21 (6.2.A.01) Tokamak Complex

21.1 Functions, Basic Configuration and Interfaces

21.1.1 Functions

The main functions of the tokamak complex are the following;

1) House and support the systems, and provide adequate space for the systems to operate and to be maintained
2) Provide a suitable environment for the system and personnel inside
3) Provide a confinement boundary for any released tritium, activated materials, and/or beryllium dust
4) Provide a further confinement function (in case of an ex-vessel coolant leakage event)
5) Provide radiation shielding around the tokamak, the remote handling systems, and the tokamak cooling water system (TCWS), and for other areas that may contain radioactive components or materials.

21.1.1.1 House and Support the Systems, and Provide Adequate Space

The tokamak complex provides space for the systems located within the building, and must have enough strength to support the systems. The tokamak complex resists external hazards, including seismic events, extreme weather (hurricanes, tornadoes, rainfall, snow, etc. as specified in the PDS) in order to prevent failure of the systems.

21.1.1.2 Provide a Suitable Environment for the Systems, Equipment, and Personnel

The tokamak complex provides the following systems for a suitable environment;

- access pathway for the RH transportation system
- lighting, service power, and welding power
- fire protection
- service fluid distribution system
- drainage systems
- grounding system
- heating, ventilation, and air conditioning (HVAC) system
- radiation protection and monitoring system
- access control and personnel escape system
- shielding
- communication system

Many of these building systems are commonly found in large industrial buildings, but there are some special features of the tokamak and its complex that generate some uncommon requirements:

- personnel lifts, to provide access to the various floors, as the vertical height inside the tokamak complex is more than 40 meters;
- a seismic monitoring system to provide data to the CODAC system;
- a thorough and robust grounding system;
- access control system;
- shielding;
- breathing air.

21.1.1.3 Provide a Confinement Boundary

21.1.1.3.1 Confinement Boundary in the Tokamak Building

The tokamak building plays a role in the prevention of the release of radionuclides to points where members of the public may be exposed. All significant sources of radionuclides must be confined by at least two independent barriers including the walls of the equipment.

The sources of radionuclides and hazardous materials are the following:
- activated corrosion products in the coolant of the TCWS
- radioactive dust and beryllium dust in the tokamak interior
- activated room air
- tritium from the plasma, the in-vessel components, the fuelling systems, and the TCWS coolant (to a lesser extent)

The role played by the tokamak building varies with the plant operating state and activity being performed as follows:
1) During all periods, the tokamak cooling water system (TCWS) vault plays the role of the confinement boundary for the inventory of TCWS in the case of an ex-vessel coolant leakage event. For the plasma, in-vessel components, and the fuel gas system, the tokamak complex is not used as the confinement barrier, as this barrier is provided by parts of these other systems.
2) During maintenance, if the confinement boundary is opened, the walls of the tokamak building become the confinement boundary.
3) During operation and baking, the TCWS vault, the NB cell, the pipe chases and the vertical pipe shafts play the role of confinement boundary in the form of pressure containment and leakage limitation.

To achieve the confinement requirements, the tokamak building has a separate ventilation system that maintains the air pressure in the confinement areas at a slight negative pressure relative to the outside air. This system will safely handle any small leaks from the confinement systems or chronic releases during maintenance when confinement is breached. The other areas, such as crane hall, which do not include tritiated equipment, have a conventional ventilation system because tritium leakage to these areas during machine operation is very unlikely. During major (open cryostat) maintenance of the machine the conventional ventilation system will be reconfigured prior to opening the cryostat to prevent tritium from entering the crane hall.

21.1.1.3.2 Confinement Function (in the case of an ex-vessel coolant leakage event)

The tokamak building design must meet the consequences of an ex-vessel coolant leakage event that is followed by potential release of radionuclides and tritium from the TCWS, accompanied by significant thermal or mechanical energy. The building is required to resist the loads that such an energy release could cause. Further, leakage must be limited to below the allowable leak rate as determined by radioactive release requirements. The air of the rooms in the confinement volume must be isolated from the other rooms at the signal of this occurrence.

21.1.1.3.3 Confinement Boundary in the Tritium Building

The major hazardous radionuclide in the tritium building is tritium. The tritium is isolated from workers and the public by two strong confinement barriers: the equipment itself (a primary boundary); and secondary enclosures such as glove boxes that contain equipment having a tritium inventory above 1 g. In some cases the building acts as a tertiary confinement barrier. For areas with glove box operations, the rooms surrounding the secondary confinement boxes can be isolated from the rest of the building. When some areas and/or rooms are potentially contaminated, the HVAC systems of the relevant areas/rooms are isolated. The air in these areas/rooms is exhausted via the atmosphere detritiation system to maintain negative room pressure with respect to the external atmosphere. The function of tritium confinement and detritiation shall be achieved by these multiple barriers and the dedicated HVAC (which is integrated with safety tritium monitors).

