 Shear stress distribution of the cross section of the blanket module due to EM force of 1.5MPa.

Appendix 3

Electromagnetic and Mechanical Analyses of the ITER Blanket/First Wall

Electromagnetic and mechanical analysis of modular type blanket module

1. Electromagnetic Analysis

1.1 Assumptions

(1) Structural assumption
- a) Blanket module: Modular-type segmented poloidally (1m pitch)
  - First wall: 10 mm^t of Cu-alloy
  - Side wall: 30 mm^t of SS316
  - Back plate: 70 mm^t of SS316
  - End wall: 15 mm^t of SS316
  - Top & bottom plate: 30 mm^t of SS316
- b) Vacuum vessel: Double-walled structure of Inconel 625

(2) Electrical connection
- Back plates are electrically connected in the toroidal direction
- No electrical connection at the FW

(3) Disruption Condition
- Centered disruption of 24 MA plasma during EOB in 10 ms (-2.4 MA/ms)

(4) Calculation Model for EDDYCAL
- 3D shell model of IB blanket and VV (OB blanket modules are not included in the model to save CPU time)
- Detailed mesh for 3 box modules around the horizontal plane, no poloidal segmentation for other region

1.2 Results of EM analysis

(1) Time evolution of total eddy current in the each part of modular-type box structure is shown in Fig. 1 and Fig. 2.

(2) Distribution of eddy current and EM load in 3 box-type modules around horizontal plane of IB is shown in Fig. 3.

(3) Detail distribution of eddy current in a modules located on the horizontal plane is shown in Fig. 4.

(4) Vertical EM load calculated for the box structure at horizontal plane is illustrated in Fig. 5.

- Vertical load of box module:	± 4.7 MN
in side wall:	± 3.33 MN
in support rib:	± 1.33 MN
- Total vertical load of full poloidal modules:	± 41.4 MN

2. Stress analysis of box-type IB modules

2.1 Assumptions

(1) Blanket box structure

- Box structure of blanket module is supported by "support rib" of 50 mm thickness.

- Inside of box structure is reinforced by radial and lateral ribs.

- Thickness of end wall is increased from 15 mm to 30 mm.

Stress analysis model of a box structure is shown in Fig. 11. Three box structures around horizontal plane are analyzed by using fine meshing.

Element loads calculated by EM analysis were employed for loading condition.

(2) Boundary conditions

- Toroidal movements of back plate were constrained along the edge of back plate

- Vertical movement of full poloidal sector is constrained by beam element which represents the blanket supporting structure.

2.2 Results of stress analysis performed by using MSC/NASTRAN

(1) Deformation of box-type blanket modules located around horizontal plane is shown in Fig. 12. The maximum displacements calculated are as follows;

- Max. in toroidal direction: ±0.95 mm
- Max. in vertical direction: ±0.65 mm
- Total Max. (abs.): ±1.2 mm

(2) Distribution of Von Mises stress in modular-type blanket modules around horizontal plane is shown in Fig. 13. Stress distribution inside of box structure is shown in Fig. 14. Maximum stress of 150 MPa is calculated at the support rib and back plate.

(3) Detailed distribution of FW, end wall, back plate, side wall, support rib, inner ribs and top/bottom plate are shown from Fig. 15 to Fig. 21.

The maximum stress calculated are summarized as follows;

- First wall: 33 MPa
- End wall: 151 MPa
- Back plate: 123 MPa
- Side wall: 113 MPa
- Support rib: 283 MPa
- Inner rib: 28 MPa
- Top/bottom plate: 98 MPa

The maximum stress of 283 MPa calculated for the inter-region between support rib and back plate can be reduced by the optimization of corner thickness and curvature

3. Preliminary conclusion

(1) Stress level of side wall calculated for the box-type blanket modules under the 10 ms centered disruption seems to be acceptable without electrical connection of first wall.

(2) However, further optimization of the design and wall thickness will be required the stress concentration at support ribs.

(3) Further investigation is also required to evaluate the additional stresses caused by inner pressure and thermal stresses.

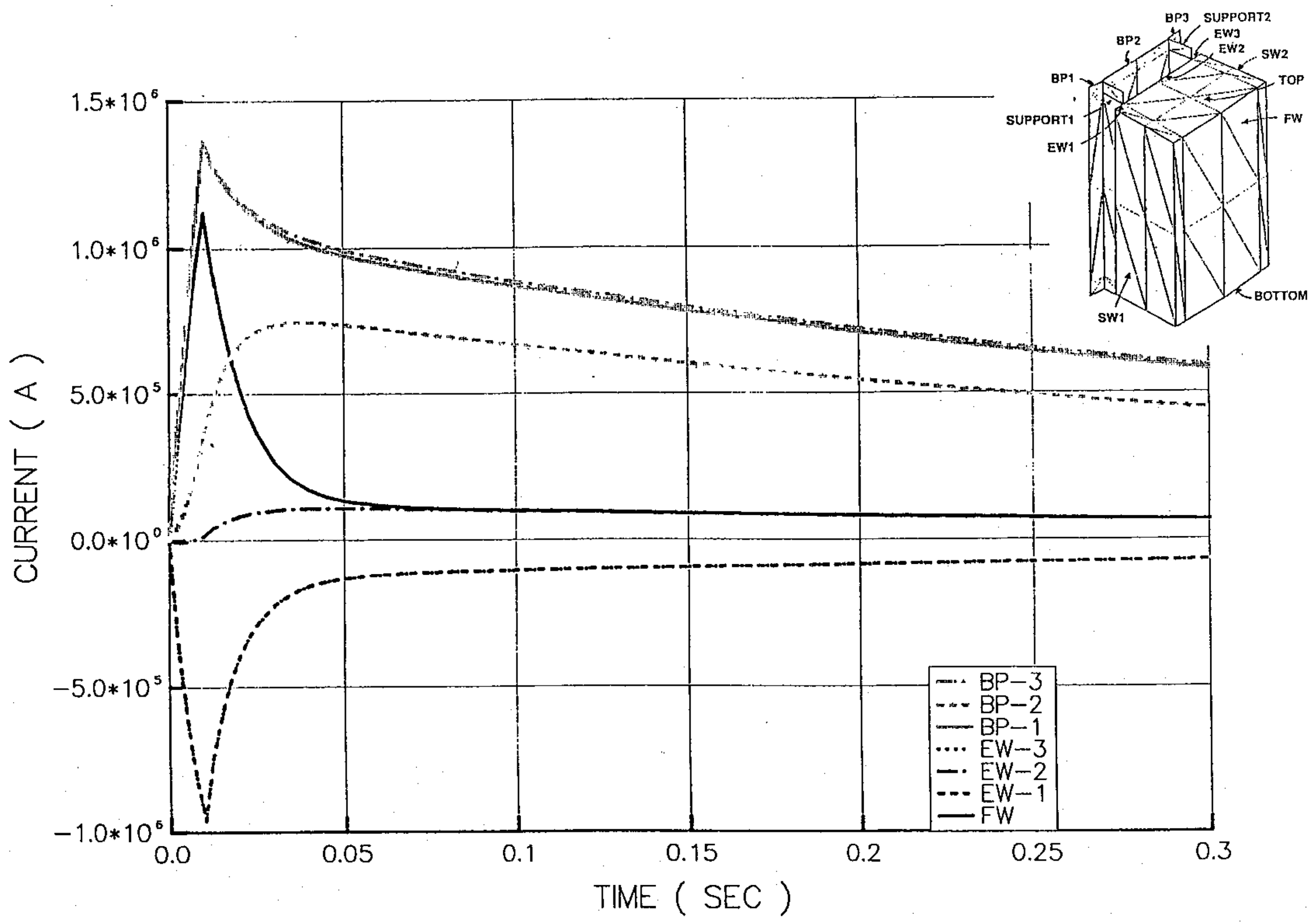


Fig.A − 3 − 1 Time evolution of total eddy current in a modular − type inboard blanket module.

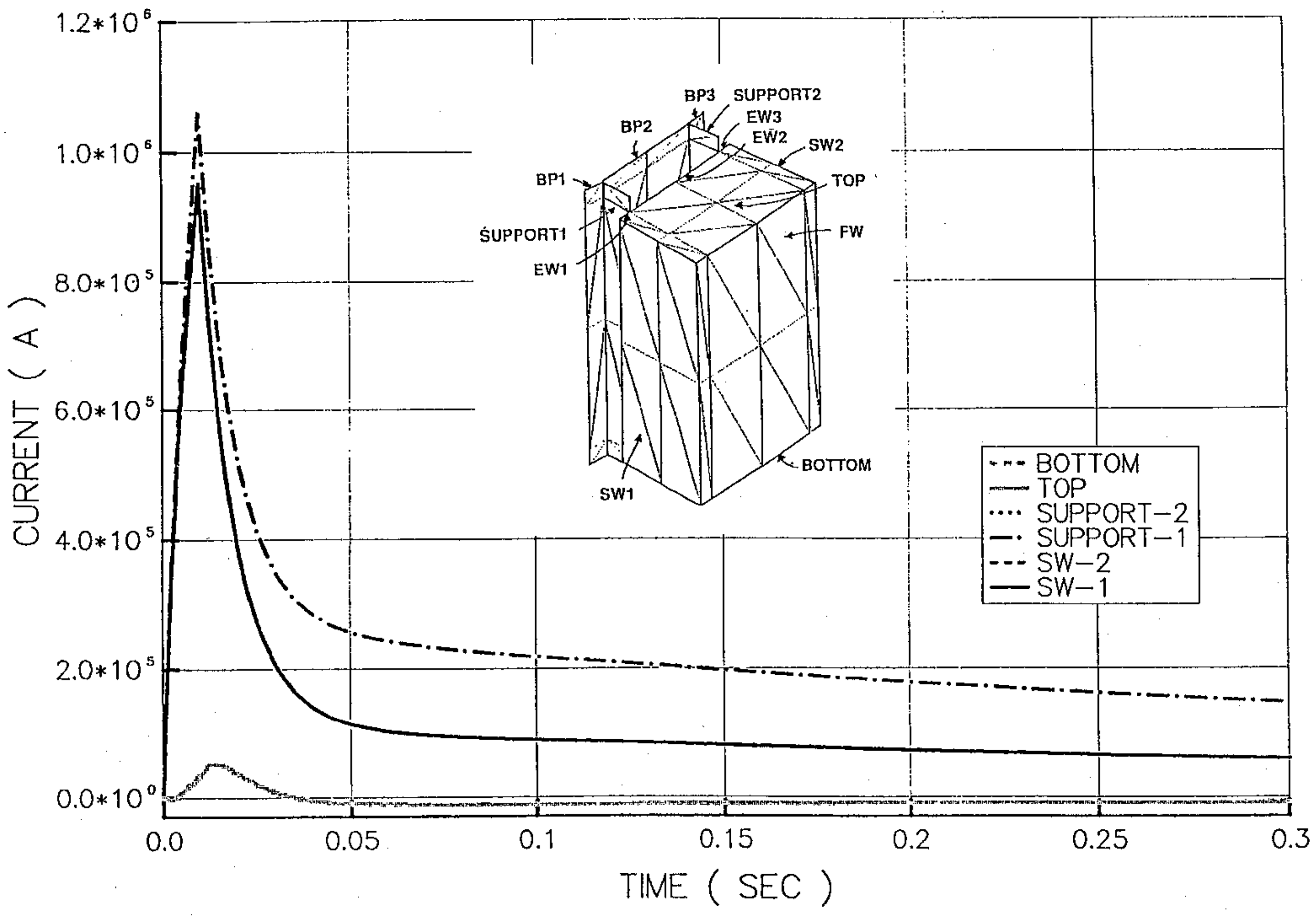


Fig.A - 3 - 2 Time evolution of total eddy current in a modular - type inboard blanket module.

