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Original Article

Analysis of multiple spurious operation scenarios of Korean PHWRs using guidelines of nuclear power plants in U.S.

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ABSTRACT

Multiple spurious operations (MSOs) mean multiple fire induced circuit faults causing an undesired operation of one or more systems or components. The Nuclear Energy Institute (NEI) of the United States published NEI 00-01 as guidelines for solving MSOs. And this guideline includes MSO scenarios of pressurized water reactor (PWR) and boiling water reactor (BWR). Nuclear power plant operators in U.S. analyzed MSOs under MSO scenarios included in NEI 00-01 and operators of PWRs in Korea also analyzed MSOs under the scenarios of NEI 00-01. As there are no pressurized heavy water reactors (PHWRs) in the United States, MSO scenarios of PHWRs are not included in the NEI 00-01 and any feasible scenarios have not been developed. This paper developed MSO scenarios which can be applied to PHWRs by reviewing the 63 MSO scenarios included in NEI 00-01. This study found that seven scenarios out of the 63 MSO scenarios can be applied and three more scenarios need to be developed.

1. Background

1.1. Regulation trends of U.S.

The United States Nuclear Regulatory Commission (U.S.NRC) confirmed that multiple circuit faults can have a negative effect on safe shutdown devices based on test results and incidents. NRC published EGM 09-002 in 2009 where it requested multiple spurious operation (MSO) analyses to be made within six months from the issue of R.G 1.189 (rev.2) [4] and any detected problems to be fixed within two years. Most of American nuclear power plant operators performed analyses on MSOs as per NEI 00-01 [3], a guideline for post-fire safe-shutdown circuit analysis, and took measures to address problems for improvements.

1.2. Regulation trends of Korea

Article 12 (Details of post-fire safe-shutdown analysis) of the Notice No. 2015-11 of the Nuclear Safety and Security Commission [1] required nuclear power plant operators to perform circuit analysis of MSOs in post-fire safe-shutdown analysis. Also, Korea Institute of Nuclear Safety (KINS), the Korean regulatory agency of nuclear energy, in 5.3.1 (Verification and evaluation of post-fire safe-shutdown circuits) and 10.6 (Fire protection of nuclear plants) of the Regulatory Guideline on Pressurized Water Reactor (PWR) it published in June 2016, provided that post-fire safe-shutdown circuit analysis can be performed by referring to NEI 00-01 [3] approved by RIS 2005-30. Accordingly, Korean nuclear plant operators have analyzed MSOs based on NEI 00-01 [3], the guidelines for post-fire safe-shutdown circuit analysis.

1.3. Purpose

Nuclear power plants in operation in Korea can largely be classified into pressurized water reactors (PWRs) and pressurized heavy water reactors (PHWRs). Designed by the Atomic Energy of Canada Limited (CANDU Power), PHWRs differ from PWRs in terms of plant layout, design concept of major systems, and the concept of safety system isolation. For example, PWRs focus on securing the redundancy of systems and equipment which perform the same safety function. But PHWRs focus on securing the diversity of systems and equipment which perform the same safe function.

MSO scenarios of PHWRs are not included in the NEI 00-01 [3] because there are no PHWRs in U.S. and MSO scenarios which can be applied to PHWRs have not been developed. Therefore, this paper developed MSO scenarios which can be applied to PHWRs

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currently in operation in Korea by reviewing the 63 MSO scenarios of NEI 00-01 (rev.3) [3].

2. Characteristics of PHWRs

The representative characteristics of PHWRs can be classified into types of moderators, operation modes, and goals and functions required for accomplishing post-fire safe-shutdown. PHWRs use natural uranium (0.72%) as fuel and heavy water as neutron moderator and allow boiling of about 4% unlike PWRs which do not permit boiling. Accordingly, PHWRs and PWRs have different operation modes as shown in Table 1.

R.G 1.189 (rev.2) [4], the fire protection rules of PWRs, states that a set of multiple systems and components necessary for accomplishing hot shutdown must be free of fire damage when a fire breaks out in nuclear power plants, and that, despite simultaneous failure of multiple systems and components necessary for cold shutdown, at least one system must be repaired and restored in 72 h.

On the other hands, CAN/CSA-N293-12 (2012) [2], the fire protection rules of PHWRs, does not have any separate rules related to systems and components for hot shutdown and cold shutdown, and states that the ability to perform safety functions must be secured to achieve safe shutdown under all operation modes. Comparison of safety functions of PWRs and PHWRs is shown in Table 2.

PWRs (OPR-1000) consist of containment building, primary auxiliary building, secondary auxiliary building, complex building, fuel building, turbine building, and emergency diesel generator building. PHWRs have reactor building, service building, turbine building, secondary control and emergency diesel generator area. For PWRs, the main control room designed according to the concept of "alternative shutdown" and the remote shutdown control panel which can operate identical systems and components are located in the same building. On the contrary, PHWRs are designed for "dedicated shutdown" and operate the secondary control area which uses different systems and devices from those of the main control room. The secondary control area is located in a room outside of the building where the main control room sits (See Fig. 1).

The safety system of PWRs consists of redundant systems (Train A, B) and components which perform the same function based on the concept of redundancy. In contrast, the safety system of PHWRs consists of two separate systems (Group 1 and Group 2) which perform the same function, based on the concept of diversity. To maintain each group's functional independence, the safety system of PHWRs is designed to keep functional independence and meet physical isolation requirements and to deal with "random failure" (safety system is activated in case of problems with control of the main process system or when measured variable value exceeds the set limit) and "common mode failure" (functions of multiple systems are paralyzed by a single accident). Group 1 gets its power supply from the normal power system and is controlled by the main control room. Group 2 is powered by the emergency power supply system and is controlled by the second control area. (See Fig. 2).

Additional considerations for MSO analysis of PHWRs in terms of types and characteristics of safety systems of PHWRs are as follows:

- Reactor trip system: Reactor trip systems of PHWRs are divided into the first shutdown system that inserts control rods and the second shutdown system which controls the concentration of gadolinium. Unlike PWRs, PHWRs do not use boric acid solution to control reactivity.
- Auxiliary feed water and shutdown cooling system: Auxiliary feed water system of PHWRs has only one pump, unlike PWRs that have redundant system pumps. If the auxiliary feed water system function is lost, residual heat removal function is performed by the shutdown cooling system.
- Shutdown cooling system: The shutdown cooling system of PHWRs is designed to supply coolant to the primary side under normal pressure, unlike residual heat removal system or safety injection system of PWRs.
- Main steam system: Both PWRs and PHWRs have atmospheric steam discharge valves, and main steam safety valves. As for PHWRs, subcooling of the primary side caused by the opening of valves does not have a negative effect on the residual heat removal function as negative reactivity is inserted. As for PWRs, in case of subcooling in the primary side due to the opening of the valves, positive reactivity is inserted and core power increases, which can have a negative effect on the residual heat removal function.
- Systems which act as a barrier to fission product release: CAN/CSA-N293-12 [2], the fire protection regulations of PHWRs, states that, in order to prove that radioactive substances or fission products of the reactor coolant system are not leaked, the integrity of reactor coolant system, reactor auxiliary system, and containment system must be secured and coolant which exceeds the capacity of the pressure and inventory system must not be leaked.

