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Accidents and Level 2 Probabilistic Safety Analysis
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Formal Handling of the Level 2 Uncertainty Sources and Their Combination with the Level 1 PSA Uncertainties

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Main Objectives

**Different Uncertainty Sources & Types
=> Different Impact on Level 2 Risk & RI-DM**

- ◆ To provide approaches for formally handling typical sources of uncertainty employed in the Level 2 PSA.
 - Its Emphasis is put on
 - Why uncertainty analysis is required in Level 2 PSA ?
 - Which kind of uncertainty sources is expected in Level 2 ?
 - Which uncertainties are explicitly accounted for, which ones are not ?
 - How to quantify them in the framework of Level 2 PSA ?

- ◆ To provide a formal approach for consistently integrating the Level 1 & 2 uncertainties whose underlying events are different in nature for each other.
 - Each Uncertainty is addressed in Random/aleatory events & deterministic events

Background_Uncertainties in PSA

Different Type & Source of Uncertainty in PSA & Its Impact ?

Types	Random/Aleatory	Epistemic (Model/Parameter)	Completeness
Underlying Uncertainty Sources	<p>Data uncertainty (Data mining & screening, Component failure data, Plant-to-plant data variability)</p> <p>Level 1 PSA Model: IE, Component & human reliability, unavailability</p>	<p>Level 1 PSA Model:</p> <ul style="list-style-type: none"> ➢ Probability Model Parameter (Binomial / Exponential / Poisson model) ➢ Model (or System) Success Criteria ➢ ET/ FT, CCF, HRA Model Themselves ➢ Functional Dependency between Systems <p>Level 2 PSA Model:</p> <ul style="list-style-type: none"> ➢ Phenomenological parameter model ➢ L1-2 Interface & CET/APET model itself ➢ Phenomena-to-phenomena & System-to-phenomena Dependency 	<ul style="list-style-type: none"> ➢ Decision-making Process (based on the combined information of PSA/DSA) ➢ Missing Information ➢ Quantification (Logic & Methods, Truncation Error)
Uncertainty Quantification	<ul style="list-style-type: none"> - Statistical analysis - Sensitivity analysis 	<ul style="list-style-type: none"> - Statistical analysis - Sensitivity analysis 	<ul style="list-style-type: none"> - Sensitivity analysis
	<p>Statistical combination of epistemic and aleatory uncertainties (Multi-stage statistical analysis)</p>		
Risk Impact (in Practices)	<p>When the random/aleatory and epistemic uncertainty are simultaneously considered in the PRA model, the impact of the epistemic uncertainty on the overall uncertainty is much greater when compared to that of the random/aleatory events.</p>		

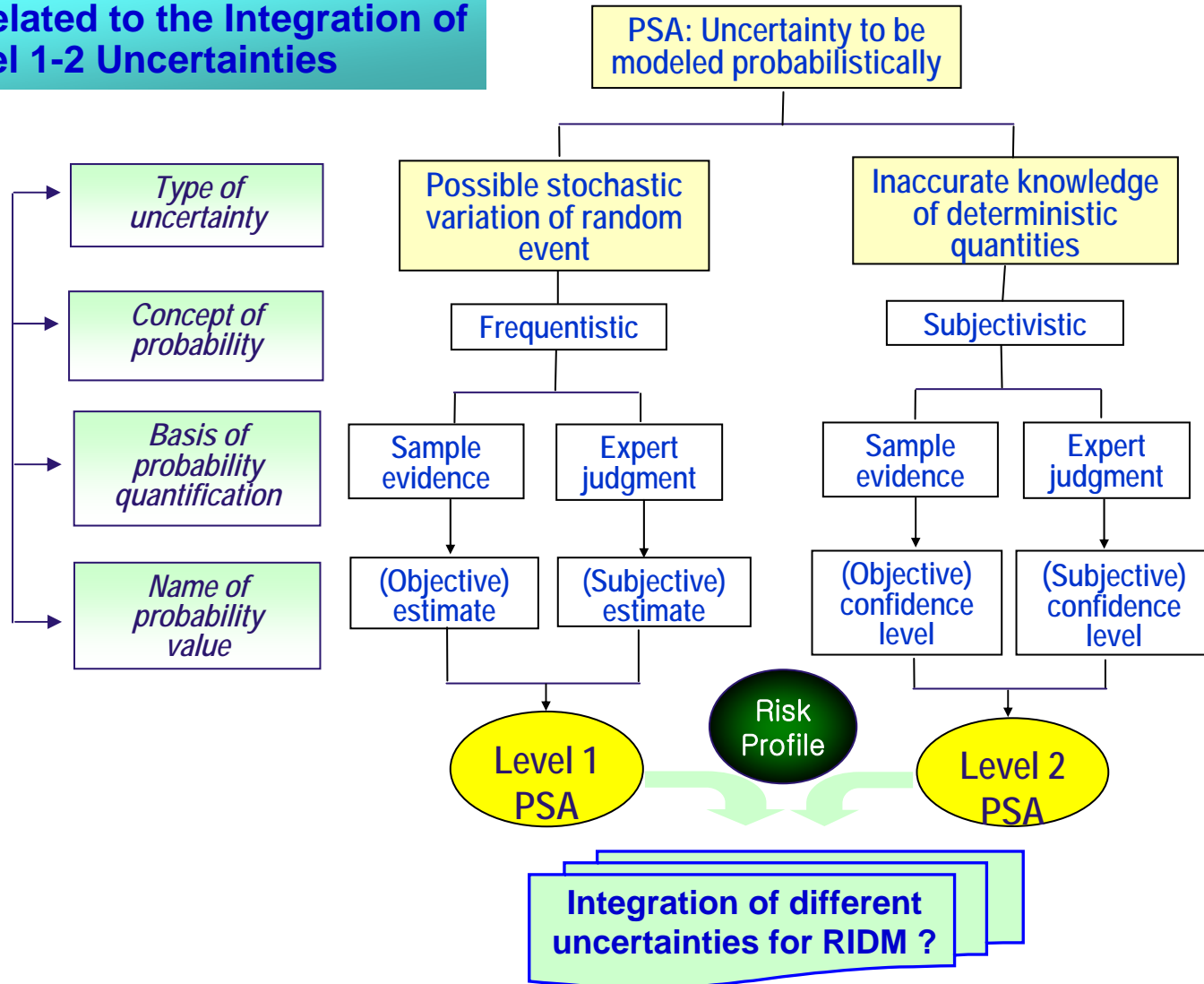
Background_Uncertainty in Level 2

Why Uncertainty is Addressed in Level 2 PSA ?

- The Level 2 is a probabilistic treatment of potential accident pathways expected during severe accidents & its major tool is CET/APET which looks at the accident as a series of snapshots in time and static model in nature.
- The accident pathways & subsequent impact on CF employed in the CET/APET are considered as deterministic events in nature, from the viewpoint that they are uniquely determined by the prior conditions (PDS).
- *There is no uncertainty in the choice of the deterministic accident pathways, if and only if the prior conditions are fixed in the CET/APET. The problem is that we have a limited knowledge about those conditions leading to the subsequent accident pathway.*
- *This is the reason why we need a probabilistic analysis for the accident pathways deterministic in nature, including phenomenological uncertainties, whose possibilities are given with the analyst's degree of belief.*

Background_Integration of uncertainties

An Issue Related to the Integration of Level 1-2 Uncertainties



Characterization of Level 2 Uncertainty Sources



Characterization of Level 2 Uncertainty

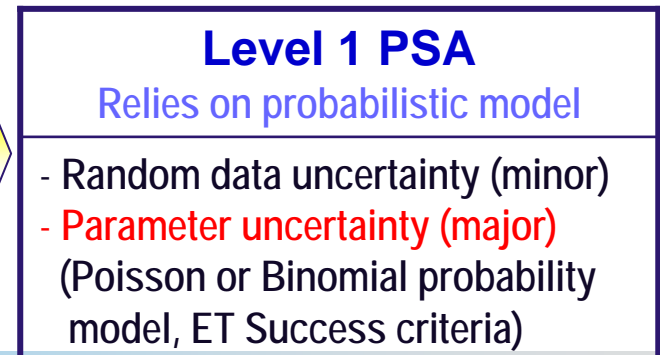
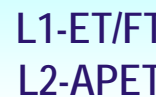
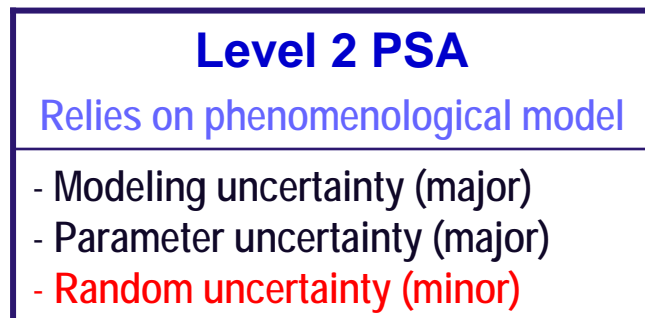
Major Portion of Level 2 Uncertainties?

