Introduction of PSA Applications in the Nuclear and Petrochemical Industries

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Outline

I、 Introduction

II、Development of the RIA Tools, Risk Engine and Risk Monitor

III、Development of the RIR/SDP Tool, PRiSE

IV、Development of Risk-Informed Fire Analysis, ISI, and OLM

V 、QRA Application on LNG

VI、Conclusions

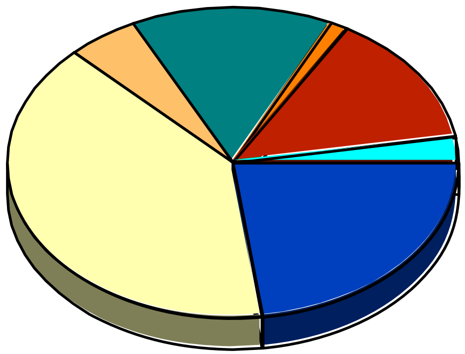
工欲善其事
必先利其器

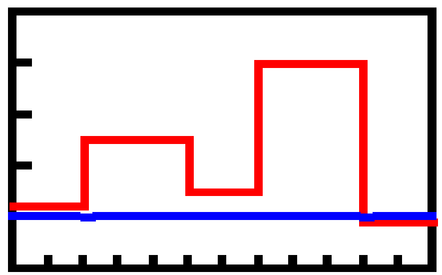
I、Taiwan in the History of PRA Technology

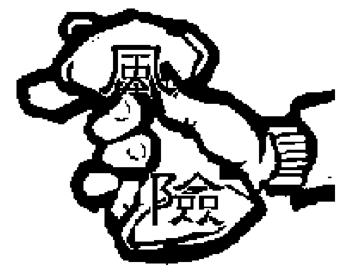
Date	Events and Effects
1970	1975 USAEC issued WASH-1400
	1979 Three Mile Island Accident
1980	1982 ROCAEC initiated the first PRA program for domestic NPPs in Taiwan
	1985 1st Kuosheng PRA was accomplished
	1987 1st Maanshan PRA was accomplished
	1988 USNRC issued GL88-20, IPE (Individual Plant Examination) was requested for all US NPPs
1990	1990 USNRC issued NUREG-1150 (PRA studies for 5 selected NPPs)
	1991 1st Chinshan PRA was accomplished
	1993 US utilities issued IPEs for NRC review
	1995 USNRC issued "The PRA Policy Statement" and agency-wide PRA implementation plan
	1995 Power operation living PRA project was accomplished in Taiwan for 3 operating NPPs
	1996 Shutdown PRA framework was accomplished in Taiwan for 3 operating NPPs
	1997 ~ Now : Taipower Integrated Risk Monitor is established in Taiwan for 3 operating NPPs
	1998 NRC released risk-informed applications associated Regulatory Guide 1.174~1.178
2000	2000 ~ Now : PRA models are ready for risk-informed applications

I、PRA Development in Taiwan

Establishment → ***Refinement*** → ***Application***





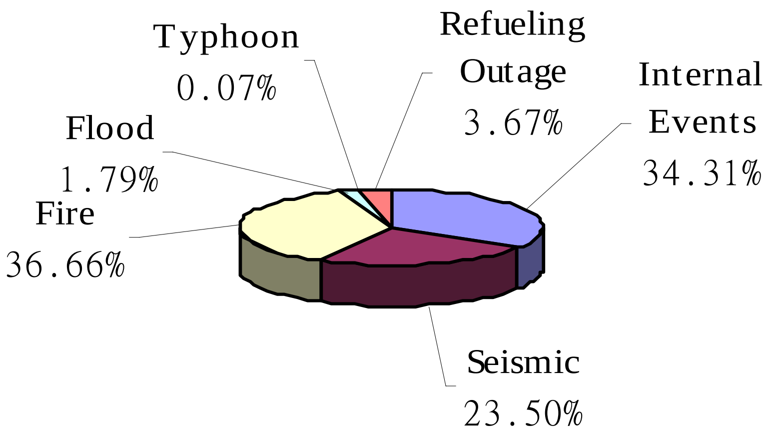


1982-1992
- Static PRA (completed Level 2 PRA)
- NPP modification & improvement

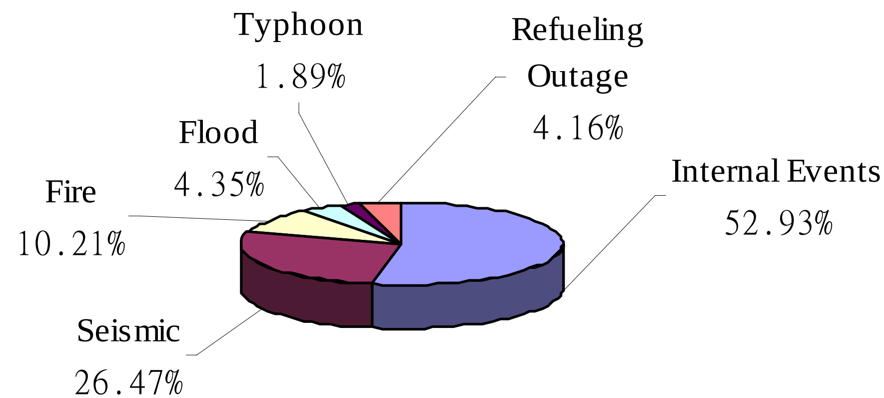
1993-1996
- Living PRA
- Up-to-date models
- Shutdown & power models

1997-Now
- TIRM-2
- RIFA-2 & RIFADISP
- INER fault tree engine, INERFT
- OLM (PWR & BWR RHR)
- RI-ISI
- LNG QRA

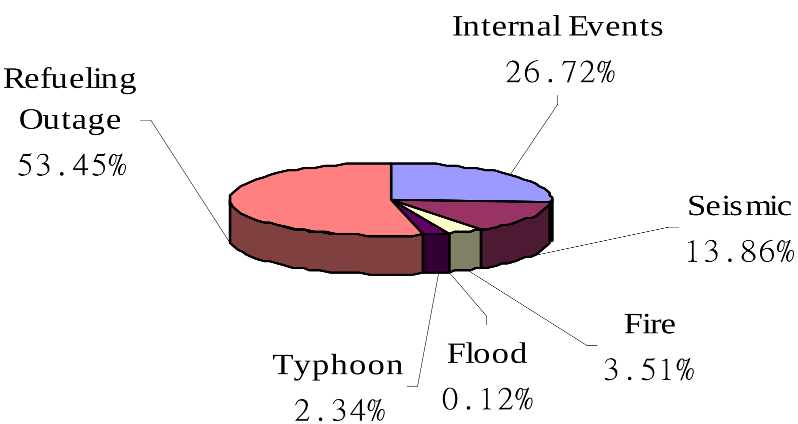
I、 Risk Contributions for Different Types of NPPs



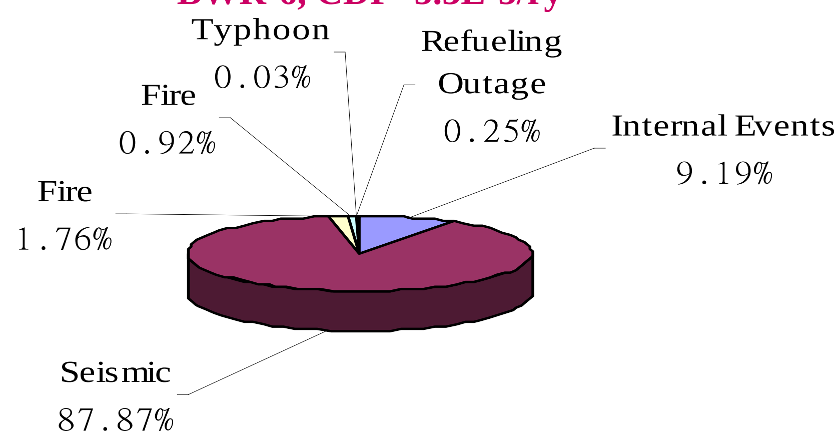
BWR-4, CDF=2.1E-5/ry



BWR-6, CDF=5.3E-5/ry



PWR, CDF=6.0E-5/ry



ABWR, CDF=3.5E-6/ry

I、Introduction (1 of 3)

- The Probabilistic Risk Assessment (PRA) group of INER has developed and maintains the PRA models of all the nuclear power plants (NPPs) for Taiwan Power Company (TPC) over 25 years since PRA was first introduced to Taiwan's NPPs
- These PRA models cover internal and external events, power operation and shutdown mode, with LERF (Large Early Release Frequency) calculation modules
- The PRA group has completed a dedicated risk monitor with indigenous model solver engines, which are now adopted by the domestic three NPPs to monitor daily operation risks

I、Introduction (2 of 3)

- A window-based tool with the Significance Determination Process (SDP) context to help the resident inspectors of Taiwan’s nuclear regulatory body to perform the Phase 2 SDP assessment of the Reactor Oversight Process (ROP) has also been completed

- Staff of INER was invited to present a 30-minute talk on the PRiSE at the 523th ACRS meeting chaired by Dr. G. B. Wallis on June 2, 2005

I、Introduction (3 of 3)

- Since 2003, the Minister of Taiwan's Atomic Energy Council, Dr. Min-Shen Ouyang has been reiterating that AEC's overall goals in regulating Taipower's operating LWRs are threefold: "Safety First, Deregulation, and Administrative Simplification."

