

22 Radiological and Environmental Monitoring Systems

22.1 Functions, Basic Configuration, and Interfaces

22.1.1 Functions

22.1.1.1 Radiological Monitoring and Protection System

The primary function performed by the radiological monitoring and protection system is to provide radiological monitoring and protection to personnel from penetrating (ionising) radiation. The function is accomplished by a combination of fixed and movable radiation/contamination monitors working in conjunction with a dosimetry and bioassay system.

22.1.1.2 Environmental Monitoring System

The primary function performed by the environmental monitoring system is to provide environmental information as necessary to ensure compliance with host site regulatory environmental requirements. This function is accomplished by a combination of fixed and movable environmental monitors working in conjunction with a sampling and inspection program.

22.1.2 Basic Configuration

22.1.2.1 Radiological Monitoring and Protection System

The radiological monitoring and protection system (RM&PS) consists of the following subsystems:

- fixed area monitoring system
- portable monitoring system
- personnel dosimetry system
- personnel bioassay system
- personnel protective equipment
- health physics (HP) control and records center

The function is implemented on a local and plant-wide basis. Local functions include active monitoring with readout and alarms for local personnel response. Plant-wide functions are integrated through the CODAC system and the interlock system. Examples of plant-wide functions include general site radiological and toxicological alarms that apply to all site personnel, based on actual or potential hazards. The HP control and records center shall be located in the personnel building and shall record measurements and alarm all conditions and operations affecting the exposure of workers in access zones B and C and surrounding access zone A areas. The dosimetry and bioassay programs are also a plantwide function and are administered in a graded approach consistent with the radiological hazards present or potentially present in a given area.

The radiological status of each monitored facility is linked to the access control system which also has local and plant-wide coverage.

In addition, radiological protective equipment, such as bubble suits and breathing air systems

for personnel are described in Chapter 23 (6.6.B).

22.1.2.2 Environmental Monitoring System

The function is implemented on a local and plant-wide basis. Local functions include active monitoring with readout and alarms for local personnel response. Plant-wide functions are integrated through the CODAC system and the interlocks system. The sampling and inspection program is also a plantwide function and is administered in a graded approach consistent with the environmental hazards present or potentially present in a given area.

22.1.3 **Interfaces**

22.1.3.1 Radiological Monitoring and Protection System

The RM&PS has interfaces with the following WBS elements:

WBS Title

- 1.8.A Pellet Fueling System
- 2.3.B Ex-Vessel Remote Handling Equipment
- 2.4.F Cryostat Venting & Overpressure Protection System
- 2.6.F Additional Heating PHTSs
- 3.2.A Tokamak Exhaust Processing
- 3.2.B HDT Isotope Separation
- 3.2.E Water Detritiation
- 3.2.F Atmosphere Detritiation
- 3.2.H Tritium Plant Analytical Facilities
- 3.2.J Tritium Plant Control Systems
- 4.5.D Data Management System
- 4.5.E CODAC Synchronization System
- 4.5.F CODAC Network & Communication System
- 4.6.A Interlocks System
- 4.6.C Access Control
- 4.6.D Fusion Power Shutdown System
- 5.5.N Diagnostic Engineering (Generic)
- 6.1.A Site General Layout
- 6.2.A Tokamak Buildings
- 6.2.B Hot Cell Building
- 6.2.E Auxiliary Buildings
- 6.2.G Radwaste and Personnel Buildings
- 6.2.H Laboratory Office Building
- 6.2.K Control Building
- 6.2.L Emergency Power Supply Building
- 6.2.M Site Services Building
- 6.2.S Utility Tunnels & Site Improvements
- 6.3.A Hot Cell Docking and Storage
- 6.3.B Hot Cell Waste Processing and Storage
- 6.3.C Hot Cell Component Repair (Hot Cell Maintenance)
- 6.3.D Low Level Waste Processing

22.1.3.2 Environmental Monitoring System

The environmental monitoring system has interfaces with the following WBS elements:

