Accident Sequence Precursor Analyses Of Taiwan Nuclear Power Plants

by
Yuan-Ching Chou and Ching-Hui Wu

2005 Asia-Pacific Conference on Risk Management and Safety

Outlines

- Introduction
- Data Source of Potential ASP
- Selection of Potential ASP
- Quantification of Potential ASP
- Results and Discussion
- Future Work

Introduction

- Probabilistic Risk Assessment
  (PRA in nuclear industry,1975~Today)
- Accident Sequence Precursor
  (ASP of USNRC, 1979~Today)
- Major Purpose of ASP (SECY-04-0210):
  "To identify, document and rank those nuclear power plant operating events that most likely to lead to inadequate core cooling and severe core damage, if additional failures had occurred"

Introduction (cont'd 1)

- Major procedures of US ASP Analysis

1. A computerized search to identify LERs involving failures of core damage mitigation functions;
2. An expert check to determine potential ASPs for detailed analysis;
3. Quantification of potential ASPs by using Standardized Plant Analysis Risk (SPAR) models;
4. Identification of ASPs; and
5. Review and insight analysis of ASPs.

Introduction (cont'd 2)

- Quantified Criteria of ASP:
  CCDP greater than 10^{-6} for precursors involving initiating event
  ΔCDP greater than 10^{-6} for precursors involving component failure

- Trend of US nuclear power plant core damage risk
  (from FY1993 through FY 2002, SECY-04-0210)

$CCDP > 10^{-3}$	No trend
$10^{-3} > CCDP > 10^{-4}$	Decreasing trend – almost statistically significant
$10^{-4} > CCDP > 10^{-5}$	Decreasing trend – statistically significant
$10^{-5} > CCDP > 10^{-6}$	Increasing trend – statistically significant

Introduction (cont'd 3)

- **PRA development in Taiwan**

1. First PRA for the 2nd nuclear power plant
   (1982~1985, by AEC, TPC and INER)
2. PRA models for three nuclear power plants
   (1985~1991, by TPC and INER)
3. Living PRA for three nuclear power plants
   (1991~1996, by TPC and INER)
4. Risk informed applications of PRA
   (1996~today, AEC, TPC and INER)

Data Source of Potential ASP

- Atomic Energy Council annual reports
- Atomic Energy Council inspection reports
- Atomic Energy Council safety review reports
- Atomic Energy Council reportable event reports (RER)

Selection of Potential ASP

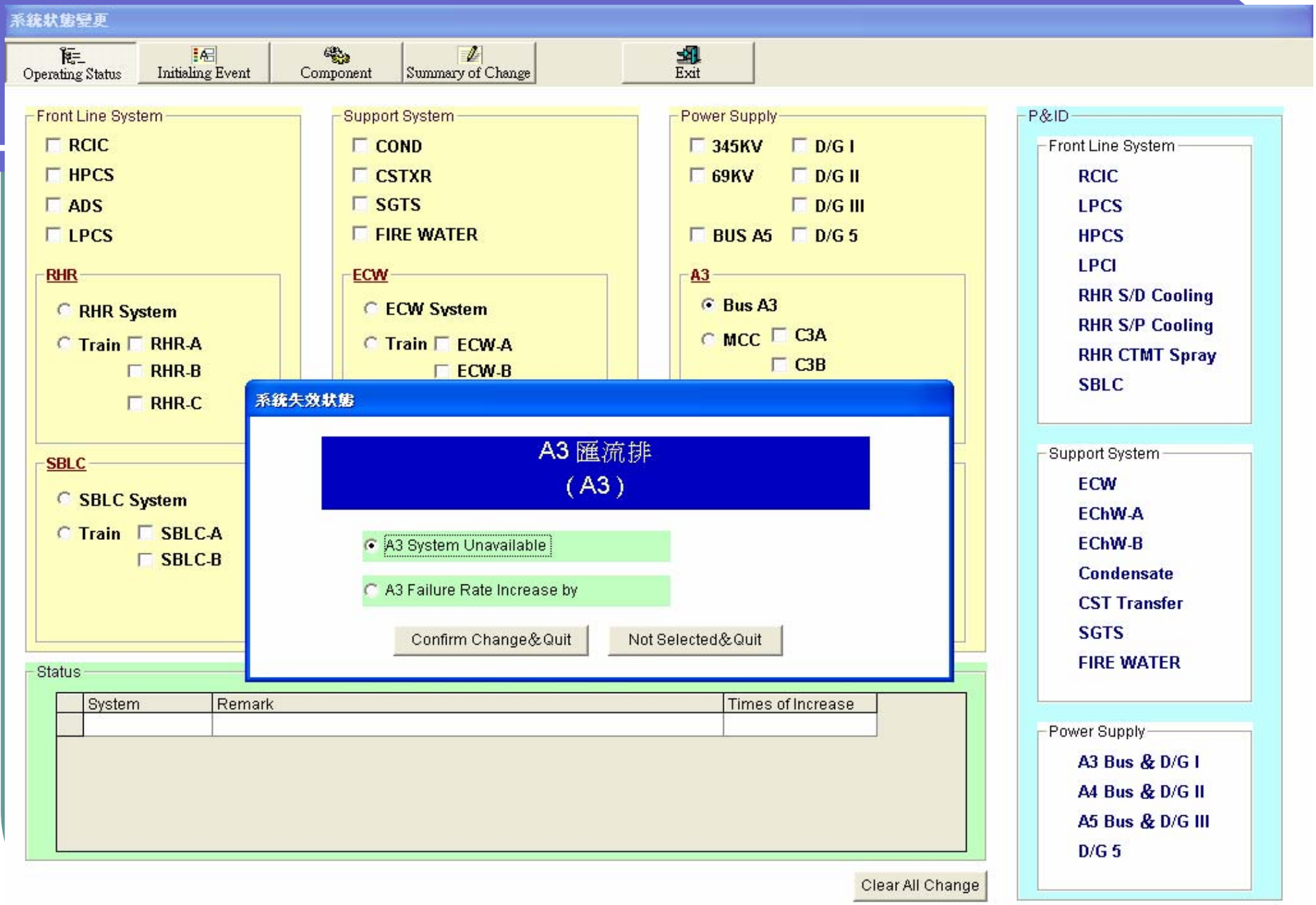
- 45 RERs for all three nuclear power plants from 2001 to 2005
- Criteria of exclusion from detailed analysis:

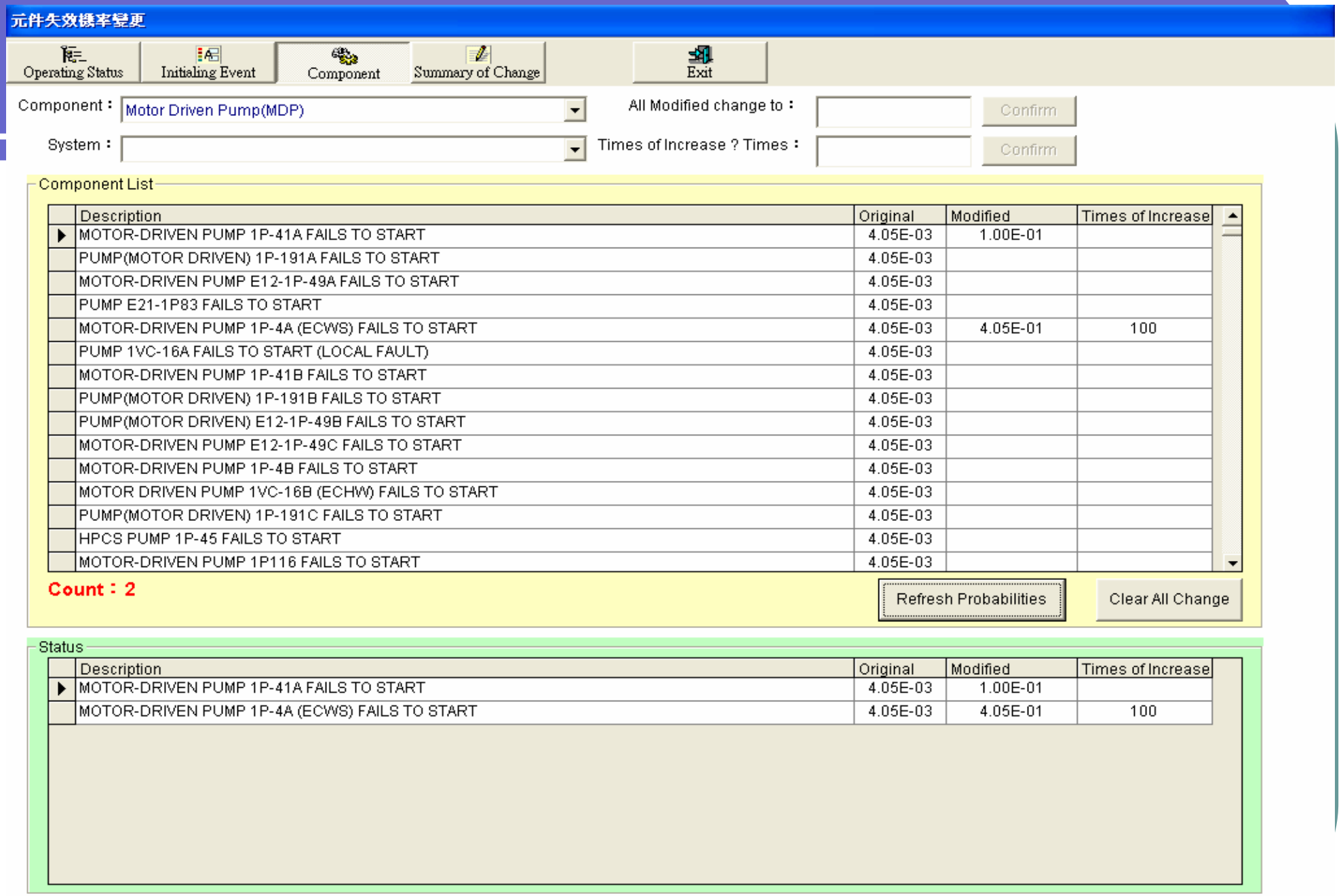
1. Events occurred during reactor shutdown;
2. Events involving containment system failure only;
3. Events with no appreciable impact on safety system;
4. Events involving shutdown by normal procedure.