  (安全第一、法規鬆綁、簡政便民)

- The second and third points are new policy, and are an indication that things are moving to a pro risk-informed direction. Taiwan's regulatory body is working with Taipower management to "gradually introduce" risk-informed practices into Taiwan

II、 Development of the RIA Tool, Risk Engine

- The development of Taiwan's risk engine has paved a successful path for providing the helpful tools for Risk-Informed Regulations/Applications
- The module includes a super risk engine, the INERISKEN (INER RISK ENgine) to solve PRA model within one minute through the advanced PRA model in the form of top-logic fault tree
- The results showed that INERISKEN has an excellent performance and can be used in the associated applications
- In addition to the nuclear industry, INERFT (INER Fault Tree) is applied to other petrochemical industries in Taiwan

II、 Development of the RIA Tool, Risk Monitor (1 of 7)

- On the basis of the accomplished living PRA models on all of the three Taiwan's NPPs, INER and TPC have collaboratively developed a risk monitor, the Taipower Integrated Risk Monitor (TIRM), for each NPP
- Due to the TIRM's robust function and its successful development, since June of 2001, Taiwan's nuclear regulatory body has requested that each NPP evaluate shutdown risk before TPC performs refuelling outages and calculate the associated risk profile daily by the TIRM

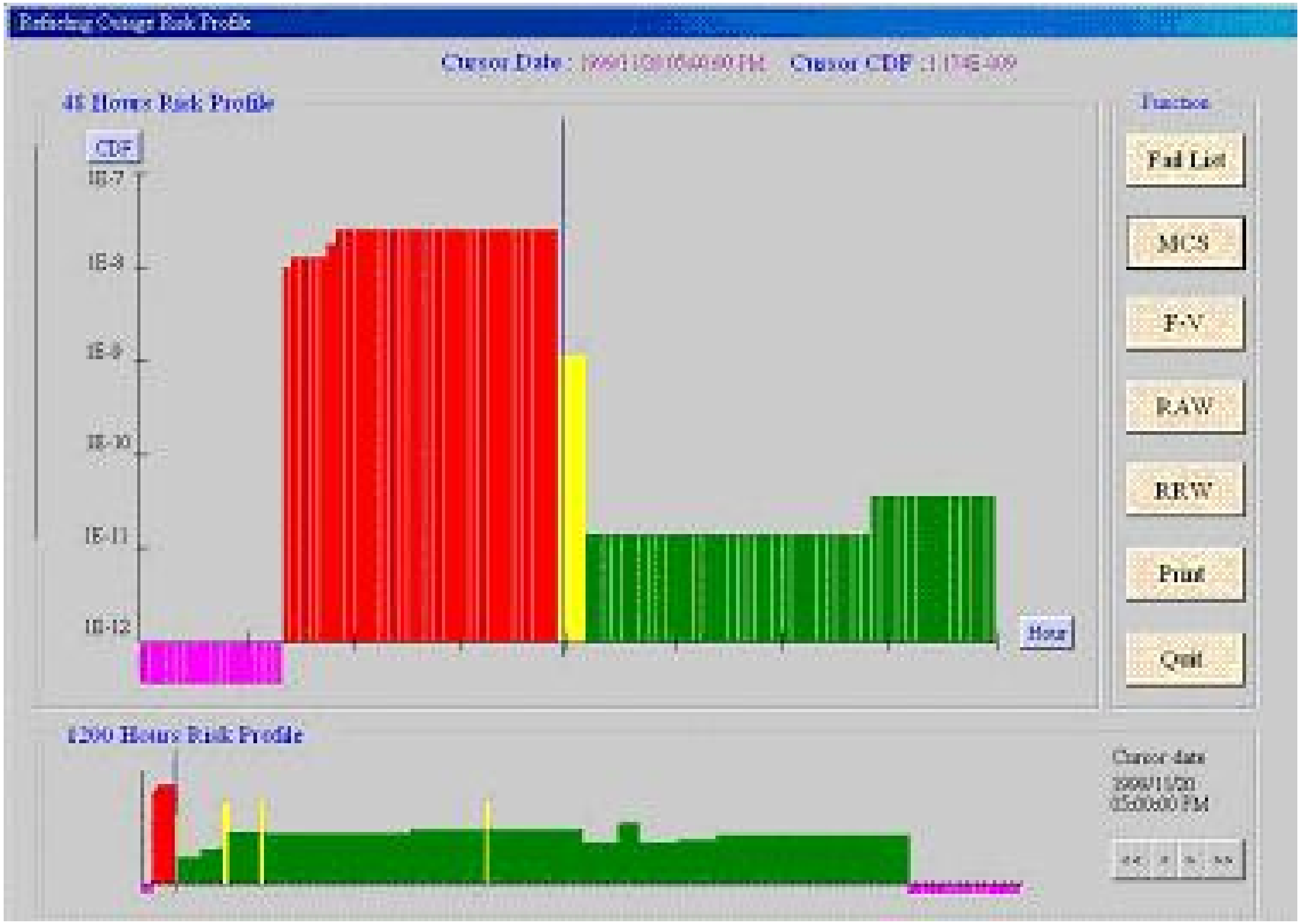
II、 Development of the RIA Tool, Risk Monitor (2 of 7)

- For further risk-informed applications, only Core Damage Frequency (CDF) index in the TIRM is not sufficient
- A new risk engine, the INERISKEN, developed by INER was incorporated into the TIRM-2
- By introducing the new powerful risk model solver INERISKEN, the TIRM-2 is designed to have more capabilities of performing both CDF and LERF calculations and to run faster than TIRM does

II、 Development of the RIA Tool, Risk Monitor (3 of 7)

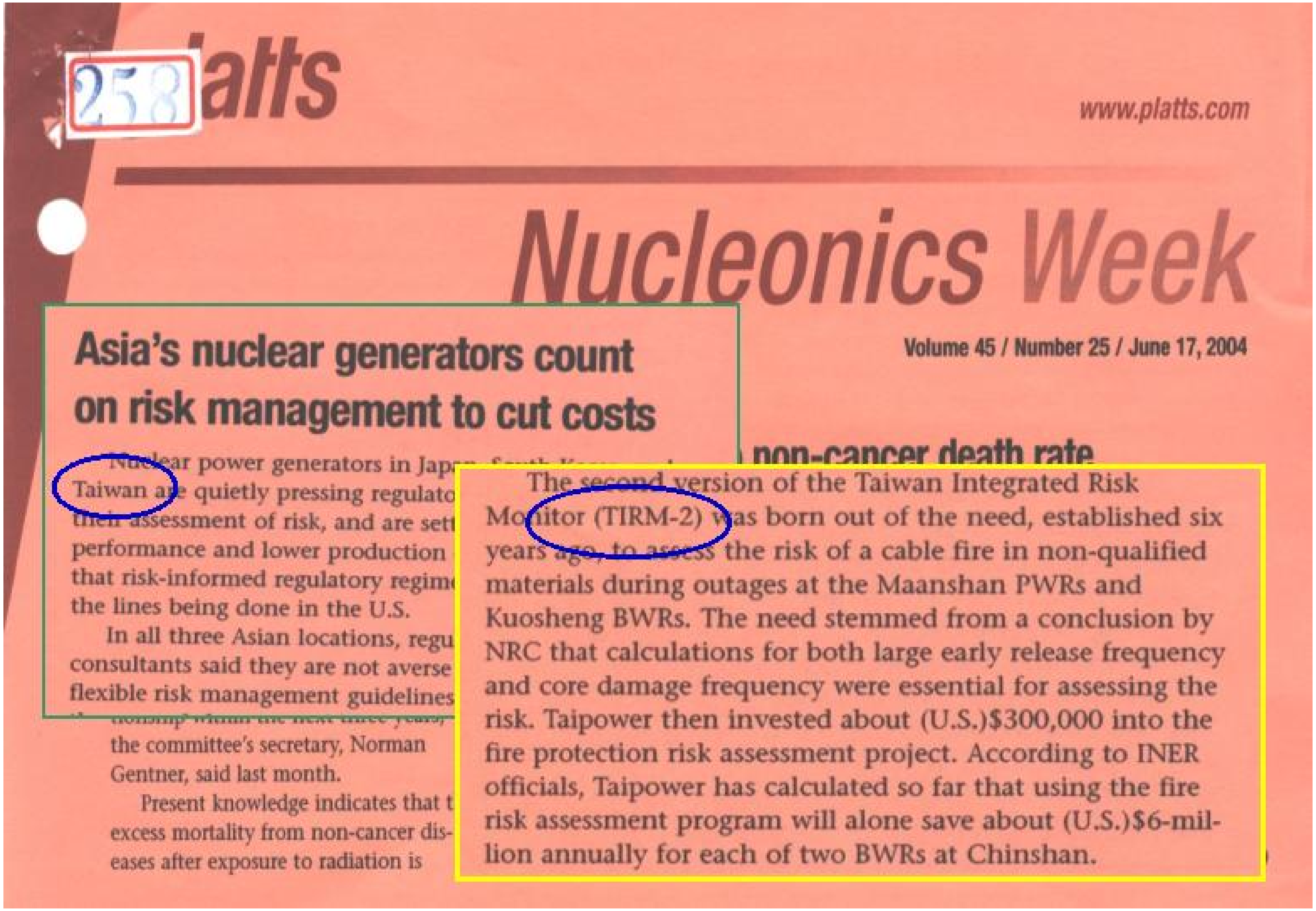
Risk Profiles with CDF and LERF at Power Operation in TIRM-2

II、 Development of the RIA Tool, Risk Monitor (4 of 7)



Risk Profiles during Refuelling Outage in TIRM-2

II、 Development of the RIA Tool, Risk Monitor (5 of 7)



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Nucleonics Week

Volume 45 / Number 25 / June 17, 2004

Asia's nuclear generators count on risk management to cut costs

Nuclear power generators in Japan, South Korea, and Taiwan are quietly pressing regulato… their assessment of risk, and are sett… performance and lower production … that risk-informed regulatory regim… the lines being done in the U.S.

In all three Asian locations, regu… consultants said they are not averse … flexible risk management guidelines…

The second version of the Taiwan Integrated Risk Monitor (TIRM-2) was born out of the need, established six years ago, to assess the risk of a cable fire in non-qualified materials during outages at the Maanshan PWRs and Kuosheng BWRs. The need stemmed from a conclusion by NRC that calculations for both large early release frequency and core damage frequency were essential for assessing the risk. Taipower then invested about (U.S.)$300,000 into the fire protection risk assessment project. According to INER officials, Taipower has calculated so far that using the fire risk assessment program will alone save about (U.S.)$6-million annually for each of two BWRs at Chinshan.

… non-cancer death rate

… the committee's secretary, Norman Gentner, said last month.

Present knowledge indicates that t… excess mortality from non-cancer diseases after exposure to radiation is

II、 Development of the RIA Tool, Risk Monitor (6 of 7)

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Inside NRC

Volume 26 / Number 16 / August 9, 2004

INTERNATIONAL REGULATION

Risk-informed outage fire protection moving ahead for all Taipower LWRs

Acting on needs expressed beginning six years ago by Taiwan Power Co. (Taipower) for better fire safety during outages, a computer code to assess fire outage risk for the two Kuosheng BWRs and two Maanshan PWRs was established in 2002 by Taiwan's regulator, the Atomic Energy Council (AEC) and its Institute of Nuclear Ene[rgy Research] (INER) in Lungtan. A second, more advanced i[...] code was finished last year and is now in use f[...] the fire risk profile of all reactors, including th[...] Chinshan BWR-4 plant.

One Taiwanese expert said that the current [...] age fire risk management software and hardwa[...] puts Taipower, INER, and AEC "somewhat ahe[...] which has "just begun" development for certa[...] tions.

In part on the basis of computer code development, this spring, Taipower officials said, AEC has awarded some

The code for fire risk analysis was set up for use with the Taiwan Integrated Risk Monitor (TIRM), which was developed by INER in parallel with development of risk-informed regulations. The second advanced version of the risk monitor is TIRM-2. It was ready in June 2003, Kao said.

The code development was financed by an investment by Taiwpower of some (U.S.)$300,000. Use of the second version at the two Chinshan reactors so far, officials said, has saved the utility about $6-million.

