Risk monitor during shutdown of CANDU NPPs

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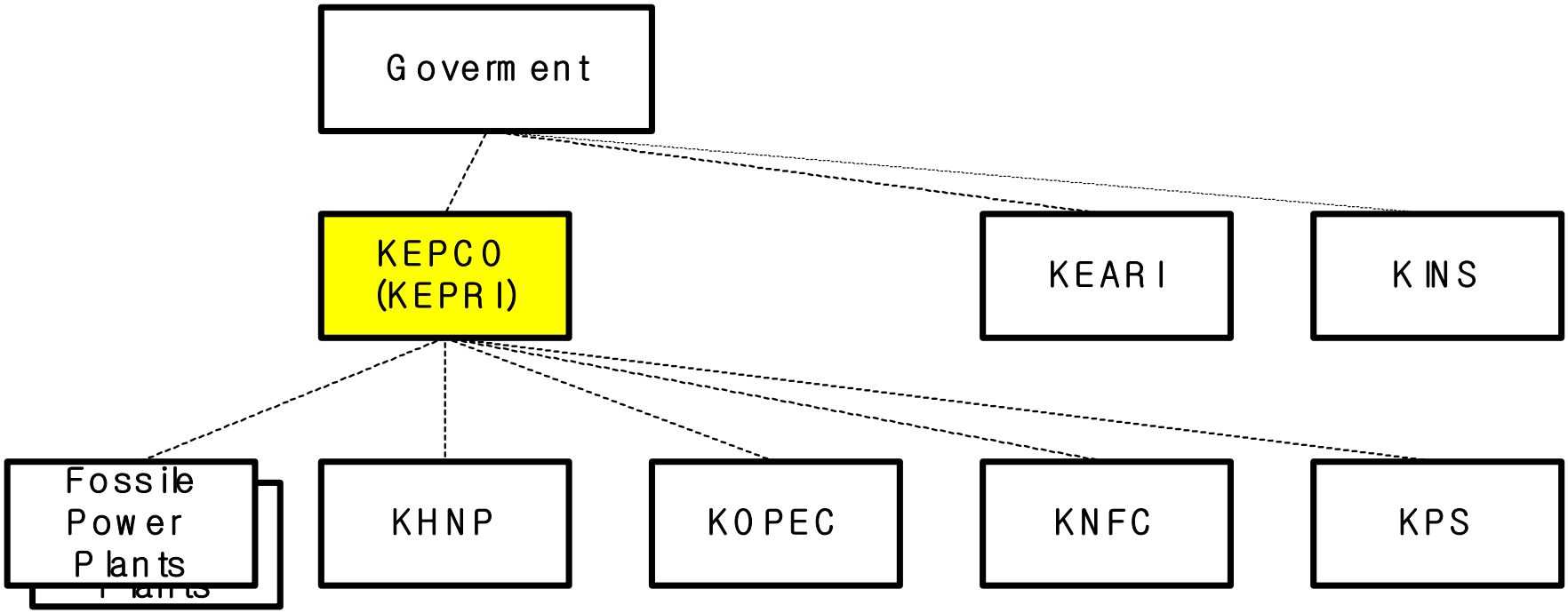
Introduction