Type	Epistemic uncertainty (on Deterministic Events)	Aleatory uncertainty (on Random/Stochastic Events)
Sources	- Parameter uncertainty - Modeling uncertainty	Data uncertainty (component failure rates, unavailability et.)
Measures	- Subjective probability (model) - Probability distribution (PDF) (model parameter)	Probability distribution (PDF) about Probability or Variability (random/stochastic data)

Trend

Trend

Deterministic Model



Characterization of Level 2 Uncertainty

Different Expression of Level 2 Uncertainties

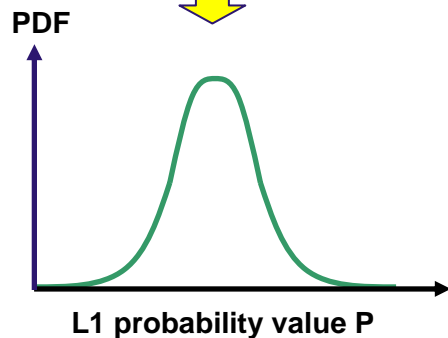
Level 1 PSA (ET/FT)

- System functionality-related events
- Probabilistic event (occurrence only)
- Continuous random probability event (probability between 0 and 1)
- Uncertainty: PDF about the random/stochastic probability

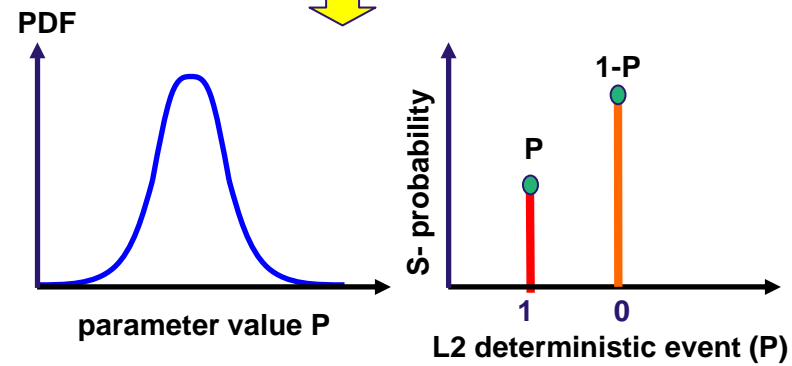
Level 2 PSA (APET)

- Occurrence & magnitude-related events of deterministic physical phenomena
- Uncertainty of occurrence/nonoccurrence events: (uncertainty = DOB on the event itself)
- Uncertainty on magnitude: subjective PDF on its values

L1-2 Interface (Bridge Tree, PDS)



FT basic event & ET branch



APET branch (for CFP)

APET branch (modeling)

Characterization of Level 2 Uncertainty

Why Separate Uncertainty Types in PSA ?

◆ In Level 1-2 PSA

- To provide a clearer insight into 'What might actually happen and with what probability (in Level 1)' and 'How well we know a given problem & how much our knowledge about it might change with additional information (in Level 2)'.
- To provide a proper propagation of different uncertainties addressed in Level 1-2 for a consistent decision-making on the risk.

◆ In Level 2 PSA

To separate the question of **how well our APET model represents an accident pathway from the question** as to how well we understand the underlying phenomena for the accident progression.

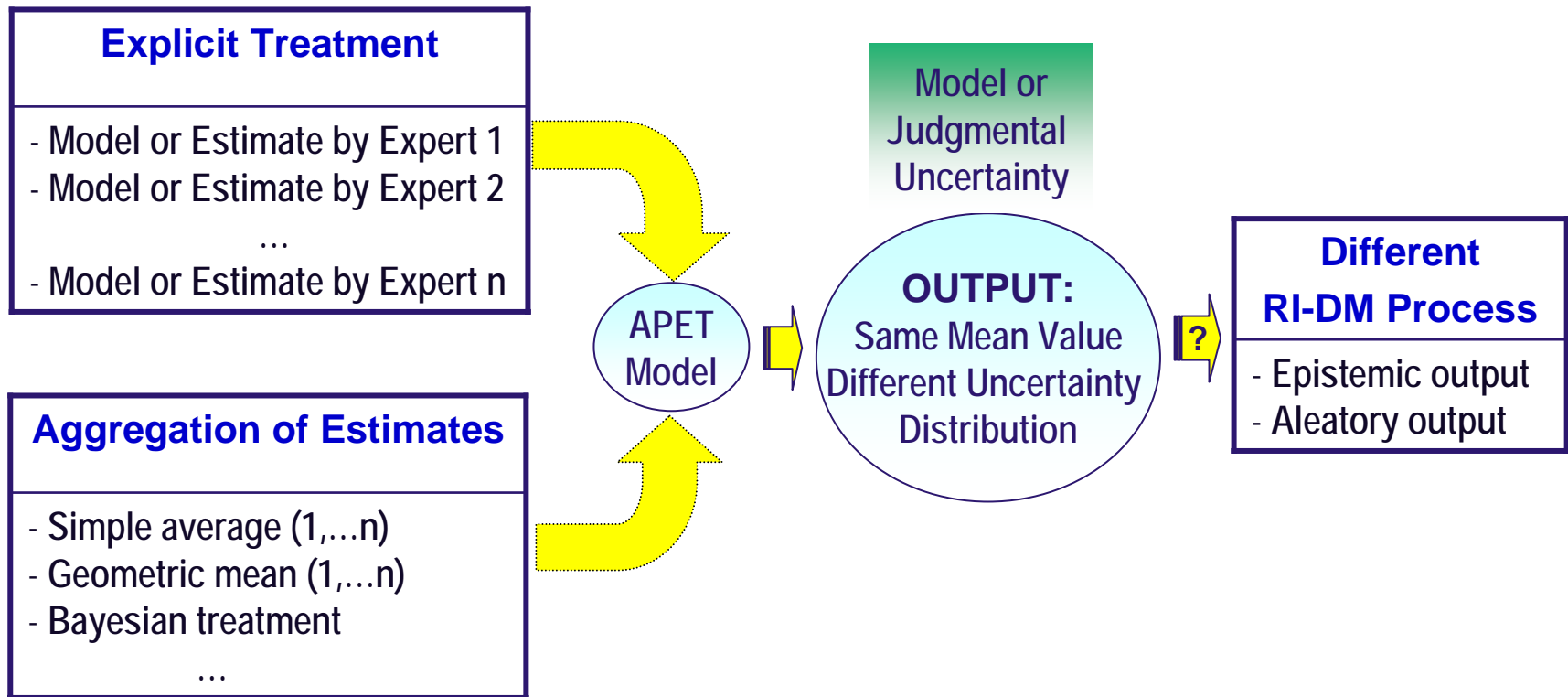
Characterization of Level 2 Uncertainty

Potential Sources of Random Phenomena in L2 PSA

	Depends on the level of decomposition & qualification for the event in question
Case 1	<p>APET sequence-to-sequence variability of a physical parameter</p> <ul style="list-style-type: none"> - Variation of a physical parameter due to various Level 1 accident sequences belong to the PDS - When such a variation was observed in practical experiment, it would be due to various conditions that are not adequately explained. <p>=> Redefinition of the PDS or Its Treatment as a Source of Uncertainty</p>
Case 2	<p>Variability of a physical parameter due to a limited resolution of IEs</p> <ul style="list-style-type: none"> - If PDS is not defined, a probability of a specific Level 2 phenomenon (DCH, H-burn, SE) leading to CF is a fraction of the event among all Level 1 CD sequences that result in it. - If PDS is properly defined, those CD sequences are treated within the framework PDS. Whereas, a specific sequence often loses its information once it is assigned to its PDS. <p>=> Redefinition of the PDS into More Detailed Level</p>
Case 3	<p>Its Variability due to a limited resolution of prior conditions</p> <ul style="list-style-type: none"> - Even when a PDS is specified as an IC, there is a question for a peak pressure often neglects the existence of subsequences or phenomena that are unspecified in various ways in PDS (e.g., any technically reasonable melt temperature randomly varying at the time of CD) <p>=> How to Treat Some Factors making the Population of the Initial Material Properties a Stochastic Process ?</p>

Characterization of Level 2 Uncertainty

Treatment of Heterogeneous Opinions Among Experts in Level 2 APET ?