3. Analysis of MSO scenarios

In order to determine the applicability of each scenario to PHWRs, materials for evaluating design and safety, such as Design Criteria, Design Manual, Design Guide, Technical Specification, Final

Table 1
Operation mode - PHWR vs. PWR.

Classification	PHWR			PWR		
Operation mode	Reactivity conditions (K_{eff})	Reactor power	Coolant system Reactor vessel outlet Header temperature (°C)	Reactivity conditions (K_{eff})	Reactor power	Cold leg temperature(=A) (°C)
1. Power operation	≥0.99	>2%	>260	≥0.99	>5%	≧ 177
2. Low power standby	≥0.99	>2%	>100	≥0.99	≤5%	≧ 177
3. Hot standby	No applicable			<0.99	0	≧ 177
4. Hot shutdown	<0.99	0	>100	<0.99	0	177 > A > 99
5. Cold shutdown	<0.99	0	≤100	<0.99	0	≤99
6. Guaranteed shutdown	No applicable	0	≤90	No applicable		
7. Refueling	No applicable			≤0.95	0	≤57

Table 2
Comparison of safety functions - PHWR vs. PWR.

Classification	PHWR	PWR
Fire protection regulations	CAN/CSA-N293-12(2012)	R.G 1.189(rev.2)
Articles	5.4 Nuclear Safety Objectives and Performance Criteria	5.1 Post-fire Safe-Shutdown Performance Goals
Safety functions	a. Reactor Shutdown	a. Reactivity Control Function
	b. Barrier to Fission Product Release	b. Reactor Coolant Makeup Function
	c. Decay Heat Removal	c. Reactor Heat Removal Function
	d. Monitoring of Plant Parameters	d. Process Monitoring Function
	e. Support Services	e. Supporting Function

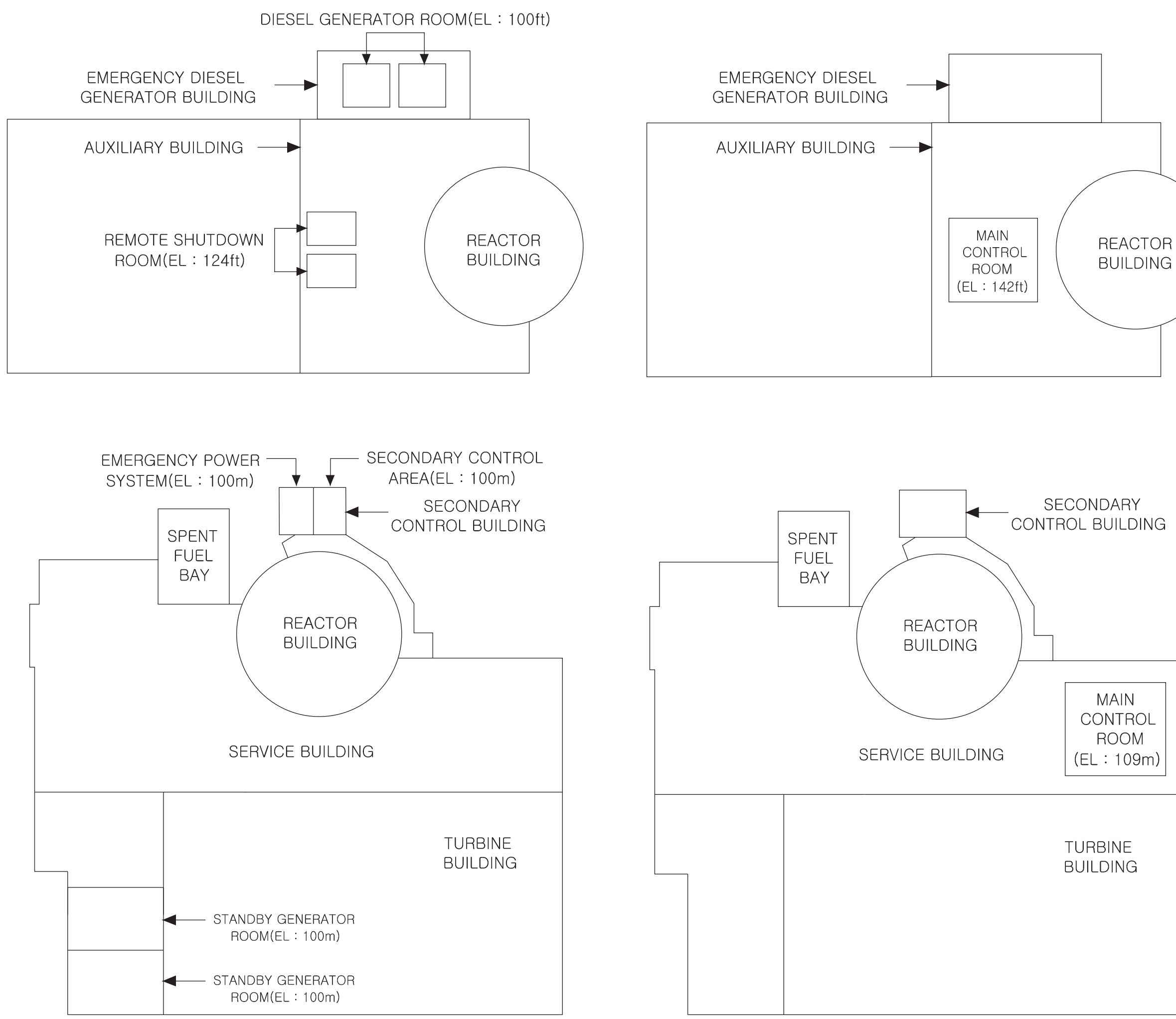

Fig. 1. Schematic Diagram of arrangement of PWR (Top) and PHWR (Bottom).

Safety Analysis Report, Probabilistic Safety Assessment Report, Operating Procedures (General, Abnormal, Emergency), and Electrical Diagram (Wiring, Cable Block, Schematic, and Control Logic) were analyzed. Furthermore, to provide analysis results to expert panels (in the fields of Fire Protection, Fire Safe Shutdown Analysis, Probabilistic Safety Assessment, Operations, System Engineering, and Electrical Circuits), statements, success path drawings, and component combinations by scenario were prepared. Finally, MSO scenarios for PHWRs were developed through meetings with the expert panels. The criteria to determine the applicability of scenarios of NEI 00-01 [3] to PHWRs are as follows. And details of each scenario are shown in 4.1–4.3. The analysis shows that seven MSO scenarios of 63 scenarios listed in the NEI 00-01 [3] can be applied to PHWRs and three scenarios need to be newly developed.

- Newly developed scenarios: in case that it is difficult for scenarios of NEI 00-01 [3] to be applied to PHWRs according to their characteristics.