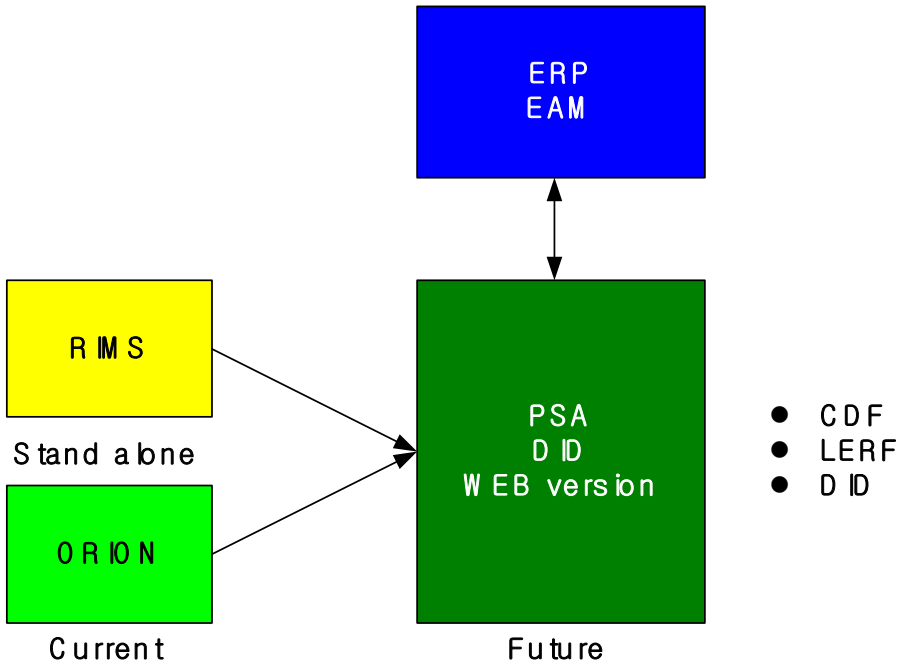


Introduction

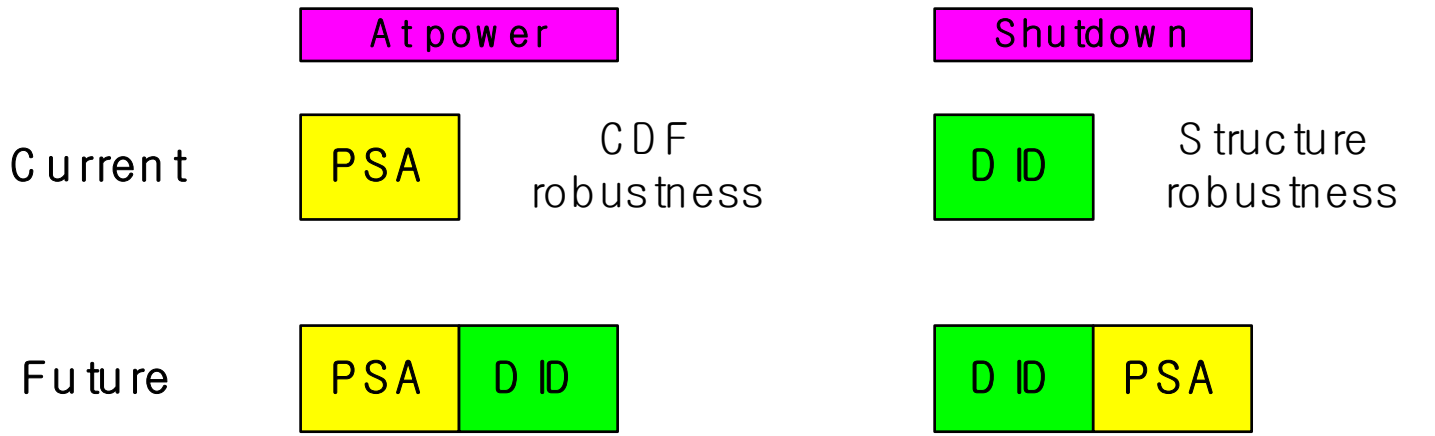
- In the middle of 1990 nuclear power plant safety policy for a severe accident was issued by Minister of Science and Technology(MOST), a strong suggestion of implementing PSA, severe accident program, risk monitor, and periodic PSA update. PSAs(L1, L2, Internal/External, at power), and SAMGs were actively performed for construction plants and operating plants.
- Maintenance rule (MR) has been recently introduced to enhance safety and performance of the component, system, structures(SSCs), and plants.
- Prototype MR for Uljin Units 3,4(PWR), covering (a)(1), (a)(2), (a)(3) was finished in 2005 and (a)(4) in 2007. The (a)(4) requires risk monitoring before and after maintenance activities using PSA or DID.
- At power, risk monitoring was implemented with PSA using RIMS software, automatically indicating CDF and LERF along with plant configuration change.
- It is determined that due to LPSD PSA limitations as an on-line risk monitor, Defense-in-Depth method is adopted as risk monitor during shutdown instead of LPSD PSA.