Characterization of Level 2 Uncertainty

The Reason why randomness of phenomena is less considered in L2 PSA ?

- ◆ Most of potential accident progressions can be modeled in APET, whose nature is deterministic since IC & BC are pre-specified in PDS.
- ◆ For a specified PDS, the impact of the randomness of phenomena is not so much when compared with that of the Level 2 epistemic uncertainty (e.g., magnitude of DCH, H-burn, steam explosion).
- ◆ The complexity of the Level 2 phenomena makes it difficult to strictly define their occurrence criteria (e.g., what criteria for the occurrence of DCH, H-burn, S/E ?, while alpha mode failure or S/E leading to cont. failure are clearly defined for their occurrence). => Best estimate approach for deterministic scenario in APET
- ◆ There is no reason for an analysis of the accident pathways or random phenomena that cannot be clearly identified.

Formal Treatment of Level 2 Uncertainties

- ◆ Phenomenological Uncertainty
- ◆ APET Modeling Uncertainty
- ◆ Utilization of Expert Judgments



Level 2_Phenomenological Uncertainty

Estimation of the APET Branch Probability in Variable Situations

Cases	Given: Peak pressure (P_{peak})	Given: Failure pressure (P_{fail})	Containment failure probability (P_{cf})
Case 1	Point estimate	Point estimate	If $P_{peak} > P_{fail}$, $P_{cf} = 1.0$ If $P_{peak} < P_{fail}$, $P_{cf} = 0.0$
Case 2	Uncertainty	Uncertainty	The convolution of the two uncertainty distributions results in $0.0 < P_{cf} < 1.0$.
Case 3	Point estimate	Uncertainty	The cumulative failure probability for a given pressure results in $0.0 < P_{cf} < 1.0$.
Case 4	Uncertainty	Point estimate	(a) Obtain point values ($P_{peak,i}$, $i=1$ ton) from a given peak distribution; (b) The application of Case 1 to each pressure value results in $P_{cf} = 1.0$ or 0.0 ; (c) The arithmetic average of all results in $0.0 < P_{cf} < 1.0$.

Level 2_ Phenomenological Uncertainty

Example: Estimation of CFP due to HPME

Example Plant Parameters:

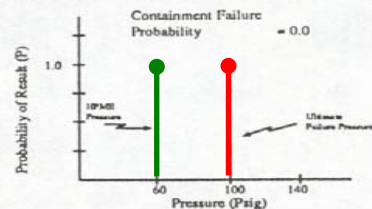
- Containment Failure Pressure = 100 psig; ● Load
- Containment Design Pressure = 40 psig; ● Capacity

Bounding Calculations of Containment Loads Provide:

Threshold Approach

CFP = 0.0

- If Calculated HPME Pressure = 60 psig; then
- Assume Failure Probability = 0.0;

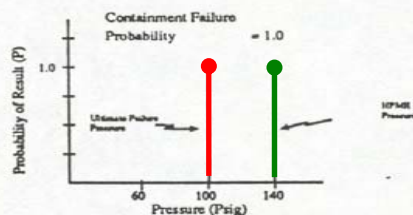


CASE 1 Bounding Assumption: $P_{HPME} \ll P_{failure}$

Threshold Approach

CFP = 1.0

- If Calculated HPME Pressure = 140 psig; then
- Assume Failure Probability = 1.0;

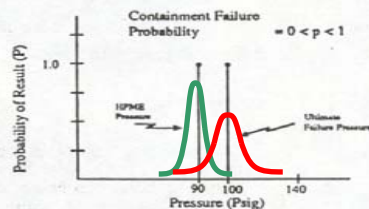


CASE 2 Bounding Assumption: $P_{HPME} > P_{failure}$

Detailed Approach

$0.0 < CFP < 1.0$

- If Calculated HPME Pressure = 90 psig ($2 \times p_d < p < p_{cf}$);
- Consider Containment Fragility Curve; Uncertainty In HPME Pressure; and
- Failure Probability > 0.0 .

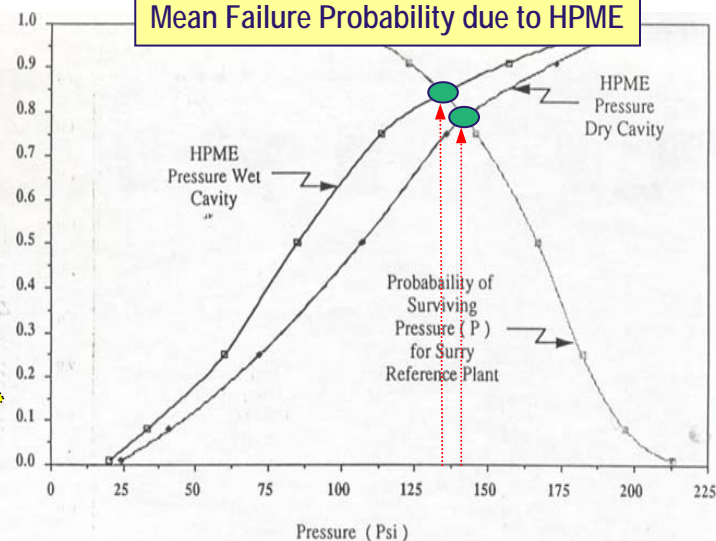


CASE 3 Uncertainty in Containment Failure Due to HPME

Estimation of CFP Probability

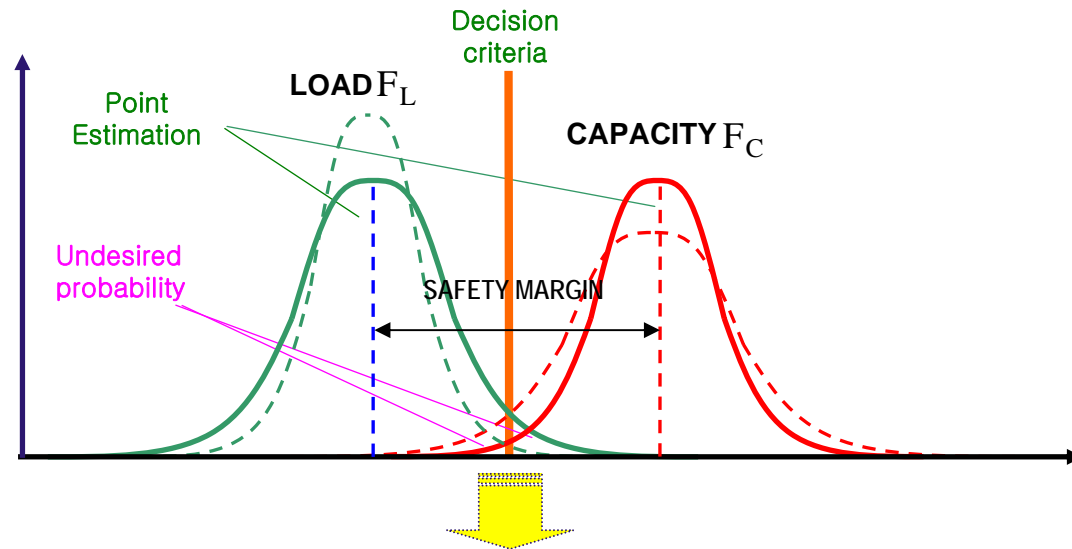
Types	Load	Capacity
Threshold Approach	Uncertainty or point value	Point value
Detailed Approach	Uncertainty	Uncertainty
Judgment only	Expert judgments	Expert judgments

Mean Failure Probability due to HPME



Level 2_ Phenomenological Uncertainty

Convolution Integral Estimation of Mean CFP under Load & Capacity PDFs



Mean Failure Probability

$$P(L > C) = \int_{c=-\infty}^{c=+\infty} \int_{l=c}^{l=+\infty} f_C(c) f_L(l) dl dc = \int_{c=-\infty}^{c=+\infty} f_C(c) [1 - F_L(c)] dc$$

Level 2_Phenomenological Uncertainty

How to Propagate Load & Capacity Distributions ?

