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Extension of Surveillance Test Interval of Safety Injection Pump for APR-1400 Reactors to Improve Reliability and Availability of the Pump

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1. Introduction

Safety Injection System (SIS) one of the engineered safety features (ESF) systems which provide protection in the highly unlikely event of an accidental release of radioactive fission products from the Reactor Coolant System (RCS), particularly as the result of a loss-of-coolant-accident (LOCA). The safety features function to localize, control, mitigate, and terminate such incidents and to hold exposure levels below applicable limits [1].

The safety injection system is comprised of four independent mechanical trains without any tie line among the injection paths and two electrical divisions. Each train has one active Safety Injection Pump (SIP) and one passive Safety Injection Tank (SIT) equipped with a Fluidic Device (FD), each train provides 50% of the minimum injection flow rate for breaks larger than the size of a direct vessel injection line. For breaks equal to or smaller than the size of a direct vessel injection line, each train has 100% of the required capacity. The low pressure injection pumps with common header installed in the conventional design are eliminated, and the functions for safety injection and shutdown cooling are separated [2].

The arrangement of safety injection system for APR-1400 as shown in figure (1).

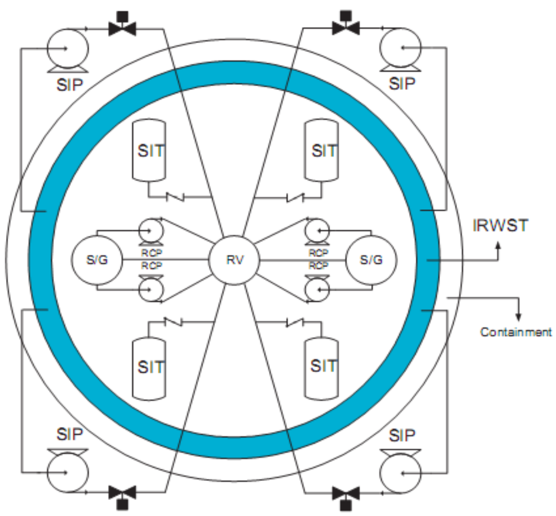

Fig. 1.Safety injection system arrangement.

1.1 Functions of safety injection pump

The four safety injection pumps are horizontal, multistage and centrifugal pumps driven by induction motors. Each pump can deliver water from In containment Refueling Water Storage Tank (IRWST) to the reactor vessel down comer via the Direct Vessel Injection nozzle (DVI), the functions of safety injection pump stated below [2].

- The primary function of the safety injection pumps is to inject borated water into the RCS if a break occurs in the reactor coolant pressure boundary.
- Safety injection pump flow is throttled to reduce RCS pressure to conditions that allow the initiation of shutdown cooling system operation for long term mode during shutdown cooling operations following a small break.
- Safety injection pumps can be utilized to achieve safe shutdown by providing makeup for volume contraction and by providing sufficient boron to achieve and maintain necessary shutdown margins.
- Safety injection pumps can also be utilized to provide injection flow during feed and bleed operations when Pilot Operated Safety Relief Valve (POSRV) is used for decay heat removal.

2. Methods and Results

2.1 Surveillance test extension

For APR-1400 the safety injection pump is tested every three months by running the system for about one hour, as well as related valves according to In-Service Test Program (ITP) in Technical Specifications (TS) and Limiting Condition of Operation (LCO) [2]. The extension of Surveillance Test Intervals (STIs) is performed to reduce the unnecessary maintenance activities performed on the pump this will improve the availability and reliability of the pump, system and the plant overall and reduce the maintenance cost as well. In this paper we study the extension of safety injection pump surveillance test and the economic impact from this extension, extending the surveillance test interval of APR-1400 Safety Injection Pump (SIP) from three months to six months would lead to an improved pump's availability, eliminate the unnecessary maintenance tasks and this will optimize maintenance activities. The new unavailability of the SI pump due to the change in STI is calculated from equation (1).

2.2 Unavailability of SIP due to Test &Maintenance

Table I: Current and proposed changes in STI.

