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(Received May 30, 1995)

Typical test modules for water-cooled and helium-cooled ceramic breeder blankets have been designed, and their major design parameters are summarized. Among various candidates studied in Japan at present, BOT(Breeder Out of Tube)type of blanket is exemplified here. The integration scheme of the test module into ITER basic machine is also shown. Even with other type of blanket, the integration scheme won't be affected. The composition and space requirement of cooling and tritium recovery systems for the test module have also been studied.

Keywords : Fusion Experimental Reactor, Breeder Blanket, Blanket Test Module, Breeder Out of Tube

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This work is conducted as an ITER technology R&D and this report corresponds to the 1994 comprehensive task agreement for design task(Task No.:G16TD59, ID No.:D3, Title:Integration of Test Modules in the Main Blanket and Vacuum Vessel Design)

+ Department of ITER Project
* Kawasaki Heavy Industries Co.

テストモジュールおよび関連系統設計

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（1995年5月30日受理）

水冷却およびヘリウム冷却ブランケットを対象として，ITER工学試験で使用する代表的テストモジュールの構造概念および設計パラメータの検討を行った。また，本テストモジュールのテストポートへの設置概念についても検討した。ここでは，BOT（Breeder-Out of-Tube）型のブランケットを例として示したが，動力炉用ブランケットとしては，現在，他の型式のブランケットについても種々検討されており，これらは今後の設計検討およびR＆DによりITERでの工学試験実施までに概念の絞り込みが行われるものである。尚，テストポートへのテストモジュール設置に関わる炉本体との取り合いに関しては，上記と異なるブランケット概念に対しても本検討との大きな差異は生じない。関連系統としては，主として冷却系およびトリチウム回収系について検討した。試験結果の精度を維持するため，また，他のポートに設置されるであろうテストモジュールとの冷却およびトリチウム回収条件が異なるであろうことから，これらはテストモジュール毎（あるいはテストポート毎）に独立して設置されることが望ましく，ここでは，各系統の機器構成および設置スペースについて示した。

本作業は，ITER工学設計活動の一環として実施したもので，本報告は1994年ITER設計作業契約（Task No.：G16TD59，ID No.：D3）に基づくものである。

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Contents

Introduction 1
1. Water-cooled Blanket 1
  1.1 Test Module Concepts 1
  1.2 Ancillary System 2
2. Helium-cooled Blanket 3
  2.1 Test Module Concepts 3
  2.2 Ancillary System 3
Acknowledgement 5
References 5

目　　次

序.. 1
1.　水冷却ブランケット 1
  1.1　テストモジュール概念 1
  1.2　関連系統.. 2
2.　ヘリウム冷却型ブランケット 3
  2.1　テストモジュール概念 3
  2.2　関連系統.. 3
謝　　辞.. 5
参考文献.. 5

Introduction

Development of tritium breeding blankets in Japan has been concentrated on ceramic breeder blankets with water coolant and also helium coolant. Thus test modules and their ancillary systems are developed for water-cooled and helium-cooled ceramic breeder blankets here.

1. Water-Cooled Blanket

1.1 Test module concepts

Test procedure in ITER proposed for water-cooled ceramic breeder blanket [1] is shown in Fig. 1. Also based on the proposed test specifications [1], the module size to be used in each test is indicated in Fig. 2. Here, a test module to be used for the reliability enhancement test which will be installed in ITER for the longest period is studied. As for blanket concept, although a focusing on limited numbers of DEMO blanket candidates is needed by the start of in-ITER testing, there are various candidates proposed/studied in Japan at present. Figure 3 shows an example of a water-cooled test module. Preliminary design parameters of this test module are summarized in Table 1. In this example, BOT (Breeder Out of Tube) type of blanket is taken into account. However, boundary conditions with the basic machine, ITER, won't be different even if other type of blanket is applied. A ferritic steel, F82H, is adopted as the structural material of this test module. The inlet/outlet temperatures of the water coolant are 280/320 °C corresponding to those of a conventional PWR plant.

The integration of the test module into ITER basic machine is shown in Fig. 4. This test module is proposed to be inserted in the horizontal port. A shield plug will be installed behind the test module through which coolant pipes are connected to its ancillary system.

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The integration of the test module into ITER basic machine is shown in Fig. 4. This test module is proposed to be inserted in the horizontal port. A shield plug will be installed behind the test module through which coolant pipes are connected to its ancillary system.

1.2. Ancillary System

The test module should be ancillarily equipped with its own cooling and tritium recovery systems for its precise instrumentation and different test conditions from other test modules. Flow diagram of the cooling system for above-mentioned test module is shown in Fig. 5. The cooling system consists of two circulators installed in parallel for redundancy in case of events/accidents, a cooler, a pressurizer, and a purification unit. During burn time, water coolant leaving the test module flows through the cooler and the circulator. During off-burn time, a bypass line of the cooler is opened and the heater is put into line in order to keep temperatures of the test module. Thermal power removed from the test module is finally transferred to the heat removal system of the basic machine via the cooler. Layout plan of the test module cooling system is shown in Fig. 6. Space required to equip this cooling system is about 12 m x 8 m x 8 m^H.

The functions of tritium recovery system are to recover tritium produced in the test module, to analyze tritium recovered and contained in helium sweep gas, and to control atmosphere in the test module breeding region by varying gas flow rate and adjusting gas composition. Flow diagram of the tritium recovery system for the same test module above is shown in Fig. 7. This system consists of analytical section, tritium recovery section and gas adjusting section. In the analytical section composed of ceramic electrolysis cell, moisture adsorption bed and ionization chambers, tritium is measured in the form of HT and HTO separately and continuously. In the tritium recovery section, tritium is removed from helium gas by catalytic oxidation and adsorption, then recovered as HTO in moisture adsorption bed which is designed to be able to be in line over one week continuously. In addition to the moisture adsorption beds, liquid nitrogen-cooled cold trap is equipped for additional removal of impurities. Gas adjusting section controls the sweep gas composition by adding hydrogen gas and so forth. Layout plan of the test module tritium recovery system is shown in Fig. 8. As this system handles tritium of relatively high concentration, most of the system needs to be contained in a glove box of about 4 m x 1 m x 2.5 m^H.

It should be noted that capacities of these systems are estimated for the test module to be used in the reliability enhancement test, i.e., about 1 m^W x 2 m^H x 0.5 m^D. Therefore, they should be reestimated when a larger module such as for the segment demonstration test is used.

2. Helium-Cooled Blanket

2.1 Test module concepts

Test procedure and module sizes for helium-cooled blanket are the same as those for the water-cooled blanket shown in Figs. 1 and 2. A test module to be used for the reliability enhancement test is also studied here. As same as for the water-cooled blanket, candidates of helium-cooled DEMO blanket proposed/studied presently in Japan will be converged onto the limited numbers of them by the start of in-ITER testing. Figure 9 shows an example of a helium-cooled test module. Preliminary design parameters of this test module are shown in Table 2. In this example, BOT type of blanket is taken into account. However, boundary conditions with the basic machine, ITER, won't be different even if other type of blanket is applied. A ferritic steel, F82H, is adopted as the structural material of this test module, and because of this, the coolant outlet temperature is set to be lower than that employed in the candidate designs [1]. Advanced structural materials such as refractory metal alloys, TiAl, and so forth might be applied depending on their development

The integration of the test module into ITER basic machine is similar to that of the water-cooled blanket shown in Fig. 4 except larger pipe size for the helium-cooled blanket.

2.2 Ancillary System

For individual precise instrumentation and different test conditions from other test modules inserted in other ports, each test module should be ancillarily equipped with its own cooling and tritium

It should be noted that capacities of these systems are estimated for the test module to be used in the reliability enhancement test, i.e., about 1 m^W x 2 m^H x 0.5 m^D. Therefore, they should be reestimated when a larger module such as for the segment demonstration test is used.