Approaches	Load PDF (f_L)	Capacity PDF (f_C)	Failure probability (P_{cf})
Method 1 ⁽¹⁾ (NUREG-1150)	Load sample (LHS, MCS) P_L^i	Capacity sample (LHS, MCS) P_C^j	If $P_L^i > P_C^j$ $P_{cf} = 1.0$. Otherwise, $P_{cf} = 0.0$
Method 2 ⁽²⁾ (Theofanous et al.)	Load sample (DPD) $P_L^i = \int_{P_L^{i-1}}^{P_L^i} f_L(l) dl$	Capacity sample (DPD) P_C^j	If $P_L^i > P_C^j$, $P_{cf} = P_L^i$ Otherwise, $P_{cf} = 0.0$
Method 3 (In many cases)	Load sample (LHS, MCS) P_L^i	Capacity PDF itself (no sampling)	$P_{cf}^i = \int_0^{P_L^i} f_C(c) dc$
Question ?	<p>- Mean probability value is the same for methods 1 & 3, but distributions are different. (Method 1: distribution of deterministic events, Method 3: distribution on mean probabilities)</p> <p>- Is the Containment failure a random event or deterministic event for a given load ?</p>		

(1) F.T. Harper, et al., NUREG/CR-4551, Vol.2, Part 1, Rev.1 (SNL, 1990); J.C. Helton et al., RESS, Vol.35 (1992)

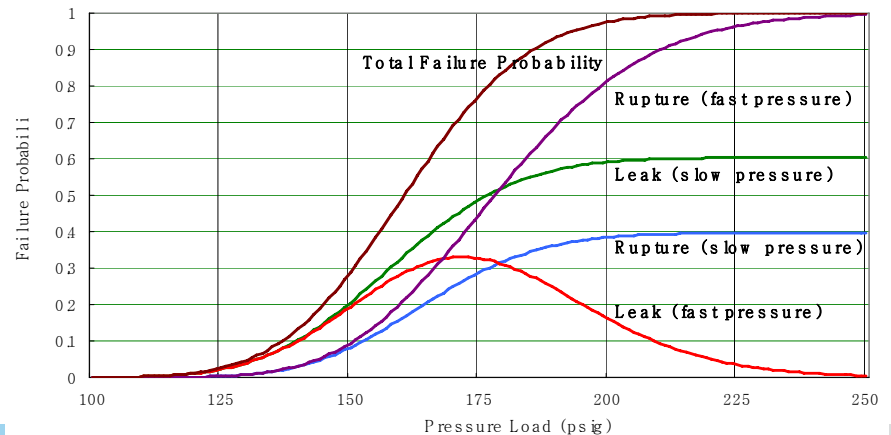
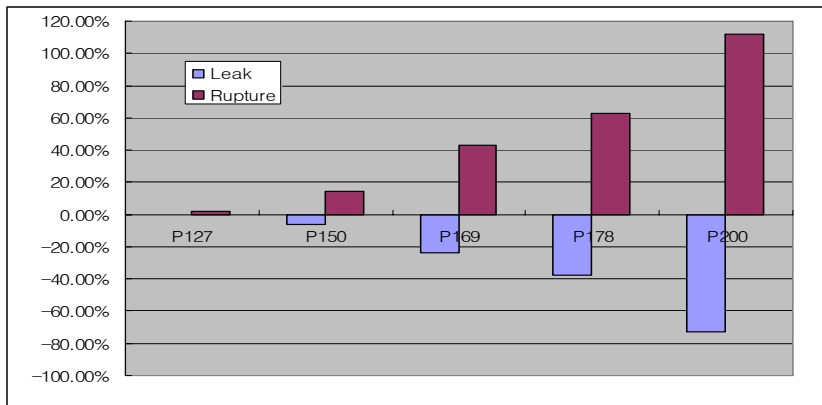
(2) T.G. Theofanous et al., NUREG/CR-5423; S. Kaplan, Nuclear Technology Vol.102 (1993)

Level 2_Phenomenological Uncertainty

Impact of Different Pressurization Rates on CFP ?

Pressure types	Classification Criteria & Accident Sequences (NUREG-1150)
Slow (quasi-static)	<ul style="list-style-type: none"> Defined as the pressure rise that is slow compared to the time. It takes a leak to depressurize the containment. Stems from a gradual production of steam/non-condensable gases (gradual over-pressurization sequences)
Rapid (dynamic)	<ul style="list-style-type: none"> Pressurization rate is fast w.r.t to the thermodynamic time constants, but quasi-static w.r.t. the structural responses. HPME, H-burn (detonation/deflagration), Ex-vessel Steam spikes. Exception: In-vessel Steam Explosion -> Direct Rupture or CR (No probabilistic, but deterministic approach)

Bound for Rupture Mode m_2	Bound for Leak Mode m_1
$\sum_{i=slow} P_{s,i}(m_2) \leq \sum_{i=slow,fast} P_{r,i}(m_2) \leq \sum_{i=fast} P_{f,i}(m_2)$	$\sum_{i=fast} P_{f,i}(m_1) \leq \sum_{i=slow,fast} P_{r,i}(m_1) \leq \sum_{i=slow} P_{s,i}(m_1)$



Level 2_APET Modeling Uncertainty

Different Formulation for Modeling Uncertainty in APET Branch

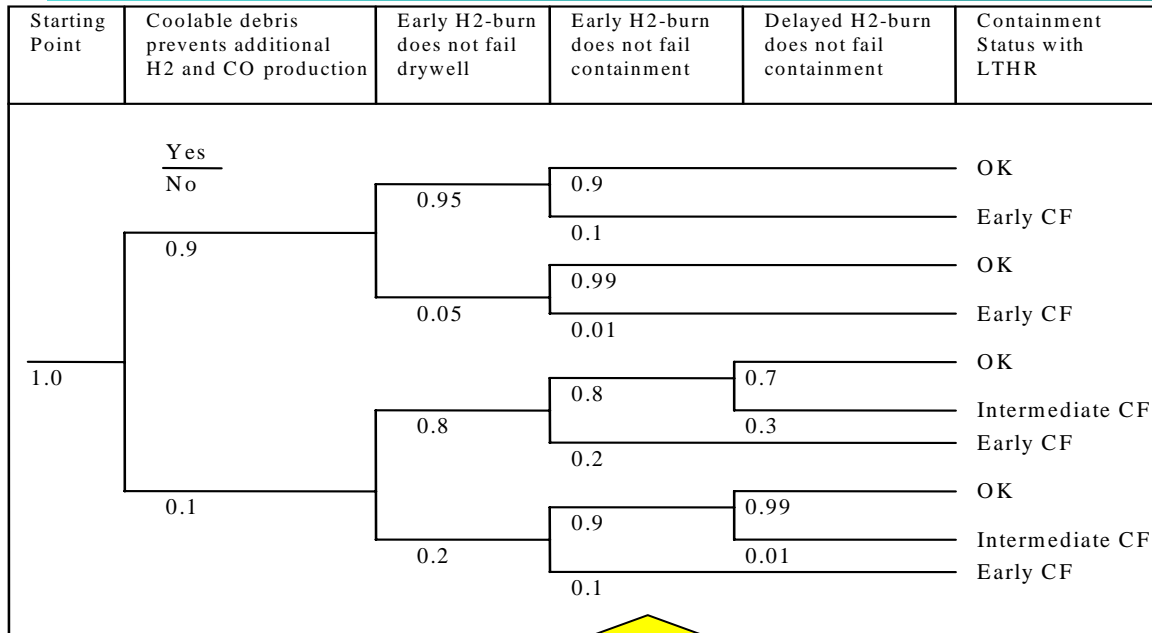
Formulation of Variation In Branch Probability	Expression of Uncertainty	Variation in Estimated Probability		Functional Form of Probability Distribution
Probabilistic variation based on Subjective Scale	Continuous Probability	Interval Probabilities [p^ℓ , p^u] (1)		Subjective Function (e.g., Triangular Form)
Linguistic Probability (Probability Variation based on Formularized Scales)	Continuous Probability	Probability Expression Certain Highly Likely Very Likely Likely Indeterminate Unlikely Very Unlikely Highly Unlikely Impossible	[P_interval] (2) p = 1.0 [0.995, 1.0] [0.95, 0.995] [0.70, 0.95] [0.30, 0.70] [0.05, 0.30] [0.005, 0.05] [0.0, 0.005] p = 0.0	Formularized Function (e.g., Flat Function)
Probabilistic Variation based on Experts' Weights	Discrete Weights	Discrete Sets of Branch Probabilities $\sum_i p_{ij} = \sum_j w_j = 1$ p_{ij} : probability of i -th branch in j -th branch set w_j : experts' weight assigned to j -th branch set		Discrete Weights