21.1.1.4 Provide Radiation Shielding

21.1.1.4.1 Radiation Shielding in the Tokamak Building

During tokamak operations, the reinforced concrete bioshield wall, the removable bioshield plug, and the bioshield lid (integrated into the cryostat head) completely surround the cryostat, providing protection against direct radiation from the fusion reactions as well as from radiation from activated materials inside the vacuum vessel and other radioactive components within the cryostat. Additional shielding during tokamak operation is provided for radiation streaming from the penetrations of the cryostat/bioshield and from high energy ^{16}N and ^{17}N radiation from the coolant in the vessel and the in-vessel PHTSs. Further shielding is provided at the outer end of some port cells, with shielding doors that allow for access into the port area of the tokamak, for maintenance purposes.

During maintenance activities, activated plasma-facing components such as shield/blanket modules, divertor cassettes, diagnostic equipment, etc. will be transported using unshielded casks. The building provides shielding along the transportation passageway for the components removed from the tokamak ports. Casks with irradiated components from the ports are remotely moved around the gallery to the lift, and then to grade level. They are then transported to the hot cell building.

21.1.1.4.2 Radiation Shielding in the Tritium Building

The tritium building has no general shielding requirements. However, local shielding may be required for locations where there may be an accumulation of radioactive materials in the fuel cycle systems.

21.1.2 Basic Configuration

The tokamak complex consists of two major portions on a common basemat that are called tokamak building and tritium building.

The main system accommodated in the tokamak building is the tokamak itself, contained within the cryostat. The cryostat and supporting in-cryostat systems and equipment are located in the centre of the tokamak building, inside the bioshield structure, in an area called “the pit”.

The tokamak itself requires electrical power, heating and current drive, cooling water, cooling helium, hydrogen, deuterium, and tritium supply, vacuum pumping, and diagnostics. The equipment related to these requirements must be located close to the cryostat. The tokamak complex needs to support all this equipment at each level. The space around the central “pit” is called the gallery.

Each system requires services, such as power supply, cooling water, etc. Thus, cables, pipes and ducts have to be installed in the tokamak complex, to be connected to the site infrastructure.

A heating, ventilation and air conditioning (HVAC) system is necessary for the environment around equipment and workers in the galleries. As ducts for HVAC systems for the tokamak complex serve a safety function, and ducts cannot follow the large deformations that may occur during a seismic event, the HVAC systems should be installed within the tokamak complex. The relation between the tokamak and the tritium handling facilities does not require close proximity, therefore the tritium plant, the HVAC systems, the vacuum pumping, the tokamak fuel supply, and other tokamak direct services, are housed in a separate portion of the tokamak complex called the tritium building.

The tokamak is made up of many large and heavy components, and requires heavy lift cranes to enable assembly and maintenance of these components. A crane lift capacity of up to 1,500 t is required. This capacity is supplied from two (2) 750 t capacity cranes, each with 2 hooks of 375 t capacity, and able to operate in conjunction with one another. In addition, 100 t hooks are provided on each of the 375 t hoists.

21.1.3 Interfaces

21.1.3.1 Major Systems in the Tokamak Complex

The major systems to be installed in the tokamak complex are shown in Table 21 (6.2.A.01)-1.

Table 21 (6.2.A.01) -1 Major Systems installed in the Tokamak Complex

Tokamak building	Pit	Tokamak
		Cryostat
		Systems mounted in the ports
		Connections from outside of the pit
	Galleries	Cryodistribution equipment
		Magnet feeders
		TCWS
		NB H&CD
		EC H&CD, IC H&CD and LH H&CD systems connections and waveguides and conductors
		Remote handling system (including lift)
		Diagnostic systems
		Power supply to all the equipment and to the building services
		Control device of the equipment
		Water supply to the equipment
		HVAC
		Other utilities
	Crane hall	1500 t crane
Tritium building		Fuel cycle subsystems
		Long term tritium storage system
		Atmosphere detritiation systems
		Tritiated water holding tanks systems
		Water detritiation system
		Power and utilities for tritium plant
		Tokamak building HVAC system
		Tritium building HVAC system

21.1.3.2 Interfaces

The buildings have interfaces with the following WBS elements:

WBS	**Title**
1.1 - 1.3	Magnet System
1.8	Fueling and Wall Conditioning
2.2	Machine Assembly and Tooling
2.3	Remote Handling Equipment
2.4	Cryostat
2.6	Cooling Water System
3.1	Vacuum Pumping and Leak Detection Systems
3.2	Tritium Plant
3.4.B	Cryodistribution
4.1	Coil Power Supply and Distribution
4.2.C	NB H&CD System Power Supplies
4.3.C	Steady State Electrical Power Distribution
4.5	CODAC
4.6	Interlocks System

5.1	Ion Cyclotron Heating & Current Drive System
5.2	Electron Cyclotron Heating & Current Drive System
5.3	Neutral Beam Heating & Current Drive System
5.4	Lower Hybrid Heating & Current Drive System
5.5	Diagnostics
6.1.A	Site General Layout
6.2.A.04	Laydown, Assembly & RF Heating Building
6.2.A.06	Diagnostic Hall & TF Fast Discharge Resistors and Capacitors
6.2.B	Hot Cell Building
6.2.G.02	Personnel Access Control Building
6.2.S	Utility Tunnels & Site Improvements
6.3	Hot Cell Processing and Waste Treatment
6.4	Radiological and Environmental Protection
6.5	Liquid Distribution, including Water
6.6	Gas Distribution and Compressors

21.2 Design Requirements

21.2.1 General

The requirements for the tokamak complex are derived from DRG1 and section 21.1.1.

