Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

The Safety Assessment of OPR-1000 for Station Blackout Applying Combined Deterministic and Probabilistic Procedure

May 8, 2015

KINS
한국원자력안전기술원
KOREA INSTITUTE OF NUCLEAR SAFETY

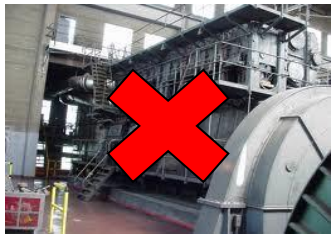
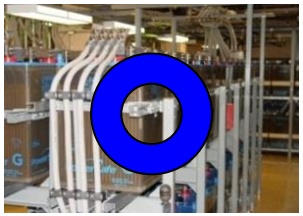
Dong Gu Kang
Seung-Hoon Ahn, Dae-Hyung Cho

Table of Contents

1. Introduction
2. Combined Deterministic and Probabilistic Procedure (CDPP) for BDBA Assessment
3. CDPP Application to OPR-1000 SBO Accident
4. Reevaluation of Station Blackout Risk
5. Conclusions

Introduction

- Station Blackout (SBO)
  - AC power is essential for safe operation and accident recovery
    - Normally supplied by offsite power
    - Onsite power (EDG, AAC) if offsite power is lost
  - Total loss of AC power (offsite/onsite) → **SBO**

- Risk of SBO
  - Historically, SBO is an important contributor to overall plant risk
  - Important contributors to SBO risk
    - Turbine-driven pumps (TDPs), DC battery depletion time, Characteristics of Offsite power restoration