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The integration of the test module into ITER basic machine is similar to that of the water-cooled blanket shown in Fig. 4 except larger pipe size for the helium-cooled blanket.

2.2 Ancillary System

For individual precise instrumentation and different test conditions from other test modules inserted in other ports, each test module should be ancillarily equipped with its own cooling and tritium recovery systems. Flow diagram of the cooling system for this helium-cooled test module is shown in Fig. 10. The cooling system consists of two main circulators installed in parallel for redundancy in case of events/accidents, a heater, a main cooler, a filter, a helium gas make-up unit, and a purification unit. During burn time, helium gas leaving the test module flows through the main cooler, the filter and the main circulator. During off-burn time, a bypass line of the main cooler is opened and the heater is put into line in order to keep temperatures of the test module. Thermal power removed from the test module is finally transferred to the heat removal system of the basic machine via the main cooler. Layout plan of the test module cooling system is shown in Fig. 11. Space required to equip this cooling system is about 16 m x 8 m x 10 m^H.

The functions of tritium recovery system are to recover tritium produced in the test module, to analyze tritium recovered and contained in helium sweep gas, and to control atmosphere in the test module breeding region by varying gas flow rate and adjusting gas composition. Since tritium generated in this helium-cooled test module is recovered by separate helium sweep gas from the coolant, that is the same as for the water-cooled test module, components equipped in the tritium recovery system and their specifications are similar to those for the water-cooled test module. Flow diagram of the tritium recovery system for the helium-cooled test module mentioned above is shown in Fig. 12. Layout plan of the test module tritium recovery system is shown in Fig. 13. As this system handles tritium of relatively high concentration, most of the system needs to be contained in a glove box of about 4 m x 1 m x 2.5 m^H.

It should be noted that capacities of these systems are estimated for the test module to be used in the reliability enhancement test, i.e., about 1 m^W x 2 m^H x 0.5 m^D. Therefore, they should be reestimated when a larger module such as for the segment demonstration test is used.

Acknowledgement

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 all of members who support this work.

References

[1] Japan Home Team, ITER Task Report : Test Program Development, Task No./G16TD55, ID No./D2

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Table 1 Preliminary design parameters of test module for water－cooled ceramic breeder blanket

Blanket type	BOT (Breeder Out of Tube)
First wall area	2 m^2 (1 m^W x 2 m^H)
Thickness	0.6 m
Neutron wall load	1.2 MW/m^2
Surface heat load	0.2 MW/m^2
Structural material	F82H
Coolant	Pressurized water
Inlet/outlet temperature	280/320 °C
Pressure	15 MPa
Flow rate	45 t/h
Breeder material	Li_2O sphere (< 1 mm dia.)
^6Li enrichment	natural (mixture type) 30 % (separate type)
Operating temperature	450-600 °C
Multiplier material	Be sphere (< 1mm dia.: mixture type) Be block (separate type)
Local tritium breeding ratio	1.5 (mixture type) 1.2 (separate type)
Heat deposition	2.9 MW

Table 2 Preliminary design parameters of test module for helium-cooled ceramic breeder blanket

Blanket type	BOT (Breeder Out of Tube)
First wall area	2 m^2 (1 m^W x 2 m^H)
Thickness	0.6 m
Neutron wall load	1.2 MW/m^2
Surface heat load	0.2 MW/m^2
Structural material	F82H or advanced material
Coolant	He
Inlet/outlet temperature	360/400 °C (first wall)
	400/480 °C (breeding zone)
Pressure	9 MPa
Flow rate	18 t/h (5.2 kg/s)
Breeder material	Li_2O sphere (< 1 mm dia.)
^6Li enrichment	natural (mixture type)
	30 % (separate type)
Operating temperature	450-600 °C
Multiplier material	Be sphere (< 1mm dia.: mixture type)
	Be block (separate type)
Local tritium breeding ratio	1.6 (mixture type)
	1.3 (separate type)
Heat deposition	3.0 MW