The requirements below are not complete as some equipment is still being designed. However, it is expected that this section identifies all the requirements for the overall configuration and general conceptual design of the building.

21.2.1.1 Tokamak Embedment

To facilitate tokamak assembly and reduce building costs, the base of the tokamak shall be embedded so that the elevation of the connection between the hot cell and the level in the tokamak building with most frequent access needs is at grade. The total vertical build of the tokamak pit and crane hall shall include the systems and equipment located outside the bioshield, the tallest lift during tokamak assembly, the space required for the cranes, and the structural space needed for the building roof trusses. The tokamak itself does not control the overall vertical height of the building.

21.2.1.2 Tokamak Coil Replacement

The pit and access into the cryostat at the basemat level shall support the replacement or repair in situ of the lower PF coils. Also, the removal and replacement of any TF coil plus VV segment shall be considered in the layout of the crane hall and the laydown and assembly hall. These are considered class 3 remote maintenance operations, and are not expected to occur during the ITER lifetime, however the tokamak building shall not preclude the possibility of such activities.

21.2.1.3 Removal of Ports and Plasma-Facing Components

The tokamak building shall provide space for the remote handling transportation vehicles that move objects to and from the ports at the divertor, equatorial, or upper port levels, taking into account the minimal removal of other objects or systems.

21.2.1.4 Integration of Tokamak Building and Tritium Building

Safety-related ducts and piping containing tritium connect the tokamak building and the tritium building. Their deformation and/or failure during a seismic event cannot be tolerated. As a result, the two buildings shall be integrated onto a common basemat.

21.2.1.5 Systems, Components, and Connections in the Tokamak Complex

The tokamak building shall provide space for the tokamak (inside the cryostat), access to the 54 tokamak ports at the divertor, the equatorial, and the upper port levels, and space for all systems, components, and connections which are required to be located close to the tokamak, and all other systems, components, and connections which are required to be located in the same building as the tokamak, as shown in the following table.

Table 21 (6.2.A.01) -2 Systems, Components and Connections in the Tokamak Complex

System	Remarks
Tokamak Building	
Cryostat Systems and components permanently attached to the cryostat	Containing the tokamak vacuum vessel, magnets, and all connections to and through the cryostat to feed these in-cryostat components. The building shall provide space for it, and also adequate space above it for removal of the cryostat head for major maintenance activities in the cryostat. The building shall accommodate the equipment and systems which are permanently attached to the cryostat and components which must be near the cryostat, including the neutral beam (NB) injectors, radiofrequency heating & current drive (H&CD) launchers , and most diagnostic equipment.
Fluid, electrical, cryogenic, and mechanical penetrations of the cryostat	Space for the conductors, piping, and mechanical apparatus which must connect to cryostat penetrations, including magnet feed cold terminal boxes and flexibility features, vacuum and fuel gas delivery systems, and thousands of electrical and control connections.
Auxiliary cold boxes, dewars, and thermal buffers of the cryodistribution system	
Diagnostics, heating, vacuum and fuelling, test blanket modules, magnet feed, cryogenic feed and cooling systems	The building shall provide a suitable environment for personnel to approach, inspect and maintain this equipment whenever such approach is not precluded by tokamak operations or other conflicting activities or conditions.

Table 21 (6.2.A.01) -2 Systems, Components and Connections in the Tokamak Complex (cont'd)

System	Remarks
Tokamak cooling water systems (TCWS) for blanket/shield, divertor, NB H&CD, and vacuum vessel	This includes pumps, heat exchangers, piping, valves, and water treatment equipment. Any component the failure of which could lead to a significant discharge of potentially radioactive fluid must be in the TCWS vault (or connected areas, such as the upper and lower pipe chases, the vertical pipe shafts, or the NB cell).
Vacuum vessel air-cooled heat exchanger	On the roof of the building.
Divertor cassettes, test blanket modules, and other horizontal access plasma-facing components	For the access and removal of divertor cassettes and other plasma facing components (PFC) using remote handling equipment through access ports. The building shall provide space to allow these objects to be transported in RH casks from any port to the hot cell building. During such transport, the tokamak building shall provide adequate shielding to prevent any radiation hazard to the public or to workers in occupied buildings. For buildings and rooms where workers cannot be protected, the building and remote handling systems shall be designed to accomplish the task without the need for workers in these areas.
Vacuum vessel pressure suppression tank	This tank is an extension of the vacuum vessel, which is connected to the torus by ducts with rupture disks, to minimise any overpressure of the vacuum vessel.
Tokamak assembly space	Including lifts of the magnet and vessel sub-assemblies weighing up to 1500 t. The building layout shall permit all large tokamak parts to be placed into the pit from above. Crane access to the laydown and assembly area shall be provided.
Building cranes	A crane with a lift capacity of up to 1,500 t. This capacity is supplied from two (2) 750 t capacity cranes, each with 2 main hooks, and able to operate in conjunction with one another. Smaller hooks of 100 t capacity shall be available from each main hook.
Maintenance space	Normal maintenance, materials handling equipment, and tool storage. Further, the building shall provide space for storage of removable bioshield plugs and other in-cell components, during maintenance of in-vessel components where access to the vacuum vessel is required.
HVAC and building service space	To be connected to the HVAC systems in the tritium building, but also to include a system of local air coolers and blowers to maintain the tokamak building atmosphere at the desired conditions.