[...]rity performance data

[...]rably scaled

the Washington, D.C. area to be extra vigilant—NSIR officials provided an

[...] financial institutions and advised federal agencies in

[...] zens living near nuclear power plants

(Continued on page 11)

II、 Development of the RIA Tool, Risk Monitor (7 of 7)

Table 4-6 Overview of Risk Monitor software packages

Name	Year first released	Owner of the software	Solution method(s) and algorithms	Integrated approach	Available for purchase	Countries where used
Risk Supervisor	Not known	Regulatory body, Hungary	Risk Spectrum [10] solution engine used to so models.	No	Yes	Hungary
DynaRM	2002	KAERI	Requantif using KIR			Korea
RIMS	2003	KOPEC	Requantif using FO			Korea
TIRM-2	2003[11]	TPC & INER	Requantif using INE			Taiwan

Notes for Table 4-1

[1] 1988 refers to first use in Heysham 2 control room after commis ... se.

[2] 1988 refers to the original VAX installation. The 1996 release w

[3] Denotes the release as an EPRI product. SAIC was performing i

[4] Licence required for solution engines.

[5] PSIMEX solution engine, which is distributed as part of the star

[6] ORAM (shutdown risk) was released in 1992, SENTINEL (at p

[7] PSALink is owned by Erin Research Inc. User requires licence f

[8] Separate licence required for RSAT (RiskSpectrum).

[9] Separate licence required for RSAT.

[10] Separate licence required for RiskSpectrum.

[11] TIRM-2 is a further development of TIRM, which was released in 2000.

RISK MONITORS

A Report on the State of the Art in their Development and Use

Produced on behalf of IAEA and OECD WGRisk

Issue 7, April 2004

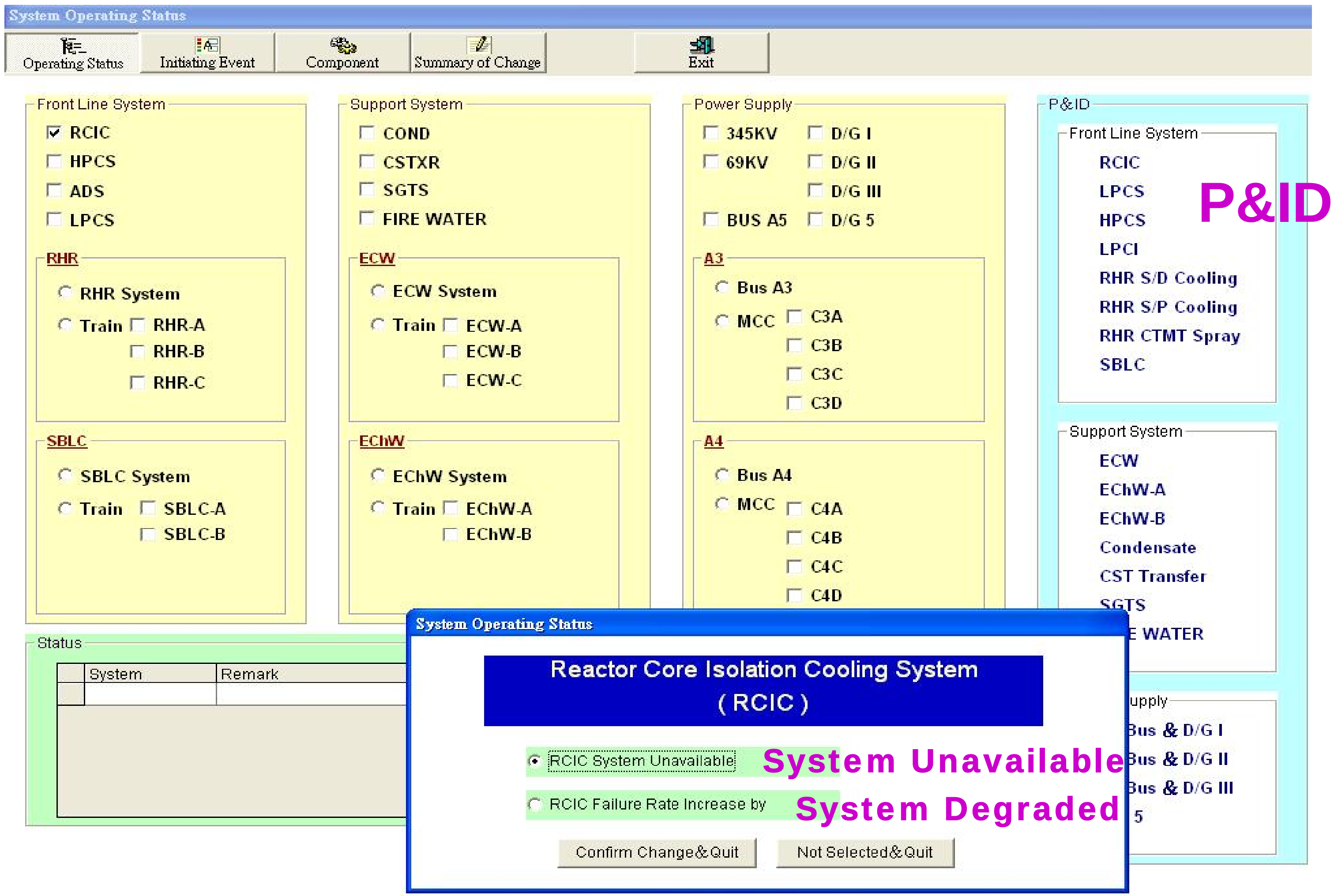
III、Development of the RIR/SDP Tool, PRiSE (1 of 8)

- **P**RA Model Based **Ri**sk **S**ignificance **E**valuation
- A computer tool to evaluate risk significance of inspection findings under the request from TAEC
- Risk significance is determined by ΔCDF and indicated by four different color codes (G W Y R)
- Risk-informed and efficient process to evaluate inspection findings
- Provide bases of decision making for inspectors

III、Development of the RIR/SDP Tool, PRiSE (2 of 8)

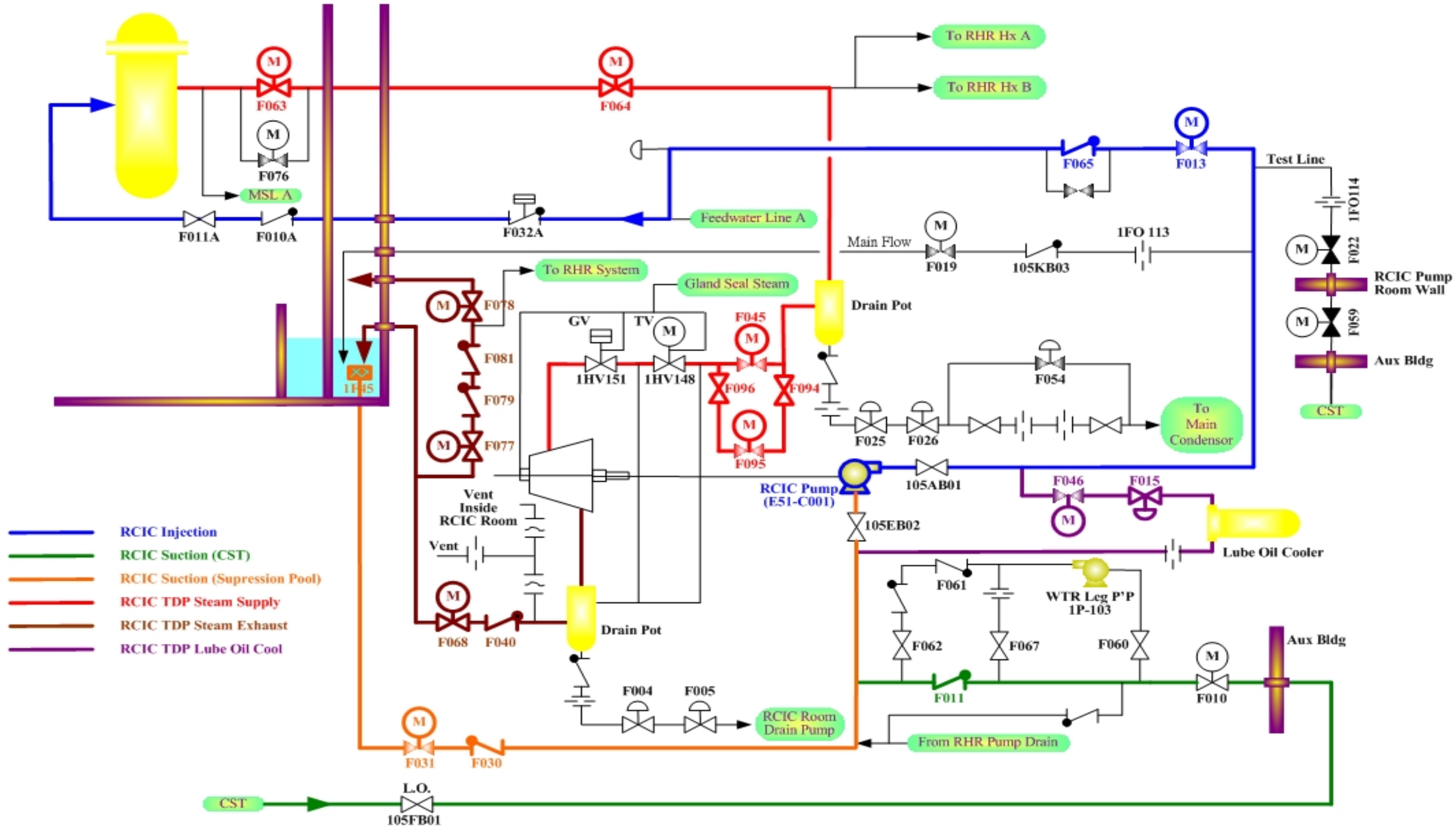
- Taiwan AEC decides to adopt a new approach, so called "Green/Red Lights" scheme, for nuclear safety oversight starting from January of year 2006
- The "Green/Red Lights"-scheme approach is inspired from the revised Reactor Oversight Process (ROP) of the USNRC
- Under this scheme, the performance indicators are provided by the utility and inspection findings of the resident inspectors provide the inputs to the regulatory action considerations