WBS Title

- 3.2.B HDT Isotope Separation
- 3.2.E Water Detritiation
- 3.2.F Atmosphere Detritiation
- 3.2.H Tritium Plant Analytical Facilities
- 3.2.J Tritium Plant Control Systems
- 4.5.D Data Management System
- 4.5.E CODAC Synchronization System
- 4.5.F CODAC Network & Communication System
- 6.1.A Site General Layout
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- 6.2.H Laboratory Office Building
- 6.2.K Control Building
- 6.2.L Emergency Power Supply Building
- 6.2.M Site Services Building
- 6.2.S Utility Tunnels & Site Improvements

22.2 Design Requirements

22.2.1 Radiological Monitoring and Protection System

22.2.1.1 Specific

22.2.1.1.1 Personnel Radiation Monitoring and Protection

The RM&PS shall provide a combination of monitoring and protection functions to ensure that plant worker doses do not exceed ITER guidelines. The limits and project guidelines for occupational exposure are given in Table 22-1.

Table 22-1 Limits and Project Guidelines for Occupational Exposure

Dose Limits	
ICRP recommended limit for annual individual radiation worker dose	50 mSv 20 mSv averaged over 5 years
ICRP recommended limit for annual individual non-radiation worker dose	1 mSv
Project Guidelines	
Project guideline for annual individual worker doses	5 mSv/a
Project guideline for individual dose per shift	0.5 mSv/shift
Collective annual worker dose target averaged over life time of plant	0.5 man-Sv
ALARA threshold for dose rates	100 μ Sv/h
ALARA threshold for collective worker dose to operate and maintain a system for a year.	30 pers-mSv
ALARA threshold for collective worker dose for a task performed less often than annually.	30 pers-mSv
<i>Note, an 'ALARA threshold' is a level that triggers a formal ALARA assessment during the ITER design phase. This does not imply that ALARA reviews will not be performed when the design is below the thresholds.</i>	

22.2.1.1.2 Exposure Level Control

The fixed area monitoring system and portable monitoring system shall be implemented in radiation access zones B and C (see Table 22-2) to determine personnel exposure conditions (see Tables 22-3 and 4) within the values established for exposure conditions 2 and 3, respectively. Table 22-5 presents this zone and exposure conditions information in another way. The fixed area monitoring system shall provide audible/visual alarms both locally and in the HP control and records center if the conditions are exceeded.

Table 22-2 Access Limitations and Conditions

Zone	Access		Access Conditions*	
	Limitations		Exposure	Contamination
A	No RWP ^o required for access.		1	WHITE only
B	No RWP required for a radiation worker. RWP required for NRW or non-site personnel.		1, 2	WHITE or GREEN
C	All personnel require RWP with appropriate level of approval depending on the hazard conditions and the class of personnel requiring access.		1, 2, 3	WHITE, GREEN, or AMBER
D	These are restricted access areas, entry occurs only under an RWP with a high level of approval from both an operational and a radiological safety view.		1, 2, 3, 4	WHITE, GREEN, AMBER, RED
^o Radioactive work permit * The exposure conditions and contamination conditions for access control are defined in Tables 22-3 and 4.				

Table 22-3 Exposure Control Conditions

Exposure Condition	Airborne and Total Dose Rate Conditions	Acceptable in Zone
1	No airborne, and, external dose rate < 0.5 $\mu\text{Sv/h}$.	A, B, C, D
2	Exceeding condition 1 but total dose rate (internal + external) < 10.0 $\mu\text{Sv/h}$	B, C, D
3	Exceeding condition 2 and, < 100 DAC and < 1 mSv/h	C, D
4	> 100 DAC or > 1 mSv/h	D

Notes: DAC = Derived air concentration,
 Unprotected exposure to 1 DAC = 10 $\mu\text{Sv/h}$
 1 DAC HTO = $3.1 \times 10^5 \text{ Bq/m}^3 = 8.4 \times 10^{-6} \text{ Ci/m}^3$

Table 22-4 Contamination Control Conditions

Contamination Condition	Description of Area Contamination Conditions	Acceptable in Zone
WHITE: (no detectable contamination)	No surface contamination. No reasonable possibility of cross-contamination.	A, B, C, D
GREEN: (potential, infrequent cross-contamination)	No loose contamination or airborne is tolerated but may be subject to temporary cross-contamination. Airborne should not exceed 1 DAC.	B, C, D
AMBER: (controlled contamination)	Identified and controlled surface contamination is tolerated. However, contamination levels should be ALARA, considering risk of exposure, capability of available protective equipment, possibility of contamination spread, and cost. Airborne contamination should not exceed 100 DAC.	C, D
RED: (permanent contamination)	Permanent and higher levels of contamination are only tolerated in RED areas.	D