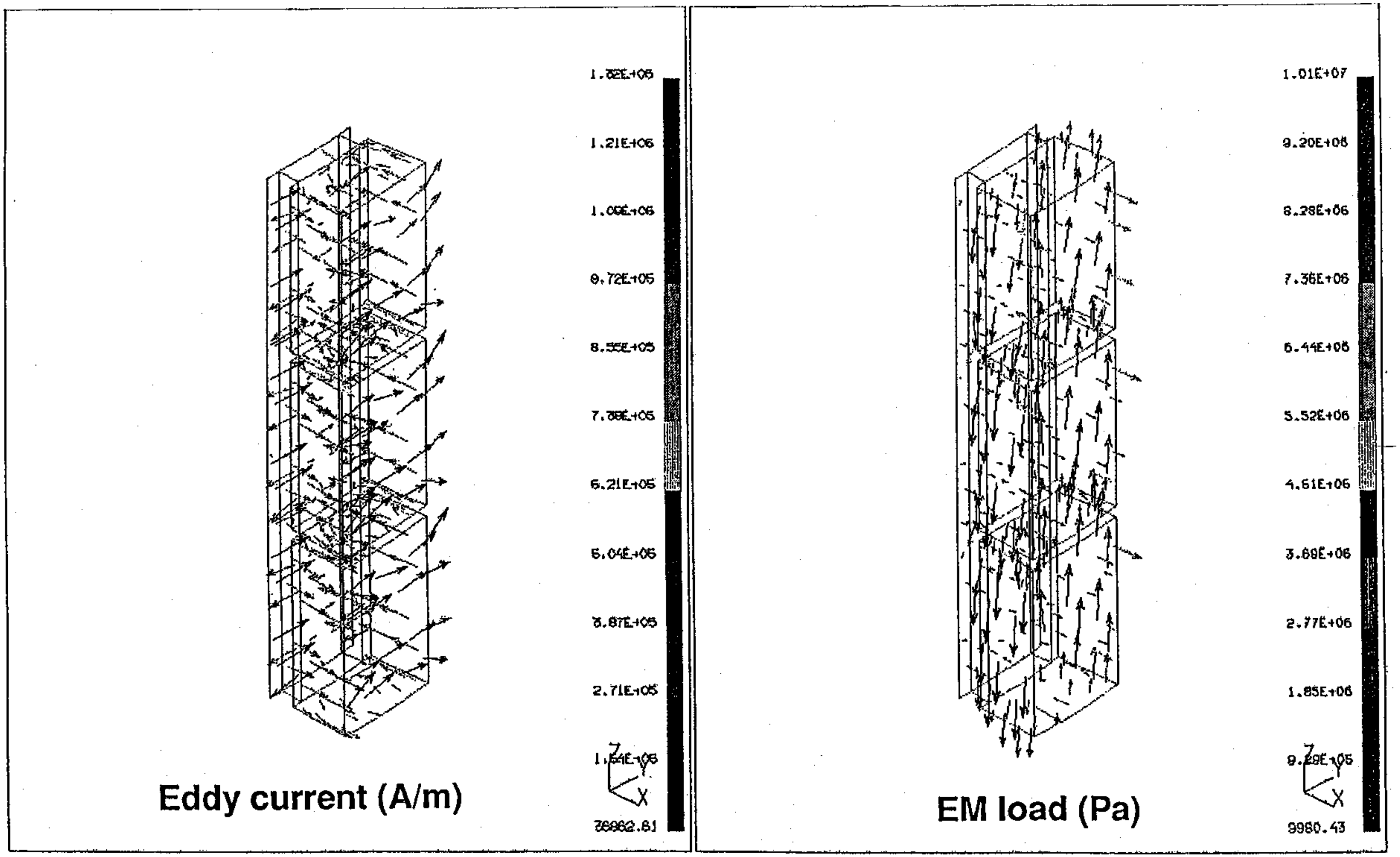


Fig.A－3－3 Dstribution of eddy current and EM load in a modular - type inboard blanket module at 10ms after centered plasma disruption.

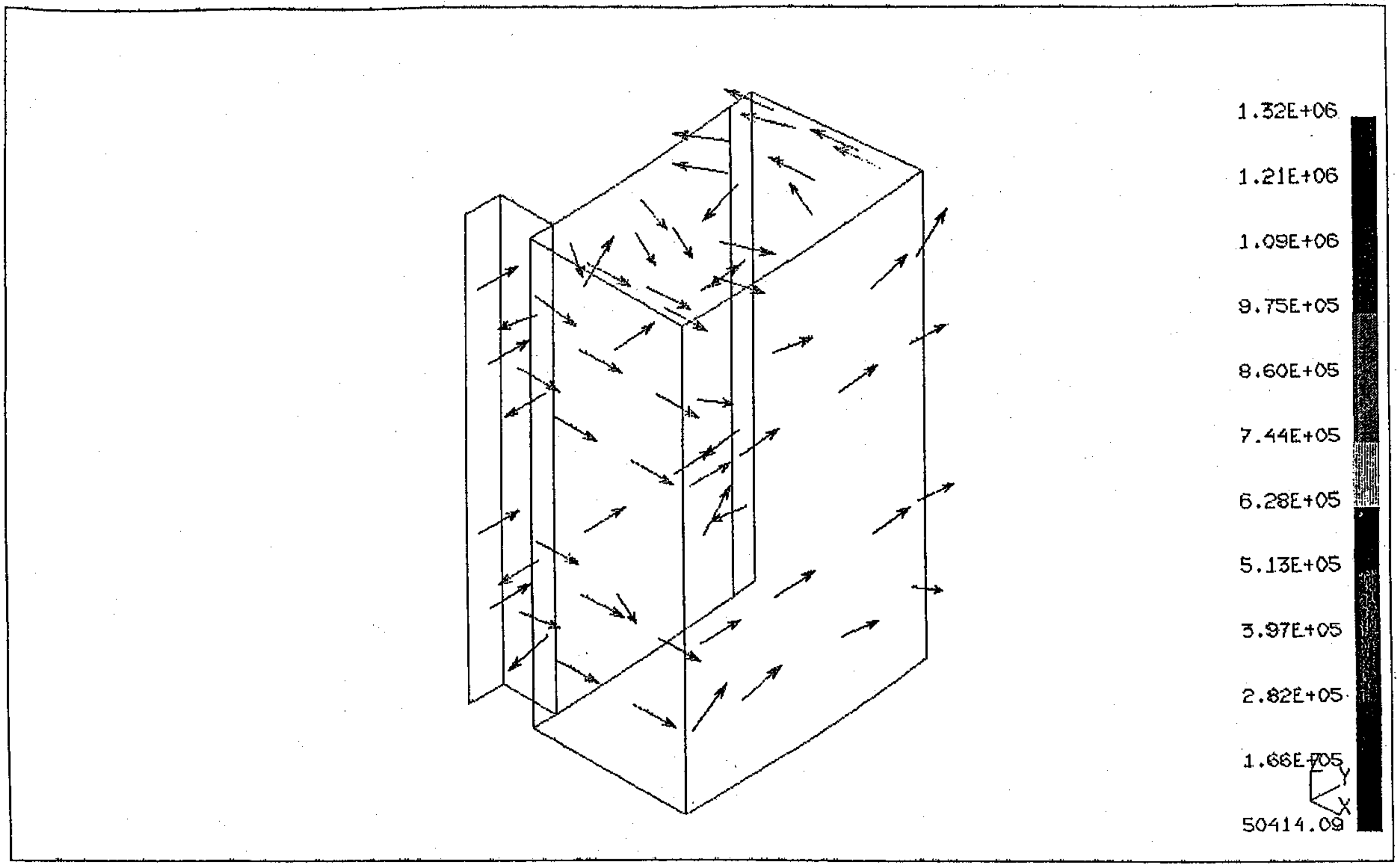


Fig.A − 3 − 4 Eddy current in a modular − type inboard blanket module due to 10ms centered plasma disruption.

