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ITER PLANT SYSTEMS

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FOREWORD

Development of nuclear fusion as a practical energy source could provide great benefits. This fact has been widely recognized and fusion research has enjoyed a level of international co-operation unusual in other scientific areas. From its inception, the International Atomic Energy Agency has actively promoted the international exchange of fusion information.

In this context, the IAEA responded in 1986 to calls for expansion of international co-operation in fusion energy development expressed at summit meetings of governmental leaders. At the invitation of the Director General there was a series of meetings in Vienna during 1987, at which representatives of the world's four major fusion programmes developed a detailed proposal for a joint venture called International Thermonuclear Experimental Reactor (ITER) Conceptual Design Activities (CDA). The Director General then invited each interested party to co-operate in the CDA in accordance with the Terms of Reference that had been worked out. All four Parties accepted this invitation.

The ITER CDA, under the auspices of the IAEA, began in April 1988 and were successfully completed in December 1990. This work included two phases, the definition phase and the design phase. In 1988 the first phase produced a concept with a consistent set of technical characteristics and preliminary plans for co-ordinated R&D in support of ITER. The design phase produced a conceptual design, a description of site requirements, and preliminary construction schedule and cost estimate, as well as an ITER R&D plan.

The information produced within the CDA has been made available for the ITER Parties to use either in their own programme or as part of an international collaboration.

As part of its support of ITER, the IAEA is pleased to publish the documents that summarize the results of the Conceptual Design Activities.

CONTENTS

9/10

I. INTRODUCTION

Experience of fission reactor design and operation shows that auxiliary plant systems (balance of plant) essentially affect the operational characteristics of a reactor. The design of plant systems must begin simultaneously with the design of the main reactor systems, and these two designs must be closely interconnected. Incorporation of plant system requirements on zoning, optimization of communications, transportation capabilities, emergency systems, redundancies, etc. is essential at early stages of the design.

On the other hand, the absence of a decision on the site and the absence of a choice of reference blanket essentially limit plant system design opportunities, especially in the area of heat transport.

The ITER plant systems conceptual design is based on two plant design workshops [1 - 2], some other meetings [3 - 5], and homework performed between them.

Chapter II, HEAT TRANSPORT SYSTEM, includes a general heat transport scheme stipulated by safety requirements and a list of heat loads to be removed. It also describes the primary cooling circuits for the divertor, first wall, blanket and vacuum vessel, circuits for baking and conditioning, secondary (intermediate) cooling circuits and contains considerations concerning the ultimate heat sink.

Chapter III, ELECTRICAL DISTRIBUTION SYSTEM, describes the general principles of the system development, the four lasses of power supply required, the electrical distribution system loads in the different classes of power supply, and the basic diagram of the plant electrical distribution system.

Chapter IV, RADIOACTIVE EQUIPMENT HANDLING, HOT CELL, WASTE STORAGE, sets out the requirements for radioactive equipment handling, the hot cell, and waste management; presents the total amount of radioactive materials to be disposed of and the annual fluxes of radioactive waste from the reactor.

Chapter V, SUPPLY SYSTEM FOR FLUIDS AND OPERATIONAL CHEMICALS, describes ITER needs in respect of water of different quality and predestination as well as different gases, steam and operational chemicals, and presents requirements for drain systems.

Chapter VI, ENGINEERED SAFETY SYSTEMS, presents qualitative analyses of failure scenarios as well as methods of burn stability control and emergency shutdown control. It describes requirements for confinements, emergency cooling and emergency power supply systems.

Chapter VII, TOKAMAK BUILDING, presents analyses of tokamak building functions and design requirements; provides the drawings (elevation views and plans); describes the building layout.

Chapter VIII, PLANT LAYOUT; AUXILIARY BUILDINGS AND STRUCTURES, presents a typical preliminary listing of systems and equipment to be housed in the ITER auxiliary buildings and structures as well as preliminary estimates of dimensions of the buildings and structures. It also presents possible ITER site layouts for the operation and construction phases.

Chapter IX, SITE REQUIREMENTS, presents analyses of necessary, desirable, undesirable, and unacceptable site characteristics.

ITER plant systems conceptual design was done by a limited group of specialists and should be considered primarily as the starting point for engineering design activities (EDA) in the corresponding areas. At the same time, we expect that at the beginning of the EDA some technical decisions presented here, especialy on the tokamak building layout and on heat transport systems will be revised.

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II. HEAT TRANSPORT SYSTEM

II.1. INTRODUCTION

The heat transport system should remove heat deposited in different components of the reactor and discharge it to the environment. All the major systems requiring cooling are, as a rule, serviced by separate cooling loops. However, in some cases it is reasonable to use one circuit for cooling different components

The system should also have the ability to provide heat for use in bakeout and conditioning of the in-vessel reactor components (first wall, divertor, blanket) and vacuum vessel.

Low temperature and low pressure water was selected as the coolant and as the medium for torus component conditioning and for bakeout of components not containing graphite structures. Helium will be used for bakeout of in-vessel components containing graphite structures. Considerations on emergency cooling are given in Chapter VI.

This chapter incorporates results of analyses performed by different national teams ([1] - [5]). The conceptual design of the system is still uneven: some parts are relatively detailed, other are absent. More comprehensive design work must be done in this area.

II.2. SCOPE OF THE SYSTEM AND HEAT LOADS TO BE REMOVED

The heat transport system should remove heat from all the equipment where an essential amount of heat will be released.

The reactor operation will be divided into two major operation phases: the physics phase and the technology phase. The reference fusion power in the physics phase is 1.08 GW and in the technology phase 0.86 GW. The physics phase corresponds to mainly inductive scenarios and the technology phase to long-pulse hybrid and steady-state modes of operation. It is obvious that the heat loads during these two operation phases in some components will be different.

The heat loads to be removed from different reactor systems in different operation phases and the number of cooling circuits required are shown in Table II-1.

Since the heat transport system should service the reactor in both operation phases without any modification, the largest of the two heat loads for each system has been taken as the basis for the conceptual design.

Up to 1800 MW must be removed from the reactor. About 230 MW must be removed continuously during ITER operation and approximately 1570 MW represents transient heat loads. The major sources of heat are the blanket/shield and the first wall (up to 1225 MW). Up to 240 MW will be released in plasma heating/current drive equipment. The divertors provide up to 170 MW.

TABLE II-1. NOMINAL HEAT LOADS

System	Number of circuits	Inductive operation (MW)	Steady-state operation (MW)
Blanket 1,2)	2	665	530
First wall 1,2)	2	510	525
Shield 2)	2	200	160
Divertor 2)	2	170	140
Plasma heating/current drive equipment 2)	1	115 3)	240
Cryogenic plant	1	70	30
PF magnet power supply equipment 2,4)	1	30	30
Primary cooling system pumps	-	25	25
Secondary cooling pumps	-	20	20
Ultimate heat sink 6)	-	25	25
Vacuum vessel 2)	1 or 2	20	15
Electr. distribution, PIC 5)	1	20	20
Active control coils 2)	2	10	10
Fuel cycle [7]	2 or 1	5	5
Atmosphere detritiation, HVAC [7]	1	5	5
Bus bars of TF magnets	1	5	5
Utility	1	5	5
Service water pumps	1	5	5
Others 6)	1 -2	45	45
Total		1800	1720

1) The sum of the heat loads for the blanket and the first wall will not exceed 1025 MW at any one time in the physics phase and 935 MW in the technology phase.

2) These heat loads occur during pulses.

3) Maximum heat load that occurs during 20 s of neutral beam injector operation; 65 MW should be removed during 130 s of lower hybrid system operation.

4) Heat loads released in bus bars, tyristors, resistors, and transformers.

5) Protection, instrumentation and control system.

6) The dominant part is connected with potential increase of power supply for ultimate heat sink. This includes also heat loads in the RF antennae, vacuum ducts, removable shield plugs, vacuum pumping system as well as afterheat in activated components removed from the reactor.

Heat in some components to be cooled is released mainly during pulses. However, afterheat may continue to be released in them after reactor shutdown and must be removed as well. The total afterheat in the first wall, blanket/shield and vacuum vessel (without divertors) is up to 3.65 MW just after reactor shutdown. An hour after shutdown it is 2.8 MW, in a day 180 kW and in a month 90 kW.

Taking into consideration uncertainties and a possible excess of nominal heat loads, in particular fusion power, a margin of 25 % was used in the conceptual design.

The cooling of components where the coolant may be contaminated with radioactive materials, especially tritium and corrosion products, requires intermediate (secondary) circuits between the primary cooling circuits and an ultimate heat sink.

II.3. COOLING SYSTEMS FOR FIRST WALL AND DIVERTORS

Up to 680 MW of heat will be released in the first wall and divertors during pulses. About 11 MW will be released additionally in the primary circuit pumps. After the pulses the cooling system must remove afterheat, e.g. afterheat in the first wall will be up to 1.6 MW just after shutdown.

Typical flow diagrams of the primary cooling circuits for the first wall and divertors are shown in Figs. II-1 and II-2. The major parameters of these circuits are given in Table II-2.

According to our estimations, the tritium concentration in the first wall and divertor coolants will be about 1 Ci/l (40 GBq/l). Therefore, for safety reasons, the primary cooling circuits for the first wall and divertors are divided into four separate loops each.

In the heat exchangers the primary water flowing inside the tubes will transfer its heat to the water of the secondary circuits equipped with pumps, buffer tanks, pressurizers, filters and chemical purification facilities. The parameters of the primary/secondary heat exchangers (for one heat exchanger) are given in Table II-3.

If the ultimate heat sink of these cooling systems is water taken from a river or from the sea and the overall warming of the discharged water is 7°C, a raw water flow rate of 24 m^3/s is required to discharge 690 MW.

If wet cooling towers are used as the ultimate heat sink, about 0.3 m^3/s = 25,000 m^3/d of water is required to compensate only for evaporation from the secondary first wall and divertor circuits. We expect that the tritium concentration in these secondary circuits will be 10^{-5} - 10^{-4} Ci/l (0.4 - 4 MBq/l). In this case from 240 to 2400 Ci/d (10 - 100 TBq/d) would be released to the environmental atmosphere with evaporated water of the secondary first wall and divertor circuits. This means that, if wet cooling towers are used, a third coolant circuit is necessary in the first wall and divertor cooling systems.

The same comments certainly apply to RF antennae cooling systems and, possibly, cooling of removable shield plugs. However, the corresponding design studies were not yet performed.

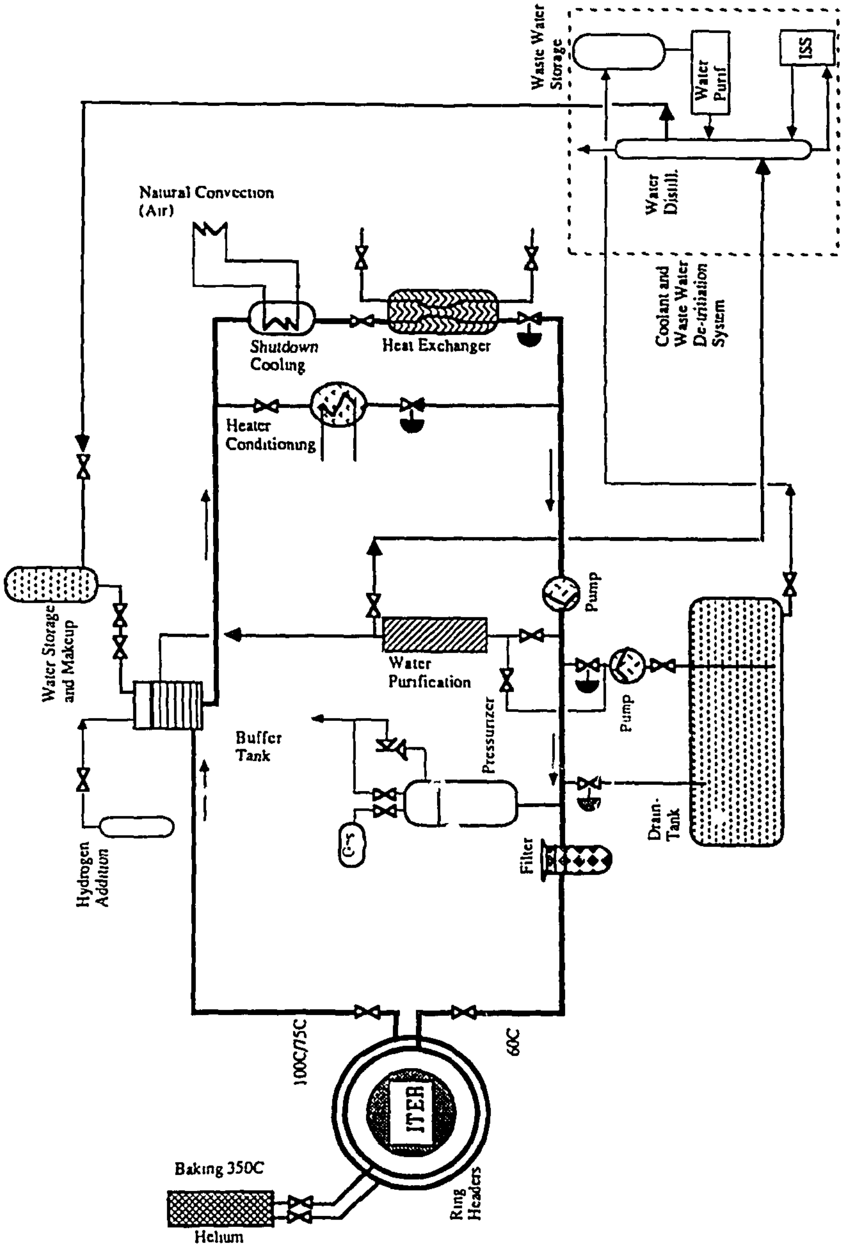

Fig. II-1. Typical cooling loop configuration First Wall and divertor

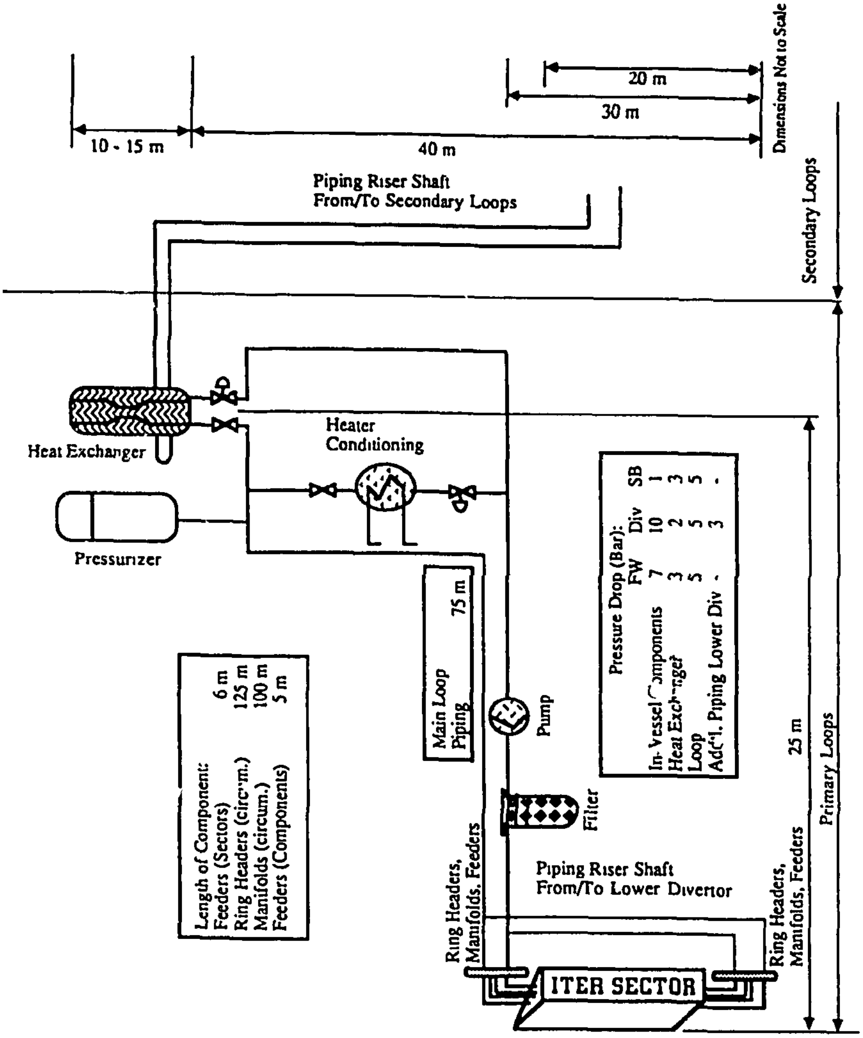

Fig. II-2. Primary loops for First Wall and divertor

TABLE II-2. MAJOR PARAMETERS OF PRIMARY COOLING SYSTEM

Parameter	First wall	Divertor	Blanket/ Shield	Vacuum vessel
Power (MW)	525	170	865	20
Pressure (MPa)	1.7	3,5	1.5	1
Inlet temperature (°C)	60	60	60	50
Outlet temperature (°C)	100	75	100	70
Flow rate (kg/s)	3280	3120	5360	240
(m^3/s)	3.37	3.25	5.51	0.24
Loop number	4	4	4	1
Velocity in pipes (m/s)	4	4	4	4
Pressure drop (MPa):				
in-vessel components	0.7	1	0.1	0.1
heat exchanger	0.3	0.16	0.3	0.084
loop	0.5	0.8	0.5	0.5
total	1.5	≈2	0.9	≈0.7
Tritium concentration				
(Ci/l)	1	1	0.01	
(TBq/m^3	40	40	0.4	
Pump power (MW)	4.8	6.4	5	0.2
Circuit volume (m^3)	321	356	503	89
Outer diameter of pipes (mm)	559	559	687	323.9

II.4. COOLING SYSTEMS FOR BLANKET/SHIELD, VACUUM VESSEL AND ACTIVE CONTROL COILS

The primary cooling system for the blanket/shield is also divided into four separate loops since the high heat load to be removed (up to 865 MW) requires huge equipment, e.g. the primary/secondary heat exchanger, if one loop is used, will have a diameter of 5.3 m and a weight of 530 t. The primary cooling systems of the vacuum vessel and active control coils require one loop. The flow diagrams of the cooling systems for the blanket/shield, vacuum vessel and active coils are similar to those shown in Figs. II-1 and II-2.

The major parameters of the primary cooling system for the blanket/shield, and the vacuum vessel are shown in Table II-2. The parameters of their primary/secondary heat exchangers (for one heat exchanger) are given in Table II-3. In the blanket/shield heat exchangers the primary water is inside the tubes. In the vacuum vessel heat exchanger the primary water is between the tubes.

The necessity of a second (intermediate) cooling circuit for the vacuum vessel and of a third cooling circuits for the blanket/shield and active coils has not yet been determined. However, most likely, the third cooling circuits for the blanket/shield will be required.

TABLE II-3. PARAMETERS OF PRIMARY/SECONDARY HEAT EXCHANGERS

Parameter	First wall	Divertor	Blanket/ shield	Vacuum vessel
Number	4	4	4	1
Diameter (m)	2.17	2.12	2.78	1.09
Heat transfer surface (m^2)1)	1290	650	2110	160
Volume (m^3)	6.5	2.6	12.25	1.2
Weight (t):				
vessel	49.2	27.4	79.7	5.7
tubes	12.4	6.1	20.3	1.5
tube sheets	14.2	13.6	23.3	3.0
total	75.8	47.1	123.3	10.6
Tube sheet thickness (m)	0.3	0.3	0.3	0.25
TUBE SIDE:				
Inlet temperature (°C)	100	75	100	15
Outlet temperature (°C)	60	60	60	25
Flow rate (kg/s)	820	780	1340	480
(l/s)	840	810	1380	495
Tube type	U-type	U-type	U-type	straight
Tube number	1060	1010	1740	320
Tube dimensions (mm) 2)	18x1	18x1	18x1	24x1
Tube bundle length (m) 3)	11	5.7	11	6.7
Water velocity (m/s)	4	4	4	4
Pressure drop intubes (kPa) 4)	300	160	300	84
SHELL SIDE:				
Inlet temperature (°C)	35	35	35	70
Outlet temperature (°C)	50	50	50	50
Flow rate (kg/s)	1100	800	1795	240

1) Corresponding to inner tube diameter

2) Inner diameter x wall thickness.

3) In the heat exchangers of the first wall, divertor and blanket/shield circuits it is approximately half the tube length; in the vacuum vessel heat exchangers it is the distance between the tube sheets.

4) Including the pressure drop in the inlet/outlet of the tubes.

The shield cooling concept also requires additional development. Here the shield cooling is combined with the blanket cooling. However, it may appear that a separate cooling circuit for the shield will be preferable. The problem is complicated by the absence of a reference blanket design. In some blanket design options it is reasonable to combine the cooling of shield components with the cooling of the blanket and first wall. However, separate cooling of removable shield plugs as well as vacuum ducts (and possibly also of neutral beam injector ducts) will most likely be preferable.

II.5. COOLING OF PLASMA HEATING AND CURRENT DRIVE EQUIPMENT

Plasma heating and current drive equipment will operate with relatively short pulses in inductive operation regimes and quasi-continuously in current drive regimes. In a typical inductive operation regime 115 MW of heat is released during 20 s in neutral beam injector components (ion dumps, neutralizers, profile control devices, accelerators, etc.); 65 MW is released during 70 s in lower hybrid system equipment, mainly in klystrons, and 60 MW is released during 60 s in electron cyclotron system equipment, mainly in gyrotrons. These heat releases do not overlap. In the steady-state regimes all these heats will be released simultaneously. The duration of the release will be from 800 s to over 10,000 s. Radioactivity of coolants (cooling of RF antennae is not considered here) is small. Therefore, cooling systems do not require intermediate circuits.

II.6. COOLING OF OTHER EQUIPMENT

Among other systems to be cooled the highest heat load is provided by the cryogenic plant (up to 70 MW in the inductive regimes). However, we expect that in such a big cryogenic plant efficiency may attain 300 W/W [6], and with net refrigeration at 4.5 K of 160 kW the

Other systems to be cooled include: some power supply equipment of the poloidal field coils (about 30 MW), equipment of the electrical distribution system, the protection, instrumentation and control system, and utilities (all together about 25 MW), fuel cycle and vacuum pumping equipment (10 MW) [7] and bus bars of toroidal field magnets (about 6 MW). Furthermore, the cooling system should remove afterheat released in activated components removed from the reactor. All the cooling circuits of the above- mentioned systems do not require intermediate circuits. The only exception is small cooling circuits of some fuel cycle equipment.

II.7. BAKING AND CONDITIONING

A baking system is required to heat all the surfaces and bulk materials inside the vacuum vessel after their exposure to water or air to minimize the oxygen content before plasma operation. Baking is also desirable before torus opening to reduce the amount of tritium on the plasma facing surfaces. The typical baking time is about 24 h. Graphite components of the divertor and first wall require temperatures of about 350°C. They will be heated by helium at a pressure of 4 MPa (see Fig. II-1). Metallic components (in particular of the blanket, shield, and vacuum vessel) should be kept at temperature above 180°C. A heating medium for this purpose is not yet chosen. It has been decided that the ITER design will preclude the use of any water in any of the primary coolant circuits above 150°C for any reasons [8].

Conditioning applies principally to the surfaces in contact with the plasma, i.e. first wall, protective tiles, and divertor plates (see Figs. II-1 and II-2). The required frequency and characteristics are strongly dependent on the first-wall materials, the operating cycle, and the method of conditioning chosen. The purpose of conditioning is twofold: to reduce the amount of oxygen and other gaseous impurities , and to reduce the quantity of hydrogenic species available to the plasma from the plasma facing components [9].

There is a need to distinguish between 'infrequent conditioning' (e.g. after a hard disruption), where 250°C may be needed for graphite materials and 180°C is required for metallic materials, as well as relatively frequent conditioning at the end of 'prolonged' intervals between shots or non-power producing periods, where increasing the water temperature to 150°C in both the first wall and divertor may be useful [10]. Conditioning operations at temperatures not exceeding 150°C will be performed with water. A heating medium for temperatures over 150°C is not yet chosen.

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III. ELECTRICAL DISTRIBUTION SYSTEM

III.1. INTRODUCTION

The site Electrical Distribution System (EDS) serves to receive power from the grid, transform it to the required voltages, and distribute it to the plant and tokamak loads as required. In order to carry out this mission, the EDS will consist of the following major components:

a) Switchyard to receive the power from the grid, transform this power from the grid voltage (400 kV) to the distribution voltages (10 - 66 kV), and provide the switching interface between grid and plant and tokamak distribution systems for various operating states.

b) Tokamak distribution system (TDS) for heavy (pulsed) loads imposed by plasma operation, and

c) Plant distribution system (PDS) for the normal plant operating loads. The plant distribution system includes standby (emergency) power and uninterruptible power supplies (using battery backup). The proposed system is shown schematically in Fig. III-1. The PDS is shown in Fig. III-2.

III.2. SYSTEM FUNCTIONS

The basic function of the Electrical Distribution System is to supply electric power to all facility loads at the voltage and current required and with the degree of security of supply needed to operate the plant, protect the facility from damage, and ensure the safety of plant, staff, and public under all conditions.

The various tokamak and plant loads are divided into different classes of power supply, depending on the degree of security of supply required. Since standby power and uninterruptible power are expensive and limited in capacity, it is essential that only those loads which really require this kind of power are so supplied.

The four classes of power supply are defined as follows:

Class 4: indefinitely interruptible AC supply for those loads which can be interrupted indefinitely without resulting in plant damage or safety hazards to either staff or public. Class 4 power is supplied by the grid. This class of power supplies the normal facility operating loads.

Class 3: temporarily interruptible alternating current (AC) supply for those loads which can be interrupted briefly (say 5 minutes) without resulting in plant damage or safety harzards, but where longer interruptions may cause such problems. Class 3 is supplied by Class 4 (grid) power when available, or by standby generators. This class of power supplies loads which are needed to achieve and maintain safe shutdown in the event of loss of grid power.

Class 2: uninterruptible AC supply for those loads requiring a very secure continuous power supply. This class of power is obtained by the use of invertors (or motor generators) driven by Class 1 power. This class of power supplies safety and protective (AC) loads which must be available at all times.

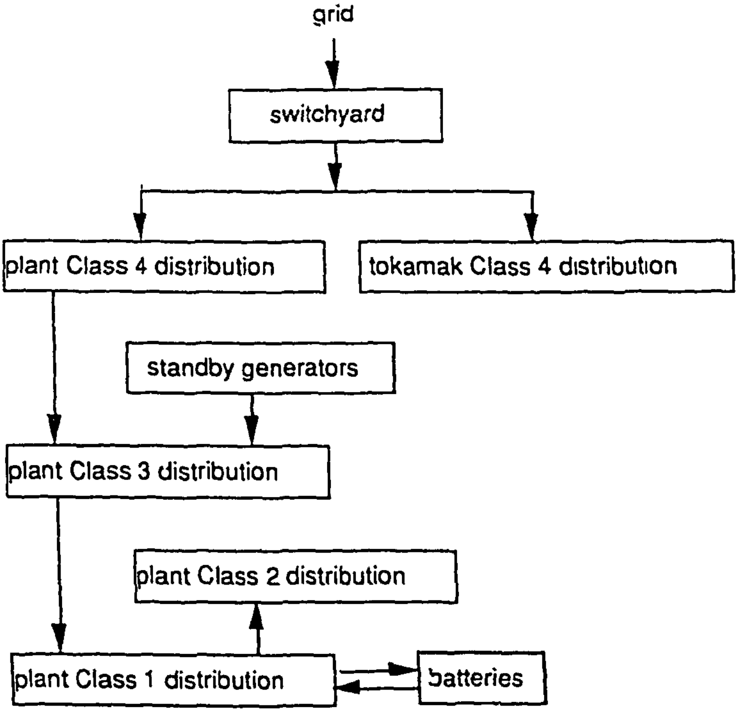

Fig. III-1. Electrical distribution system schematic

Class 1: uninterruptible direct current (DC) supply for those loads requiring the utmost continuity of supply. This class of power is supplied by batteries, which are continuously recharged by Class 3 power through rectifiers. This class of power supplies safety and protective (DC) loads which must be available at all times.