III、Development of the RIR/SDP Tool, PRiSE (3 of 8) Safety-Related System List



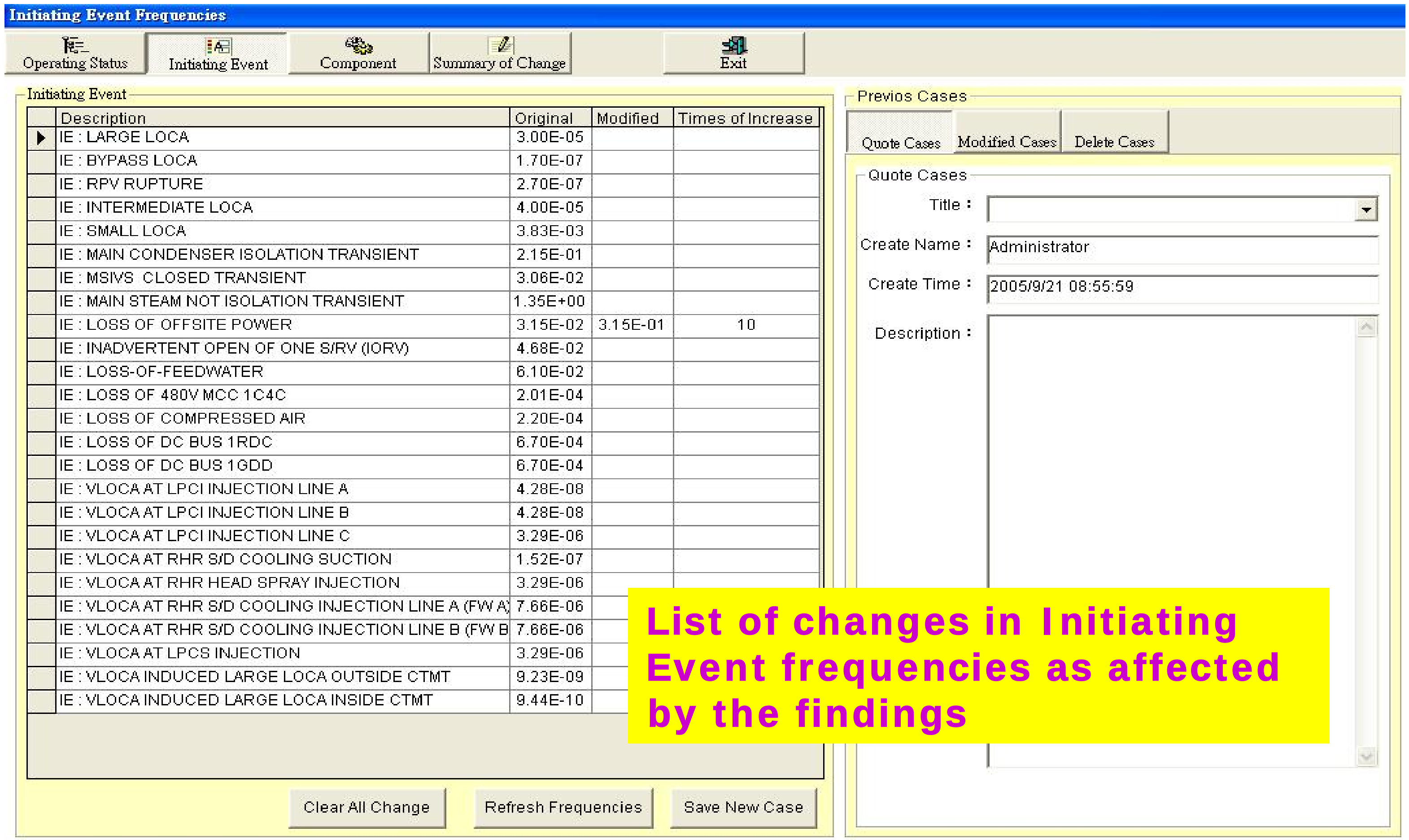
III、Development of the RIR/SDP Tool, PRiSE (4 of 8) Display of SSCs modeled in PRA

Component modeled in PRA shown in color



Reactor Core Isolation Cooling System (RCIC)

III、Development of the RIR/SDP Tool, PRiSE (5 of 8)

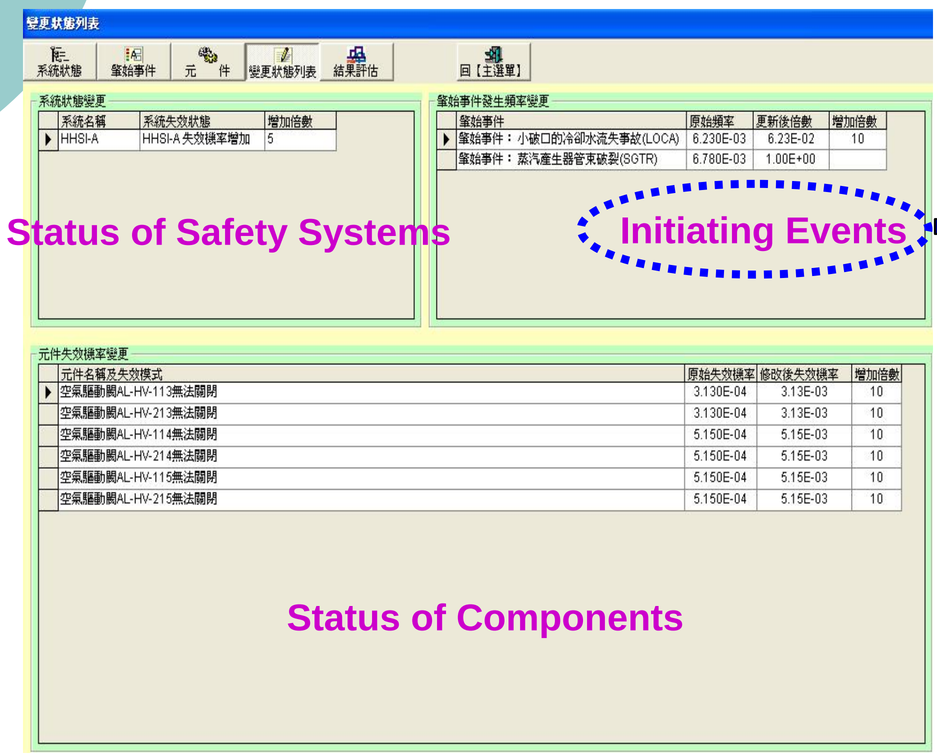


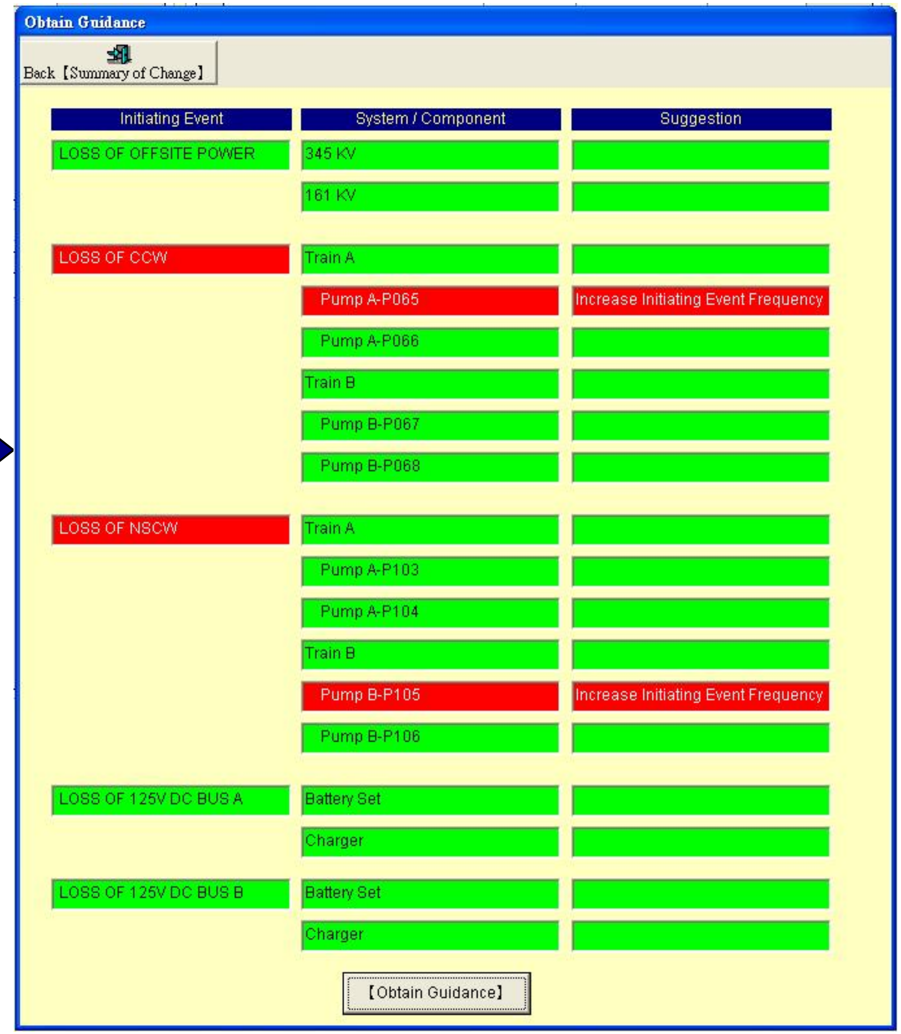
Description	Original	Modified	Times of Increase
IE : LARGE LOCA	3.00E-05		
IE : BYPASS LOCA	1.70E-07		
IE : RPV RUPTURE	2.70E-07		
IE : INTERMEDIATE LOCA	4.00E-05		
IE : SMALL LOCA	3.83E-03		
IE : MAIN CONDENSER ISOLATION TRANSIENT	2.15E-01		
IE : MSIVS CLOSED TRANSIENT	3.06E-02		
IE : MAIN STEAM NOT ISOLATION TRANSIENT	1.35E+00		
IE : LOSS OF OFFSITE POWER	3.15E-02	3.15E-01	10
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		
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		