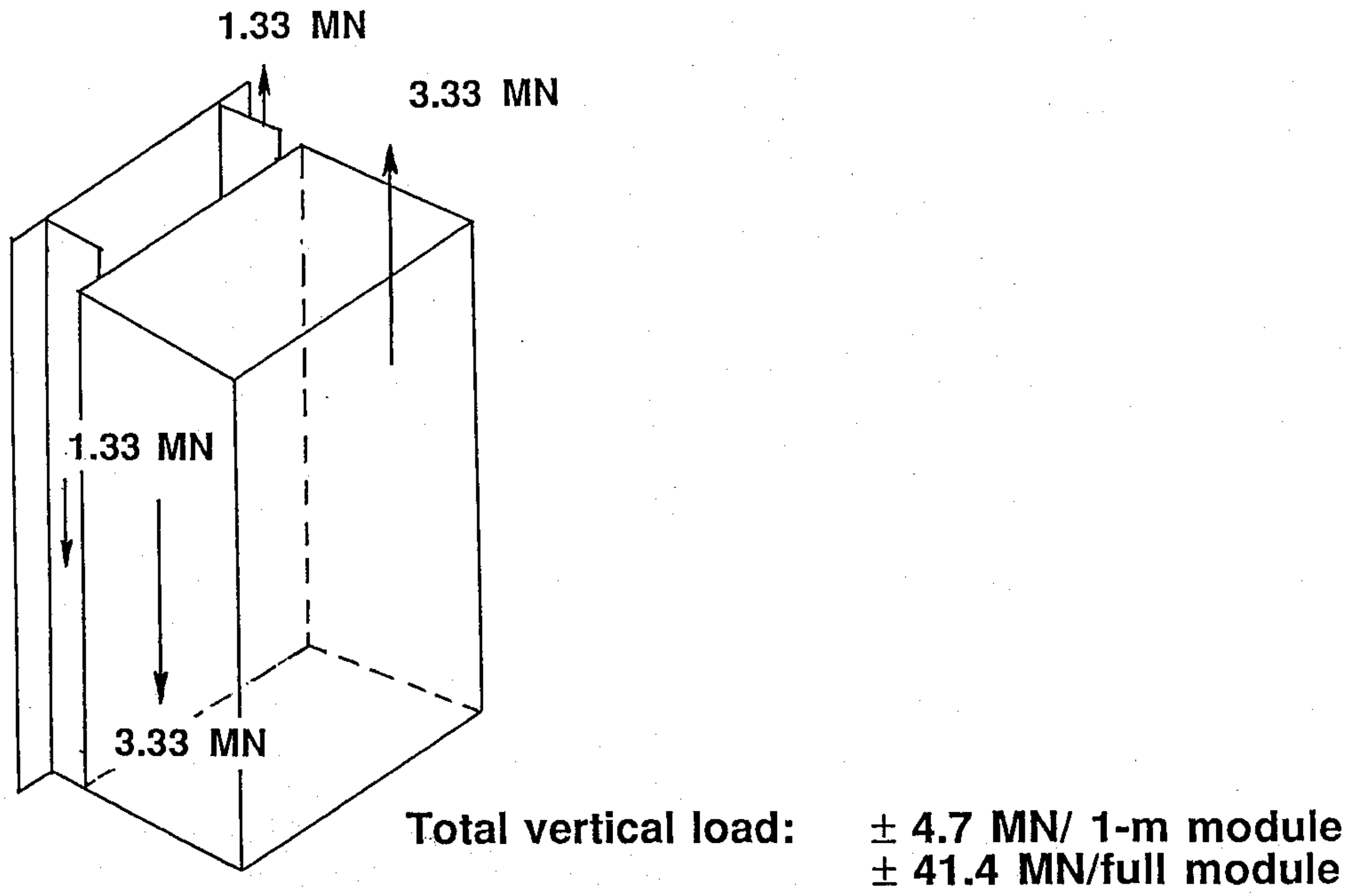


Fig.A－3－5 EM load of a modular－type inboard blanket module due to 10ms centered plasma disruption.

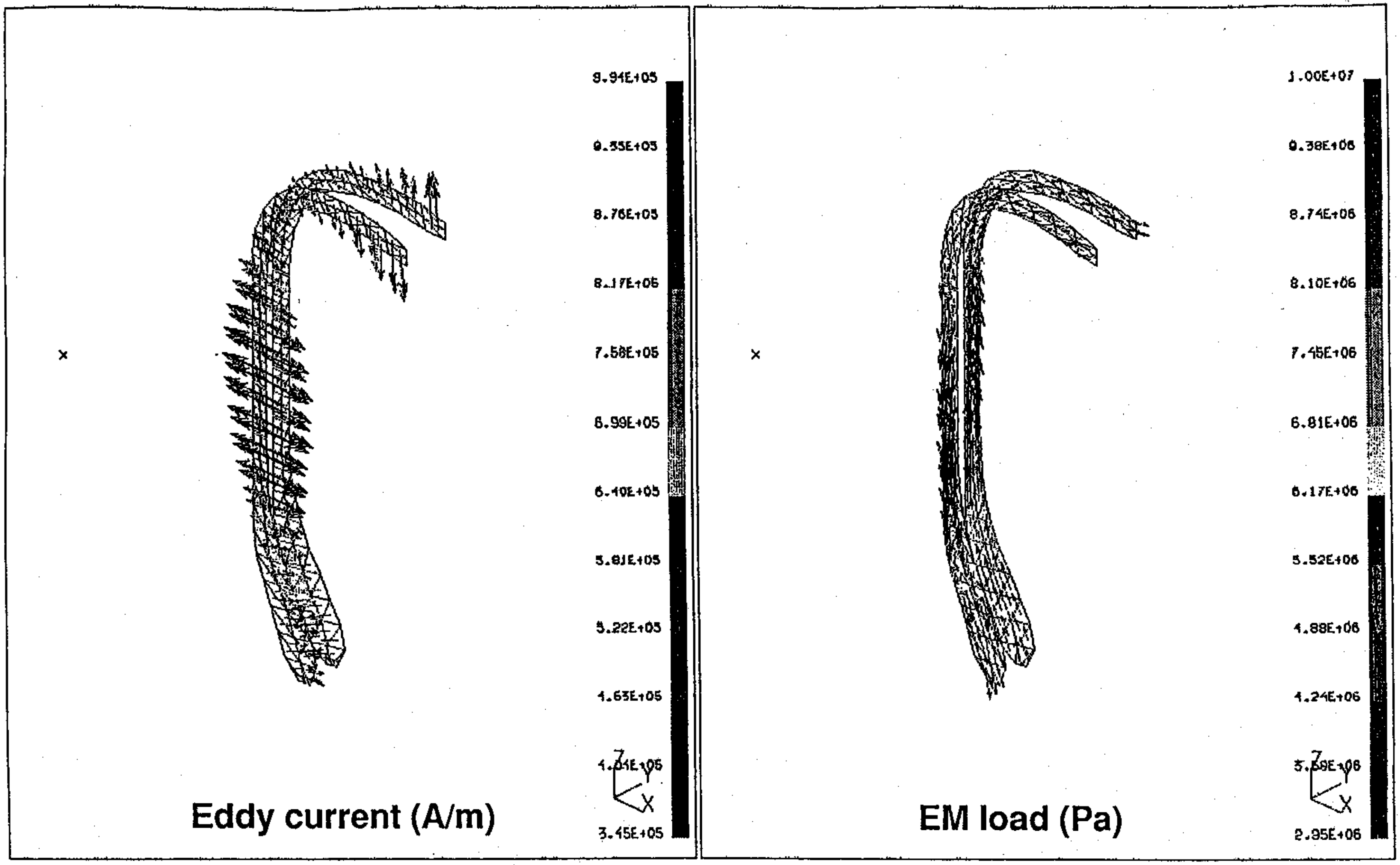


Fig.A－3－6 Dstribution of eddy current and EM load in the side wall of inboard blanket module at 10ms after centered plasma disruption.

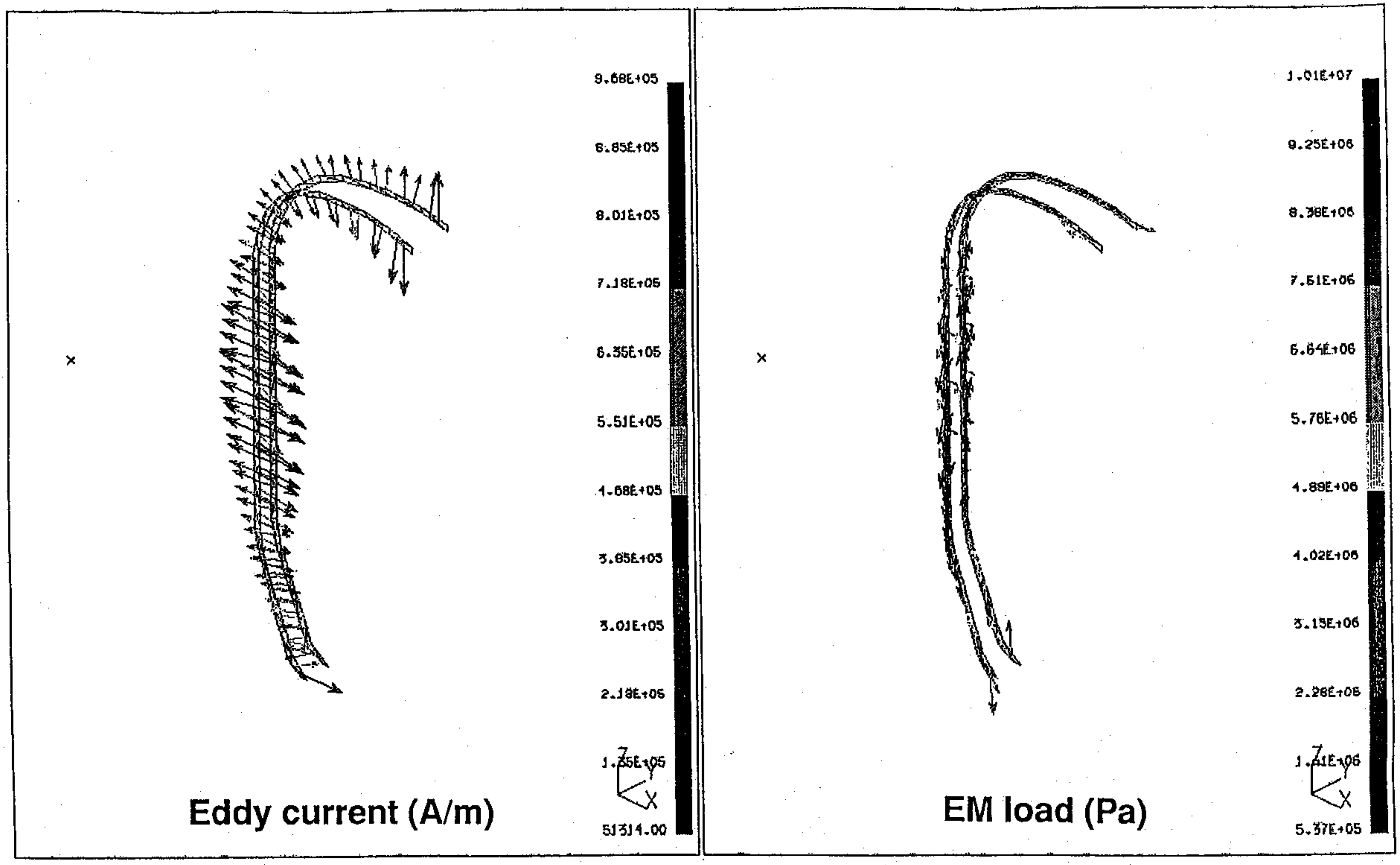


Fig.A − 3 − 7 Dstribution of eddy current and EM load in the support rib of inboard blanket module at 10ms after centered plasma disruption.