III.3. SYSTEM DESCRIPTION

The switchyard is the interface between the grid and the facility receiving power from the grid. Power is then transformed from the grid voltage (assumed to be 400 kV) to the voltages which will be used in the facility. The magnet supplies and other tokamak power supplies (505 MW) have not yet been specified in detail but it is likely that, by virtue of size, they will be of relatively high voltage (33 - 110 kV). The voltage supplied to the plant can be lower (10 - 20 kV) since the load will be significantly less. A preliminary estimate puts the plant load at 135 MW excluding the cryogenic systems, which may require up to an additional 70 MW. The switchyard will also contain the various high voltage breakers and disconnect switches needed to meet load demands for different grid

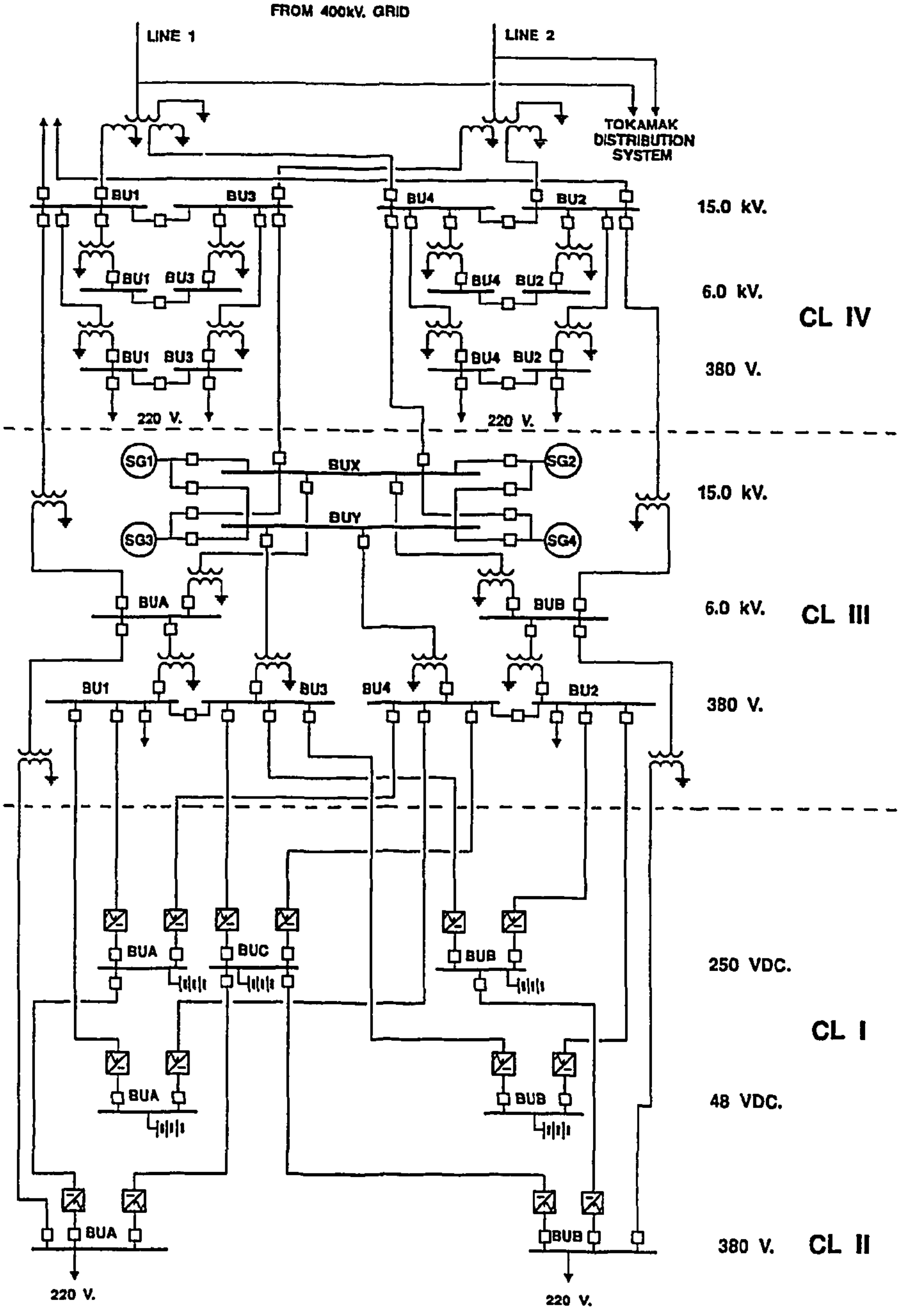

Fig. III-2. Plant electrical distribution system and system configurations, and the instrumentation, transfer logic and controls for these operations.

Downstream from the switchyard, the EDS is divided into two main parts, namely the tokamak distribution system and the plant distribution system.

The tokamak distribution system is primarily a high voltage system (33-110 kV) designed to supply the heavy (and often pulsed) loads which are needed for tokamak operation. Included in this distribution system are the magnet power supplies and various plasma fuelling and heating power supplies. Also included in this system will be the static volt-ampere-reactive (VAR) compensation and any energy storage equipment required.

The tokamak distribution system consists of Class 4 power with no provision made for backup or uninterruptible power for these heavy loads. Thus in the event of loss of grid power, power will be lost to these loads and tokamak operation will cease. Any requirements for temporarily interruptible power (e.g. for afterheat cooling) and uninterruptible power (e.g. for essential control and instrumentation) would be supplied from the plant distribution systems. The poloidal field coils PF1-7 are supplied via underground cables from the switchyard. Each coil is supplied from a system of semiconductor power convertors and transformers which are combined to produce a load on the supply which has an optimal content of reactive power and harmonics.

To reduce the reactive power required as well as stabilize the site voltage, a static VAR compensator (SVC) is envisaged as being necessary. This will consist of capacitors varied by mechanical or electronic switches in parallel ts with reactors whose currents are controlled rapidly by power semiconductors. If the site is assumed to be situated in a network consisting of a large installed capacity of reasonably localized power stations, it is assumed that the rapid variations in input power (0 - 710 MW about a fixed load of 230 MW) can be supplied by the system, via the stored mechanical energy in the machines, whilst keeping speed variations within the system frequency limits. In this case there is no economic reason for using energy storage on the site: rotating energy storage machines are both inefficient and expensive to purchase and require extra manpower to run and maintain.

The power convertors will be contained in a building remote from the main tokamak building, with the transformers located in an open area adjacent to the building. Depending on the supply voltage chosen, each PF coil group of transformers will be supplied via its own switchgear to give fault protection against short-circuits of the converters. The converters will be able to withstand the fault currents (400 kA) during the fault clearance time. These switches may be placed further away in the switchyard containing the 400 kV/(33 - 110 kV) grid transformers, as will the static VAR compensation equipment. The power electronics for the static VAR system would be housed in a building which will also contain the protection system cubicles for the site high voltage network and for the site end of the incoming 400 kV supply.

The power supplies for the additional heating systems (NBI, LHW, ECW) have a lower installed capacity compared with the PF supplies but a similar peak load and will also be supplied by the TDS.

The plant distribution system consists of Class 4, 3, 2 and 1 power to supply those loads which are required to operate independently of the TDS. A one-line diagram of the proposed plant distribution methods is shown in Fig. III-2. Each class of power has its internal transformer and distribution systems to meet the voltage and current requirements for the particular class of power. In addition, for every class of power, internal redundancy of buses and automatic transfer instrumentation, logic and control will be provided to reestablish supply to affected buses in the event of loss of normal power. The systems are so configured that unaffected areas can be supplied through alternative paths, thus limiting the consequences of any component failure to a single bus, rather than affecting whole areas of the distribution system.

Class 4 will consist of 4 groups of buses with voltages ranging from 15 kV to 220 V (or 120V, depending on site location). Higher voltages are provided by heavy loads such as cryogenic systems, the various cooling systems and vacuum pumping systems. Other voltages will be used for various smaller pumps, fans, lights and numerous applications inherent in the plant.

Class 3 will consist of multiple buses and voltages (2 x 15 kV transfer buses, 2 x 6 kV, 4 x 380 V and 2 x 220/120 V). Normal supply for Class 3 will be from Class 4. In the event of loss of the normal Class 4 supply, power would be restored either from an alternate Class 4 supply or from the partner bus. If this is not possible, then Class 3 will separate from Class 4, and the standby generators will be started to pick up the Class 3 loads. This process is used in nuclear power plants and, by employing gas turbine units, can provide power levels of up to 60 MW within 3 - 4 minutes.

Class 1 is entirely DC power (for maximum simplicity and reliability) and consists of three 250 V and two 48 V buses supplied by batteries at all times. When Class 3 power is available, the batteries are continuously fed by rectifier units to ensure that the batteries remain fully charged. The capacity of Class 1 batteries under full load should be at least 45 minutes to give operators a chance to restore Class 3 power in the event that the automatic process has failed. Given these capacities, it is obvious that the short (<5 min) interruptions of Class 3 will have no effect on Class 1 (since it is supplied by batteries). Each battery bank has two rectifiers to ensure continuity of supply in the event of rectifier failure. Note that there are no connections between adjacent buses. This is done to ensure that there can be no crosslinked failure between Class 1 buses. Class 1 loads can, however, be supplied from both buses, using diodes/fuses for isolation.

As noted, Class 2 power is supplied by Class 1 through invertors to provide uninterruptible AC power. Although all loads are not yet established, it is unlikely that high voltages will be required and only 380 V and 220 (or 120 V) buses are shown. To ensure that functions are not lost due to bus or breaker failure, critical loads will be duplicated or supplied simultaneously from two buses with break/make connections of sufficient speed to avoid interruption. In the event of invertor failure, an alternative supply from one of two Class 3 sources is provided. In this case the affected bus is not an uninterruptible supply, but, given the expected redundancy of the loads, this situation should be acceptable for the short periods of time required to restore a supply from Class 1.

III.4. RELIABILITY DESIGN FEATURES

To meet the expected stringent reliability requirements and to keep partial power system failures from having a cascading failure effect, the system proposed has the following features:

a) The design assumes that two lines (circuits) will connect the facility to the grid. To maximize the separation of pulsed and steady state loads, it is assumed that one circuit will supply the tokamak (pulsed) loads while the second will supply the plant loads. In the event of loss of one circuit, the tokamak loads would be shed (plasma shutdown) and the remaining circuit would supply the plant loads.

b) Since each bus has multiple supply paths and buses have double breakers, any single failure can be limited to a single bus. This provides redundant backup capability with a high degree of independence.

c) Each class of power is subdivided into two, three or four segments with limited cross ties to provide redundancy without excessive crosslinks.

d) The distribution system will have automatic fast transfer logic systems which will sense the loss of supply to a bus, determine what alternative supplies are available and will carry out switching to connect the affected bus to a viable power supply.

e) Physical separation of redundant buses will be provided for protection against common causes of failure (e.g. fires).

f) Triplicated 250 V DC buses are proposed to provide three independent channels of safety system instrumentation to permit the use of single failure resistant 2 out of 3 channel voting logic on safety systems.

g) The use of four standby generators is proposed, each with the capability of providing power for the entire emergency load. This permits one to be on maintenance, one to fail to start, and one to fail during operation without compromising safety.

h) Suitable test capability will be required to allow periodic testing of all poised systems and automatic transfer systems as well as periodic operation of all circuit breakers and disconnectors without adversely affecting system operation or compromising safety. Depending on the reliability requirements, such testing may have to be on-power testing.

III.5. POWER SUPPLY REQUIREMENTS

The electrical power needs of various ITER systems are shown in Table III-1. During the inductive operation (physics phase) ITER will require a continuous electric power supply of about 230 MW. An additional supply of up to 480 MW is needed to provide for transient power demands. Thus, the peak power demand is up to 710 MW. A typical change of the plasma heating/current drive power load as well as of the total power load during an inductive operation pulse is shown in Fig. III-3.

During the steady-state operation (technology phase) ITER will require up to 635 MW of continuous electric power supply.

TABLE III-1. ELECTRIC POWER NEEDS

System	Inductive operation (MW)	Steady-state operation (MW)
PF magnets	355[1,3)]	50
Plasma heating/current drive	190[1,2,3)]	385
Cryogenic system	70	30
Primary cooling system	25	25
Ultimate heat sink	25	25
Electrical distribution, PIC[4)] system and utility	25	25
Secondary cooling system and heat sink	20	20
Fuel cycle, detritiation, HVAC	10	10
Active control coils	10[3)]	10
TF magnets	5	5
Experimental facilities, diagnostics	5	5
Others[5)]	45	45
Total	710	635

1) The sum of the power supply needs for the magnets and the plasma heating/current drive system will never exceed 470 MW.

2) Maximum power consumption that occurs during 20 s of neutral beam injector operation; 115 MW should be supplied during 70 s of lower hybrid system operation and 80 MW should be supplied during 60 s of electron cyclotron system operation.

3) Transient loads.

4) Protection, instrumentation and control system, including instrument air needs.

5) The dominant part represents potential increase of power supply for ultimate heat discharge system. This includes power supply needs for vacuum pumping, baking, conditioning and service water.

The exact system loads (class, voltage and power) still remain to be specified as the design develops. A preliminary assignment of class and estimates for some major loads are made below. These estimates will be updated as the design progresses. This updating may affect the selection of bus ratings and/or voltages, but is not expected to require altering of the concept presented below.

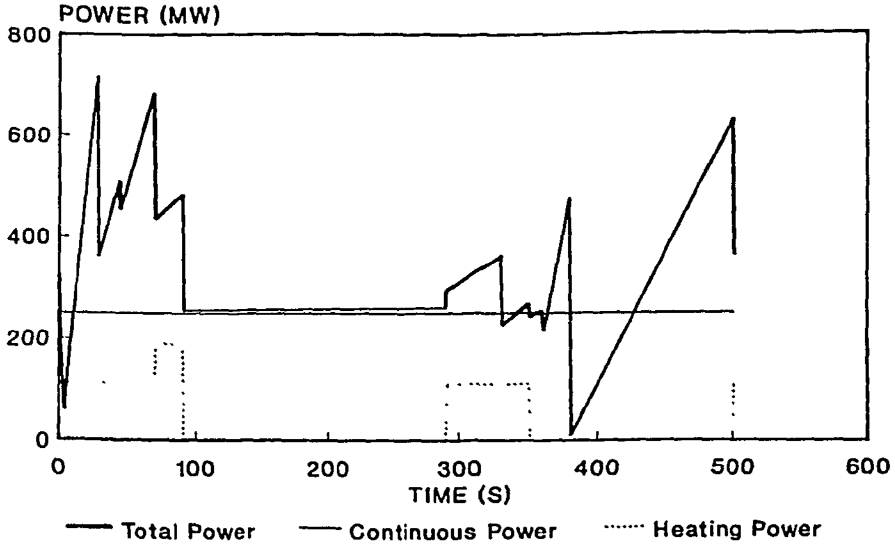

Fig. III-3. Site power (MW) during a pulse

III.5.1. Tokamak distribution system loads (preliminary)

CLASS 4 LOADS	MW	VOLTAGE
Poloidal field power supplies	355*	66 kV
Toroidal field power supplies	5	66
Active control coil power supplies	10	66
NBI power supplies	190*	66
RF heating power supplies	115*	66
Electrical distribution (TDS)	15	66
Experimental facilities (incl. diagnostics)	5	66
Fuelling power supply	0.1	66
Total	505	66

* Loads are not simultaneous. Maximum total for these loads is 470 MW.

III.5.2. Plant distribution system loads (preliminary)

CLASS 4 LOADS	MW	VOLTAGE
Cryogenics (interruptible)	70	15 kV/6 kV
Primary cooling	25	15 kV
Secondary cooling	20	15 kV
Third cooling circuits and heat sink	25	25 kV
Electrical distribution (PDS), PIC	5	25
Tritium processing (most)	5	6 kV - 220 V
Service water (most)	5	15 kV/6 kV
Instrument air (most)	5	6 kV
Plant lighting	5	380/220 V
Atmosphere detritiation	2	6 kV - 380 V
HVAC (most)	2	6 kV - 380 V
Others *)	35	6 kV - 380 V
Total	205	

*) - The dominant part represents potential increase of power supply for ultimate heat sink discharge system. This includes also power supply needs for diagnostics, vacuum pumping, baking and conditioning

CLASS 3 LOADS		
Class 1 rectifiers	5	6 kV
Decay heat removal systems	3	6 kV
Tritium process (shutdown only)	1	380 - 220 V
Containment atmosphere processing	2	6 kV - 380 V
Confinement atmosphere processing	1	6 kV - 380 V
Atmosphere detritiation	1	380 V
Cryogenic system (protective)	1	6 kV
Service water (protective)	1	6 kV
Instrument air (protective)	1	380 V
HVAC (protective)	1	6 kV - 380 V

CLASS 2	MW	VOLTAGE
	1 (total)	
Safety system instrumentation and control		220 V
Process instrumentation and control		220 V
Process control computers (all)		220 V
Fire protection monitoring		220 V
Access interlocks and control		380/220 V
Emergency AC lighting		220 V
Radiation monitoring		220 V
Communication systems		220 V
CLASS 1 LOADS	4 (total)	
Class 2 invertors		250 V
EDS protective relaying		250/48 V
EDS switching logic and actuators		250 V
Safety system instrumentation		250/48 V
Protective instrumentation and control		250/48 V
Emergency DC lighting		250 V

Taking into consideration uncertainties, a margin of 25% was used in the conceptual design.

IV. RADIOACTIVE EQUIPMENT HANDLING, HOT CELL, WASTE STORAGE

IV.1. INTRODUCTION

During its lifetime, ITER will produce flows of failed components, graphite dust, broken protection tiles, and components tested in the machine.

All these will be activated and are likely to be tritium contaminated, some of them possibly containing a large tritium inventory. For economic reasons, and possibly for waste disposal, a fraction of this tritium has to be recovered.

After tritium recovery, as for the other un-repairable, non-tritiated components coming to the hot cell and waste management they have to be conditioned as wastes. This will be the task of the hot cell and waste management system.

IV.2. DESIGN AND PERFORMANCE REQUIREMENTS

IV.2.1. Design requirements

To accommodate the ITER operation scenario, the hot cell design should be modular and as compact as possible, the design of this system being linked to the amount of waste components processed.

The hot cell should be designed to perform the following functions:

- receive solid and liquid wastes,
- transfer these components for inspection,
- inspect and dismantle components,
- sample and analyse,
- decontaminate, detritiate,
- immobilize liquid wastes,
- segregate materials if required,
- package solid wastes,
- provide intermediate storage for shipping casks.

The storage will consist of a buffer volume in order to minimize the hot cell processing capacity. The minimum during the physics phase will be the capacity to store:

- 2 inboard blanket segments,
- 2 top divertor modules,
- 2 bottom divertor modules,
- 1 central upper, 1 central lower and 2 lateral outboard blanket segments.

The available total storage capacity should be enough to store 64 divertor plates if their replacement is required. In this event it is assumed that no blanket segment will be present at the same time. Provisions for active cooling of these components have to be made.

The diagnostics and sampling should offer the possibility of making a detailed examination of failed components and of taking samples of the failed part(s). Another sampling requirement is that it be possible to take multiple samples for tritium measurement. This subsystem must also have the possibility of collecting samples, identifying them and putting them into transport containers. A sample processing chain should be included in the hot cell system.

The repair and control subsystem should be equipped in such a way that components to be repaired can be decontaminated, repaired and checked. A storage area for repaired components should be provided.

A tritium recovery subsystem is required to recover tritium from highly tritium contaminated pieces of equipment and to process graphite (metallic) dust and protection tiles. Special care has to be taken for the possible presence of ^{14}C or other radioactive gaseous species that may have a strong impact on the tritium recovery processes and the waste conditioning and disposal.

After or without tritium recovery, failed equipment has to be dismantled, compacted and conditioned in waste containers ready for transportation.

Several auxiliary groups of equipment have to be used in the hot cell:

- cooling water subsystem,
- atmosphere detritiation subsystem,
- remote maintenance equipment,
- control.

IV.2.2. Performance requirements

IV.2.2.1. Lifetime

The lifetime of the hot cell system must include the decommissioning period. As a consequence the lifetime must be at least 30 years.

IV.2.2.2. Availability

This system must have a minimum impact on machine operation. The only availability requirement is therefore that the system be capable of receiving large components and temporarily storing them with a reliability of >95 % over the machine lifetime.

IV.2.2.3. Layout

The hot cell layout must be modular and as compact as possible subject to remote handling requirements. Care has to be taken to prevent the spread of contamination from one zone to another. Intercell air locks and partial decontamination of transfer equipment should be foreseen. Personnel and equipment access via air locks must be provided.

IV.2.2.4. Tritium

Components should be designed and constructed from materials able to withstand tritium and gamma radiation effects over the lifetime of the facility. In particular, materials which give off corrosive by-products when exposed to tritium should not be used.

The tritium inventory should be kept as low as possible. The localized tritium inventory should not exceed 150 g.

IV.2.3. Key parameters

The key parameters are given in Tables IV-1 to IV-7.

IV.3. MAINTENANCE APPROACH AND ITS IMPLICATIONS FOR THE HOT CELLS

IV.3.1. Requirements

The main maintenance requirements are as follows: ·

- avoidance of contamination spread,
- minimization of breaks in the containment barriers,
- compatibility with the remote handling technology,
- compatibility with and minimum impact on building layout,
- compatibility with safety regulations and constraints.

IV.3.2. Maintenance approach

As a general rule, failed components will be disconnected from the machine or its auxiliaries and transported to the hot cell for inspection (and in rare cases for repair) or to waste storage. Maintenance of failed components is not envisaged to be made in-situ (exceptions will be considered if the equipment repair is "fast").

Depending on the frequency of replacements and on the dimensions of the components to be replaced, several maintenance options are proposed:

1) In-situ repair of equipment (as an exception) with a minimum of waste to be transported to the hot cell (e.g. by using an articulated boom housed in a maintenance bay attached to the torus).

2) Use of transfer flasks for infrequent interventions in areas where space around the component is foreseen (e.g. for replacement of a blanket segment).

3) Use of a transfer corridor for relatively long interventions (e.g. for replacement of the lower poloidal field coil).

Different ways of transporting radioactive equipment to the hot cell are envisaged in the building layout.

TABLE IV-1. PLASMA FACING COMPONENTS, BLANKET, SHIELDING AND DUST

Components	Number in the system	Replacement rate %/a	Materials	Size m	Weight kg	Fluxes a-1	Beta/gamma activity Bq/unit
First wall tiles							
Radiative	1600		C or CFC	0.32 x 0.16 x 0.02	2		TBD
Scheduled replacement		30				500	
Unscheduled replacement		10				160	
Conductive	70000		C or CFC	0.1 x 0.1 x 0.02	0.4		TBD
Scheduled replacement		10		0.1 x 0.1 x 0.02		7000	
Unscheduled replacement		5				3500	
Divertor tiles	200000		C or CFC	0.02 x 0.05 x 0.02	0.04		TBD
Scheduled replacement		100	C or CFC	0.02 x 0.05 x 0.02		$2x10^5$	
Dust			C + Metal	1 µm		10^3kg	TBD
Outboard blanket							
Central lower segments	16	1/2	SS 316L	4 x 1 x 1.9	51	0.5	7.2×10^{17}
Central upper segments	16	1/2	SS 316L	6.5 x 1 x 1.5	65	0.5	"
Lateral segments	32	1/2	SS 316L	14 x 1 x 1.6	150	0.5	"
Lower shielding plugs	32	3/15	SS 316L	4 x 0.7 x 0.8	15	0.2	"
Key plugs	16	1/15	SS 316L	3 x 2 x 1.8	72	0.07	"
Inboard blanket	32	1/2	SS 316L	13 x 0.65 x 0.65	36	0.5	2.5×10^{17}
Divertor plates	32	64	Mo/SS or Cu/SS	3.5 x 1.2 x 0.8	1.5	32	

TABLE IV-2. PLASMA HEATING AND CURRENT DRIVE: ELECTRON CYCLOTRON SYSTEM

Components	Number in the system	Failure rate a^{-1}	Materials	Size	Weight	Fluxes a^{-1}	Beta /gamma activity
Windows	28	0.5/window	Sapphire	Diameter 0.1 m, e = 2 mm, L = 0.3 m	10 kg	14	TBD
1st mirror	1	1/10	C/Cu alloy	1.07 m x 1.37 m x 0.1 m	1300 kg	0.1	TBD
2nd mirror	1	1/5 - 10	C/Cu alloy	0.74 m x 0.9 m x 0.1 m	600 kg	0.2	TBD
3rd mirror	1	1/10	C/Cu alloy	1.44 m x 1.95 m x 0.1 m	2500 kg	0.1	TBD
4th mirror	1	1/5 - 10	C/Cu alloy	2.66 m x 1.86 m x 0.1 m	4400 kg	0.2	TBD
Waveguides	28	0.1/guide	TBD	Diameter 0.1 m	500 kg	2.8	TBD
Cryopumps	2	TBD	SS 316L	TBD	TBD	TBD	TBD
Bellows	1	1/15	SS 316L	Diameter 1 m	200 kg	TBD	TBD
Antenna box	1	TBD	SS 316L	12 m x 3 m x 2.5 m	90 t	TBD	TBD
Large valve	1	TBD	SS 316L	2.6 m x 2.2 m x 0.3 m	11.5 t	TBD	TBD
Valves	28	1/5-10	SS 316L	Diameter 0.1 m	30 kg	TBD	TBD

TABLE IV-3. PLASMA HEATING AND CURRENT DRIVE: LOWER HYBRID SYSTEM; NBI

Components	Number in the system	Failure rate a^{-1}	Materials	Size m	Weight t	Fluxes a^{-1}	Beta/gamma activity
Lower hybrid system							
Windows	100	0.2/window	BeO/Al_2O_3	Diameter 0.1, e = 0.02	0.005	20	TBD
Valves	100	TBD	SS 316L	Diameter 0.2	0.100	TBD	TBD
Launchers	2	0.5	Cu Alloy	5 x 1 x 1.5	0.300	0.5	TBD
Waveguides	100	TBD	Cu Alloy	Diameter 0.1, length 50	0.700	TBD	TBD
Bellows	4	1	SS 316L	0.9 x 2.1 x 2.65	0.800	1	TBD
Bellows	2	1/2	SS 316L	1.8 x 2.8 x 4.3	2.3	0.5	TBD
Cryopumps	4	TBD	SS 316L	TBD	TBD	TBD	TBD
NBI							
Flight tubes	9	1/15	SS 316L	28 x 2 x 0.1	TBD	1/15	TBD
Modules	9	1/15	SS 316L	Diameter 4, length 16	70	1/15	TBD
Neutralisers	9	1/10	Cu	2 x 3 x 0.5	4	0.1	TBD
Ion sources	9	9	SS/Cu/Ba	2.6 x 1.6	1 - 2	9	TBD
Valves	18	TBD	SS 316L	2 x 0.5 x 0.5	2	TBD	TBD
Bellows	6	1/2	SS 316L	2 x 4 x 1.4	2.2	0.5	TBD

TABLE IV-4. VACUUM SYSTEM

Components	Number in the system	Failure rate a^{-1}	Materials	Size m	Weight t	Fluxes a^{-1}	Beta/gamma activity
Turbopumps	8	2/15	Light alloys	Diameter 1.25; length 3.65	1.5	0.15	TBD
Magnetic bearings	16	1/2	Light alloys	Diameter 1.25; height 0.5	0.2	0.5	TBD
Emergency bearings	8	1	Light alloys	Diameter 1.25; height 0.3	0.1	1	TBD
Cryopumps	24	1/4	SS & Al	3.65 x 2.5	10	0.25	TBD
Internals	24	1/2	Al	1.9 x 2.5	1.5	0.5	TBD
Insulation valves	8	1/2	SS 316L	Diameter 1.5	0.5	1/2	TBD
Seals	8	2	Elastomer	Diameter 1.5	0.002	2	TBD
Bellows	16	1/4	SS 316L	Diameter 1.8; length: 2	2.5	0.25	TBD
Manifolds	8	1/15	SS 316L	Diameter 2.5; length: 11	8	0.2	TBD
Valve boxes	24	1/4	SS 316L	Diameter 1; height 1.2	1	0.25	TBD
Valves	11 x 24	2	SS 316L	TBD	TBD	2	TBD
Roughing pumps	12	1	SS 316L	Diameter 1.8; height 2.9	13	1	TBD
Bellows	24	2	SS 316L	TBD	TBD	2	TBD
Valves	24	2	SS 316L	Diameter 0.1	0.030	2	TBD
Filters	8	TBD	TBD	TBD	TBD	TBD	TBD

TABLE IV-5. COOLING SYSTEM

Components	Number in the system	Failure rate a^{-1}	Materials	Size m	Weight	Fluxes a^{-1}	Beta/gamma activity
Primary loop							
Pumps	10	1/2	SS 316L	Diameter 0.8; length1.5	1 t	0.5	TBD
Heat exchanger	10	1/10	SS 316L; incoloy	Diameter: 2; length: 15	100 t	0.1	TBD
Pressuriser	10	1	SS 316L	Diameter 2.4; height 12	68 t	1	TBD
Valves	40	10%/15	SS 316L	Diameter 1; length 0.3	1.5 t	0.2	TBD
Instrumentation	200	5%	SS/Cu	TBD	5 kg	10	TBD
Secondary loop							
Pumps	6	1/2	SS 316L	Diameter 1; length 2	2 t	0.5	TBD
Heat exchanger	6	1/10		Diameter 2; length 15	100 t	0.1	TBD
Buffer tank	6	2/15	SS 316L	TBD	TBD	0.2	TBD
Valves	24	10%/15	SS 316L	Diameter 1.5; length 0.3	2 t	0.2	TBD
Instrumentation	60	5%	SS/Cu	TBD	5 kg	3	TBD

TABLE IV-6. REMOTE HANDLING SYSTEM

Components	Number in the system	Failure rate a^{-1}	Materials	Size	Weight t	Fluxes a^{-1}	Beta/gamma activity
Cranes*	20		SS or C steel				
Mechanisms	100	5%	SS or C steel		1-2	5	TBD (low)
Cables	30	30%	SS or C steel		0.5	1	TBD (low)
Manipulators	20 - 30	10%	SS or light alloy		0.5	3	TBD
IVVS/booms**	4	100%/15	SS		10	0.3	TBD (highest)
Motors	60	100%	SS/Cu		0.1	60	TBD (highest)
Blanket handling units	3	50%/15	SS or C steel		50-200	0.1	TBD
Mechanisms	60	10%			0.5	6	TBD
Miscellaneous	400	20%	SS		0.100	80	TBD

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* Cranes will be repaired and are not considered as waste.