Current STI		Proposed STI	
Current surveillance interval	3 Months	Proposed surveillance interval	6 Months
Current Surveillance Test duration	60 minutes	Proposed Surveillance Test duration	60 minutes

Unavailability of SIP due to extension of STI calculated from the following equation [3]

$$Q\ tm = \frac{[T1xF+T2]}{\text{Cycle time}} \quad (1)$$

Where:
Q tm: SIP unavailability due to test and maintenance
T_1: (Surveillance test+ Overhaul Test)
F: Testing frequency
Cycle time: Tow refueling periods
T_2 : Corrective maintenance time = (Downtime frequency x total cycle time x MTTR) = 8.42x10-5/hx36x30x24hsx20.9hrs =45.61hrs
Main Time To Repair (MTTR) = 20.9 hours.
Based on the historical record of the SI pump operation and performance, the MTTR of the SI pumps in Ulchin power plant units is 20.9 hours [4].

2.3 *Fault Tree model to calculate core damage frequency.*

The new unavailability calculated for the SIP due to extension of surveillance test interval is added to our modified APR-1400 safety injection system fault tree model to calculate the new Core Damage Frequency (CDF), using (SAREX,KEPCO E&C) [5]. SAREX is the computer software that can conduct reliability analyses or probabilistic safety assessments of industrial facilities including nuclear power plants. SAREX is developed by Korea Power Engineering Company (KOPEC). It's currently used in performing PSAs of nuclear power plants as well as in developing input models and software programs of risk monitoring systems, which can assess the increase in risk that may be resulted from maintenance activities in nuclear power plants. For the purpose of safety injection system fault tree construction. The new unavailability value is added to our modified APR-1400 SIS fault tree and the program executed to evaluate the new core damage frequency occasioned by the change in the surveillance interval the results is shown in table (II).

The extension for STI leads to an increase in SI pump availability and a corresponding increase in reliability. Total core damage frequency will be decreased due to the increase in pump availability. The decrease in the CDF resulting from SIP surveillance test extension to six months with a corresponding unavailability of 2.29E-3 can be calculated using SAREX software. Table (II) shows results of the base core damage frequency (CDF1) corresponding to STI three months and the core damage frequency (CDF2) which are corresponding to STI sex months. Reliability of SIP calculated from the following equation:

$$R\ (t) = 1 - Q\ tm \quad (2)$$

Where:
R (t): Reliability of the pump
Q tm: Unavailability of the pump
R (t) = 1-0.0020679 = 99.793

Unavailability value of 0.0022993 translates to reliability of 99.793 % in two refueling periods for the safety injection pump. From table (II) the new surveillance test interval is sex months.

Table II: Results of CDF change due to the unavailability of SIP during test for current and proposed STI.

STI (Month)	Duration (Minutes)	Unavailability due to T&M	CDF
3	60	0.0022993	1.25269E-06
6	60	0.0020679	1.24668E-06

From the following equation we can calculate the change in the CDF.

$$\Delta CDF = CDF1 - CDF2 \quad (3)$$

Where:
CDF1: Core Damage Frequency for the base case and,
CDF2: Core Damage Frequency the proposed case.
From table (2) the change in CDF due to increasing the surveillance test interval from three months to six months is 6.0194x10-9.
ΔCDF = 6.0194x10-9.

If the application of the proposed STI results in a decrease in CDF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to CDF. The CDF will decrease by 6.0194x10-9 and satisfying the acceptance criteria for CDF changes of regulation guide 1.174 [6].

As in figure (2). There are three regions as follow:

Region I

- Applications that result in increases to CDF above 10-5 per reactor year would not normally be considered.

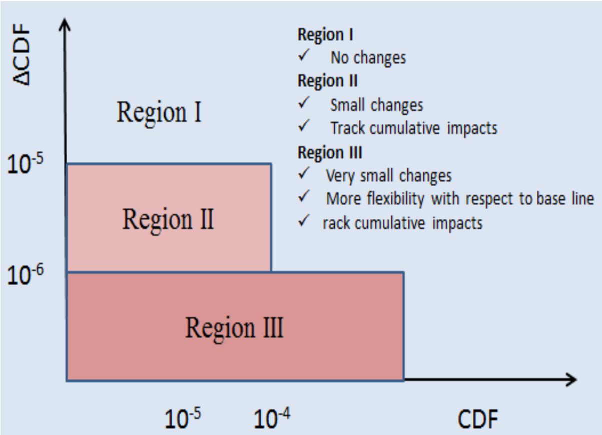

Fig.2.Three region for CDF changes acceptance criteria.

Region II

- When the calculated increase in CDF is in the range of 10-6 per reactor year to 10-5 per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than 10-4 per reactor year.

