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Analysis of Safety-Critical Component Failure Modes in Nuclear Power Plant (NPP)

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1. Introduction

For the past two decades, the nuclear industry has attempted to move toward a condition-based maintenance philosophy using new technologies developed to monitor the condition of plant equipment during operation. Specifically, techniques have been developed to monitor the condition of sensors and their associated instrument loops while a plant is operating. Traditionally, instruments must be recalibrated at each refueling outage in accordance with nuclear regulations. One concern with periodic calibrations is that only the sensor's operating status is checked at every fuel outage, meaning that faulty sensors may remain undetected for periods of up to 24 months. Also, the traditional periodic maintenance method can lead to equipment damage and incorrect calibrations due to adjustments made under non-service conditions, increased radiation exposure of maintenance personnel, and possibly, increased downtime. In fact, recent studies have shown that less than 5% of the process instruments are in a degraded condition that requires maintenance [1].

Currently, Korea Atomic Energy Research Institute developed the NSSS Integrity Monitoring System (NIMS) which consists of 4 monitoring systems, Loose Part Monitoring, Internal Vibration Monitoring, Reactor Coolant Pump Vibration Monitoring, and Acoustic Leak Monitoring. So far, most developed monitoring systems are monitoring the specific status of target systems. Therefore, developed monitoring systems cannot evaluate status/integrity of components or systems.

In this study, the failure modes of safety-critical components are analyzed in nuclear power plant to develop the monitoring technology.

2. Safety-Critical Component

2.1 The Safety Functions

The concept of safety function introduces a systematic approach to mitigating the consequences of an event based on a hierarchy of protective actions. Carrying out the safety functions is implicit if the operator can quickly identify the initiating event from his event procedures. If the operator has difficulty for any reason, the systematic safety function approach allows us to accomplish the overall task of mitigating consequences. A safety function is defined as one or more actions that prevent core melt or minimize radiation releases to the general public. Action may result from automatic of manual actuation of a system, from passive system performance, or form natural feedback inherent in the plant design.

The actions described above may be separated into ten safety functions needed to mitigate events and contain radioactivity. These safety functions may be divided into four classes [2]:

1) Anti-core melt safety functions
2) Containment integrity safety functions
3) Indirect radioactive release safety functions
4) Maintenance of the vital auxiliaries needed to support the other safety functions

2.2 The Safety-Critical Components

The Safety-critical components included in safety-critical system can be usually divided into motor-driven valves (MOV) and pumps. In this paper, among the various pumps included in safety-critical component, high pressure safety injection pump (HPSIP) was selected for analysis of failure modes.

2.2.1 Motor-Driven Valves (MOV)

In Nuclear power plants (NPPs), Motor-driven valves (MOV) have been used to isolate the system flow. The piping systems in a typical nuclear power plant have hundreds of MOVs. Many of these valves are safety-related, which means that the safety of the plant depends on the ability of these valves to close or open when called upon to operate under the plant's design basis conditions [3].

2.2.2 High Pressure Safety Injection Pump (HPSIP)

The HPSI system is part of the emergency core cooling system (ECCS) that performs emergency coolant injection and recirculation functions to maintain reactor core coolant inventory and adequate decay heat removal following a loss-of coolant accident (LOCA). The HPI system is typically not in service during normal plant operations.

The HPSIP train segment includes the motor and associated breaker, but excludes the electrical power bus itself. Also, included with this segment is the pump and associated piping from and including the pump suction header up to and including test recirculation line is included if the associated tap off connects prior to the discharge isolation valve [4].

Table I: The design factor of HPSIP

Discharge Head	2850 feet (1235 psig, at rated flow)
Flow Rate	850 gpm (includes minimum)
Design Pressure	2050 psig
Design Temperature	350 F
Shutoff Head	4530 ft
Max. Flow	1165 gpm (includes minimum)
Head at Max. Flow	1580 ft (685 psig)
Horsepower	1000
Voltage	4160 Vac
Design Speed	3560 RPM

3. Results

The failure modes of HPSIP and MOV are analyzed respectively. The failure modes of HPSIP are divided into pump set faults and motor faults. As shown in Table 1, pump set faults consist of bearing, seal, O-ring, volute, shaft, impeller, balance and coupling faults. Table I is not intended to be diagnostic tables [5].

Table Ⅱ: The failure modes of HPSIP

Pump Set	Reason for Outage
Bearing	Wear Solidification and hardened oil Unbalance
Seal	Failure to stage Wear Dirt accumulation Excessive leakage Oscillation Cracked seal faces
O-ring	Corrosion Transform of ring deterioration
Volute	Wear of rotor Erosion
Shaft	Crack Unbalance Corrosion
Impeller	Wear Corrosion and wear due to cavitation Loosing due to change of current
Balance	Wear
Coupling	Unbalance Leakage of seal water Wear Cracked
Motor	Broken rotor bar Burn out Corrosion of motor due to high temperature

4. Conclusions

In this paper, the failure modes of safety-critical components are analyzed in nuclear power plant to develop the monitoring technology. The Safety-critical components are divided into motor-driven valves (MOV) and pumps. Therefore, MOV and high pressure safety injection pump analyzed the failure modes. These data will be used to develop the monitoring technology.

REFERENCES

[1] EPRI, “On-Line Monitoring of Instrument Channel Performance Volume 3: Applications to Nuclear Power Plant Technical Specification Instrumentation,” Final Report # 1007930, EPRI, Palo Alto, CA. 2004

[2] W.R.Corcoran et al., “The Critical Safety Functions and Plant Operation, Nuclear Technology”, Vol.55, 690-712, 1981.

[3]U.S Nuclear Regulation commission, “Gate Valve and Motor-Operator Research Findings”, NUREG/CR-600, INEL-94/0156

[4] DH.Lee, SG.Park, SD.Hong, BH.Lee, “Degradation characteristics of pumps in nuclear power plants”, The Korean Society for Noise and Vibration Engineering, 08S-24-05, 2008.

[5] ASME OM-S/G-2003, “Standards and guides for operation and maintenance of nuclear power plants”, The American Society of Mechanical Engineers, 2004.