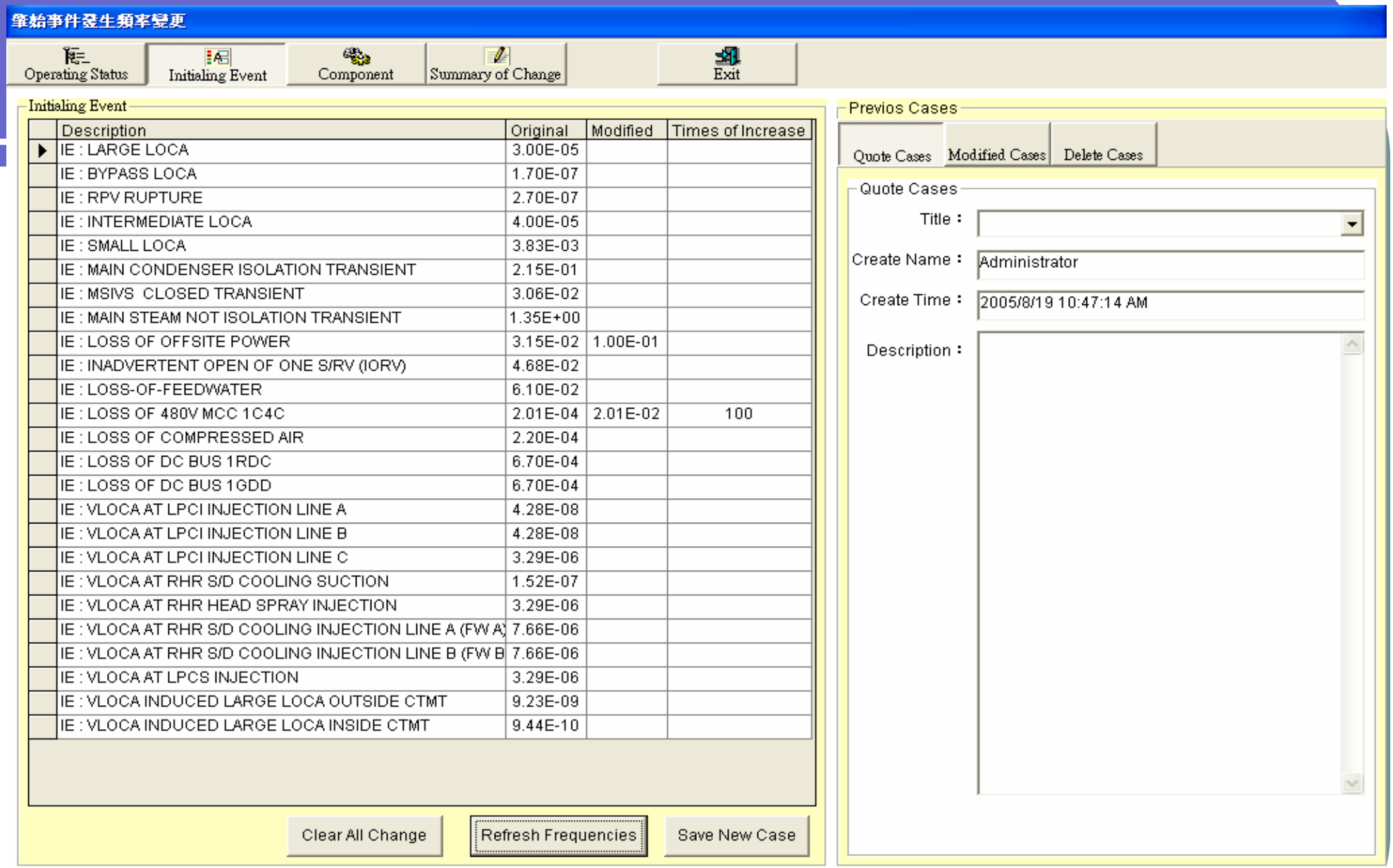
Quantification of Potential ASP