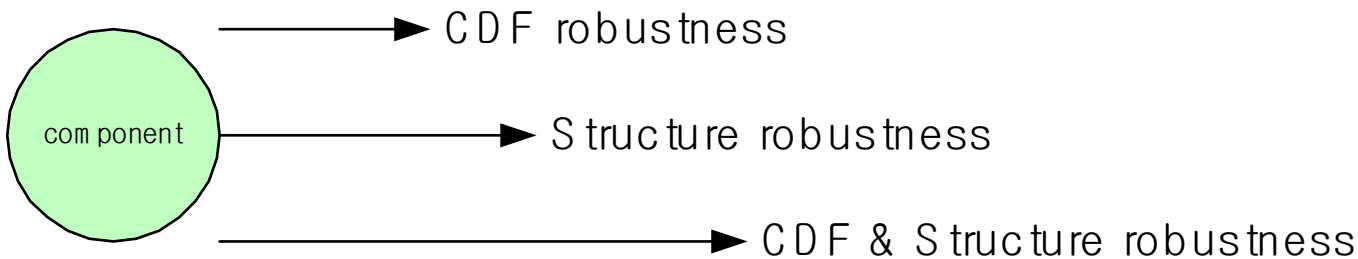
Introduction

- Defense-In-depth means how many redundant functions are available along with plant configuration.
- We have developed DID method and its implementation software tool, ORION.



Introduction





Defense-In-Depth

- Review documents
  - the several concepts of DIDs referred in IAEA safety series, risk-informed regulation, NUMARC 91-06, and ERPI ORAM documents.
- The DID obtained from these DIDs having following characteristics
  - Evaluating safety rating using DID information obtained from SFAT
  - Obtaining key safety functions
  - Evaluating diversity of key safety functions as a target of safety evaluation
  - Establishing contingency plan
  - Considering common cause failure, human error in contingency plan
  - 4 colored codes, “Red”, “Orange”, “Yellow”, “Green” for rating safety status, and ‘RED’ being out of technical specifications.
  - Simplified shutdown PSA for getting insights of safety rating

Safety Function Assessment Trees

- SFAT
  - SFAT(Safety function assessment Tree) evaluates defense-in-depth associated with key plant safety functions necessary to provide adequate protection and public health and safety.
- 9 key safety functions:
  - reactivity control, core cooling, secondary side heat removal, pressure control, inventory control, containment integrity, electric powers(AC and DC), and cooling water
- 8 POSs
  - The shutdown period grouped into 8 plant operating states(POS) by PHT temperature, PHT pressure, PHT vent, and decay heat level
- 72 SFATs
  - Develop 72 SFATs, which depict the level of safety by color representing along with plant configurations
- Dependent FT
  - Plant configuration automatically determined by dependency fault trees