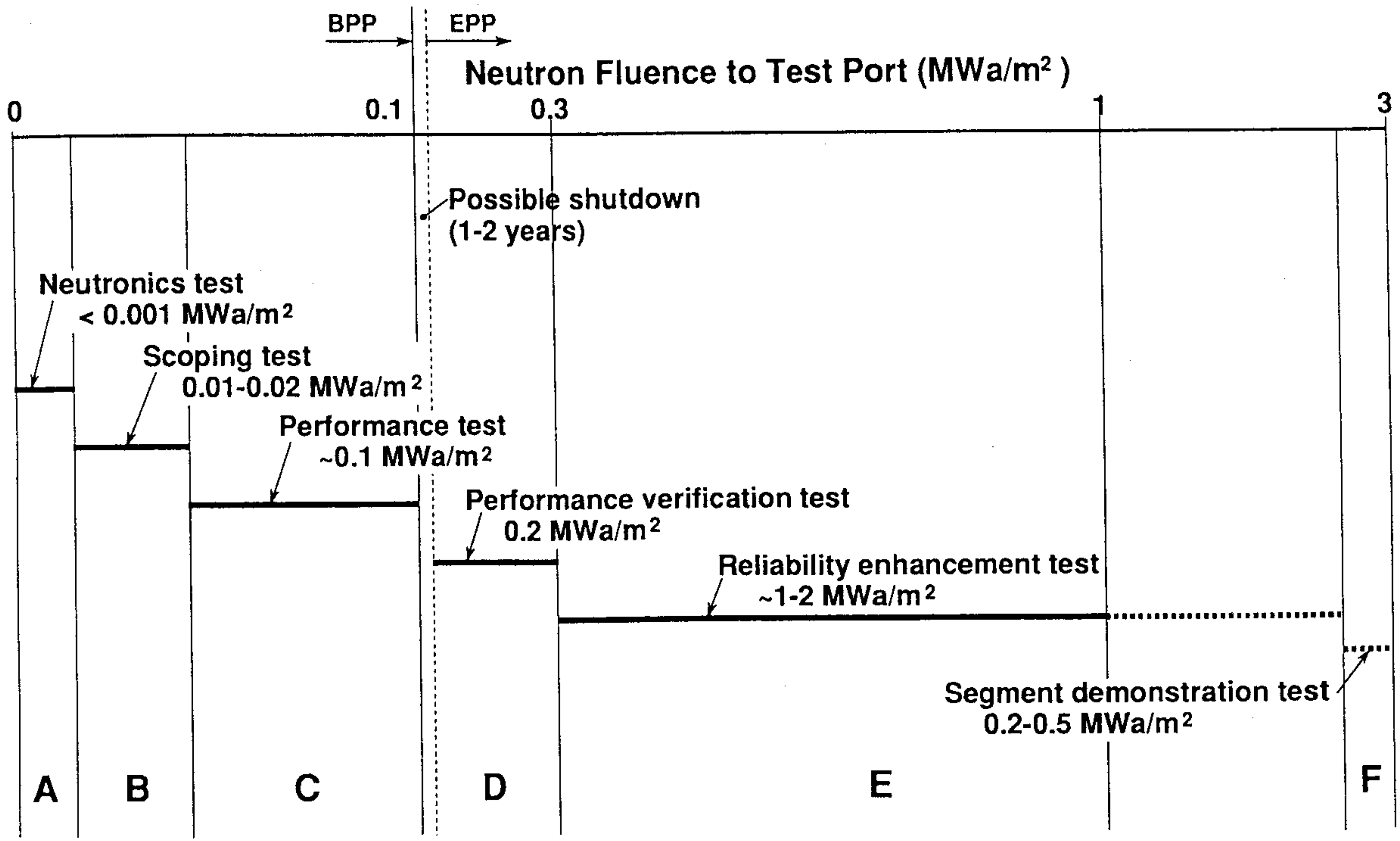


Fig.1 Test procedure in ITER

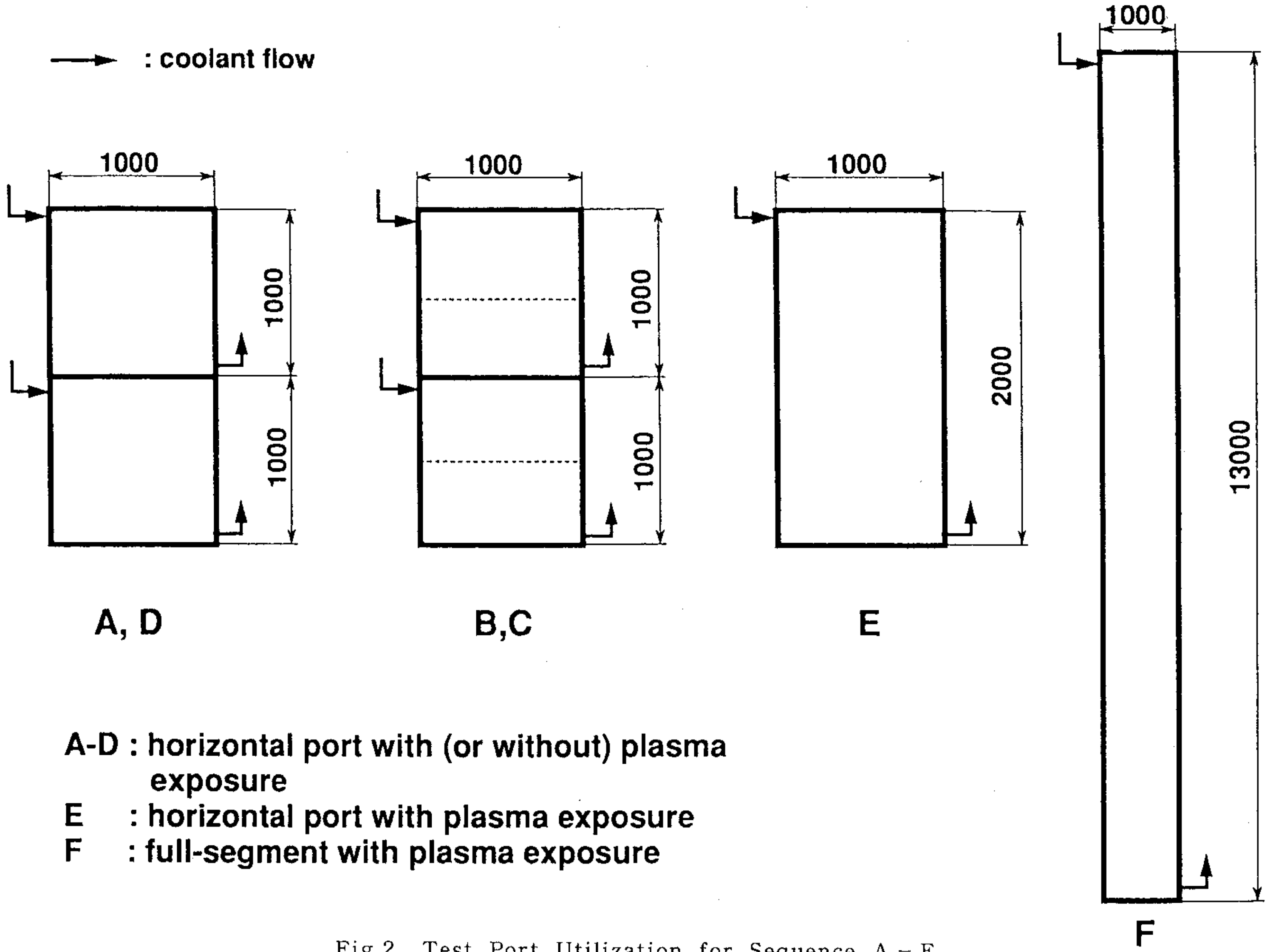


Fig.2 Test Port Utilization for Sequence A – F

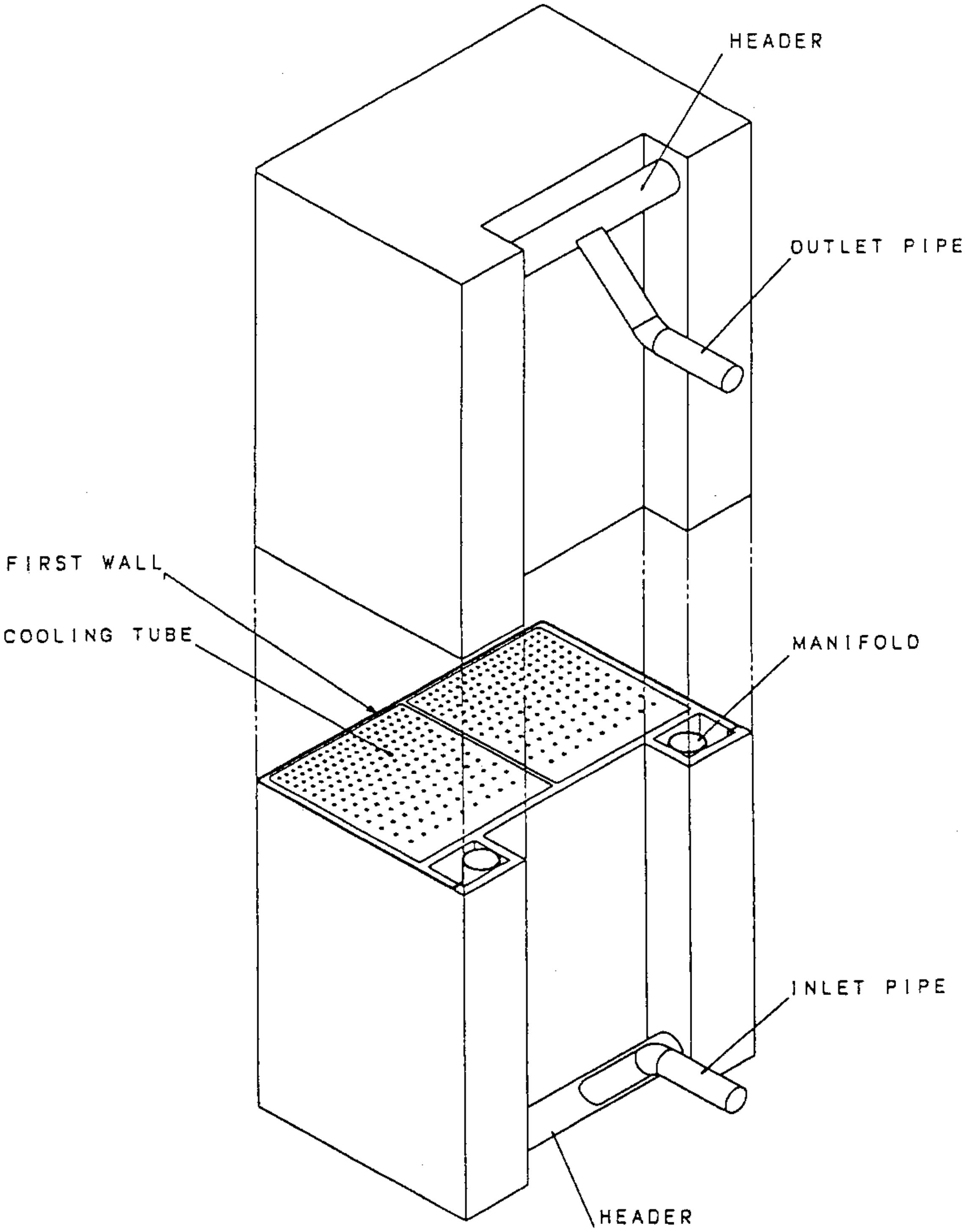