- Safety assessment of OPR-1000 for SBO using CDPP

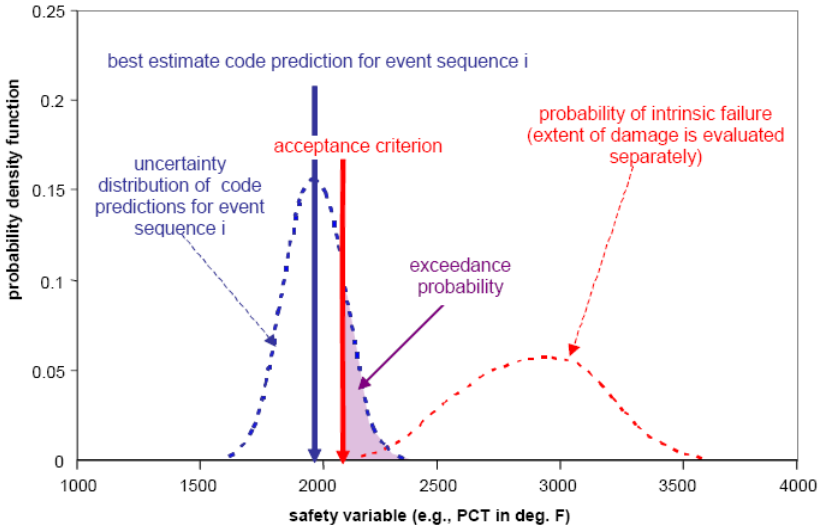
CDPP for BDBA Assessment

Terminology

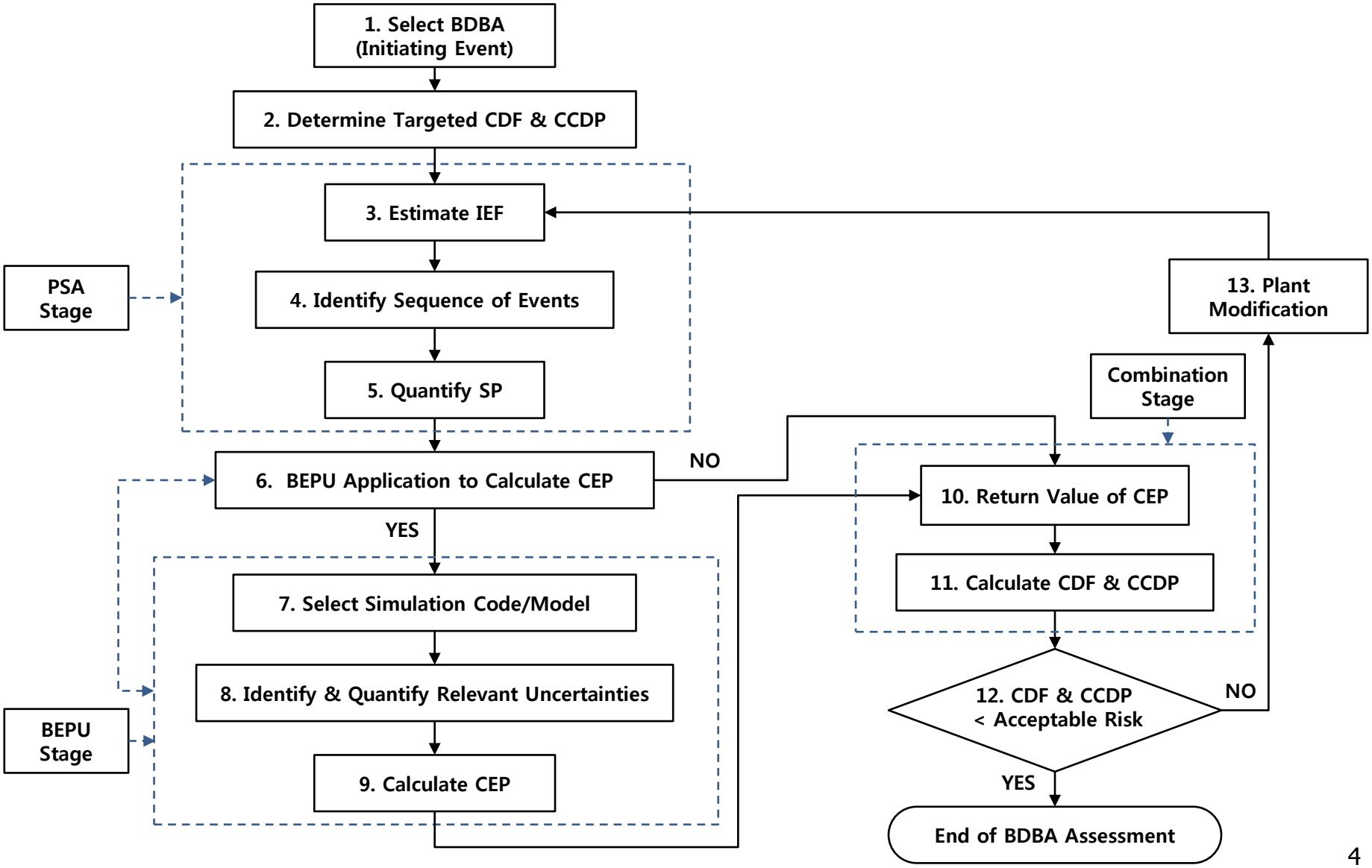
$$P(CD) = P_{seq} \cdot P_{cond,exc}$$

$$\lambda_{CD} = \lambda_{IE} \cdot P(CD) = \lambda_{IE} \cdot P_{seq} \cdot P_{cond,exc}$$

- Conditional exceedance probability (CEP, $P_{cond,exc}$)
  - Probability that core will be damaged for a specific initiating and its sequence event
  - Acts as a go-between PSA and BEPU results