** IVVS = in-vessel vehicle system

TABLE IV-7. TRITIUM SYSTEM, VENTILATION AND DETRITIATION FILTERS

Components	Number in the system	Failure or exchange rate a^{-1}	Materials	Size	Weight kg	Fluxes a^{-1}	Beta/gamma activity
Tritium system							
Pumps	100	2%	SS 316L	TBD	TBD	2	TBD
Valves	10000	1%/15	SS 316L	Diameter 20mm	~1	7	TBD
Filters	200	100%	SS 316L	TBD	TBD	200	TBD
Instrumentation	2000	10%	SS 316L	TBD	2	200	TBD
Catalyst	TBD	TBD	Pd/Al_2O_3	TBD	TBD	TBD	TBD
Electrolysers	20	4	SS 316L	TBD	100	4	TBD
Getters	>150	100%15	U/LaNi/ZrCo	TBD	5	10	TBD
Molecular sieves	50 t	10%	Zeolites	TBD	-	5t	TBD
HVAC filters (type 4)	1600	50%	SS Fibre	0.6 x 0.6 x 0.3	24 6	800	TBD
HVAC filters (type 2/3)	1200	50%	SS Fibre	0.6 x 0.6 x 0.3	24 6	600	TBD
Detritiation filters	200	100%	SS Fibre	0.6 x 0.6 x 0.3	24 6	200	TBD

IV.4. INTEGRATED GENERAL HOT CELL MAINTENANCE EQUIPMENT

The handling and maintenance equipment required in the hot cell and waste management system are mainly conventional equipment such as master slave manipulators, overhead cranes, and cutting and welding tools. Where more specific tools are concerned, equipment developed and used to maintain the machine will be duplicated in the hot cell for some specific areas where large items have to be handled, e.g. in the storage cell. Processes used in the hot cell will have their specific handling tools developed in the same frame as the processes themselves.

IV.5. GRAPHITE PROCESSING

ITER is likely to produce significant quantities of graphite dust coming from the sputtering of the graphite or carbon-fibre-composite (CFC) armour of the first wall and divertor plates during the physics phase. This dust is expected to contain a large fraction of tritium in T_2 or DT chemical form or linked to carbon atoms as hydrocarbon compounds. Saturation occurs at room temperature for a H/C ratio equal to 0.44 and reaches a H/C ratio lower than 0.1 for temperatures higher than 400 °C.

The graphite tiles that protect plasma-facing components may likewise contain large quantities of tritium. In both cases this tritium content has to be recovered, because kilogram quantities of tritium will likely be involved over the duration of the physics phase. This is required in order:

- to "close" the fuel cycle, i.e. to minimize the impact on fuel supply,
- to facilitate waste storage and disposal, i.e. to simplify storage and disposal procedures and improve safety,
- to facilitate tritium inventory measurements which will likely be required,

Depending on the content of ^{14}C and other radioactive gases in the graphite, different processes could be used for this purpose:

1) graphite outgassing at high temperature,
2) graphite combustion,
3) graphite immobilization in a stainless steel (SS) melt.

Each of these processes must be tested before selection can take place.

IV.5.1. Functional requirements

The functional requirements listed below are common to all processes used to recover tritium from graphite. The system must:

- receive graphite dust batches, graphite tiles and vacuum, ventilation and tritium system filters charged with graphite dust;
- transform these wastes into a form acceptable to the processing system;
- sample components/dust in order to measure their tritium and ^{14}C content;

- recover the tritium content;
- condition the residual waste for final disposal;
- transfer the recovered tritium to the tritium system for further processing.

IV.5.2. Performance requirements

IV.5.2.1. Storage

This storage will constitute a buffer for the processing system, giving the possibility of minimizing the processing capacity and transforming the batch processing into semi-continuous processing. The minimum storage capacity should be:

- 10 kg of graphite dust collected in one container,
- 100 kg of graphite tiles coming from either the plasma chamber or a dismantled plasma-facing component,
- five filters of 1 m^2 x 2 cm each.

IV.5.2.2. Sampling

A fraction of the dust or a fragment of a tile has to be taken out of the system and stored in a small container to be sent to a laboratory able to measure tritium and ^{14}C content. In addition, measurement of the gamma activity should be performed.

IV.5.3. Process description

IV.5.3.1. Graphite outgassing

This is the most direct method to recover most of the tritium trapped in the graphite. This process will be the simplest if no radioactive gases other than tritium, in molecular form or as a hydrocarbon, are contained in the graphite. Tritium and tritiated hydrocarbons are released from the graphite at high temperature (above 1000 °C on the basis of present experiments). The residual tritium fraction depends on the selected temperature. It should be as small as possible to minimize the economic and regulatory impacts. A target value of < 1 Ci/kg (40 GBq/kg) is proposed.

IV.5.3.2. Graphite combustion

This process is the most attractive if the content of ^{14}C and other radioactive gases in the graphite is below the release limit. After being crushed as required, graphite can be oxidized into carbon dioxide in an air/oxygen flow. The tritium and hydrocarbon content will be oxidized at the same time into water and carbon dioxide in accordance with the reactions:

$$C + O_2 = CO_2$$

$$2\,Q_2 + O_2 = 2\,Q_2O$$

$$CQ_4 + 2\,O_2 = CO_2 + 2\,Q_2O,$$

where Q = H, D, T.

After being cooled, the combustion gases pass through a cold trap working at -40 °C in which the major fraction of the water will be trapped with a small quantity of CO_2. Leaving this cold trap, the gas flow could be sent to a molecular sieve bed in which the residual water could be trapped. Gas flow leaving the molecular sieve bed will only contain the residual CO_2, which could be sent to the stack.

The water recovered during the trap and molecular sieve bed regeneration should be sent to the tritium system, in which the tritium will be recovered.

This process results in a minimum of solid wastes to be stored or disposed of.

IV.5.3.3. Graphite immobilization in a stainless steel melt

This method is convenient if, at the same time, tritium has to be recovered from the structural steel of failed components and from graphite with a high ^{14}C content. Graphite could be processed in the same furnace that can be used to recover tritium from steel.

One of the possible methods of recovering tritium from steel is to melt it under vacuum. The required temperature is above 1500 °C. At this temperature the largest fraction of tritium or tritiated hydrocarbon will outgas from the graphite and the carbon will be immobilized in the steel.

The furnace size for this purpose is small and relatively unsophisticated by industry standards, the quality and the quantity of the steel produced not being the objective. With an average graphite (contaminated with ^{14}C) flow of 10 kg/d a furnace with a 100 kg/d steel processing capacity will be sufficient (this ratio corresponds to the weight ratio of graphite to steel in the plasma-facing components).

The recovered gas must be free of any steel vapour and must be controlled for other impurities. If chemical species incompatible with the fuel cleanup system are present, such as fluorine, chlorine, lead, and arsenic, these impurities must be eliminated before routing the gas to the tritium system. As it is yet unknown which of these impurities might be present, a first purification step should be provided close to the furnace.

IV.5.4. Remote maintenance requirements

The graphite may be contaminated with metallic particles coming from plasma-facing components and diagnostics. These particles would create a gamma field large enough to necessitate that all the operations of the graphite processing system be done remotely. A remote handling facility for the dust is therefore taken as the design basis. In view of the relatively small size of the items to be processed, master slave manipulators should be considered in conjunction with an overhead crane. For processing first wall and divertor plate assemblies, equipment for cutting the items and removing tiles from support structures must be provided.

IV.5.5. Operational conditions and restrictions

IV.5.5.1. Lifetime

The graphite processing device will be used from the first active operation of ITER to at least the end of the physics phase. The design lifetime for this equipment should therefore be at least 6 years.

IV.5.5.2. Availability

This system has no immediate impact on machine operation, provided a sufficient tritium reserve is available to offset that tied up in the graphite. However, in view of the large tritium inventory that could be present in the graphite, an availability of >98% is proposed.

IV.5.5.3. Interfaces

The graphite processing system will interface with the tritium fuel management and storage systems, the atmosphere detritiation system, and possibly the coolant system. More generally, this system will interface with the electric power supply, the waste management system, and the general control system.

IV.5.6. Design constraints

The amount of waste must be minimized. All components containing a significant amount of tritium (> 150 g) must be doubly confined [1].

Tritium containing streams must not come into contact with oil, sulphur compounds, halogens, and arsenic. Organic materials must be avoided when possible.

The overall leak rate of the system must be $< 10^{-6}$ mbar x l/s. The component leak rate must be $< 10^{-8}$ mbar x l/s.

REFERENCE

[1] BUENDE, R., FLANAGAN, C.A., OLLIVIER, G., "A Guide for Implementing Failure Modes, Effects and Critcality Analyses (FMECA) of Components", ITER-IL-SA-3-9-1 (March 14, 1989).

V. SUPPLY SYSTEMS FOR FLUIDS AND OPERATIONAL CHEMICALS

V.1. INTRODUCTION

This group of systems includes all the central and laboratory systems that provide for supply, storage, treatment, distribution, and safe discharge of fluids (including gases) needed by ITER. These systems also supply operational chemicals (see Fig. V-1).

The fluids required are water, steam, and various gases: deuterium, hydrogen, helium, nitrogen, compressed air, argon, SF_6, ammonia, freon, acetylene, oxygen, and natural gas (see Table V-1). The supply of tritium is not a task of this group of systems.

The main types of necessary operational chemicals are: various chemicals, ion-exchange resins, transformer oil, and fire-extinguishing materials.

The systems include protection, instrumentation, and control equipment connected to the site control network. They are connected to the site power distribution network. This group of systems also includes conventional heating installations.

V.2. WATER AND STEAM SUPPLY SYSTEMS

At the conceptual design stage, when the site has not been selected and the potential water resources near the site are unknown, it is premature to take decisions on details of water supply systems. These systems include sources of industrial water (of different quality) and of potable (drinking) water, fire protection water supply system, emergency cooling water reservoir, and facilities for preparing hot and chilled water. A steam generation facility and steam distribution network are also in this group of systems.

Besides the distribution network, water supply systems are equipped with facilities for water treatment and storage.

V.2.1. Industrial water supply systems

ITER will require a spectrum of industrial water of different quality.

V.2.1.1. Raw water

Raw water from the sea or from a river, lake, pond, or water reservoir may be used as an ultimate heat sink of the heat transport (cooling) systems, directly or in wet type cooling towers. Raw water may be used for fire fighting purposes as well. The raw water supply system includes facilities for raw water intake, filtration, chlorination (if necessary) and pumping.

TABLE V-1. GASES REQUIRED FOR ITER OPERATION

Gas	System	Amount in reactor kg	Make-up kg/a	Note
Deuterium	Fuel facing components	3.6	-	Maximum in physics phase
"	Fuel component	$2 \cdot 10^{-4}$	9	At fusion power of 1.08 GW
"	Glow discharges	-	0.12	100 m^3/s; 10^5 s; 0.1 Pa
Hydrogen	Purification of inert gases from O_2	-	$2 \cdot 10^3$	200 ppm at 12,000 m^3/h
"	Suppression of water radiolysis	32	200	2 MPa, volume of H_2 of 18 m^3; 2 %/d
"	Plasma physics experiments	$3 \cdot 10^{-4}$	11	Of spectral purity, 7,000 shots
Helium	Inert atmosphere	3600	$13 \cdot 10^3$	Vacuum pump and fuelling rooms, etc
"	Cryogenics (magnet tests)	$9 \cdot 10^3$	500	10 %/a, 200 days
"	Cryogenics (operation)	$21 \cdot 10^3$	500	2%/a, in magnets: 11 t
"	Purge gas in blanket	9	80	At 25% availability
"	Plasma physics experiments	$5 \cdot 10^{-4}$	20	During the first 2.5 years, 6,000 shots
"	Glow discharges	-	0.4	100 m^3/s; 10^5 s; 0.3 Pa
Nitrogen	Inert atmosphere	$50 \cdot 10^3$	$180 \cdot 10^3$	NBI room, glove boxes of tritium system
"	Plasma cutting	-	$30 \cdot 10^3$	[1]
"	Cryogenics (magnet tests)	$50 \cdot 10^3$	$3 \cdot 10^3$	10 %/a, 200 days
"	Cryogenics (operation)	$300 \cdot 10^3$	$6 \cdot 10^3$	2 %/a

TABLE V-1. (CONT.)

Gas	System	Amount in reactor kg	Make-up kg/a	Note
Nitrogen	Pneumatic actuation of valves	-	TBD	In nitrogen atmosphere of glove boxes
Compressed air	Pneumatic systems, surfaces cleaning	-	$50 \cdot 10^6$	[1]
"	Instrument needs and breathing	-	$9 \cdot 10^6$	[4]
Helium-3	Plasma physics experiments	$4 \cdot 10^{-4}$	up to 1	3,000 shots, with recovering and reusing
Argon	Ar-spraying cryogenic pumps	-	700	At 25% availability, 7.5 mol/h
"	Arc welding	-	$110 \cdot 10^3$	[1]
SF_6	High voltage power supply cable	1100	-	9 lines, about 30 m long, 400 kPa
Ammonia	Air conditioning	800	110	
Freon	Chilled water preparation	-	TBD	
Acetylene	Acetylene brazing and cutting	-	$6 \cdot 10^3$	[1]
Oxygen	Acetylene brazing and cutting	-	$70 \cdot 10^3$	[1]

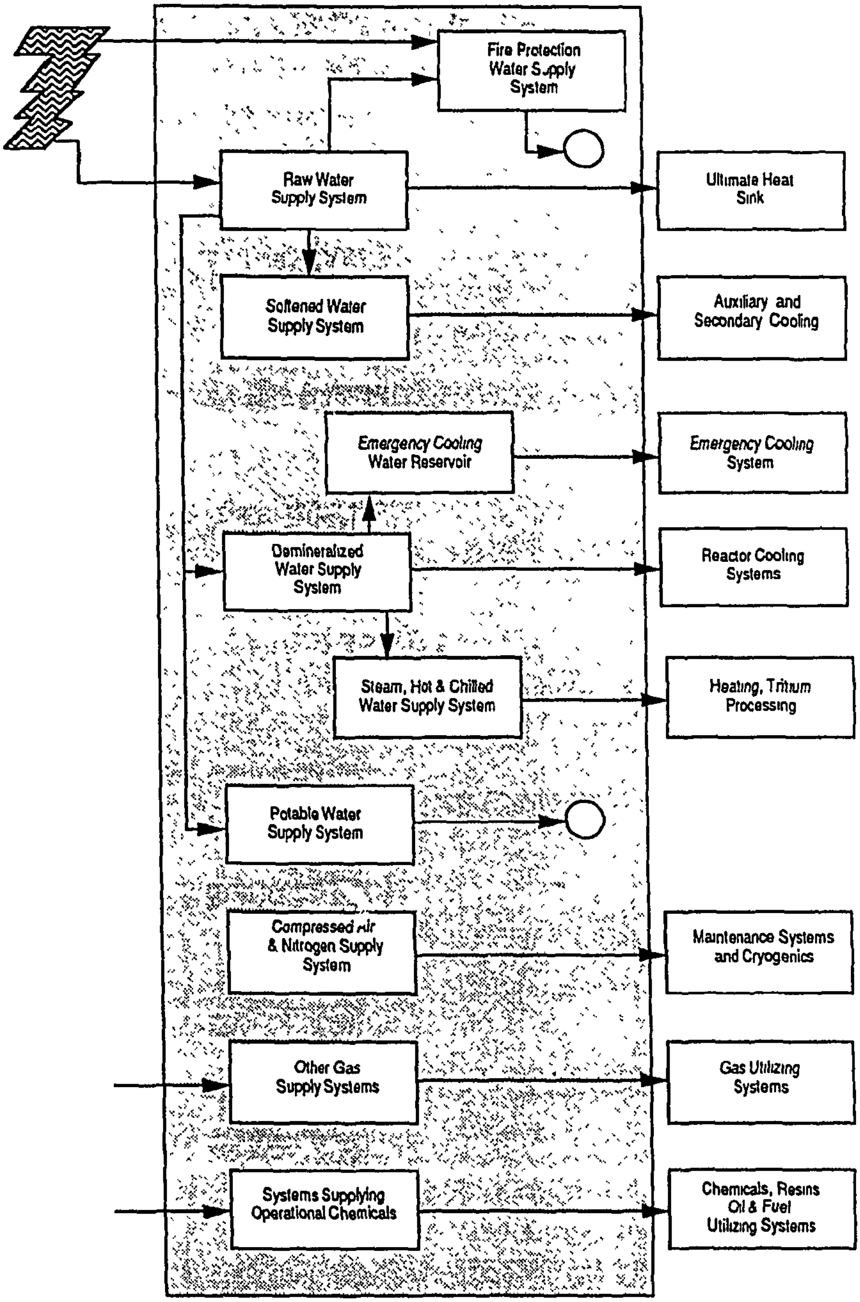

Fig. V-1. Fluid supply systems

If the cooling water from a river or from the sea is used as an ultimate heat sink (of 1.8 GW), a typical requirement is to limit the overall warming of the discharged water to 7°C. In this case a flow rate of approximately 60 m^3/s is required for cooling and dilution of the discharged water. If the combination of uncertainty and margin amounted to 25%, this value would increase to 80 m^3/s $=300{,}000\ m^3/h$.

Wet type cooling towers require up to 3,400 m^3/h = 0 94 m^3/s of water to compensate for evaporation, wind (drift) losses, and blow down. According to conservative estimation, other irretrievable water losses may amount to 0.17 m^3/s (0.14 m^3/s for steam production, watering and other technical needs, and about 0.03 m^3/s for drinking and other domestic purposes) [1]. Fire fighting requirements are estimated as approximately 0.13 m^3/s [1]. Thus, the total make-up capacity of the raw water supply system is 1.3 m^3/s. If the combination of uncertainty and margin is 25%, this capacity would increase to 1.6 m^3/s.

If the raw water is fresh, it may be used (most likely after chlorination) as service water for equipment decontamination, floor washing, and in toilets. The service water should be supplied to upper and lower floors of buildings by two groups of pumps to compensate the hydrostatic head.

V.2.1.2. Softened water

Softened water will be produced from raw water and may be used for cooling of cryogenic equipment, power supply bus bars, thyristors, resistors, and transformers and some plasma heating equipment. Softened water may also be used as a coolant for secondary circuits of the main reactor components, and in laundries. The system includes on-site facilities for water softening, de-aeration, and purification as well as storage of softened water, and a distribution network around the site to all the systems requiring softened water.

V.2.1.3. Demineralized water

Taking into consideration the stringent cooling conditions in plasma facing components (especially in the divertor), the high cost of torus components, activation of impurities, and the possibility of stress corrosion cracking, it is reasonable to use demineralized water as primary coolant of the main reactor components. Because of high voltage, the neutral beam injectors also need demineralized water for their cooling.

The system includes on-site facilities for demineralization of raw water, water de-aeration, purification and chemical conditioning as well as an emergency cooling water reservoir and a distribution network around the site to all systems requiring demineralized water. It is possible that an autonomous emergency cooling system with a capacity of 20 % of the normal flow rate will be required.

Requirements with respect to chemical impurities in the demineralized water to be used for cooling system filling and make-up as well as during reactor operation are given in Table V-2 [1].

TABLE V-2. DEMINERALIZED WATER REQUIREMENTS

Characteristic	At filling and make-up	During operation
Hydrogen ion exponent, P_H at 25°	7.0	6.5 - 8.0
Specific electrical conductivity, $(\text{ohm}\cdot\text{cm})^{-1}$	$\leq 10^{-7}$	$\leq 10^{-6}$
Concentration of chloride ions, g/m^3	≤20	≤50
Iron concentration, g/m^3	≤20	
Oxygen concentration, g/m^3	≤30	≤30
Hardness, $g(\text{equiv.})/m^3$	≤3	≤10
Oil products concentration, g/m^3	≤100	≤100

TABLE V-3. COOLING WATER DEMANDS

System	System volume m^3	Make-up flow rate m^3/a
Primary cooling circuit	3,000	400
Secondary cooling circuit	5,500	350*
Other consumers	500	500
Total	9,000	890

* - for closed circuit.

Cooling water requirements (volumes to be filled and make-up flow rates) were roughly estimated and are shown in Table V-3 [1]. The final decision concerning the types of industrial water to be used in different cooling circuits will be made on the basis of cost analyses and site capabilities.

Any additional treatment of the water for specialized applications with ITER systems will be performed by this system as well.

V.2.2. Potable water supply system

The potable water is required for drinking and domestic needs. The potable water supply system includes a treatment facility for preparation of potable water from raw water, storage of potable water, and a site distribution network. The capacity of the system is estimated to be about 3000 m^3/d. The head in the system should be about 500 kPa.

V.2.3. Fire protection water supply system

Raw water should be used for fire fighting purposes. There will be two fire protection water supply systems: external and internal. The capacity of the external system is up to 120 l/s, and the internal system capacity is about 10 l/s.

Each system is equipped with separate pumps and hydrants. The head in the external fire protection water supply system should be about 1.5 MPa, and in the internal system about 1 MPa. The system includes a site distribution network and is connected to the local fire control system.

V.2.4. Steam, hot and chilled water supply system

The system includes boilerhouse outfitting, facilities for preparing chilled water, and a site distribution network for steam, hot water (e.g. for site central heating, startup heating), and chilled water (to tritium processing system and probably to air conditioners). It must be connected to the demineralized water supply system.

V.3. GAS SUPPLY SYSTEMS

Various gases, in particular deuterium, hydrogen, helium-3, natural helium, nitrogen, argon, SF_6, ammonia, freon, compressed air, acetylene, oxygen and natural gas, are required for ITER operation and maintenance.

V.3.1. Deuterium

Deuterium will be used first in plasma physics experiments, during commissioning of the tokamak device (zero-activation phase) after studies with hydrogen plasmas. In this stage it may be used separately or in a mixture with helium. Then up to 2,000 shots with a mixture of deuterium and helium-3 are planned in the low-activation phase. Following that, experiments with deuterium-tritium plasmas will begin. The total number of pulses during this high-activation phase will be approximately 7,000. The total first-wall fluence in the Physics Phase will be about 0.05 $MW{\cdot}a/m^2$. ITER operations in the Technology Phase will be with D-T plasmas as well. The phase duration is planned to be 10 - 15 years. A neutron fluence of 1 $MW{\cdot}a/m^2$ should be achieved.

During the Physics Phase, up to 3.6 kg of deuterium will be absorbed in various reactor systems: about 2.3 kg in graphite of plasma facing components, graphite dust and the graphite processing system; up to 0.9 kg in tritium processing and fuelling systems; the remainder, 0.4 kg, in blanket, vacuum pumps, waste management facilities, coolant, etc. During the Technology Phase, about 2.5 kg of deuterium will be absorbed. The inventory of deuterium (in a mixture with tritium) in the plasma chamber at an ion density of $7{\cdot}10^{19}$ m^{-3} is 0.2 g. Consumption of deuterium as a fuel component at a fusion power of 1.08 GW and at 25% availability is about 9 kg/a.

Another application of deuterium is for glow discharges for torus conditioning. About 10^5 l/s of deuterium at a pressure of 0.1 Pa will be used for this purpose during 10^5 s. The total amount of deuterium consumed for conditioning is estimated as 10 m^3(STP) = 2 kg or 0.12 kg/a.

V.3.2. Hydrogen

The highest consumption of hydrogen is for purifying inert gases from oxygen. At an inert gas purification rate of 12,000 m^3/h and an air ingress rate supplying 1.2 m^3/h of oxygen, the concentration of oxygen leaving the inert gas rooms is 100 ppm. A stoichiometric quantity of 200 ppm of hydrogen at 200 ppm is added for catalytic reaction with oxygen under reducing conditions [2]. The consumption of hydrogen is 2.4 m^3/h (STP) = 1.9 t/a. During maintenance of in-vessel components, the torus will be filled with helium. In these periods, the purification of helium filling the torus, maintenance bays and transfer units from oxygen will also be required, and the additional consumption of hydrogen will amount to 0.2 m^3/h.

Hydrogen will be used for the suppression of water radiolysis in the reactor primary circuits. For this purpose, up to 20 % of the primary circuit pressurizers (their total volume is 90 m^3) will be filled with hydrogen (partial pressure of 2 MPa). The hydrogen inventory in the pressurizers will be 32 kg. Hydrogen losses are expected to amount to 2 %/d, i.e. the losses will amount to about 200 kg/a.

Hydrogen of high purity will be used in plasma physics experiments during the zero/low-activation phase. It is planned that about 7,000 shots having an average duration of 500 s/shot will be made with natural hydrogen in this phase during the first three years of reactor operation, requiring about 11 kg/a = 120 m^3(STP)/a of the gas. Thus, the total demand for hydrogen is estimated to be up to 2.2 t/a.

V.3.3. Natural helium

Some volumes adjacent to the torus require an inert atmosphere. It is expected that rooms and boxes having a total volume of about 20,000 m^3 will be filled with helium (see Section VII.4.). The helium pressure is to be slightly positive with respect to the pressure in surrounding rooms with an air atmosphere served by the Recirculating Air Detritiation System (RADS). Helium losses are expected to be about 1 %/day. Thus, up to 70,000 m^3 (STP) = 13 t of helium must be added to the volumes covered with this gas every year.

Up to 21 t of natural helium will be used in cryogenic systems during reactor operation [3]. About 11 t will be in the magnets, approximately 6.5 t in the fuelling system, the neutral beam injectors, the cryopumps, the tritium processing facilities and the emergency storage, and up to 3.5 t in the refrigerator, piping, and storage. Helium losses are estimated to be about 2 %/a, i.e. 500 kg/a. During magnet tests, about 9 t of helium should be in the test facility [1] and its losses may increase to 10%/a [3]. If the tests require 200 days, helium make-up may total up to 500 kg.

Like hydrogen, helium will also be used in plasma physics experiments in the zero-activation phase. About 6,000 shots having an average duration of 500 s/shot should be made with helium in this phase during 2.5 years. Helium recycling in these experiments is expected to be 0.9. Thus, helium consumption is expected to amount to up to 20 kg/a.

Furthermore, helium will serve as the purge gas in the solid blanket for tritium transport to tritium recovery facilities. The helium inventory for this purpose is about 50 m^3(STP) = 9 kg. Make-up is expected to be approximately 0.2 m^3(STP)/h = 80 kg/a at an availability of 25%.

About 10^5 l/s of helium at a pressure of 0.1 Pa will be spent during glow discharges for torus conditioning. According to rough estimates, the total duration of glow discharges is 10^5 s. This means that about 30 m^3(STP) = 5 kg (0.4 kg/a) of helium will be consumed for torus conditioning. Thus, the total helium make-up is expected to amount to 13.6 t/a.

V.3.4. Nitrogen

Nitrogen is presently the primary candidate as an inert gas to fill the neutral beam injector room (about 33,000 m^3) and the glove boxes of the tritium processing system (about 2,000m^3). It is possible that nitrogen will also be used as an inert gas in diagnostic rooms having a volume of up to 5,000 m^3. The total volume of these rooms and boxes is about 40,000 m^3. The pressure of the nitrogen is to be slightly positive with respect to the pressure in the surrounding rooms served by the RADS. Losses of nitrogen are expected to be about 1 %/day. Thus, the make-up of nitrogen should be up to 150,000 m^3(STP)/a = 180 t/a. In the rooms and boxes filled with nitrogen, this gas will also be used for pneumatic actuation of valves. Furthermore, according to rough estimates [1], up to 30 t/a of nitrogen will be required for plasma cutting.