Note (1) ℓ lower bound, u = upper bound

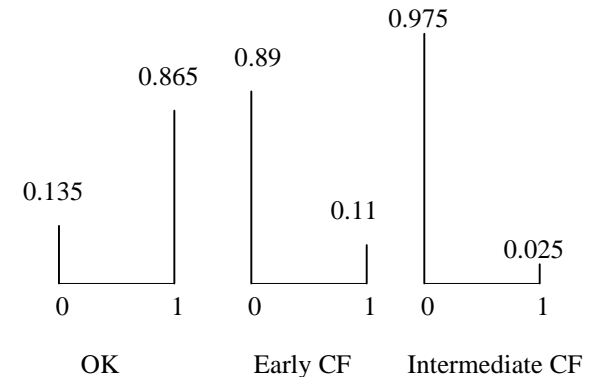
(2) Nominal value based on Flat Function in NUREG-1150 Surry study

Level 2_APET Modeling Uncertainty (ex1)

Example APET for Sample Calculation



End Points of APET



Model Uncertainty Expression of Branch Probability

Input model 1	Top Event 1	Uncertainty
Model element 1	Branch 1 (1,0)	0.9
Model element 2	Branch 2 (0,1)	0.1
Composite probability distribution (0.9,01)		

Level 2_APET Modeling Uncertainty(ex2)

Expert-to-Expert Variation in Branch Probability

Branch Model	Top Event 1	Top Event 2	Top Event 3	Top Event 4
The first branch model	(0.90, 0.10) ^a 0.8 ^b (0.80, 0.20) 0.1 (0.75, 0.25) 0.1	(0.95, 0.05) 0.5 (0.90, 0.10) 0.3 (0.85, 0.15) 0.2	(0.90, 0.10) 0.7 (0.85, 0.15) 0.2 (0.75, 0.25) 0.1	
The second branch model		(0.80, 0.20) (0.80, 0.20) (0.90, 0.10)	(0.99, 0.01) (0.95, 0.05) (0.85, 0.15)	
The third branch model			(0.80, 0.20) (0.80, 0.20) (0.90, 0.10)	(0.70, 0.30) 0.5 (0.80, 0.20) 0.3 (0.75, 0.25) 0.2
The fourth branch model			(0.90, 0.10) (0.80, 0.20) (0.75, 0.25)	(0.99, 0.01) (0.90, 0.10) (0.85, 0.15)

Note: ^a uncertainty distributions given by each expert, ^b degree of belief imposed by experts (or weights)

Mathematical Expression
Discrete Sets of Branch Probabilities
$\sum_i P_{ij} = \sum_j w_j = 1$
P_{ij} : Probabilities of i -th branch in j -th branch set
w_j : Experts' weight assigned to j -th branch set

End States	Uncertainty in mean frequency				
	5 %	50 %	95 %	mean	s.d
Output Variable					
OK	0.7515	0.8724	0.8869	0.8524	0.039
Early CF	0.0959	0.1068	0.2234	0.1248	0.037
Intermediate CF	0.013	0.0194	0.046	0.0228	0.01

Impact of LOCA Seq. Regrouping on LERF

UCN 3&4 SCET-LRF Model

N O	PDS Events		SCET Events	Sensitivity Results	
	SLOCA	MLOCA	RCSDPRES	Cases	LERF*
1	MEDIUM	MEDIUM	SLOCA: DPRESS NO MLOCA: DPRESS NO	Base	1.240E-6
2	HIGH	MEDIUM	SLOCA: DPRESS NO MLOCA: DPRESS NO	S-1	1.284E-6
3	HIGH	MEDIUM	SLOCA: DPRESS NO MLOCA: DPRESS YES	S-2	1.284E-6
4	MEDIUM	MEDIUM	SLOCA: DPRESS NO MLOCA: DPRESS YES	S-3	1.240E-6

- (1) Regrouping of PDS ET (CD) sequences into the Relevant LOCA PDS
- (2) Propagation into PDS-CET/DET-LERF Model

1.240E-6 < The Impact on LERF < 1.284E-6
(3.5 % increase)

Level 2_APET Modeling Uncertainty (ex4)

Uncertainty in Implementing SAM Strategy: RCS Depressurization after CD with SDS

Level 1 ET (before CD)	PDS (ET) (after CD)	Level 2 APET Model (as Yes or No Event for a Given PDS)
When modeled	When not modeled	The operation of SDS after can not be considered in APET, since the event was not explicitly modeled in PDS. (No Problem)
When not modeled	When modeled	The operation of SDS after can be considered in APET, since the event was explicitly modeled in PDS. (No Problem)
When modeled	When modeled	The operation of SDS after CD is considered in APET, but it becomes a phased-mission problem.
<p><u>Results:</u></p> <p>A Same Mitigation System, but Two Different Human Action</p>		<p>⇒ Multiple modeling of the same mitigation system</p> <p>⇒ Successive treatment of the same FT events (before & after CD)</p> <p>⇒ Inconsistent FT MCSs for the SDS-related sequences</p> <p>Phased-Mission Reliability Analysis Method for Resolving Such a Problem ?</p>

Level 2_Use of Expert Judgments

Formal Use of Expert Judgments in PSA and SA Analysis

❑ Why the expert judgments are necessary (*PSA-SA uncertainty*)

- √ Large: *Lack of relevant data and the correct model*
- √ Small: *EJ is inherently involved in the whole process of analysis*

❑ Different applicability in practical situations

- √ Resource availability: *qualified experts, time, budget, information ...*
- √ Elicitation approach: *formally-structured, less-structured, simplified*
- √ Analysis scope: *detailed, specific analysis*

➡ *What approach to apply? What means to optimally use them?*

❑ Discrimination between formal and informal

- √ Robustness of the expert's knowledge
- √ Effective trace of the elicitation process
- √ Substantiation of judgmental information

➡ *How to use the formal approach in variable situations?*

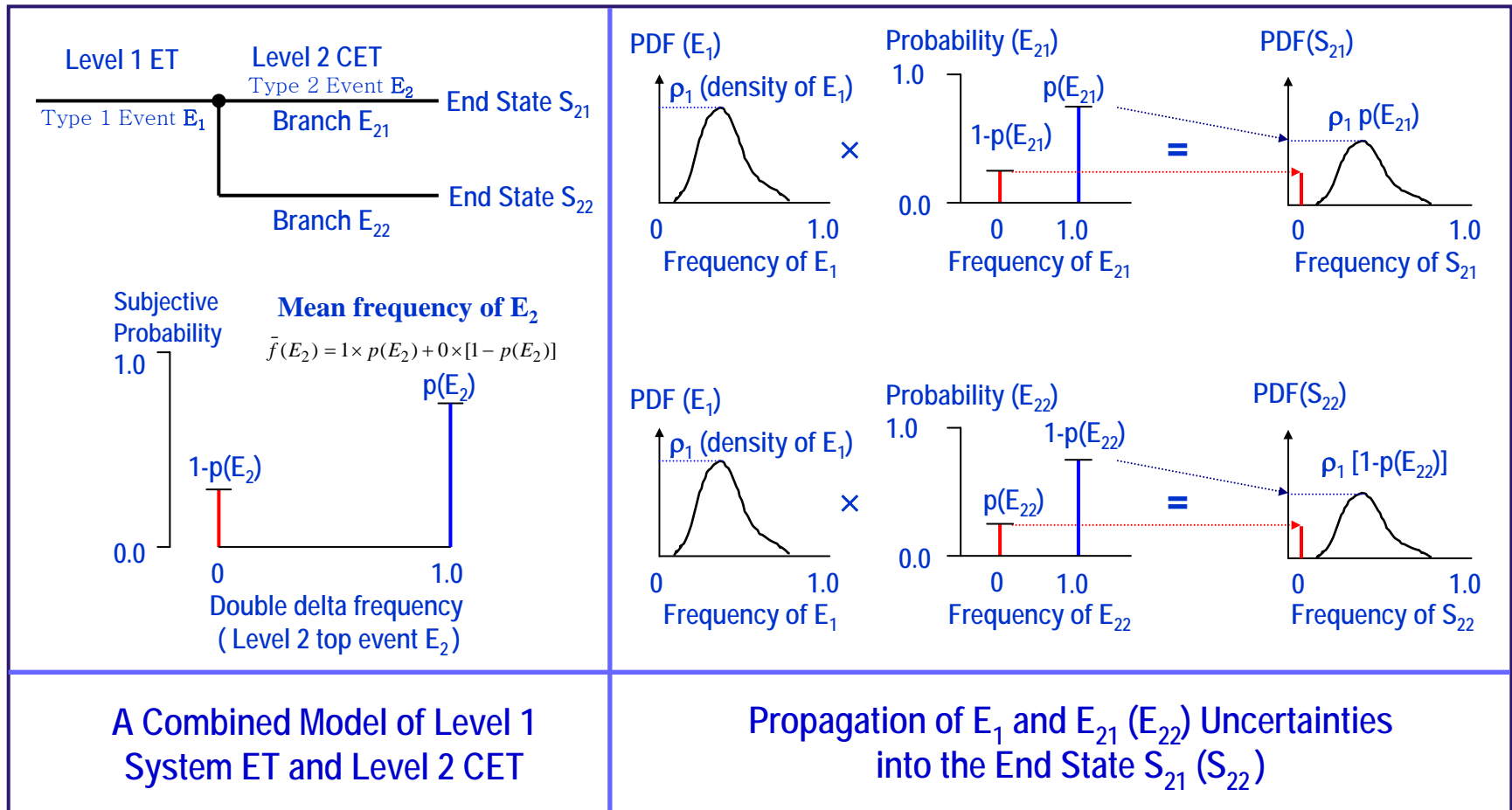
Formal Integration of Level 1-2 Uncertainties