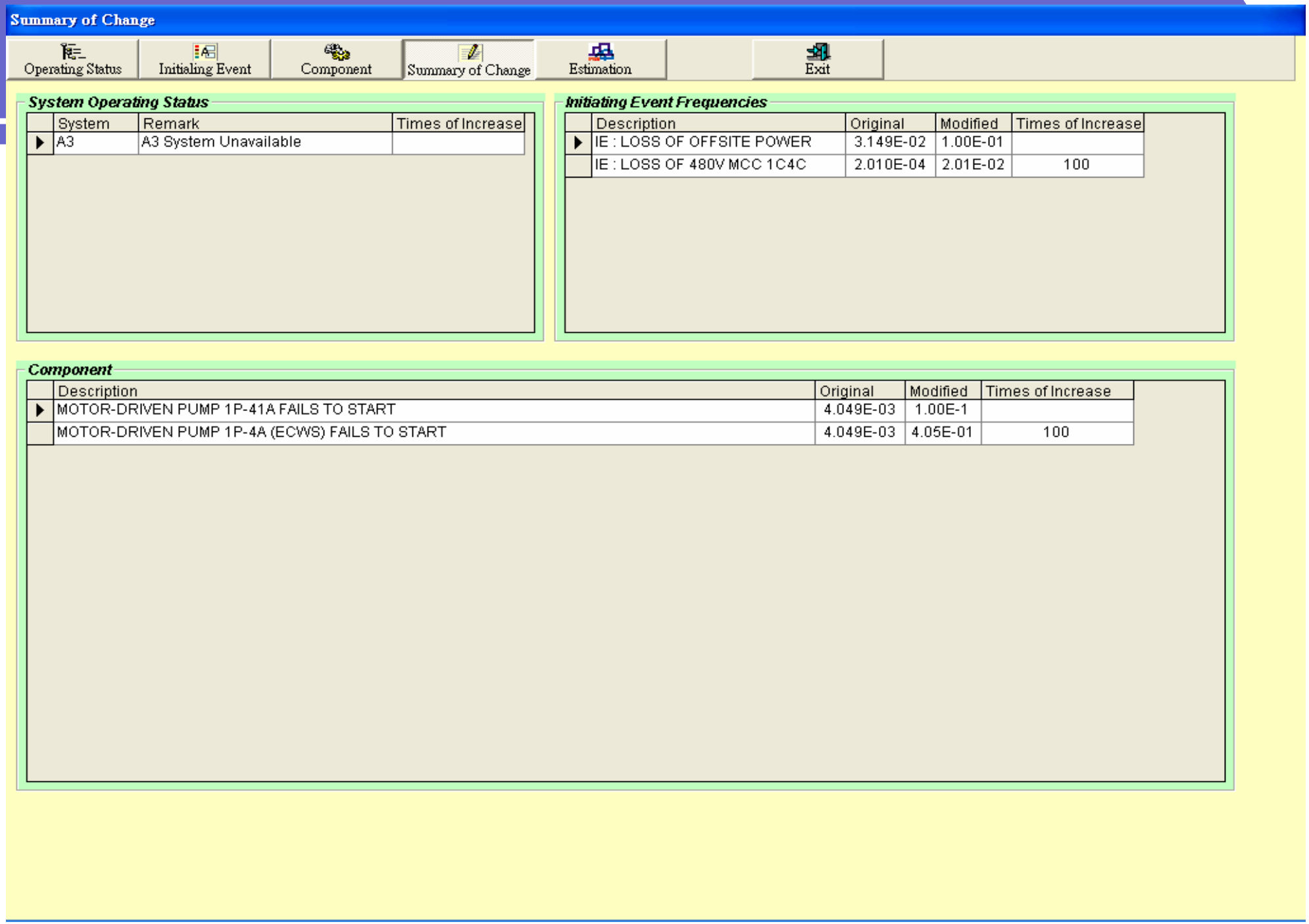
- PRiSE (PRA Model Based Risk Significance Evaluation) model