Probably, nitrogen will also be required in the cryogenic refrigerator. During reactor operation, about 300 t of liquid nitrogen will be in the cryogenic system. The losses are estimated to be about 2 %/a, i.e. 6 t/a. During magnet tests, the nitrogen inventory in the test facility is estimated as 50 t [1] with losses of 10 %/a. During 200 days of tests, the nitrogen make-up may amount to 3 t. Thus, the total nitrogen make-up is expected to be up to 260 t/a.

V.3.5. Compressed air

Up to $40 \cdot 10^6$ m^3(STP)/a) = 50,000 t/a of compressed air is required for actuation of pneumatic systems and for cleaning surfaces contaminated with radioactive dust [1].

About 8,000 t/a of compressed air is required to sustain an adequate atmosphere in the rooms with sensitive instruments. About 1,000 t/a of compressed air will be consumed for breathing. Thus, the total consumption of compressed air for instrument needs and for breathing is expected to amount to

9,000 t/a [4]. The system includes the compressor, peripheral equipment and a storage tank.

V.3.6. Helium-3

During the third year of the plasma physics experiments, it is planned to have up to 3,000 shots with an average duration of 500 s using helium-3 in a mixture with hydrogen or deuterium. Helium recycling in the torus is expected to be about 90% and the confinement time for particles will be about 3 s. Therefore, all the ^{3}He available in the plasma (about 0.4 g) will be pumped out during 30 s. During $1.5 \cdot 10^6$ s of operation with helium-3, about 20 kg of ^{3}He will be pumped out. Since ^{3}He is very expensive, all due measures will be taken to recover and reuse it. According to rough estimates, the total consumption of helium-3 will be up to 1 kg.

V.3.7. Other gases

Argon will be used in Ar-spraying cryogenic pumps with a flow rate of 75 mol/h. However, 90% of the argon may be recovered. Therefore its consumption at 25% availability is about 700 kg/a. Approximately 60,000 m^3(STP)/a = 110 t/a of argon is also required for arc welding [1].

SF_6 is necessary as a high voltage insulator in power supply lines for neutral beam injectors. There are nine such lines, each 30 m long with a diameter of 1 m. The total volume of these lines is about 200 m^3. SF_6 (20%) will be used in a mixture with nitrogen (80%), at a pressure of 400 kPa. The amount of SF_6 required is about 170 m^3(STP) = 1.1 t. It is expected that make-up will be negligible.

Up to 1000 m^3(STP) = 800 kg of ammonia may be required for air conditioning since freon, which is usually used for such purposes, if released, may poison the palladium catalyst in the detritiation facilities. About 150 m^3(STP)/a = 110 kg/a of ammonia will be required for make-up [1]. Freon will be used for preparation of chilled water.

About 5,000 m^3(STP)/a = 6 t/a of acetylene and 50,000 m^3(STP)/a = 70 t/a of oxygen may be required for brazing and cutting [1].

V.3.8. General considerations

Deuterium, helium, hydrogen, argon, acetylene, SF_6, freon, and oxygen will be delivered to the site from external sources in gas cylinders, stored on the site and then distributed to consumers. Therefore, the corresponding gas supply systems should incorporate unloading bays for deliveries. The natural gas supply system should have a connection to an off-site pipeline. Compressed air will be provided from on-site facilities and conveyed to consumers through a site distribution network. Nitrogen may be provided both from on-site facilities and from external sources near the site if they are available. The final decision in this respect will be made after selection of the site. At the conceptual design stage, the assumption was made that nitrogen will be provided from on-site facilities.

The discharge of some gases into the atmosphere must be minimized, especially freon (because of its adverse environmental impact), SF_6 and helium, especially helium-3, (because of high cost).

Preliminary estimates of the volumes to be filled as well as of make-up flow rates of various gases are given in Table V-1.

V.4. SYSTEMS SUPPLYING OPERATIONAL CHEMICALS

A number of chemicals are necessary for ITER operation: for water treatment and softening, for preparation of deactivating and decontaminating solutions, for regeneration of ion-exchange resins, for laundry needs, etc.

The demand for various chemicals is shown in Table V-4 [1]. Demands for ion-exchange resins required for bypass purification of water in the primary and secondary reactor cooling circuits and for treatment of liquid wastes prior to their discharge are shown separately in Table V-5 [1].

A number of other operational materials are required for normal ITER operation as well, in particular transformer oil (for transformers, pumps, fans), fuel for stand-by diesel generators, fire-prevention and fire-extinguishing materials.

The system includes the necessary storage and facilities for preparation of various solutions (deactivating, decontaminating), regenerates, etc.

TABLE V-4. CHEMICALS REQUIRED

Purpose	Chemical	Demand t/a
Deactivating solutions, resin regenerates	NaOH (42%)	40
"	KOH (40%)	2
"	HNO_3	120
Deactivating solutions	H_2SO_4 (92%)	20
"	$KMnO_4$	2
"	$H_2C_2O_4$ (oxalic acid)	40
"	NaCl	0.1

TABLE V-4. (CONT.)

Purpose	Chemical	Demand t/a
Deactivating solutions and water softening	H_3PO_4 (93%)	10
Water coagulation	$FeCl_3$ or $Al_2(SO_4)_3$	100
Water purification	Quartz sand	20
Cleaning of cooling systems after assembly	$K_2C_2O_4$	40
"	N_2H_4 (64%)	15
Cleaning of cooling systems, deactivation	dry citric acid	0.2
Deactivation plus laundry	Sulphanol	250
Water treatment	Cl_2 (gas)	10
"	NaCl	100
"	CO_2 (gas)	2
Gases purification	Active carbon	10
Oxidation of hydrogen	Pd (catalyst)	0.1

TABLE V-5. ION-EXCHANGE RESINS REQUIRED

System	Resin type	Initial inventory m^3	Make-up rate m^3/a
Upper divertor (primary cooling circuit)	CSAR RR	2	0.3
"	ASAR RR	1.5	0.3
Lower divertor (primary cooling circuit)	CSAR RR	2	0.3
"	ASAR RR	1.5	0.3
First wall and antenna (primary cooling circuit)	CSAR RR	3	0.4
"	ASAR RR	2	0.4
Blanket (primary cooling circuit)	CSAR RR	2	0.3
"	ASAR RR	1.5	0.3
Shield (primary cooling circuit)	CSAR RR	2	0.3
"	ASAR RR	1.5	0.3
Total	CSAR RR	11	1.6
"	ASAR RR	8	1.6

TABLE V-5. (CONT.)

System	Resin type	Initial inventory m^3	Make-up rate m^3/a
Upper divertor (secondary cooling circuit)	CSAR	2	0.3
"	ASAR	1.5	0.3
Lower divertor (secondary cooling circuit)	CSAR	2	0.3
"	ASAR	1.5	0.3
First wall and antenna (secondary cooling circuit)	CSAR	3	0.4
"	ASAR	2	0.4
Blanket (secondary cooling circuit)	CSAR	2	0.3
"	ASAR	1.5	0.3
Shield (secondary cooling circuit)	CSAR	2	0.3
"	ASAR	1.5	0.3
Processing of liquid radioactive waste	CSAR	12	2
"	ASAR	12	2
Water desalination	CSAR	12	3
"	ASAR	12	3
Treatment of industrial and domestic water	CSAR	20	4
Tritium processing	CSAR	12	2
"	ASAR	12	2
Other treatment of radioactive liquids	CSAR	12	2
"	ASAR	12	2
Total	CSAR	79	14.6
"	ASAR	56	10.6

CSAR RR - cationic surface-active resin (radiation resistive)
ASAR RR - anionic surface-active resin (radiation resistive)
CSAR - cationic surface-active resin
ASAR - anionic surface-active resin

V.5. DRAIN SYSTEMS

This group of systems consists of:

- industrial and plant utility drainage,
- surface water drainage,
- sewerage system and
- groundwater drainage.

All the discharge systems must comply with local regulations regarding impurity levels, cleanliness, etc.

V.5.1. Industrial and surface water drainage

Industrial and plant utility drainage collects liquid waste from non-active buildings around the site (e.g. from workshops and non-active laboratories), including liquid waste after fire-fighting.

Surface water drainage collects surface sewage from site roads, roofs, car-parks, and other paved areas.

Besides collecting the waste, both the systems provide for waste monitoring, treating and discharging. The systems have a total capacity of 2.5 m^3/s. The waste water drains down into a sump-pond having a volume of 5,000 m^3. Clarified water is then pumped from the sump-pond into a water reservoir. The systems should be equipped with connection lines to the storage of a radioactive waste management system for possibly contaminated items.

V.5.2. Sewerage system

The sewerage system collects domestic effluent by gravity flow from site buildings and pumps it to purification works. The system provides also for effluent monitoring, treating and discharge. The system capacity is 150 m^3/h = 40 l/s. The system will be equipped with a connection line to radioactive waste management facilities for possibly contaminated items as well.

V.5.3. Groundwater drainage

The groundwater drainage system incorporates facilities for controlling and monitoring groundwater movement around the site, in particular waterproof diaphragm walls preventing the permeation of potential liquid waste into groundwater courses, diversion channels and holding basins for controlling external or local flooding. The system includes similar control works, wells, and clean-up facilities to ensure groundwater protection as required by site characteristics and plant safety.

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VI. ENGINEERED SAFETY SYSTEMS

VI.1 INTRODUCTION

The ITER device and facilities will be designed for optimum plant, staff and public safety. Limitation of major (but very low probability) off-site post-accident consequences will be achieved (to the greatest extent feasible) through inherent design features such as a robust building confinement, capability for radiative/convective cooling of in-vessel components and passive plasma shutdown based on inherent material properties. However, for the class of plant accidents/upsets which will have a higher expected frequency, it will be necessary to prevent significant plant damage and to further reduce possible staff and off-site dose consequences. One possible way to achieve these goals is through the use of engineered systems dedicated to preventing plant damage and releases of radioactivity, both to the plant and off-site. This concept has been developed for ITER as one option for integrating safety and system design requirements.

The first line of protection in this "defence in depth" concept is the normal process systems, i.e. those systems which are provided to perform all operational and maintenance functions in the plant. These systems should be designed so that, to the extent practicable, the failure of one component does not propagate to other components. Similarly, most process system failures should not result in plant damage or radioactive releases to plant volumes. Thus, in order to minimize the frequency of any process failure (i.e. loss of function), process systems should be robust, have adequate internal redundancy and be simple to operate and maintain.

However, some process failures can be expected which will require special protective action to ensure that the plant is not damaged or that no radioactivity is released from confinement. Such serious process failures (SPF) have public safety implications and should be minimized. It is therefore proposed that:

1. A formal process system design target be adopted in order to limit the frequency of SPF's to < 1 event/a, and
2. Engineered Safety Systems (ESS) be provided to mitigate the effects of possible severe process system failures.

These ESS's have no function in a normally operating plant, but are separate, diverse systems dedicated solely to preventing further plant damage (and thus avoiding or containing radioactivity releases) by providing:

i) rapid plasma and fuelling shutdown to prevent overheating, which can lead to further damage;

ii) cooling for afterheat removal and component cooldown to prevent damage or minimize the consequences of any damage which has occurred by:

iii) containment, within the building, of radioactivity released from process systems failures.

To ensure adequate protection, these systems must have high availability. Existing technology in fission plants suggests that an availability of

TABLE VI-1. DEFINITIONS

Process Systems:

Those systems which are provided for the proper normal operation and maintenance of the facility.

Engineered Safety Systems (ESS):

A class of systems which are provided solely to protect the plant, staff and public in the event of normal process systems failure, by providing:

- rapid plasma and fuelling shutdown to prevent overheating,
- cooling for afterheat removal and component cooldown,
- containment of radioactivity which is released from process systems.

Serious Process Failure:

Any failure of the process systems where an ESS must act to prevent subsequent plant damage or the release of radioactivity to the environment.

99.9% is achievable and is thus proposed as the design target for these systems. This basic approach is summarized in Table VI-1.

Systems described in this section may not have been previously identified in any of the design unit work programmes. Placement of the brief system requirements in this section is done without prejudice to where responsibility for further design activity will rest. Rather the intent is to ensure that initial requirements are put forward and documented for consideration and possible action by appropriate stakeholders in the design team.

VI.2. DESIGN STRATEGY FOR ENGINEERED SAFETY SYSTEMS

In order to limit the risk of ITER and attempt to meet the criteria likely to be imposed by regulatory agencies, three kinds of failure scenarios need to be addressed:

- serious process failures
- dual failures (process + its protection failure)
- catastrophic events (extreme multiple-failure scenarios).

VI.2.1. Serious process failures

The most effective protection of plant and public is the prevention of failure of the process systems which are provided for the normal operation of the plant. Because of built-in redundancy and "fail-safe" design, most individual component failures do not pose a threat to plant safety. They do however "stress" the system and so should be minimized by good design.

A total target of 1 SPF/a has been proposed for those serious failures which can threaten plant damage or the release of radioactivity. This target will be a useful standard against which to judge the adequacy of designs when later reliability analyses are performed. Design efforts to ensure this target is met on a facility-wide basis will help assure the quality of individual system designs and choice of components.

In the unlikely event of a SPF, ESS will be provided as a second line of defence, thus affording an independent means for prompt shutdown and continued cooling to prevent any damage and thus a release of radioactivity to the building or, in the event of a release to the building, prevent any escape to the environment.

VI.2.2. Serious process failure and failure of the ESS

The unavailablity target for ESS's is 10-3, so the duration of failures is very short. Using this target value, the frequency of coincidence of an SPF with ESS unavailability is 10-3 events/a.

The consequences of SPF/ESS failures obviously depend on which systems have failed. In general, however, both shutdown and cooling serve to prevent overheating, and if these operate to prevent plant damage, no release of radioactivity occurs to the building. In this case the failure of containment does not result in releases to the environment.

Similarly, in the event of either shutdown or cooling failure, leading to overheating and a subsequent release to the building, containment will serve to prevent a release to the environment.

VI.2.3. Serious process failure and multiple failures of ESS's

The occurrence of a SPF coincident with independent unavailability of two ESS's has a probability of < 10-6.

The most severe consequence of such an event would result if either shutdown or cooling failed coincidentally with containment. In this case overheating could result in in-plant releases, and the inability of containment to effectively isolate would result in some release from the building. However, by limiting mobilizable inventories e.g. to <200 g for tritium), and with a suitable choice of materials, the releases to containment are limited. Containment structures will inherently attenuate this release, further resulting in the environmental release being a fraction of any release to the building. Since the normal flow through the buildings exits via the stack, it is reasonable to expect

TABLE VI-2. DESIGN STRATEGY

Event	Frequency	Consequences
Serious Process Failure (SRF)	1/a	ESS must act to prevent plant damage or the release of radioactivity to the environment.
SPF plus failure of any ESS	$<10^{-3}$/a	Either plant damage results (with release to building) but no release to environment occurs, or plant damage is avoided (no release to building) but containment fails.
SFP plus failure of more than one ESS	$<10^{-6}$/a	Inherent design features limit dose at the boundary.

this flow path to continue and thus allow good dispersal (dilution). Therefore, the dose to an individual at the exclusion zone boundary should be limited to acceptable values even for this essentially "impossible" event. The frequency/ consequence targets for the possible scenarios are summarized in Table VI-2.

VI.3. PRELIMINARY REQUIREMENTS AND DESCRIPTIONS: ENGINEERED SAFETY

This list of ESS requirements is preliminary and is not necessarily complete at this time. The intent is to communicate the major design issues for systems judged as vital for overall facility performance.

VI.3.1. Control of ITER thermonuclear burn conditions

A major mission for ITER is the study of tokamak plasmas under ignited or near-ignited conditions, where the auxiliary power necessary for control is small relative to the fusion power and where the fusion power output can exceed 1000 MW. The success of this mission strongly depends on: (1) the ability to obtain operating points, i.e. equilibrium power and particle balance solutions, at the required fusion power, (2) the ability to maintain this operating point in a stable manner for the duration of the burn, and (3) the ability to rapidly shut down the thermonuclear reactions in the event of an accident. Accordingly, assurance that ITER can safely meet its performance objectives at full or partial fusion power in a controllable manner requires consideration of three distinct control methodologies:

Operating point control is the establishment of plasma conditions and adjustable machine parameters to yield a desired equilibrium operating point at a given fusion power while satisfying relevant physics and engineering constraints. Characteristic time scales here are seconds to minutes at full operating temperature and, therefore, adjustment of conditions to obtain the desired operating point requires a decision prior to the establishment of the burn pulse.

Burn stability control is concerned with the detection and feedback stabilization of the thermal instabilities inherent in the thermonuclear burn process. Characteristic time scales are about 1 to 10 s and time-dependent control is required.

Emergency shutdown control is concerned with the rapid reduction of fusion power in response to component failures or loss of the normal burn stability control system. Time scales required are < 10 s and, ideally, about 1 s.

Successful licensing of ITER for full power operation will surely require that we demonstrate the fullest potential for reliable stability and emergency shutdown control. Accordingly, demonstration of the controllability of the thermonuclear burn conditions for ITER and specification of control requirements for the associated hardware systems (e.g. heating, fuelling, diagnostics) should be considered as important an objective as any other major design requirement.

The physics and operational performance of the above operational modes are fully discussed in Ref. 1. Below, we provide a brief overview of burn stability control and emergency shutdown control. We also note that burn control must be part of an integrated, overall ITER control process that includes particle control and current profile control. We are now beginning to apply multi-variable optimal control techniques in a 1.5 D transport formulation to this end [1].

VI.3.1.1 Burn stability control under normal operating conditions

The requirements for burn stability control systems has been demonstrated by time-dependent transport simulations which show that potential ignited and near-ignited operating points are susceptible to thermal instabilities that, if uncontrolled, can terminate an ITER discharge within 3 to 10 seconds [2]. Fluctuations in plasma temperature causing a positive thermal excursion will result in a beta limit disruption, while negative-going excursions will shut the plasma down with the possibility of a density-limit disruption. Furthermore, the positive excursion will cause elevated fusion powers (2000 MW), thus significantly increasing the possibility of damage to plasma facing components.

A number of techniques for controlling thermal instabilities have been suggested [3]. However, we will only emphasize methods involving active feedback of power and particle sources based on standard diagnostic signals since these approaches have been identified as the most direct and the most credible control strategies available [3, 4].

Specification of a primary control scheme for ITER requires a method capable of providing stability for an entire ITER burn period of several hundred seconds (e.g. at both high and low concentrations of thermal alpha particles and for varying impurity influx) using baseline heating, fuelling and diagnostic systems. In addition, the primary scheme must provide stabilization against both positive and negative excursions. Accordingly, feedback control of neutral beam power based on total neutron flux measurements has been chosen as the primary stability control scheme for ITER. Specifically, the plasma is operated with a small amount of beam power PNB,Eq at a slightly sub-ignited operating point at high Q. Then, in response to an increase in neutron flux (indicating an increase in fusion power), the heating power is reduced under feedback control to return the plasma to equilibrium conditions. Similarly, if the neutron flux decreases, additional power is applied. This scheme is conceptually simple and it is well suited to ITER owing to the existence of extensive neutron diagnostics along with a relatively large neutral beam power capability (PNB,Max ~ 75 MW).

Modulation of particles via fuelling control of (a) total density, (b) density profile, (c) DT fuel mix, or (d) impurity concentration, may offer an additional dimension to the control phase space when taken together with auxiliary heating. Several other stability control schemes have also been suggested such as plasma compression/decompression, control of toroidal field ripple, etc [3]. However, not only are the physics and technological requirements of such schemes insufficiently developed at this time but, in many cases, there appear to be fundamental reasons why they would not be applicable to ITER. Fuelling modulation has been examined as a potential control method both by itself and in conjunction with auxiliary heating control [2]. Like the latter, this scheme is simple and relies on existing ITER systems. Also, it is applicable to both near-ignited and, under certain conditions, truly ignited operating points (i.e. Q= , PNB,Eq=0). In general, however, density control via fuelling modulation should be considered as a supplemental system to improve the performance of the primary (auxiliary heating feedback) scheme.

VI.3.1.2 Emergency shutdown control

We require emergency shutdown schemes for two distinct reasons:

(1) When our normal burn stability control scheme fails and the plasma becomes super-ignited. As described above, our typical near-ignited, high-Q operating points have a positive temperature coefficient of reactivity. Accordingly, once the plasma temperature has crossed the ignition boundary, nothing we can do with our baseline scheme of modulated control of auxiliary power can restore the equilibrium.

(2) When the plasma is operating stably at the desired operating point but an external accident event (for example a loss-of-coolant or loss-of-flow accident (LOCA/LOFA) in a torus component) necessitates a rapid reduction of fusion power in a time scale much shorter than the conventional shutdown period.

A LOCA/LOFA in the divertor will result in significant damage to the plasma facing components unless the fusion power is reduced to zero in less than 10 s [5]. For some divertor designs, the required time scale is as low as 1 - 3 s. Similar damage can occur in the event of a failure of the burn stability control

TABLE VI-3. CANDIDATE ITER EMERGENCY SHUTDOWN SCHEMES

Method	Time* Scale	Probability of Disruption	Passive** System Potential
1. Controlled reduction of auxiliary heating and/or fuelling+	slow	low	low
2. H to L mode transition	medium	low	low
3. Controlled impurity injection			
- hydrogen	medium	low	low
- medium to high Z	medium	moderate	low
4. Rapid shutoff of auxiliary heating and fuelling	medium	moderate to high	moderate
5. Vaporization of divertor substrate	medium	moderate to high	high
6. Uncontrolled central impurity injection - gravity driven "control rod" - pressure driven "bullet"	fast	moderate to high	moderate
7. Uncontrolled edge impurity injection - pressurized burst diaphragm or He capsules	fast	high	moderate
8. Interruption of vertical control	fast	100%	moderate

* relative to burn control and accident transients

** i.e. able to operate without active detection, intervention, or control

\+ method for conventional (slow) shutdown

system where a fusion power of 2000 MW can be reached in time scales of about 5 to 15 s, this range being dependent on the confinement scaling [2].

Consequently, the disparity in time scales required for emergency shutdown (1 to 10 s) relative to normal, controlled shutdown at the end of a conventional burn pulse (several tens of seconds) requires us to consider several candidate emergency shutdown schemes for ITER [6]. These are reproduced in Table VI-3 in approximate order of their time scale relative to a characteristic transient time of about 5 s. From performance requirements, our near-ignited operating points are close to the density limit, a constraint based on power balance supply to the edge plasma. A characteristic of several of the faster shutdown schemes in Table VI-3 is the tendency to initiate a density limit disruption because the fusion power decays at a faster rate than the density. We stress that density limit models are in the early stages of development and, therefore, precise statements of the severity of this phenomenon are premature. However, we point out that as ITER is designed to accommodate a number of disruptions, the disruptive termination of the plasma under emergency shutdown control is certainly more attractive than the further consequences of the initiating accident event.

An important conclusion of the emergency shutdown work thus far is the realization [6] that it may prove difficult to apply the concept of passive/inherent safety, as adopted by the fission community, to fusion in this context. This is primarily because the power producing element (the plasma) is not in intimate contact with the medium undergoing the off-normal event (the plasma facing components, blankets, etc). In Table VI-3 we have attempted to assess which schemes have the potential for passive operation and which will probably operate under active means (i.e. active detection and/or active intervention). Of the eight methods in the table, only one really lends itself to a truly passive system, i.e. vaporization of the divertor substrate due to a local temperature transient. This relies on subsequent substantial impurity ingress to the plasma edge and density limit disruption might be expected. We also note that this scheme would not be a candidate for emergency shutdown in the case of loss of normal burn stability control because of the substantial damage that the divertor would sustain.

Among the emergency shutdown schemes analysed to date, central injection of medium-Z impurities appears to hold the most promise for a rapid (few seconds) shutdown scheme that may be able to avoid a density-limit disruption. Potential for a passive scheme is, however, poor and a system operating under active detection and control would be necessary.

VI.3.2. Emergency cooling

The exact design requirements for this system cannot yet be established, but are likely to include the following:

a) Primary function: to protect process systems (mostly in-vessel components) from significant overheating and subsequent physical damage in order to prevent tokamak failure and subsequent releases to the building by providing

- backup circulation and heat sink,
- coolant injection into cooling loops, and water recovery from any breaks in these loops,
- steam suppression (if high temperature water is used as coolant/conditioning fluid).

b) The system capacity should be sufficient to remove all afterheat and provide a timely cooldown of hot in-vessel components.

c) This system must be as independent as possible of primary heat transport systems so that common mode effects will not make it inoperative at the same time as failures occur with the major cooling systems.

The specific approach to be used will be dependent on the configuration of the torus and its auxiliary systems. To the extent practicable, in-vessel component cooling through passive convective circulation should be retained and supplement by active pumping systems to ensure that post-LOFA temperatures do not exceed allowed limits for component damage.

VI.3.3. Confinement systems

Although the final confinement building will be designed to be passive to the extent possible, active parts will be required to limit contamination spread if a release occurs, while providing suitable ventilation and access at other times.

Depending on the hazard contained, a number of barriers are provided to prevent the spread of radioactivity. Barriers are normally provided as close to the source as practical, with provisions to detritiate the atmospheres contained within each barrier. Furthermore, all systems which contain (or could contain) radioactivity are located inside a final safety barrier (containment for barriers designed to withstand substantial differential pressures; or confinement for barriers designed for contamination control). This final safety barrier is considered as an Engineered Safety System.

In principle both containment and confinement are quite similar in that they are normally clean (i.e. uncontaminated) and open to a once-through ventilation system. In the event of a release of activity into a containment/ confinement area, the area is isolated, and a Recirculating Air Detritiation System (RADS) is activated to remove any free contamination.

All containment/confinement volumes are maintained subatmospheric (normally -7 kPa for containment and from -30 to -60 Pa for confinement) to prevent the outleakage of containment. This is done by taking a purge flow from the RADS discharge which is further detritiated in an Exhaust Gas Detritiation System to allowable release levels and discharged through the stack.

Air locks and vestibules are proposed for access to containment /confinement areas without breaching the containment/confinement boundary during access.

Operating pressures for multiple barriers are normally set so that air flow (leakage) is from cleaner to more contaminated areas. A possible exception to this is inert gas spaces which may be at the same pressure (to facilitate glove box operation) or even at slightly elevated pressures (to prevent air contamination of inert atmospheres). In any case, such areas are sub-atmospheric with respect to the environment to ensure that contamination cannot be spread in the event of a leak. The overall concept is shown in Fig.VI-1.

It will be necessary as part of the engineering design activity to assign a system responsibility for the integration of these systems and components into a containment/confinement which will meet the specified performance targets.

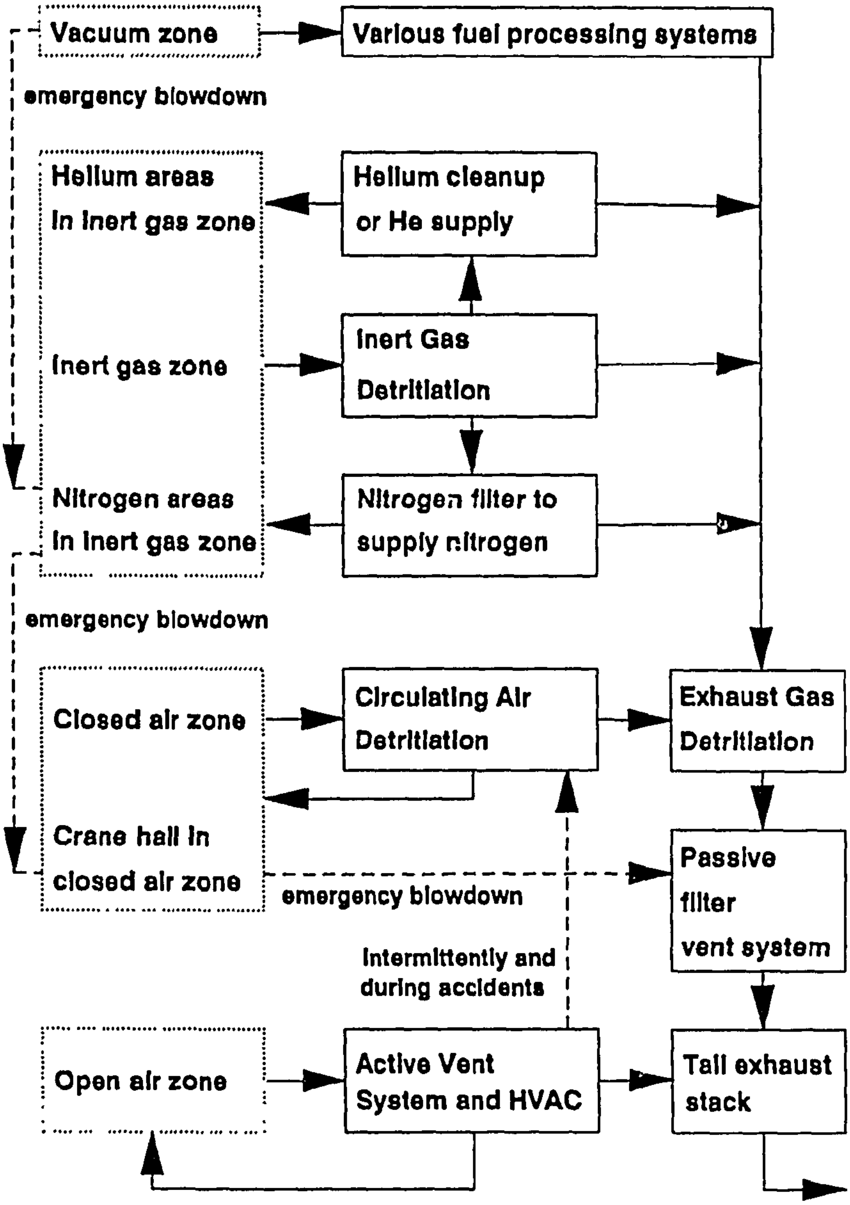

Fig. VI-1. Integration or radioactivity confinement with ventilation and tritium systems

VI.3.4 Emergency power systems

In the event of loss of off-site power, on-site standby generation and distribution of power will be provided to maintain the plant in a safe state. Battery power will be provided for functions which must be non-interruptible, with on-site combustion turbines providing back-up power generation within a short time for large loads such as coolant pumps, service water supply, etc.