Table 22-5 Radiation Zoning Matrix

Contamination Conditions	Exposure Conditions			
	<u>1</u> no airborne, and external dose rate < 0.5μSv/h	<u>2</u> exceeding condition 1 and: tot. dose rate (internal + external) < 10 μSv/h	<u>3</u> exceeding condition 2 and: < 100 DAC and < 1 mSv/h	<u>4</u> >100 DAC or >1 mSv/h
<u>WHITE:</u> None	A	B	C	D
<u>GREEN:</u> Cross-Contamination only	B	B	C	D
<u>AMBER:</u> Controlled Contamination	C	C	C	D
<u>RED:</u> Permanent Contamination	D	D	D	D

22.2.1.1.3 Contamination Level Control

The portable monitoring system in combination with the plant sampling systems (chapter 24) shall enable the determination of surface contamination conditions.

22.2.1.1.4 Access Zone Control

The fixed area monitoring system and portable monitoring system shall include personnel monitoring equipment at access zone transition locations to determine that workers do not enter a lower access zone with contamination levels higher than allowed by the lower access zone.

22.2.1.1.5 Personnel Dosimetry Systems

The personnel dosimetry system shall monitor worker doses and help assure that the total ITER exposure limits are not exceeded for all radiation/contamination hazards. Dosimetry records shall be maintained for each worker at the HP control and records center, and shall include, but not be limited to a history of personnel visits to each area, dosimetry, bioassay results, and film badge readings.

22.2.1.1.6 Personnel Bioassay System

The personnel bioassay system shall monitor and assess personnel for inhaled, ingested and otherwise absorbed radiological material. Materials required for the bioassay program shall be stored and made available to personnel at appropriate locations.

22.2.1.1.7 RM&PS Monitor and Dosimetry Ranges

Radiation and contamination monitors and dosimeters shall have ranges which exceed the expected maximum exposure rate under normal operating conditions and credible accident conditions by one order of magnitude. The lowest range shall be sensitive enough to give on-scale readings under normal background conditions.

22.2.1.1.8 Personnel Protective Equipment

Appropriate protective equipment in suitable storage areas shall be provided to help maintain worker doses within ITER limits.

22.2.2 Environmental Monitoring System

22.2.2.1 Specific

It is expected that ITER will be responsible for a program of environmental monitoring and sampling that extends both within and beyond the ITER plant site boundary. This program, described below covers the monitoring of air, precipitation, milk, drinking water, fish and surrounding water bodies. Independent programmes conducted by other agencies are not described here.

Table 22-6 ITER Environmental Monitoring Program (both on and off-site)

Sample	Frequency	Sampling Location	Analyses
Air Inhalation	Continuously sampled; analysed monthly	One HT/HTO discriminating sampler at each of 10 environmental monitoring sites	H-3 (tritium)
Immersion	Continuously sampled; analysed monthly	High volume samplers at each of 10 environmental monitoring sites	Gamma spectrometric analysis – particulate and iodine [iodine at only 1 of 10 sites]
	TLDs , changed quarterly	Three TLDs at each of 10 environmental monitoring sites	Integrated quarterly gamma dose
Precipitation	Continuously sampled; composite of buckets from each environmental monitoring station analysed quarterly	One bucket at each of 10 environmental monitoring sites	H-3 in water; gross beta in water; gross beta on sample bags
Milk	Monthly	From at least 2 farms within 10 km of the site	I-131 [composite sample] H-3 [individual sample] C-14 [individual analysis]
Drinking Water	Sampled twice daily, composite analysed weekly	From drinking water supplies to neighbouring communities	H-3
	Composite analysed monthly	From drinking water supplies to neighbouring communities	Gross beta
Fish	Annually	Near station outfall	Gamma spectrometric analysis; H-3
Surrounding water bodies	Annually	Various locations	H-3; gross beta
Active drain water	Weekly	Hold-up tanks	H-3, gross beta, gamma spectrometric analysis

Thermoluminescent dosimeters

The types and numbers of equipment recommended are to be consistent with the above monitoring requirements and the monitoring program shall be in compliance with regulatory requirements for the ITER site.

