RAMI Analysis of Neutral Beam Heating & Current Drive System for ITER

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1. Introduction

A RAMI (Reliability, Availability, Maintainability, Inspectability) analysis has been performed for the neutral beam (NB) heating and current drive (H&CD) system of ITER (International Thermonuclear Experimental Reactor) device. The objective of this analysis is to implement RAMI engineering requirements for the design and testing to prepare a reliability-centred plan for commissioning, operation, and maintenance of the system in the framework of a technical risk control to support the overall ITER Project. These RAMI requirements will correspond to the RAMI targets for the ITER project and the compensating provisions to reach them as deduced from the necessary actions to decrease the risk level of the function failure modes. The RAMI analyses have to match with the procurement plan of the system.

2. Task Processes

The methodology, which has been defined in an ITER RAMI analysis program, includes three main steps which have to be performed in close relationship with RAMI RO (Responsible Officer) and NB RO.

2.1 Input data collection for functional breakdown analysis

The whole ITER plant is considered as an assembly of systems connected between themselves and utilities. The first step of input data collection is to define a clear perimeter of the system to be RAMI analyzed and interfaces of the system with the other ITER systems, and with utilities among: power supplies, water cooling, compressed air, and CODAC infrastructure. Then, it is necessary to inventory the functions performed by the system using the IDEFØ methodology to break the functions down to the elementary components, with regard to the other systems and within the system itself, for every main operation states of ITER plant. This step corresponds to a top-down process.

2.2 RAMI Data Base

It will be translated the function breakdown as a functional description of the system by creating a project in the BlockSim toolkit™ of Reliasoft [1]. Then, it will be made a preliminary bottom-up reliability analysis by using the reliability block diagram (RBD) created in the BlockSim software.

2.3 FMEC Analysis

A list of all the function failure modes will be made, and the list indicates their causes and their effects on the function itself, the system and the overall ITER machine. For each function failure mode, the criticality level by giving figures for the severity of the effects, the occurrence of the causes and the non-detection level of the failures will be assessed. It will be translated the results in the "ITER Reliasoft XFMEA software tool™" making it possible to fill a "Function Failure Mode Identification & Analysis Card". Then, the analysis proceeds to the criticality initial evaluation for each failure mode by using the criticality diagram provided by the RAMI software and determine the risk level for each function failure.

2.4 Actions to decrease the risk level

These results propose the compensating provisions in terms of design optimizations, tests, operation procedures and maintenance actions to lower the risk level. The analysis proceeds to the criticality revised (estimated) evaluation, taking into account the compensating provisions, for each failure mode by using the criticality diagram (matrix) provided by the software and determines whether the revised risk level became acceptable or not.

3. Analysis Results

3.1 Functional breakdown analysis

An NB H&CD system shall provide neutral beam heating and current drive to the ITER plasmas. The required beam energy is 1 MeV, primarily to obtain deeply enough penetration of the neutral beam in the ITER plasmas and to heat & drive current, and finally to maximize the power per injector [2-4]. In each injector, the D^- ion beam of 40 A is neutralized to form a D^0 neutral beam, which delivers 16.7 MW to the plasma. Thus, the NB system provides H&CD power of 33 MW from two injectors, and can be upgraded to 50 MW in total with a third injector. The NB system will be able to operate for long pulses, up to 3,600 s. The specific function of NB system is only one and described as the following: The NB H&CD shall provide a heating & current drive of the ITER DT, D, H and He plasmas, accessing the H-mode and achieving Q>10. The current drive power shall provide steady-state current drive capability through on- and off-axis NB injection, which is carried out simultaneously with the heating function, achieving Q>5 for the central current drive.

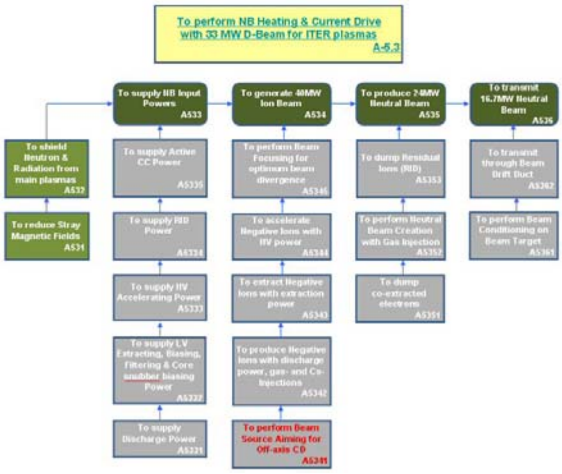

Fig. 1. Top-down levels of functional breakdown structure.