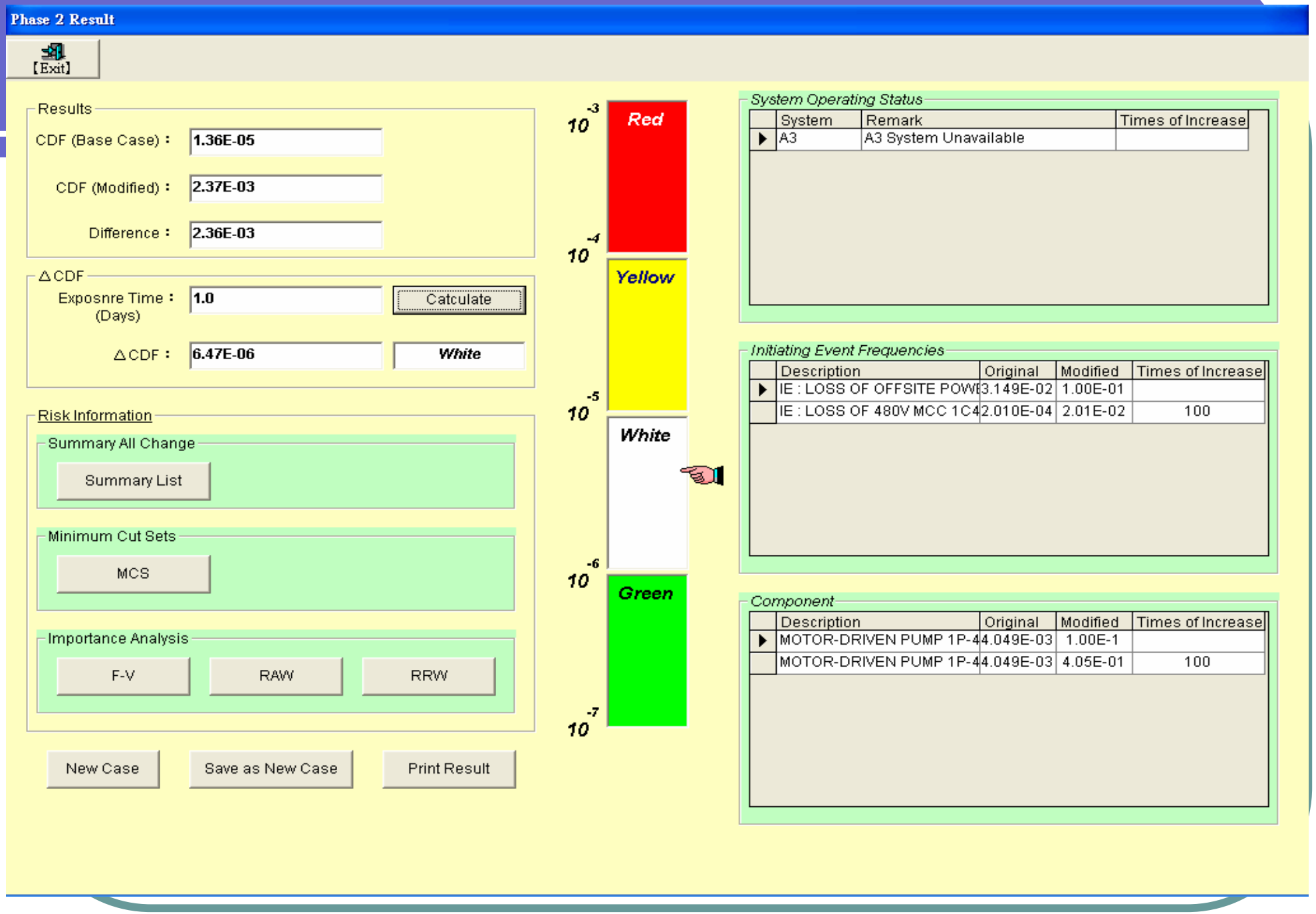
1. A fast running risk engine
2. Plant specific risk models
3. A tool for updating IE frequencies and failure prob.
4. Calculation of risk indicators (CDP, CCDP, LERF)
5. Calculation of risk importance (FV, RRW, RAW)
6. Used by regulator, utility and research institute.