Table 21 (6.2.A.01) -2 Systems, Components and Connections in the Tokamak Complex (cont'd)

System	Remarks
Component anchors and supports	Anchors and attachment points for the tokamak machine support structure (ring pedestal support columns) and the cryostat support, as well as support for all other equipment in the building.
Plant exhaust	The plant exhaust provides an elevated and single point release point for all ITER plant gaseous effluents that may contain radioactive or other hazardous materials.
Internal communications and walkways	The stairs, lifts, and passageways for personnel working in the tokamak building.
Tritium Building	
Water detritiation system (WDS)	
Tritiated water holding tank systems	
Atmosphere detritiation systems (ADS)	Consisting of standby room air detritiation system, standby and normal vent detritiation systems, glovebox detritiation system, tokamak emergency detritiation system, etc.
Storage and delivery system (SDS) and long term storage vault	
Tokamak exhaust processing system (TEP)	Consisting of front–end permeator system, impurity detritiation system, etc.
Isotope separation system (ISS)	
The tritium plant analytical system (ANS)	
Test blanket module tritium recovery system	
Vacuum pumping systems	
Instrumentation and shop space for tritium plant	
HVAC and building service space	For the entire tokamak complex and other building services, with connections to the plant exhaust.
TCWS vault cooler & dryer	
Chiller system & component cooling water system	
Load centre	The tritium plant dedicated electrical load centre.

Table 21 (6.2.A.01) -2 Systems, Components and Connections in the Tokamak Complex (cont'd)

System	Remarks
Internal communications and walkways	The stairs, lifts, and passageways for personnel working in the tritium building.

The tokamak complex shall accommodate these system listed above, and must provide space for their operation and maintenance.

21.2.1.6 Seismic

21.2.1.6.1 SL-2 Seismic Loads

The tokamak complex is safety importance class (SIC) and shall withstand SL-2 seismic conditions with peak horizontal and vertical accelerations as specified in the PDS and shall meet functional requirements for seismic classification. Note that the design has been analysed by the JA HT and found to be satisfactory (see the DDD).

The complex is considered to have withstood these conditions if no damage occurs to SIC components that would impair their safety function. The plant exhaust located on the roof of the tokamak complex shall be SIC and shall withstand SL-2 seismic conditions and shall meet functional requirements for seismic classification. The vacuum vessel heat exchanger on the roof of the building be SIC and shall meet functional requirements for seismic classification.

21.2.1.6.2 Seismic Instrumentation

The tokamak complex shall include appropriate seismic instrumentation, such as tri-axial response recorders, at the basemat and designated support location(s) necessary to evaluate the effects of an earthquake relative to the design analyses receiving regulatory approval. This instrumentation must be linked to the central control room via a seismically qualified network to provide a readout of the earthquake data for immediate evaluation.

21.2.1.7 Structural

21.2.1.7.1 Dead Loads and Equipment Load

The complex shall support its own weight as well as the weight of all installed equipment.

21.2.1.7.2 Live Loads Supported by the Slabs

The complex structure shall support the weight and forces of all movable and active components, systems, and structures located on the slabs or walls of the building.

21.2.1.7.3 Lifting/Transporting Devices and Their Loads

The structure shall support the weight and forces of all lifted loads, including the lifting devices over the full range of their travel. Structural deflection under such loading must be consistent with the required precision of the lifting devices.

21.2.1.7.4 Thermal Loads

The structure shall either resist stress induced by expansion and contraction due to changes between the as-built temperature and the maximum expected structure temperature excursions, or allow movement through the use of expansion joints.

21.2.1.7.5 External Hazard Loads

The complex shall resist the force exerted by seismic activity, wind, snow, and soil and ground water pressure, as defined in the PDS.

21.2.1.7.6 Internal Hazard Loads

Rooms and spaces within the tokamak complex which contain fluid systems with energy content sufficient to cause local pressure loading in the event of a fluid system failure shall be designed to resist the loads applied by such events. For the TCWS vault, the NB cell, pipe chases, and the vertical shafts, where the fluid systems contained may also be sources of radiation release, these pressure transient loads shall be withstood without exceeding the vault or cell design basis leak rate. This requirement may be met for spaces containing fluid systems, which are not hazardous to workers outside of the area or the public, by venting.