Region III

- When the calculated increase in CDF is very small, which is taken as being less than 10-6 per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF. While there is no requirement to calculate the total CDF. If there is an indication that the CDF may be considerably higher than 10-4 per reactor year, the focus should be on finding ways to decrease rather than increase it.

Due to the surveillance test interval extension from three months to six months, we can increase the number of condition based maintenance conducted on the pump to monitor the real status of the pump.

Condition Based Maintenance (CBM) is a maintenance strategy that uses the actual condition of the asset to decide what maintenance needs to be done. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure. Checking a machine for these indicators may include visual inspection, performance data and scheduled tests. Condition data can be gathered at certain intervals, or continuously (as is done when a machine has internal sensors) [7].

2.4 Types of Condition Based Maintenance

- Vibration analysis
  Rotating equipment such as compressors, pumps, and motors all exhibits a certain degree of vibration. As they degrade, or fall out of alignment, the amount of vibration increases. Vibration sensors can be used to detect when this becomes excessive.
- Infrared
  IR cameras can be used to detect high temperature conditions in energized equipment.
- Ultrasonic
  Detection of deep subsurface defects such as boat hull corrosion
- Acoustic
  Used to detect gas, liquid or vacuum leaks.
- Oil analysis
  Measure the number and size of particles in a sample to determine asset wear.
- Electrical
  Motor current readings using clamp on ammeters.
- Operational performance
  Sensors throughout a system to measure pressure, temperature, flow etc.

So we can add the following new condition based activities for safety injection pump maintenance activities, this maintenance task that is put into place to detect failure resistance to a specific failure mode. The detection of failure is based on a known potential failure condition.

Lubrication analysis can be used to detect wear incorrect lubrication failure mode and monitor the bearing oil quality, acoustic analysis can be used to detect the face/ shroud rubbing of impeller failure mode and monitor the impeller noise level. Infrared-thermography and motor current signature can be used to detect the failure of motor rotor, due to motor rotor band/shorting rings failure mode and monitor the circuit resistance.

2.5 Economics analysis

- The number of tests [8].
  - Number of trains: 4
  - Test interval : 3 months
  - Number of test per year : 16 times
- Number of employees required per test (Total: 6 people) [9].
  - MCR Senior Operator : 1
  - MCR Reactor Operator : 1
  - Local Reactor Operator : 1
  - Maintenance Staff(Mechanic part) : 1
  - Subcontractor Staff(Mechanic part) : 2

- Hourly labor costs:
  - Average labor cost of manager level in KHNP: 32,000 won/hour
  - Average labor cost of staff level in KHNP : 23,000 won/hour
  - Average labor cost of Subcontractor : 20,000 won/hour
- Average test duration: 1 hour
- Current labor cost per test:
  (32,000won/hour x 2persons+23,000won/hour x 2persons+20,000won/hour x 2person) x 1hour = 150,000 won/time.
- Current labor cost per year for four trains:
  150,000 won/time x 16 times = 2,400,000 won/year.
- Proposed labor cost by extending STI to six months:
  150,000 won/time x 8 times = 1,200,000 won/year.
- Reduction in labor cost for one year:
  (2,400,000 won/year -1,200,000 won/year) = 1, 2000,000.
- Reduction in labor cost for the design life:
  (2,400,000 won/year -1,200,000 won/year) x 60 years = 72,000,000 won.

It can be seen from the results above that there is a decrease in CDF due to STI extension from three months to six month and this allow the STI change, according to the CDF acceptance criteria, even the decrease in CDF is so small, this justifies the change in the technical specification so we can save time and money. With this small decrease, we do not need any improvements or modifications to compensate for that increase, due to this extension we will increase the number of condition based maintenance conducted on the pump to monitor the real status of the pump. Also from the economic point of view the total cost will reduce from 2,400,000 won/year to 1,200,000 won/year and along the design life the reduction in labor cost will be = 72,000,000 won for one unit of APR1400.

3. Conclusion

The results obtained in this work show that STI extensions for the SIS feasible without any unacceptable increase in the plant total risk, STI extensions are acceptable for safety injection system to provide plant operational flexibility in the performance of both corrective and preventive maintenance for the safety injection system. It will reduce the unnecessary maintenance activities which will improve the availability of the system and reduce the maintenance cost from 2,400,000 won/year to 1,200,000 won/year and along the design life the reduction in labor cost will be = 72,000,000 won for a unit of APR1400.

ACKNOWLEDGEMENTS

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