系統狀態變更
Operating Status
Initialing Event
Component
Summary of Change
Exit
Front Line System
RCIC
HPCS
ADS
LPCS
RHR
RHR System
Train
RHR-A
RHR-B
RHR-C
SBLC
SBLC System
Train
SBLC-A
SBLC-B
Support System
COND
CSTXR
SGTS
FIRE WATER
ECW
ECW System
Train
ECW-A
ECW-B
Power Supply
345KV
69KV
BUS A5
D/G I
D/G II
D/G III
D/G 5
A3
Bus A3
MCC
C3A
C3B
系統失效狀態
A3 匯流排
(A3)
A3 System Unavailable
A3 Failure Rate Increase by
Confirm Change&Quit
Not Selected&Quit
Status
System
Remark
Times of Increase
Clear All Change
P&ID
Front Line System
RCIC
LPCS
HPCS
LPCI
RHR S/D Cooling
RHR S/P Cooling
RHR CTMT Spray
SBLC
Support System
ECW
EChW-A
EChW-B
Condensate
CST Transfer
SGTS
FIRE WATER
Power Supply
A3 Bus & D/G I
A4 Bus & D/G II
A5 Bus & D/G III
D/G 5


元件失效機率變更
Operating Status
Initialing Event
Component
Summary of Change
Exit
Component：
Motor Driven Pump(MDP)
All Modified change to：
Confirm
System：
Times of Increase ? Times：
Confirm
Component List
Description
Original
Modified
Times of Increase
MOTOR-DRIVEN PUMP 1P-41A FAILS TO START
4.05E-03
1.00E-01
PUMP(MOTOR DRIVEN) 1P-191A FAILS TO START
4.05E-03
MOTOR-DRIVEN PUMP E12-1P-49A FAILS TO START
4.05E-03
PUMP E21-1P83 FAILS TO START
4.05E-03
MOTOR-DRIVEN PUMP 1P-4A (ECWS) FAILS TO START
4.05E-03
4.05E-01
100
PUMP 1VC-16A FAILS TO START (LOCAL FAULT)
4.05E-03
MOTOR-DRIVEN PUMP 1P-41B FAILS TO START
4.05E-03
PUMP(MOTOR DRIVEN) 1P-191B FAILS TO START
4.05E-03
PUMP(MOTOR DRIVEN) E12-1P-49B FAILS TO START
4.05E-03
MOTOR-DRIVEN PUMP E12-1P-49C FAILS TO START
4.05E-03
MOTOR-DRIVEN PUMP 1P-4B FAILS TO START
4.05E-03
MOTOR DRIVEN PUMP 1VC-16B (ECHW) FAILS TO START
4.05E-03
PUMP(MOTOR DRIVEN) 1P-191C FAILS TO START
4.05E-03
HPCS PUMP 1P-45 FAILS TO START
4.05E-03
MOTOR-DRIVEN PUMP 1P116 FAILS TO START
4.05E-03
Count：2
Refresh Probabilities
Clear All Change
Status
Description
Original
Modified
Times of Increase
MOTOR-DRIVEN PUMP 1P-41A FAILS TO START
4.05E-03
1.00E-01
MOTOR-DRIVEN PUMP 1P-4A (ECWS) FAILS TO START
4.05E-03
4.05E-01
100


肇始事件發生頻率變更
Operating Status
Initialing Event
Component
Summary of Change
Exit
Initialing Event
Description
Original
Modified
Times of Increase
IE : LARGE LOCA 3.00E-05
IE : BYPASS LOCA 1.70E-07
IE : RPV RUPTURE 2.70E-07
IE : INTERMEDIATE LOCA 4.00E-05
IE : SMALL LOCA 3.83E-03
IE : MAIN CONDENSER ISOLATION TRANSIENT 2.15E-01
IE : MSIVS CLOSED TRANSIENT 3.06E-02
IE : MAIN STEAM NOT ISOLATION TRANSIENT 1.35E+00
IE : LOSS OF OFFSITE POWER 3.15E-02 1.00E-01
IE : INADVERTENT OPEN OF ONE S/RV (IORV) 4.68E-02
IE : LOSS-OF-FEEDWATER 6.10E-02
IE : LOSS OF 480V MCC 1C4C 2.01E-04 2.01E-02 100
IE : LOSS OF COMPRESSED AIR 2.20E-04
IE : LOSS OF DC BUS 1RDC 6.70E-04
IE : LOSS OF DC BUS 1GDD 6.70E-04
IE : VLOCA AT LPCI INJECTION LINE A 4.28E-08
IE : VLOCA AT LPCI INJECTION LINE B 4.28E-08
IE : VLOCA AT LPCI INJECTION LINE C 3.29E-06
IE : VLOCA AT RHR S/D COOLING SUCTION 1.52E-07
IE : VLOCA AT RHR HEAD SPRAY INJECTION 3.29E-06
IE : VLOCA AT RHR S/D COOLING INJECTION LINE A (FW A) 7.66E-06
IE : VLOCA AT RHR S/D COOLING INJECTION LINE B (FW B 7.66E-06
IE : VLOCA AT LPCS INJECTION 3.29E-06
IE : VLOCA INDUCED LARGE LOCA OUTSIDE CTMT 9.23E-09
IE : VLOCA INDUCED LARGE LOCA INSIDE CTMT 9.44E-10
Clear All Change
Refresh Frequencies
Save New Case
Previos Cases
Quote Cases
Modified Cases
Delete Cases
Quote Cases
Title :
Create Name : Administrator
Create Time : 2005/8/19 10:47:14 AM
Description :