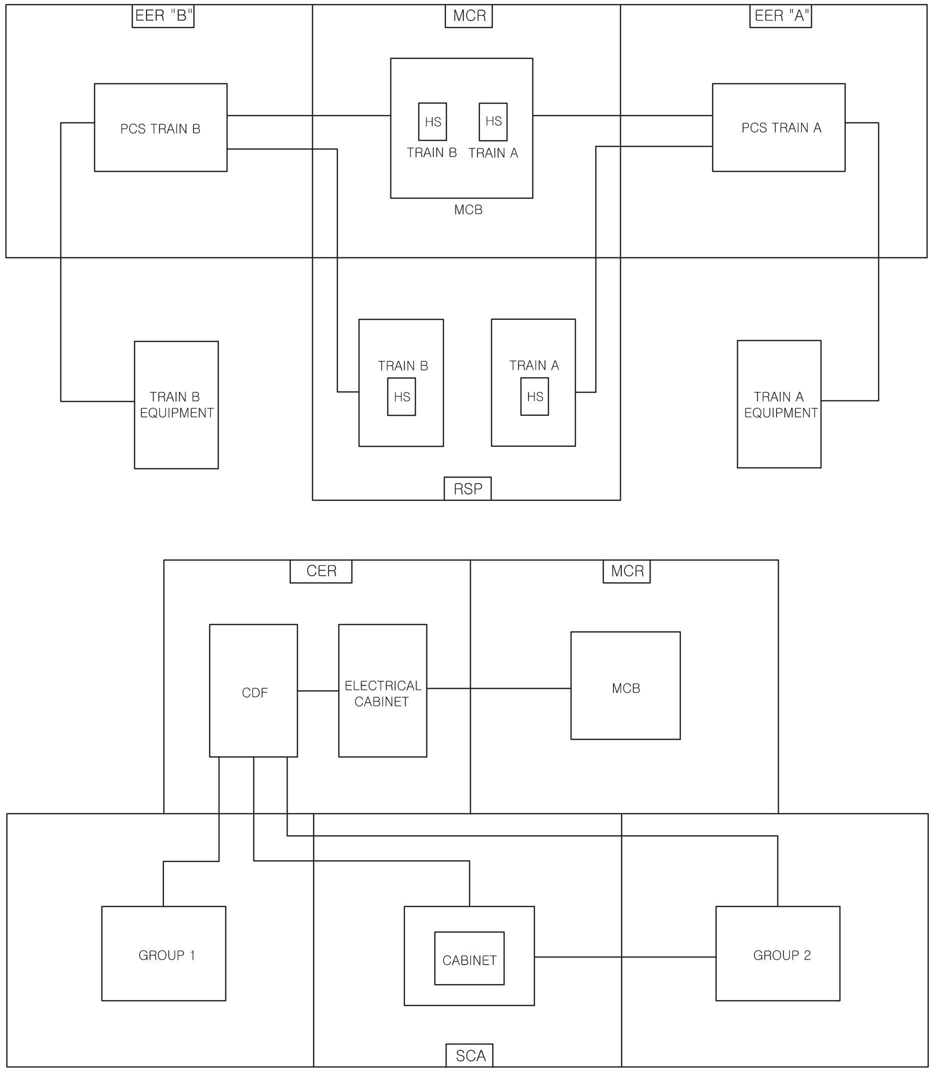

Fig. 2. Schematic Diagram of wiring of PWR (Top) and PHWR (Bottom).

- Applied scenarios: Scenarios of NEI 00-01 [3] can be applied without modification or with simple modification (e.g., changing words or component combinations).
- Non-applied scenarios: Scenarios that were already considered in post-fire safe-shutdown analyses of PHWRs (2011) [5] or scenarios whose component combinations are overlapped with those of other scenarios were not applied.

3.1. Newly developed scenarios

Scenarios 1 to 5 of NEI 00-01 [3] assume a situation where damaged sealing of reactor coolant pumps impedes inventory functions of the reactor coolant. The device of PHWRs that performs the same function as reactor coolant pump of PWRs is primary heat transport (PHT) pumps. Like PWRs, if sealing of PHT pumps is damaged, seal water is leaked and thus fission product barrier function can be lost [6]. Scenarios (Scenarios 1a, 1b, and 1c) shown in Table 3 were newly developed because scenarios 1 to 5 cannot be directly applied to PHWRs.

3.1.1. Scenario 1a: loss of PHT pump seal cooling

Following loss of recirculated cooling water, the PHT pump bearing temperature will increase to give alarm. Failure of the bearings is assumed to occur at about one hour. Bearing failure leading to a LOCA are postulated on the operator's failure to trip the PHT pumps and the automatic trip function failure. The break size is indeterminate, LOCA.

In order to experience the above conditions, while PHT pumps (P1 to P4) continue to operate or fail to stop, raw service water supply to recirculated cooling water heat exchangers (HX7001 to HX7004) must be suspended; supply valves (MV7011 to 7014 and MV7020 to MV7023) of component cooling water must be closed; PHT pump circulation valve (PV26/29/32/35) must be closed. In this scenario, the sealing integrity of PHT pumps can be lost (See Fig. 3).

3.1.2. Scenario 1b: loss of PHT pump seal cooling

Following loss of service water, if hot heavy water from the purification system through the bleed bypass orifice is not isolated, hot heavy water from purification system mixes with cold heavy water from storage tank to provide the feed pump total flow. It is assumed that the resultant hot heavy water (after mixing with cold heavy water) will cause failure of the PHT pump seals after 40 min. The bleed flow should be isolated on recognition of the loss of service water to prevent seal failure. If the operator fails to isolate the bleed flow or fails to trip the PHT pumps, seal failures occur

Table 3
New scenarios comparative table - PHWR vs. PWR.

PHWR		PWR	
Scenario No.	Description	Scenario No.	Description
1a	{(Loss of RCW) OR (Spurious isolation of RCW flow to motor bearing)} AND constantly operation (or fail to tripping) of PHT pump(s)	1	Spurious isolation of seal injection header flow AND Spurious isolation of CCW flow to Thermal Barrier Heat Exchanger (TBHX)
		2	Spurious opening of valves causing flow diversion away from seals, AND Spurious isolation of CCW flow to thermal barrier heat exchanger
1b	Loss of RCW (occur temperature increase in purification system) AND Spurious opening of D_2O Purification system isolation valve AND Spurious opening of Discharge isolation valve AND Spurious opening of level control valves	3	Loss of all seal cooling to any RCP(s). See Scenarios 1 & 2, AND Spurious re-initiation of seal cooling (i.e., seal injection or CCW to TBHX)
		4	Loss of all seal cooling to any RCP(s). See Scenarios 1 & 2, AND Fire prevents tripping, or spuriously starts, RCP(s)
1c	Loss of RCW to Degasser condenser heat exchanger AND {(Spurious opening of level control valves) OR (Spurious opening of isolation valve)}	5	Loss of all seal cooling to any RCP(s). See Scenarios 1 & 2, AND Spurious isolation of No. 1 seal leak-off valve(s)