- ◆ Integration of Level 1-2 Uncertainties
- ◆ Integration Logic of Level 1-2 Models
- ◆ Integration Tool of Level 1-2 Models



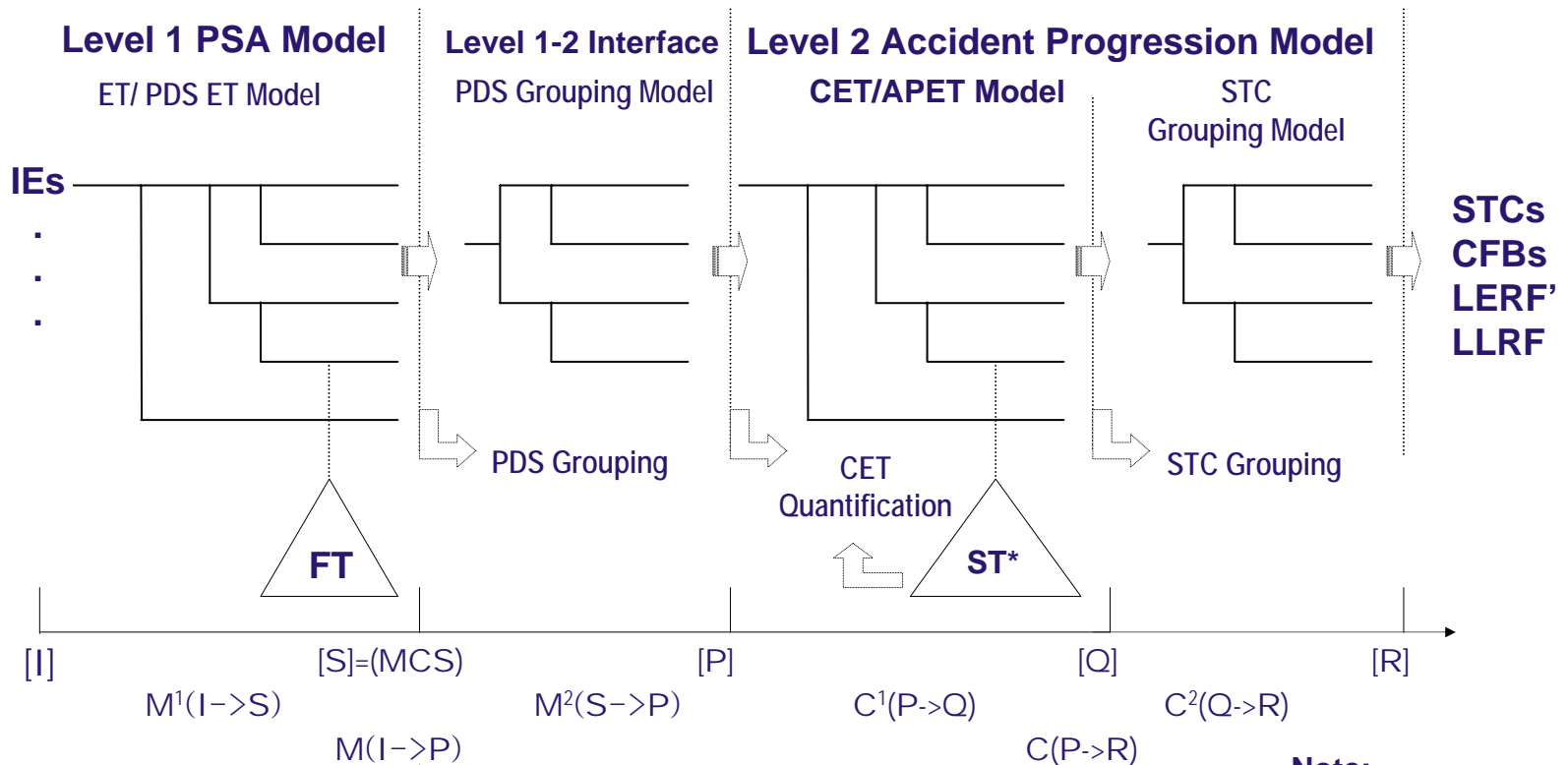
Integration of Level 1-2 Uncertainties

Statistical Combinations of the Level 1-2 Uncertainties In the Frequency Format of APET Branch Probability



Integration Logic of Level 1-2 Models

Integration of the Level 1 ET/FT-PDS ET-Level 2 PDS/APET



STCs
CFBs
LERF'
LLRF

$$M = M(IE \rightarrow MCS) \times M(MCS \rightarrow PDS)$$

$$C = C(PDS \rightarrow STC)$$

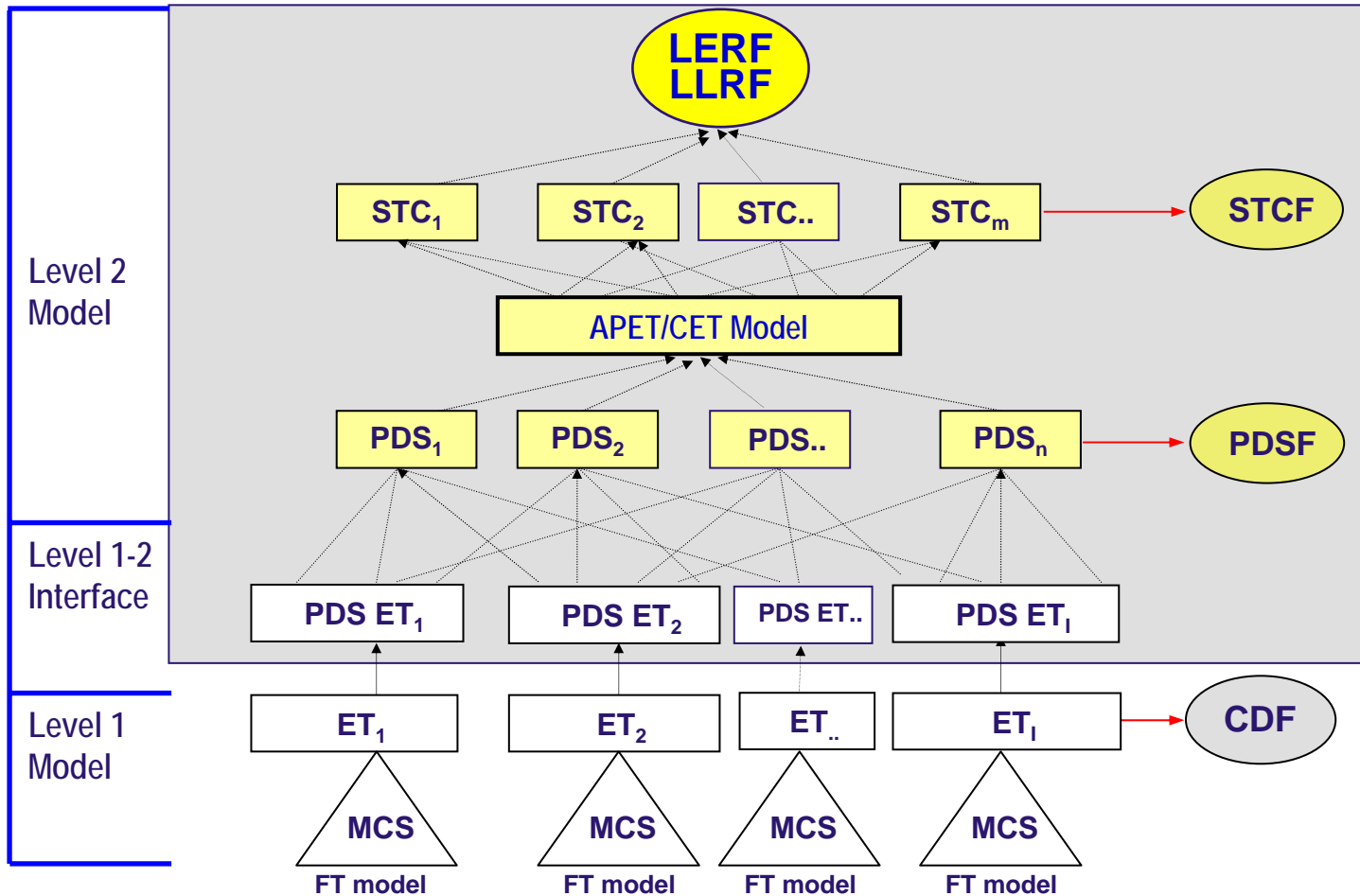
$[R] = P \times C = I \times M \times C = S \times M^2 \times C$
An Integrated Single Model
(Boolean Expression for Level 1 and 2 Events)