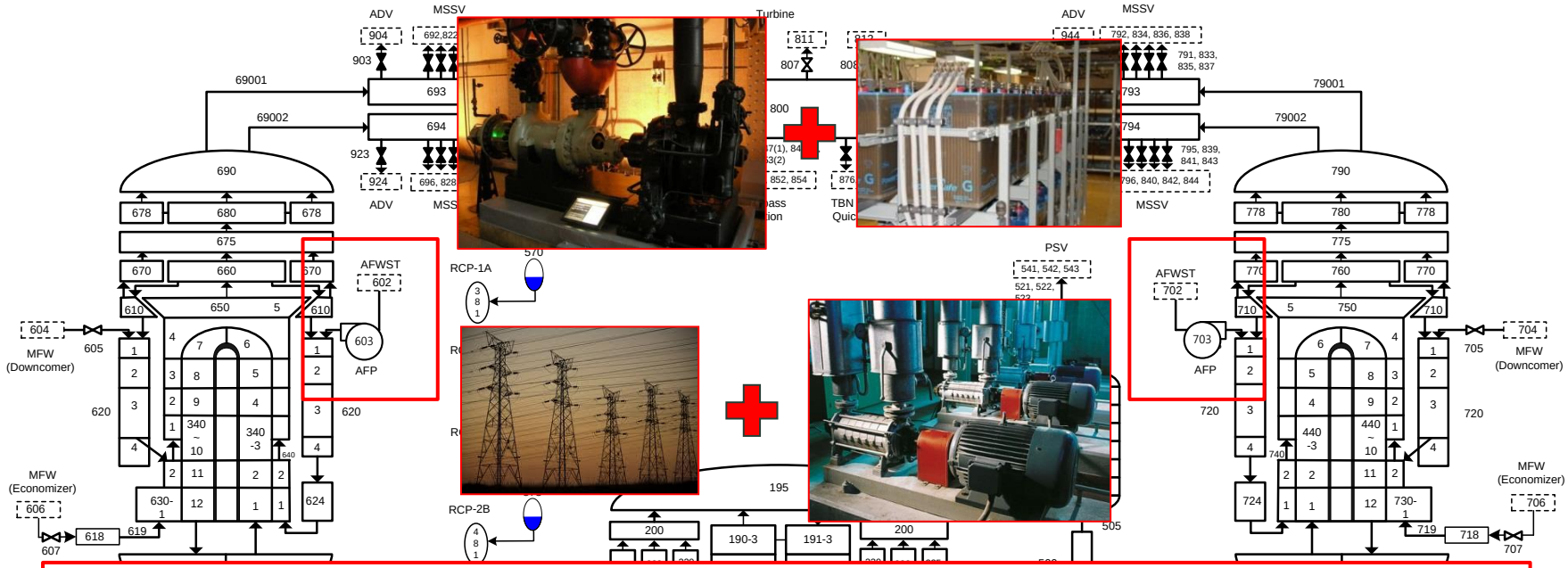


CDPP for BDBA Assessment



Application to OPR-1000 SBO

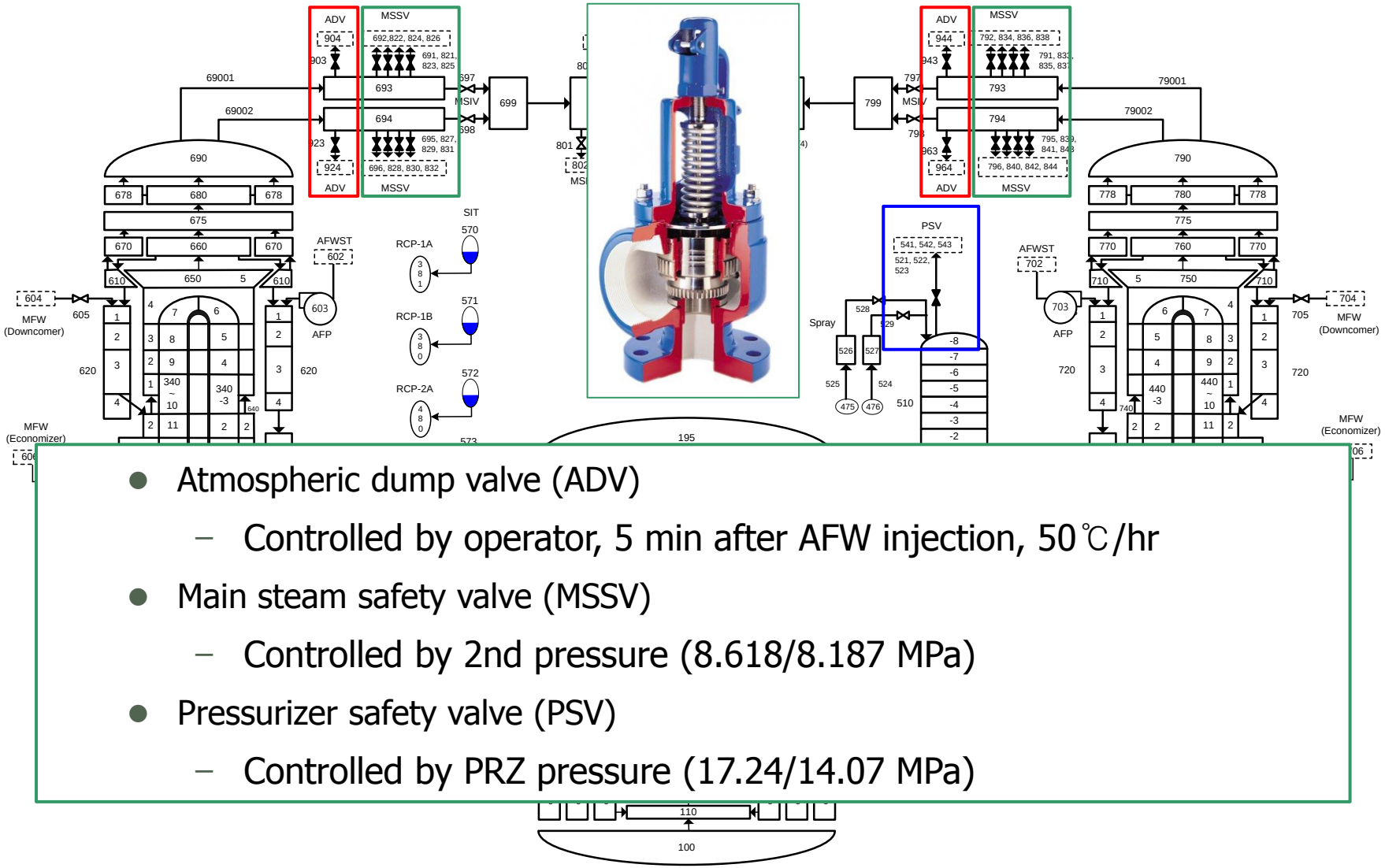
❑ System/Component for SBO mitigation



- DC battery : 4 hours
- Turbine driven pump (TDP) : when DC battery available
  - SG low level (23.8% WR)
  - Aux. feedwater injection with time delay of 46.45 sec after SG low level
- Recover offsite power : RACE (1 hr), RACL (7 or 11 hr)
- Motor driven pump (MDP) : when offsite power recovered

Application to OPR-1000 SBO

- System/Component for SBO mitigation

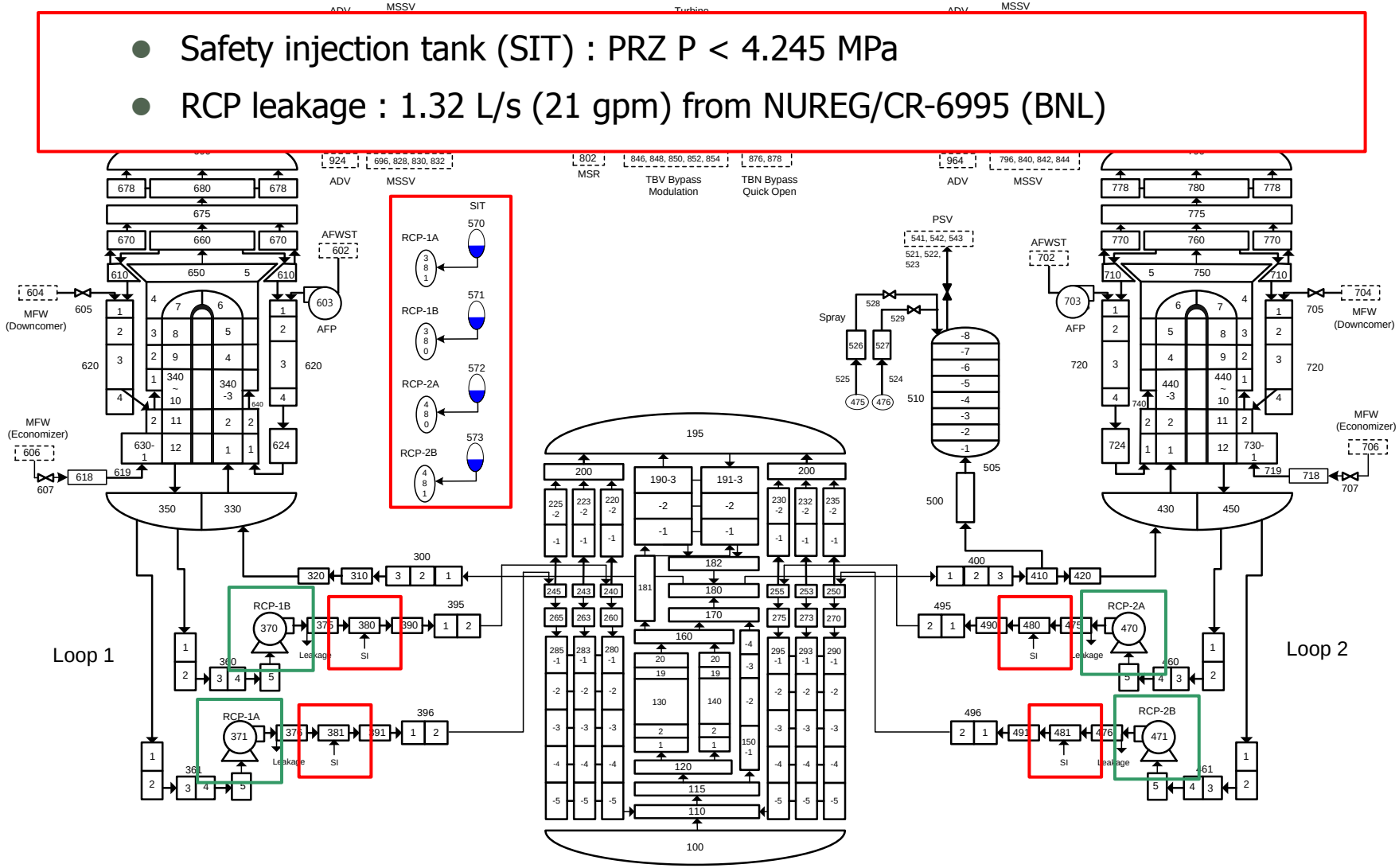


- Atmospheric dump valve (ADV)
  - Controlled by operator, 5 min after AFW injection, 50℃/hr
- Main steam safety valve (MSSV)
  - Controlled by 2nd pressure (8.618/8.187 MPa)
- Pressurizer safety valve (PSV)
  - Controlled by PRZ pressure (17.24/14.07 MPa)

