Reliability and Safety Analyses of Upgraded Bulk Coolant Gamma Monitors of Dhruva

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Introduction

Dhruva, a 100 MWth research reactor, located at BARC Mumbai, provides a state-of-the-art facility for nuclear physics & engineering studies, and for production of radioisotopes useful for medical & industrial applications. This reactor is fueled by metallic Uranium, moderated, and primarily cooled by D_2O through three coolant loops. As primary coolant is in direct contact with clad of fuel assemblies, γ activity of D_2O is monitored continuously so that its unintended rise during failure of clad can be detected early; thereby limiting activity levels. Each of these three coolant loops have three identical Bulk Coolant Gamma (BCG) monitors (BCGM1/M2/M3, Ch-A/B/C) installed to track γ activity of D_2O. A reactor trip is generated in case of detection of high coolant activity by atleast two monitors of a coolant loop.

BCG monitors of Dhruva are classified as Safety Class-IA systems [1]. As per safety guide D-10; for Class-IA system performance criterion is the safety attribute. Hence, reliability and safety analyses along with Failure Mode & Effect Analysis (FMEA) of these monitors are carried out to check their compliance. The paper highlights the methods and standard used for the analysis along with results of the analysis.

Upgraded BCG monitor

Upgraded BCG monitor [2] consists of a 1″×1″ NaI(Tl) scintillator coupled to a Photo Multiplier Tube (PMT) based detector probe and an Electronic Processing Channel (EPC), as shown in Fig.1. The detector probe is installed in a well in D_2O circuit and is interfaced with EPC; located in Auxiliary Equipment Room (AER); using two RG-58 cables, one for carrying detector signal & other for carrying High Voltage (HV) for biasing PMT dynodes. EPC comprises of a signal processing module with HV (SPM), a Counting/Alarm generation module (C&RM), a low voltage DC module (LV) and 230V AC Power Supply (PS) module; all housed inside a ½ size, standard 19″ bin. The detector current changes in proportion to γ activity, is converted into voltage in EPC and used for generation of Coolant Activity High Trip. The monitor also has an isolated current output (4-20 mA) for online trending; and has several online diagnostics viz HV cable open, Low HV, HV Fail, Low Detector Signal, LV Fail & Built-in Scram facility to check effectiveness of High Activity trip.

Fig. 1 Upgraded BCG Monitor of Dhruva

Reliability Analysis of BCG monitors

The modules of EPC are composed of electronic components. Under the assumption that time to failure of EPC modules follows exponential distribution, for the reliability estimation of these modules, failure rate estimation using RIAC-HDBK-217Plus [3] has been used. Failure rate of detector probe is taken from operating experience and product handbook. The module-wise estimates of failure rates along with their Mean Time Between Failures (MTBF) are listed in Table 1 [4].

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MTBF of one channel is obtained using the modules' failure rates and channel Reliability block diagram (RBD) which is series connection of all modules of one channel. Similarly, MTBF of BCGM of one coolant loop is estimated using the RBD of Fig. 2. Considering failure rate of voting logic as zero, 100% diagnostics coverage and Mean Time to Repair (MTTR) as 8 hours, availability of BCGM of one coolant loop is estimated. These attributes are presented in Table 2 [4].

Table 1: Module-wise Failure Rates at 25 ^{o}C

Module	Failure Rate λ (FPMH)	MTBF (hrs)
LV	1.734	5,76,701
C&RM	0.674	14,83,679
SPM	0.302	33,11,258
PS	1.342	7,45,156
Back Plane	0.0037	27,02,70,270
Detector Probe	5.0	2,00,000

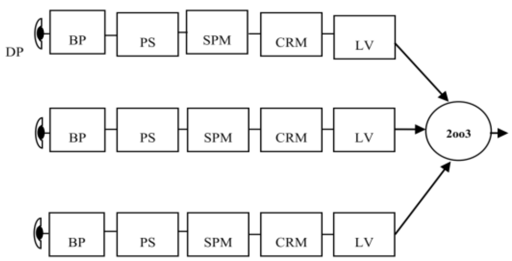

Fig.2 RBD of BCGM for One Coolant Loop

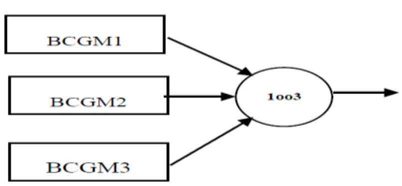

Fig.3 RBD of BCGM Reactor Trip

Table 2: Dependability attributes

Entity	Attribute	Value
One channel	λ_{ch} (FPMH)	9.055
	MTBF (hrs)	1,10,436
BCGM of one loop	Availability	0.9999
	MTBF (hrs)	92,030

Safety Analysis of BCG monitors

For system safety analysis, Probability of Failure on Demand (PFD) as per IEC 61508 [5] is estimated as BCG is a low demand system. PFD for BCGM of one loop is estimated to be 5.71×10^{-4}, considering 2-out-of-3 coincidence logic, MTTR of 8 hours, proof test interval of 3 months and no diagnostic coverage. The overall PFD, considering RBD of Fig. 3, is 1.866×10^{-10}.

FMEA of BCG monitors

Module level FMEA for BCG monitors is carried out for identifying & assessing potential failure modes of each module; and their effects on overall system functionality is analyzed. From this analysis, it is seen that every failure mode either leads to generation of fail-safe outputs or with the help of online diagnostics it is annunciated to draw Operator's attention.

Conclusions

Based on the above analyses, one BCGM has an Availability of 99.99%, MTBF of 92,030 hours and PFD of 5.71×10^{-4}. The overall PFD comes out to be 1.866×10^{-10}, thereby meeting the performance criterion [1,5]. By carrying out module-level FMEA, all possible failure modes of BCG monitors are identified and an investigation of effects of these modes provides assurance of detection of these faults, reducing their likelihood through reliability centered maintenance, and thus increasing availability of these monitors.

References

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