Nuclear Safety Functions of ITER Gas Injection System Instrumentation and Control and the Concept Design

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Abstract The ITER Gas Injection System (GIS) plays an important role on fueling, wall conditioning and distribution for plasma operation. Besides that, to support the safety function of ITER, GIS needs to implement three nuclear safety Instrumentation and Control (I&C) functions. In this paper, these three functions are introduced with the emphasis on their latest safety classifications. The nuclear I&C design concept is briefly discussed at the end.

Keywords: ITER, GIS, I&C, nuclear safety

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(Some figures may appear in colour only in the online journal)

1 Introduction

GIS is an essential system for ITER [1]. It is provided by the Domestic Agency of China through a Procurement Arrangement (PA). In 2011, the conceptual design for the GIS was reviewed. Based on this review, the scope of GIS, its plant breakdown structure and its conceptual mechanical design are introduced in Ref. [2]. Another publication giving a global view of GIS is Ref. [3], which discusses the general requirements at the system level focusing on the aspects of gas puffing.

ITER is a nuclear facility, INB-174 (French nuclear installation number). It needs to maintain operational safety and needs to be capable of being brought to a safe state in case of incidents or accidents. The design, construction and operation of this nuclear facility are required to follow a licensing process in compliance with the French nuclear regulation.

Ref. [4] introduces the ITER safety and licensing status and discusses the basis of the safety performance of a fusion facility, and of ITER in particular. As stated in this paper, the two nuclear safety functions of ITER are confinement of radioactive materials and limitation of exposure in the whole lifecycle of the ITER project. The nuclear safety functions can be achieved through physical control, administrative control, instrumented control or the combinations. The GIS safety I&C functions are discussed in the second section. In the third section, there is an introduction to the concept design of these I&C functions, mainly the part within the GIS scope.

For the present phase of the ITER lifecycle and for the Protection Important Components (PIC) described in this paper the protection important activities are defined by the nuclear operator as for example safety demonstration, qualification of components, calculation codes, propagation of the defined requirements to the contractors or activities subject to monitoring and surveillance. It shall be noted that the present design is subject to evolution until its final approval by the nuclear operator.

2 GIS safety I&C functions

GIS is mainly involved in one of the ITER safety functions, confinement of radioactive materials. The preliminary safety analysis has identified PIC classification as SIC-1 and SIC-2 (SIC is the abbreviation of Safety Important Class, the safety classification in the ITER project).

The I&C categorization proposed in the present paper corresponds to on-going detailed design. Three safety I&C functions are allocated to GIS in support of the “confinement of radioactive materials”, namely, tritium process confinement of GIS, fusion power shutdown and isolation of Gas Fuelling System (GFS) from the vacuum vessel.

2.1 Tritium process confinement

ITER GIS gets gases from the Tritium Plant and provides them to fuel, control and terminate the plasma.
The GIS gases process lines are the first confinement of the tritium (the second confinement being the tokamak building). The volume inside the process lines can be divided into two parts: downstream flow from the gas injection valve until the exit of the gas fueling lines, this part of volume is connected with the ITER torus in vacuum; upstream from the gas injection valve until the interface with the Tritium Plant, this part of the volume is kept at the sub-atmospheric pressure level of about 0.9 bar absolute. The boundary of the first part of the volume is the first barrier of the confinement. In case there is a vulnerable component, e.g., bellows, a second layer would be added as the second barrier. This will be discussed in section 2.3. For the second part of the volume, there is a guard pipe enclosing all the process lines [5]. This guard pipe forms the second barrier of the first confinement.

These GIS components are categorized at the highest quality class and are designed, manufactured and installed with high standards. Based on the experiences it is highly unlikely to leak with this structure mainly consisting of continuously welded seamless stainless steel pipes. Despite that, the tritium confinement is monitored by continuous leak detection during the operation and regular maintenance.

The details of the leak detection are discussed in Ref. [6], though its conceptual scheme for the fueling manifolds is shown in Fig. 1. GIS fueling manifolds can be imagined as a tree with the root at the interface with the Tritium Plant and the branches stretching in two floors of the tokamak building to supply gases to the required physical interfaces. All the process lines are enclosed by a guard pipe and there is continuous nitrogen flow in this enclosure being constantly monitored. The nitrogen gas is fed into the enclosure from the farthest end of each branch so that all the space within the enclosure is covered by the purging flow. The purging gas is converged and exhausted to the Tritium Plant. There are detectors installed before this exhaust point to the Tritium Plant. The flow-rate of each gas feeding point is chosen to ensure all the technical restrictions being considered, such as, response time, gas load to the Tritium Plant, sensitivity of the sensors and buoyancy in the vertical part of the pipes.