Application to OPR-1000 SBO

System/Component for SBO mitigation

- Safety injection tank (SIT) : PRZ P < 4.245 MPa
- RCP leakage : 1.32 L/s (21 gpm) from NUREG/CR-6995 (BNL)

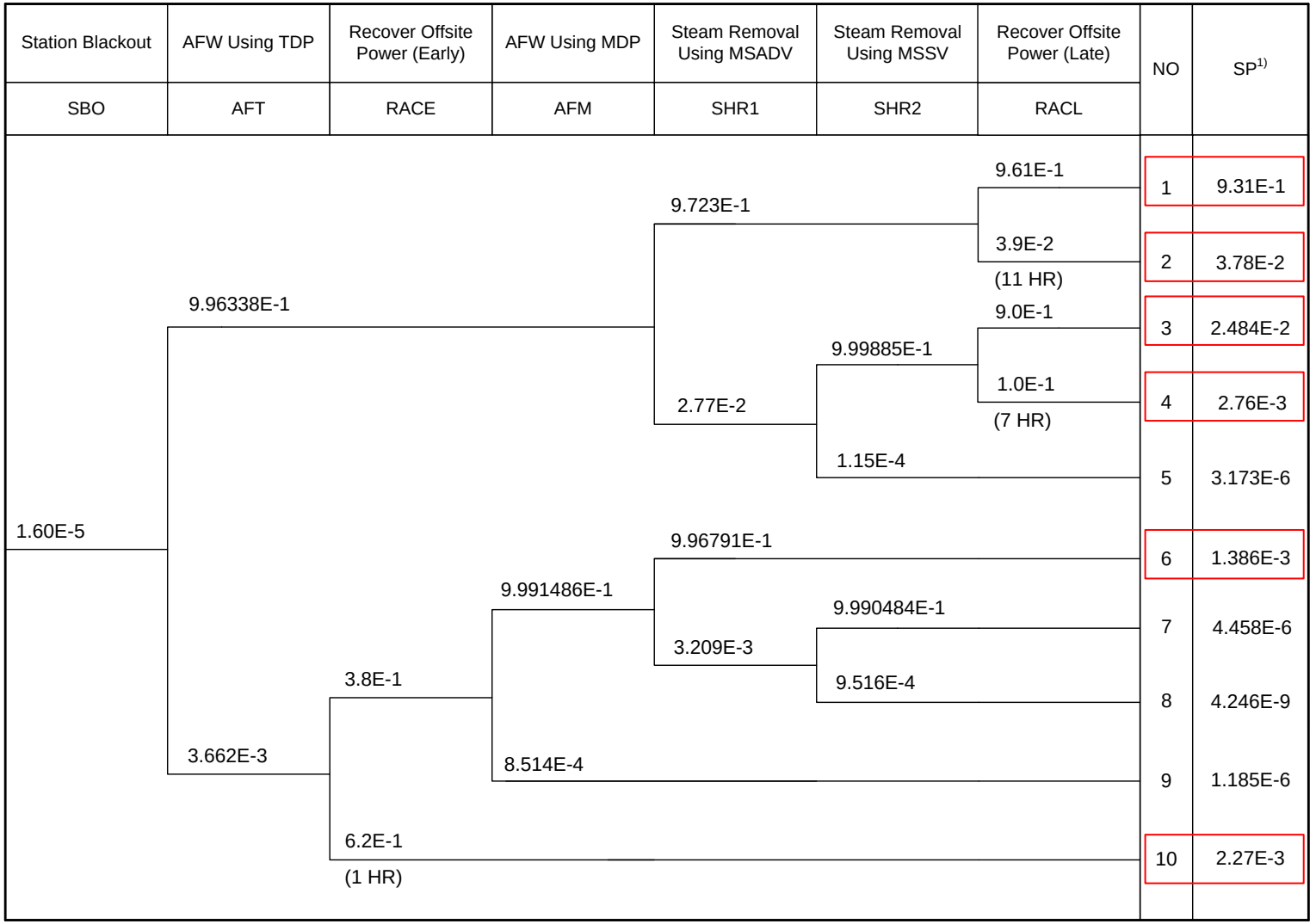


Application to OPR-1000 SBO

- Step 1 : Select BDBA (Initiating Event)
  - Station Blackout
  - Starting t=0 when LOOP occurs
- Step 2 : Determine Targeted CDF & CCDP
  - CDF < 5.4E-7, CCDP < 3.3E-2
    [less than 10% of total CDF (5.44E-6)]
- Step 3 : Estimate IEF
  - From PSA data, IEF(SBO)=1.60E-5 based on domestic operation experience database

Application to OPR-1000 SBO

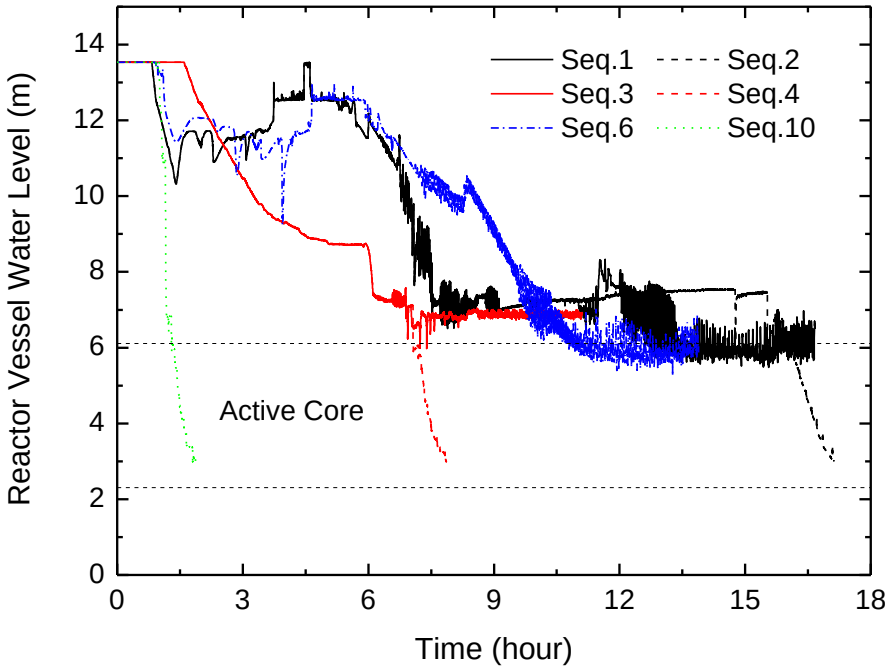
- Step 4 & 5 : Identify Sequence of Events & Quantify SP