Safety Function Assessment Trees

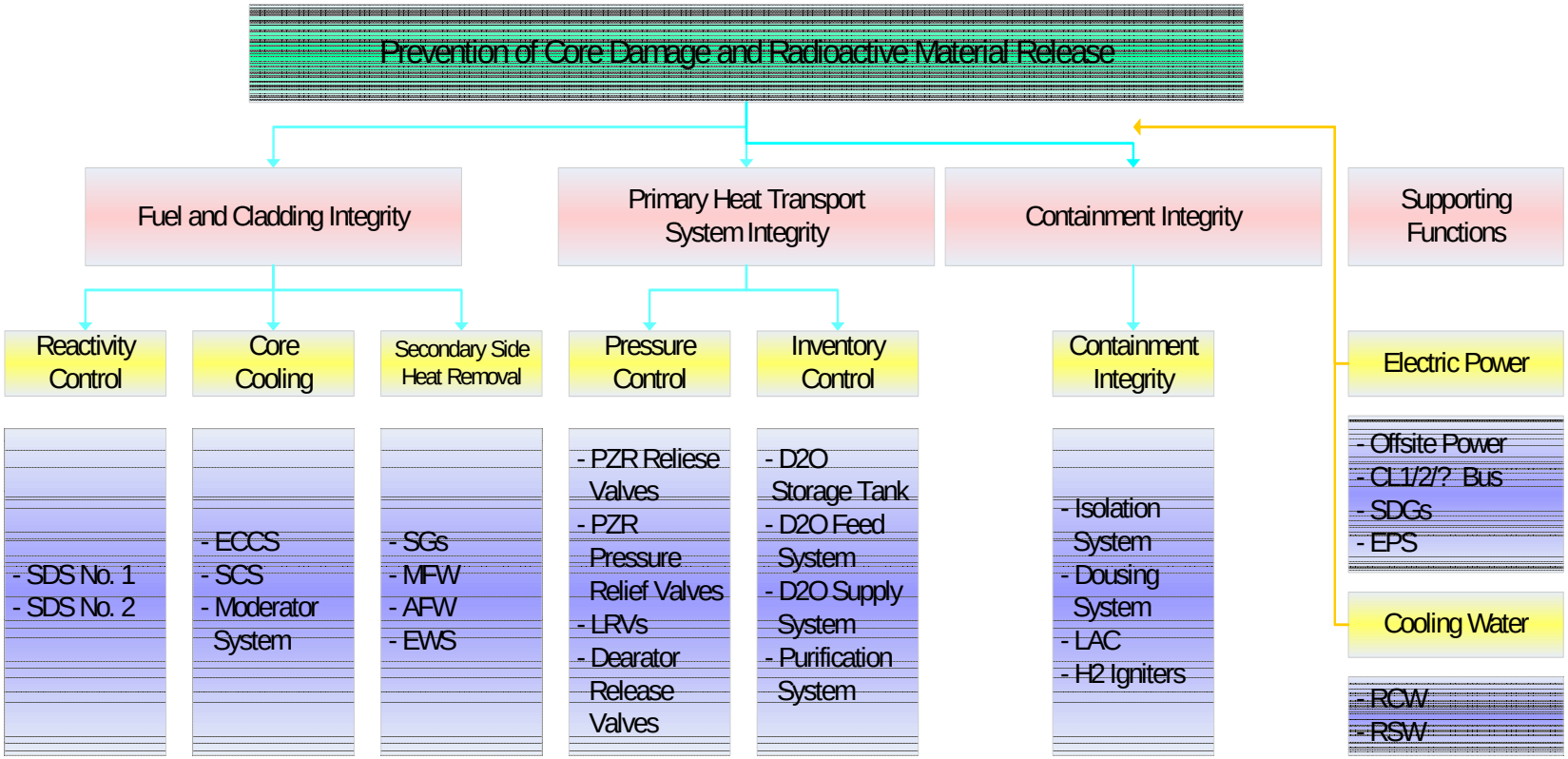


Figure 1: Safety Functions and the associated systems

POS

Table 1: Plant Operating States

POS	PHT Temp	PHT Press	PHT Level	Op. Mode	PHT Status	Decay Heat Level
A	290	9.89	FLOODED	1,2	INTACT	HIGH
B	260	9.89	FLOODED	3	INTACT	HIGH
C	149	7	FLOODED	3	INTACT	LOW
D	100	3	FLOODED	4	INTACT	LOW
E	54	0.5	HEADER	5	INTACT	LOW
F	54	0.1	HEADER	5	LGVENT	LOW
G	100	7	FLOODED	4	INTACT	HIGH
H	260	9.89	FLOODED	3,2	INTACT	HIGH