List of changes in Initiating Event frequencies as affected by the findings

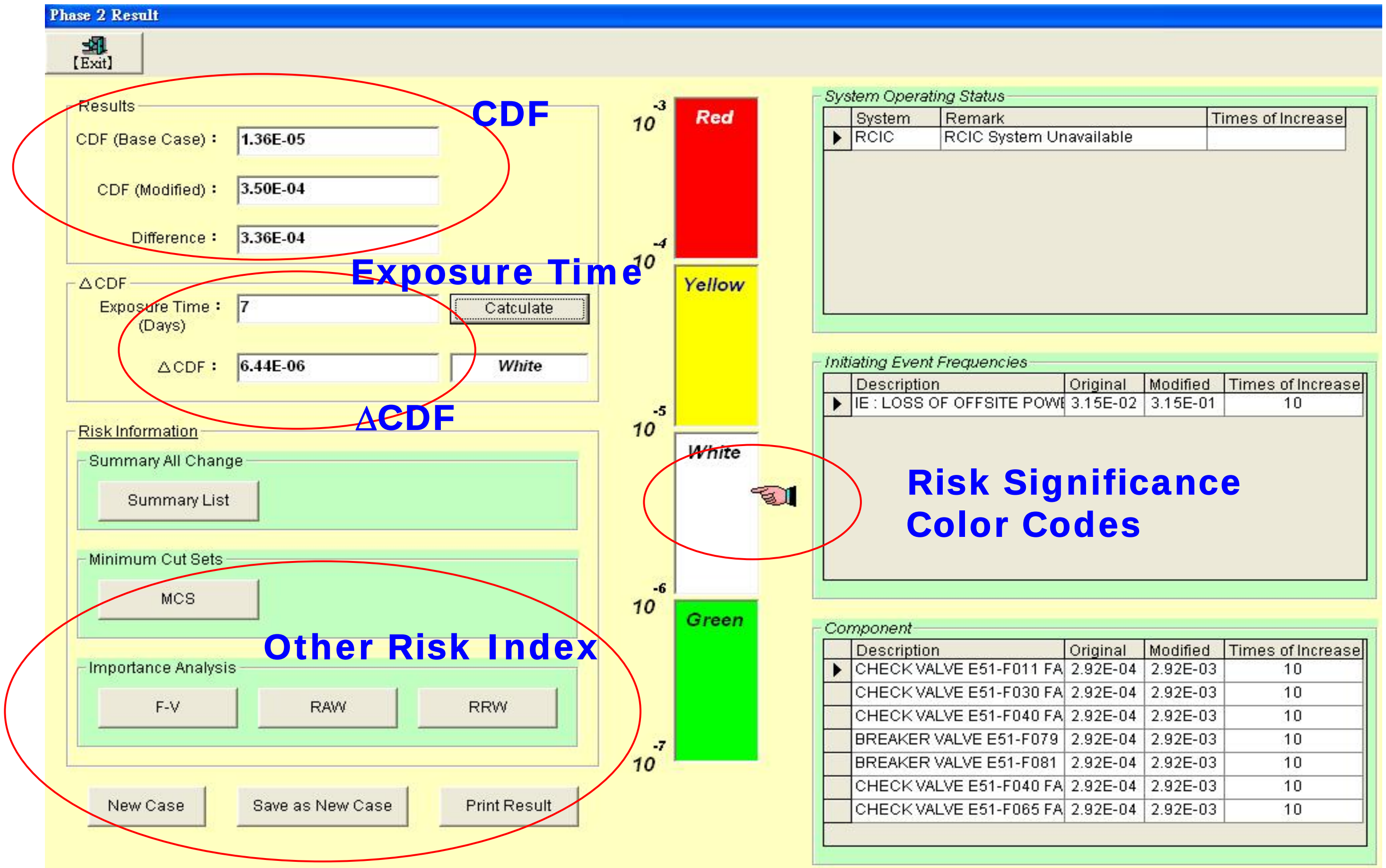
III、Development of the RIR/SDP Tool, PRiSE (6 of 8)
Final List of Changes & IE change guidance (new feature)

IEs affected by deficiency are shown in Red color





III、Development of the RIR/SDP Tool, PRiSE (7 of 8)
Significance Determination Results



III、Development of the RIR/SDP Tool, PRiSE (8 of 8)

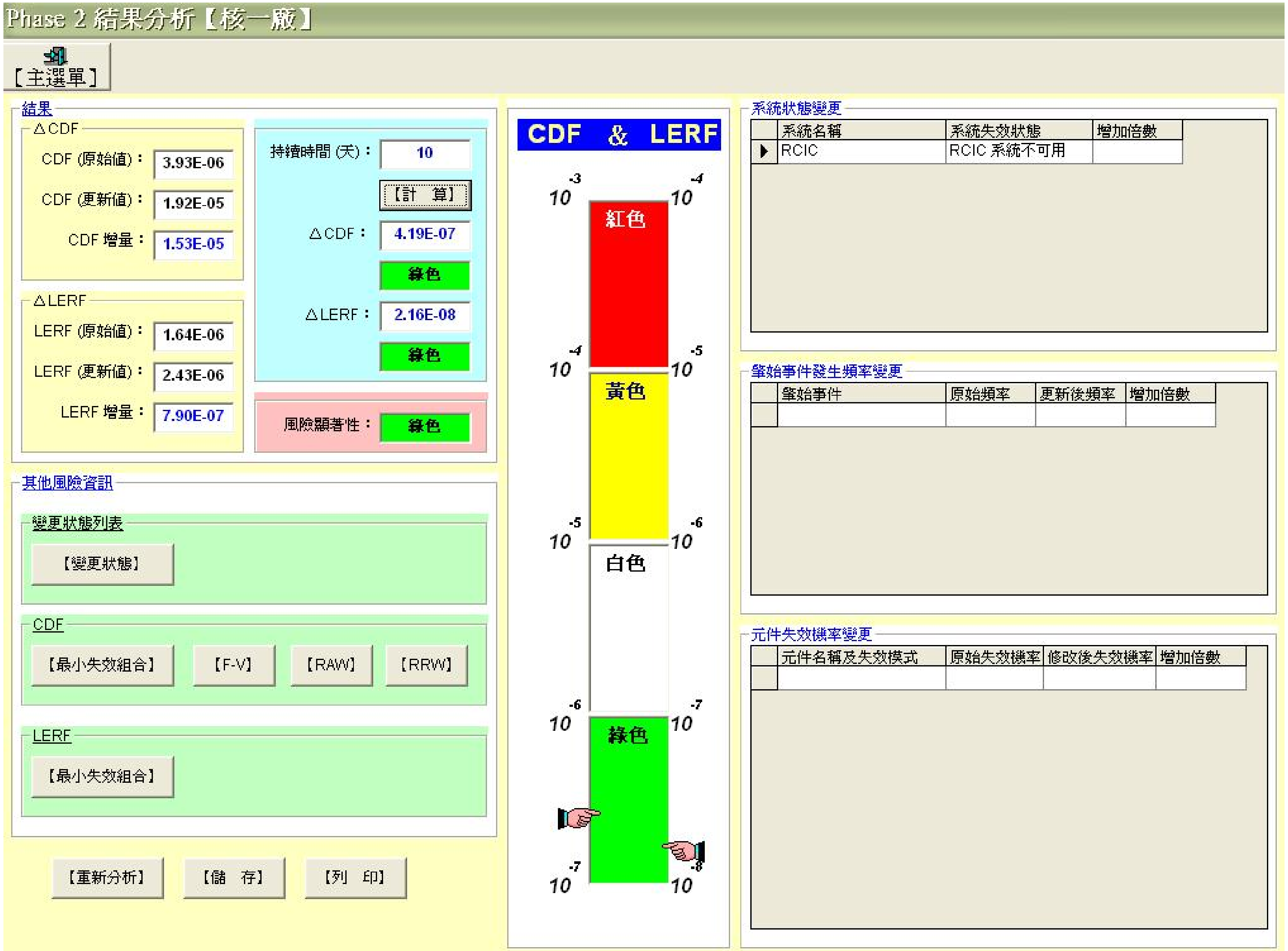
- Three dedicated versions (BWR-4, BWR-6, PWR) of PRiSE2.0 have been released to inspectors for daily use since February of 2006
- Current version includes internal events for power operation with the feature for containment integrity assessment (LERF)
- It is expected that the shutdown feature of the PRiSE will be released in 2009 and external events feature will be available in 2010

III 、Comments on the PRiSE

Comments proposed by Professor George Apostolakis (MIT Professor, Former ACRS Chairman) toward the presentation of PRiSE at the 26th Annual Meeting of the Chung-Hwa Nuclear Society, Taiwan, December 1, 2004:

This computer tool replaces the table that the USNRC has developed for performing Phase 1 and 2 (and Part of Phase 3) of the SDP. I have expressed the view in the past that these tables are awkward, so I was very pleased to see that INER is developing PRiSE. What facilitated the development of PRiSE was the use of the INERISKEN engine, which solves the PRA model in less than a minute.

III、Development of the RIR/SDP Tool, PRiSE 2.0 Significance Determination Results with LERF



IV、Development of Risk-Informed Fire Analysis and ISI (1 of 3)

- Due to the unavailability of qualified fire wrap material for BWR-4 cable trays, plant people found that it was very difficult to meet the current requirements of Appendix R
- Use of the advanced PRA technology and associated code allows the TAEC/TPC staff to perform risk-informed fire analysis, post-fire safety shutdown function analysis, and assessment of cable tray fire wrap, to serve as the technical basis for Appendix R exemption requests and they have been approved by TAEC for the BWR-4 in December of 2005, and for the BWR-6 and the PWR in October of 2006

IV、Development of Risk-Informed Fire Analysis and ISI (2 of 3)

Layout of Cables in Fire Area(s)

Result of Quantitative Analysis

Case	Cable Tray Wrapped	CDF	Delta	LERF	Delta
APP. R (base	Train A	2.48E-07		2.57E-08	
Current State	No wrapping	3.41E-06	3.16E-06	3.06E-07	2.80E-07
RIFA Option 1	Cable tray and conduit CV01	7.29E-07	4.81E-07	5.75E-08	3.18E-08
RIFA Option 2	No wrapping, but with other improvements for cable tray and conduit CV01: a. Fast-response fire detection and suppression (< 1 min.) b. Fire watching camera and alarm for monitoring hot spots of degraded cables	8.37E-07	5.88E-07	6.74E-08	4.17E-08

Qualitative Analysis

Layout for COMPBRN

Exit

Sub-Scenario	Pilot Fire	Target	Fire Initiating Frequency	FG, i	FS, i	FNS,i	
4I-L3	Train A Cable Tray CW01 669 pound	Train B Cable Tray DZ01	1.35E-05	1.00E+00	3.00E-02	1.00E-02	1.
4I-L4	Train B Cable Tray DZ01 706 pound	Train A Cable Tray CW01	1.43E-05	1.00E+00	7.50E-02	1.00E-02	1.
4I-L5	Train B Cable Trays 4228 pound	None					
4I-L5-1	Train B Cable Tray DX01 841pound	None	1.70E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-2	Train B Cable Tray DX02 841pound	None	1.70E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-3	Train B Cable Tray DX03 809 pound	None	1.64E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-4	Train B Cable Tray DY01 235 pound	None	4.74E-06	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-5	Train B Cable Tray DZ01 706 pound	None	1.43E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-6	Train B Cable Tray DZ02 708 pound	None	1.43E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-7	Train B Cable Tray FC01 44 pound	None	8.82E-07	1.00E+00	1.00E+00	1.00E+00	1.
4I-L5-8	Train B Cable Tray FD01 44 pound	None	4.41E-07	1.00E+00	1.00E+00	1.00E+00	1.
4I-L6	Train A Cable Trays 4380 pound	None					
4I-L6-1	Train A Cable Tray CT01 746 pound	None	1.51E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L6-2	Train A Cable Tray CT02 746 pound	None	1.51E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L6-3	Train A Cable Tray CU01 685 pound	None	1.39E-05	1.00E+00	1.00E+00	1.00E+00	1.
4I-L6-4	Train A Cable Tray CU02 687 pound	None	1.39E-05	1.00E+00	1.00E+00	1.00E+00	1.