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VII. TOKAMAK BUILDING

VII.1. INTRODUCTION

The development of the ITER tokamak building layout has three basic functions:

- to establish a basis for more detailed tokamak building design during the engineering design activities (EDA),
- to provide a reference for establishing a safety position,
- to be used as a basis for cost estimates.

The ITER design philosophy is that the tokamak building should contain only those systems which are directly connected with the tokamak or for safety reasons must be located close to the tokamak.

The evolution of the tokamak building design is reflected in a series of reports and papers mostly presented during ITER plant design workshops ([1] - [11]).

VII.2. FUNCTIONS

The functions of the tokamak building are to house the reactor and systems closely associated with it: heat transport, fuelling, plasma heating and current drive, vacuum pumping, maintenance equipment, diagnostics, atmosphere decontamination, heating, ventilation and air conditioning. The building should also provide adequate space for assembly, operation and maintenance, provide radiation shielding and containment of hazardous materials during routine operation and accidents, and protect the tokamak and auxiliary equipment from damage due to external events.

Other structures are closely coupled to the tokamak building to minimize communication paths and meet safety requirements. They are discussed in Chapter VIII.

VII.3. DESIGN REQUIREMENTS

The design requirements are provided in three areas for clarity. They are: functional or operational, safety and structural.

VII.3.1. Functional requirements

Functional requirements for the tokamak building are derived from the operational and maintenance requirements established by the system designers. The structure is to provide adequate space for the installation, operation and maintenance of the systems located within it. The interrelation of these systems with others is to be considered. Where clear needs exist this interrelation should be taken into account in the layout.

Access routes will be identified for all major equipment in the building in the context of initial installation and subsequent removal to a hot cell in the adjacent structure.

Provisions must be made to maintain major equipment by means of remote handling devices which will include provision for redundancy. Provision will be made also for containment and transfer equipment required by maintenance and confinement procedures as well as associated lifting and material handling equipment.

VII.3.2. Safety requirements

The safety of the public and the plant and its operators imposes safety requirements on the tokamak building structure. The building structure must be a final barrier between the reactor and the environment and contain all the radioactive material within the plant for controlled release. The internal pressure in the building will be slightly sub-atmospheric; and the building structure will be designed, on the one hand, to withstand pressure difference, and on the other hand, to ensure that the inleakage into the building will not be more than 1% of the total building volume per day. In addition, the building will withstand a positive overpressure of up to 30 kPa.

Zoning shall be used to limit the spread of contaminants; this approach will provide for clean and contaminated areas. The layout of all the systems will comply with this philosophy. There is a need to blanket some equipment and systems with an inert atmosphere to ensure that in the event of a system failure, air ingress to the plasma chamber is not feasible. Certain areas within the plant will be designated to have an inert environment.

Shielding must be provided to protect equipment as specified by system designers, e.g. superconducting magnets. In addition, biological shielding will be provided to protect personnel required to enter those areas deemed accessible. There is adequate space in the ITER reference layout to accommodate these requirements.

VII.3.3. Structural requirements

The specified design loads for the tokamak building shall comply with codes in existence in the host country and shall include the effect of earthquakes, wind and snow loads, tornadoes and tornado-generated missiles and floods. In addition, accidental pressure and temperature excursions in the building, and reaction loads due to failed components such as pipe break and pipe whip, shall be considered. The structure shall be designed to withstand a seismic event without loss of containment.

VII.4. BUILDING LAYOUT

Elevation views and plan views of the tokamak building are given in Figs. VII-1 to VII-9. Figures VII-7 and VII-8 show options with compound

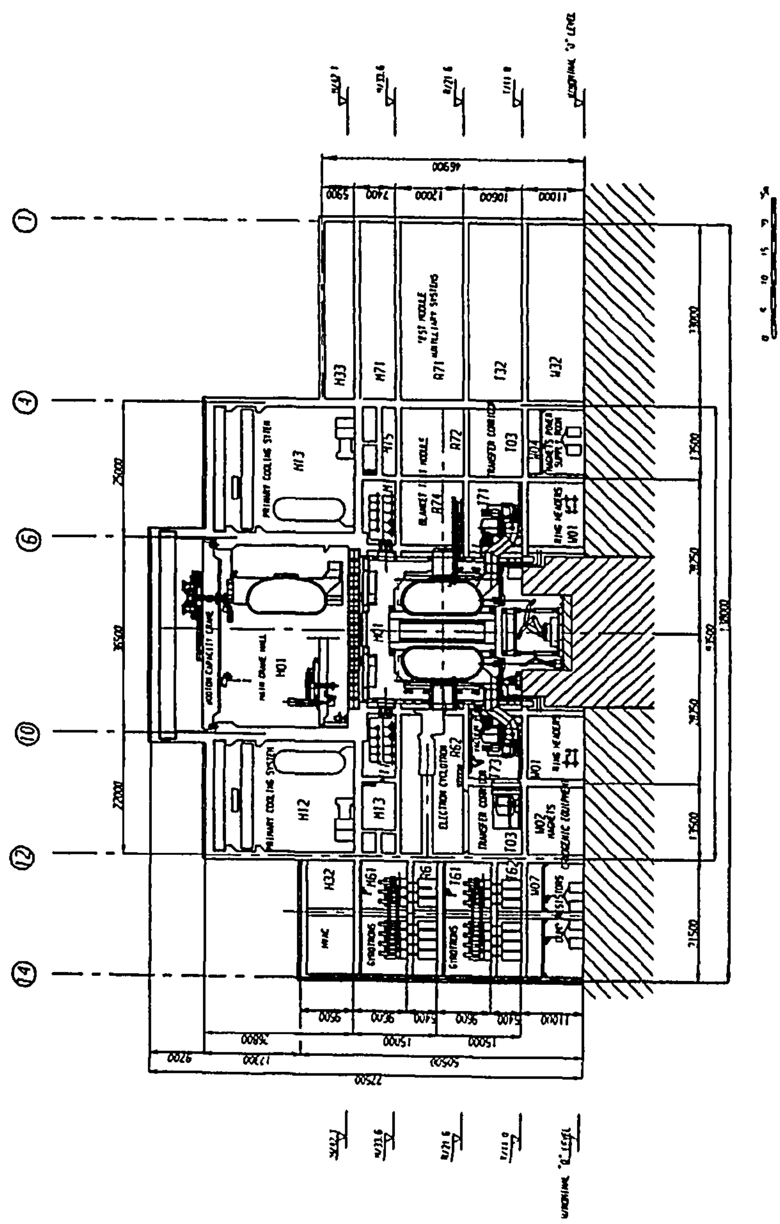

Fig. VII-1. Basic device building elevation view (section A-A)

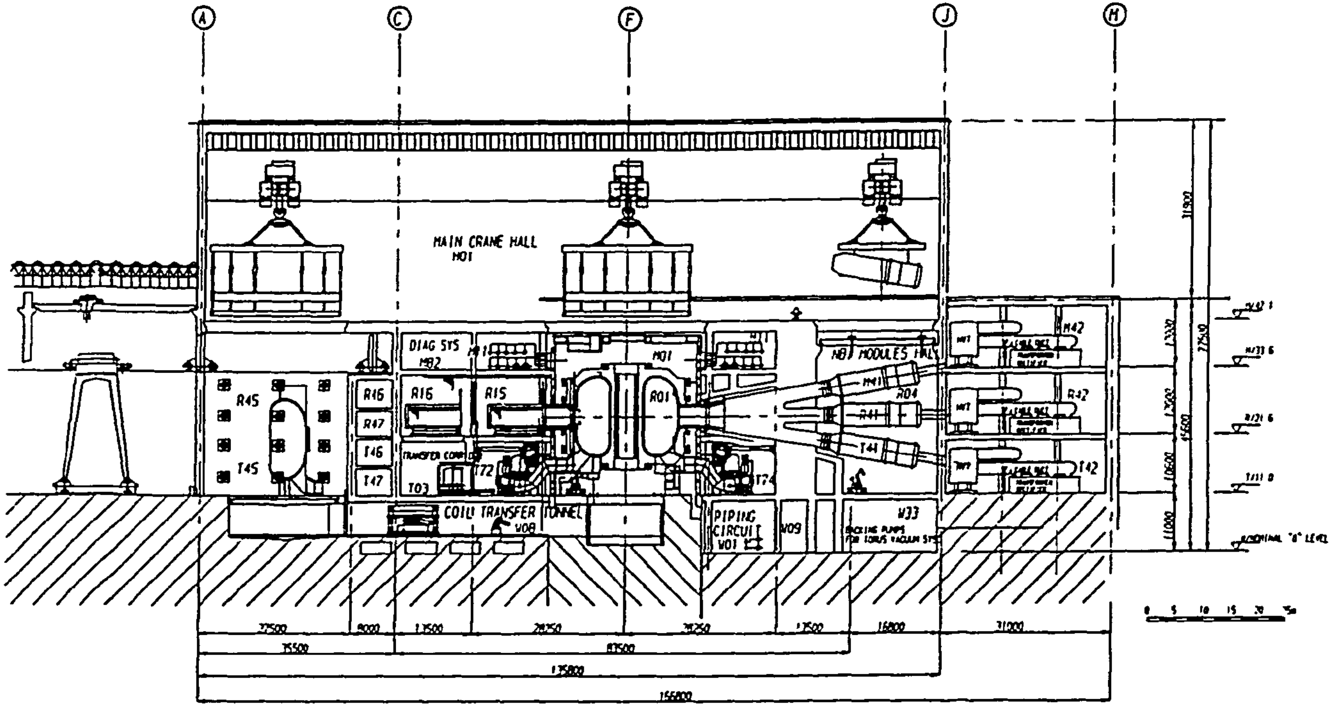

Fig. VII-2. Basic device building elevation view (section B-B)

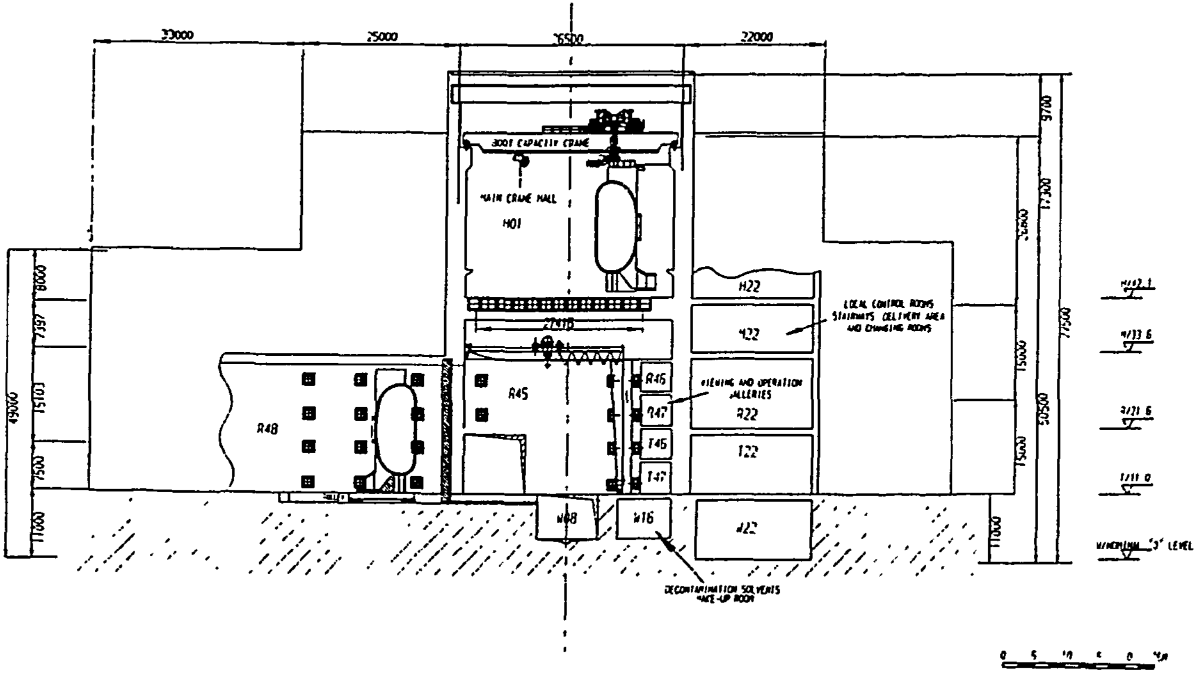

Fig. VII-3. Basic requirement scheme elevation view (section C-C)

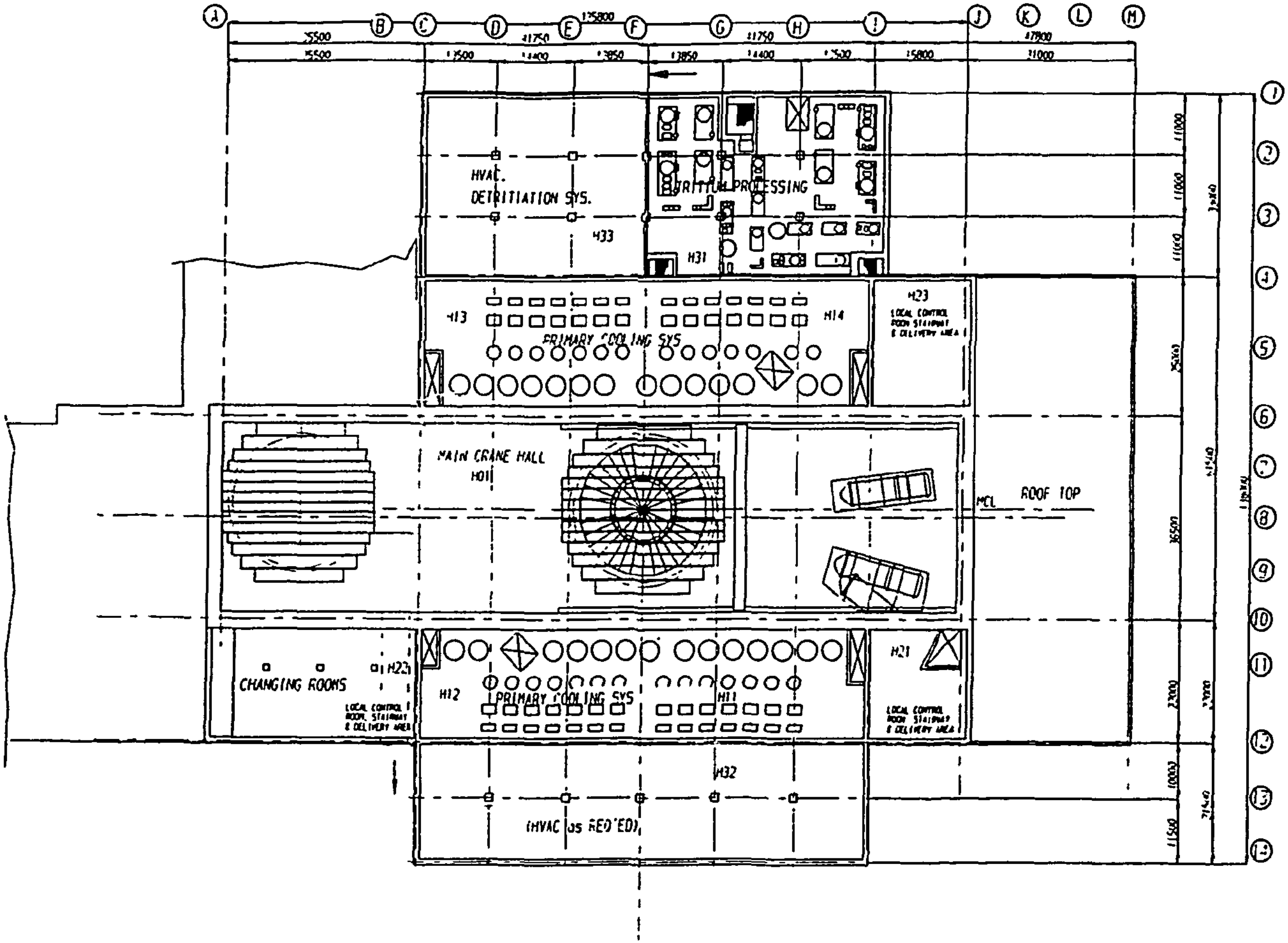

Fig. VII-4. Basic device building plan view (level H)

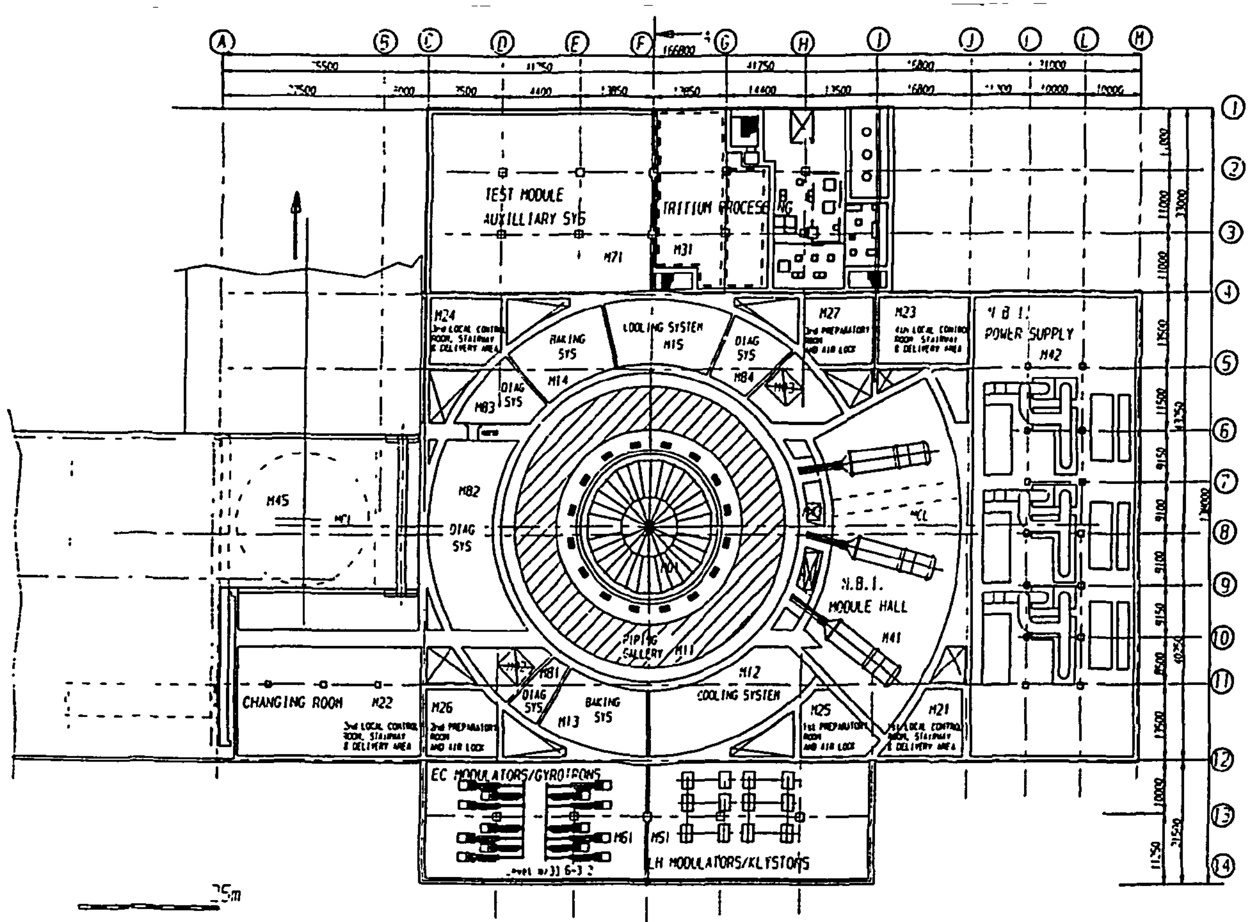

Fig. VII-5. Basic device building plan view (level M)

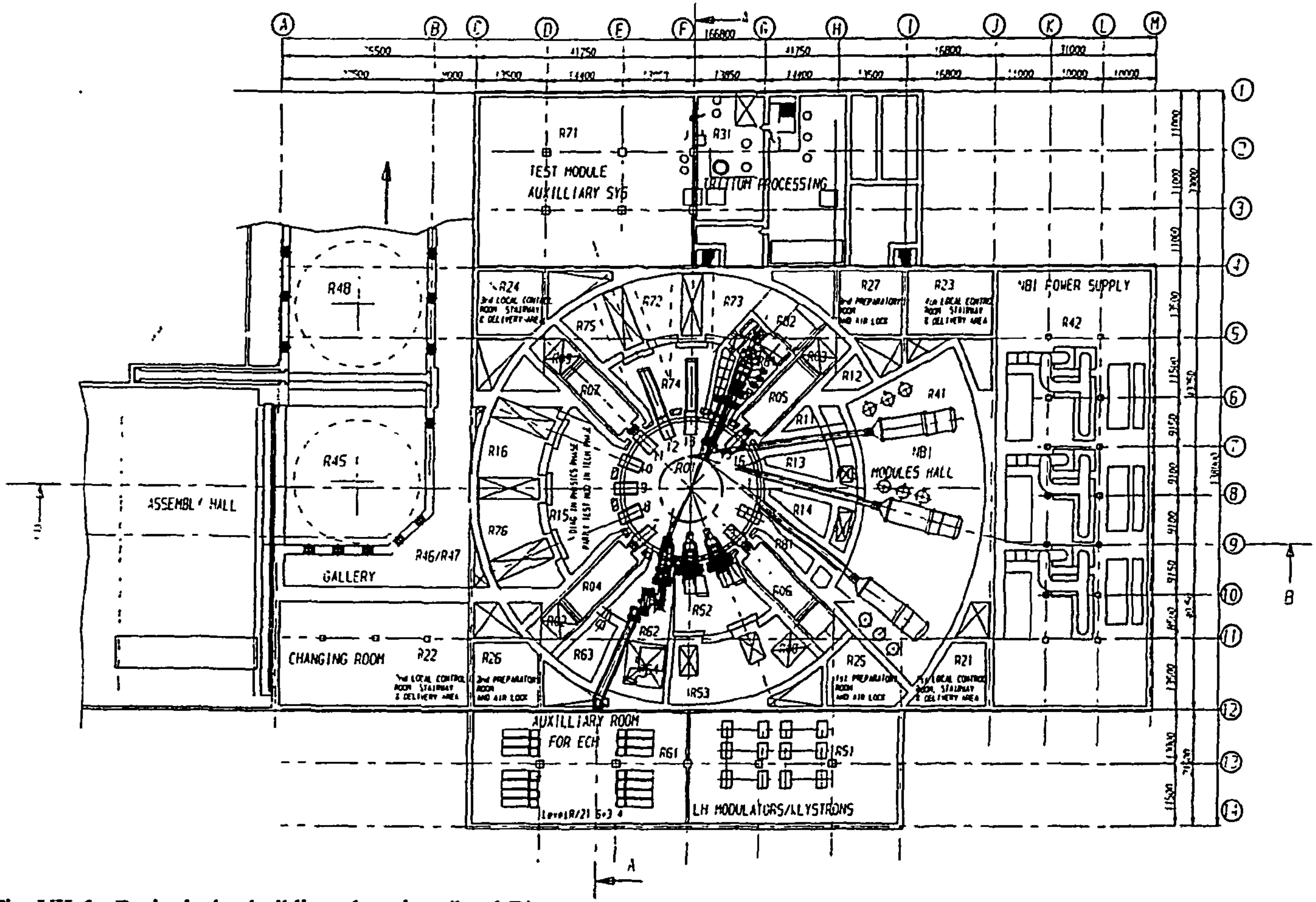

Fig. VII-6. Basic device building plan view (level R)

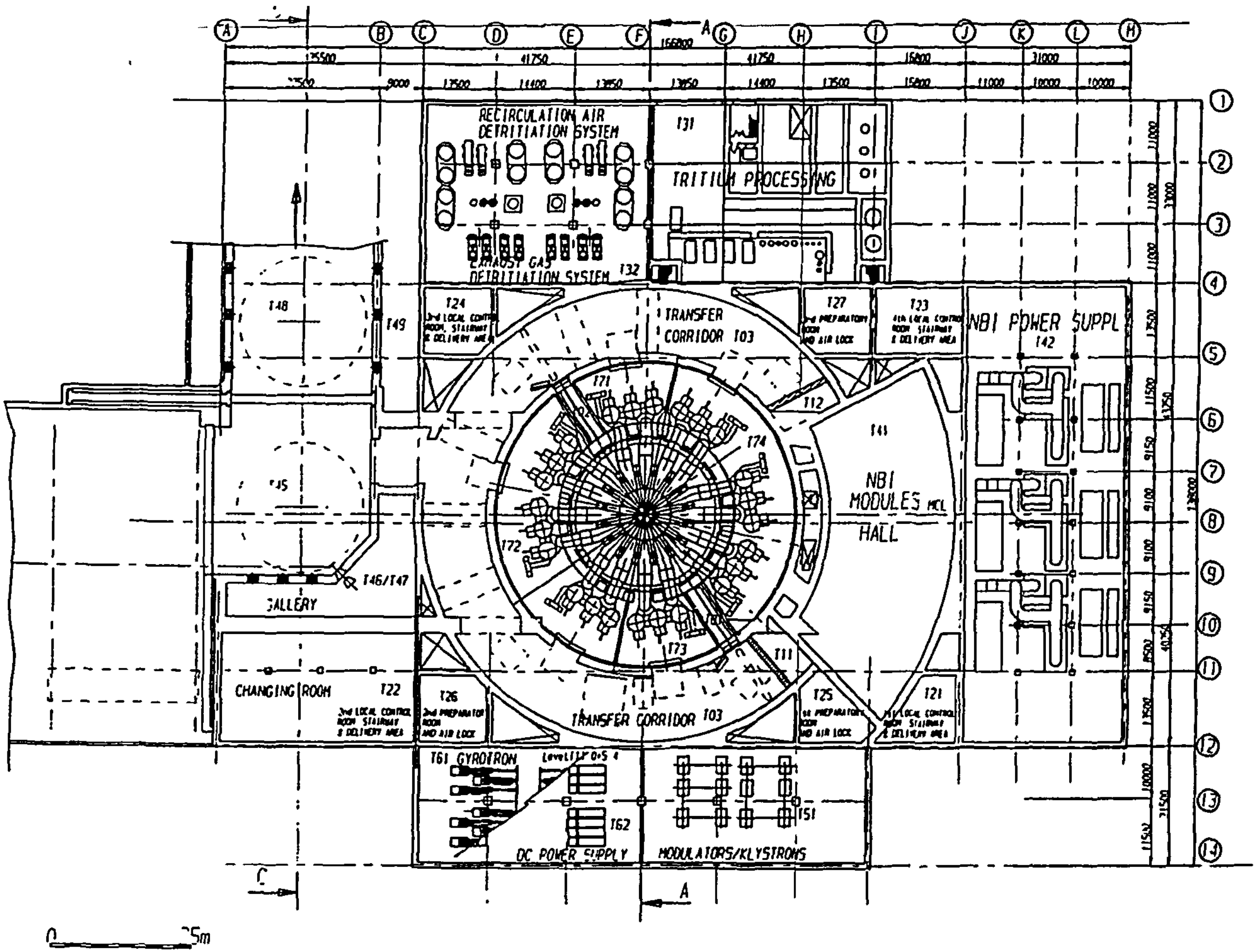

Fig. VII-7. Tokamak building basic requirement scheme plan view (level T)

