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RAMI Approach for ITER

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ABSTRACT

ITER is an experimental nuclear device with an ambitious scientific and technological programme. To be able to reach its objectives an assessment of the technical risks has to be performed. The RAMI approach is one of the main stages of the technical risk control and it focuses on the operational functions required by the operation of ITER rather than on physical components. The ITER RAMI Process presented in this document, along with elements of the analysis performed on the Tokamak Cooling Water System provided as examples, consists of four major steps: (1) performing functional analysis, (2) analyzing initial failure modes, effects and criticality, (3) initiating risk mitigation actions to ensure compatibility with RAMI objectives, (4) integrating as RAMI requirements.

1. Introduction

ITER is constructed and will be operated to fully optimize the available time [1]. The machine operation will be carried out in three 8 h-shifts during typically 16-month operation periods separated by 8-month shutdown periods for maintenance and/or further installation. Named from its main components (**R**eliability: continuity of correct operation, **A**vailability: readiness for correct operation [2], **M**aintainability: ability to undergo repairs and modifications and "**I**nspectability": ability to undergo visits and controls), the RAMI approach, devised by ITER Organization to perform a technical risk assessment [3], uses an association of methods and dedicated software tools, allowing to define requirements for the operational functions and providing the means to ensure that they are met.

2. ITER RAMI process

The RAMI process begins during the design phase of a system because corrective actions are still possible at this stage, mainly in terms of design changes or choices, tests before assembly, allowance for accessibility and inspectability in the system integration, input for the operation or definition of the frequency of maintenance and of the list of spare parts. The process defined by Iter Organization (IO) and applied for the analysis of the Plant Systems, is focused on the functions required to operate ITER and their failure criticality. It is declined in 4 steps:

- *Functional Analysis* (*FA*): Creation of a complete functional breakdown describing the considered system from its main functions to the basic functions and components;
- *Failure Modes, Effects and Criticality Analysis* (*FMECA*): Establishment of a list of function failures, their causes and effects, according to their importance with respect to the machine operation availability; evaluation of the Severity of the effect and Occurrence of the cause of main failure modes and discrimination between major, medium and minor risk by using a criticality chart (*O*, *S*);
- *Risk mitigation actions*: Initiation of actions in terms of design, tests, operation and maintenance to reduce the risk levels. A new criticality assessment is made to evaluate the benefits of the risk mitigation actions. Then consistency between expected RAMI results and assigned RAMI targets for the system main functions is checked;
- *RAMI requirements*: Integration of the RAMI targets and required risk mitigation actions into system specifications.

The following sections develop this process and provide examples taken from the analysis performed on the Cooling Water System.

2.1. Functional analysis

The analysis of the systems is performed with a functional breakdown to define the structure of the system, function-wise and an assessment of reliability and availability performance of the functions by using Reliability Block Diagrams (RBDs).

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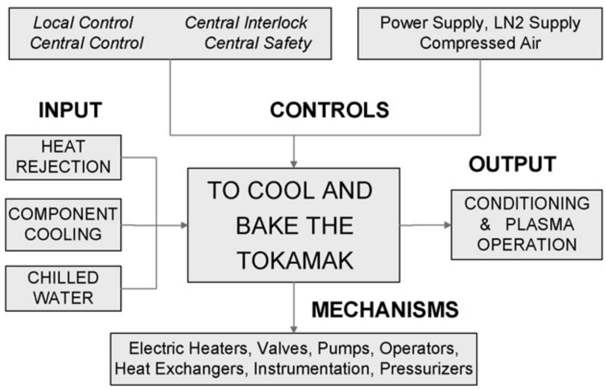

Fig. 1. Simplified functional analysis of TCW system showing the basic Input, Controls, Output and Mechanisms (ICOMs).

2.1.1. Functional breakdown

The functional breakdown of the considered system is a top-down description of the system as a hierarchy of functions on multiple levels, from the main functions fulfilled by the system to the basic functions performed by the components. The methodology is inspired by the **IDEFØ** (**I**ntegration **DE**finition **F**unction–language **Ø**) approach [4], based on the **SADT** (**S**tructured **A**nalysis and **D**esign **T**echnique) methodology [5].