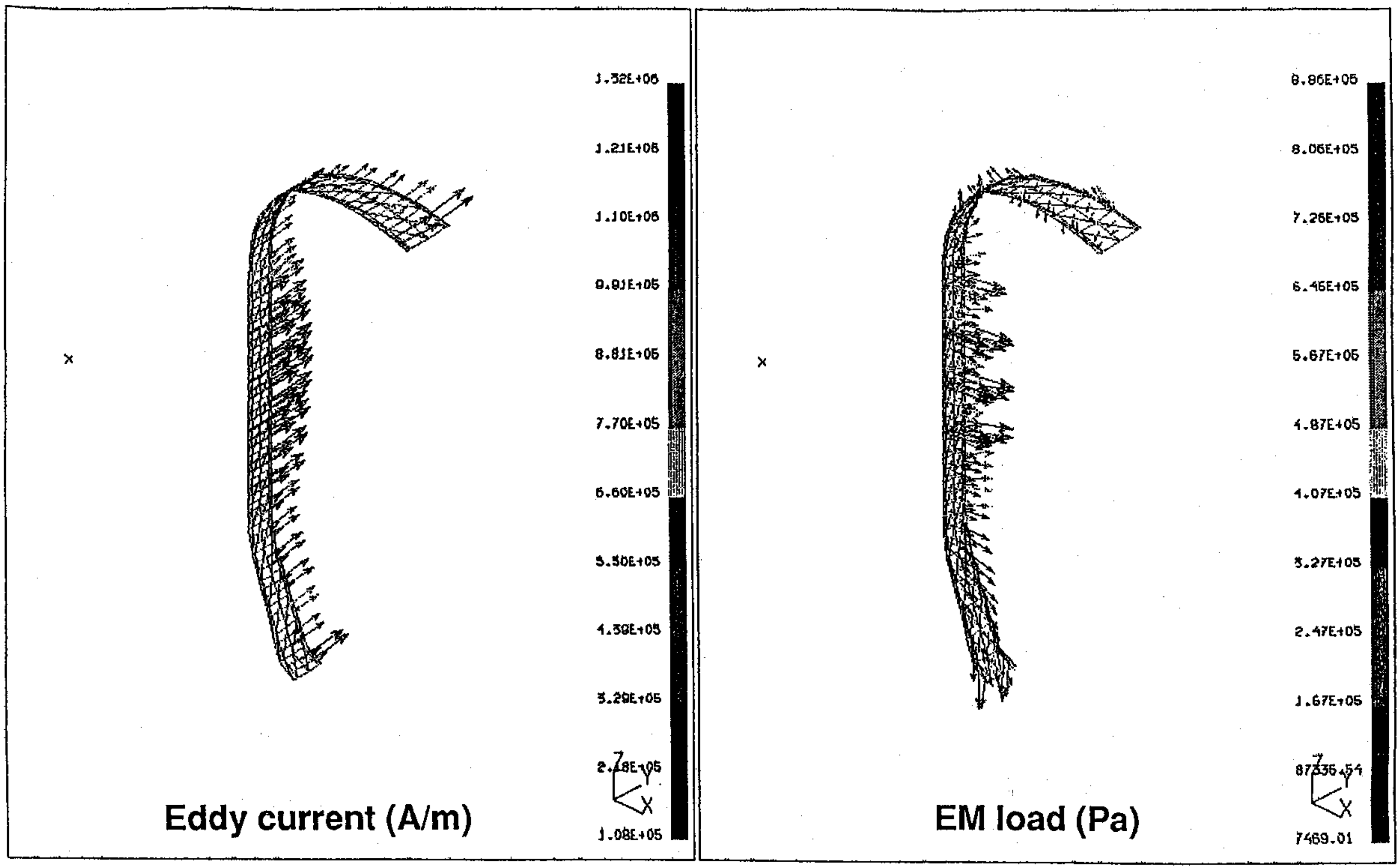


Fig.A − 3 − 8 Dstribution of eddy current and EM load in the back plate of inboard blanket module at 10ms after centered plasma disruption.

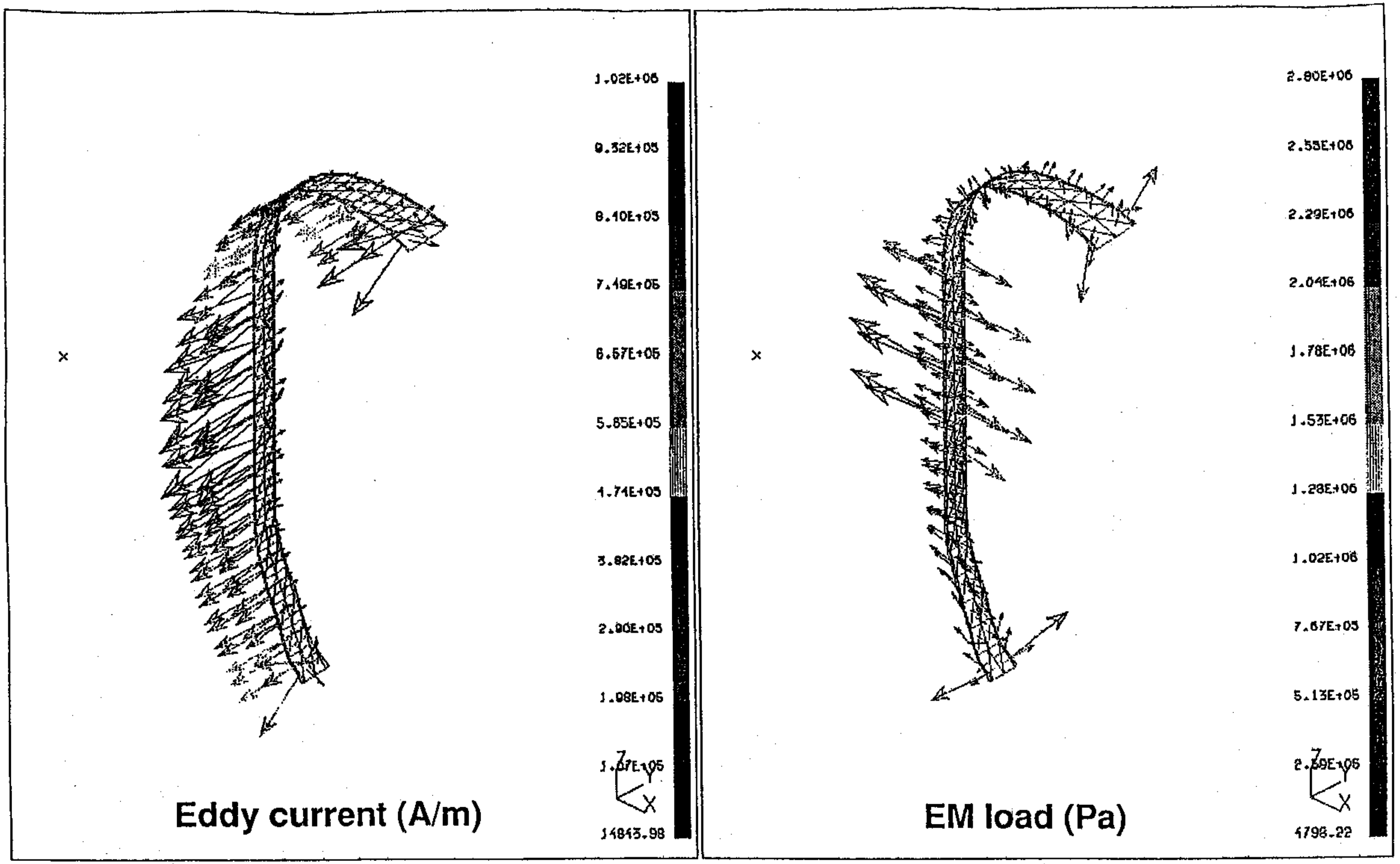


Fig.A－3－9 Dstribution of eddy current and EM load in the end wall of inboard blanket module at 10ms after centered plasma disruption.

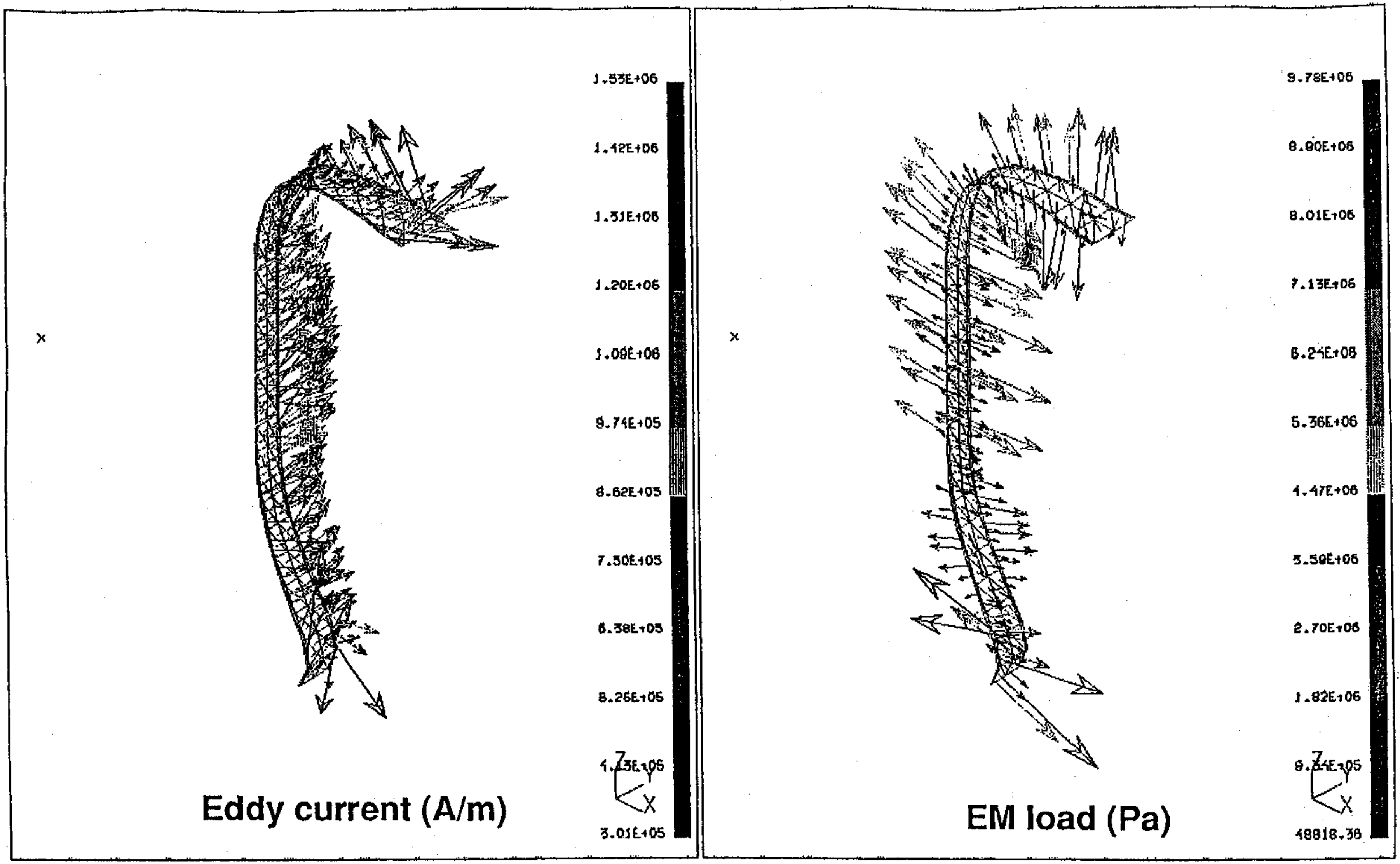


Fig.A－3－10 Dstribution of eddy current and EM load in the first wall of inboard blanket module at 10ms after centered plasma disruption.