Two pressure barriers are maintained between the tritium process line and the atmospheric pressure by keeping the process lines at the nominal pressure of about 0.9 bar absolute and the enclosure between the two barriers at about 0.95 bar absolute. In this way, in the unlikely case when there is a crack on the tritium process line (the first barrier of the first confinement) the flow leaking outwards will be prevented by the pressure difference in the opposite direction. Nevertheless, because of the active characteristics of tritium, there will be some molecules fleeing into the enclosure through the crack. Still they will be confined by the guard pipe (the second barrier of the first confinement) and detected by the enclosure gas monitoring. Since the tritium detector is usually very sensitive, even the extremely low concentration will be detected so that the operators can make further analysis and decisions. The actuating signals are from the monitoring of the purge flow. There will be an alarm for the operators but not necessarily automatic operation.

![Conceptual leak detection scheme of ITER GIS fueling manifolds](image)

**Fig.1** Conceptual leak detection scheme of ITER GIS fueling manifolds. The sketch shows tritium flows from the Tritium Plant building on the left to the right-hand side. The sketch is a simplified side view showing only one process line inside the guard pipe (instead of six process lines in the real case). The six GIS Gas Valve Boxes (GVBs) and three Pellet Injection System (PIS) GVBs in the lower level are represented by two boxes. The two identical boxes in the upper level represent the four GIS GVBs in this level. The one box on the upper right corner represents the four connections to the Disruption Mitigation System (DMS). The manifolds in two levels are connected by the manifolds through the “vertical shaft” as marked in the figure.
This I&C function is not required for ITER to reach a safe state. Instead, it is used to detect incidents or accidents. In case of failure, no incident or accident will be initiated and the exposure risk is not significant either. It is required to ensure the function of confinement monitoring. According to the on-going design, the I&C category is proposed to be SIC-2C.

It is also necessary to analyze the extremely unlikely (if not impossible) case of the double-guillotine break of the fueling manifolds. In this case, the guard pipe and the process lines are broken at the same time due to whatever reason. For this case, prompt detection and automation are needed. A safety signal is triggered once the process line pressure rises beyond a threshold, e.g., 0.92 bar absolute. Automatically and immediately the fueling manifolds shall be segregated reliably from the Vacuum Vessel and the Tritium Plant. The inventory of hydrogen isotopes in this sector is at a low level and the impact of the potential risk is small. The actuating signals are from the monitoring of the process line pressure. There will be automatic operation of closing the valves to segregate the process lines from the Vacuum Vessel and the Tritium Plant.

This I&C function is required to limit the consequences of an accident that would lead to significant risks of exposure. According to the on-going design, the I&C category is proposed to be SIC-1B.

The above discussion is on the fueling manifolds of GIS. There are also independent manifolds for neutral beam gas supply in which there are pressurized process lines. The general leak detection principle will be the same: monitoring the purging gas as SIC-2C I&C function, while monitoring the process lines’ pressure as SIC-1B I&C function.

### 2.2 Fusion power shutdown

It is essential to bring ITER to a safe state in case of accidents or incidents. There are different scenarios to terminate the plasma during the ITER operation [7]. Among them, Fusion Power Shutdown System (FPSS) is the last line of defence. It shall be able to stop the plasma assuredly to prevent the potential risk of exposure in case of accidental events, such as, the ex-vessel loss of coolant, plasma current exceeding safety limit.

ITER FPSS is based on massive gas injection technique. The key technical requirement is to inject a sufficiently large amount of neon into the ITER torus within a sufficiently short period of time upon request. The system is extremely rarely, if not never, used, and the maintenance is simple. Though it is a part of the GIS procurement, it is physically independent from the remaining part of the GIS. The mechanism of the potential risk, R&amp;D on the transient behavior studies and the configuration of the system can be found in Ref. [8].

The actuating signals are from the concerned plant systems. There will be automatic operation of opening the massive gas injection valves of the FPSS. This I&C function is needed to bring ITER into a safe state and the operation is required to limit the consequences avoiding significant risks of exposure. According to the on-going design, the I&C category is proposed to be SIC-2B.