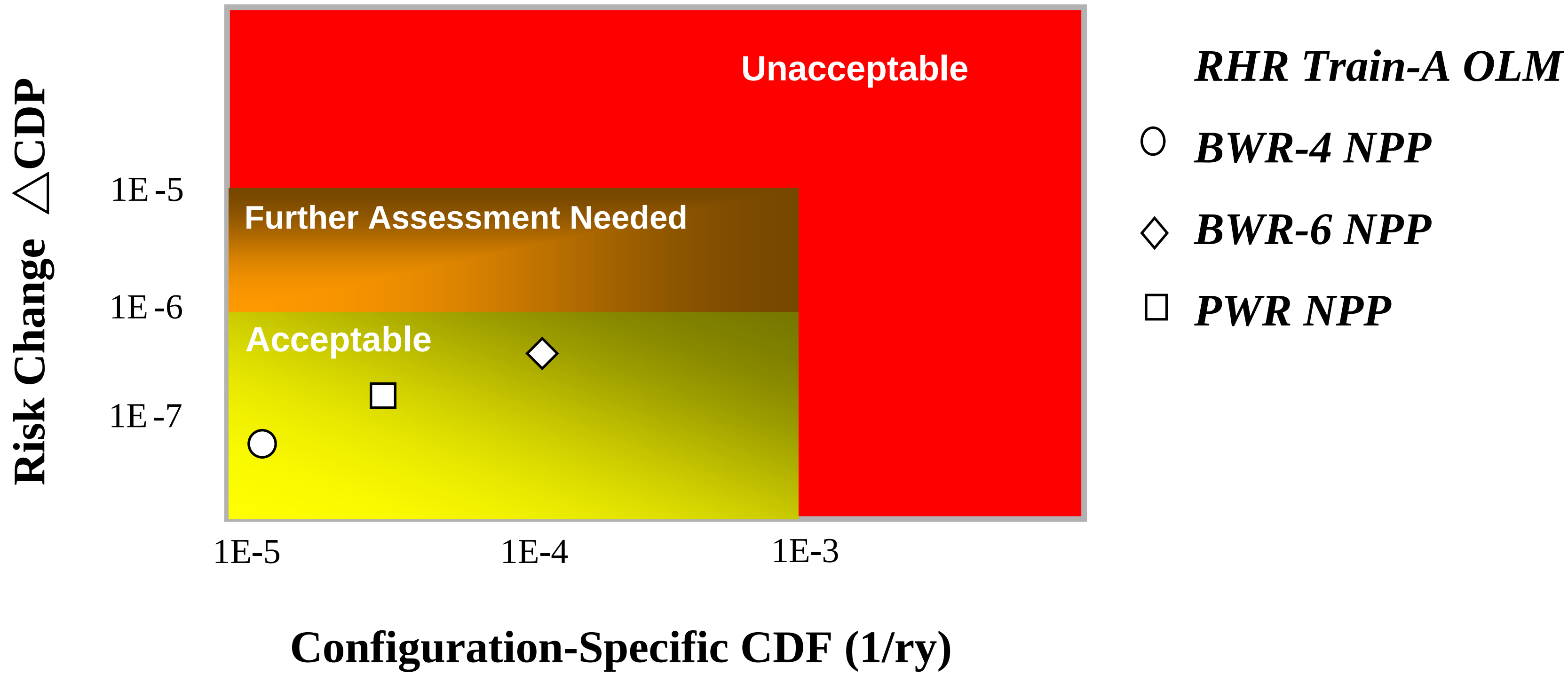
Detailed Photos Exit

Display of Wrap Options from RIFA-2

IV、Development of Risk-Informed Fire Analysis and ISI (3 of 3)

- INER has also established the methodology for the evaluation and development of a pilot, plant-specific RI-ISI program for a BWR-6 plant in Taiwan
- The number of inspection elements selected in the RI-ISI evaluation has been decreased to only 50, representing a reduction of up to 56% in comparison with 113 inspections in the current ASME inspection program and the plant staff will have more time to focus on those RI safety-related elements
- Extend containment ILRT interval from 3 times per 10 years to once per 10 years

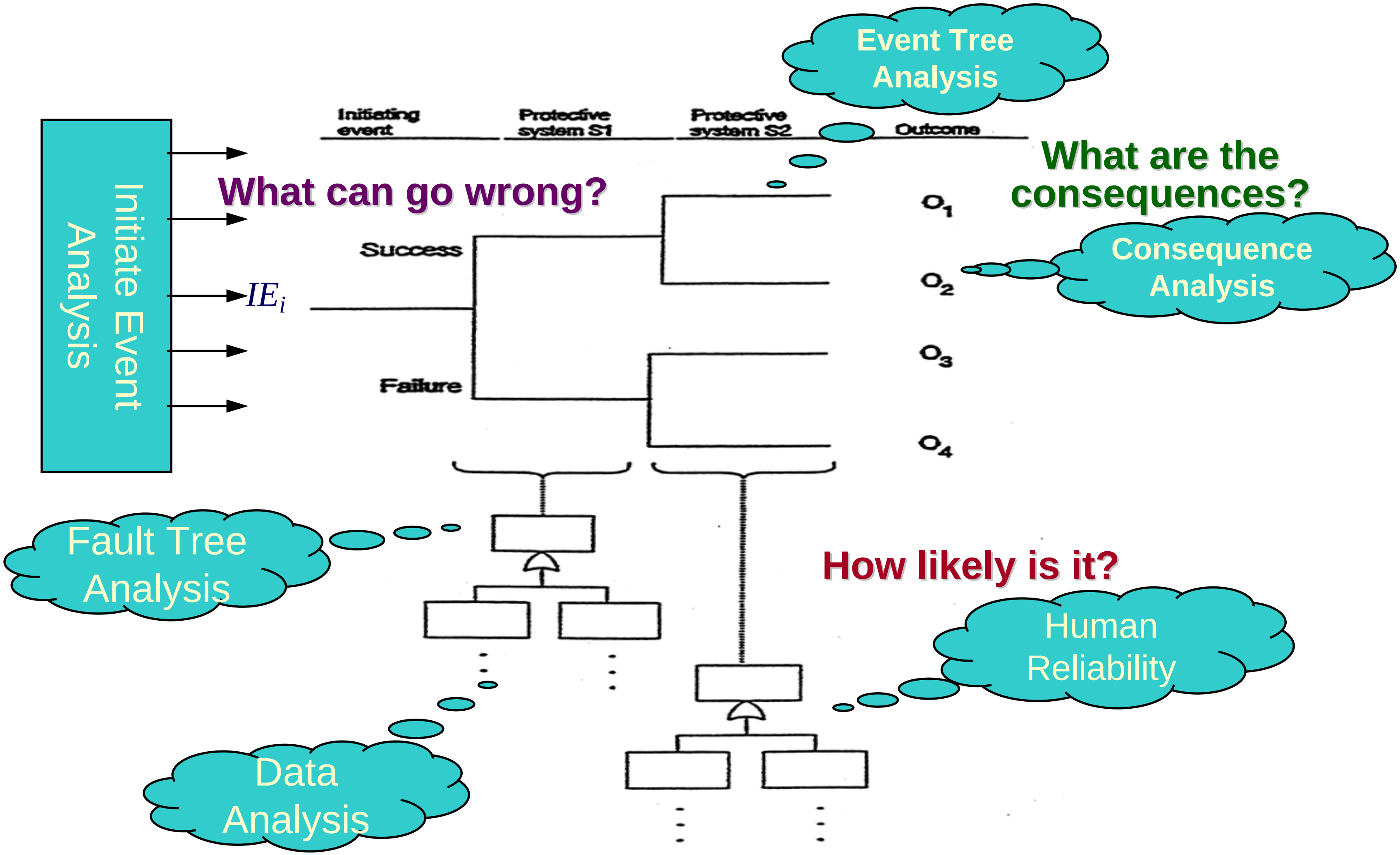
IV、 On-Line Maintenance Case Studies



V 、QRA Application on LNG (1 of 5)

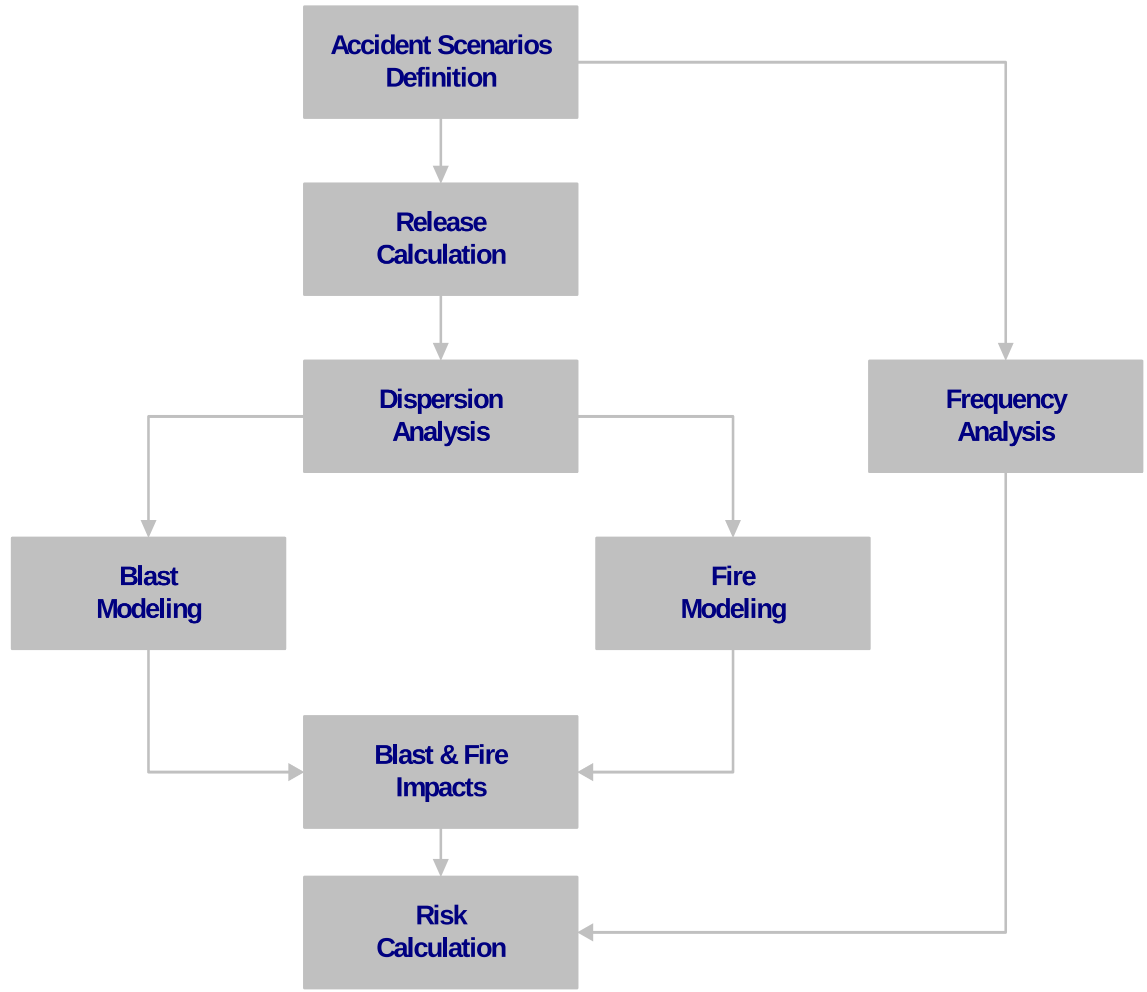
- The INER applies the PRA technology and provides the Quantitative Risk Assessment (QRA) technical service to evaluate the potential risk and quantitative safety for the three first-phase Liquefied Natural Gas (LNG) tank systems of the LNG plant in Taiwan
- The results of this assessment has be used as the basis for applying an exemption from Taiwan's regulatory body's requirements of periodic internal inspection for LNG tanks
- To provide the true picture of the risks posed by the LNG facilities, the QRA that includes all plausible release scenarios will be conducted in two stages, the first stage includes the auxiliary attachment and piping of LNG tank systems, and the second stage includes all equipments of the LNG plant
- Another project to perform the external events QRA on tanks system of the LNG Plant has been granted in September 2008