22.2.2.2 Plant Exhaust Monitoring

ITER will have one gaseous exhaust point located at the top of the tokamak building. The gases will be monitored before they are released to atmosphere for tritium, air activation products and radioactive particulate. Both on-line and sampling instruments will be used together with volumetric flow measurements to provide information for compliance monitoring and on-line indication of discharge rates and daily integrated discharges.

22.2.3 General Requirements: for both Personnel Radiation Monitoring and Protection and for Environmental Monitoring Systems

22.2.3.1 Electrical

All instruments which may be adversely affected by power interruption shall be powered by a class II power supply. Each of the fixed monitors shall be hardwired to its individual circuit breaker.

22.2.3.2 Nuclear

All monitoring equipment shall be designed to function over an extended period of time in the radiation fields in which they are installed. Sensitive components, such as fiber optics, shall have a planned schedule of replacement where necessary to avoid radiation-induced failure.

22.2.3.3 Seismic

Portions of the RM&PS including the fixed area monitoring system and the HP control and records center shall be required to withstand a seismic load corresponding to a ground motion acceleration of 0.2 g (with a probability of 10^{-4} per year at the 50% confidence level as portrayed in the seismic hazard curve). The remaining portion of the RM&PS shall be required to withstand a seismic load corresponding to a ground motion acceleration of 0.05 g.

22.2.3.4 Instrumentation and Control

22.2.3.4.1 Monitoring System Network

The RM&PS shall have a dedicated network for transmitting signals and information that are indicative of recognized accidents. This network may not be utilized or shared by any other instrumentation and/or control system. The network must provide the capability for separate redundant signals.

22.2.3.4.2 Logic Processing, Control and Display

The logic processors, operator control interface and display information required for accident monitoring shall be located in the main control room and shall be separate from the CODAC. Data will also be collected from monitors by a dedicated network to an independent processing device.

22.2.3.5 Grounding/Insulation

Normally, all electrical equipment shall be firmly grounded to the site grounding grid. In special circumstances, high reliability requirements may dictate use of ungrounded equipment.

22.2.3.6 Materials

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 22-7 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

22.2.4 Operations and Maintenance

The operations and maintenance (O&M) requirements for the RM&PS are derived from the functions of the radiological monitoring and protection systems.

22.2.4.1 Operability

The RM&PS shall be designed such that minimum operating requirements can be met as specified in safety analyses.

22.2.4.2 Maintainability

Radiation and contamination monitoring equipment shall be standardized and modularized to the extent practical to enhance maintenance and reduce outage duration.

22.2.5 Surveillance and In-service Inspection

22.2.5.1 On-line Testing

All monitors shall have the capability of being tested on-line (without removal from service). If the monitor is connected to a circuit which actuates equipment or alarms, these functions can have a bypass and return-to-armed capability such that unwanted alarms and actions during testing are avoided, noting that in many cases the alarm actions will have to be tested simultaneously.

22.2.5.2 Source Testing for Fixed Area Alarming Tritium Monitors

All these tritium monitors shall have the capability of being tested in their field location with

a radioactive source appropriate for the instruments design function. No internal check sources are to be fitted to these monitors.

22.2.5.3 Source Testing for Fixed Area Alarming Gamma Monitors

All these gamma monitors shall have the capability of being tested in their field location with a radioactive source appropriate for the instruments design function. No internal check sources are to be fitted to these monitors as the routine detection of normal background will be used to confirm operation.

22.2.5.4 Calibration

All radiation/contamination monitors shall have the capability of being calibrated with secondary radioactive standard sources and other electronic means appropriate for the instruments design function. Calibration records and data shall be held in the HP control and records center.

22.2.6 **Quality Assurance (QA)**

The RM&PS equipment including the fixed area monitoring system, the HP control and records system shall be designed, manufactured, tested, commissioned, operated, maintained and decommissioned in compliance with the ITER QA program as it applies to safety importance class (SIC) systems. The remaining equipment shall be consistent with the QA requirements of non-SIC systems.