Fig.3 Schematic view of water - cooled test module

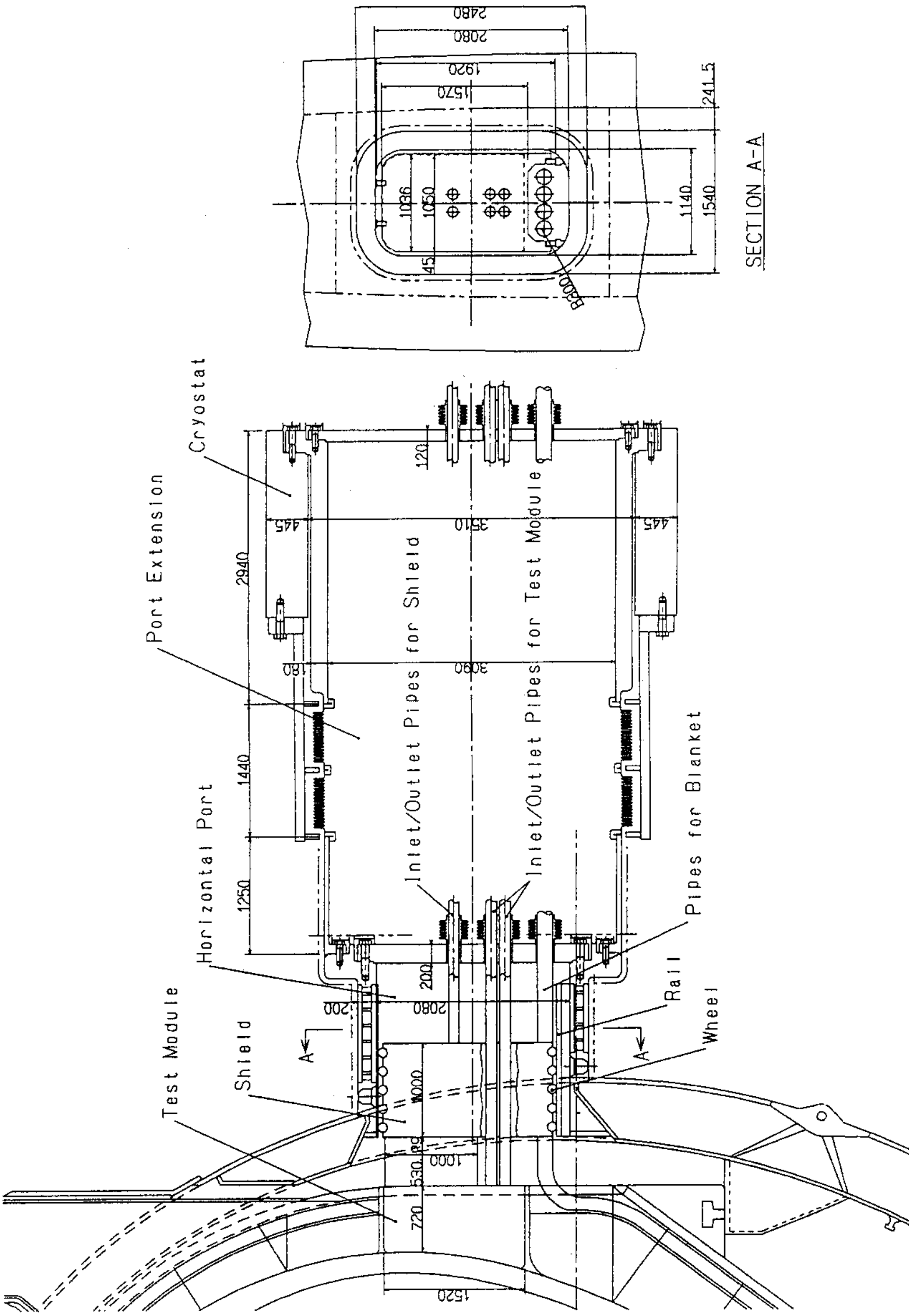


Fig.4 Test module integration into ITER basic machine

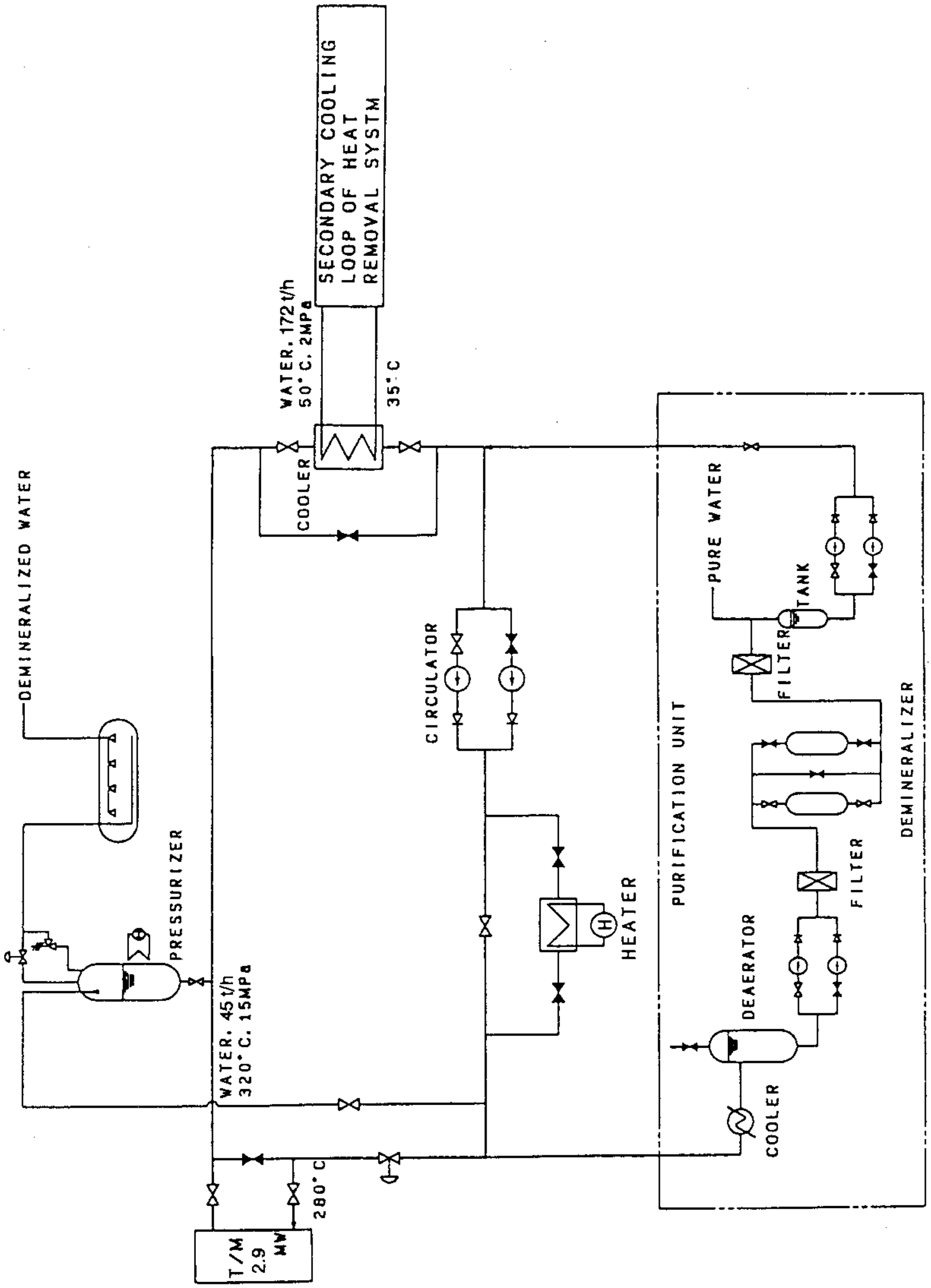
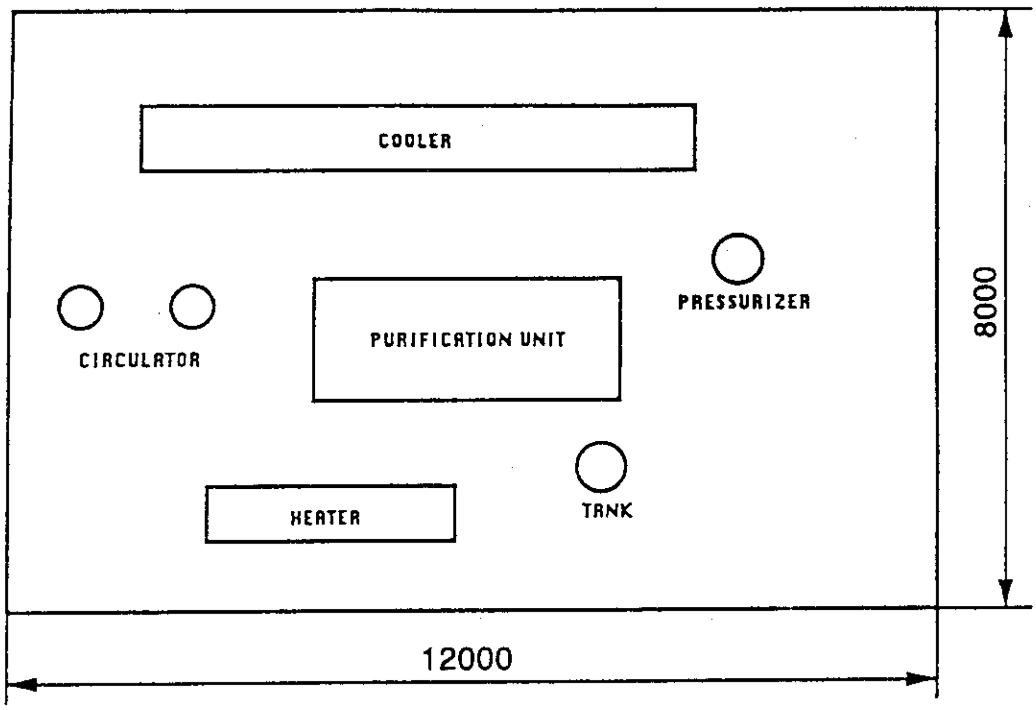