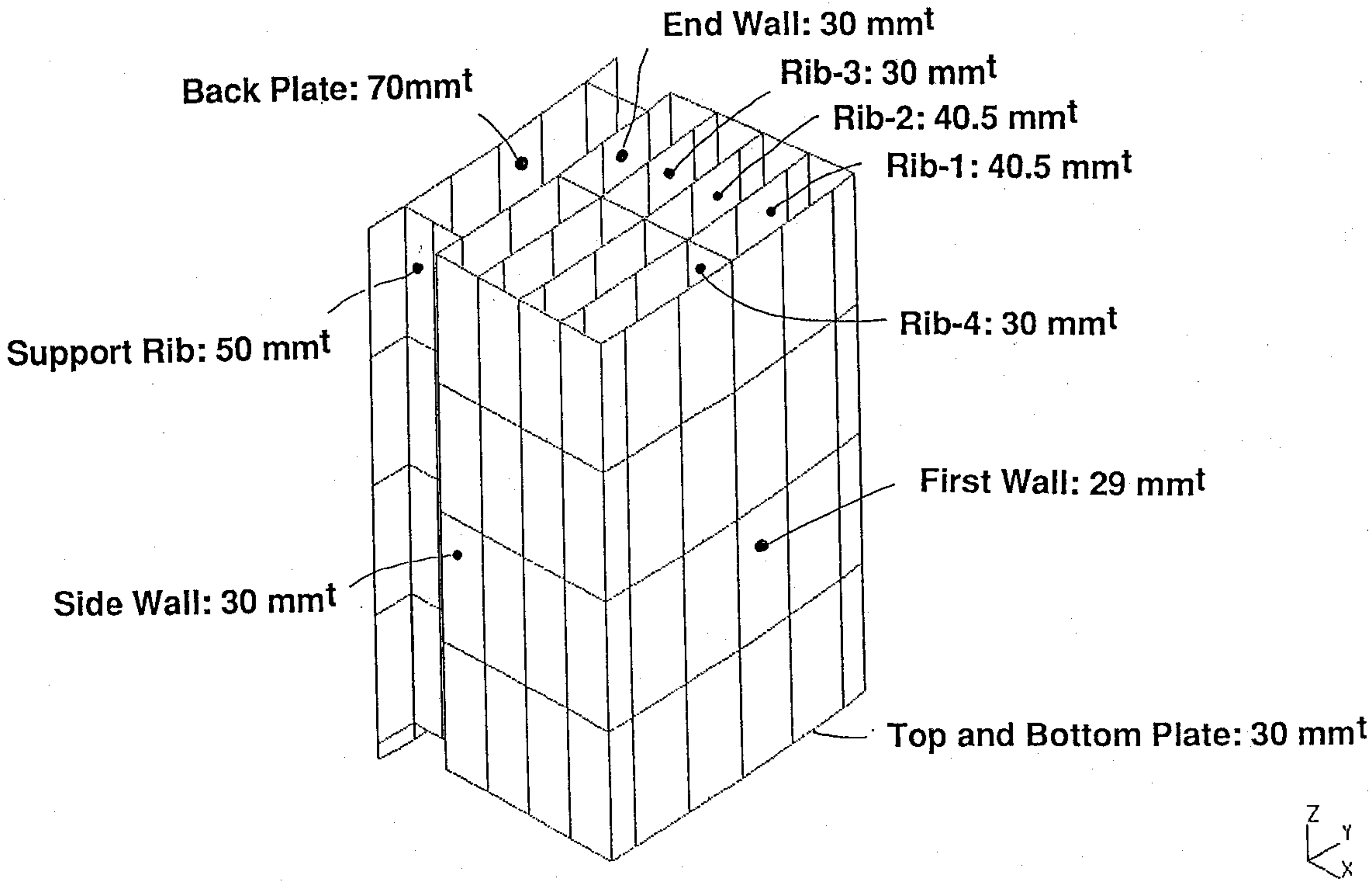


Fig.A − 3 − 11 FEM model for the stress analysis of the modular − type inboard blanket module.

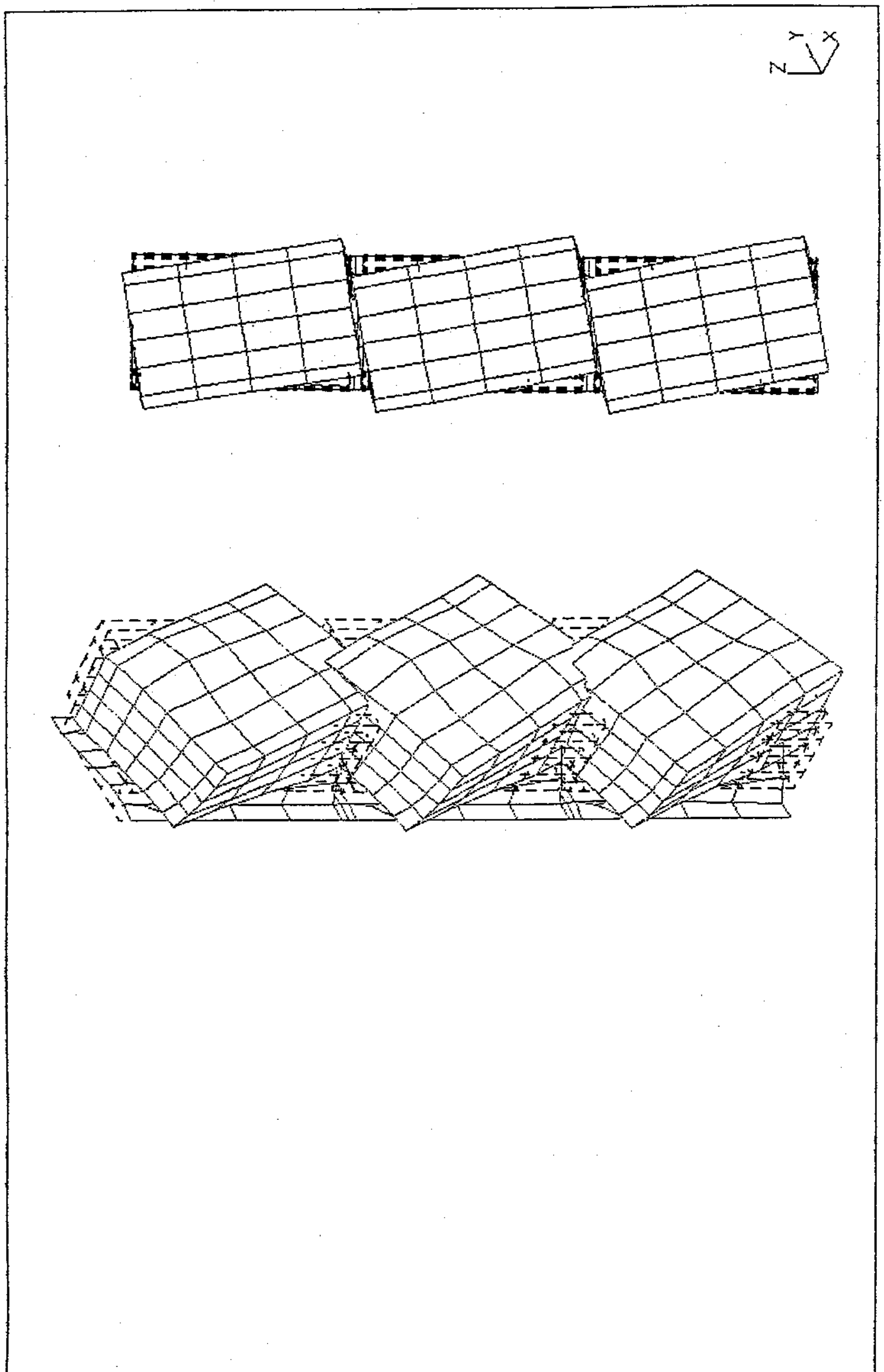


Fig.A－3－12 Deformation of the modular－type inboard blanket module due to centered plasma disruption.

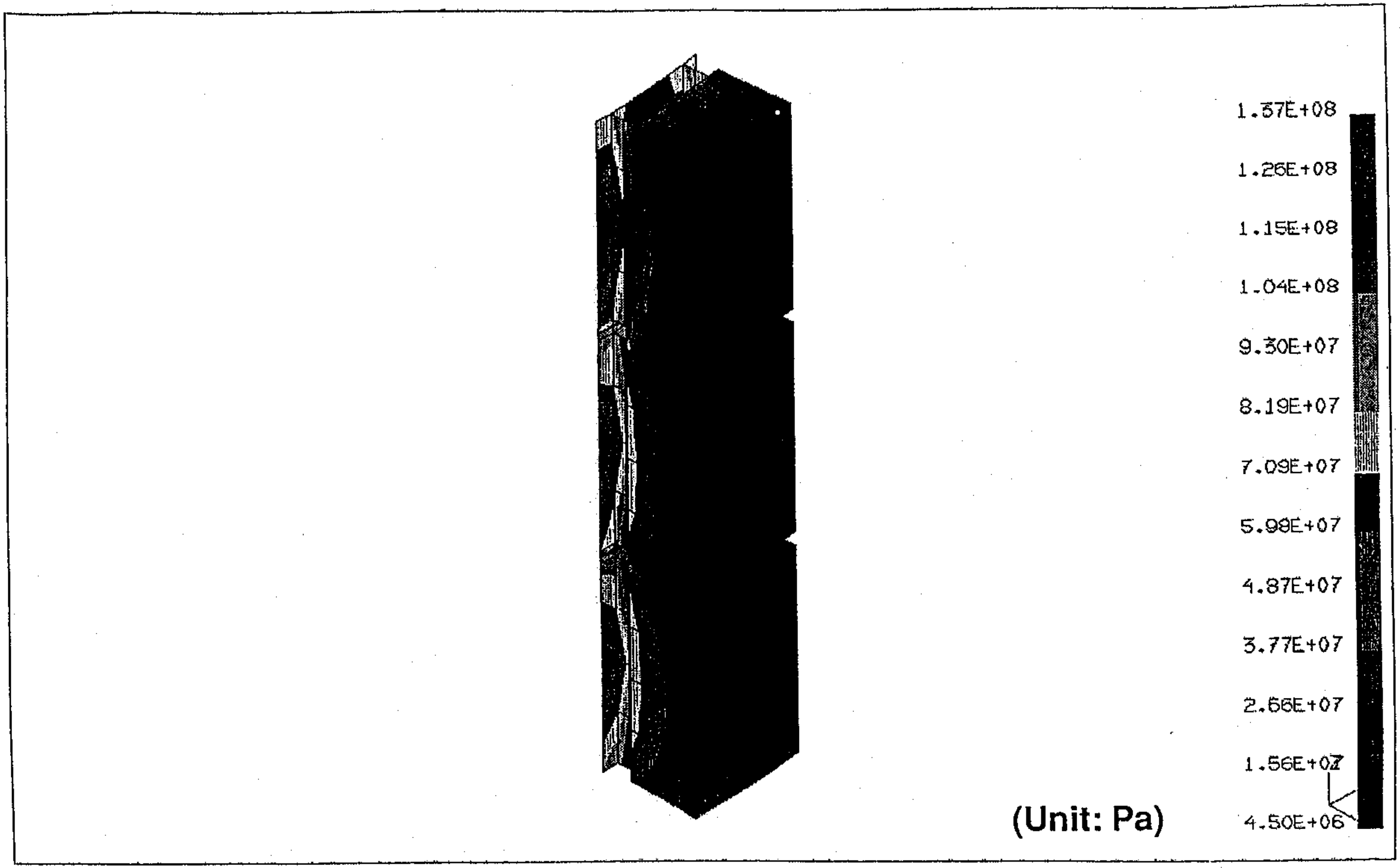


Fig.A − 3 − 13 Distribution of Von Mises stress in the modular − type inboard blankeet module due to EM load of centred plasma disruption.