V 、 QRA Application on LNG (2 of 5)



V 、 QRA Application on LNG (3 of 5)

Analysis process for the QRA of an LNG Storage Tank system



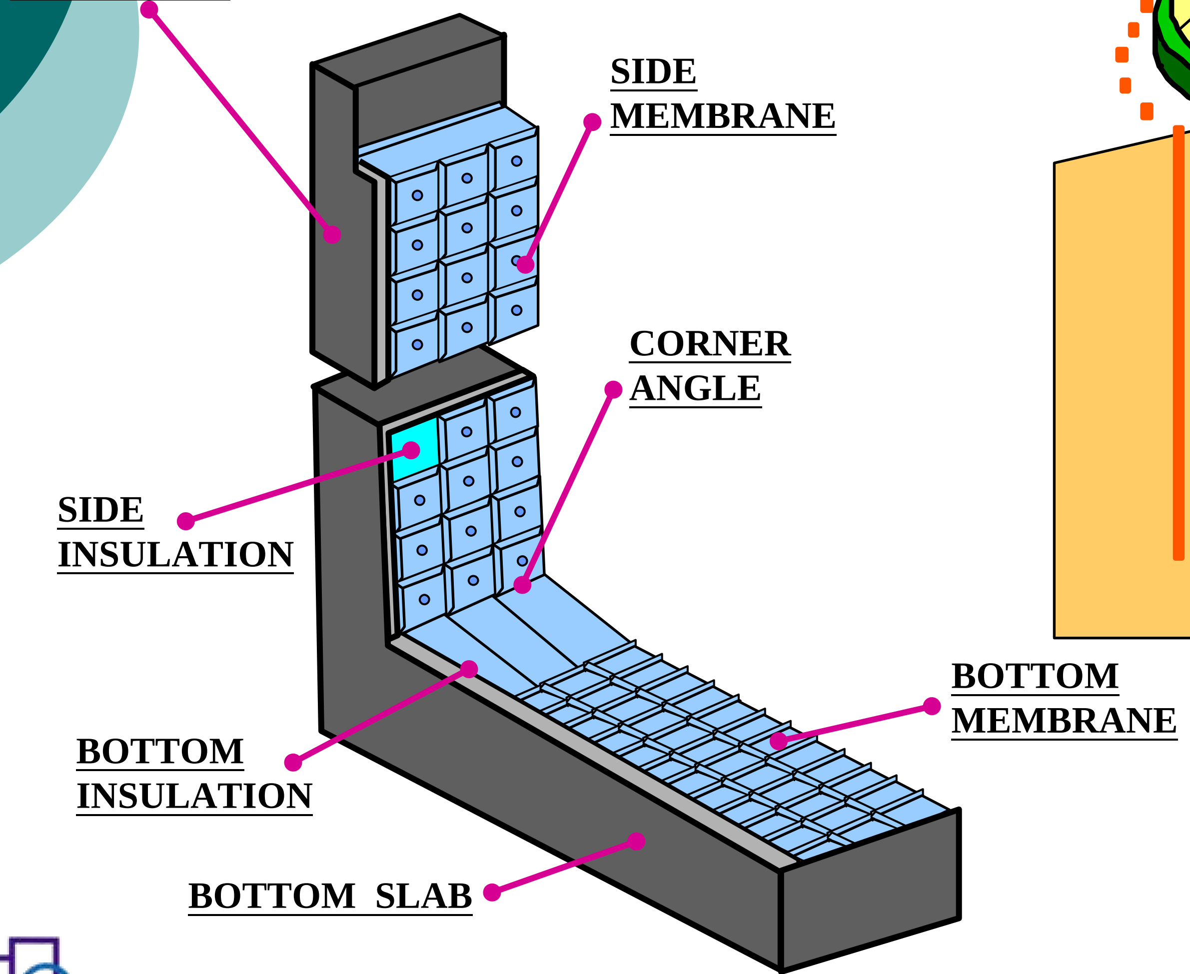
V 、 QRA Application on LNG (4 of 5)

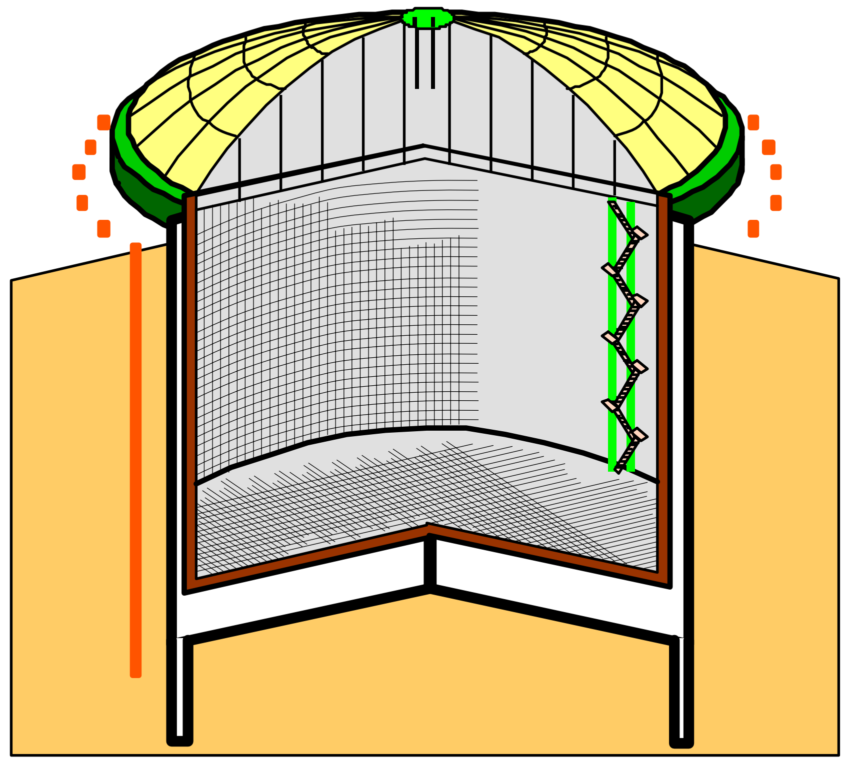
Bird's Eye View of LNG Plant

V 、 QRA Application on LNG (5 of 5)

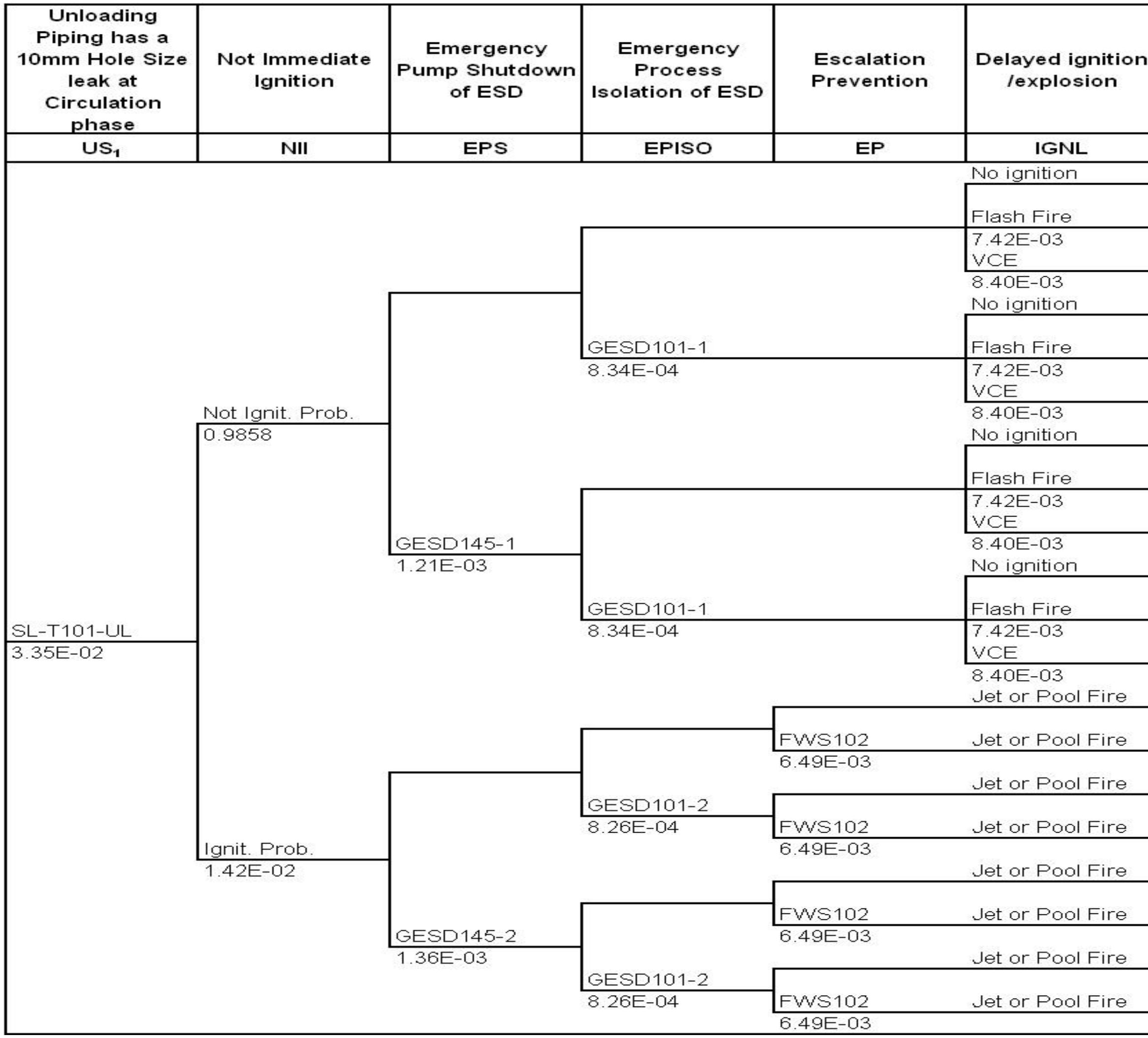
In-ground Storage Tank of LNG

Slide 9(B)