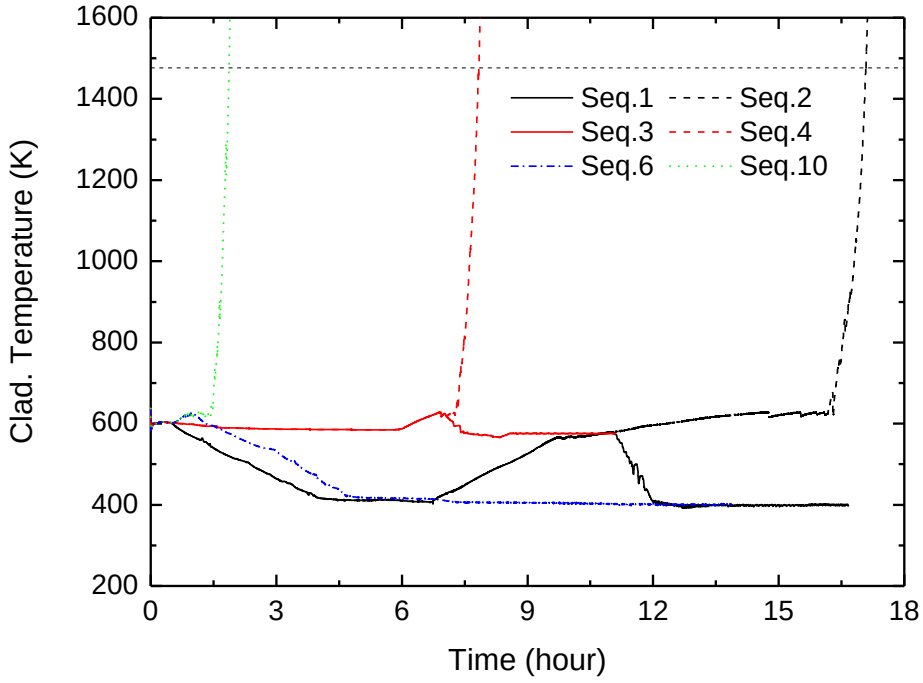


Application to OPR-1000 SBO

❑ Step 6 : BEPU Application to Calculate CEP

- Preliminary estimation of CEPs for six sequences





- Sequence 2, 4, 10 result in core damage : $P_{cond,exc}$ ~ 1.0
- Sequence 1 has enough margin (CD occurs ~ 17 hr) : $P_{cond,exc}$ ~ 0.0
- Sequence 6 has enough margin (RV water inventory) : $P_{cond,exc}$ ~ 0.0
- BEPU application for sequence 3 (CD ~ 7.8 hr)

Application to OPR-1000 SBO

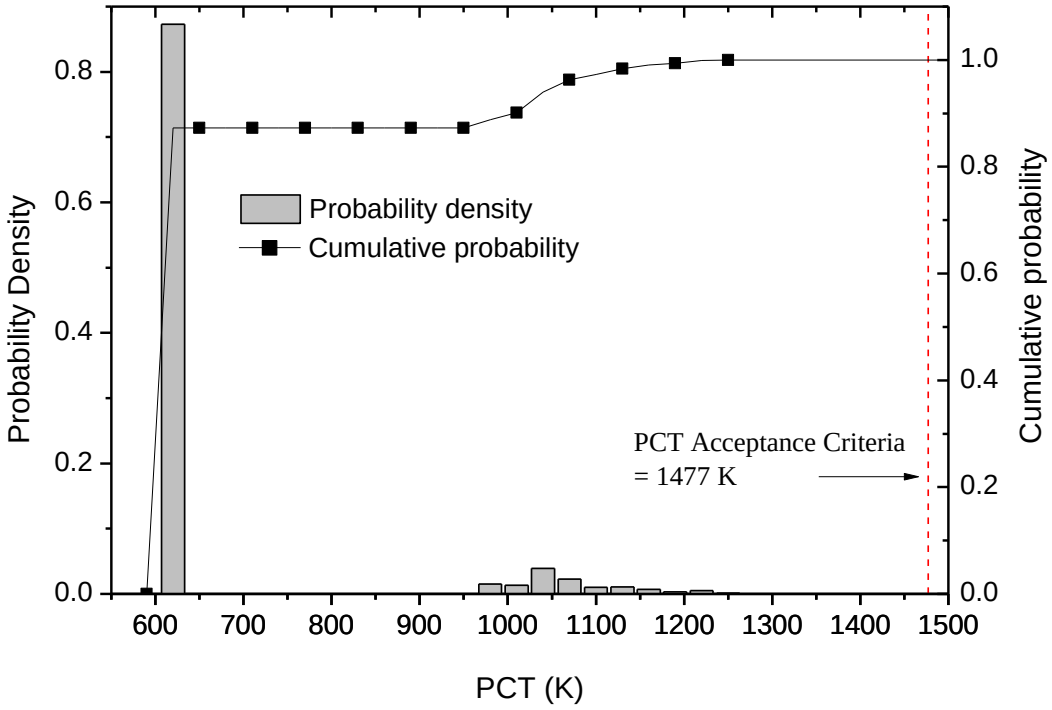
- Step 7 : Select Simulation Code/Model (MARS-KS)
- Step 8 : Identify & Quantify Relevant Uncertainties