Summary of Change
Operating Status
Initialing Event
Component
Summary of Change
Estimation
Exit
System Operating Status
System
Remark
Times of Increase
A3
A3 System Unavailable
Initiating Event Frequencies
Description
Original
Modified
Times of Increase
IE : LOSS OF OFFSITE POWER
3.149E-02
1.00E-01
IE : LOSS OF 480V MCC 1C4C
2.010E-04
2.01E-02
100
Component
Description
Original
Modified
Times of Increase
MOTOR-DRIVEN PUMP 1P-41A FAILS TO START
4.049E-03
1.00E-1
MOTOR-DRIVEN PUMP 1P-4A (ECWS) FAILS TO START
4.049E-03
4.05E-01
100


Phase 2 Result
【Exit】
Results
CDF (Base Case) : 1.36E-05
CDF (Modified) : 2.37E-03
Difference : 2.36E-03
△CDF
Exposnre Time : (Days) 1.0
Catculate
△CDF : 6.47E-06
White
Risk Information
Summary All Change
Summary List
Minimum Cut Sets
MCS
Importance Analysis
F-V
RAW
RRW
New Case
Save as New Case
Print Result
10-3
Red
10-4
Yellow
10-5
White
10-6
Green
10-7
System Operating Status
System | Remark | Times of Increase
A3 | A3 System Unavailable |
Initiating Event Frequencies
Description | Original | Modified | Times of Increase
IE : LOSS OF OFFSITE POWE | 3.149E-02 | 1.00E-01 |
IE : LOSS OF 480V MCC 1C4 | 2.010E-04 | 2.01E-02 | 100
Component
Description | Original | Modified | Times of Increase
MOTOR-DRIVEN PUMP 1P-4 | 4.049E-03 | 1.00E-1 |
MOTOR-DRIVEN PUMP 1P-4 | 4.049E-03 | 4.05E-01 | 100

Results and Discussion

- Quantification results of potential ASP involving initiating events
- Quantification results of potential ASP involving component failures
- Insight of ASPs
- Discussion of all potential ASPs
- Discussion of a station blackout event

Table 1: Potential ASP Involving Initiating Event (2001 ~ 2005)

RER #	Plant (type)	Event Date	Description	CCDP
RER-94-31-001	3rd (PWR)	3/25/05	Unit 1 general transient, main feedwater available, steam generator low-low level trip.	5.76E-7
RER-94-32-001	3rd (PWR)	1/29/05	Unit 2 general transient, main feedwater available, reactor trip.	2.01E-7
RER-93-11-001	1st (BWR)	1/24/04	Unit 1 general transient, main condenser not isolated.	1.93E-7
RER-92-32-07-0	3rd (PWR)	12/9/03	Unit 2 general transient, main feedwater available, reactor trip.	2.01E-7
RER-92-31-003	3rd (PWR)	9/1/03	Unit 1 general transient, main feedwater available, reactor trip.	2.01E-7
RER-92-31-004	3rd (PWR)	9/4/03	Unit 1 loss of offsite power	6.01E-6
RER-92-32-003	3rd (PWR)	9/1/03	Unit 2 general transient, main feedwater available, reactor trip.	2.01E-7
NA	1st (BWR)	9/26/02	Unit 1 general transient, main condenser not isolated.	1.93E-7
NA	3rd (PWR)	6/6/02	Unit 2 general transient, main feedwater available, reactor trip.	2.01E-7
NA	2nd(BWR)	4/27/02	Unit 1 general transient, main condenser not isolated.	5.68E-7
NA	2nd(BWR)	9/19/01	Unit 2 general transient, main condenser not isolated.	5.68E-7