22.2.7 **Reliability Assurance**

The mean time between failure (MTBF) shall one per year for mechanical and electrical failures.

22.2.8 **Other**

22.2.8.1 Criteria for the Operation, Alarm Handling and Data Acquisition from the Monitors of the ITER RM&PS and Environmental Monitoring System

22.2.8.1.1 Introduction

The ITER RM&PS and environmental monitoring systems primarily serve a safety function to detect hazardous conditions. These systems will have the capability of generating continuous data, which will be stored and accessed using computer data acquisition techniques. The following criteria need to be taken into account when designing these systems to ensure that, as far as possible, the integrity of the safety function is not compromised.

22.2.8.1.2 Safety Function

- a. Monitors should be capable of operating at their place of installation independently of other systems and services, with the possible exception being the supply of electrical power. Either a guaranteed power supply or local uninterruptable power supplies (UPS) is to be used. The minimum time for monitors to run from any form of UPS when the main

- power has failed is typically one hour.
- b. Monitors should have, where specified, local audible and visual alarms. These are to be triggered from internal circuitry in the monitor when the measured parameter exceeds a pre-determined level. This level should be set only by controls in the monitor and these controls should not be accessible except to authorised personnel. The local audible and visual alarms are provided to warn personnel in that area that a hazard exists and personnel should be trained on actions to be taken in the event of an alarm. Not all monitors will require local alarms, such as the gaseous exhaust monitor, as they may be located in areas where there will normally be no personnel.
 - c. The monitors should have no switches, controls etc. accessible to personnel except authorised personnel. An exception to this criterion is that a means to mute an audible alarm can be provided, in situations where continued audible alarming may disrupt remedial activities (such as in the control room). This feature is a function of acceptability to licensing authorities.
 - d. The alarm condition of these systems is to be monitored by a central facility via hard-wired links. The signal monitored should come from volt-free contacts of a relay operated in a fail-safe configuration. from the trigger circuitry in the monitor. Fail-safe means that in normal operation the relay should be energised and the closed contacts monitored by the central facility. In the alarm condition the relay is to be de-energised and the open circuit state detected by the central facility and displayed accordingly. In this configuration a monitor will also give an alarm if the monitor losses power or if there is a break in the wiring between the monitor and the central facility.
 - e. Monitors may also provide a signal if a fault in the monitor is detected, which can also be monitored by CODAC.

22.2.8.1.3 Data Acquisition

Data will be routinely collected from monitors, either automatically or, such as in the case of samplers, manually. Automatic collection will be by a computer-based data acquisition system as defined and adopted by ITER. Such data should be processed so they are capable of being displayed in real time either in tabular or graphical form with indication of any alarm state. All data collected should be archived electronically for later analysis as required. Data acquisition techniques must not compromise the safety function of monitors. The rate at which data is collected is important, and depends upon specific local requirements.

Gamma, neutron, alpha and beta monitors essentially count pulses and usually generate a signal proportional to the pulse rate. Tritium monitors based on ionisation chambers produce analogue signals. For data acquisition by computer to take place some form of analogue-to-digital or pulse counts-to-digital conversion has to take place. These conversions are to be performed by individual instruments, so that each instrument produces a common form of output, and can be installed in any RM&PS location within the ITER plant.

22.3 Codes and Standards

The radiological monitoring and protection and environmental monitoring systems are a major part of the ITER HP program. They shall be supplied and operated to codes and standards that make them compatible with objectives of the HP program. The HP program will be determined by the relevant IAEA and ICRP codes and standards applicable at the time and throughout the lifetime of ITER and its decommissioning phase. The host country may also impose additional codes, standards and procedures to which ITER will adhere. The

quality assurance standards to be adopted for the production of the necessary equipment will be appropriate, normally from the ISO 9000 series, noting that standard and well-proven devices and techniques will be chosen for ITER. Enhancements to these systems will also be selected from proven devices and techniques

Operational practices will be subject to continuous review procedures to ensure that best practices are employed using experience gained at ITER and other nuclear plants.

Standard references in this practice are those recommended by the IAEA, and ICRP, such as ICRP-60.