21.2.1.8 <u>Vacuum</u>

Building spaces which could be subjected to accidental evacuation due to cryostat or vacuum vessel air ingress events (usually described as loss of vacuum accidents, or LOVAs) shall be designed with adequate vent connections to the atmosphere to preclude the development of significant differential pressure loads, or shall be designed to withstand such loads.

21.2.1.9 <u>Electromagnetic</u>

Structural members in the magnetic fields generated during tokamak operation can have significant electrical currents induced, and shall have their steel rebar installed such that good electrical contact is established between contacting rebars. These rebar networks shall be connected to the basemat grounding grid. Because the dynamic behaviour of ITER stray magnetic fields is slow (with periods of 100 s to 1,000 s), the presence of ferromagnetic material in the reinforced concrete of the tokamak complex has been judged to be acceptable. There is no requirement to use non-magnetic materials in the construction of the ITER tokamak complex.

21.2.1.10 <u>Assembly</u>

21.2.1.10.1 Cryostat, Tokamak Machine Support Base Installation

The tokamak building shall provide the cryostat support bracket and the anchors and embedded bolts for the ring pedestal support columns. The design of these elements shall be integrated to assure assembly sequence compatibility, and location accuracy.

21.2.1.10.2 Crane Hall Cleanliness

During assembly, the space in the crane hall and tokamak pit shall meet air quality requirements that include maintenance of temperature in the range 20°C to 25°C ± 2°C up to an elevation of + 5 m, relative humidity below 70%, and a without dust. These conditions are to be maintained from the point of turnover of the building for assembly until the cryostat top is installed, except for periods when doors are opened and/or large numbers of workers are present.

21.2.1.10.3 Embedded Plate Installation

The tokamak building shall provide embedded plates for temporary braces during the tokamak assembly. These same embedments will be used later to anchor the upper lateral restraints of the cryostat.

21.2.1.10.4 Floor Loads for Heavy Components

The tokamak building floors shall be designed to support heavy loads resulting from the laydown of heavy components (but not for the magnitude of weight of the VV and the magnet TF coils and subassemblies during ITER construction). These loads are born by the main floor slab of the laydown, assembly and RF H&CD building.

21.2.1.10.5 Interface with Construction Schedule

The installation of the tokamak complex services (such as the 1500 t crane, HVAC, fire protection, communications, lighting and service power, service air and compressed air, etc.), shall be co-ordinated with the tokamak assembly schedule.

21.2.1.11 Testing

The tokamak complex shall be constructed to appropriate codes and standards, which include requirements for construction and commissioning testing of: materials, welding, piping systems, electrical systems, and other building services components. In addition to construction-related inspection and testing, the tokamak complex must be designed to accommodate functional testing of building support systems such as fire detection and mitigation systems. Specific testing requirements will be imposed on the building features listed below.

21.2.1.11.1 TCWS, NB Cell, Pipe Chases, and Vertical Shafts Pressure Testing

Connections and instrumentation shall be provided to enable the initial pressure load and periodic pressurised leak rate testing of the TCWS vault, NB cell, pipe chases, and vertical shafts.

21.2.1.12 Electrical

21.2.1.12.1 Building Lighting Service

The complex shall be provided with appropriate permanently installed electrical lighting which shall include an emergency lighting circuit.

21.2.1.12.2 Building Electrical Service

The complex shall distribute low voltage power for services and welding to points within the buildings.

21.2.1.12.3 Building Electrical Grounding Grid

The complex shall have an electrical grounding grid with connections to the plant-wide grounding grid network, and with robust grounding terminals at specified locations inside the building.

21.2.1.12.4 Lightning Protection System

The complex shall have lightning protection systems with connection to specified grounding grid terminals.

21.2.1.13 Potable Water and Drainage

21.2.1.13.1 Restricted Areas

There shall be no potable water supply to or sanitary drainage facilities from potentially contaminated areas. This restriction is designed to avoid the potential of worker ingestion of contaminated potable water and the potential for radioactive contamination of sanitary drains. Portable facilities including drinking water containers and self-contained decontamination showers will be permitted under the supervision of the plant health protection procedures.

21.2.1.13.2 Roof Drains

The tokamak complex shall have roof drains that connect to the yard drain system.

21.2.1.13.3 Floor Drains

Floor drains within contamination control areas shall always connect to sumps and collection tanks. The contents of the sumps and collection tanks will be pumped to the low-level radwaste systems if contaminated (see WBS 6.3). Floor drains from non-contamination controlled zones (white zones) will connect to the plant industrial sewer system (see WBS 6.5.D). In the radioactive (or potentially radioactive) areas of the tokamak building, floor drains are not provided. Equipment will be contained in local curbs to contain "casual" water spills. Water resulting from large spills and/or ex-vessel coolant leakage events will flood these curbed areas and will overflow the vault area, will cascade down the vertical pipe shafts into the lower pipe chase, and will be collected in a sump on the basemat level, from where it will be pumped to the radwaste building to be treated as low level liquid radwaste.