Note:
ST*=Supporting Tree

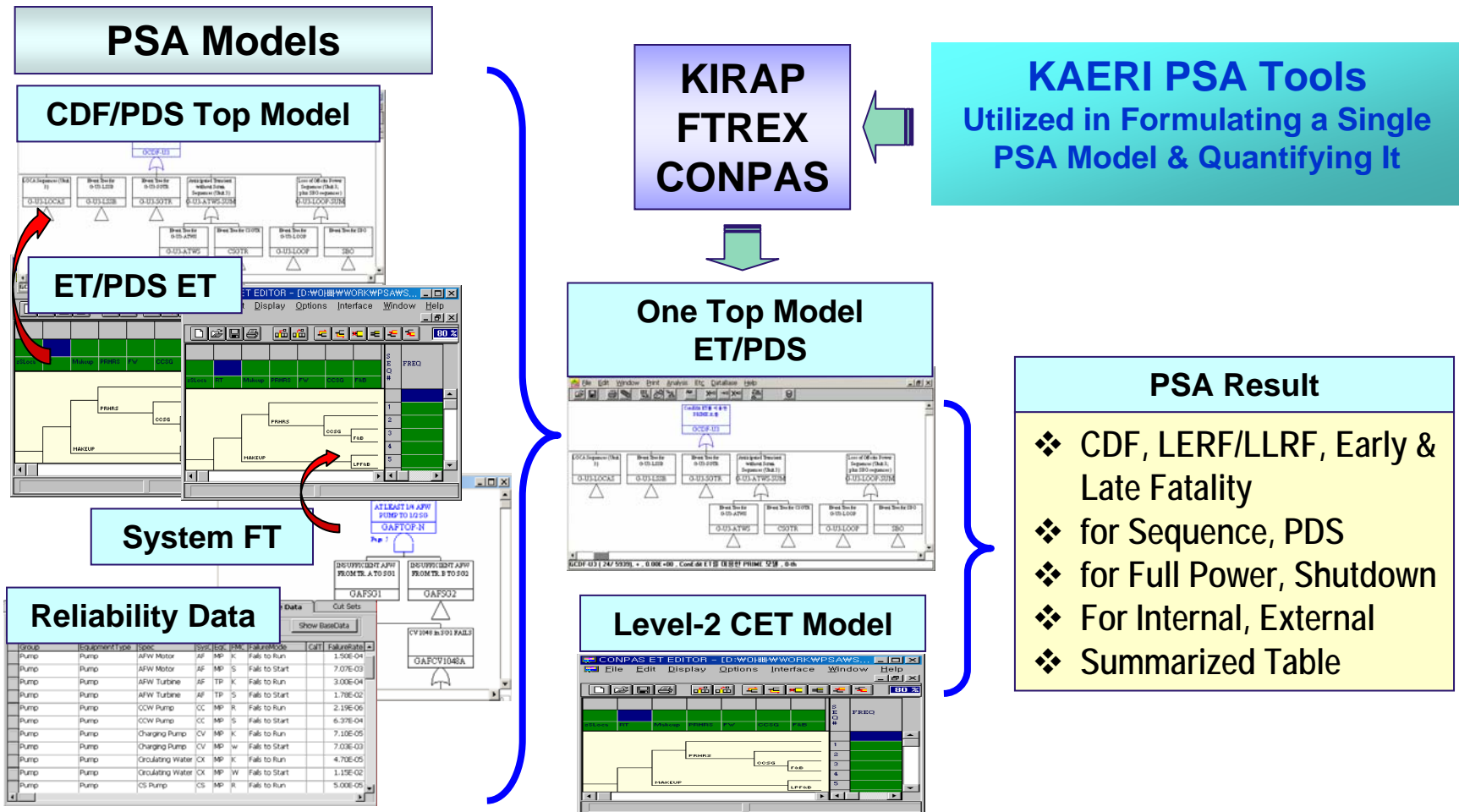
$$r_k = \hat{c}_k = \sum_j \sum_{kk \in k} (p_j \cdot q_{j,kk}) / \sum_{j=all} p_j$$