Guaranteed shutdown

Drained to heater level

Safety Function Assessment Trees

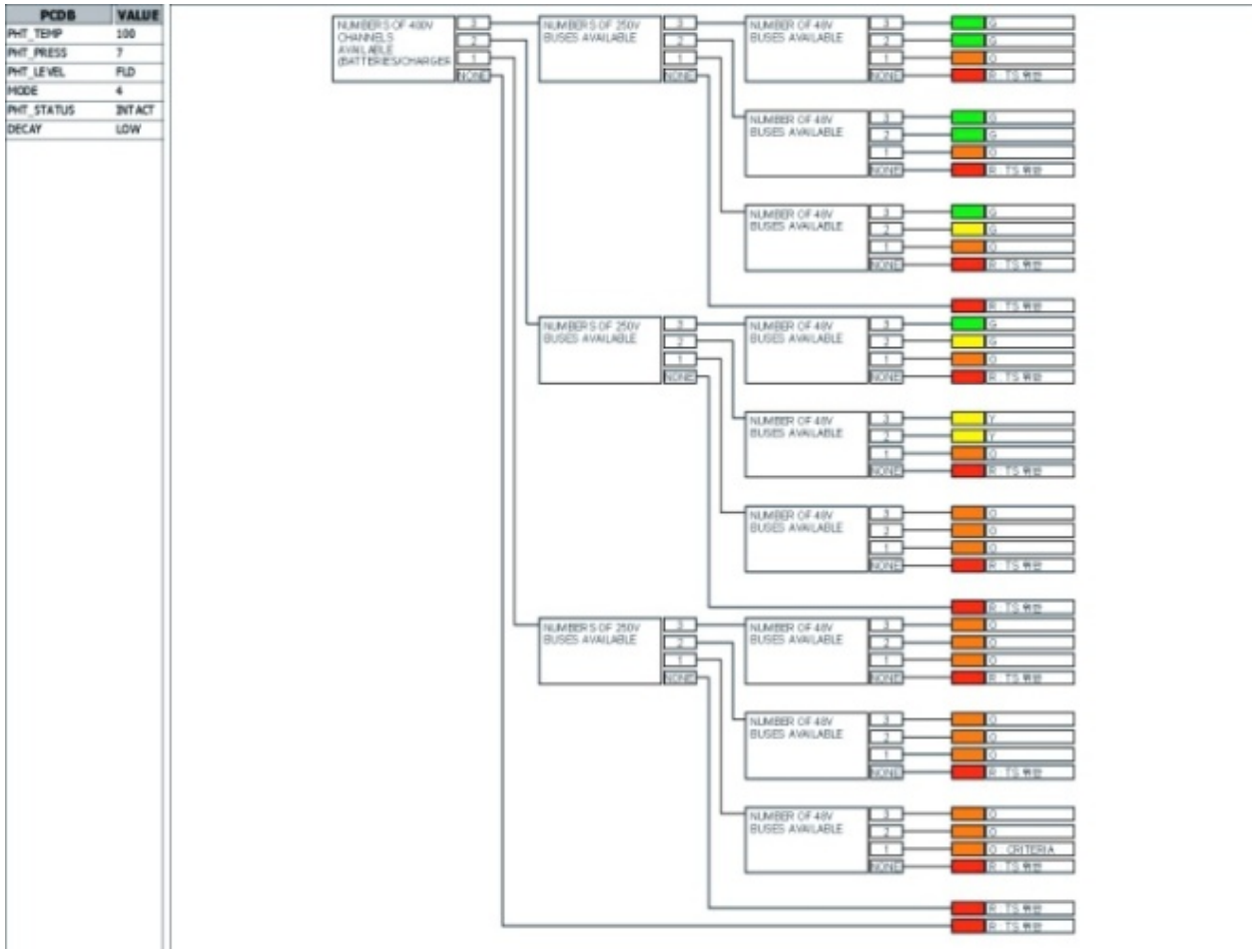


Figure 2: SFAT: Electric Power - POS G

Safety Function Assessment Trees

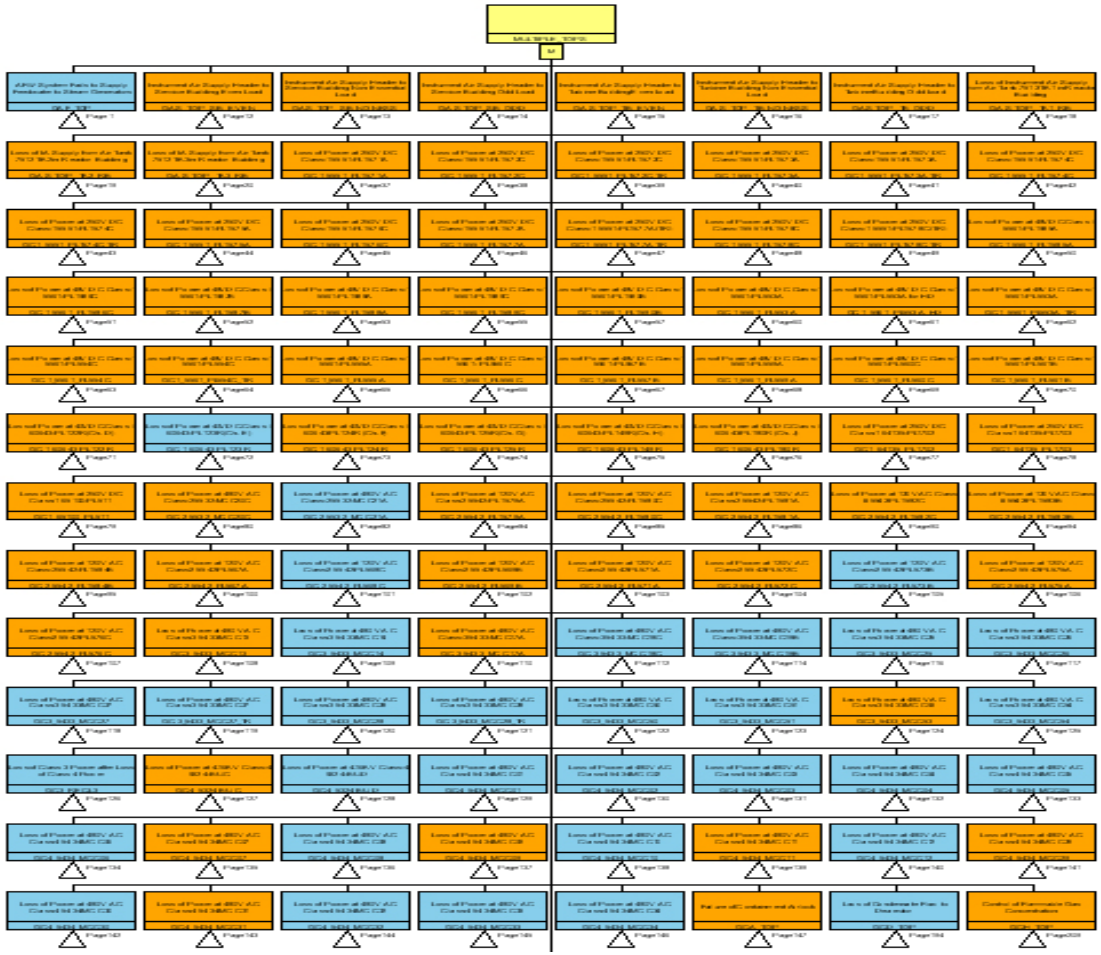


Figure 3: Dependency Fault Tree

Shutdown PSA

- Shutdown PSA has limitations in plant thermo-hydraulic phenomena, and human error model and so on.
- PSA, however, is necessary to obtain insights on risk profiles and to confirm risk colors determined by SFAT.
- To compensate qualitative results from SFAT, simple PSA with 4 initiating events(IE) is developed for both POS E and POS F
  - Four IEs are Loss of Shutdown Cooling System, Loss of Service Water System, Loss of Class IV, and Loss of inventory leakage.
- To identify thermal margin during loss of shutdown cooling and thermal siphoning phenomena depending on the available number of steam generators, perform safety analysis using RELAP MOD3
- Table 2 shows that risk colors resulted from PSA is more conservative than those from SFAT.

Shutdown PSA

Case	Variable Condition	No. of Avail.	CDF(/yr)	Increase. Rate (%)	SFAT Color
Case 1	EPS	1	5.74E-5	5.9	YELLOW
Case 2	EPS	0	3.80E-4	39.3	RED
Case 3A-1	CLASS II 120V BUS	0	3.80E-4	39.3	RED
Case 3A-2	EPS	0	3.80E-4	39.3	RED
Case 3B-1	CLASS II 120V BUS	0	9.6E-6	1.0	RED
Case 3B-2	EPS	2	9.6E-6	1.0	RED

Table 2: Risk results depending on the number of available safety trains

Risk Management

- ORION(Outage Risk Indicator of NPPs) software developed for risk management using SFAT.
  - Schedule planning: outage schedules and maintenance activities issued be rearranged depending on risk colors.
  - Risk management: risk colors of the plant be evaluated along with plant configurations.
- Perform risk management of overhaul schedule of Wolsong Unit 4. In the overhaul schedule one of the critical maintenance activities is the installment of BUS circuit breaker surge equipment
- The draft risk profile presented in the top of Fig. 4 is evaluated with the raw and crude schedule data directly imported from ERP(Enterprise Resources Program). The bottom of Fig. 4 is the risk profile after adjusting the schedule of the installment of BUS circuit breaker surge equipment.
- Figure 5 shows that risk profiles through PSA along with adjusting the schedule of MPECC isolation valve maintenance work.