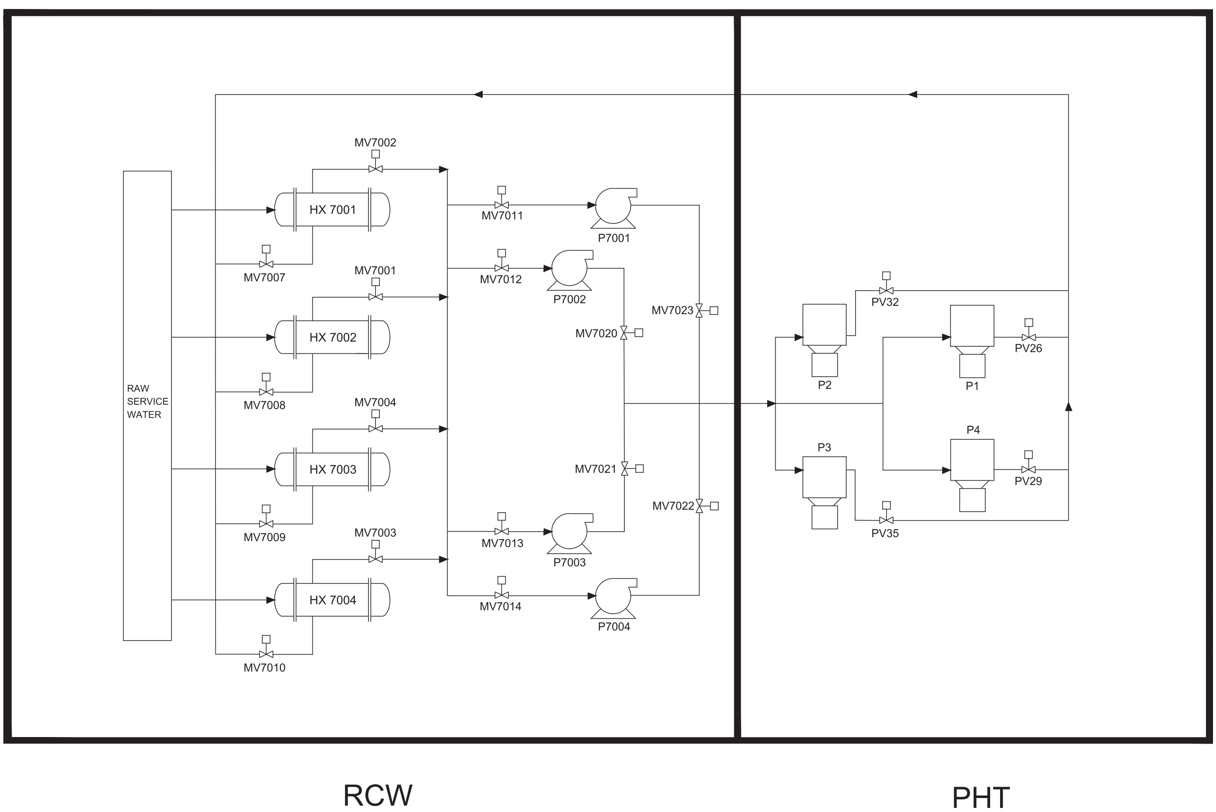

Fig. 3. Scenario 1a Schematic diagram of success path.

leading to a LOCA.

In order to experience the above conditions, while raw service water supply to recirculated cooling water heat exchangers (HX7001 to HX7004) or D_2O purification system heat exchanger (HX2) is suspended, hot heavy water from D_2O purification system must be mixed with cold heavy water stored in a D_2O storage tank (TK1) as blocking valves of D_2O Purification systems (LCV14/15, PV25) are opened. And then this heavy water must be supplied to PHT pumps (P1 to P4) via D_2O feed pumps (P5/6). Under this scenario, the sealing integrity of PHT pumps can be lost (See Fig. 4).

3.1.3. Scenario 1c: loss of PHT pump seal cooling

If loss of recirculated cooling water occurs while degassing is in progress and the degasser condenser is not isolated, the hot heavy water reaching the D_2O feed pump will be pumped to the PHT pump seals. The seals are assumed to fail within 5 min resulting in a small LOCA from both loops at maximum total leakage of 50 kg/s (110 lb/s). The pressurizer will empty in about 13 min after the seal failures and fuel failures will occur within 1 h unless heat transport system loops are maintained full by makeup from the emergency core cooling system.

In order to experience the above conditions, while temperature in the outlet (TK2) increases because raw service water cannot be supplied to recirculated cooling water heat exchangers (HX7001 to HX7004) or to pressure and inventory control system heat exchanger (HX1), hot heavy water supplied from outlets of degasser condenser must be mixed with cold heavy water stored in a D_2O storage tank (TK1) as their outlet valves (LCV8/15, PV16) fail to be isolated. And then this heavy water must be supplied to PHT pumps (P1 to P4) via D_2O feed pumps (P5/P6). Under this scenario, the