The failures of components, highlighted at the level of the basic functions, lead to failure of the main function they are related to. Through this failure of a main function, it is a specific part of the whole operation of the system and of the machine that can be impacted. Fig. 1 displays a simplified view of the whole Tokamak Cooling Water System in the IDEFØ-inspired modelling. The main functions of the TCW System are primary heat transfer from the plasma-facing components, chemical and volume control draining, drying and refilling of the cooling loops. The Tokamak Cooling and Baking function can allow for conditioning and plasma operation (output) only if the other parts of the Cooling Water System (heat rejection, components cooling and chilled water as input) are operational. In order to perform this main function, it also needs both controls (control systems and utilities) and mechanisms (components and operators).

2.1.2. Reliability block diagrams

After having breakdown the main functions (Fig. 2), the next step in the RAMI analysis is a bottom-up approach relying on RBD to estimate the reliability and availability of each of its main functions according to given operating conditions. The RBD approach uses the functional breakdown as a basis, but concentrates on the reliability-wise relationships linking the function-blocks. Several diagrams allow describing the multiple levels in a hierarchy consistently with the functional breakdown, while the input data is fed to the lowest level blocks (components or basic functions), allowing to compute the resulting reliability and availability for the upper levels, up to the main functions of the system or the whole system itself. This input data consists in the reliability parameters such as the Mean Time Between Failure (MTBF) and maintenance parameters such as the Mean Time To Repair (MTTR) that can be obtained from various sources such as manufacturers' specifications, reliability database and industry standards, previous experience compiled on other scientific devices, or assumptions made following the personal experience of the RAMI analysts and experts available at the time of the analysis. In some cases, the available data may not be completely pertinent regarding the very specific experimental conditions the components will face on ITER, therefore an appropriate interpretation or estimation has to be carried out.

As the number of components and functions increases and the systems configuration is more complex, the calculations have to take into account elements such as series, parallels, *k*-out-of-*n*, redundancy. . . to provide reliability and availability ratings. Each of the 3 loops of the First Wall and Blanket (FW/BLK) Cooling regroups five key sub-functions: (1) coolant chemistry control, (2) coolant flow control, (3) radioactive products confinement, (4) coolant pressure control, (5) coolant temperature control. Fig. 3 displays the reliability block diagram of the first loop of FW/BLK Cooling (function level on the left), with the detail of the FW/BLK temperature control function (component level on the right). Reliability related data such as the MTBF and MTTR for the components or basic functions are gathered from various sources (experience on other facilities, published data) in order to allow computing initial reliability and availability of the system.

2.2. Initial failure modes, effects and criticality analysis

In parallel to the reliability block diagrams, a FMECA is performed to list the function failure modes and evaluate their risk level. As a function of this risk level, a decision is made to either accept or mitigate the failure modes. The FMECA uses both the functional breakdown and the RBD as input. The basic principles of the FMECA, as they are applied on every basic function identified

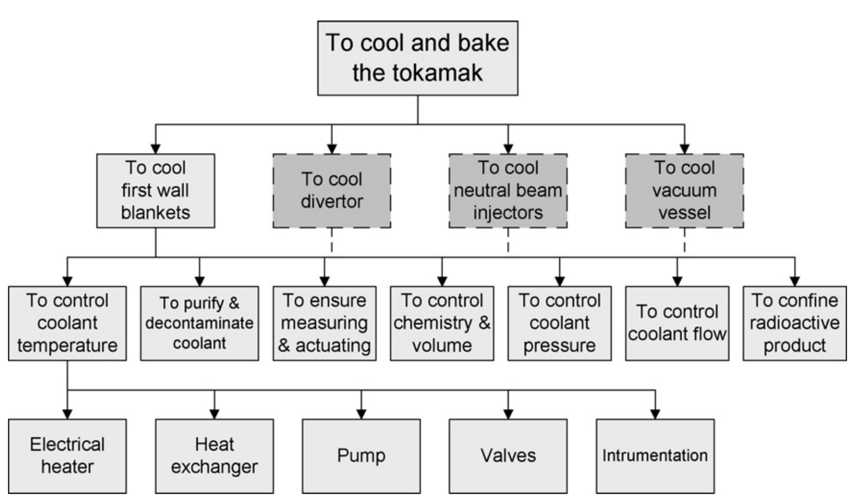

Fig. 2. Breakdown of the main function "To cool First Wall-Blanket Module" in basic functions and components.