No	Parameter	Distribution	Mean	Range
1	Core power	Normal	1.0	0.98~1.02
2	Decay heat	Normal	1.0	0.934~1.066
3	PSV break CD	Normal	0.947	0.729~1.165
4	RCP seal leakage (L/s)	Uniform	1.32	0.06~2.58
5	Aux. feedwater flow rate (m^3/min)	Uniform	1.985	1.89~2.08
6	SG low water level signal (%)	Uniform	21.5	19.9~23.1
7	PSV opening pressure (MPa)	Uniform	17.24	17.06~17.41
8	MSSV opening pressure (MPa)	Uniform	8.618	8.273~8.963
9	SIT actuation pressure (MPa)	Uniform	4.245	4.031~4.459
10	SIT water temperature (K)	Uniform	302.6	283.2~322
11	SIT water volume (m^3)	Uniform	52.63	50.69~54.57
Core heat transfer & SG tube outer wall heat transfer				
12,13	Critical heat flux	Normal	0.985	0.17~1.8
14,15	Nucleate boiling heat transfer	Normal	0.995	0.53~1.46
16,17	Transition boiling criteria	Normal	1.0	0.54~1.46
18,19	Liquid convection heat transfer	Normal	0.998	0.606~1.39
20,21	Vapor convection heat transfer	Normal	0.998	0.606~1.39
22,23	Film boiling heat transfer	Normal	1.004	0.428~1.58

Application to OPR-1000 SBO

❑ Step 9 : Calculate CEP

- 1,000 calculations (direct Monte-Carlo method) for sequence 3
  - Most of PCTs lie within the range of 635~643 K
  - All PCTs occurs immediately after the accident (4 sec)
  - There is not the case beyond PCT limit : CEP ~ 0.0



Parameter	Result
No. of Case beyond 1477 K	0
$P_{cond,exc}$	~ 0.0
Average PCT	694.3 K
Max. PCT	1261.3 K
Min. PCT	635.7 K

Application to OPR-1000 SBO

❑ Step 10~12 : Calculated CDF & CCDP < Acceptable Risk

Sequence No.	IEF	SP	CEP	CCDP	CDF
1	1.6E-5	9.31E-1	~ 0.0	~ 0.0	~ 0.0
2	1.6E-5	3.78E-2	~ 1.0	3.78E-2	6.048E-7
3	1.6E-5	2.484E-2	~ 0.0	~ 0.0	~ 0.0
4	1.6E-5	2.76E-3	~ 1.0	2.76E-3	4.416E-8
5	1.6E-5	3.173E-6	~ 1.0	3.173E-6	5.077E-11
6	1.6E-5	1.386E-3	~ 0.0	~ 0.0	~ 0.0
7	1.6E-5	4.458E-6	~ 0.0	~ 0.0	~ 0.0
8	1.6E-5	4.246E-9	~ 1.0	4.246E-9	6.794E-14
9	1.6E-5	1.185E-6	~ 1.0	1.185E-6	1.896E-11
10	1.6E-5	2.27E-3	~ 1.0	2.27E-3	3.632E-8
Sum				4.2834E-2	6.8535E-7

- Calculated CDF & CCDP for BDB LOCA meet the acceptable risk

$$\mathrm{P(CD|SBO)} = 4.2834 \times 10^{-2} \lessdot 3.3 \times 10^{-2}$$

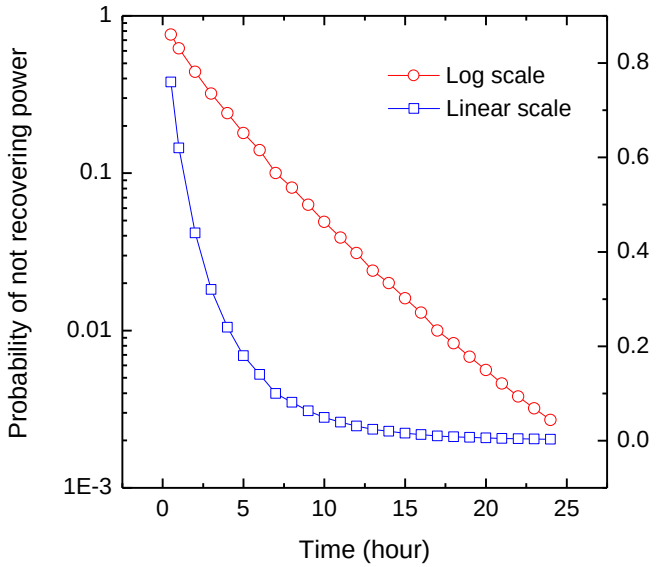
$$\lambda_{\mathrm{CD}}(\mathrm{SBO}) = 6.8535 \times 10^{-7} \lessdot 5.4 \times 10^{-7}$$

Reevaluation of SBO Risk

- Reevaluation of SBO Risk
  - Update of LOOP frequency reflecting latest operating experience
  - Change of availability of component/system
  - System design modification (DC battery capacity improvement)
  - Change of TH analysis methodology in PSA
- Unavailability of offsite power restoration
  - Most important contributor in SBO risk
  - Time of offsite power restoration (RACL, RACE) by TH analysis
  - Too much conservatism in RACL time of sequence 1,2
    - 11 hours (RACL time) vs 17.08 hours (CD time)
  - SBO risk is reevaluated by proper estimation of RACL time

Reevaluation of SBO Risk

- Reset of RACL time
  - Unavailability of offsite power recovery
  - SP of sequence 1, 2 : EPRI PRA assumption
  - CEP of sequence 1 : BEPU calculation



  - For RACL at 13 hours

$$\mathrm{P(CD|SBO)} = \sum_{i=1}^{10} P_{seq}(i)\, P_{cond,exc}(i)$$

$$= P_{seq}(1)P_{cond,exc}(1) + P_{seq}(2)P_{cond,exc}(2) + \sum_{i=3}^{10} P_{seq}(i)\, P_{cond,exc}(i)$$

$$= 0.9455P_{cond,exc}(1) + 0.02325 \times 1.0 + 5.034 \times 10^{-3} \quad < 3.3 \times 10^{-2}$$