Fig.5 Flow diagram of cooling system for water - cooled test module



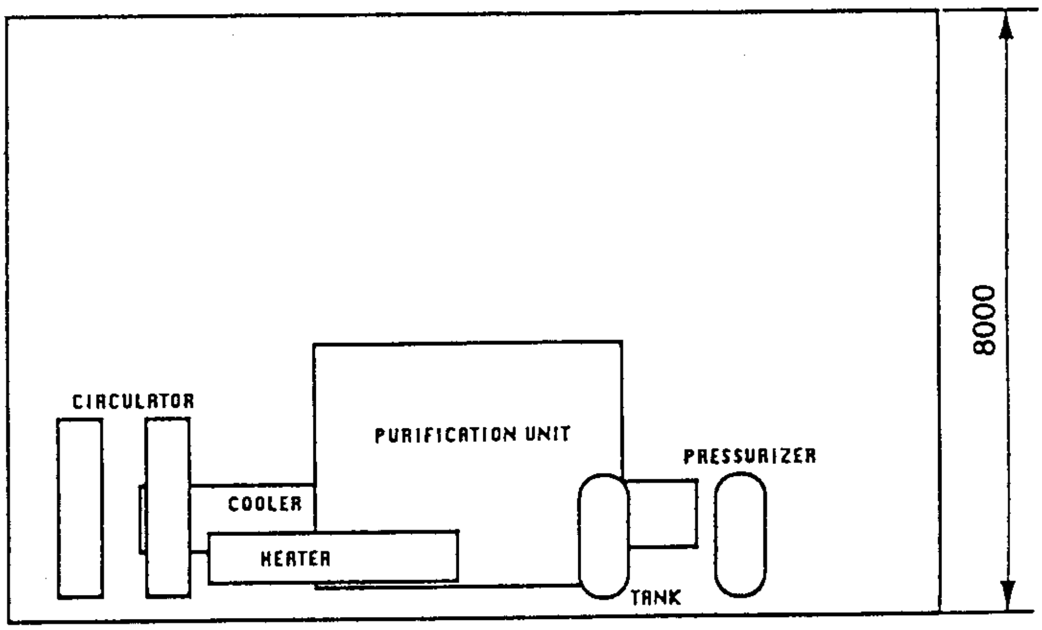
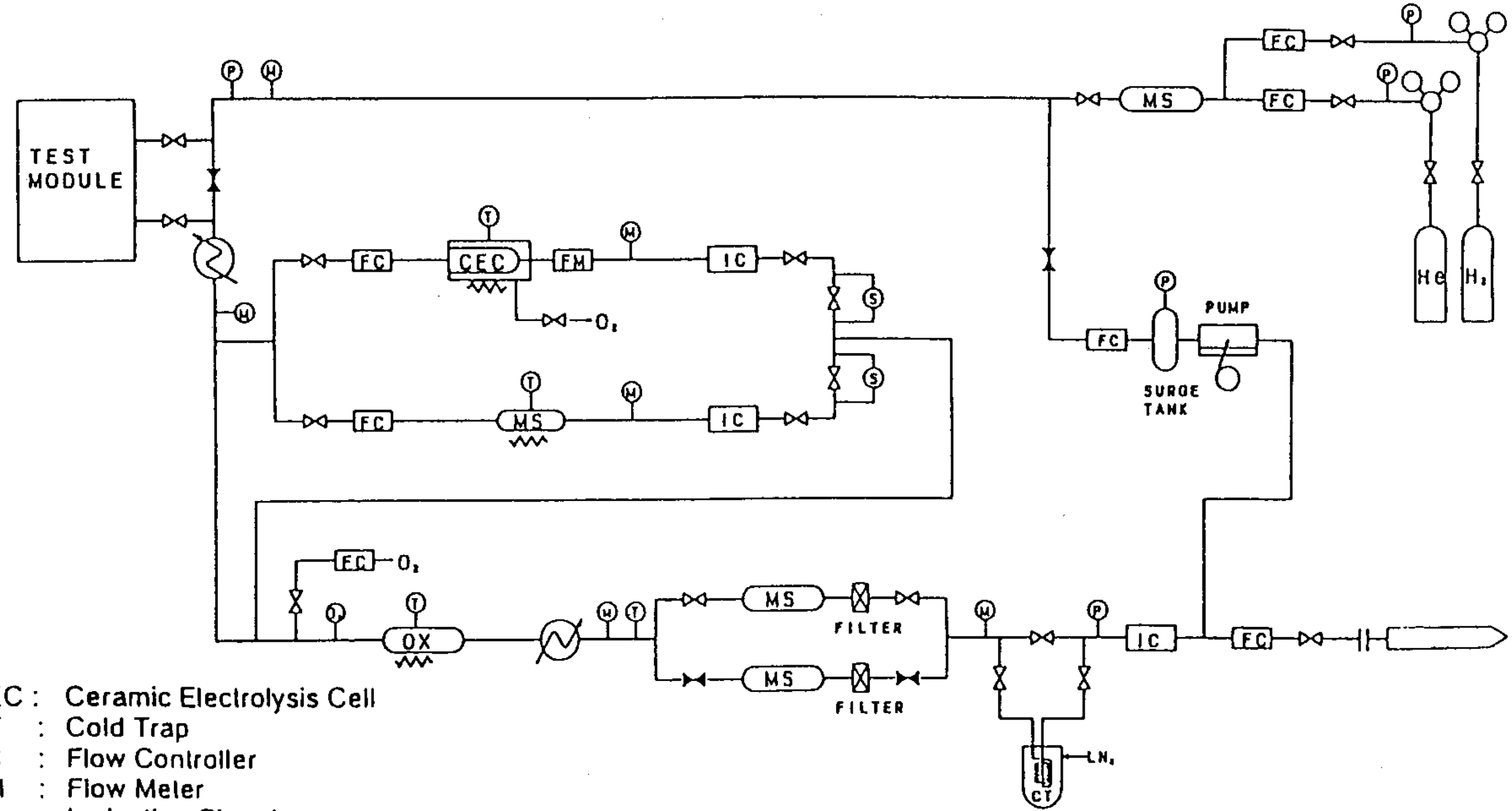