Table 2: Potential ASP Involving Unavailability (2001 ~ 2005)

RER #	Plant (type)	Event Date	Description	ΔCDP
RER-94-12-002	1st(BWR)	4/3/05	Unit 2 RCIC unavailable for 0.4 days	1.68E-8
RER-94-20-001	2nd(BWR)	2/25/05	Unit 1 Loss of 69 kV power for 0.1 days Unit 1 Division III DG and HPCS unavailable for 0.76 days	1.45E-9 9.91E-8
RER-93-22-001	2nd(BWR)	6/21/04	Unit 2 HPCS unavailable for 0.16 days	2.09E-8
RER-92-32-004	3rd (PWR)	9/4/03	Unit 2 4.16kV Bus unavailable for 0.1 days	5.56E-7
RER-92-31-005	3rd (PWR)	9/4/03	Unit 1 Feedwater isolation for 0.1 days	1.37E-10
RER-92-11-001	1st(BWR)	1/21/03	Unit 1 HPCI unavailable for 16 days	1.09E-6
RER-92-11-002	1st(BWR)	4/24/03	Unit 1 RCIC unavailable for 0.5 days	2.10E-8
RER-92-11-005	1st(BWR)	7/24/03	Unit 1 HPCI unavailable for 1.0 days	6.82E-8
RER-92-11-006	1st(BWR)	9/1/03	Unit 1 RCIC unavailable for 0.01days	4.19E-10
NA	2nd(BWR)	9/5/01	Unit 1 Loss of 69kV power for 0.06 days	8.71E-10
NA	2nd(BWR)	9/5/01	Unit 2 Loss of 69kV power for 0.06 days	8.71E-10

ASP Involving Initiating Event

- Date: September 4 of 2003
- Plant/Unit: The 3rd NPP/Unit 1
- Operating Condition: About to connect to the grid
- Initiating Event: A circuit breaker failure in switch yard causing a loss of offsite power (LOOP) event
- Dominant Sequence:

  1. RPS, RCS, TB driven AFW, ECCS and Depressurization system are successful
  2. Secondary heat removal system and bleed & feed function fail due to long term failure of emergency DGs

ASP Involving Unavailability

- Date: January 21 of 2003
- Plant/Unit: The 1st NPP/Unit 1
- Operating Condition: Full Power
- Unavailability: Fast-start test failure of HPCI system

  (unavailable time is conservatively assumed as 16 days)
- Dominant Transient: Loss of feedwater event
- Root Cause: Vaporization of water in test line
- If the unavailable time is 1 day, then the ΔCDP becomes 16 times less.

Discussion of All Potential ASPs

- Potential ASP involving initiating event (Table 1)
  - 7 of 11 ASP candidates occurred in the 3rd NPP
  - 3 of these 7 events caused by failure of offsite power
  - 2 of these 7 events caused by failure of I&C cards
  - 2 of these 7 events caused by failure of FCV and TBCV
- Potential ASP involving component failure (Table 2)
  - 5 of 11 ASP candidates occurred in the 1st NPP
  - 3 of these 5 events caused by test failure of RCIC
  - 2 of these 5 events caused by test failure of HPCI
  - 3 out of 4 candidates from the 2nd NPP caused by failure of 69KV power supply

Discussion of A Station Blackout Event

- Date: March 18 of 2001
- Plant/Unit: The 3rd NPP/Unit 1
- Operating Condition: Shutdown
- Initiating Event: LOOP caused by a fire event at A-PB bus at unit 1
- Component Failure: 2 EDGs of unit 1 failed to supply power and caused a SBO event
- Termination: The 5th EDG lined up to the train-B switch of unit 1

Station Blackout Event (cont'd)

Table 3: Risk Analysis for 318 SBO Event (C.H. Wu et al.)

Analysis Stage	Operational Modes	Initiating Event	Time Duration	CCDP
1	Hot Standby	SBO	15 min.	3.1E-2
2	Hot Standby	SBO	1.75 hours	3.3E-3
3	Hot Standby	LOOP	4 hours	6.5E-4
4	Hot Shutdown	LOOP	11.5 hours	2.9E-4
5	Cold Shutdown	LOOP	52 hours	8.6E-5
6	Cold Shutdown	Partial LOOP	58 days	4.6E-8

Future Work

- To enlarge the scope of data source;
- To establish formal review processes of selection of potential ASPs;
- To include shutdown condition into the scope of analysis; and
- To set up a peer review procedure for the whole analysis.