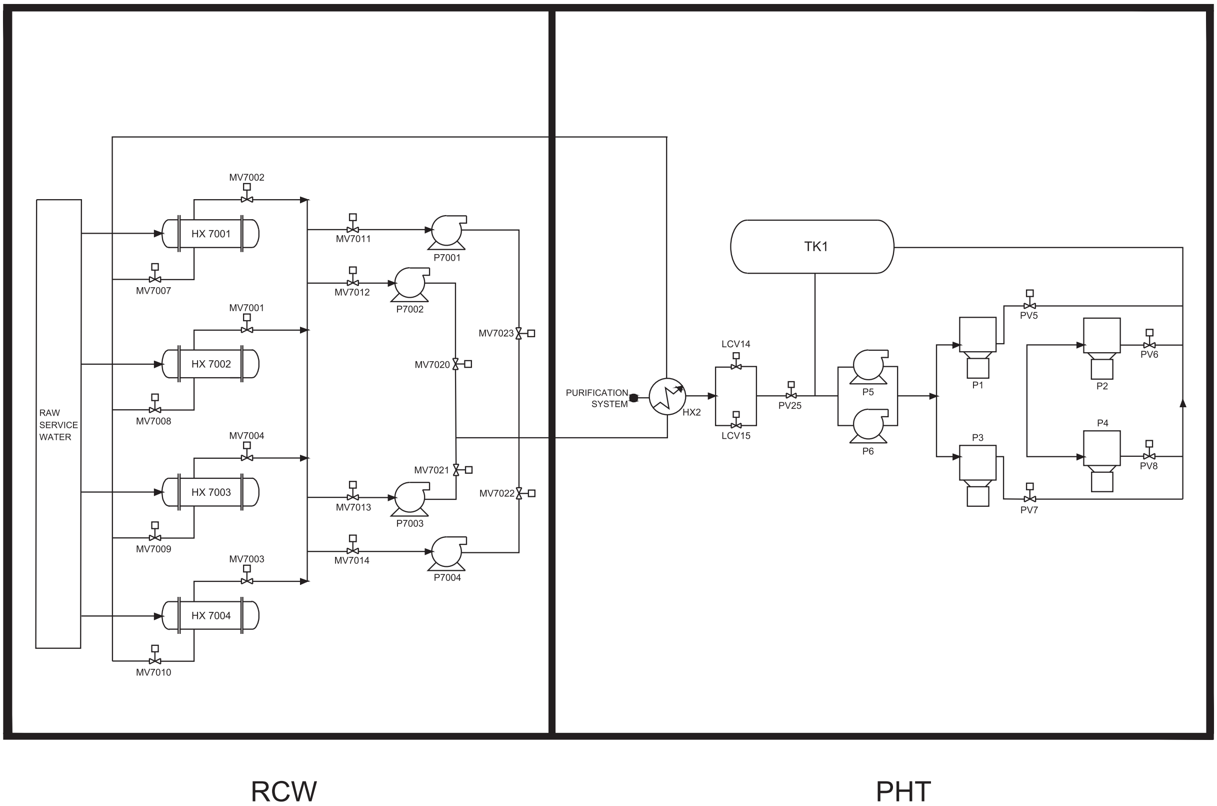

Fig. 4. Scenario 1b Schematic diagram of success path.

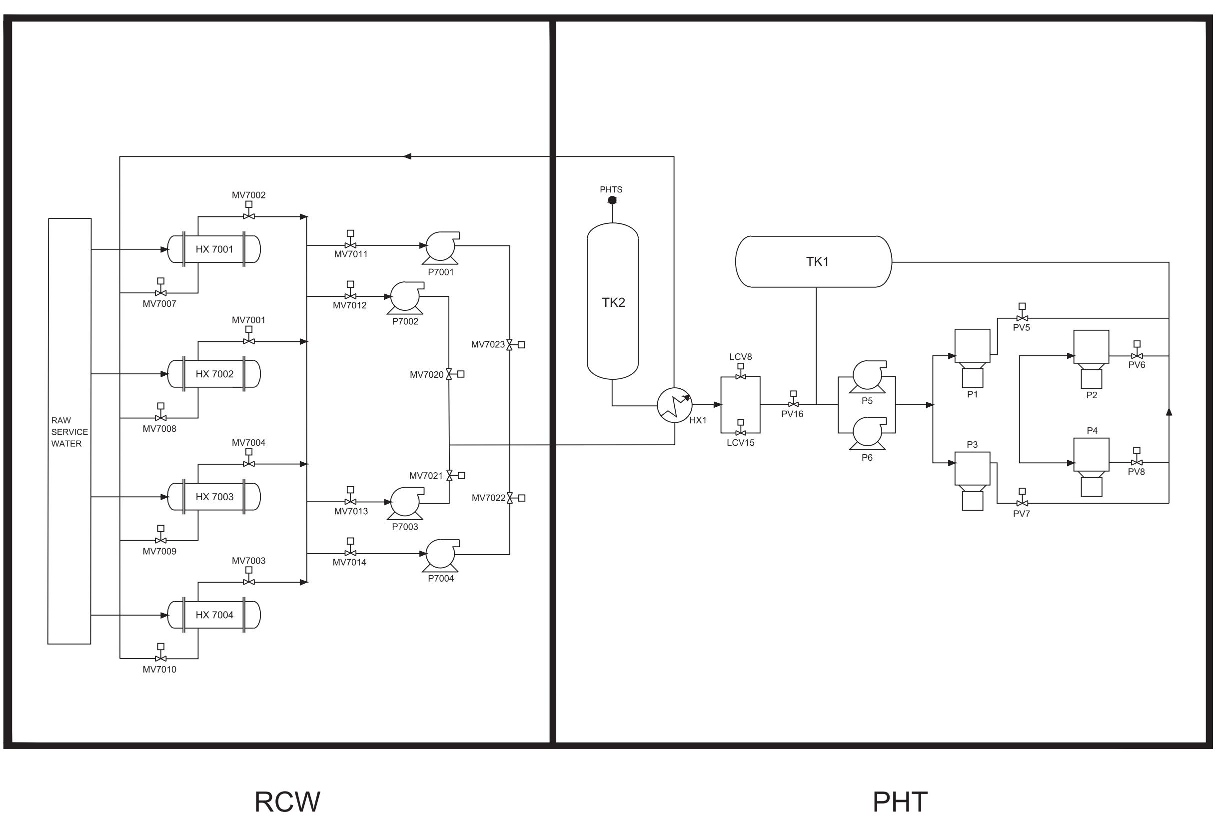

Fig. 5. Scenario 1c Schematic diagram of success path.

sealing integrity of PHT pumps can be lost (See Fig. 5).

3.2. Applied scenarios

Among the 63 MSO scenarios in Appendix G, NEI 00-01 [3], seven scenarios can be applied to PHWRs. Scenarios 30, 31, and 51 related to the auxiliary feed water system of PHWRs can be excluded if the valve of flow paths whose flow rates can be adjusted is considered in the post-fire safe-shutdown analysis [7]. Therefore, this paper does not explain about these three scenarios and included detailed analytical results about the remaining four scenarios.

3.2.1. Scenario 18

This scenario occurs as multiple pressure relief valves of pressurizer are opened.

Unlike PWRs, PHWRs have degasser condensers on the outlet of the pressurizers. The scenario occurs under the following sequences. While the total stock of coolant is discharged into the degasser condensers as pressurizer pressure relief valves (PV47/48), pressurizer steam bleed valves (PCV5/6), and liquid relief valves (PV3/4/12/13) installed on the flow path leading from pressurizer (TK1) to degasser condenser (TK2) are opened. Pressure relief valves of degasser condensers (RV11, RV21), blocking valves (PV22) and temperature control valves (TCV23) of condensers are opened (See Fig. 6). Under this scenario, the residual heat removal function is negatively affected.

3.2.2. Scenario 36

This scenario can happen when, with the opening of pressurizer spray valves, coolant pumps are activated (or fail to stop), and pressurizer electric heaters fail.

When the reactor power of PHWRs is less than 5% FP, pressurizer isolation valves are closed and pressurizer and PHT are segregated, leading to operation in solid mode. And the pressure of the PHT is controlled by the feed and bleed function. Because PHWRs permit core boiling of 4%, high pressure emergency core cooling system can manually be inserted if the pressure of the PHT decreases and thus subcooling margin falls.

This scenario could occur under the following sequence. While the flow paths from the PHT to the degasser condensers (PV3/4/12/13, PV5/6/47/48) are opened, pressurizer heater (HTR1 to HTR5) fails, the flow paths from purification systems to pressurizers are opened (PV7/9), and D_2O feed flow paths (MV13/22) are blocked (See Fig. 7). This scenario could have a negative effect on the residual heat removal function.

3.2.3. Scenario 37

This scenario happens when the electric heaters of pressurizer are activated and the spray system of the pressurizer or auxiliary spray system fails.