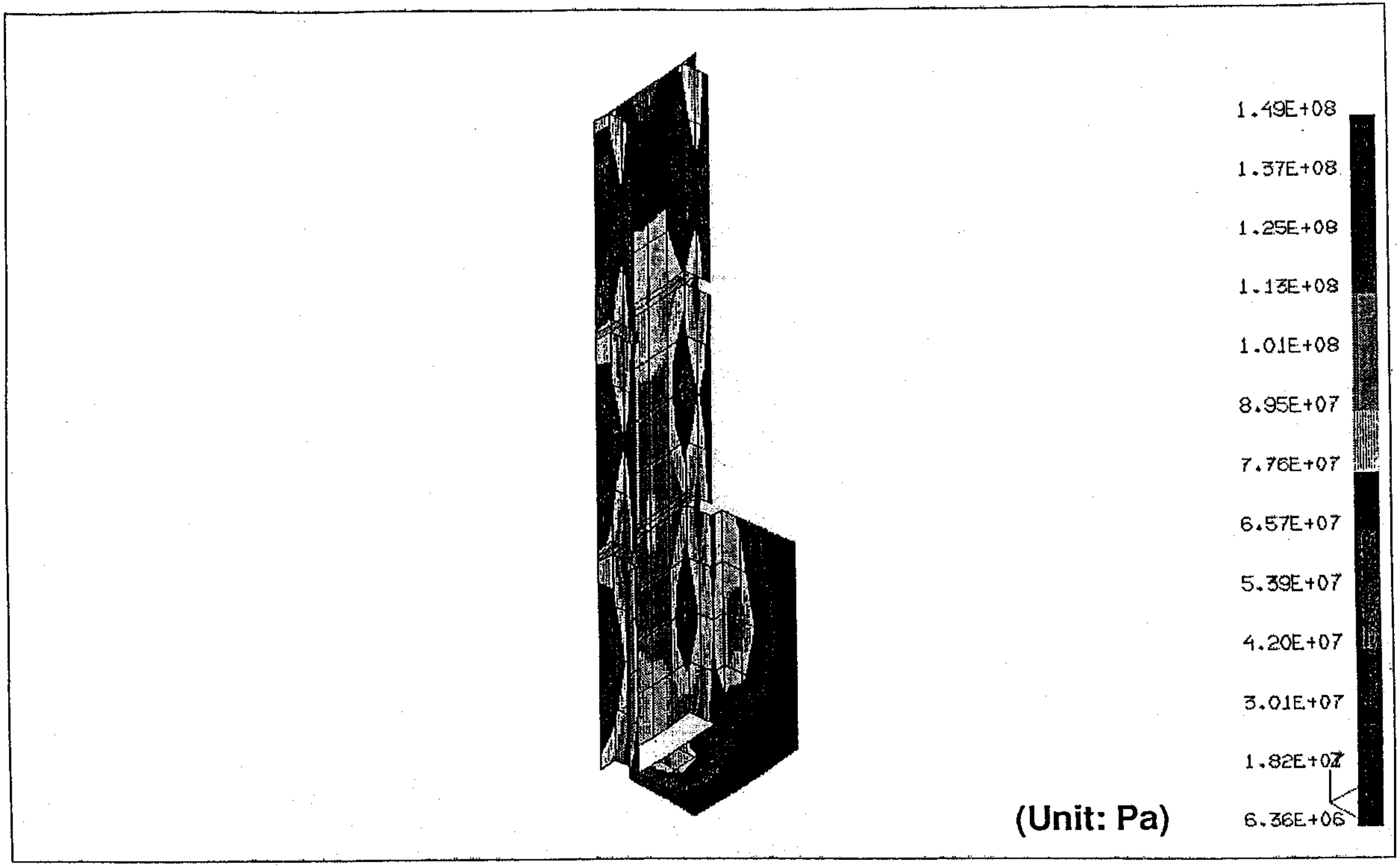


Fig.A − 3 − 14 Distribution of Von Mises stress in the modular − type inboard blanket module due to EM load of centered plasma disruption.

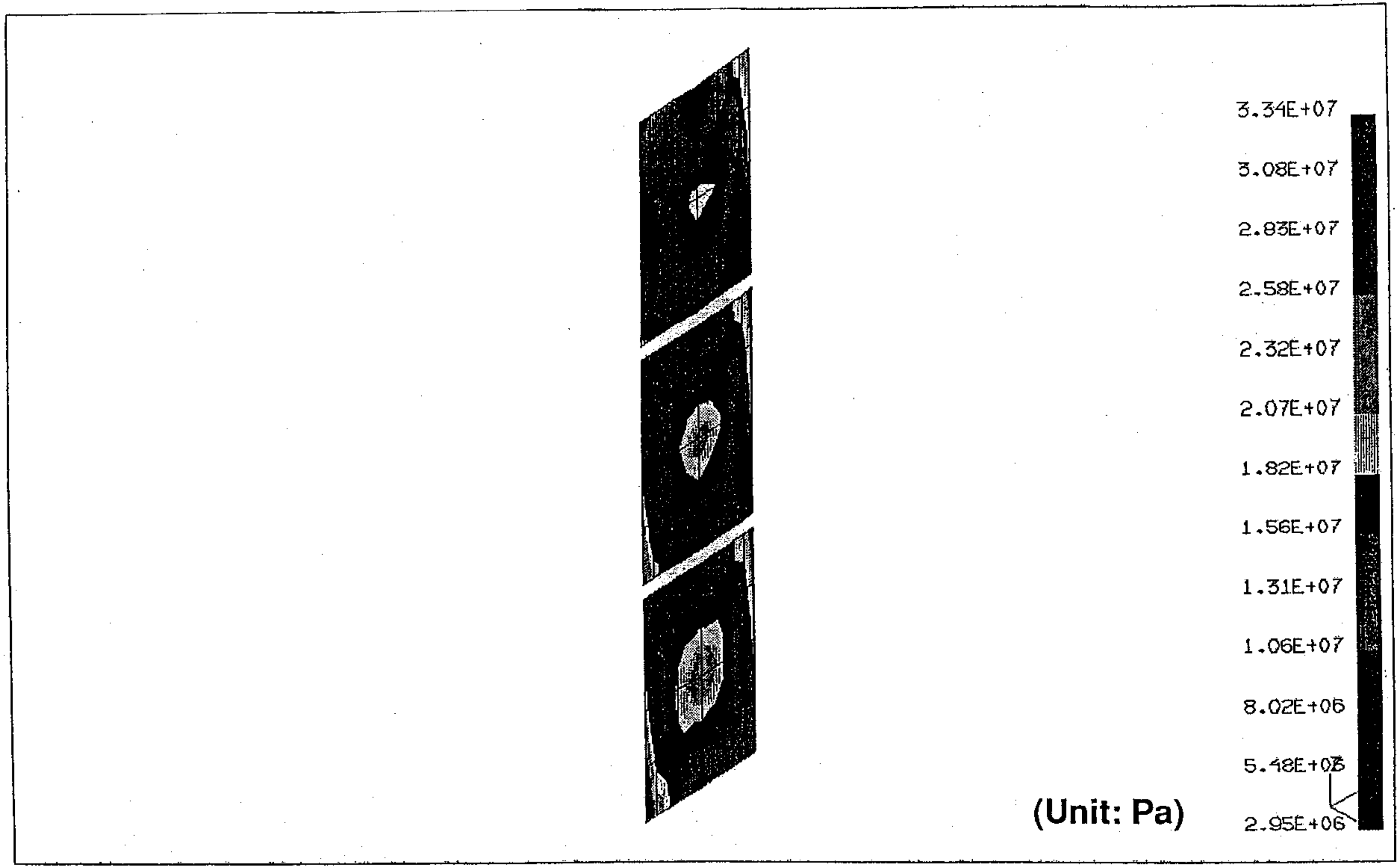


Fig.A－3－15 Distribution of Von Mises stress if the first wall of inboard blanket module due to centered plasma disruption.