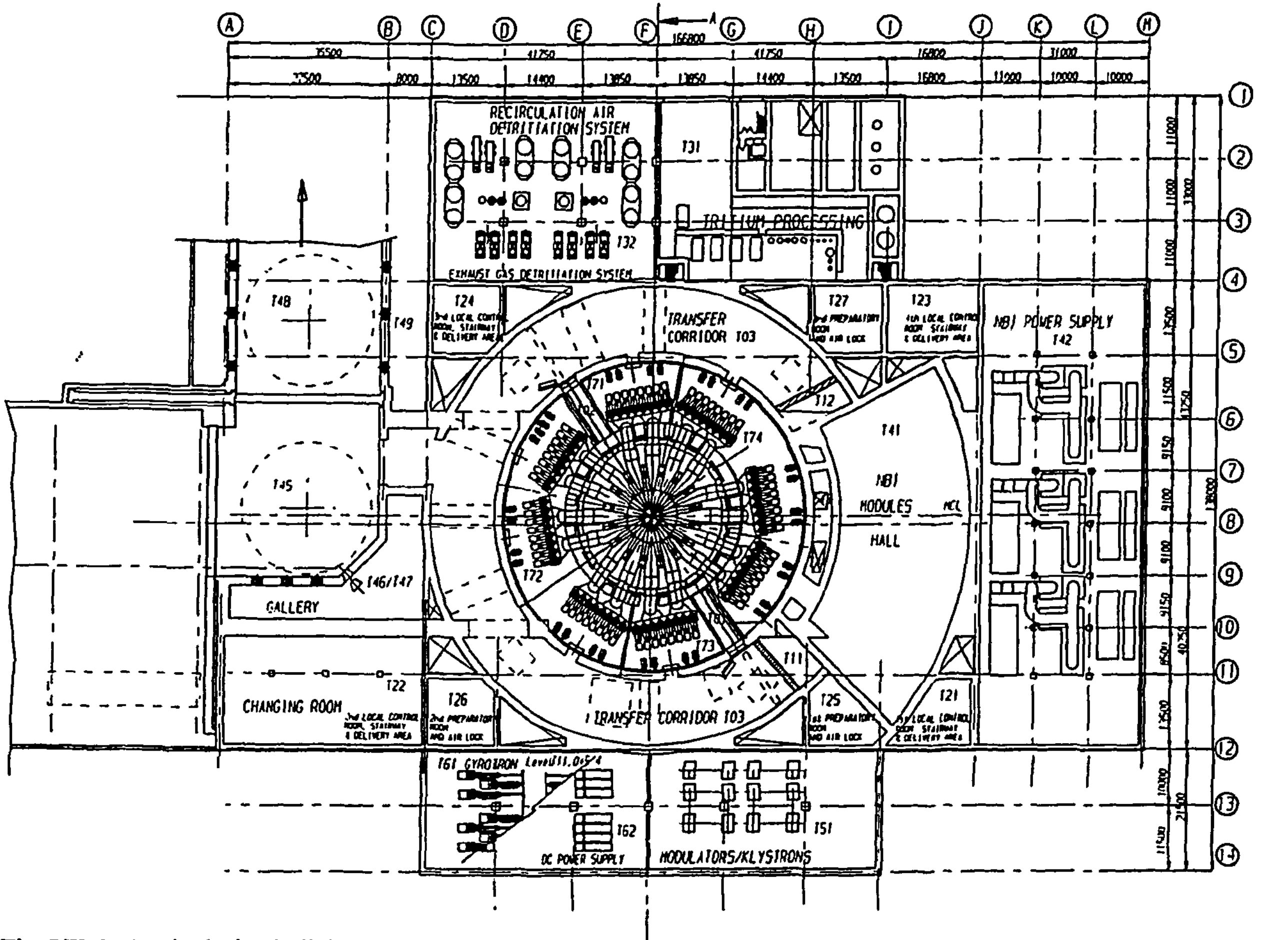

Fig. VII-8. Basic device building plan view (level T)

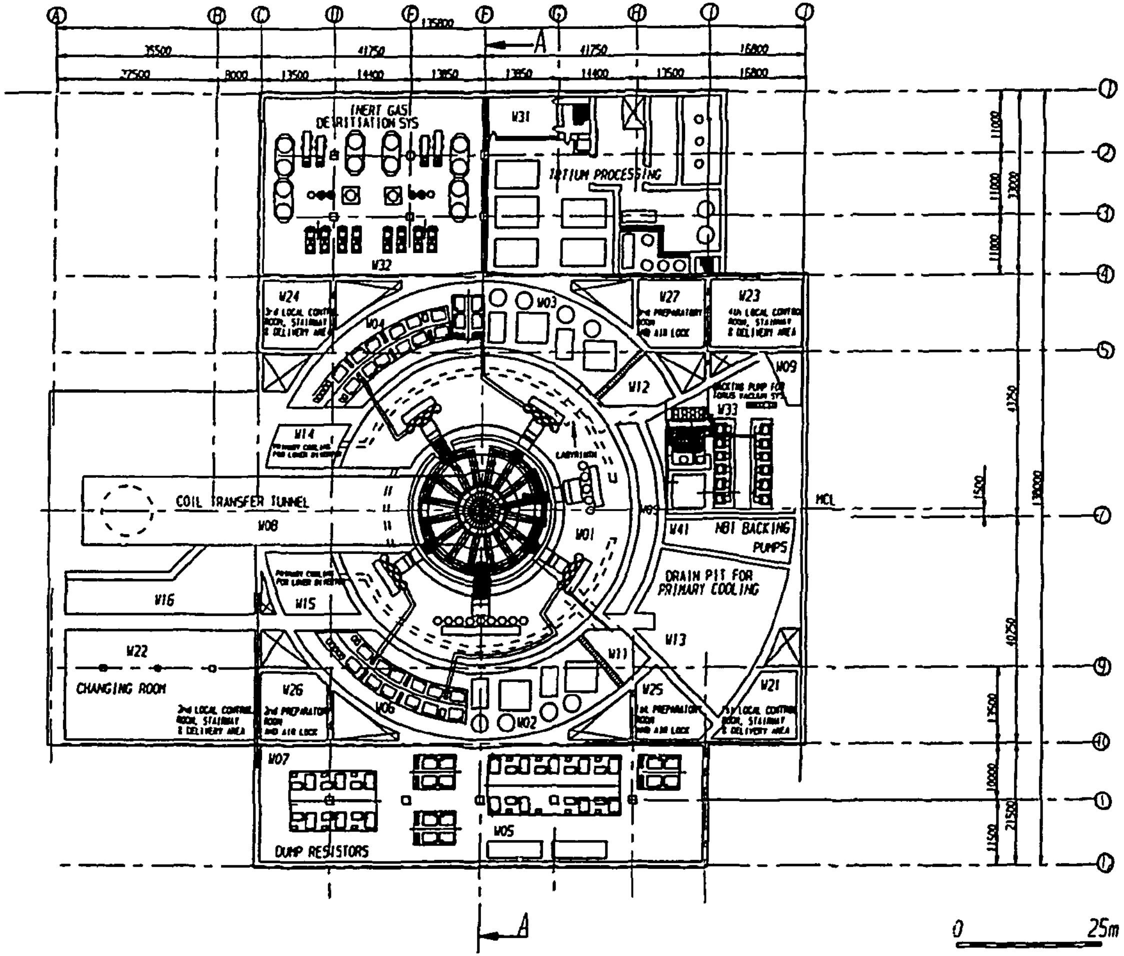

Fig. VII-9. Basic device building plan view (level W)

TABLE VII-1. LIST OF ITER TOKAMAK BUILDING ROOMS

ELEVATION H (Fig VII-4)

HO1 : Main crane hall
H11 : Primary cooling system (heat exchangers, pressurizers, pumps, etc.)
H12 : Primary cooling system (heat exchangers, pressurizers, pumps, etc.)
H13 : Primary cooling system (heat exchangers, pressurizers, pumps, etc.)
H14 : Primary cooling system (heat exchangers, pressurizers, pumps, etc.)
H21 : Local control room, stairways
H22 : Local control room, stairways, changing room
H23 : Local control room, stairways
H31 : Tritium processing structure: HVAC and ADS room
H32 : Tokamak building heating, ventilation and air conditioning (HVAC)
N33 : Tritium processing structure HVAC and ADS room

ELEVATION M (Fig. VII-5)

M01 : Tokamak vault
M02 : Transfer unit hatch
M03 : Transfer unit hatch
M11 : Ring headers/manifolds gallery
M12 : Vacuum vessel water cooling system room
M13 : Baking system room
M14 : Baking system room
M15 : Cooling water decontamination room
M21 : Local control room, stairways
M22 : Local control room, stairways, changing room
M23 : Local control room, stairways
M24 : Local control room, stairways
M25 : Preparatory room, air-lock
M26 : Preparatory room, air-lock
M27 : Preparatory room, air-lock
M31 : Tritium recovery room
M41 : Neutral beam injector (NBI) modules hall
M42 : NBI power supply structure
M43 : Service shaft
M44 : Service shaft
M45 : Transfer and decontamination cell
M51 : Lower hybrid waves (LHW) modulators/klystrons room
M61 : Electron cyclotron waves (ECW) modulators/gyrotrons room
M71 : Test modules auxiliaries room
M81 : Diagnostics room
M82 : Diagnostics room

TABLE VII-1. (CONT.)

M83 : Diagnostics room
M84 : Diagnostics room

ELEVATION R (Fig. VII-6)

R01 : Tokamak vault
R02 : Transfer unit hatch
R03 : Transfer unit hatch
R04 : Transfer unit room
R05 : Transfer unit room
R06 : Maintenance bay room
R07 : Maintenance bay room
R08 : Maintenance bay hatch
R09 : Maintenance bay hatch
R11 : Diagnostics room
R12 : Diagnostics room
R13 : Diagnostics room
R14 : Diagnostics room
R15 : Diagnostics/test modules room
R16 : Diagnostics/test modules room
R21 : Local control room, stairways
R22 : Local control room, stairways, changing room
R23 : Local control room, stairways
R24 : Local control room, stairways
R25 : Preparatory room, air-lock
R26 : Preparatory room, air-lock
R27 : Preparatory room, air-lock
R31 : Cryodistillation & tritium laboratory
R41 : NBI modules hall
R42 : NBI power supply structure
R43 : Service shaft
R44 : Service shaft
R45 : Transfer & decontamination cell
R46 : Inspection & operation gallery
R47 : Inspection & operation gallery
R48 : Hot cell access passageway
R51 : LHW modulators/klystrons room
R52 : LHW launchers room
R53 : LHW transfer room
R61 : ECW power supply and auxiliaries room
R62 : ECW antennae room
R63 : ECW control room

TABLE VII-1. (CONT.)

R64 : ECW hatch
R71 : Test modules auxiliaries room
R72 : Test modules room
R73 : Test modules room
R74 : Test modules room
R75 : Test modules room
R76 : Test modules room
R81 : Pellet injectors room
R82 : Gas puffing room

ELEVATION T (Figs. VII-7 and VII-8)

T01 : Maintenance passageway
T02 : Maintenance passageway
T03 : Transfer corridor
T11 : Diagnostic equipment
T12 : Diagnostic equipment
T21 : Local control room, stairway
T22 : Local control room, stairway, changing room
T23 : Local control room, stairway
T24 : Local control room, stairway
T25 : Preparatory room, air-lock
T26 : Preparatory room, air-lock
T27 : Preparatory room, air lock
T31 : Cryodistillation & tritium storage
T32 : Tokamak building RADS room
T41 : NBI modules hall
T42 : NBI power supply structure
T43 : Service shaft
T44 : Service shaft
T45 : Transfer & decontamination cell
T46 : Inspection & operation gallery
T47 : Inspection & operation gallery
T48 : Hot cell access passageway
T49 : Inspection & operation gallery
T51 : LHW modulators/klystrons room
T61 : ECW modulators/gyrotrons room
T62 : ECW power supply and auxiliaries room
T71 : Plasma exhaust system cell
T72 : Plasma exhaust system cell
T73 : Plasma exhaust system cell
T74 : Plasma exhaust system cell

TABLE VII-1. (CONT.)

ELEVATION W (Fig. VII-9)

W01 : Magnet system cryogenic valve boxes/lower divertor ring headers
W02 : Intermediate cryogenic equipment for magnets
W03 : Intermediate cryogenic equipment for magnets
W04 : Dump resistors
W05 : Dump resistors
W06 : Dump resistors
W07 : Dump resistors
W08 : Transfer tunnel for poloidal field coil No 5
W09 : Transfer corridor
W11 : Diagnostic equipment
W12 : Diagnostic equipment
W13 : Water cooling drain tank pit
W14 : Lower divertor cooling circuit cell
W15 : Lower divertor cooling circuit cell
W16 : Decontamination solvents make-up room
W21 . Local control room, stairways
W22 : Local control room, stairways, changing room
W23 : Local control room, stairways
W24 : Local control room, stairways
W25 : Preparatory room, air-lock
W26 : Preparatory room, air-lock
W27 : Preparatory room, air-lock
W31 : Tritiated water treatment, fuel clean-up system room
W32 : Inert gas detritiation system room
W33 : Main exhaust backing pumps room
W41 : NBI backing pumps room

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cryopumps and turbomolecular pumps, respectively, for the primary vacuum pumping system. The functions of all the ITER tokamak building halls, rooms and cells are listed in Table VII-1.

The tokamak with the first wall, divertor, blanket, shield, vacuum vessel, magnets, and cryostat is housed in the tokamak vault situated in the very centre of the tokamak building. This vault has a cylindrical shape with a radius of about 13 m and a height of 30 m and is under vacuum. There is a pit with remote handling equipment under the vault.

The tokamak vault is surrounded by an almost annular structure housing equipment closely connected with the tokamak. Some volumes adjacent to the torus require an inert atmosphere. In particular, the vacuum pump room (12,300 m^3), the pellet injector room (700 m^3), the maintenance bays (2,000 m^3), as well as boxes around the test modules (4,000 m^3), the lower hybrid (LH) and the electron cyclotron (EC) system components contacting the plasma chamber, and the gas puffing equipment will be filled with an inert gas, the primary candidate being helium. The total volume of this inert environment is about 20,000 m^3. Nitrogen is the primary candidate as an inert gas to fill the neutral beam injector (NBI) room, having a volume of about 33,000 m^3 and some diagnostics rooms. The volume of the diagnostics rooms to be filled with nitrogen during the physics phase may be up to 5,000 m^3. Further design will aim to minimize the volume to be filled with an inert gas; until such design is performed, it is assumed that the indicated space will be filled with the inert gas.

Other volumes of the rooms containing plasma heating and current drive systems, equipment serving test modules, diagnostic systems, and gas puffing facilities in this (main) part of the building as well as rooms for some equipment of the heat transport system (ring headers, manifolds, feeders, baking circuit) will be filled with air served by the Recirculating Air Detritiation System (RADS). The relative pressure in these rooms will be slightly negative with respect to the pressure in the inert gas zone and in surrounding rooms served by the Active Ventilation System. This central part of the building includes transfer corridors as well. It has an outer radius of about 42 m and a height of 30 m. The outer radius of the NBI hall is about 59 m.

There is a crane hall and rooms for large equipment of the primary heat transport system (primary heat exchangers, pressurizers, buffer tanks, etc.) over the main part of the building, above the level of 42.1 m.

Peripheral parts of the building house the LH sources, gyrotrons and auxiliary equipment of the EC system, test module auxiliary equipment, some diagnostic devices, Atmosphere Decontamination Systems (ADS), Heating, Ventilation and Air Conditioning System (HVAC), air-locks, and changing rooms. The tritium processing systems and NBI power supply occupy separate structures adjacent to the tokamak building. These two structures are described in Chapter VIII.

The lower parts of the building (below a level of 11 m) house dump resistors, some cryogenic equipment, primary coolant drain tanks, equipment of lower divertor heat transport circuits, a number of diagnostic devices, current lead cooling circuit, backing pumps for the torus vacuum system and for the NBI, decontamination solvent make-up facility, and a coil transfer tunnel.

The tokamak building is not rectangular, but the largest dimensions are 167 m long, 138 m wide, and 77.5 m high. The total volume is about 1,100,000 m^3 (together with tritium processing and NBI power supply structures). The total tokamak building volume without tritium processing and NBI power supply structures is about 890,000 m^3. A more detailed description of the tokamak building layout is given below.

VII.4.1. Main crane hall

The tokamak configuration is based on vertical assembly and maintenance schemes. The major components and their appropriate lifting gear set the height of the crane hall (H01 in Figs. VII-1 - VII-4). The crane hall is 135 m long, 34 m wide, and 32 m high. The hall length was set taking into account the space necessary for component handling, hatch cover, and handling gear laydown requirements. There is also space to stack components including poloidal and toroidal coils as well as the vacuum vessel sectors during disassembly. The volume of the hall is about 147,000 m^3. This large volume will accommodate overpressures in the tokamak building in case of system failures.

A linear crane was selected over a polar design as being more practical. It allows direct transport of components from one area to another without additional handling. A capacity of 800 t has been established. This suggests the possible selection of a pair of 500 t cranes which may provide flexibility in crane operation and most likely reduce assembly time. One of these cranes can also service the NBI modules which are located within the limits of its travel. A second option is to separate the NBI crane hall from the main crane hall and this will be examined during the EDA. The main crane rails are situated in an upper penthouse which is 40 m wide. They are supported by the crane hall walls.

There is an additional bridge crane at a lower height level above the tokamak which is intended to handle maintenance tools so as to facilitate maintenance operations.

The crane hall also contains tools and handling gear for the initial assembly of the tokamak. It can be isolated from the rest of the building and provides a sealed, shielded area for machine dissassembly if required.

The neutron and gamma cameras placed on the floor of the main crane hall will be designed to be easily replaceable.

The crane hall structure forms part of the containment barrier against uncontrolled release of radioactive material to the environment. The roof of the crane hall is made of precast concrete beams with sufficient shielding incorporated to meet radiation protection requirements. The thickness of the crane hall walls is determined by the crane weight, its capacity, and the potential roof load. The roof and wall thickness satisfy the shielding needs as well.

VII.4.2. Heat transport system rooms elevation (M)

The heat exchangers, pressurizers, buffer tanks and pumps of the primary cooling circuits of the first wall, upper divertor, blanket/shield and vacuum vessel as well as pumps of the emergency cooling system are housed in structures H11 - H14 situated in parallel with the crane hall on the crane hall level (Figs. VII-1, VII-4). These rooms are served by the RADS (since the primary coolant contains activated corrosion products and tritium) and are accessible for maintenance after shutdown, if required. Cranes are provided for the installation and maintenance of the equipment.

The ring headers and manifolds of the same primary circuits are placed on the next elevation below the crane hall, behind an annular concrete structure around the reactor vault (room M11; Figs. VII-1, VII-2, VII-5). Some rooms on this elevation will also house a baking system (rooms M13 and M14), the equipment required for chemical decontamination of the primary heat transport systems (M15) as well as large and sensitive components of diagnostic systems (rooms M81 - M84).

The area directly above the reactor is free for access to the top of the machine for assembly and maintenance.

Vll.4.3. Tokamak mid-plane elevation (R)

The rooms on this floor house most of the systems which interface directly with the tokamak and as such are not normally accessible by plant personnel. The allocation of the equatorial ports on the machine determines the arrangement of the associated reactor systems at this elevation. The port allocation is specified in the reports dealing with machine configuration and assembly and are not described here. The layout of the support systems is shown in Figs. VII-1 and VII-2 (elevation views) and VII-6 (plan view). The major systems which set building size are described briefly below.

Vll 4.3.1. Plasma heating and current drive systems

There are three reference plasma heating and current drive systems, which include: electron cyclotron, lower hybrid and neutral beams.

The EC system consists of 24 rf channels (plus 4 hot spares) which are brought together at the tokamak and transmit the EC waves via mirrors (one of which is movable) into the plasma. Each channel is made up of: a dc power supply, a 1 MW gyrotron, initializing optics, a run of corrugated waveguides approximately 45 m in length, fast valves or shutters, and a rf window assembly. The EC waves will be injected into the plasma through port six at the equatorial plane. The antenna protrudes 9 m from the outside of the cryostat. Therefore, withdrawal space is required behind the antenna for maintenance. The antenna maintenance will be performed inside the enclosure without hands-on operations. Nevertheless, provision has been made for additional shielding around the antenna. The room is supplied with a crane for maintenance. The gyrotrons do require access and are located one level below and one level above in an accessible area (rooms M61, T61; see Figs. VII-1, VII-5, VII-7, VII-8). The ducting between the gyrotrons and EC room R62 (Figs. VII-1, VII-6) should not be longer than 50 m to reduce transmission losses. Gyrotron power supply equipment is housed in rooms R61 and T62, under the gyrotron rooms.

The LH system will be housed in room R52. It uses two movable launchers, made up of 1600 waveguides, and will occupy the lower half of two adjacent ports, 4 and 5 (Fig. VII-6). The waveguides will be driven from an rf transmitter system comprising approximately 100 klystrons (rooms M51, R51, T51; Figs. VII-5 - VII-8). The launcher system extends 5 m inside the cryostat and requires withdrawal space. It is feasible to remove the launcher assembly in a flask for maintenance.

The NBI system comprises 9 source modules, arranged in 3 vertical arrays of 3 modules. Each array will be aimed through a port (1, 15, or 16) which is aligned with a tangent to the magnetic axis of the tokamak. A source module will be about 4 m in diameter and 15 m long and will be connected to the torus through a 25 m long duct. These modules will be housed in a hall (M41-R41-T41) adjacent to the central part of the tokamak building (Figs. VII-2, VII-5 - VII-8). The outer radius of the NBI module hall is about 59 m. Power supplies for this system are housed in a separate structure (M42, R42, T42) adjacent to the building (see Chapter VIII). Backing pumps for the NBI are housed in room W41 (Fig VII-9).

VII.4.3.2. Fuelling systems

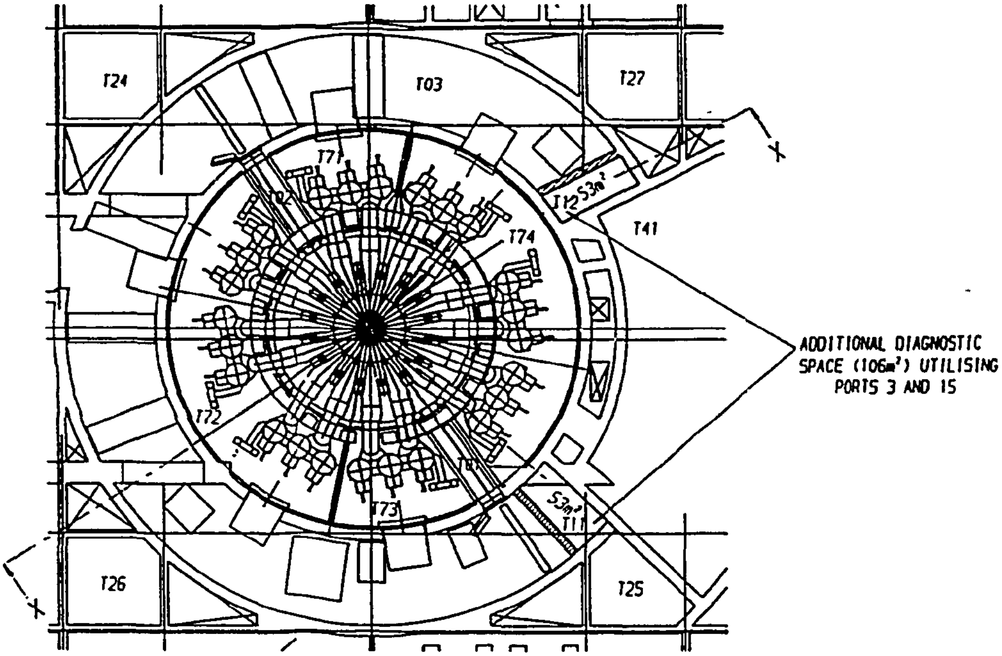
Fuelling of the tokamak will be accomplished by two systems: pellet injection and gas puffing. This equipment is to be remotely maintained although a hands-on maintenance design is also possible. The pellet injector and pellet forming equipment are located in a separate room R81 covered with a liner (Fig VII-6) with an air-lock entry. Gas puffing equipment is housed in room R82. The area is equipped with air detritiation capability.

VII.4.3.3. Test modules

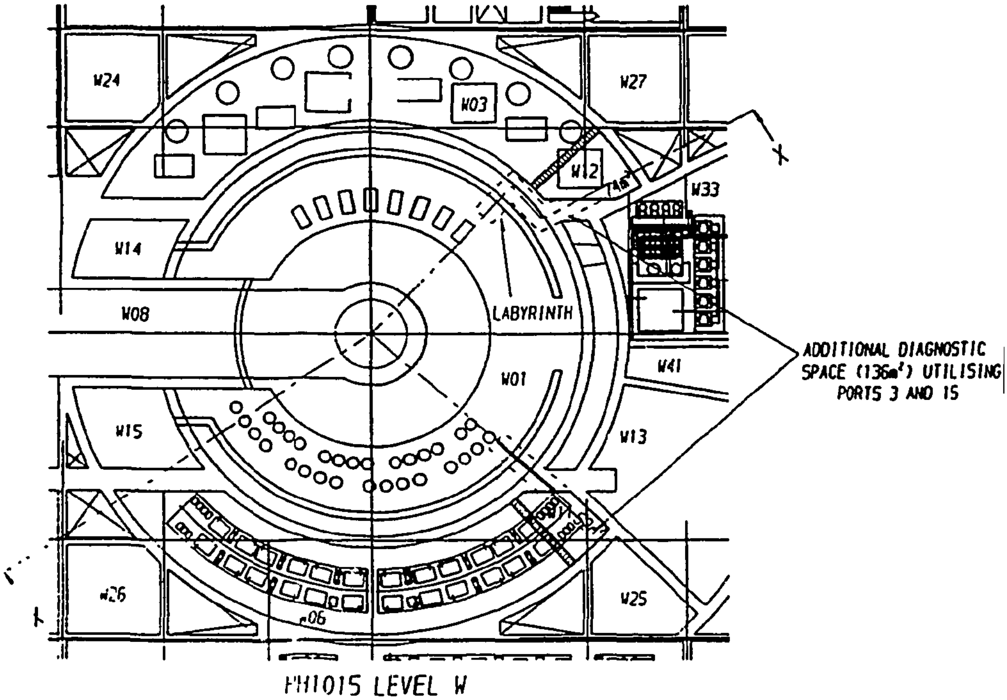
The space requirements for equipment of test modules are substantial. These modules will occupy three ports during the physics phase and five ports during the technology phase. Test module equipment requires numerous penetrations into the cryostat and vacuum vessel. Therefore, it is located in an accessible area close to the machine to minimize communication lengths and tritium inventories (rooms R72 - R76, Figs. VII-1, VII-6, VII-10). The test equipment is mounted on skids for easy replacement or changeover. Maintenance of the test modules will be done by remote handling systems and transporter flasks will be employed. Auxiliary equipment for test modules is housed in rooms R71 and M71 (Figs. VII-5, VII-6). During the technology phase some additional test module equipment will be housed in rooms R15 and R16.

VII.4.3.4. Maintenance rooms

The mid-plane floor and other floors of the building are provided with an array of hatchways (M02/R02, M03/R03, R08, R09), transfer shafts (M43/R43/T43, M44/R44/T44), and corridors (T03, W08) as well as strategically placed material handling equipment to accommodate the diversity of maintenance tasks. Four of the machine ports (3, 7, 11, 15; see Fig. VII-6), located 90 degrees apart, have been dedicated to in-vessel maintenance equipment. The decision on the specific equipment has yet to be made but the



HH2015 LEVEL T



HH1015 LEVEL W

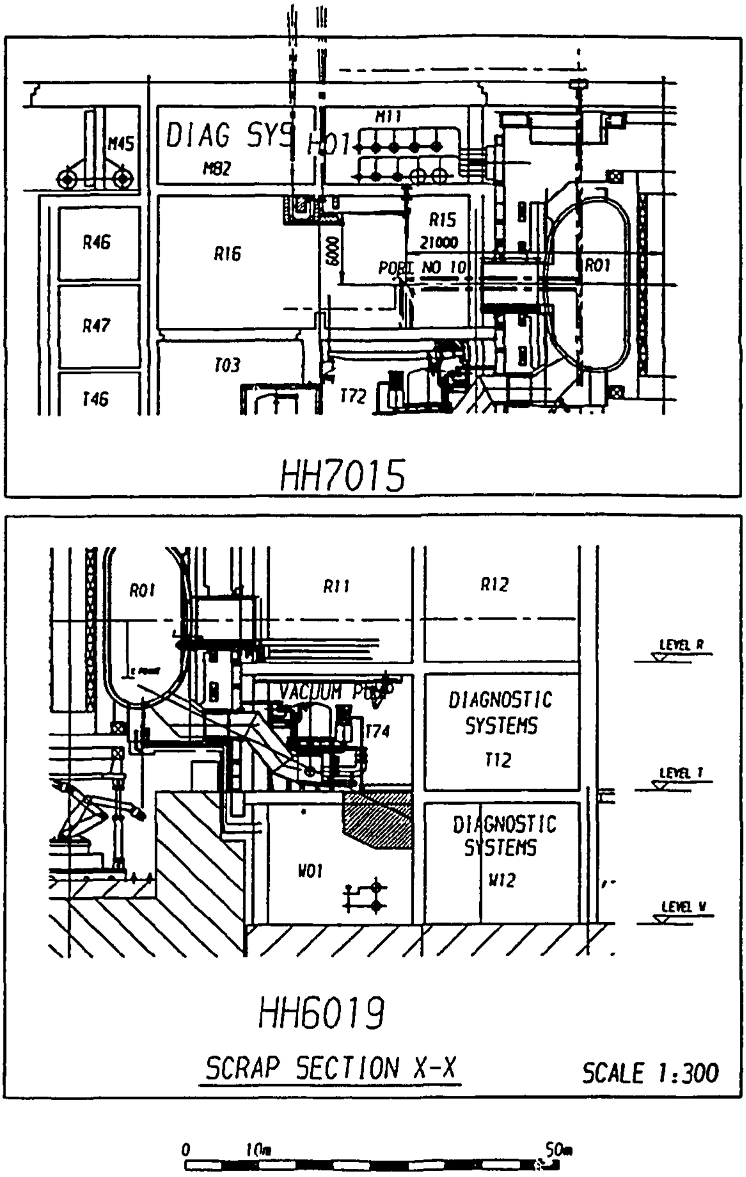


Fig. VII-10. Basic device building diagnostic layout proposal layout can accommodate either an articulated booms (rooms R06 and R07) or an in-vessel vehicles (rooms R04 - R05; Fig. VII-6). The port selection is such that retrieval of failed equipment is possible through one of the other ports.