### 2.3 Isolation from the vacuum vessel

During the ITER operation, gas injection lines are connected to the torus. In case of the adverse situation of the torus pressure surpassing that of the injection line, or even that of the gas supply (0.9 bar absolute), hazardous substances might have the risk of spreading out beyond the Vacuum Vessel boundary. To avoid this, pressure of the Vacuum Vessel shall be monitored and once a threshold pressure is reached, all vacuum lines connecting to the Vacuum Vessel shall be isolated, including the GIS lines. The actuating signals are from the monitoring of the torus pressure. There will be automatic operation of closing the valves to segregate the torus from the GIS injection lines.

This I&C function is for detection and mitigation of the hazard, and the risk concerning the half inch gas injection lines is low. According to the on-going design, the I&C category is proposed to be SIC-2C.

In section 2.1, there is mention of a second layer around the vulnerable components as the second barrier. This kind of enclosure usually has small volume and is filled with inert gas at about 0.5 bar absolute. The possible variation of the pressure helps the judgment on whether there is a leak on the first barrier or the second. The loss of the integrity of a single barrier will not initiate an incident or accident, the risk of exposure is low. The actuating signals are from the monitoring of the enclosures’ pressure. There will be an alarm for the operators but not necessarily automatic operation.

This I&C function is to ensure the monitoring of the confinement and, according to the on-going design, the I&C category is proposed to be SIC-2C.

### 3 Concept design of the GIS nuclear safety I&amp;C

All the I&amp;C of any ITER PA need to comply with the ITER Plant Control Design Handbook (PCDH), which defines standards, specifications and interfaces applicable to the ITER central controls and each plant system I&amp;C. This PCDH has been generally finalized in 2013 and is available on public CODAC web pages [9].

ITER I&amp;C consist of two horizontal layers, central control and plant system control and are vertically divided into three parts: CODAC, interlock and safety. They are connected through a few networks. PCDH defines the rules for standardization through the lifecycle of the plant system I&amp;Cs, so that all the ITER plant systems can be integrated as a whole [10,11].
It should be noted that nuclear safety I&C is a quite independent part. The communication between this part and the CODAC or interlock is only at the central control layer and is only in one direction, i.e., the Central Safety System (CSS) can provide signals to CODAC or Central Interlock System (CIS) for monitoring only. The nuclear safety I&C functions need to be equipped with their dedicated sensors, actuators, networks, cubicles and controllers.

Fig. 2 shows the nuclear safety I&C hierarchy by an example of a standard function. From bottom to top, safety signals are detected by sensors and judged at the Plant Safety System (PSS) level. Usually more than one plant system is involved in a function and CSS coordinates the required actions in all the relevant PSS. Data about this safety function are shown on the safety Human Machine Interface (HMI) for the operators and are sent to CODAC and/or CIS for information.

For the tritium process confinement function, the monitoring SIC-2C I&C function only involves GIS PSS and requires no actuator.

The “double guillotine” SIC-1B I&C function, the FPSS SIC-2B I&C function and the vacuum vessel isolation I&C function all involve other PSS and actuators are needed. Monitoring the integrity of a single barrier SIC-2C I&C function is a bit different from others because the pumping PSS will provide the sensor and no actuator is needed. It is a GIS function provided by another plant system due to the PA arrangements.

It is common that a nuclear safety I&C function involves multiple plant systems developed by different suppliers with different schedules. Therefore, it is important to trace and coordinate during the design. The physical and functional interfaces are recorded in the interfacing documents and reviewed in each stage for each plant system. Besides, CSS manages each of these functions at the project level and ensure the PCDH standards be met during the whole process. These are the essential bases for achieving the ITER goals successfully and safely.

4 Summary

ITER GIS consists of three parts: GFS for gas puffing; Gas Distribution System for distributing gases from Storage and Delivery System in Tritium Plant to clients like GIS and PIS; FPSS for terminating plasma reliably in case of accidents. Besides its functions for ITER plasma operation, GIS I&C also includes an essential part for nuclear safety to support safety function of ITER.

This article discusses all these three nuclear safety I&C functions of ITER GIS: tritium process confinement of GIS, fusion power shutdown and isolation of GFS from the vacuum vessel, and the latest ITER classifications are given.

The standard nuclear safety I&C design concept is shown. For these nuclear safety I&C functions, the preliminary design is expected to be reviewed in late 2016 and the final design review is expected in late 2017.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER organization.

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