This functional breakdown was then transferred into Microsoft Visio following guidelines derived from the IDEFØ methodology. The next step of the functional breakdown was to implement this approved functional breakdown in the BlockSim7 software using RBD structures, and to complete it with components reliability and maintenance data in order to estimate the resulting reliability and availability of the functions. Initial reliability and availability are 91.6 % and 91.7 %, respectively. In these results, the NB system must be reliable at least for the duration of an experimental day, i.e. 16 hours between routine maintenance shifts. For an availability calculation, it is expected to have around 1000 hours of cumulated plasma pulse time over ITER lifetime of about 20 years.

3.2 Failure mode analysis and RAMI data base

After the functional breakdown analysis, the failure mode analysis has been carried out for the NB H&CD system in XFMEA_4 software. For the failure mode analysis, postulated failure modes, causes, and effects were listed by a discussion with RAMI RO and NB RO in ITER organization. Then, these postulated failures were saved as the input data of XFMEA_4. Each failure cause has to given weight by value 1 to 6 (and 5 for detection) for its severity, occurrence & detection scales. Total 232 failures were listed for the NB system in ITER machine. First analysis is to give initial severity, occurrence & detection scales considering system is installed and commissioned first time with mean time between failure (MTBF) values of the components and without considering any actions on design change, test between system operation, critical operation stage and maintenance between system operations. Second analysis is to suggest actions on design change, test between system operation, critical operation stage and maintenance between system operations according to revised (expected) severity, occurrence & detection scales. After the action suggestions, the revised reliability and availability are 91.7 % and 97.2 %, respectively.

3.3 FMEC analysis results

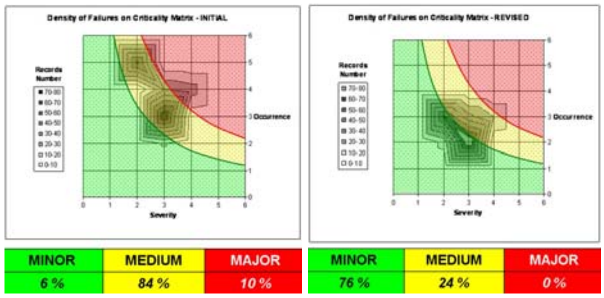

Fig. 2. Initial (left side) and revised (right side) criticality charts of the NB system for the ITER machine.

3.4 Preliminary operation and maintenance plan

XFMEA analysis suggests major and minor actions to bring down the criticality level of failure modes. These actions are related to design, operation, testing and maintenance. The operation states of the NB H&CD system are supported by a system requirement document (SRD) in addition to action supported by XFMEA [4]. Operation plans cover testing actions and detection methods for the failure mode of basic functions with a checking of interlock system before start of operation. Maintenance plans are also proposed for all basic function of the NB system for long term and short term. The spare parts required to maintain the system are also covered in the maintenance plan. In order to improve the maintainability of the NB system and to reduce the overall cost of the project, the some components shall be considered for standardization so that the other systems may use the standardized components.

4. Conclusions

The RAMI analysis of the ITER NB H&CD system has been performed, and the actions were suggested for mitigation of the major risks of failures. There has been requested spare parts and proposed the standardization for the preliminary operation and maintenance plan of the system. There was no-major risk of failures remaining in the NB system after implementation of the actions. The basis of RAMI requirements for the system has been prepared for the first time and will be included in a SRD.

REFERENCES

[1] http://www.reliasoft.com/.
[2] PBS 5.3 (PBS 53-01,-02,-03) in ITER IDM.
[3] DDD 2001 (DDD 53) : NB H&CD.
[4] SRD-42, SRD-42C, SRD-53.