For PHWRs, the pressure of PHT can rise when one and more pressurizer heaters (HTR1 to HTR5) operate and the flow paths (PV47/48, PCV5/6) from pressurizers to degasser condensers are closed. As pressure of PHT rises, liquid relief valves are opened. And pressure relief valves are opened when pressure of degasser condensers increases by leaked coolant (See Fig. 8). If this scenario occurs, it can have a negative effect on fission product leakage prevention.

3.2.4. Scenario 56e

This scenario occurs when pressurizer pressure relief valves are opened due to inadvertent signals (High pressure of pressurizer).

Pressurizer pressure relief valves of PHWRs (PV47/48) are designed to be opened by the 2/3 logic when pressurizer pressure (① of Fig. 9) I rises above 108.6 bar. Pressurizer steam bleed valves (PCV5/6) are opened as they reach the highest pressure of four reactor outlet headers transmitters (② of Fig. 9). Liquid relief valves (PV3/4/12/13) are opened by the 2/3 logic when pressure of reactor outlet headers of PHT rises above 102.4 bar. And degasser condenser relief valves (RV11/21) are opened by the 2/3 logic when pressure of reactor outlet headers of coolant systems (② of Fig. 9) exceeds 112.7 bar.

This scenario can occur when pressurizer relief valves (or

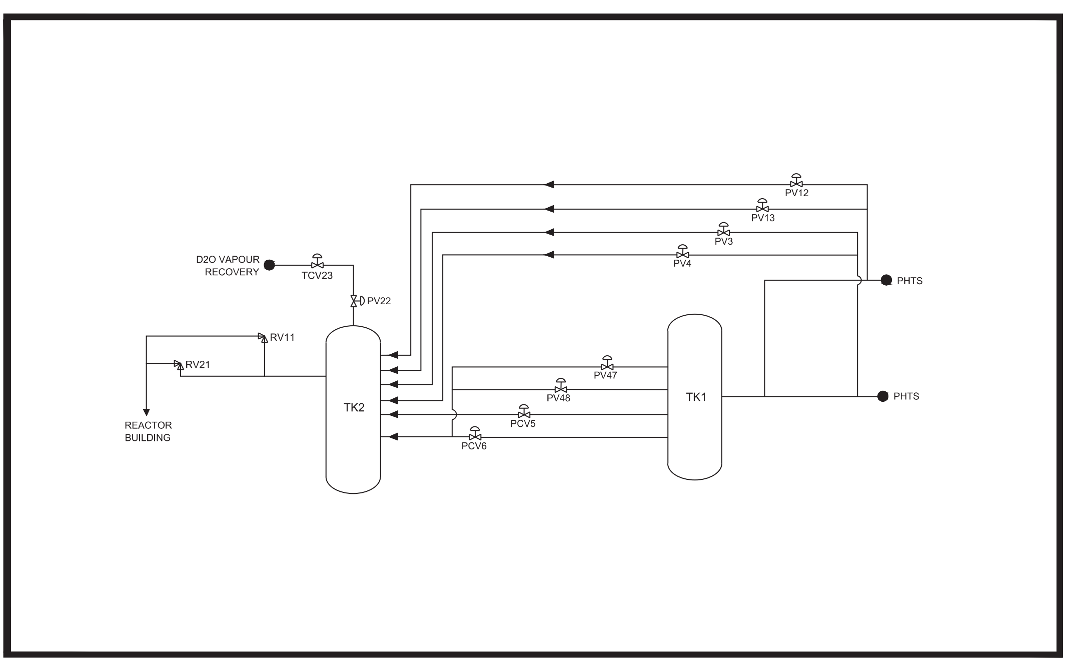

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Fig. 6. Scenario 18 Schematic diagram of success path.

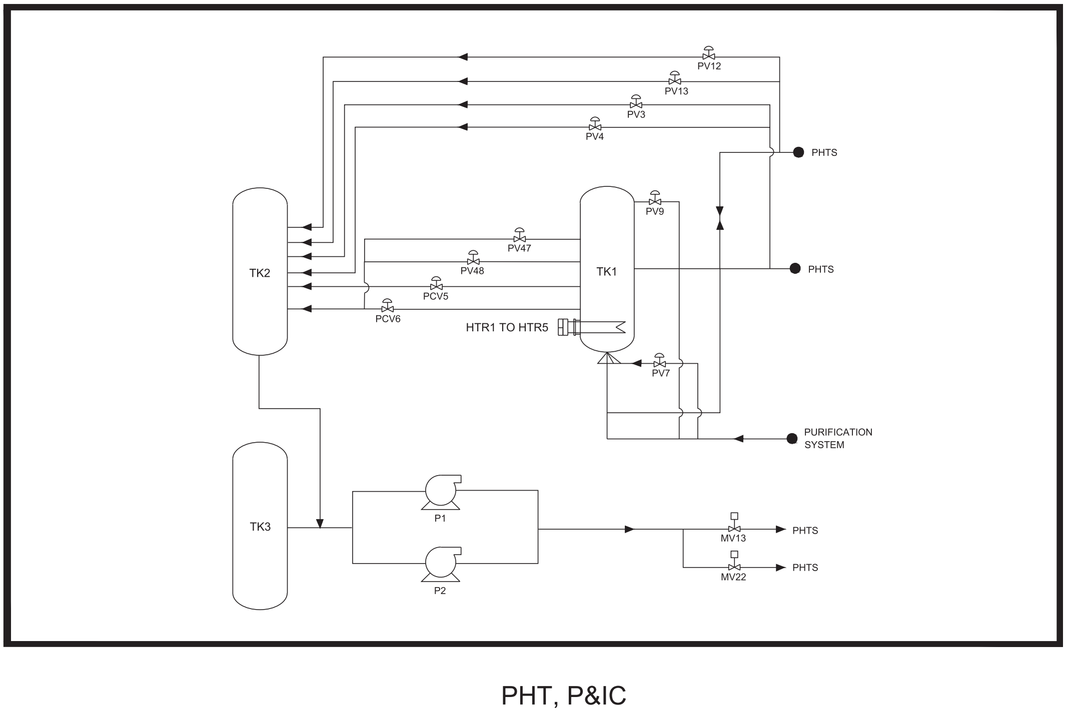


Fig. 7. Scenario 36 Schematic diagram of success path.