$\mathrm{P_{cond,exc}}(1) < 4.99 \times 10^{-3}$

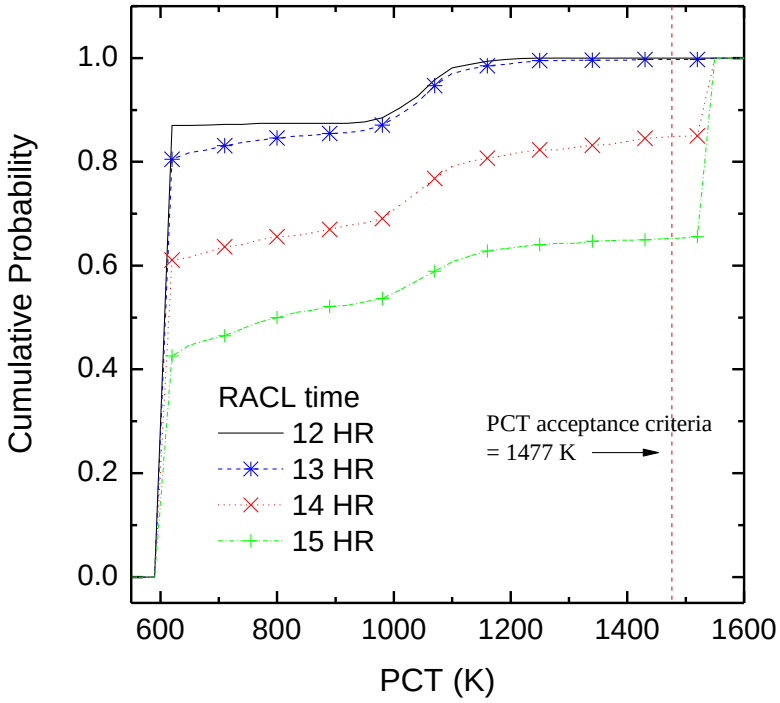
$\mathrm{P_{cond,exc}}(1) < 9.02 \times 10^{-3}$ for RACL at 14 hours

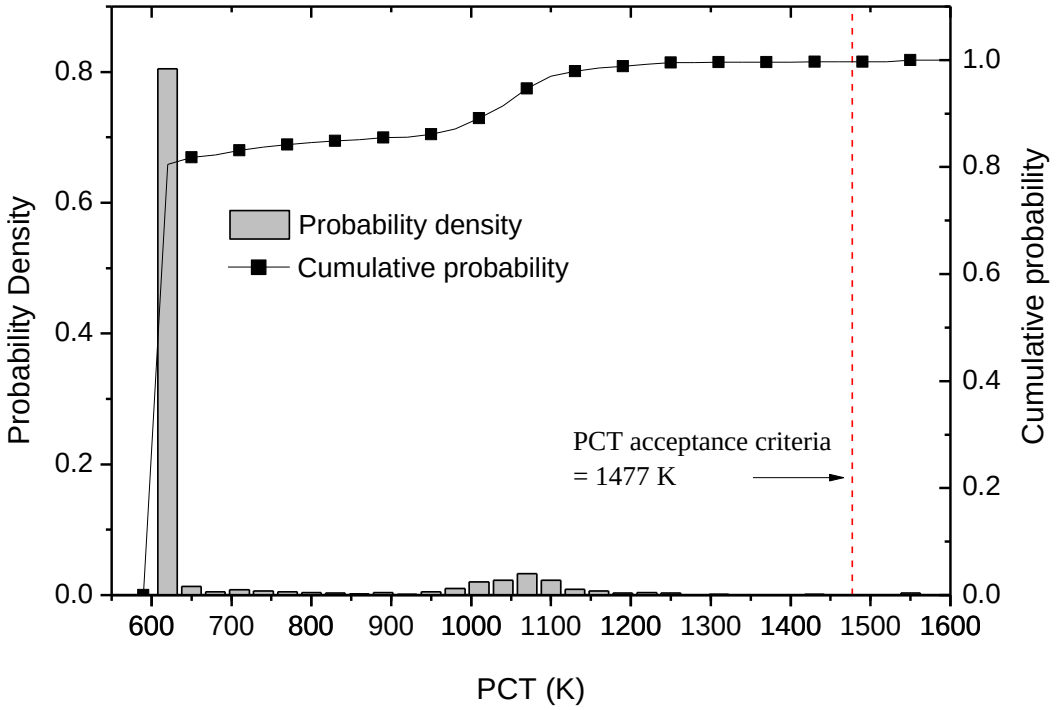
$\mathrm{P_{cond,exc}}(1) < 1.307 \times 10^{-2}$ for RACL at 15 hours