VII.4.3.5. Diagnostic system rooms

Five ports are required for diagnostics during the physics phase and three during the technology phase. Diagnostic equipment will occupy port 2 (probably shared with nuclear testing), port 14 shared with fuelling system, and during the physics phase also ports 9 and 10. The decision on port 8 utilization will be made in the beginning of the EDA. Furthermore, diagnostic equipment will partly occupy ports 3 and 15 (see Fig. VII-10).

During the physics phase, the diagnostic equipment will occupy rooms R11 - R16. Some of this equipment is long and will not allow a wall separating rooms R15 and R16. The recommended atmosphere in rooms R15 and R16 (during the physics phase) is nitrogen. Possibly, some diagnostic equipment will be housed also in pellet injectors room R81. It is planned to remove some of the diagnostic equipment from rooms R15 and R16 during the transition from the physics to technology phase. The diagnostic equipment will have individual shielding.

VII.4.4. Vacuum pumping elevation (T)

The torus vacuum pumping system is located at this level (rooms T71 - T74; Figs. VII-1, VII-2, VII-7, VII-8). There are eight pumping stations, each serving two sectors of the tokamak. A station consists of three large compound cryogenic pumps (CCP) each with a regeneration/isolation valve and a single turbomolecular pump (Fig. VII-7) or of eight turbomolecular pumps (TMP; see Fig. VII-8). Backing pumps for the torus vacuum system are located under this elevation, in room W33 (Figs. VII-2, VII-9).

Some space is reserved for diagnostic equipment (rooms T11 and T12).

VII.5. CONCLUSIONS

An arrangement of equiment in the tokamak building for ITER has been developed with no major or significant compromise of safety, operation and assembly ease. This has been accomplished using accepted standards and to stated design principles and guides as outlined in this chapter.

The building arrangement is a reasonable representation of the space required to allow assembly, operation and maintenance of the present machine.

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VIII. PLANT LAYOUT: AUXILIARY BUILDINGS AND STRUCTURES

VIII.1. INTRODUCTION

The function of the buildings and structures is to house the tokamak and the infrastructure required for reactor operation in a safe and environmentally benign manner; to protect the staff and public from hazards contained on site; to protect the plant from external hazards; and to protect the economic investment in the plant.

This chapter specifies the design guidelines and principles used, the functions to be provided for, the design requirements, and a brief description of key structures on the proposed site layout.

Figures are included for the site layout and an integrated construction site plan. A listing is provided of typical contents of the structures and of preliminary estimates of their dimensions (Table VIII-1). A list of site services by structure is included as well (Table VIII-2).

VIII.2. PLANT LAYOUT

The layout of ITER facilities is determined by design guidelines (Sections VIII.3 & VIII.4) which deal with system requirements, safety, operational and economic considerations as well as personnel access and structural integrity requirements.

The tokamak building is the central structure around which the balance of the plant is arranged. Included is a network of roads and plant services required for safe, efficient operation of the facility.

The arrangement of the structures on the site was established with a view to keeping distances between each to a minimum and to providing for construction and operational needs.

Auxiliary systems have been grouped together to minimize cost and inventories. The tritium processing structure, service building, neutral beam injector (NBI) power supply structure, hot cell, cryogenic plant, control centre, and standby generator buildings are among the structures housing these systems (see Figure VIII-1).

The tritium processing systems are located in a structure forming a single whole with the tokamak building, near the pellet injector and gas puffing rooms, thus minimizing the length of connecting lines and the tritium inventories.

The service building is located at one end of the tokamak building and houses systems and services associated with the operation of the nuclear facility. These systems and services are outlined in Chapter VII. Their typical listing is given in Table VIII-1.

The NBI power supply structure, like the tritium processing structure, forms a single whole with the tokamak building. It is adjacent to the NBI module hall of the tokamak building.

TABLE VIII-1. LISTING OF ITER BUILDINGS AND SYSTEMS

Bldg #	Bldg Name	Bldg Size m	Contents
2100	SITE SERVICES & BUILDINGS		
2110	Site Service Centre	40 x 20 x 8	Fire Hall Garage First Aid Station
2120	Heating Plant	40 x 40 x 40	Steam Raising System Fuel delivery System Control Room
2150	Site Sewage Plant	40 x 20 x 8	
2160	Water Treatment Plant	100 x 30 x 8	Control Room Aux Service Water System Pumps Carbon Filters Cation Exchanger Polyelectrolyte Tank & Pumps Acid & Caustic Tanks Chlorination Room Electrical Equipment Secondary Cooling Pumps 3 - 50% Heat Exers 3 - 50% Circ' Pumps Drain Tank Resin Handling System Chemical Control System Storage /Pressurization Tank Demin Water Supply

2200	**ADMINISTRATION & SUPPORT BUILDINGS**		
2210	Administration Centre	60 x 90 x 30	General Offices Conference Rooms Cafeteria & Food Prep Area Reception Area Library Computer Room Telephone Room Storage Rooms Mechanical Equipment Rooms Electrical Room Records Storage Vault Duplicating Services Security Monitor Station
2240	Tokamak Services Bldgs	60 x 80 x 36	Non Active Shops Welding Booth Instrument Air System Service Air Systems Breathing Air Systems Common Instrument Air Clean Room Lapping Room Machine Tool Bays Material Storage Tool Room Paint Booth Laydown Area Instrument Repair Monitor Repair Area Chemistry Lab Health Physics Lab Change/Shower Rooms Medical Treatment Area Work Control Area HVAC Equip/Non Active Area

TABLE VIII-1. (CONT.)

Bldg #	Bldg Name	Bldg Size m	Contents
2300	TOKAMAK & AUXILIARIES BUILDINGS		
2310	Tokamak Building	100 x 84 x 78	Magnets [TF & PF] Main Vacuum Pumps Primary Coolant System Secondary Coolant System R.F. Heating Equipment Fuelling Systems Diagnostic Equipment Material Handling Equipment Maintenance Equipment Atmosphere Cleanup System Containment System Cryogenic System Equipment
2320	Tokamak Aux Structures	84 x 22 x 26 42 x 33 x 36 35 x 65 x 40	Secondary Coolant System Leakage Collection System Air Dryers Containment Syst Equipment Tokamak Aux Heating System Air Detritiation System Reactor Coolant Dump Tank Fuel Transfer & Cleanup System Neutral Beam System R.F. Heating equipment Cryogenic Systems Tritium Systems Mockup Area Transfer Chambers Magnet Power Supply Test Module Aux Systems

2400	**NUCLEAR UTILITIES BUILDINGS**		
2410	Hot Cell	35 x 35 x 30	Decontamination equipment Transfer Chambers Atmosphere Detrit/Drying Syst Robotic Repair & Storage Machine Shop (Active) Shielded Storage Area Maintenance Work Area Detritiation Systems Equipment Cranes & Hoists Inspection Equipment Active Laboratory
2440	Tritium Processing Bldg	42 x 33 x 36	Plasma Exhaust Processing Tritium Inventory & Supply Syst General Tritium Processing Breeder Tritium Processing Ventilation Systems Inert Cover Gas Vacuum HTCD Cold Box Vacuum TPB Ventilation TPB Exhaust Detritiation Tritiated Water Processing Isotopic Enrichment Depleted Water Processing Cryogenic Distillation LTCD Cold Box Vacuum IEB Ventilation IEB Exhaust Detritiation IEB Emergency Air Cleanup

TABLE VIII-1. (CONT.)

Bldg #	Bldg Name	Bldg Size m	Contents
2460	Radioactive Materials Mg'mt	100 x 80 x 20	Active Liquid Waste Treatment Filters Ion Exchange Column Storage Tanks Dispersal Tanks Decontam Solution Collection Active Gaseous Waste System
2500	**CONVENTIONAL BUILDINGS & STRUCTURES**		
2510	Electrical Blds & Switchyard	140 x 80	
2530	NBI Power Supply Bldg	30 x 80 x 35	Hi Voltage Transformers SF6 Cable Duct Transformer/Rectifiers
2540	Cryogenics Plant	60 x 80 x 10	Refrigerators (4) Helium Supply Helium Compressors (3 stages) Oil Seperators Control Room Tokamak Cryogen Supply
2550	Gas Storage Building	40 x 20 x 8	
2560	Standby Generators	20 x 20 x 12	

2600	**INSTRUMENT & CONTROL STRUCTURES**		
2610	Control Centre	80 x 40 x 36	Control Equipment Rooms Computer Rooms Process Control Equipment Computer Maintenance Area Office Area & Record Storage Cable Spreading Area Hot Cell Control Room Rad Waste Processing Cntl Room Control Room
2700	**EXPERIMENTAL FACILITIES**		
2710	NBI Test Bldg	30 x 10 x 15	Power supplies Beam line structure Ion sources Cryo equipment Cranes & Hoists Beam dump Diagnostics Safety interlock equip. Cooling Water Equipment

TABLE VIII-2. LISTING OF ITER SERVICES BY STRUCTURE

	AIR				DRAINS					ELECTRICAL						
BUILDINGS	Breathing Air	Instrument Air	Service Air	Cryogenics	Active Drains	Inactive Drains	Sewage Drains	Yard Drainage	Ground Water Drain	Class 1 power	Class 2 power	Class 3 power	Class 4 power	Lighting	Emergency Lighting	Standby power
Tokamak Building	✓	✓	✓	✓	✓				?	✓	✓	✓	✓	✓	✓	✓
Aux Services Bldg.	✓	✓	✓		?	✓	✓		?	✓	✓	✓	✓	✓	✓	?
Administration Bldg.			✓			✓	✓			✓	✓	✓	✓	✓	✓	
Control Center		✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓
Tritium Building	✓	✓	✓	✓	✓	✓	✓		?	✓	✓	✓	✓	✓	✓	✓
NBI Power Supply Bldg	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
Magnet Power Supply Bldg.		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
Cryogenic Plant		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓
Switch Yard			✓					✓				✓		✓	✓	
Magnet Fab Shop		✓	✓	?		✓	✓	✓		✓		✓	✓	✓	✓	
NBI Test Facility		✓	✓	✓		✓	✓			✓		✓	✓	✓	✓	
Site Shops		✓	✓			✓	✓	✓		✓		✓	✓	✓	✓	
Standby Generators		✓	✓			✓		✓						✓	✓	
Heating Steam Plant		✓	✓			✓	✓	✓		✓		✓	✓	✓	✓	
Gas Storage Bldg.						✓	✓				-	✓		✓	✓	
Secondary Recirc Cooling																
Hot Cell Area	✓	✓	✓	?	✓				✓		✓	✓	✓	✓	✓	
Water Teatment Bldg.		OA				✓	✓	✓				✓	✓	✓	✓	
Rad Waste Storage Bldg.	✓	✓	✓		✓		✓			✓	?	✓	✓	✓	✓	✓
Sewage Treatment Bldg.			✓			✓	✓	✓		✓		✓	✓	✓	✓	
Guard House						✓	✓			✓				✓	✓	

FIRE			GASES					HVAC				WATER SYSTEMS										MON		COM	
Fire Detection	Fire Sprinkler	Halon Bottles	Laboratory Gases	Argon	Helium	Nitrogen	Carbon Dioxide	Heating Steam	Air Conditioning	Ventilation	Air Detritiation	Low Pressure Water	Hi Pressure Water	Aux Service Water	Recirculating Cooling	Standby Service Water	Fire Hydrant System	Domestic Water	Demineralized Water	Chilled Water	Raw Water Cooling	Security Monitoring	Radiation Monitoring	Communications Radio	Telephone
✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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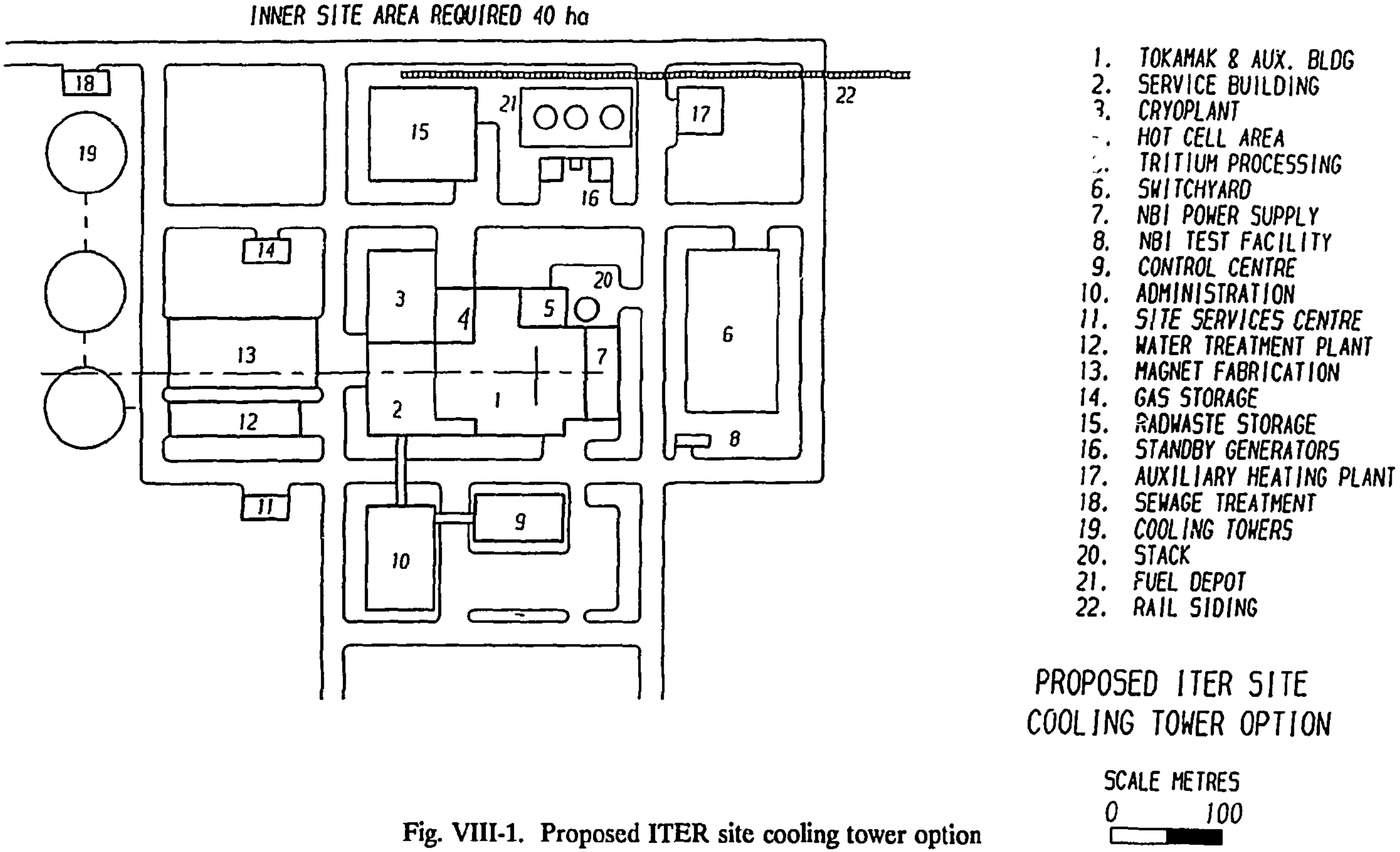

Fig. VIII-1. Proposed ITER site cooling tower option

The hot cell is joined to the tokamak building and provides for direct transfer of components from it. Space has been set aside to provide for expansion of the hot cell.

The cryogenic plant has been situated to minimize the cost of ducting and helium inventory and is located beside the hot cell.

The control centre is located about 140 m from the tokamak building in an effort to minimize electromagnetic effects on operating personnel and equipment in it. The control centre is also near the administration building (40 m) to make efficient use of these services. The two structures are connected with a covered elevated walkway.

Additional structures required (listed in Figure VIII-1) are contained in an area of 40 ha. Construction facilities could occupy up to an additional 20 - 80 ha.

The layout provides adequate access for construction activities as well as meeting the operational requirements.

VIII.3 FUNCTIONAL REQUIREMENTS

VIII.3.1. Principles and guidelines

The basis for the layout rationale is contained in the following principles:

1) The tokamak building should contain only those systems connected to the tokamak or required for safety and/or operational reasons.
2) Buildings containing radiological hazards should be grouped in one zone.
3) Plant services and routine movement of personnel and materials across this zone should be controlled. Common systems should be grouped together except when safety considerations require that they be separated.
4) Hazards should be segregated where reasonably practicable.
5) Space should be provided for future expansion of facilities as required.

The functional requirements for auxiliary buildings are to:

a) Support, contain and protect the tokamak and its ancilliary systems.
b) Protect employees, and the public residing beyond the exclusion zone.
c) Provide a safe working environment.
d) Protect the economic investment.

The tokamak and auxiliary structures are discussed in Chapter VII but a brief functional requirement is included here so as to make clear the scope of the auxiliary structures (balance of plant) requirements. The tokamak building will provide adequate space for the reactor and its support systems which include its operation and maintenance, as well as component transfer and handling functions. Tritium fuel delivery systems, safety systems and plant protection are also included. The design philosophy is that all other functions be provided in auxiliary structures.

VIII.3.2. Auxiliary structures

The auxiliary structures are arranged in four categories: tokamak auxiliary systems, support services, common site services and construction services. A listing, by category, of the services pertaining to each follows.

Tomakak auxiliary systems include:

Reactor control equipment
Plant operation
Plasma heating and current drive system
Cryogenic systems
Plasma exhaust
Magnet power supply
Standby power supply
Mock-up and assembly
Data acquisition
Diagnostics
Heat transport system
Fuelling system
Fuel storage
Test module systems
Switchyard
Air detritiation

Support services inlcude:

Heating, ventilation, air conditioning
* Shops and stores
Administration
* Health physics facilities
Security
Maintenance
* Emergency services.
Offices and laboratories.
* Library.
* Medical treatment centre.

Common site services in the plant layout are:

Water supply/distribution
* Heating and steam generating plant
* Water treatment
Lighting
Security alarm
* Microwave tower
Site roads/parking
* Dock facility
Fire protection
* Sewage treatment
Drainage
Power distribution
Communications
* Meteorology tower
* Vehicle maintenance
* Rail siding

* = facilities which might exist at a host site and be made available to ITER.

Construction services include:

Material storage
Fuel supply
Pipe fabrication
Formwork fabrication
Project offices
Magnet fabrication
Temporary power/water
Excavated material storage
Welding shop
Warehouses
Equipment maintenance
Steel fabrication
Concrete plant.
Parking (2,000 vehicles)
First aid station.
Construction roads
Machine shop
Woodwork shop

VIII.4. DESIGN REQUIREMENTS AND DESCRIPTIONS

This section outlines requirements with a brief description of the structure and contents. There is a hierarchical need for systems to be close to the reactor for safety and operational reasons. Some typical systems are listed in Table VIII-1; this listing could be expanded to include others when identified. Table VIII-2 lists services by structure.

VIII.4.1. Structures for tokamak auxiliary systems.

The tokamak auxiliary systems are those required to provide for the safe operation and shutdown of the tokamak. These systems are housed in several structures located adjacent to and around the tokamak and include:

Tokamak service building
Control centre
N.B.I. power supply
Standby generators
Switchyard
Tritium processing systems
Cryogenic plant
Hot cell
Radwaste storage building
Test module auxiliaries

The tokamak building also housing some auxiliary systems is covered in detail in Chapter VII.

VIII.4.1.1. Tokamak service building

This building is appended to the tokamak building and houses non-nuclear services. Typical of the systems provided are breathing, instrument and service air compressors, instrument repair shop, chemistry and health physics labs, shower/change rooms, medical treatment centre, heating, ventilating and air conditioning equipment (HVAC), work planning areas, and storage facilities. In addition power supply equipment, battery rooms and switch gear for local motor control centres for systems in this structures should also be accommodated.

VIII.4.1.2. Control centre

A preliminary layout suggests a structure with three levels. Access to the building is at the ground elevation where offices and work planning areas for the operations staff could be located. Control computers could also be located at this level. The basement level can be reserved for running cables. The second floor could contain the main control computers and control rooms to operate the tokamak and the hot cell, with adjacent work planning areas. It is suggested that operation of the switchyard and other common plant services also be from the control centre to provide an integrated approach to the operation of the facility as a single unit. Access to the plant is via a covered elevated walkway to the administration building. This structure need not survive a seismic event but its failure (as a structure) must not compromise the ability to shut down the tokamak nor the operation of any essential system required to function after a seismic event.

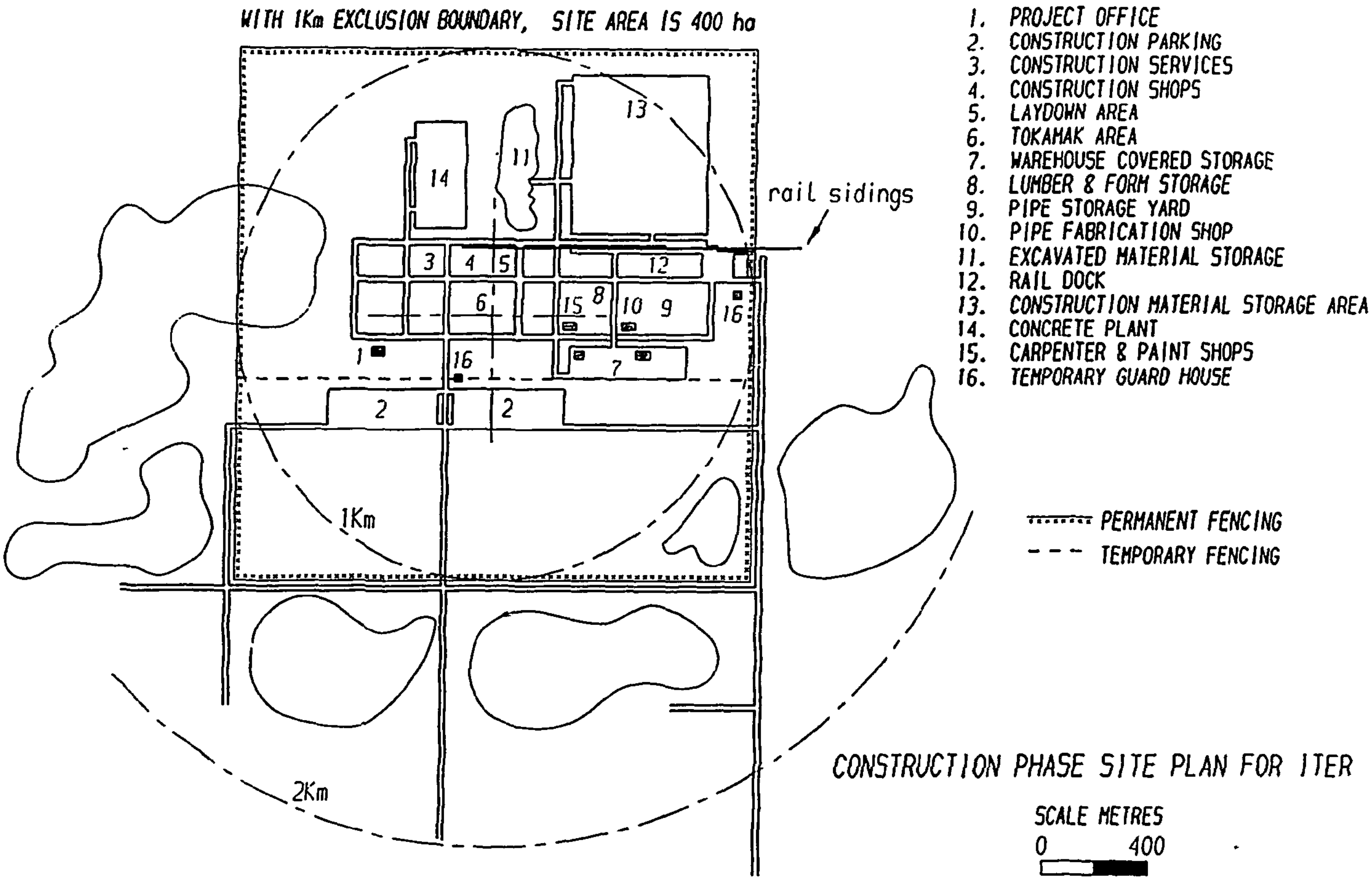

Fig. VIII-2. Construction phase site plan for ITER

VIII.4.1.3. Cryogenic plant

The cryogenic plant is a single story structure housing the cryogenic equipment which includes a 100 kW helium refrigerator (4 x 25 kW cold boxes) supplied by banks of compressors in parallel. This layout is based on 10 first stage compressors, 20 second stage and 6 third stage compressors. There is an oil separator, a helium dewar, a liquid nitrogen dewar and liquid nitrogen dumps. Space is provided for a control room and electrical panels. The supply and return lines (about 300 mm in diameter) are routed through the reactor service building to the load centres. Heating the cryolines is negligible even over a distance of 200 to 300 m and hence the building location is not a concern.

VIII.4.1.4. NBI power supply structure

The NBI power supply structure is located adjacent to the NBI system. This gives good access for the installation and servicing of the power supply system, which includes large transformer and rectification equipment as well as large SF_6 cable ducting. The structure is also close to the main switchyard to minimize the length of connecting bus. If the size of the transformer equipment changes appreciably, there is space (with this exterior location) to accommodate it. In addition there may be a need for an on site NBI test cell.

VIII.4.1.5. Fuel cycle systems structure

This structure covers an area of 33 m by 44 m and is 46 m high. It has five full floors of which two have a partial mezzanine. The structure is adjacent to the tokamak building from the side of fuelling rooms. It is located in a quadrant between the NBI power supply structure and the vacuum pump room W07. The individual elevations and important sections are indicated in Figs. VIII-3 and VIII-4. Systems for fuelling, their associate emergency fuel storage and plasma exhaust pumps are an integral part of the fuel cycle, but these units are located in the tokamak building. The fuel cycle structure (FCS), which is a wing of the tokamak building, contains systems for: fuel purification and impurity treatment; waste water storage, treatment and tritium extraction; isotope separation; tritium extraction from solid breeder and from test modules; tritium storage, shipping and receiving; tritium and health physiscs laboratories; atmosphere detritiation; control centre and maintenance facilities.

The building design requirements were: minimal length and simplest configuration of process lines between serviced and servicing systems, vehicle access to receiving area, maintainability of major components, and a single point access control.

Access to the facility takes place at the ground floor in the centre of the building between the cryo-distillation (CD) and tritium storage room. At this point a single access control point for the entire building is provided. A vertical "tower" (6 m x 8 m) contains stairs, personnel and a freight elevator for transporting tritium-free and uncontaminated equipment.