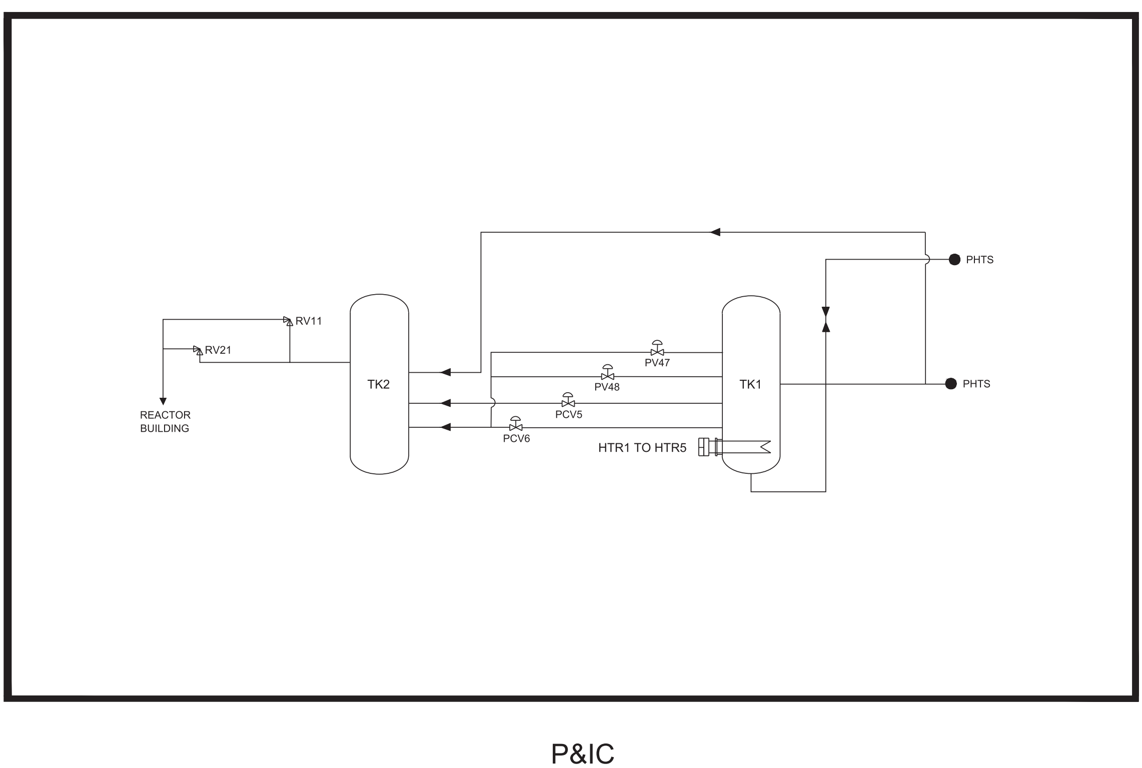
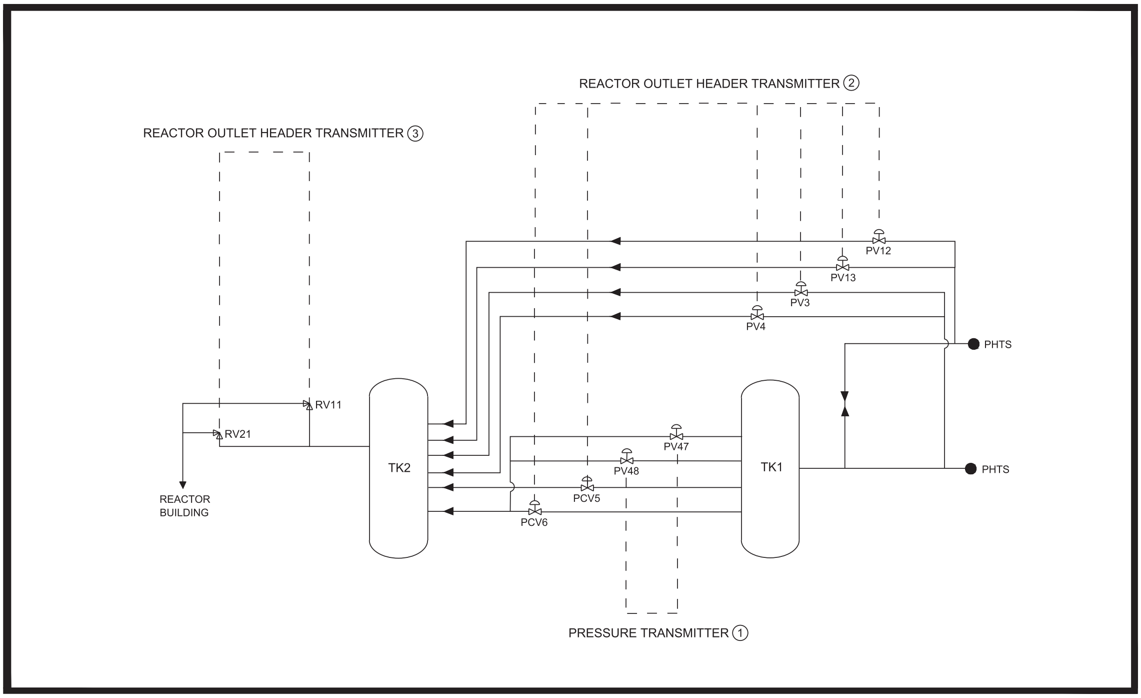


Fig. 8. Scenario 37 Schematic diagram of success path.

pressurizer steam bleed valves or liquid relief valves) are opened due to inadvertent signals of the transmitters which measure pressure of reactor outlet headers, and degasser condenser relief valves are simultaneously opened (See Fig. 9). If the scenario occurs, it can have a negative effect on the residual heat removal function.

3.3. *Non-applied scenarios*

NEI 00-01 [3] states that for MSO analysis, post-fire safe-shutdown analysis results of each plant need to be reviewed. For MSO analysis of PHWRs, scenarios associated with systems and devices



P&IC

Fig. 9. Scenario 56e Schematic diagram of success path.

that were already analyzed as per existing post-fire safe-shutdown analysis, or scenarios related to systems and devices that were already used under other scenarios were classified as non-applied scenarios.

In addition, in the event of the loss of functions listed under scenarios, if power is supplied from shutdown cooling systems and emergency power supply systems and safety function is retained with systems which can be controlled at the secondary control area (shutdown system #2, emergency core cooling systems, and emergency water systems), such case is classified as non-applied scenario. Reasons for classification of scenarios as non-applied are listed under Table 4.

Table 4
Reasons for non-applied scenarios.

No.	Title(NEI 00-01)	PWR System	PHWR System	Reasons
1	Loss of all RCP Seal Cooling – injection	RCS	PHTs	Note 1)
2	Loss of all RCP Seal Cooling - diversion	RCS	PHTs	Note 1)
3	Thermally Shocking RCP Seals	RCS	PHTs	Note 1)
4	Catastrophic RCP Seal Failure	RCS	PHTs	Note 1)
5	RCP Seal No.2 Failure	RCS	PHTs	Note 1)
6	Letdown Fails to Isolate and Inventory Lost to CVCS	CVCS	P&ICs	Note 2)
7	Letdown Fails to Isolate and Inventory Lost to PRT	CVCS	P&ICs	Note 2)
8	Excess Letdown Fails to Isolate	CVCS	P&ICs	Note 2)
9	RCS Makeup Isolation	CVCS	P&ICs	Note 3)
10	Charging Pump Failure – VCT, RWST	CVCS	P&ICs	Note 3)
11	Charging Pump Failure - RWST	CVCS	P&ICs	Note 3)
12	Charging Pump Failure - VCT	CVCS	P&ICs	Note 3)
13	Charging Pump Failure – Letdown, CCW	CVCS	P&ICs	Note 3)
14	Charging Pump Failure - runout	CVCS	P&ICs	Note 3)
15	RWST Drain Down via Containment Sump	CSS	CDS	Note 2)
16	RWST Drain Down via Containment Spray	CSS	CDS	Note 2)
17	Interfacing System LOCA	SIS	ECCS	Note 2)
19	Pressurizer PORV and Block Valve	RCS	PHTs	Note 2)
20	Reactor Head Vent Valves	RCGVS	–	Note 2)
21	Excess RCS Makeup	CVCS	P&ICs	Note 2)
22	Primary Sample System	PSS	DSS	Note 2)
23	Inadvertent Steam Dumping - MSIV	MSS	MSS	Note 3)
24	Inadvertent Steam Dumping – MSIV, CSDV	MSS	MSS	Note 2)
25	Inadvertent Steam Dumping – bypass MSIV, CSDV	MSS	MSS	Note 2)
26	Inadvertent Steam Dumping – Drain, TDAFW	MSS	MSS	Note 2)
27	Turbine Driven AFW Pump Steam Supply	MSS	MSS	Note 2)

