The Alternative Design Features for Safety Enhancement in Shutdown Operation

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1. Introduction

PSA can be used to confirm that the new plant design is complied with the applicable safety goals, and to select among the alternate design options.

A shutdown PSA provides insight for outage planning schedule, outage management practices, and design modifications. Considering the results of both LPSD PSA studies and operating experiences for low power and shutdown, the improvements can be proposed to reduce the high risk contribution.

The improvements/enhancements during shutdown operation may be divided into categories such as hardware, administrative management, and operational procedure.

This paper presents on an example how the risk related to an accidental situation can be reduced, focusing the hardware design changes for the newly designed NPPs

2. The Proposed Alternative Design from the Insights of LPSD PSA

Figure 1 shows a graphical representation of the risk profile associated with a typical KSNP refueling outage. The risk can be seen to reach its peak during PSV test . and the second critical state of the plant corresponds to situations for which the reactor coolant system is open associated with a low water inventory. As shown in the table 1, the LPSD PSA's results for KSNP[Ref 1] indicate that several dominant core damage sequences include the special initiating events and failure of the recirculation operation. In order to reduce significantly the CDF due to this sequence it is considered that most efficient solution is to improve the hardware failure by several means, and moreover to implement an automatic system.
The specific improvement for 3 dominant events is suggested based on the PSA results in this paper. Those are minimizing the probability of an initiating event and increasing the availability of systems to cope with initiating events.

1) The PSV LOCA frequency in POS 2

As shown in the table 1, the PSV LOCA event (I-PLP02) due to stuck open during PSV popping test is the most dominant cutest.
One of the enhanced safety features to reduce this probability is the adoption of POSRVs(Power Operated Safety and Relief Valves) instead of PSV. The data for the POSRV fail to close is obtained from the experiences of French operating plants [Ref 2], and the failure rate from the operating experiences is quite low compared to that of PSVs presented in the KSNP as shown in the table 2. If the POSRVs are applied , the CDF due to PSV LOCA may be reduced almost 2 order of magnitude.

2) The loss of shutdown cooling frequency due to over draining in POS 5

As shown in the table 1 and 2, the loss of shutdown cooling during mid-loop operation (POS 5) due to excessive draining of the RCS (I-SOP05) is the second dominant cutset. This initiating event can occur when the RCS level is lowered to mid-loop operation level to carry out SG inspections. At this level, an extra lowering of the RCS level can induce vortex occurrence (water-air mixture) on the inlet side of the SCS pumps.

The enhanced safety features against this event is to add the a diverse signal consisting of LPSI pump low suction pressure to actuate the HPSI pumps during mid-loop to reduced the overdraining probability
Even though the additional instrumentations related with monitoring the RCS level have been provided in the KSNP, the proposed alternative design can reduce the initiating frequency moreover.

3) The probability of recirculation failure due to containment sump plugging in POS 4,5 and 6

As shown in the table 2, the most important cutest is the containment sump plugging events in POS 4,5 and 6 (SISPP-POS456).
The majority of the maintenance activities are started during these POSs. The sump plugging failure

probability will be increased due to the many obstacles during these POSs. The sump represents the lowest point in the containment and any water discharged from the RCS will drain back into the sump. In order to reduce the plugging probability, the new sump design is proposed. The stack-type sump which are much more expanded on the surface area compare to the existing sump is effective, and the retaining filter stop smaller debris at the sump inlets. This alternative design may reduce the failure probability to one order of magnitude.

3. Conclusions

The specific improvement examples are suggested based on the LPSD PSA results in this paper. In order to reduce significantly the CDF due to the special events it was considered that most efficient solution by several means. With all these improvements the estimated total CDF can be reduced the one order of magnitude.

REFERENCES

[1] SINKORI Unit 1&2 LPSD PSA REPORT, 2009
[2]APR-1400 SSAR CHAPTER 19, 2003.
[3]NUREG/CR-6144, "Evaluation of Potential Severe Accidents During Low Power and Shutdown Operations at Surry, Unit 1", Final Report, BNL, September 1995.
[4] NUREG-1449, "Shutdown and Low-Power Operation at Commercial Nuclear Power Plants in the United States ", Final Report, USNRC, September 1993.

Table 1. Minmal cutsets of LPSD PSA for the current KSNP design

No	%	minimal cutsets			
1	21.4	I-PLP02 a)	SIMVWD2675676		
2	8.6	I-SOP05 b)	HR-MK-SOP05	HR-FS-SOP05-FS2-DE1	
3	7.7	I-S1P05	HR-RS-S1P05	HR-RS-IEPAL	SISPP-POS456
4	4.9	I-SOP05	SIMPSPP01BB	SISPP-POS456 c)	
5	4.7	I-S2P05	HR-RS-S2P05	HR-RS-IEPAL	SISPP-POS456
6	3.6	I-PLP02	SISUPSUMP		
7	2.6	I-CCP05	HR-RS-S2P05	HR-RS-IEPAL	SISPP-POS456
8	2.6	I-PLP02	HR-DPI-SL	SIMVW8MVQ4	
9	1.7	I-SOP05	NR-MVRS	SIMVO658B	SISPP-POS456
10	1.7	I-SOP05	NR-MVRS	SIMVO306B	SISPP-POS456
11	1.7	I-SOP05	NR-MVRS	SIMVO656B	SISPP-POS456
12	1.3	I-SOP05	SISPP-POS456	VYCQSHV02BB	
13	1.2	I-SOP05	SISPP-POS456	VYOPVHV234AB	VYSKYHV02BB
14	1.2	I-PLP02	SIMV0675A	SIMVO676B	
15	1.2	I-SOP05	HR-RS-S1P05	HR-RS-IEPAL	SISPP-POS456
16	1	I-PLP02	HR-DPI-SL	SIMPWD2PP02A02	
17	0.9	I-PLP02	HR-DPI-SL	SIMPKD2PP02A02B	
18	0.7	I-S2P04B	SIMPSPP01BB	SISPP-POS456	
19	0.7	I-PLP02	HR-DPI-SL	VYCQWD2HV04A04B	
20	0.6	I-S2P06	NR-MVRS	SIMVO306B	SISPP-POS456

Note a) I-PLP02 : PSV LOCA initiator in POS 2

b) I-SOP05 : loss of shutdown cooling initiator due to over draining in POS 5

c) SISPP-POS456 : Containment sump plugging event in POS 4,5,&6

Table 2. Estimated values for the proposed alternative designs

rank	(F-V)	event	used value (mean)	estimated value (mean)	comments
1	0.46	SISPP-POS456	1.00E-01	1.00E-02	1 order reduction
2	0.36	I-PLP02	6.00E-03	1.70E-05	2 order reduction
3	0.27	I-SOP05	1.77E-03	9.00E-04	50% reduction

Fig 1. The risk profiles during refueling outage for typical KSNP