21.2.1.14 HVAC

21.2.1.14.1 HVAC for Contamination Control

The HVAC forms the tritium confinement barrier together with the N-VDS and S-VDS in the tokamak building and the tritium plant building, and with HC-VDS in the hot cell building and the radwaste building. The HVAC emergency isolation valves shall be actuated (within 30 s) to isolate the potentially contaminated rooms/areas, when the relevant room air tritium monitor signals an excessive tritium concentration. The isolation valve actuators shall have a full redundancy and safety class pressurised actuation air.

All areas in the tokamak complex which are subject to contamination control shall be equipped with HVAC systems that exhaust through the plant exhaust. All areas which are assigned a confinement function shall be equipped with tritiated water removal capability in the exhaust stream, either atmosphere detritiation capability or dryers. The HVAC in all areas where confinement functions terminate shall be equipped with HEPA filters and have the ability to divert exhaust flow through the ADS or dryers.

21.2.1.14.2 HVAC Pressure Gradients

The complex shall be constructed such that HVAC pressure gradients in the airflow system are in the opposite direction of the contamination gradients of the areas associated with the complex. Pressure gradients shall be associated with contamination control area designations as follows:

White:	Atmospheric or higher,
Green:	-1 mbar gauge,
Amber:	- 2 mbar gauge,
Red:	- 3 mbar gauge.

21.2.1.14.3 Temperature, Humidity, Particulates, Gaseous Contaminants

The HVAC systems shall provide air quality (temperature, humidity, purity, freshness) sufficient to meet the requirements of the workers and equipment located in the complex (see section 21.2.1.10).

21.2.1.14.4 Reliability

The HVAC system shall have sufficient redundant capability including pre-filters, cooling and heating coils and high-speed fans to ensure that the requirement of section 21.2.1.14.2 is met during all normal operating conditions.

21.2.1.14.5 Air Flow Control

All air supply and return systems shall be fully interlocked with controlled access points. Whenever access control points are opened or closed, the HVAC systems shall be controlled to maintain an appropriate air balance without any interruption in service. The rooms and spaces which are assigned a containment or confinement status shall be equipped with instrumentation and controls to detect and identify off-normal pressurisation conditions. Signals from these instruments will be used to initiate mitigating actions where appropriate.

21.2.1.15 Fire Protection

21.2.1.15.1 Passive Protection

The complex shall have separate fire-rated zones for identified hazards and protected exit routes.

21.2.1.15.2 Detection and Alarm System

An automatic audible and visual alarm system incorporating a manually activated circuit shall be installed throughout the complex. The detector system shall be sensitive to flame, smoke or combustible gas, as appropriate, especially for areas of large volume such as the crane hall and other large rooms.

21.2.1.15.3 Mitigation System

An automatic mitigation system, using an acceptable halon substitute, shall be installed throughout the complex unless process requirements preclude such a system. In addition, a standpipe and hose system together with fire extinguishers, shall be installed to all areas with personnel access.

21.2.1.16 Internal Communication

21.2.1.16.1 Telephones

The complex shall be equipped with a fully automated telephone exchange/server facility for normal internal and external communications, which shall incorporate a separate emergency system, supported by an UPS.

21.2.1.16.2 Computer Network

The complex shall be connected to the CODAC system which comprises the control and data management, and to the interlocks system for machine and personnel protection. A network of PCs served from the central computers shall be distributed by screened cables to certain areas within the complex.

21.2.1.16.3 Public Address

A public address (PA) system shall be provided to all occupied areas and personnel traffic routes in and around the complex.

21.2.1.16.4 Other Communications Devices

Closed circuit television (CCTV) shall be provided throughout the building, with signals carried via CODAC to the control room for monitoring. In addition, a system of “walkie talkies” and other radio-based communications devices will be provided, with stations distributed around the complex.

21.2.1.17 Access Control

21.2.1.17.1 Radiologically Controlled and Hazardous Areas

The complex shall incorporate a system to control access to all radiologically controlled spaces within the tokamak or tritium parts of the complex, and to certain other areas when it is unsafe for workers to enter (e.g. because of radiation, contamination, electrical, microwave, or potential magnetic field hazards associated with tokamak operation). Access is to be excluded from certain parts of the tokamak building whenever the tokamak is conducting plasma operations or baking. Further, the access control system shall be designed to control all areas inside this controlled-access complex, and be able to respond to conditions other than the hazards indicated above, such as confined space work, presence of toxic substances (Be, for example), etc.).

The access control system provides for access that is controlled by card readers and door interlocks, so that on-line personnel inventories are maintained in the event of a plant-wide emergency or evacuation requirement.