Fig.6 Layout plan of cooling system for water－cooled test module



CEC : Ceramic Electrolysis Cell
CT : Cold Trap
FC : Flow Controller
FM : Flow Meter
IC : Ionization Chamber
H : Hygrometer
MS : Moisture Adsorption Bed
OX : Catalytic Oxidizer
P : Pressure Gauge
S : Gas Sampler for Analysis
T : Thermometer

Fig.7 Flow diagram of tritium recovery system for water – cooled test module

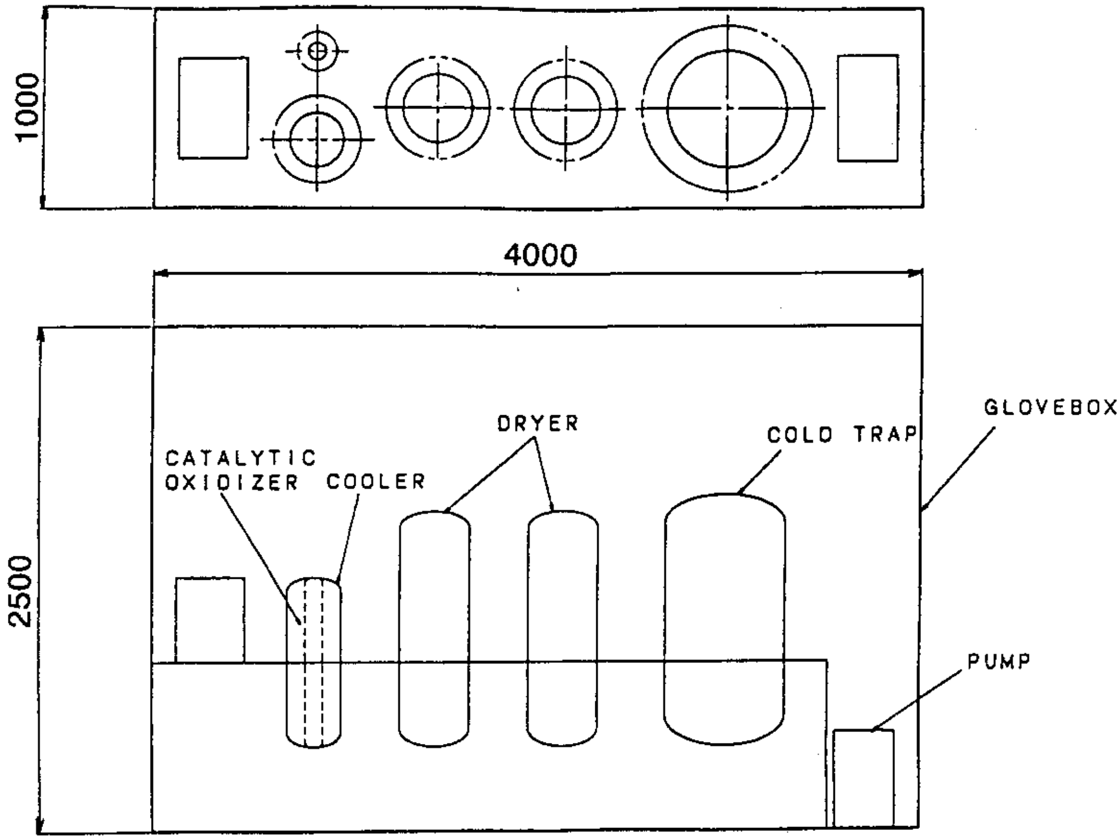


Fig.8 Layout plan of tritium recovery system for water-cooled test module

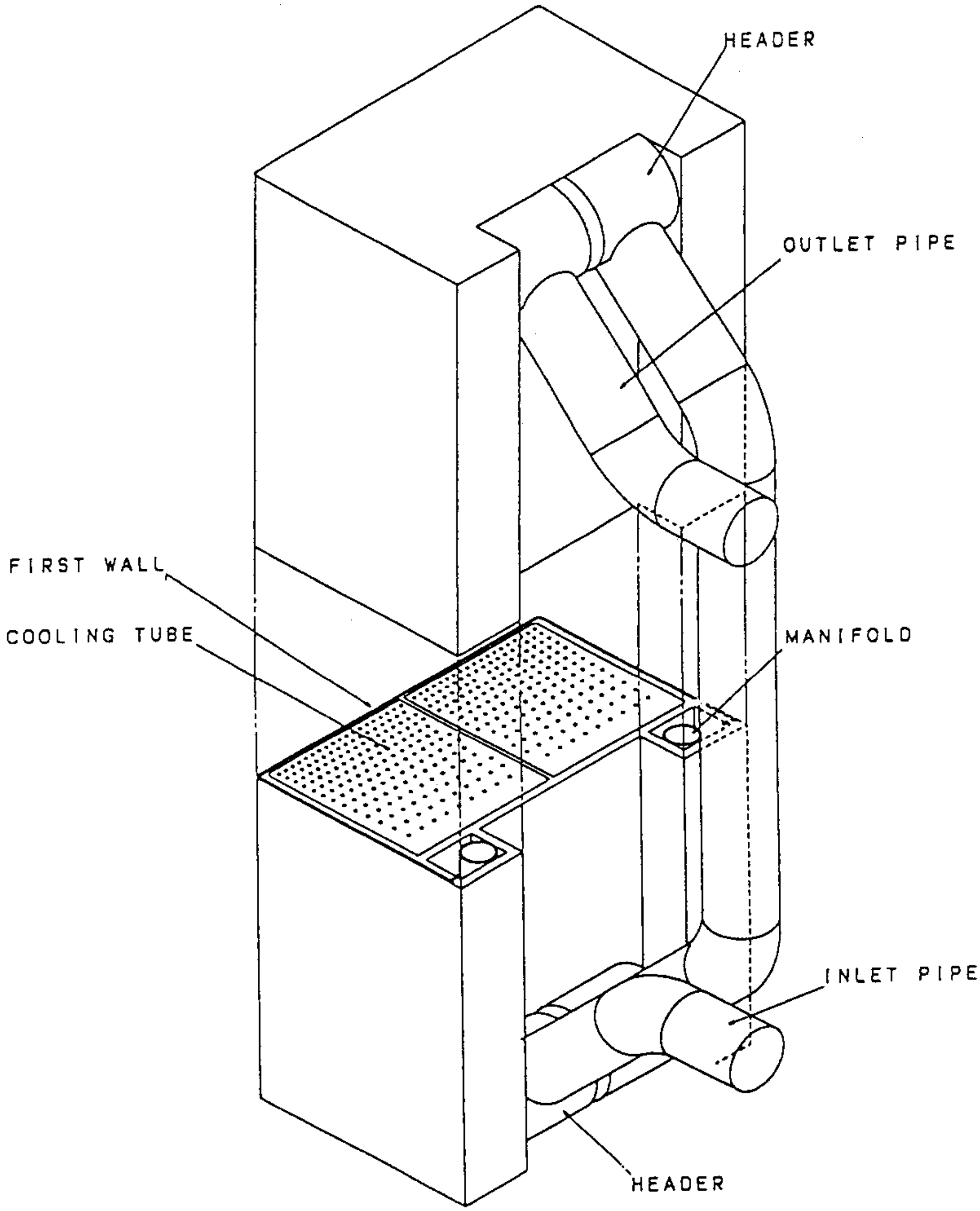


Fig.9 Schematic view of helium - cooled test module

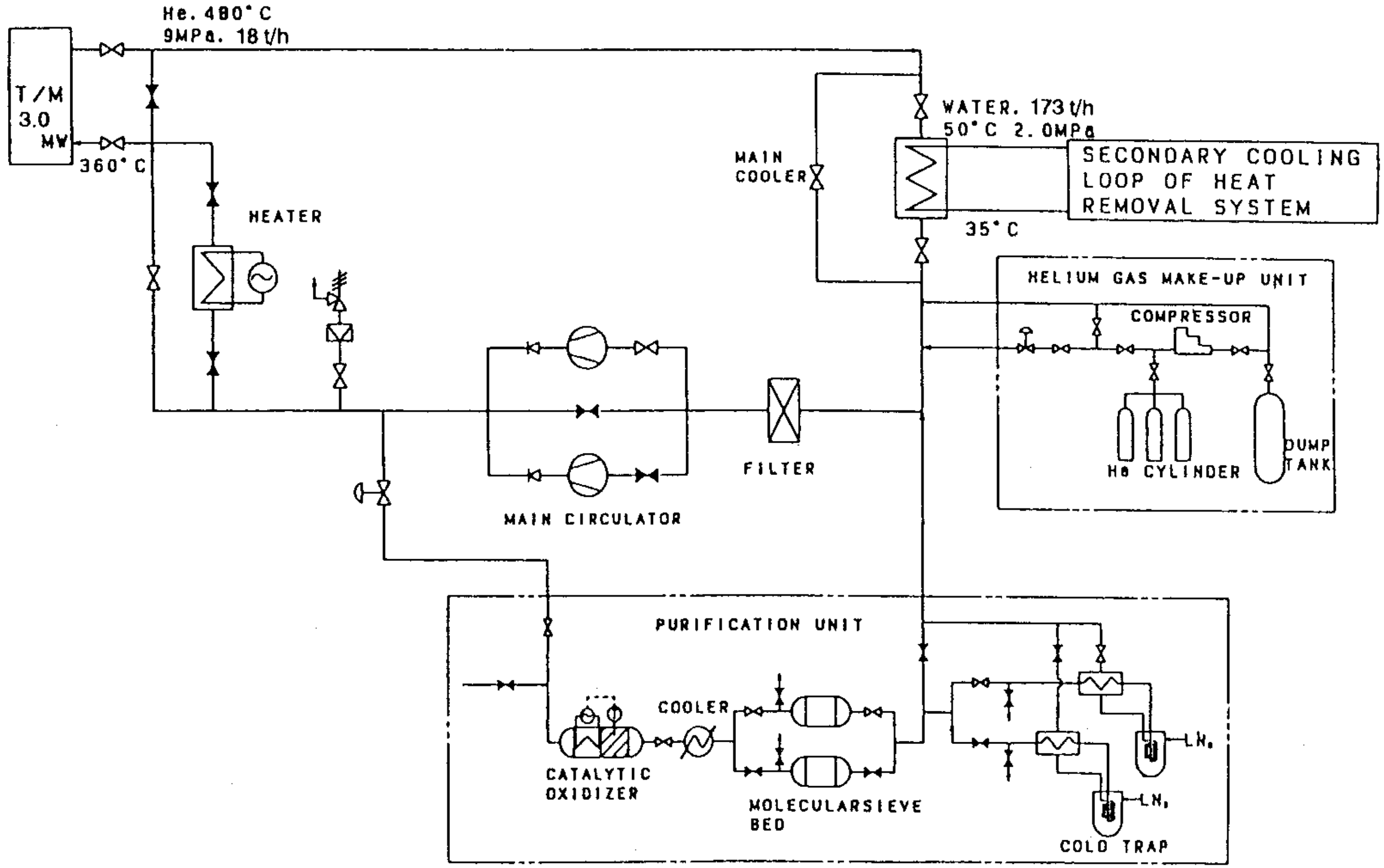


Fig.10 Flow diagram of cooling system for helium - cooled test module