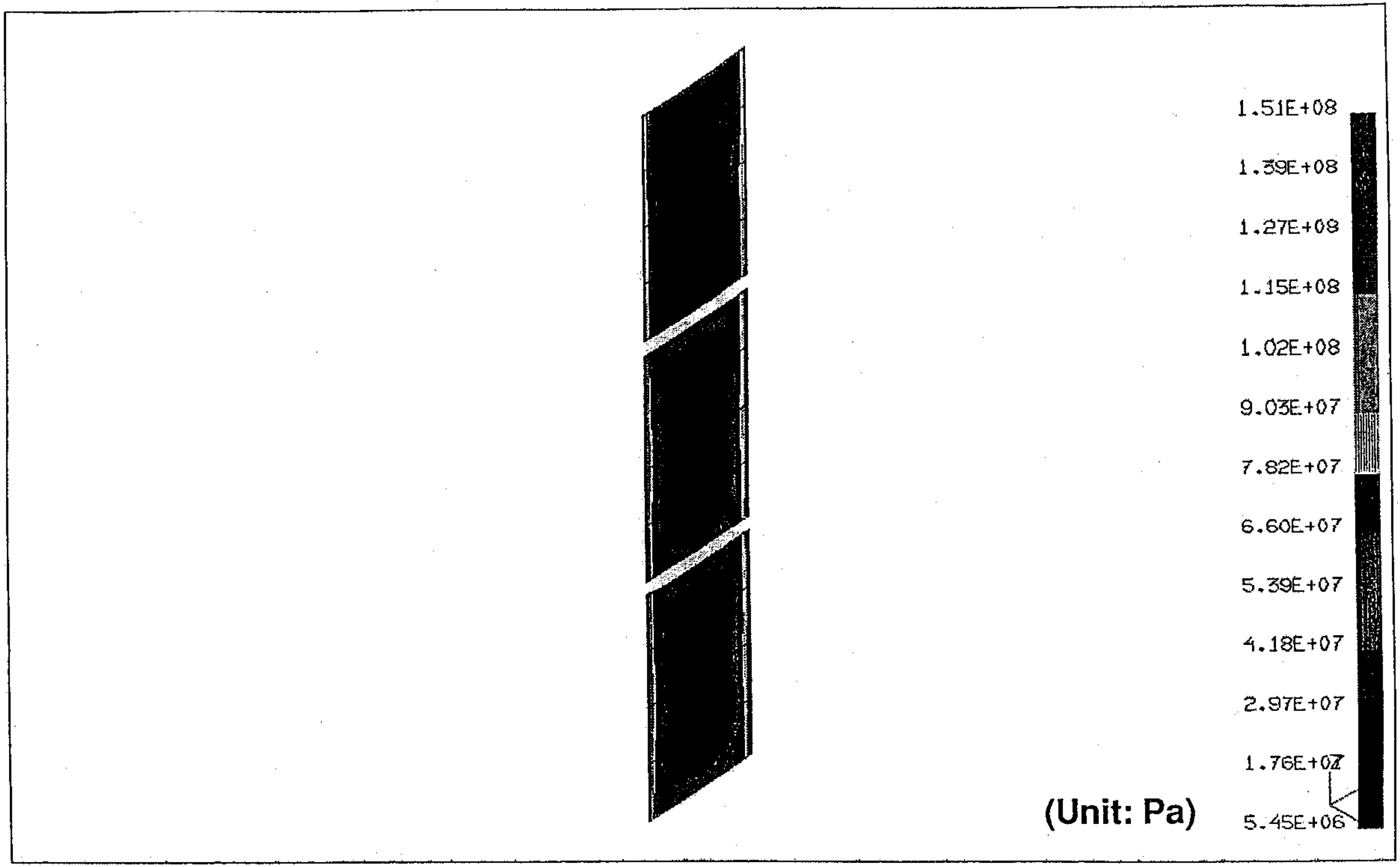


Fig.A − 3 − 16 Distribution of Von Mises stress in the end wall of inboard blanket module due to centered plasma disruption.

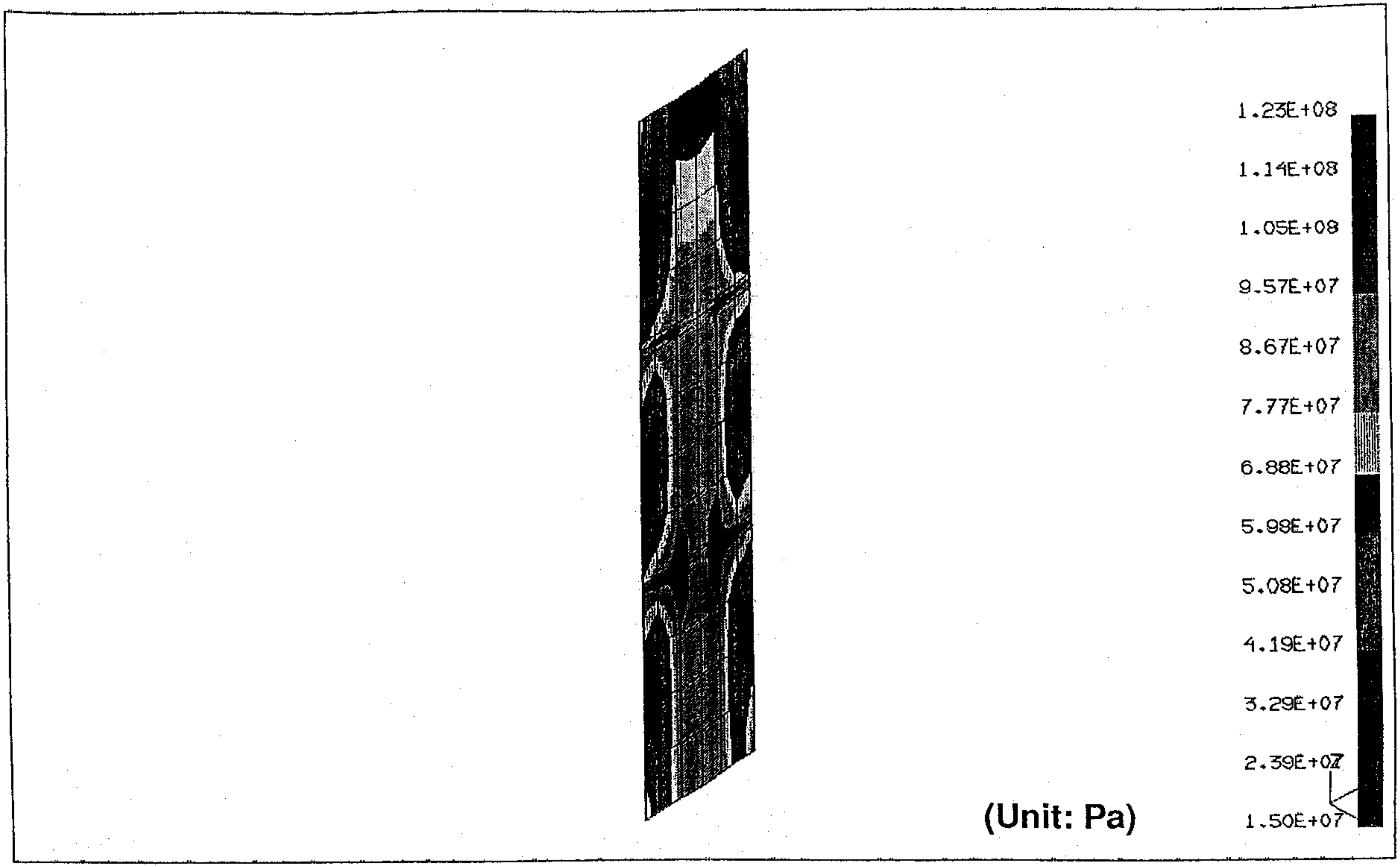


Fig.A－3－17 Distribution of Von Mises stress in the back plate of inboard blanket module due to centered plasma disruption.

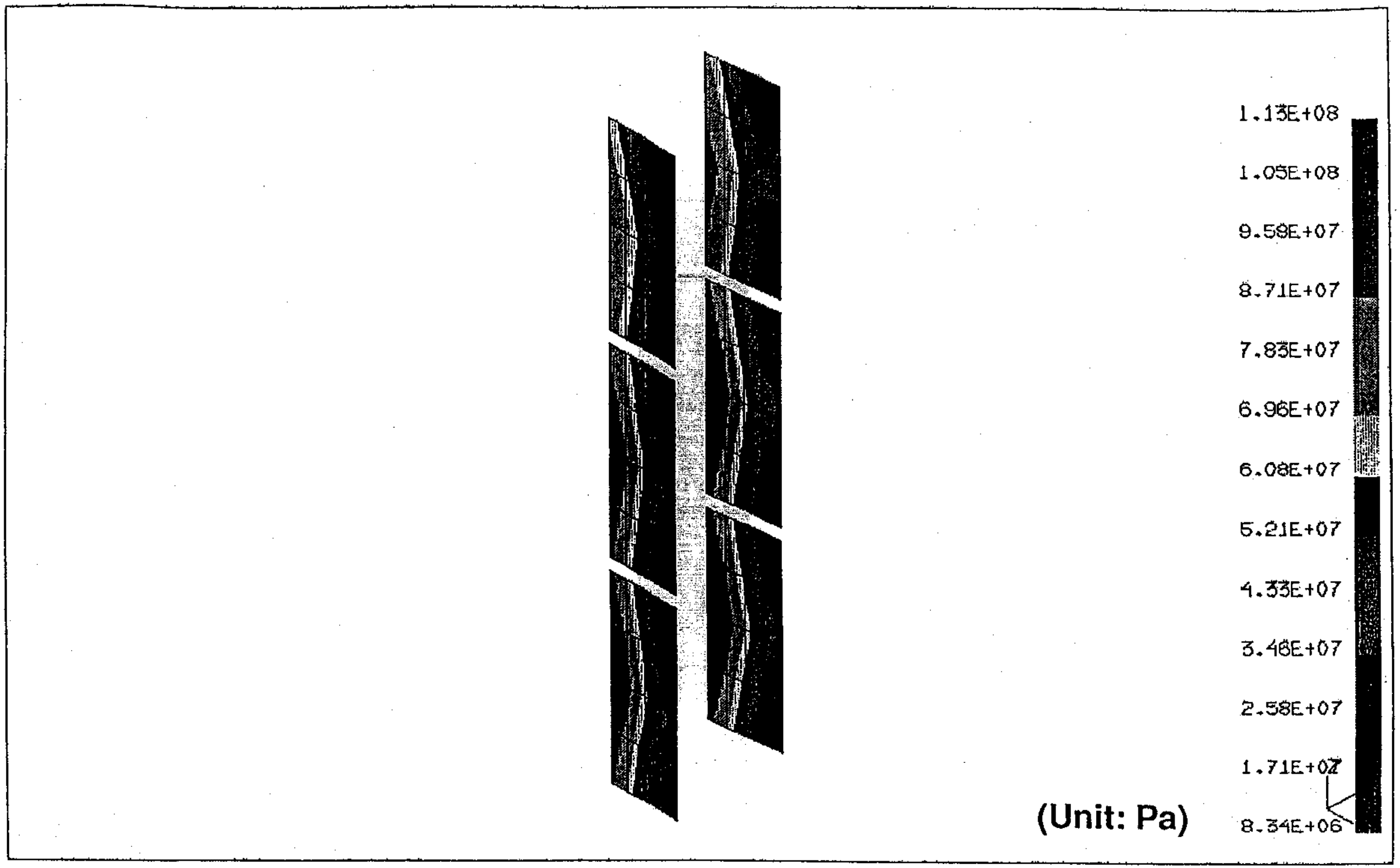


Fig.A－3－18 Distribution of Von Mises stress in the side wall of inboard blanket module due to centered plasma disruption.