Access must also be controlled in accordance with the potential for direct radiation and for contamination with radioactive materials. These constraints will require control over access to the TCWS vault and other areas within the complex during maintenance activities, especially to operations that are considered to have a high associated risk of spreading radioactive contamination. The access control system must confirm that no workers are in the gallery areas or anywhere along the pathway used to transport plasma facing objects from the tokamak to the hot cell building when such transport operations can occur.

The access control system must interface with the area radiation monitoring system to prevent re-entry into any area where alarms have been actuated by high radiation.

21.2.1.17.2 Accessible Areas

Generally, rooms in the tritium building shall be accessible at all times, unless there is a release event from one of the tritium system enclosures. In that event, workers must evacuate and not re-enter the affected room. Access into these areas, while it should be acceptable at any time, will still be controlled by card reader and door interlocks, so that on-line personnel inventories are maintained in the event of a plant-wide emergency or evacuation requirement.

21.2.1.17.3 Zone Restrictions

The complex shall be equipped with physical restrictions to prevent unauthorised personnel from entering into the four defined access control zones, A, B, C & D (and for other access control situations, such as described in 21.2.1.17.1, above). The system must be capable of allowing and recording single person entry and exit with discrete signals to the central control room via CODAC. The access control system shall include audible and visual alarms to warn of potential hazards or the need for evacuation. The alarms shall be activated automatically by monitoring instruments or manually by operator activation.

21.2.1.18 Materials

21.2.1.18.1 Building Construction Materials

The complex shall be constructed with structural steel and reinforced concrete as required in the codes specified in section 21.3.

21.2.1.18.2 Electrical

All cables will be made with copper and should have the 15 kV, 6 kV and 0.6 kV rated insulation voltage for 11 kV. Cable insulation should meet the following requirements:

- insulation material — XLPE preferred, PVC not accepted;
- max. permissible temperature of conductor:
  - continuous — 90°C,
  - under short circuit conditions — 250°C;
- acid gas content — zero halogen, according to IEC-754;
- fire retardancy — according to IEC-332-3

Table 21 (6.2.A.01) –3 IEC Relevant Material

IEC #	Technical Committee	Title
332-1 to 3	SC 20C	Test on electric cables under fire conditions
728	SC 12G	Cable distribution systems
754	SC 20C	Tests on gases involved during combustion of electric cables
840	SC 20A	Test on electric cables 30 kV to 150 kV

21.2.1.19 Cranes, Lifts and Materials Handling

21.2.1.19.1 Cranes

The crane hall, which is approximately 49 m wide, 37 m high, and 170 m long from the north end of the tokamak building to the south end of the LA & RFH Hall, shall be served by two independent 750 t bridge cranes, each equipped with two 375 t main hoists and two 100 t auxiliary hoists. The maximum load with the four main hoists synchronised shall be 1500 t. The crane rails shall span 44 m and the maximum vertical load travel shall be 40 m.

21.2.1.19.2 Large Gallery Lift

The tokamak complex shall be equipped with an industrial lift with a capacity of 100 t and a vertical travel range of 30+ m.

21.2.1.19.3 Personnel Lifts

Personnel lifts shall be installed in the tokamak complex. Four (or two, depending on the detailed design of access and egress routes in the building) personnel lifts will provide service in the tokamak building between EL-11.6 m and EL+18 m. One lift shall be provided in the tritium building, providing service between EL-11.6 m and EL+27 m.

21.2.1.19.4 Transportation

The tokamak building shall house a guided transportation system capable of transporting air cushion vehicles carrying radioactive objects between tokamak ports and the hot cell building. Objects to be transported will be less than 100 t in weight including cask weight, about 5.3 m high, 4.5 m wide, and 8.5 m long.

21.2.1.20 Decommissioning

The building shall provide the space and the crane coverage for initial tokamak assembly as well as for the handling of the largest single item from the tokamak during decommissioning.

21.2.2 Operation and Maintenance

The operations and maintenance (O&M) requirements for the tokamak complex are derived from the DRG1 and the functions of the building (as given in section 21.2.1.1, above).

21.2.2.1 Operation and Control of Building Services

Building services shall incorporate appropriate instrumentation and control subsystems to manage system operation. Manual control over lighting, power distribution, large doors, and fluid supply is expected to be adequate. Manual control with safety interlocks will be provided for building cranes and lifting devices. Building systems with no safety or radiation control function (compressed air distribution, industrial drainage, grounding, etc.) will be equipped with appropriate instrumentation and control to operate in a stand-alone mode. Operation and control of these building systems will be centralised in building control panels located within the building. The status of these building systems will be provided to the CODAC system. However, the tokamak complex building systems will not be directly controlled from the main control room.

Fire detection, alarm, and mitigation systems in the tokamak complex shall be equipped with automatic controls with manual override capability. These systems shall initiate alarms and signals, and these will be reported via the CODAC system, and will report status to the control room, but these systems will not be controlled directly from the main control room. Fire suppression systems (i.e., sprinklers, or inerting devices) are automatic.