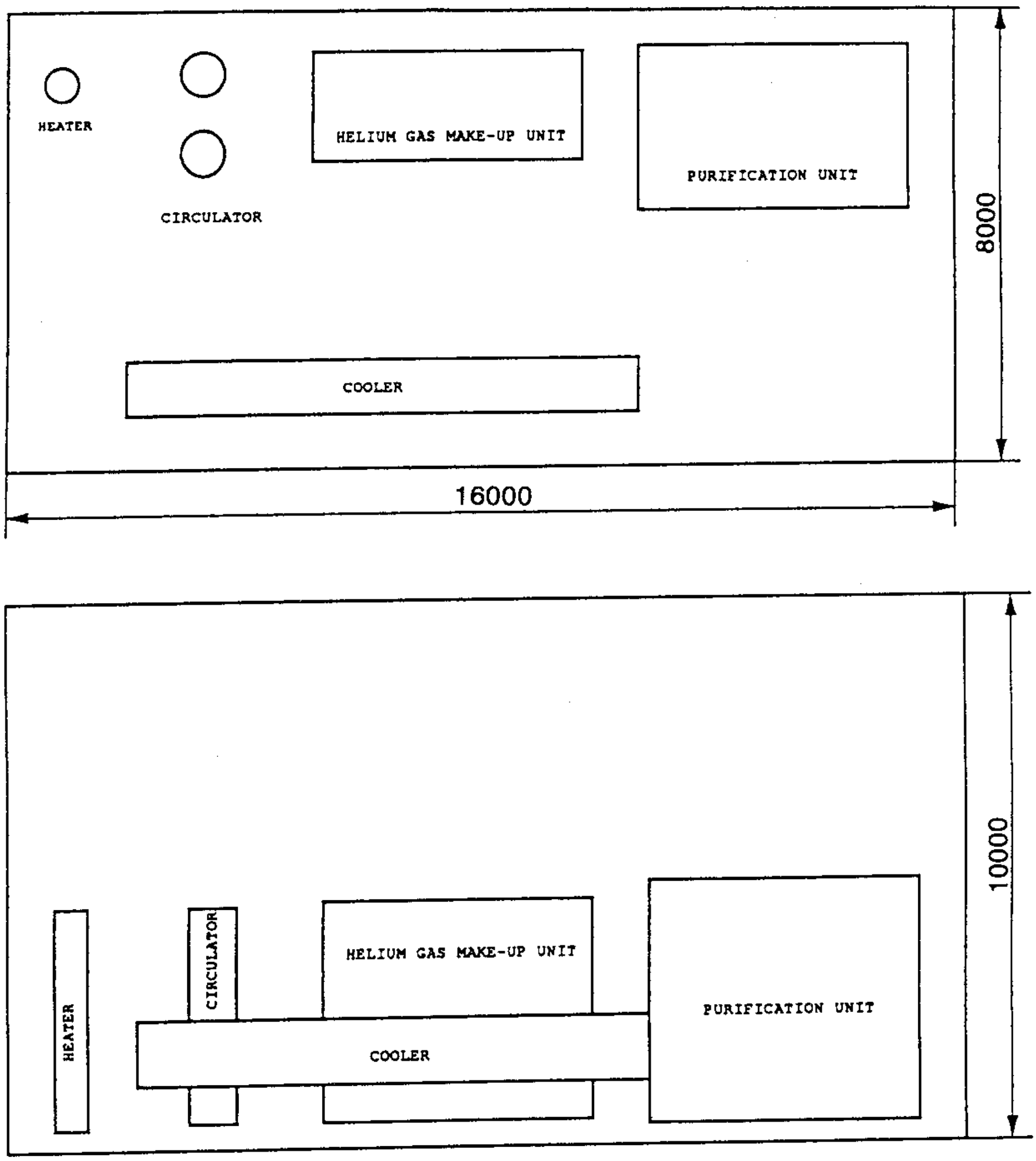
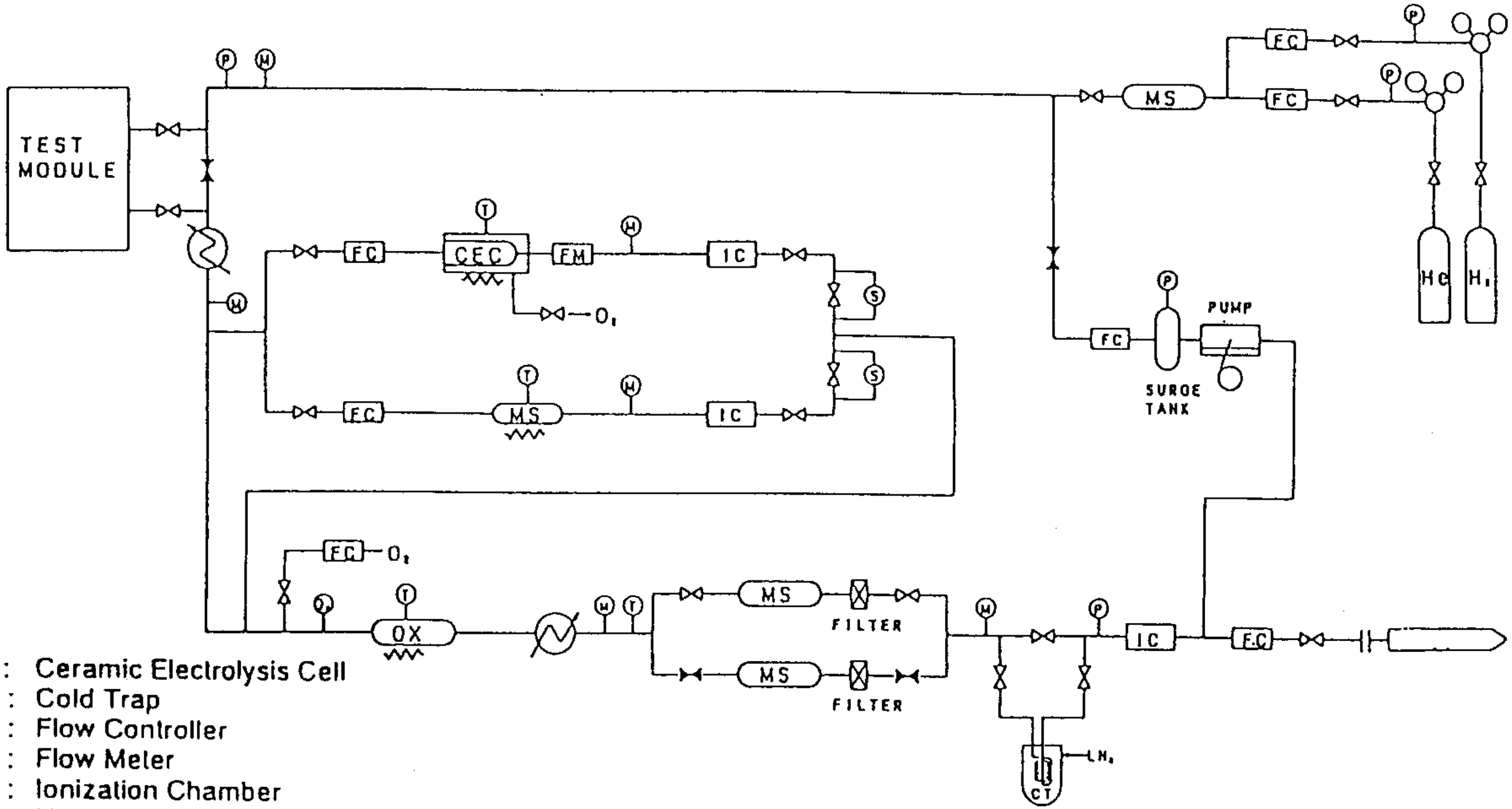


Fig.11 Layout plan of cooling system for helium-cooled test module



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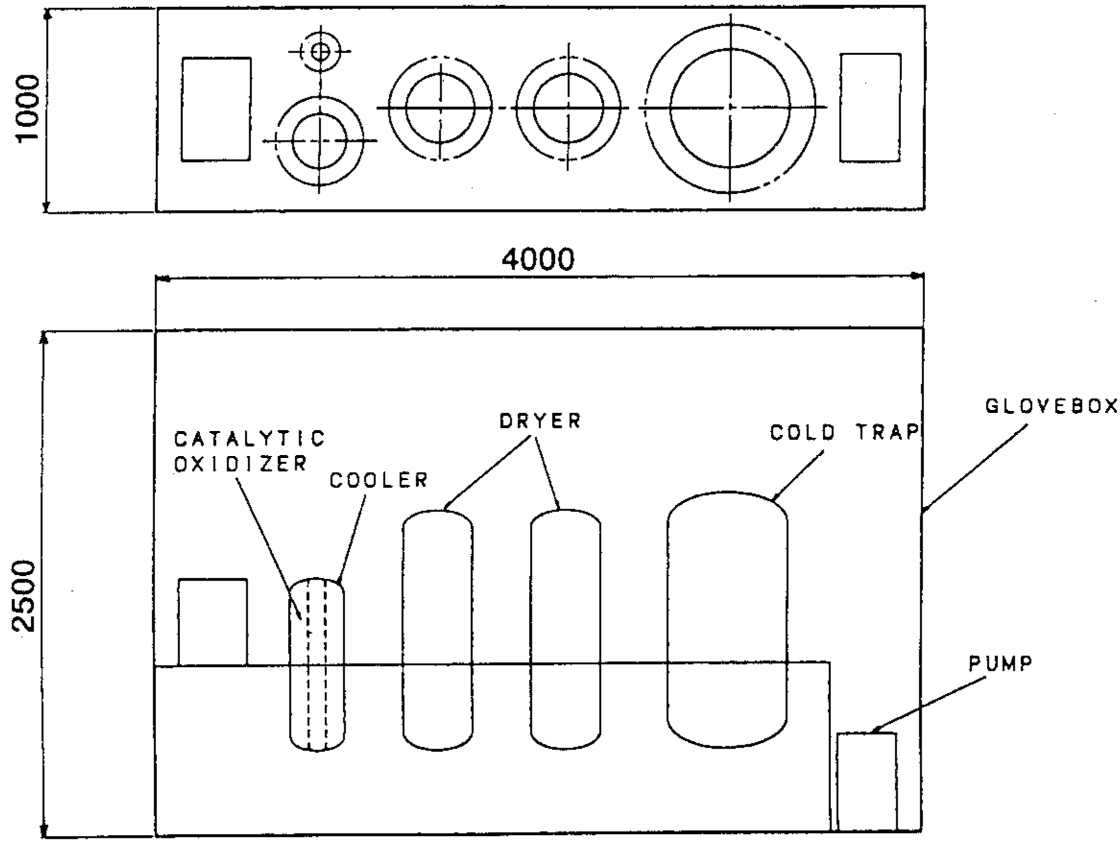

Fig.13 Layout plan of tritium recovery system for helium − cooled test module