Reevaluation of SBO Risk

❑ Step 9 : Calculate CEP

- Calculations with 1,000 input sets for each RACL time

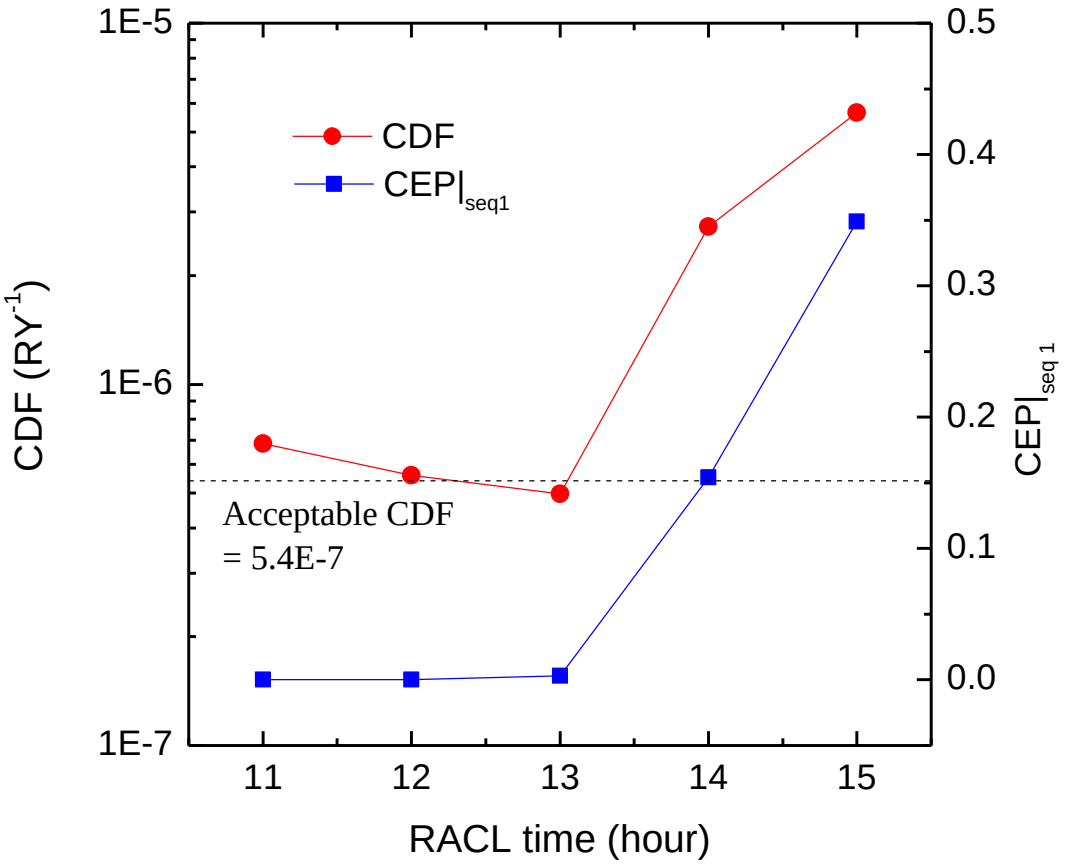




- CEPs for RACL time : 11HR (~0.0), 12HR (~0.0), 13HR (0.003), 14HR (0.154), 15HR (0.349)

Reevaluation of SBO Risk

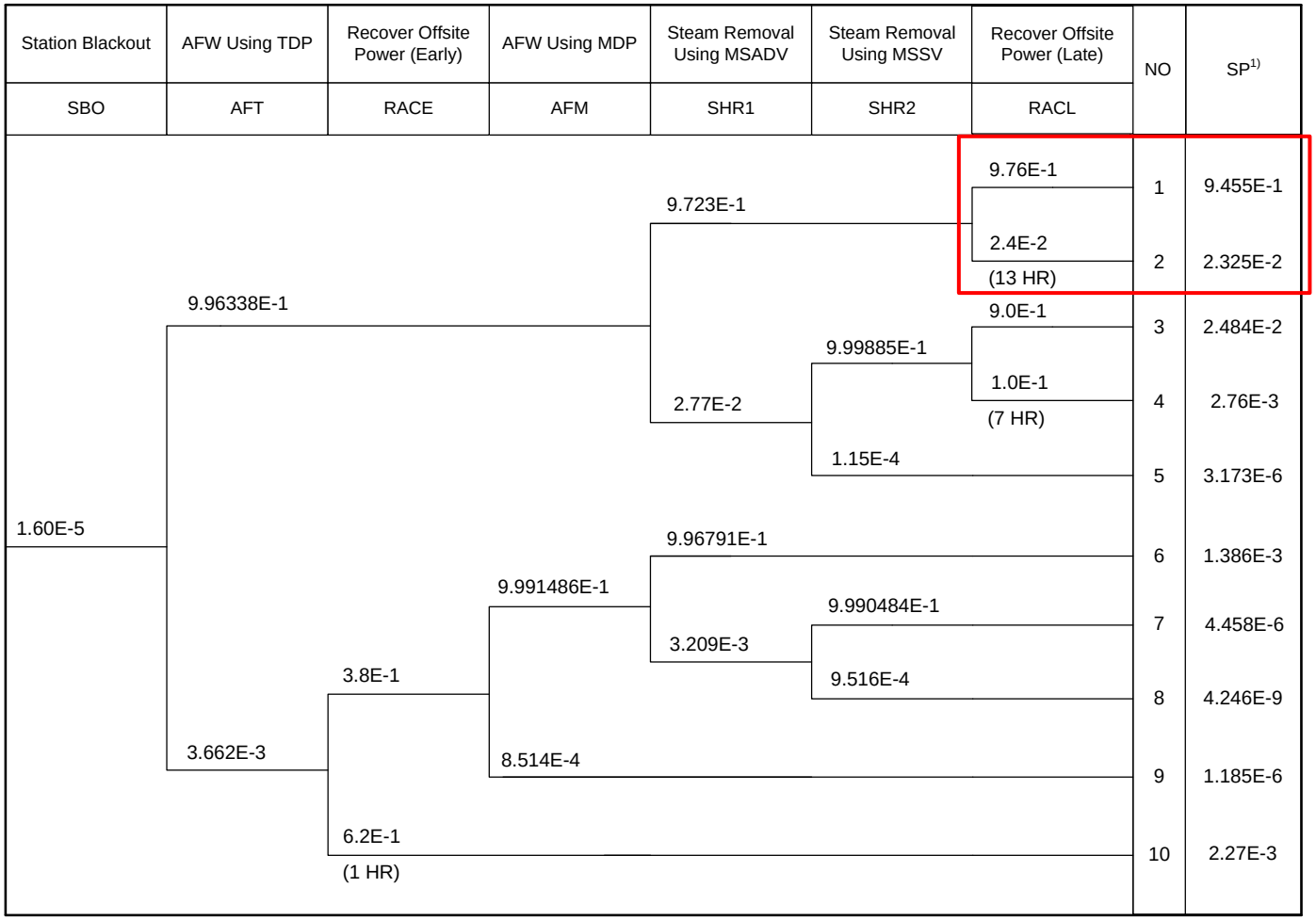
- Step 12 : CDF & CCDP < Acceptable Risk
  - Acceptable to reset RACL time to 13 hours



Reevaluation of SBO Risk

❑ Step 14 : End of Evaluation

- Confirmed that current OPR-1000 has the acceptable risk for the SBO



Conclusions

- Combined Deterministic and Probabilistic Procedure (CDPP) for BDBA Assessment
  - Three stages (PSA, BEPU, Combination) and thirteen steps
  - CEP estimated by BEPU method acts as a go-between PSA and BEPU
- Application to Station Blackout
  - Introduction to Station Blackout
  - Safety assessment of OPR-1000 for SBO
  - Reevaluation of SBO risk by proper estimation of RACL time
- CDPP is applicable to safety assessment of BDBAs in NPPs without significant erosion of the existing safety margin