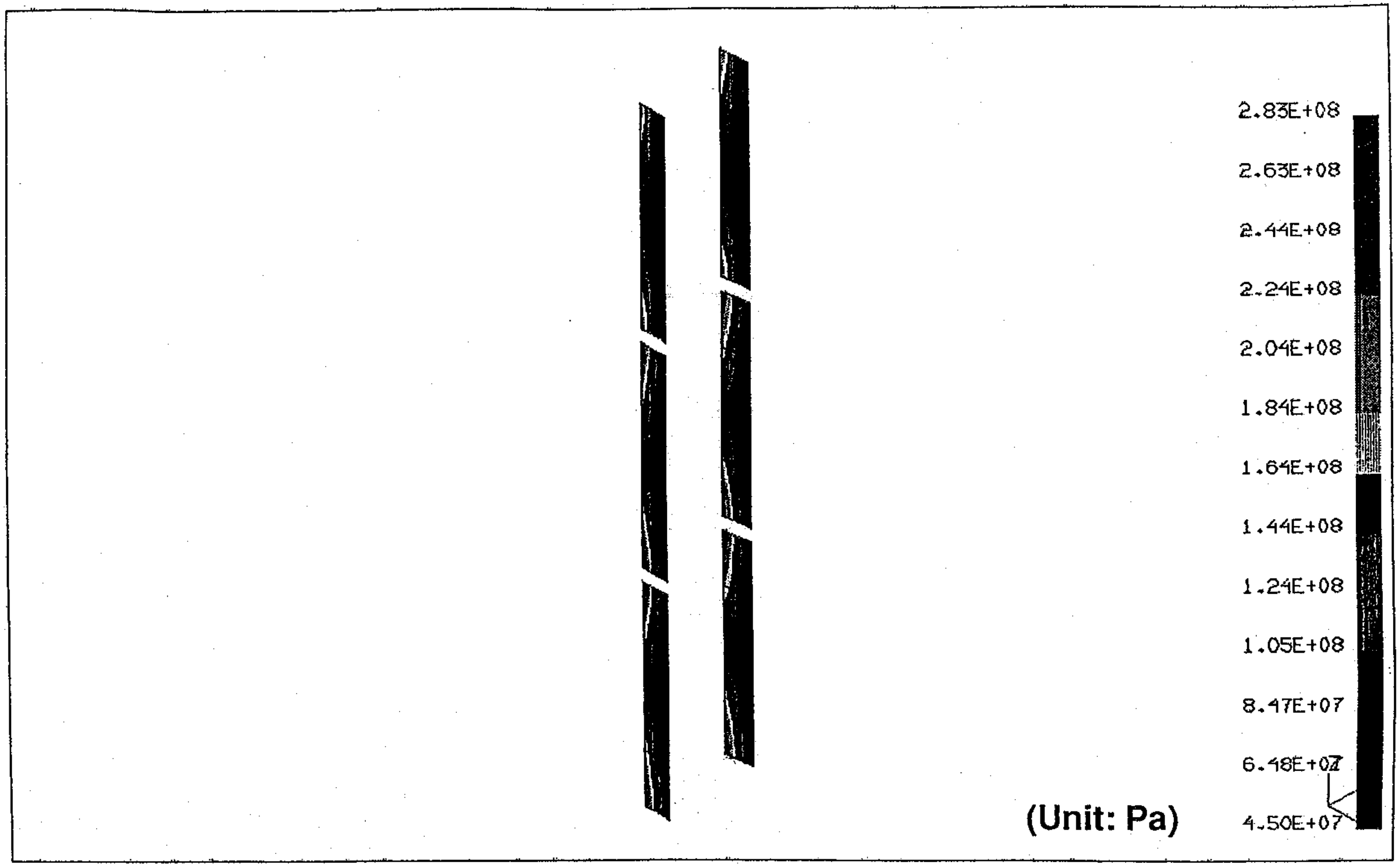


Fig.A－3－19 Distribution of Von Mises stress in the support rib of inboard blanket module due to centered plasma disruption.

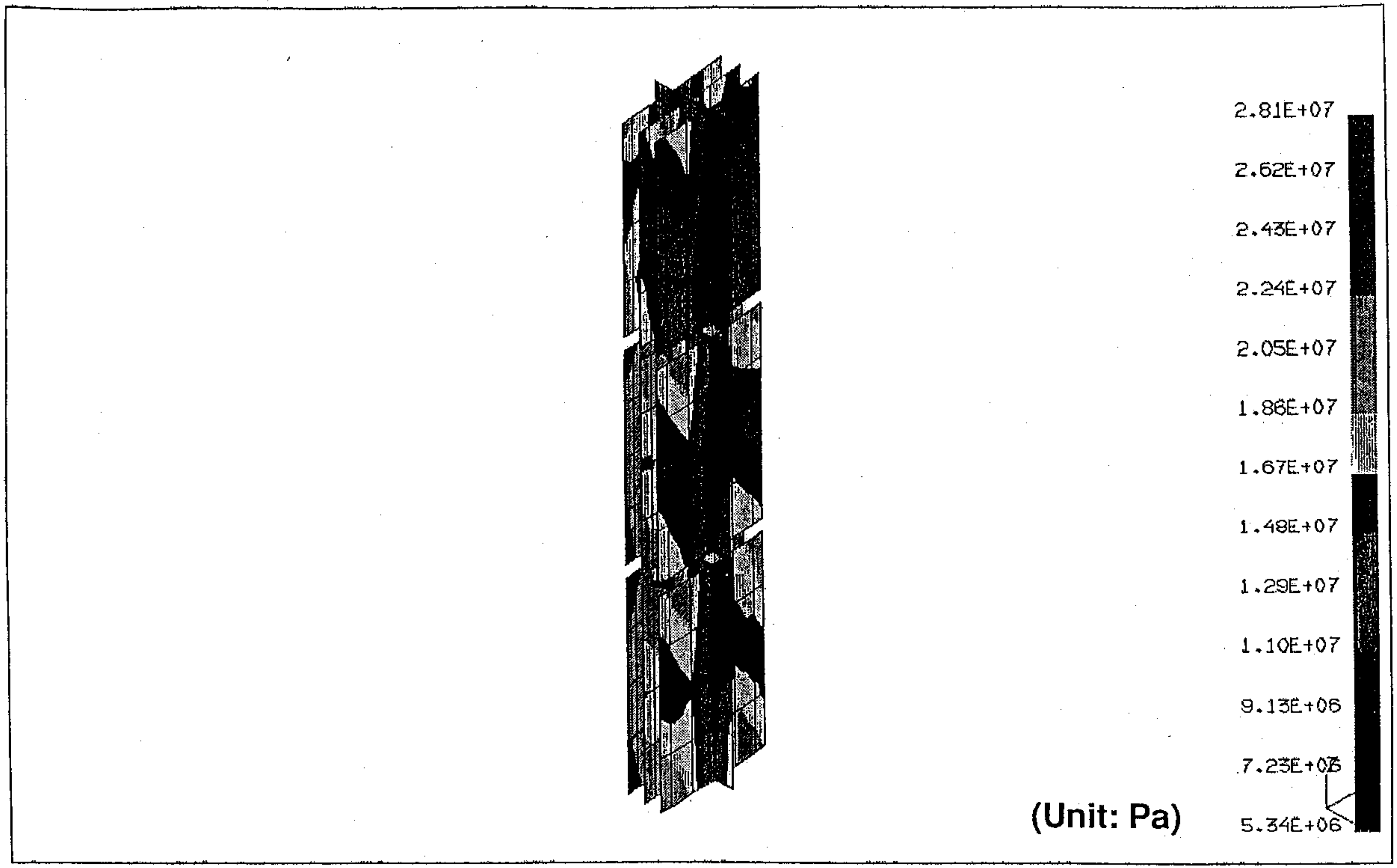


Fig.A – 3 – 20 Distribution of Von Mises stress in the inner rib of inboard blanket module due to centered plasma disruption.

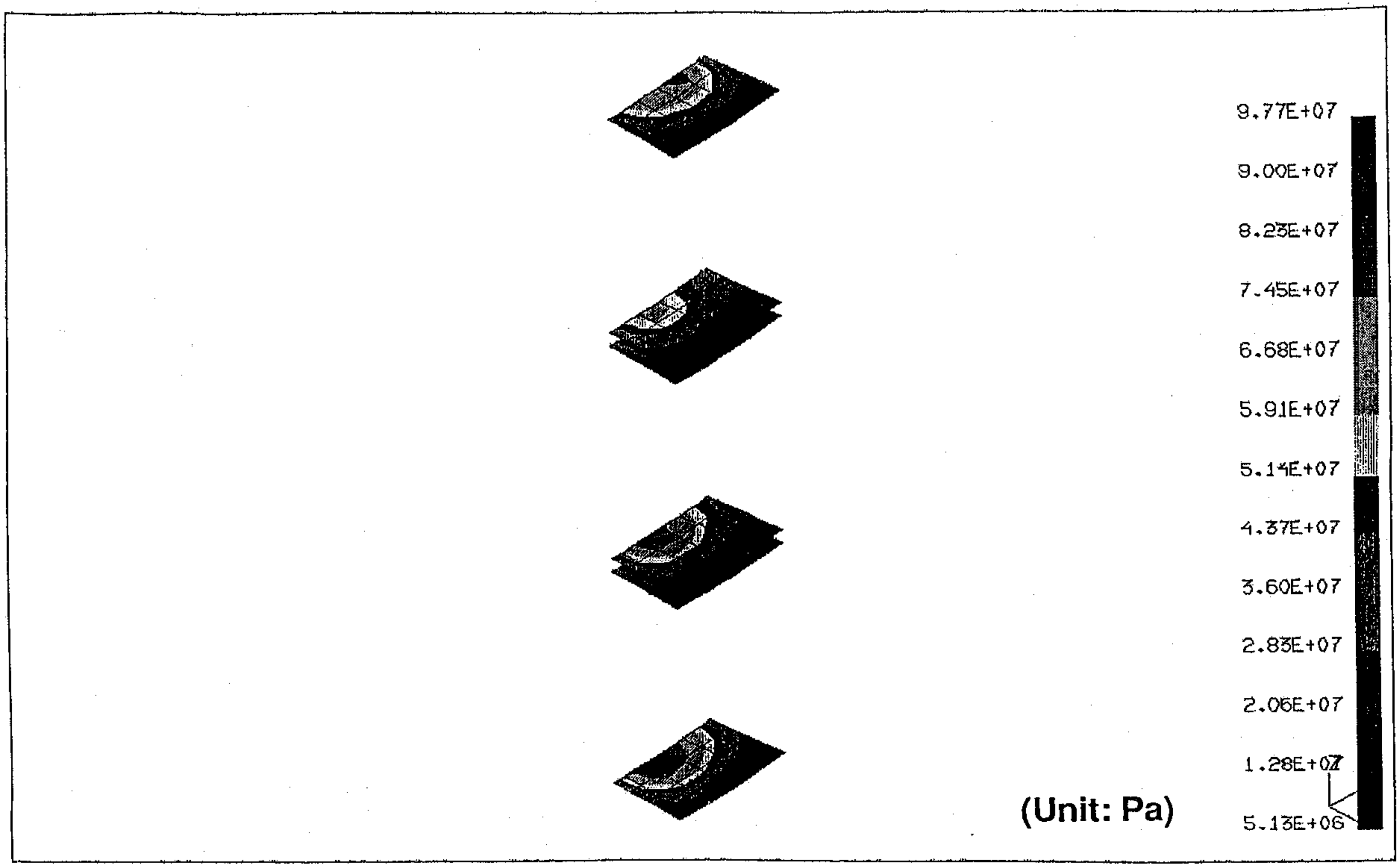


Fig.A－3－21 Distribution of Von Mises stress in the top and bottom plate of inboard blanket module due to centered plasma disruption.