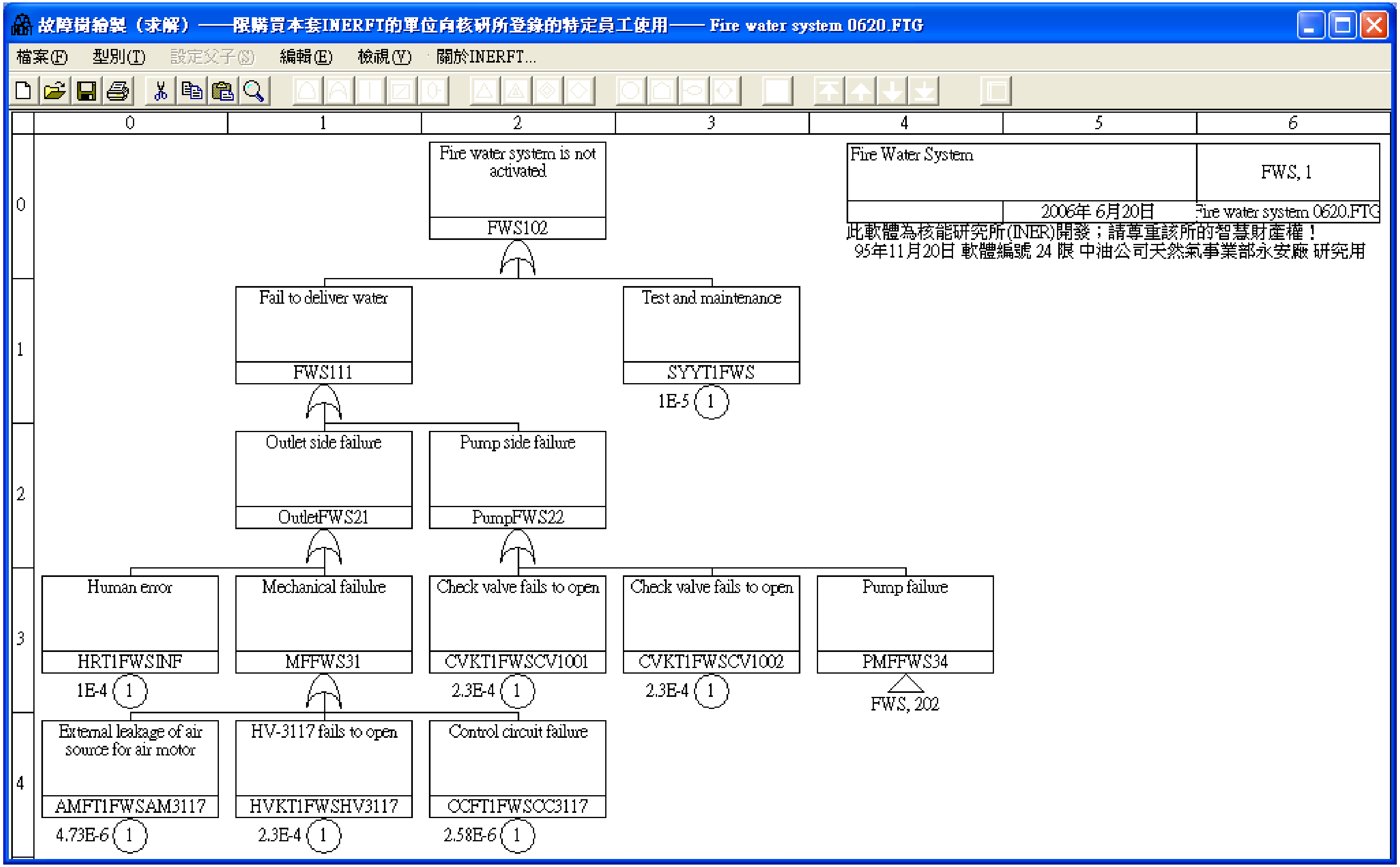


V 、 Event Tree of Unloading Piping



SEQ #	SEQUENCE DESCRIPTOR	PDS #	FREQUENCY
1	US_1	OK	3.30E-02
2	US_1IGNLF	FF	2.45E-04
3	US_1IGNLV	VCE	2.77E-04
4	US_1EPISO	OK	2.75E-05
5	US_1EPISOIGNLF	FF	2.04E-07
6	US_1EPISOIGNLV	VCE	2.31E-07
7	US_1EPS	OK	4.00E-05
8	US_1EPSIGNLF	FF	2.96E-07
9	US_1EPSIGNLV	VCE	3.36E-07
10	US_1EPSEPISO	OK	3.33E-08
11	US_1EPSEPISOIGNLF	FF	2.47E-10
12	US_1EPSEPISOIGNLV	VCE	2.80E-10
13	US_1NII	JPF	4.76E-04
14	US_1NIIEP	JPF	3.09E-06
15	US_1NIIEPISO	JPF	3.93E-07
16	US_1NIIEPISOEP	JPF	2.55E-09
17	US_1NIIEPS	JPF	6.47E-07
18	US_1NIIEPSEP	JPF	4.20E-09
19	US_1NIIEPSEPISO	JPF	5.34E-10
20	US_1NIIEPSEPISOEP	JPF	3.47E-12

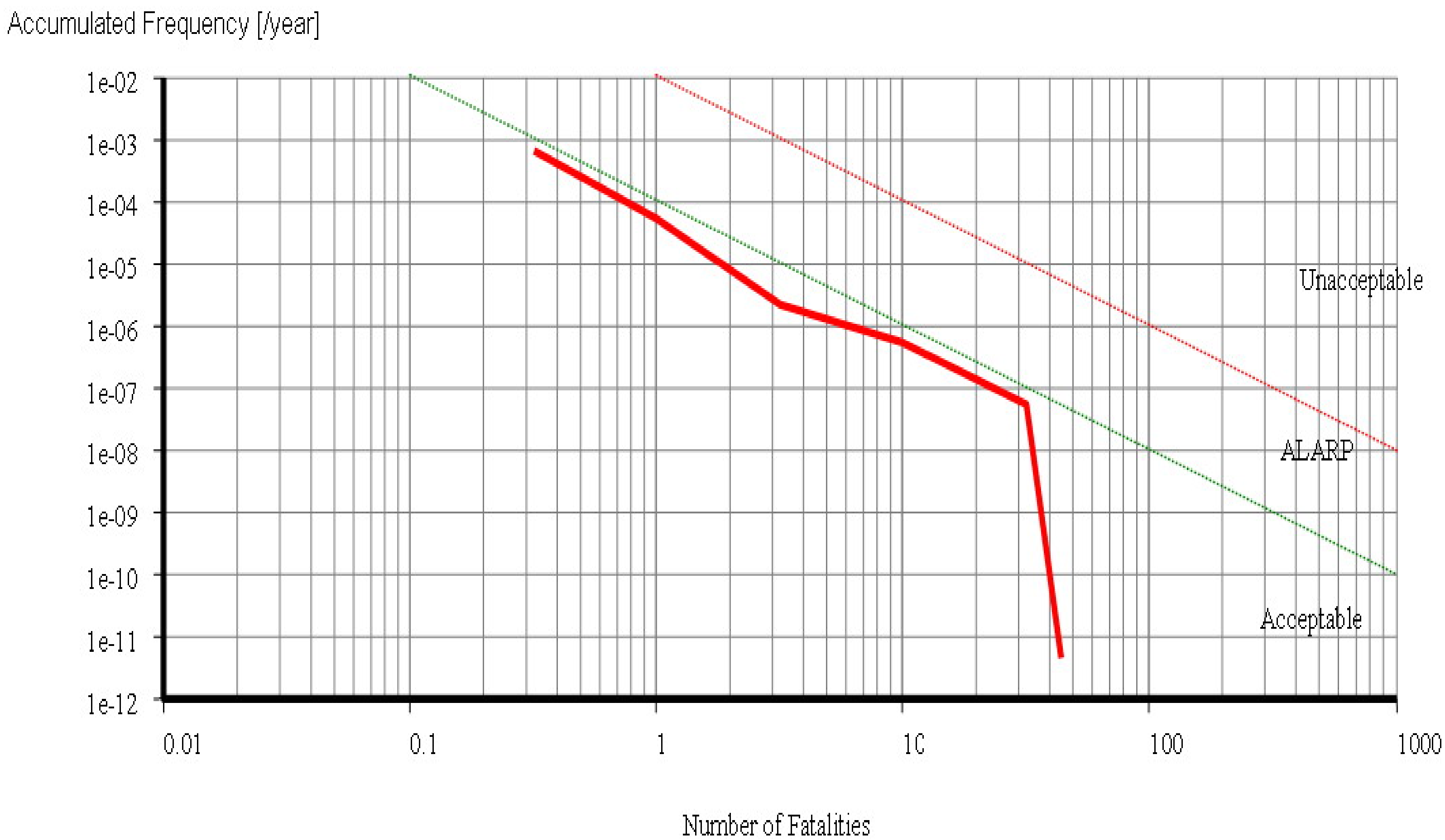
V 、 Fault Tree of Fire Water System



Individual risk caused by LNG tank systems

Societal Risk F-N curve due to LNG tank systems

(ALARP：As Low As Reasonably Practical)



VI、Conclusions (1 of 3)

- Since June of 2005, the NPPs of Taiwan are planning to implement a few of performance enhancement programs regarding the issues of power updates, life extension, and outage shortening by increasing fuel burn up

- INER is aware of the potential safety margin reductions and the PRA methodology will be adopted to estimate the synergistic safety impacts to perform these three issues at the same time

VI、Conclusions (2 of 3)

- A powerful risk monitor, TIRM-2, has replaced TIRM to provide the basis of risk-informed applications in Taiwan
- With the capability of performing CDF and LERF calculations, the TIRM-2 becomes a very helpful tool in monitoring the risk of different plant states and provides further information directly for risk-informed applications
- The PRiSE has replaced the tables that the USNRC has developed for performing Phases 1 and 2 (and part of Phase 3) of the SDP

VI、Conclusions (3 of 3)

- The view and usage of these tables are complicated and time-consuming; so that the PRiSE has provided an alternative tool for Taiwan's resident inspectors to easily solve the PRA model in less than a minute
- With these credible assessment tools and other subsequent proposed cases of risk-informed applications, a new era of risk-informed regulations and applications has been initiated in Taiwan's nuclear society
- To broaden PRA applications in petrochemical industry, energy security, anti-terrorism of infrastructures, risk assessment of tunnel fire, risk management and insurance of natural catastrophe

Thank You for the Attention!!