Risk Management

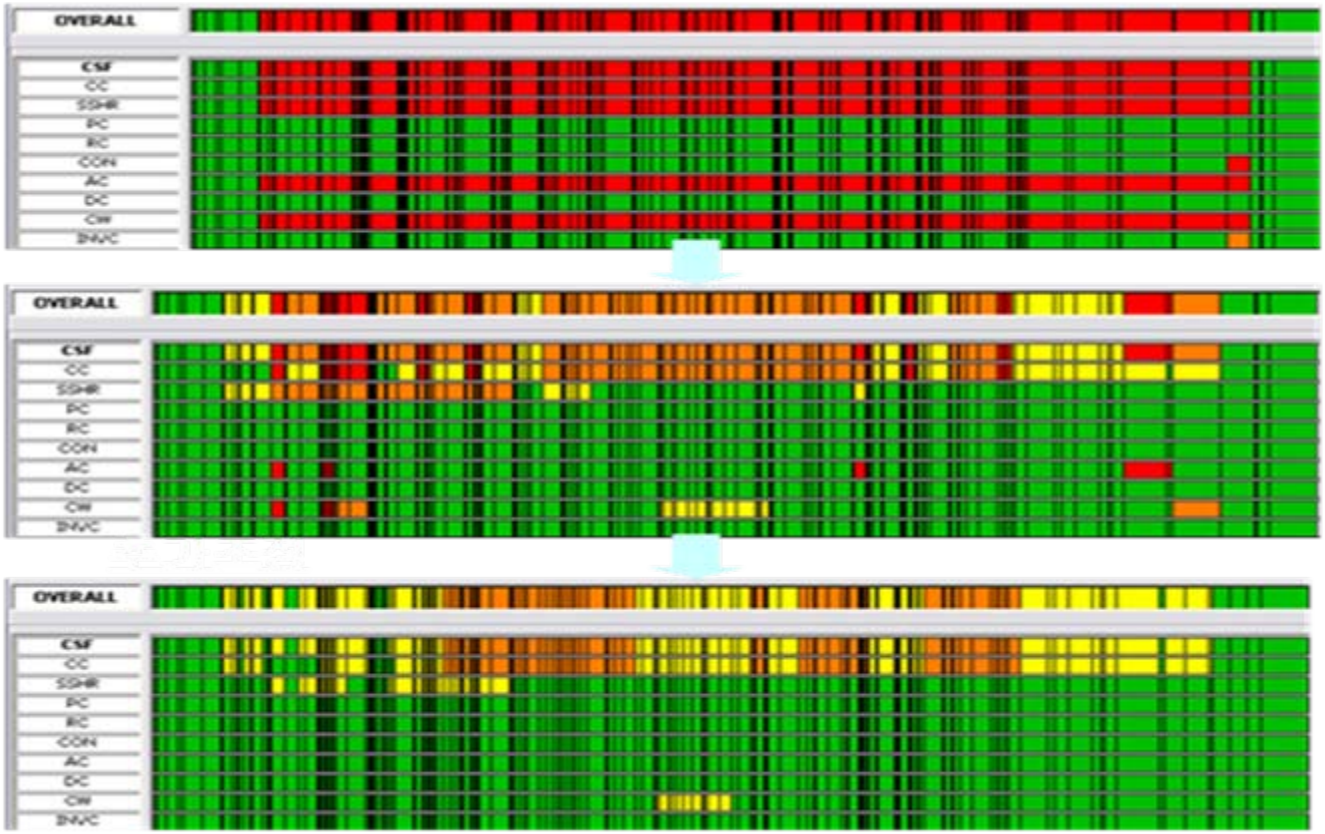


Figure 4: Risk profile with respect to the maintenance schedules using SFAT

Risk Management

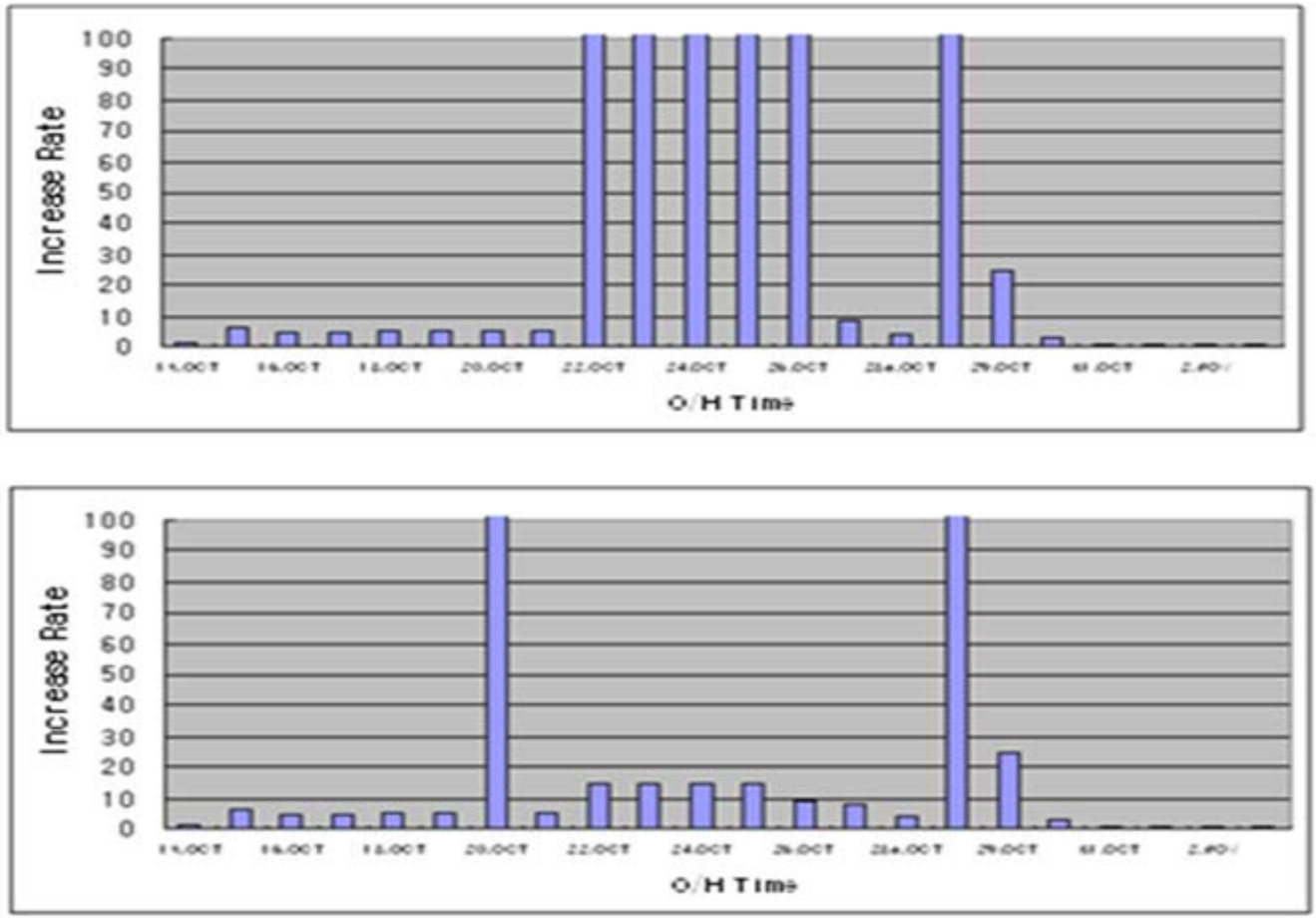


Figure 5: Risk profile with respect to the maintenance schedules using PSA

Conclusions

- MR has been recently introduced into Korea, so KEPRI has developed two risk monitoring projects for KSNP NPPs and CANDU NPPs for implementing maintenance rule.
  - One is for Uljin Units 3/4, and the other is for Wolsong Units 2/3/4(CANDU).
- In this paper, we present the risk monitor during shutdown of CANDU NPPs. It consists of defense-in-depth assessment model, SFAT, which is the main defense-in-depth evaluation method for planned outage operation, and shutdown PSA, which is developed to provide the risk insights in determine risk colors, and ORION.
- ORION has been developed for risk monitoring using DID method, with which maintenance schedule can be arranged considering safety. From the example schedule evaluation and optimization, we shows the usefulness and effectiveness of defense-in-depth evaluation with ORION.
- Risk monitoring system developed will be applied to risk management during shutdown for Wolsong Units 1,2,3, and 4.