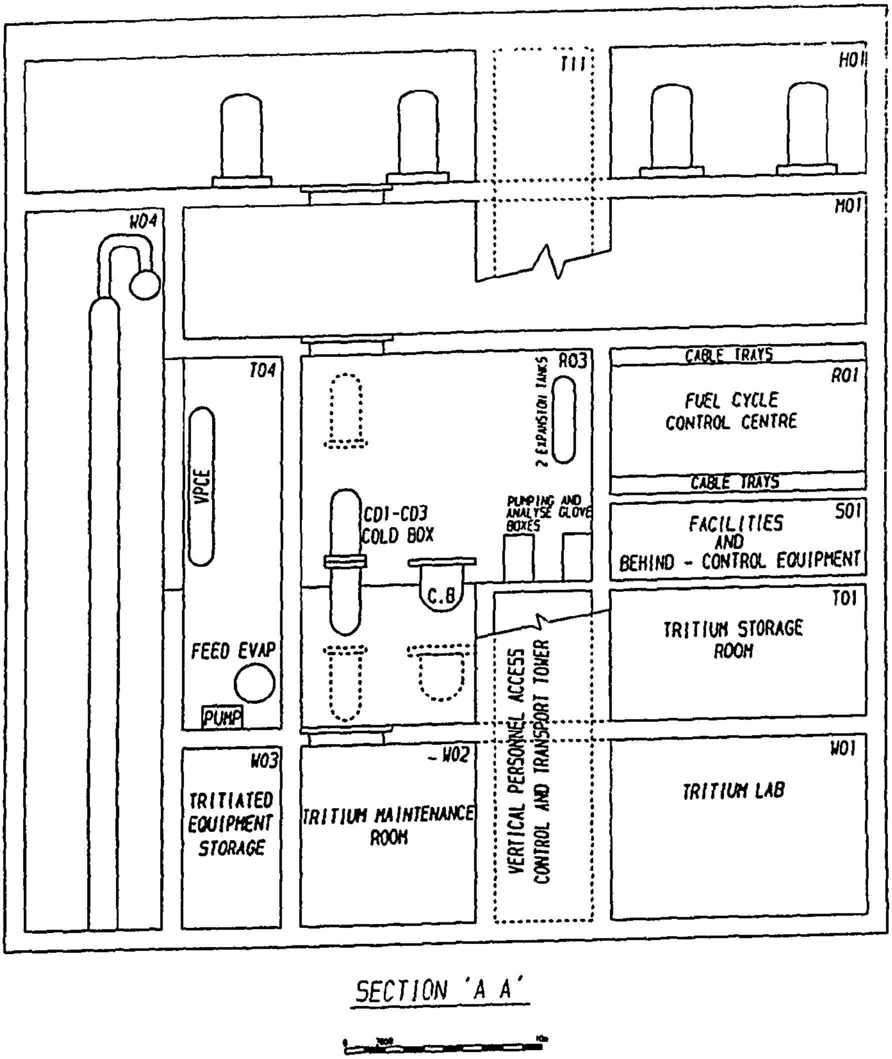

Fig. VIII-3. Tritium building

Isotope separation is located in a two-storey room T03 (Fig. VIII-4) between floors T and M and in room R03 (Fig. VIII-3). The height of the room is 19.4 m to provide space for removal of the CD shells for full access to the cryogenic components, namely to the longest CD column, which is approximately 7.5 m long.

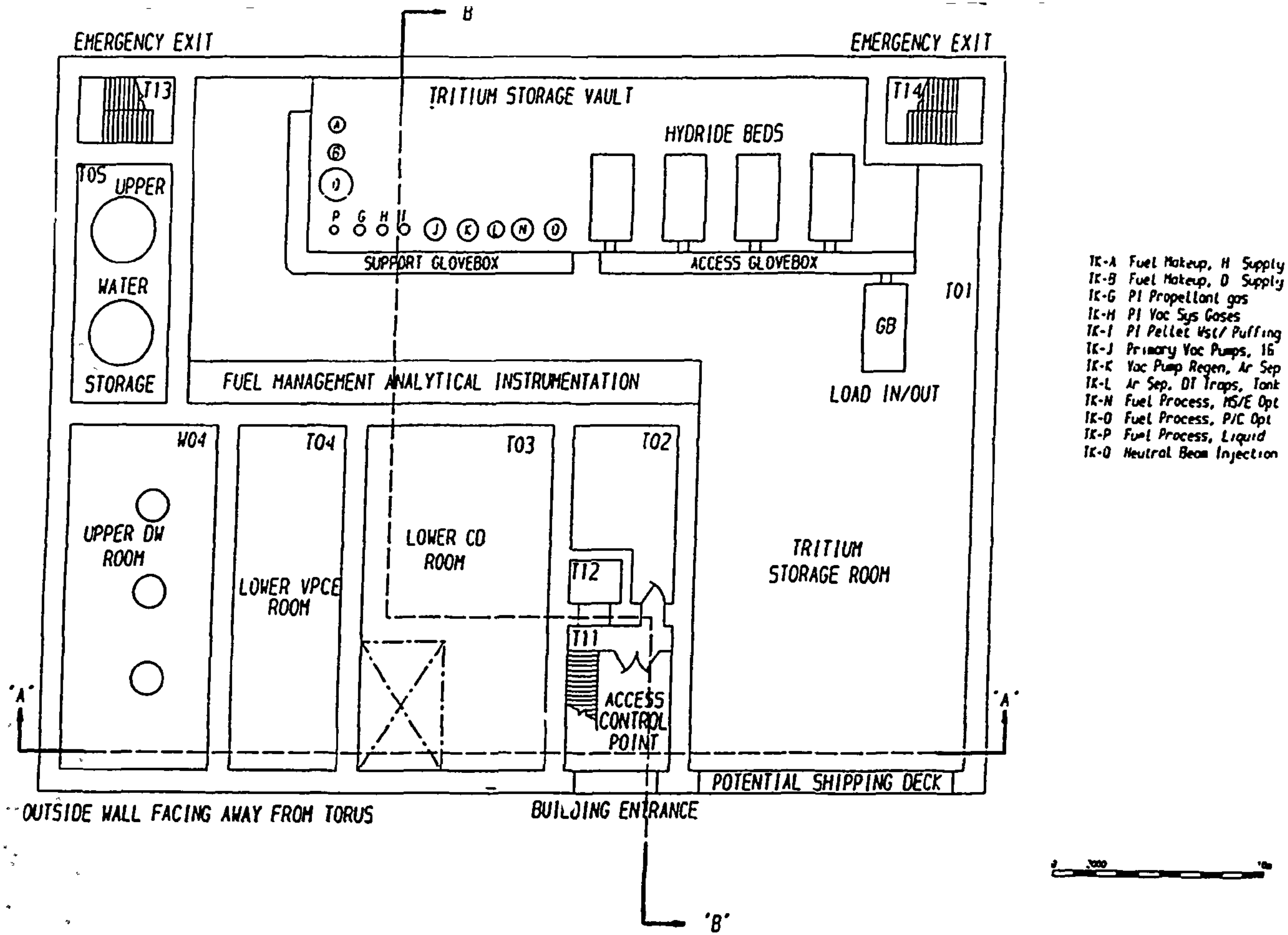

Fig. VIII-4. Tritium building

Waste water storage and treatment systems (room W06) are functionally connected and co-located. These are close to the water distillation columns and the isotope separation system. This location facilitates equipment transfer into the adjacent maintenance room W02. There will be two storage tanks 200 m^3 at the wall shared with the NBI backing pumps in the tokamak building.

Waste water tritium extraction (room W04) distillation columns for waste water (DW) are the largest single components in the FCS. These may have to be transported and handled vertically.

Tritium extraction from solid breeder and test blanket tritium recovery (rooms M05 and M01) are located on the entire floor M. There may be a need to shield part of the test blanket module tritium extraction systems.

Tritium storage, shipment and receiving (room T01) is located in an L shaped space on the ground floor of the building to provide truck access.

Tritium laboratory (room W01) is positioned near the fuel clean-up systems, which are in room W07 and which would most need the laboratory for support.

Health physics laboratory (room W01a) is above the tritium laboratory.

HVAC and atmosphere decontamination system (ADS) are placed on the top level of the building (room H01), where they cover the entire floor. This space will contain only systems to service the FCS itself. There will be a number of HVAC and ADS units distributed throughout the tokamak building to avoid difficulties in routing air to a centralized facility.

Fuel cycle process control centre is housed in room R03 (Fig. VIII-3).

There will be no **solid waste processing** in this building. Equipment that is to be replaced immediately and repaired later would be stored in the storage room adjacent to the tritium maintenance room on the lowest floor of the building (rooms W02 and W03).

VIII.4.1.6. Standby generator building

The plant protection electrical requirements as outlined in Chapter III set the load requirements for a standby power system. This system must be operational within a few minutes. Once the load list has been established, the unit(s) can be sized. In the interim the structure for standby generators has been sized on the basis of a 20 MWe gas turbine which can be housed in a 20 x 20 x 12 m high structure. The structures (two are shown in Fig. VIII-1) should withstand seismic activity and be secure from other external forces as set out in the safety requiremnt documentation. Included in the layout is a fuel pumping station containing pumps for a pair of generators. This structure is about 10 x 10 x 5 m high and located between the generators.

VIII.4.1.7. Switchyard

The switchyard for ITER contains the switching gear and towers associated with receiving electricity from a transmission grid system. If space is of concern, then the use of SF_6 switchgear might be considered to reduce the space requirement.

VIII.4.1.8. Hot cell

The hot cell is connected to the tokamak building via a transfer chamber and allows movement of tokamak components to the cell directly. The contents of the hot cell are not yet established but a representative listing is shown in Table VIII-1. Further details are given in Chapter IV.

VIII.4.1.9. Radioactive waste storage

This structure is located in the vicinity of the hot cell facilities. A rail siding could be provided and used for off site shipments. The contents of the structure are not determined but there is sufficient area to accommodate a larger building if required. Chapter IV outlines radwaste storage details.

VIII.4.2. Support services structures

Support services are those systems or operations required to ensure a well-administered facility, often referred to as site infrastructure, and include those items listed in Section VIII.3.2.2. The main structures associated with these services include the administration building, workshops, stores and site service centre. Out of necessity some of these systems may be located in other structures for convenience, e.g. a medical treatment centre could be in a separate building. In this plan, it is located in the reactor service building near the showers/change room facilities in the event that an employee requires medical treatment and physical decontamination. This arrangement makes treatment available quickly and prevents the spread of contamination by not having to transport the person over the site to a remotely located treatment centre.

VIII.4.2.1. Administration building

This structure is situated about 150 m from the reactor and is connected to the Service Building via an elevated covered bridge. The building has four elevations to house the administrative and technical staff. Computers, security monitoring systems, telephone exchanges and mechanical services are housed below grade. General offices, library, conference rooms and reception area are located on the grade elevation. The third and fourth elevations contain additional offices for staff and visitors to the project. The security interface between the administration building and the main plant buildings is located on the third elevation.

VIII.4.2.2. Gas storage structure

A gas storage structure is provided in the vicinity of the cryoplant.

VIII.4.3. Common site services

The common services listed in Section VIII.3.2.3 account for services required to operate the site and the tokamak. Some of these systems extend into many areas of the plant and in the main are housed in the following structures:

Heating plant
Sewage treatment plant
Water treatment plant
Site service centre
Fuel depot
Rail spur & siding

VIII.4.3.1. Heating plant

The heating plant contains a steam generating system and related process and control equipment to produce the steam for ITER process and heating systems. It is located in an area which will not hamper access of construction personnel or equipment to either the tokamak building or the heating plant. The heating steam and hot water could be routed throughout the site above ground level and bridged for passage over roads. There is sufficient space around the heating plant for fuel storage if the plant is to be powered by fossil fuels. If electric boilers are used, space for fuel storage is no longer a requirement.

VIII.4.3.2. Sewage treatment plant

This facility is located near the cooling ponds or towers. The station sewage is pumped to the facility for processing and the treated water returned to the cooling ponds for recycling.

VIII.4.3.3. Water treatment plant and cooling water pump house

There are several water requirements for ITER. They are described in Chapter V and include:

Raw water
Softened water
Demineralized water
Potable and domestic water
Fire protection water
Hot water
Chilled water
Emergency water

The water treatment facilities and pumps for each of these systems can be located in a common structure, with the exception of the pumps for emergency and fire protection water systems, which should be located separately to avoid common mode faults. The secondary recirculated cooling water system pumps are located in this structure as well. The structure can be arranged so that a single external crane can service equipment through removable hatches in the roof. It is likely that domestic water would have to be produced in the water treatment plant on site. Booster pumps would be needed to raise the pressure to meet site needs.

VIII.4.3.4. Site service centre

This structure could be located near the water treatment structure so that it could be excluded from an inner security boundary (along with the administration and control centre) if required. The structure would contain a vehicle maintenance garage and storage area, as well as housing fire fighting equipment and a first aid station.

VIII.4.3.5. Fuel depot

This would be a tank farm (100 m x 50 m) with appropriate dyking housing three 25 m diameter tanks for storage of liquid fuels for standby generators, site vehicles and other uses.

VIII.4.3.6. Rail siding

A rail siding is deemed advantageous to receive shipments of materials during construction and could be located so that it could be used for off site shipments of radwaste or material to be sent to test facilities.

VIII.4.4. Construction buildings and structures

During the construction phase, sufficient space should be available to allow access and operation of large equipment and permit construction operations on separate buildings simultaneously.

Temporary site power, heating steam, lighting, water and roads will also be required.

A workable layout of construction facilities which incorporates the permanent structures and minimizes disruption of work on the site is presented in Fig. VIII-2. Some facilities such as storage areas and a concrete plant are shown outside the inner site and could be dismantled and the area returned to productive use once construction activities have ceased. This is of particular interest for regions where a large exclusion area is not practicable.

The arrangement of facilities allows workers to pass through the security point after parking their cars, thus preventing unwanted vehicular traffic on the site. The car park has two separate exit routes off site to ease the traffic density during shift changes.

The project office is close to the main construction activity, near the security boundary and has its own parking facilities nearby. There are separate entrances to the site for receiving large loads and continuous shipping activities such as delivery of concrete.

Large laydown areas are provided near the rail siding to accommmodate unloading and storage needs.

Construction services and shops are located about 250 m from the main construction area to keep that area available for laydown and preassembly activity.

One of the structures identified on the site plan is the magnet fabrication facility (estimated size 120 x 60 x 35 m high), which, if constructed, should be reviewed for possible alternative use after the magnets have been built. If there is no justification for alternative uses, it should be constructed as a temporary structure and removed when magnet fabrication is complete. It may be decided to leave the structure in a retrievable state in the event that magnet failure forces additional manufacturing activity at a later date. Since this structure would be required early in the construction phase, that portion of the site, in line with the tokamak centre line is uncommitted and will be held in reserve.

VIII.5. CONCLUSIONS

A workable arrangement of facilities and services for ITER can be developed with no major or significant compromising of safety, operational ease and construction economy. This can be accomplished by using accepted standards and adhering to stated design principles and guidelines as outlined in this chapter The issue of exclusion zones can be resolved by each potential host country within their jurisdiction. The site arrangement is a reasonable representation of the space required for the essential services and structures for ITER and can be housed in an area of about 40 ha.

IX. SITE REQUIREMENTS

IX.1. INTRODUCTION

There are a number of requirements that must be considered for the ITER site. Some of these requirements are linked to characteristics that are intrinsic to any site; others (mainly safety and environmental) either may be present or could be imposed on a candidate site by regulatory and other bodies of the host country.

For some requirements, a range of acceptable characteristics exists. Selection of sites with poorer characteristics will result in design, cost, or time penalties to the project. This spectrum of site requirements and characteristics is summarized in Table IX-1. and a qualitative assessment has been provided to indicate the site features as necessary, desirable, undesirable, or unacceptable.

ITER safety and environmental impact characteristics are set out in the technical report on ITER Safety Analyses.

IX.2. KEY REQUIREMENTS

IX.2.1. Electric power supply

It is planned that ITER will have two operation phases: the physics phase, expected to last for about the first six years, and the technology phase, planned to last for about 12 years. During the physics phase ITER will require a continuous electric power supply of up to 230 MW. An additional supply of up to 480 MW is needed to provide for transient power demands. Thus, the peak power demand is up to 710 MW. During the technology phase ITER will require up to 635 MW of continuous electric power supply. These values are based on results of the conceptual design activity. Provision for a 25% margin will raise the power requirements to 795 MW maximum steady load, 600 MW for maximum transients, and 890 MW for peak power demand. The transient power demand could be covered at the expense of providing on-site energy storage, for example flywheel generators. In this case ITER peak power demand would be 635 MW. With a 25% margin it would be 795 MW.

The anticipated operations indicate a desired power change rate capability of 200 MW/s for peak power levels below 200 MW, and a rate of 60 MW/s for peak power levels above 200 MW. A smaller value of the power change rate could be acceptable if the dwell time between pulses were larger.

During the Physics Phase ITER will be operated mostly in a pulsed mode (on the average 5 - 10 pulses per day) under conditions of controlled burn lasting from 10 s to 6,000 s (reference duration of 400 s) with a dwell time of from about 300 s to long dwell times associated with a single pulse operation mode. During the Technology Phase the pulse duration will be from 800 s to over 10,000 s.

TABLE IX-1. SITE REQUIREMENTS AND CHARACTERISTICS

	Necessary	Desirable	Undesirable	Unacceptable
1.Electric power	Up to 635 MW continuous.* Electrically stiff node point.	Up to 635 MW continuous, 710 MW peak.*		
2.Heat sink	About 1800 MW.*			
3.Land area	≥40 ha.	Additional ≥20 ha for construction facilities.		
4.Geotechnical	Foundation bearing capability of 20 t/m^2.	Foundation bearing capability of 50 t/m^2.	Sites requiring extensive pilings or extensive support of excavations.	Highly compressible soils. Sites subject to subsidence from mines or caves.
5.Hydrology	Hydrological pathways to man and food chains compatible with safety.	Isolation from water courses and aquifers.	Vulnerability to floods and tsunamis.	Hydrological pathways incompatible with safety.

* - No margin is taken into account here.

TABLE IX-1. (CONT.)

	Necessary	Desirable	Undesirable	Unacceptable
6.Seismic		Low seismic design requirements.	Severe seismic design requirements.	Active fault zones. Soils subject to liquefaction. Unstable geographical features.
7.Meteorology	Compatible with safety.			
8.Waste disposal	Commitment to accept responsibility for waste. Interim storage for about 30,000 t of radioactive waste.			
9.Transportation	Safe transportation of nuclear materials. Delivery of equipment up to 9 m wide, up to 4 m high, and up to 400 t.	Heavy haulage and trunk road access. Rail link. Barge access. Delivery of components up to 23 m wide. Access to a commercial airport.	Long distances to transport materials labour and equipment.	Inability to ship tritium to site.

TABLE IX-1. (CONT.)

	Necessary	Desirable	Undesirable	Unacceptable
10. Industrial infrastructure	Sufficient for plant construction.	Accessible industrial facilities.		
11. External hazards	Must not imperil the safety of the plant.	No external hazards.	Nearby petroleum refineries and chemical plants. High pressure pipelines. Intense air traffic.	Military exercise areas. Munitions factories and depots. High toxicity risk plants.
12. Public safety	Demography and exclusion zone in accordance with safety regulations.	Low population density.		
13. Environment	Building standards and site must allow proper effluent plume.	Minimum ecological impact.		

Also of importance in considering the electric power demands is the overall reactor availability target, which is 10 per cent in the Technology Phase. An additional goal is an availability of 25 per cent during years of peak reliability.

IX.2.2. Cooling

An ultimate heat sink with a capacity of up to 1800 MW is required. About 230 MW must be removed continuously during ITER operation and approximately 1570 MW is present during operation pulses. If the combination of uncertainty and margin amounted to 25 %, these values would increase to 2250, 290 and 1960 MW, respectively. ITER operation conditions are described above.

Options for the heat sink are cooling water from a river or from the sea, or use of cooling towers. If the cooling water is taken from a river or from the sea, a typical requirement is to limit the overall warming of the discharged water to 7°C. In this case a flow rate of approximately 80 m^3/s is required for removal of 2250 MW and dilution of the discharged water. Lower flow rates may be sufficient if local regulations allow a higher temperature difference between the river/sea cooling water inlet and outlet, e.g. if warming of the discharged water by 10°C is allowed, a cooling water flow rate of 55 m^3/s would be sufficient.

Wet or dry type cooling towers could also be used. The wet type cooling towers require up to 4250 m^3/h of industrial water for discharge of 2250 MW. The dry type cooling towers do not consume large amounts of water but they do require a larger site area of about 170,000 m^2 and a larger power supply, about 65 MW. The use of cooling towers would increase the cost of the ITER plant compared with the use of cooling water from a river or from the sea as the heat sink.

IX.2.3. Land

IX.2.3.1.Land area

A land area of 40 ha, as a minimum, must be available to accommodate the main ITER systems and facilities necessary for their operation. This area must be available for 40 to 80 years, depending on the strategy adopted for decommissioning, in compliance with national and local regulations of the host site. Some additional land area may be required to provide services to the tokamak plant and staff, in particular for material testing laboratory, information centre, vehicle maintenance garage, fire control centre, main entrance gatehouse, etc. Some of these facilities may already be available if the site is adjacent to an existing research establishment.

The addition of an exclusion zone will increase the land area requirements stated above. The size of the exclusion zone will be determined by the regulations of the host country.

Additional areas may also be required to house ITER scientific and operating personnel (planned at a level of 900 - 1100 men for different operational phases) with families if such apartements are not available in nearby communities.

The land area required for construction facilities, services, and storage depends on local conditions and must be determined by a local construction contractor, taking into account that ITER construction is to last 6 years. Preliminary design estimations show that this additional land area may be about 20 ha.

Decommissioning facilities could be required at the end of ITER's lifetime to provide for intermediate storage and cooling of irradiated components, their decontamination, processing and conditioning, packaging and preparation for ultimate disposal. It is likely that the land area needed during construction would be sufficient to accommodate all decommissioning facility land area needs.

IX.2.3.2. Geotechnical requirements

The site ground should be of reasonably homogeneous structure, preferably composed of gravels, coarse sands, and very stiff boulder clays. Loose, uniformly graded sands, unstable to seismic tremors, and sensitive clays which can be liquified by shaking should be avoided. Similarly, there should be no nearby ground features which could be unstable in an earthquake, e.g. mobile slopes.

A bearing capacity of foundation strata of around 50 t/m^2 is desirable since in this case the tokamak building and other ITER technical buildings could be supported without piling placed on firm substrata. These foundation strata must be stable with respect to dynamic loads.

A uniform topography of the site is desirable. The bearing capacities must avoid excessive settlement during and after construction, especially excessive differential settlement. Areas with highly compressible soils should be avoided. The site should not be subject to subsidence, which can occur in areas of coal or mineral extraction or natural caves and cavities.

The soil conditions and natural water levels at the site should allow economic excavation. It is desirable to avoid elaborate and expensive temporary construction works. It would also be desirable to avoid drilling and blasting of deep excavations in hard rock sites.

The ground conditions can affect the final selection of the foundation level for the tokamak building and the extent to which it might be feasible to place much of the plant below surface level to improve safety and reduce the visual impact.

IX.2.3.3. Hydrological requirements

The site hydrology should be compatible with the safety considerations associated with the plant. It is desirable to have the site isolated from aquifers and water courses or it should be possible at reasonable cost to make the site ground impermeable to potential liquid waste with a waterproof diaphragm wall.

The site should not be vulnerable to flooding from streams, failed upstream dams, or inundation by the sea. Long-term sea level changes may also have to be considered.

It must be possible to discharge treated industrial and domestic waste water from the plant.

IX.2.3.4. Seismic requirements

Seismic requirements will be determined by the regulations of the host country. The seismic conditions at the site should permit the plant buildings, structures, systems, and components to withstand the effects of earthquakes and tsunami without any loss of capability to perform their safety functions.

In compliance with the regulations of the host country, the site should not be located in close proximity to potential volcanic activity or to active, or potentially active, faults or rock/soil structures which could amplify bedrock motion.

The seismic risk to an ITER site as expressed by the specified 'design earthquake' should be carefully considered since the resulting design features provided solely to accommodate the 'design earthquake' will increase the design and construction costs. Obviously, the more severe the 'design earthquake', the more extensive will be the design and construction impact and costs. Finally, the need to seismically qualify all the safety-related plant systems will similarly impact the cost of such systems.

IX.2.3.5. Meteorological requirements

The site should not be located in an area with a high incidence of tornadoes, hurricanes as well as extreme snow and ice conditions.

The local meteorology should not be vulnerable to microclimatic changes caused by cooling tower operation.

IX.2.4. Radioactive waste disposal facilities

Routine operation of ITER will result in about 450 t/a of solid activated waste (see Chapter IV). During 15 years of operation with deuterium/tritium plasma the amount of such a waste will total about 7,000 t. The amount of solid activated waste resulting from reactor decommissioning depends on the criteria used in the host country. Preliminary estimations have shown that this amount will exceed 20,000 t. Thus, the total amount of solid activated waste resulting from ITER operation may be about 30,000 t.

Liquid radioactive waste will be detritiated. The major part of it will be reused after decontamination. Imbalance liquids will be discharged into an external body of water (a source of industrial water) after additional purification to the level acceptable by local regulations. The residual liquid radioactive waste will be concentrated, solidified and temporarily held in the interim storage for solid waste on the site.

Any air discharged through the stack will be decontaminated to the level acceptable by the host country regulations.

All the treatment operations with solid, liquid, and gaseous radioactive wastes will be in compliance with the regulations of the host country.

There will be a need to provide for interim storage of irradiated reactor components, equipment, structures, and other solid and solidified waste on the site for up to 80 years.

The host site must be prepared to accept responsibility for the handling, interim storage, and preparation of all radioactive waste for ultimate disposal according to applicable regulations. The place and method of ultimate disposal of irradiated waste will be the responsibility of the host country.

IX.2.5. Transportation

Good transportation links (by water, road, rail) and capabilities of access to national and international heavy haulage routes will be necessary for the delivery of large quantities of equipment up to 9 m wide, up to 4 m high, and up to 400 tons as well as construction materials to the site. It is possible that during Engineering Design Activities the maximum width of components to be transported to the site will increase to 10 m.

A dedicated wharf, if there is a major water access, is desirable for delivery of major reactor components up to 23 m wide.

The transportation links must also provide for safe transport to and from the site of radioactive materials, including tritium and radioactive waste, in compliance with both international criteria and national regulations.

There must be convenient access to good international air travel in view of the large number of working and visiting international professionals who will travel to and from the ITER site.

IX.2.6. Industrial infrastructure

The construction and operation of ITER will require the resources of an advanced industrial economy. It will be economically desirable for the site to have reasonable access to industrial facilities and personnel within the host country. Such access is also economically desirable for many of the raw materials essential to construction, such as aggregate for concrete.

The safety of ITER operation depends upon not only the design of the plant but also the experience and expertise of the personnel selected for the operation. In this regard, it is desirable for the host site to have extensive experience in designing, building, operating, decommissioning, and regulating similarly complex facilities.

IX.2.7. External hazards

External hazards should not imperil the safety of the plant. Thus, aircraft test zones and military exercise areas, e.g. firing ranges, as well as proximity to explosion or toxicity hazards, e.g. munitions factories or depots, or to transport routes for toxic or explosive compounds are excluded.

External hazards which require reinforcement or redesign of the plant, e.g. hazards relating to petroleum and chemical plants and stores, high pressure pipelines, and areas of intense air traffic are undesirable.

IX.2.8. Public safety

The requirements ensuring an acceptably low risk to population safety will be determined by the regulatory authorities of the host country.

The acceptability of a site for ITER is closely related to the design of the plant. From a public safety point of view, a site is acceptable if there are technical solutions to site-related problems which give the assurance that the proposed plant can be built and operated with an acceptably low risk to the population of the region.

There must be sufficient separation between the general public and the plant to comply with the safety regulations of local and national bodies in the host country. The effects of routine and accidental emissions calculated for the proposed plant design, exclusion zone, and actual demography of the proposed site must satisfy the safety criteria of the host country and locality. The proposed plant design must comply with local building regulations, but should also provide for the safe dispersion of routine and accidental plumes emitted from the plant.

There must be sufficient site data available to permit the assessment of design compliance with local and national safety regulations. The data are needed for meteorology, hydrology, geotechnical considerations, seismic characteristics, population distribution, land use, aircraft frequency and momentum, and identification of any significant nearby industrial hazards.

Plausible external initiators of accidents at the plant (e.g. aircraft impact and earthquakes) must be consistent with the safety approach in the design of the building and major equipment.

IX.2.9. Environmental impact

Environmental issues are important to the ITER site selection. The project philosophy regarding site development, emission control, safety, design, construction, operation, and waste management should be firmly established before the site selection process begins. Any potential changes to the environment as well as the impact on the local community resulting from the siting of ITER must be considered and resolved during the site selection activities, in accordance with the host site regulations.

If ITER were to be located at an existing facility, ecological concerns would most likely be minimized since such concerns would presumably already have been addressed. If the ITER site is a new one, then the preferred site would be in an area of low agricultural productivity. Minimum modifications to the existing ecology should result from the plant construction and operation.

It is undesirable to consider the use of animal and bird sanctuaries, land conservation areas, and public parks as suitable for a facility like ITER.

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