(continued on next page)

Table 4 (*continued*)

No.	Title(NEI 00-01)	PWR System	PHWR System	Reasons
28	AFW Flow Isolation - Close	AFS	FWS	Note 3)
29	AFW Flow Isolation - TDAFW	AFS	FWS	Note 2)
32	CST Diversion to Condenser	AFS	FWS	Note 2)
33a	Excess Feed Flow to Steam Generator	AFS	FWS	Note 2)
33b	Excess Feed Flow to Steam Generator Fails TD Pump	AFS	FWS	Note 2)
34	Steam Generator Blowdown	SGBS	SGBS	Note 2)
35	Secondary Sample System	SSS	CCS	Note 2)
38	Inadvertent Boron Dilution	CVCS	P&ICs	Note 2)
39	Fire Prevents Reactor Trip	–	SDS	Note 3)
40	CCW Header Isolation	CCWs	RCWs	Note 3)
41	CCW to Credited Loads	CCWs	RCWs	Note 3)
42	CCW Flow Diversion to Non-Credited Loop	CCWs	RCWs	Note 2)
43	ESW Header Isolation	ESWs	RSWS	Note 3)
44	ESW to Credited Loads	ESWs	RSWS	Note 3)
45	ESW Flow Diversion to Non-Credited Loops/Systems	ESWs	RSWS	Note 2)
46	Emergency Power – Overload cause non-credited	EDG	SDG	Note 2)
47	Emergency Power – Overload cause credited	EDG	SDG	Note 2)
48	Emergency Power – without cooling	EDG	SDG	Note 2)
49	Emergency Power – spurious breaker operation	EDG	SDG	Note 2)
49.I	Emergency Power – mechanical interlocks	EDG	SDG	Note 2)
50	Generic – Loss of Pump Suction	All Systems	All Systems	Note 3)
52	Generic – Pump Outside Design Flow	All Systems	All Systems	Note 3)
53	Generic Flow Diversion	All Systems	All Systems	Note 2)
54	Loss of HVAC	HVAC System	HVAC System	Note 2)
55	Valve Failure	All MOV	All MOV	Note 2)
56a	RCS Makeup Pump Failure	ESFAS	SSSS	Note 2)
56b	Loss of all Seal Cooling – CCW, Injection Header	ESFAS	SSSS	Note 2)
56c	Loss of all Seal Cooling – CCW, Charging injection	ESFAS	SSSS	Note 2)
56d	RWST Drain Down	ESFAS	SSSS	Note 2)
56f	RCS Makeup Pump Failure	ESFAS	SSSS	Note 2)

Note 1) 3 Newly developed.
Note 2) Non-application due to the design characteristics of PHWRs.
Note 3) Non-application because it was already considered in the post-fire safe-shutdown analysis.

4. Conclusion

- Like the U.S. regulatory authorities, the Korean Nuclear Safety and Security Commission required nuclear power plant operators to solve MSO problems in its Notice No. 2015-11 of the Nuclear Safety and Security Commission [1], and the Korean nuclear operators have performed MSO analysis according to the NEI 00-01 [3] methodology.
- MSO scenarios of PHWRs are not included in NEI 00-01 [3] because there are no PHWRs in U.S. and feasible scenarios for PHWRs have not been developed.
- Therefore, this paper analyzed whether MSO scenarios included in App. G of NEI 00-01 [3] can be applied to Korean PHWRs (CANDU 6) and assessed the necessity of developing new scenarios which reflect the characteristics of the Korean PHWRs.
- In PHWRs, the secondary control area, which is similar to remote shutdown panel room of PWRs, is located away from the buildings housing the main control room. PHWRs can be securely shutdown by using devices of Group 2 that are controlled by the secondary control area even when the function of all devices of Group 1 fails.
- After analyzing the characteristics of PHWRs and conducting expert panel reviews, this research selected seven scenarios from the 63 MSO scenarios presented in NEI 00-01 [3] and developed three additional scenarios which reflect the characteristics of PHWRs.
- The number of scenarios which can be applied to PHWRs is relatively smaller than the number of scenarios applicable to PWRs, and the number of additional scenarios to develop is small possibly because of differences between PHWRs and PWRs in terms of the plant arrangement, the concept of safety system isolation, and types and characteristics of safety system.

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Abbreviations

AFS	Auxiliary Feedwater System
CCS	Chemical Control System
CCW	Component Cooling Water System
CDS	Containment Dousing System
CSDV	Condensate Safety Discharge Valve
CSS	Containment Spray System
CST	Condensate Storage Tank
CVCS	Chemical & Volume Control System
DSS	D_2O Sampling System
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
ESF	ASEngineered Safety Feature Actuation Signal
ESW	Essential Service Water System
FCV	Flow Control Valve
FWS	Feed Water System
HVAC	Heating, Ventilating & Air Conditioning)
HX	Heat Exchanger
LCV	Level Control Valve
LOCA	Loss of Coolant Accident
MSIV	Main Steam Isolation Valve
MSS	Main Steam System
MV	MOVMotor Operated Valve
P	Pump

PCV	Pressure Control Valve
PHT	Primary Heat Transfer System
PSS	Primary Sample System
PV	Pressure Valve
P&IC	Pressure & Inventory Control System
RCGVS	Reactor Coolant Gas Vent System
RCPR	eactor Coolant Pump
RCS	Reactor Coolant System
RCW	Recirculated Cooling Water System
SDS	Reactor Shutdown
RSWS	Raw Service Water System
RWST	Refueling Water Storage Tank
RV	Relief Valve
SDG	Standby Diesel Generator
SDS	Shutdown System, PHWR
SGBS	Steam Generator Blowdown System
SIS	Safety Injection System
SSS	Secondary Sample System
SSSS	Special Safety System Signal
TCV	Temperature Control Valve
TDA	FWTurbine Driven Auxiliary Feedwater System
TK	Tank
VCT	Volume Control Tank

References

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