Access control, floor drainage, and HVAC systems perform functions that are directly related to worker safety and release of radioactive material to the environment. These systems will be equipped with instrumentation and control to enable active control from the main control room. When it is authorised, devices will also be operable at building control panels in the tokamak complex. Door status indicators will be provided, and integrated with the control system for HVAC, so that different HVAC operating modes can be accommodated dynamically. The access control system will interface with tokamak protective systems and remote handling transport systems, to ensure that no workers are in unsafe locations when hazardous operations are initiated.

21.2.2.2 Maintenance of Building Services

Building maintenance requirements are standard to a large industrial building complex. Operation of most systems will be interrupted for maintenance activities, however, HVAC system including emergency isolation valves will include sufficient installed redundancy that normal service can be maintained while one unit is removed from service for maintenance.

21.2.2.3 Maintenance for Structures

This set of maintenance requirements applies to building features that provide general services for maintenance of the complex. Services unique to installed equipment are not included.

21.2.2.3.1 Expansion Joints

The building design shall provide access and methods for maintaining expansion joint seal quality.

21.2.2.3.2 Corrosion Prevention and Control

The building construction materials which may be degraded by corrosion shall have prevention and control measures which may be maintained over the life of the project including decommissioning and dismantling.

21.2.3 Surveillance and In-Service Inspection

This set of surveillance and in-service inspection requirements applies to building features that indicate the condition of the building. Surveillance and in-service inspections unique to installed equipment are not included in this section.

21.2.3.1 Fiducial Reference Marks

The tokamak complex shall contain primary and secondary fiducial reference marks permanently installed for initial assembly, maintenance and rechecking of critical dimensions.

21.2.3.2 Periodic Inspection and Testing of Safety Functions

All safety-related functions shall be implemented in a way to allow periodic inspection and testing. Containment boundaries must be testable for time to close, leak tightness, and pressure retention capability. HVAC systems must be testable for depression, air change rate, and overall air balance, to indicate leakage from one depression region to another. The access control system must be testable to assure the integrity of door status indicators and other features. The fire detection, alarm, and mitigation systems must be routinely inspected, as per the local authority's requirements.

21.2.4 Quality Assurance (QA)

The tokamak complex shall be designed and constructed in compliance with the ITER QA program. Reinforced concrete structures which are SIC and seismic classification shall be designed and constructed in accordance with American concrete institute (ACI) - 349 (or equivalent) and all the quality assurance and inspections contained therein, plus any additional requirements specified by the ITER QA program. Structural elements within the tokamak complex, which form containment boundaries, shall be subject to acceptance and periodic testing in accordance with ASME section 11 (or equivalent).

21.2.5 Reliability Assurance

There are no special reliability assurance requirements for the tokamak complex structures, except where those structures form part of a safety-related building subsystems, including not only those with a direct ITER safety function such as confinement, but also those systems that support the building, such as lighting, lifting (personnel and equipment lifts), access control, communications, fire detection, alarm, and mitigation, etc. By choosing appropriate codes and quality assurance requirements, the primary structures of the tokamak complex can reasonably be assured to meet the failure expectancy assumed in safety evaluations (on the order of 10^{-6} per year). Other measures taken to assure that building systems meet or exceed the reliability assumed in safety analyses shall include continuous monitoring with instrumentation, periodic functional testing, and suitable preventative maintenance programs.

21.2.5.1 Confinement Boundary Components

Confinement boundary components shall be designed to permit continuous status monitoring regarding pressure, temperature, and radiation levels. Status of all boundary closure devices shall be instrumented. The tokamak complex shall be designed to also support periodic functional testing at full or partial design pressure of confinement boundaries, per ASME section 11 (or equivalent). Functional testing shall include time to achieve closure, leak rate at pressure, and other parameters important to safety analyses.

21.2.5.2 HVAC Components and Equipment

The HVAC systems shall be designed with sufficiently redundant components (filters, air handling units, and depression fans) to achieve all safety requirements. Reliability of these systems will be assured by continuous monitoring, control panel alarm response and a program of preventative maintenance.

21.2.5.3 Lifting Equipment

The tokamak building overhead cranes are not redundant, and their reliability will be assured by specification, good design practice, and appropriate operation and maintenance. Cranes will be rated for continuous duty and will be subject to continuous preventative maintenance programs. Lifting beams, slings, and other lifting aids will be subject to industry rules for periodic inspection, testing, and certification, similar to rules for instrument calibration.

Reliability of the tokamak gallery lift will be assured by installation of redundancy for all hoisting devices associated with the main lift. The lift will be fully instrumented to detect any loss of level in the lift platform or other detrimental degradation.

21.3 Codes and Standards

Reinforced concrete structures which are SIC and seismic classification shall be designed and constructed in accordance with American concrete institute (ACI) - 349 (or equivalent). Structural steel elements within the tokamak complex, such as the building roof trusses, shall be designed in accordance with American institute of steel construction (AISC) "Allowable Stress Design Manual of Steel Construction" (or "the Load and Resistance Factor Design Manual of Steel Construction") or equivalent.