Integration Logic of Level 1-2 Models

A Single PSA Model to Integrate Level 1-2 Uncertainties



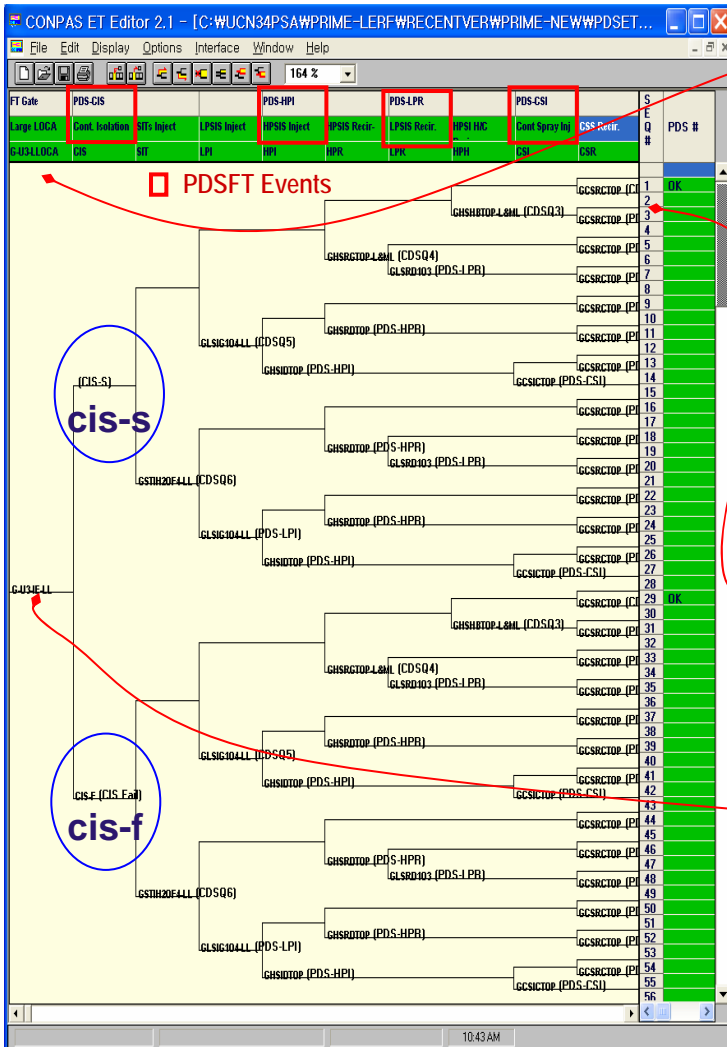
Integration Tool of Level 1-2 Models



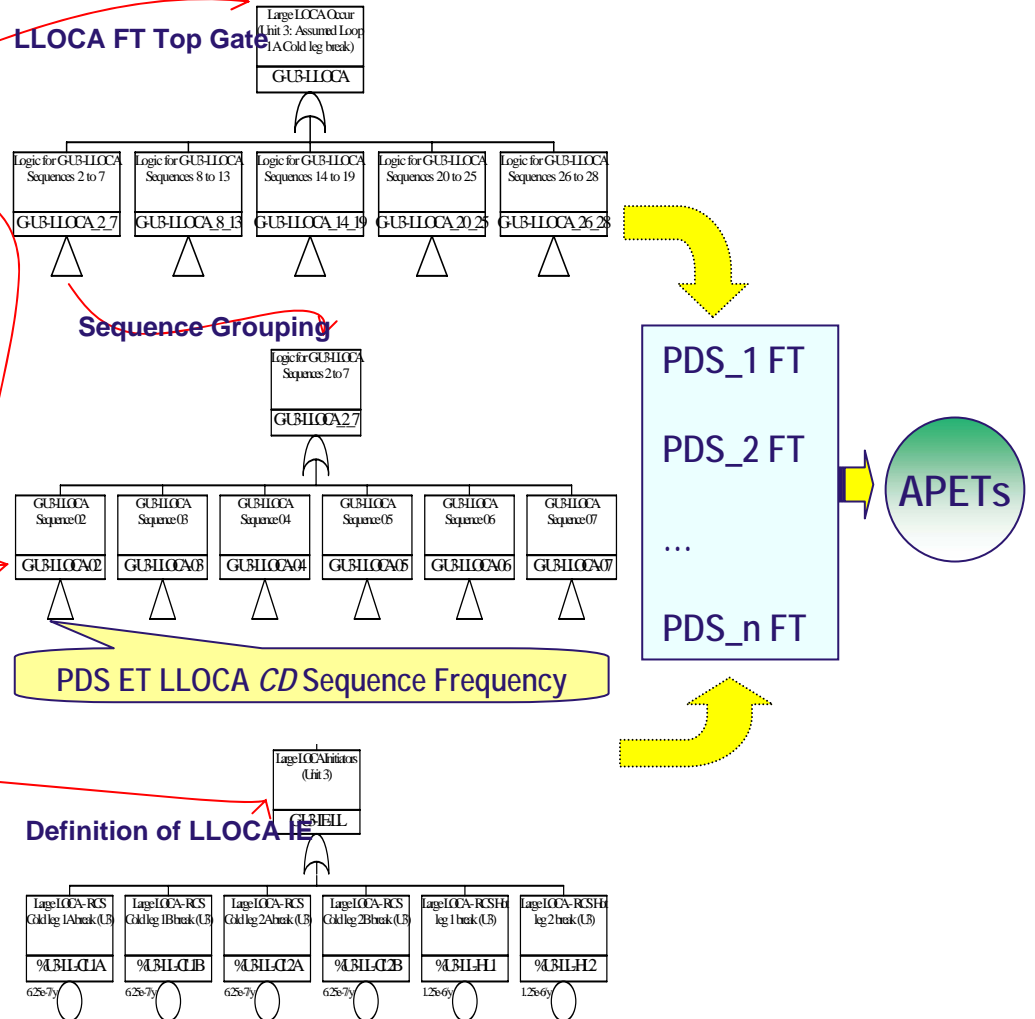
A complete binning of the Level 1 CD sequences into the relevant PDS with a type of bridge trees (PDS ETs):
No uncertainty in sense of approximation

Integration Tool of Level 1-2 Models

UCN 3&4 LOCA PDS ET



Conversion of LLOCA PDS ET into FT



Integrated Result of Level 1-2 Models

PDSET_S=f(MCS) <= Level 1 results

MCS

$PDS_1 = \dots$
 $PDS_5 = 7.89710E-12, \text{ Matched SEQ_} \# = 6$
 $SBOPDS_S35 + SBOPDS_S37 + SBOPDS_S80 + SBOPDS_S82 + SBOPDS_S93 + SBOPDS_S95.$
 $PDS_6 = 5.51380E-12, \text{ Matched SEQ_} \# = 6$
 $SBOPDS_S36 + SBOPDS_S38 + SBOPDS_S81 + SBOPDS_S83 + SBOPDS_S94 + SBOPDS_S96.$
 \dots
 $PDS_{45} = \dots$

P= f(PDSET_S)

MCS + APET Sequences

$STC_1 = \dots$
 \dots
 $STC_3 = 1.13814E-08, \text{ Matched SEQ_} \# = 34$
 $1.00959E-04 * PDS_3 + 4.37332E-04 * PDS_4 + 9.08626E-04 * PDS_5 + 3.93599E-03 * PDS_6 + 9.50711E-03 * PDS_7 + 9.50711E-03 * PDS_8 + 2.19489E-03 * PDS_9 + 9.50711E-03 * PDS_{10} + 9.50711E-03 * PDS_{11} + 9.50711E-03 * PDS_{12} + 9.50711E-03 * PDS_{13} + 2.19489E-03 * PDS_{14} + 9.50711E-03 * PDS_{15} + 9.50711E-03 * PDS_{16} + 9.50711E-03 * PDS_{17} + 9.50711E-03 * PDS_{18} + 9.08626E-04 * PDS_{19} + 3.93599E-03 * PDS_{20} + 9.50711E-03 * PDS_{21} + 9.50711E-03 * PDS_{22} + 9.08626E-04 * PDS_{23} + 3.93599E-03 * PDS_{24} + 9.50711E-03 * PDS_{25} + 9.50711E-03 * PDS_{26} + 1.75278E-05 * PDS_{33} + 7.59399E-05 * PDS_{34} + 3.15500E-04 * PDS_{35} + 1.36692E-03 * PDS_{36} + 1.52700E-03 * PDS_{37} + 1.52700E-03 * PDS_{38} + 3.15500E-04 * PDS_{39} + 1.36692E-03 * PDS_{40} + 1.52700E-03 * PDS_{41} + 1.52700E-03 * PDS_{42}.$
 $STC_4 = 1.78779E-08, \text{ Matched SEQ_} \# = 38$
 $4.97032E-04 * PDS_3 + 5.59535E-04 * PDS_4 + 4.47329E-03 * PDS_5 + 5.03582E-03 * PDS_6 + 1.55940E-03 * PDS_7 + 1.55940E-03 * PDS_8 + 2.00555E-04 * PDS_9 + 1.55940E-03 * PDS_{10} + 1.55940E-03 * PDS_{11} + 1.55940E-03 * PDS_{12} + 1.55940E-03 * PDS_{13} + 2.00555E-04 * PDS_{14} + 1.55940E-03 * PDS_{15} + 1.55940E-03 * PDS_{16} + 1.55940E-03 * PDS_{17} + 1.55940E-03 * PDS_{18} + 2.48929E-03 * PDS_{19} + 3.05182E-03 * PDS_{20} + 1.55940E-03 * PDS_{21} + 1.55940E-03 * PDS_{22} + 4.47329E-03 * PDS_{23} + 5.03582E-03 * PDS_{24} + 1.55940E-03 * PDS_{25} + 1.55940E-03 * PDS_{26} + 2.48000E-04 * PDS_{27} + 2.48000E-04 * PDS_{28} + 4.46400E-03 * PDS_{29} + 4.46400E-03 * PDS_{30} + 2.51401E-04 * PDS_{33} + 2.62253E-04 * PDS_{34} + 4.52522E-03 * PDS_{35} + 4.72055E-03 * PDS_{36} + 2.50310E-04 * PDS_{37} + 2.50310E-04 * PDS_{38} + 4.52522E-03 * PDS_{39} + 4.72055E-03 * PDS_{40} + 2.50310E-04 * PDS_{41} + 2.50310E-04 * PDS_{42}.$
 \dots
 $STC_{19} = \dots$
 $LERF = STC_3 + STC_4 + STC_{14} + STC_{16} + STC_{17} + STC_{18} + STC_{19}.$
 $LLRF = STC_5 + STC_6 + STC_7 + STC_8 + STC_9 + STC_{10} + STC_{11} + STC_{12} + STC_{13}$

R= f(PDS, CET_S)

R= f(MCS, PDSET_S, PDS_S, CET_S)

Some Insights & Concluding Remarks



Some Insights

Insights into the Formal Handling of Various Sources of Uncertainty in Level 2 PSA

- ◆ If the Level 2 events are not clearly defined at the fundamental levels, the potentials for the random/stochastic portion of the probability are inevitable even for physical events.
- ◆ The PDS/APET approach (**separating system-related event and phenomena - related event**) might be incomplete in part when the randomness of phenomena are inevitably considered even in APET.
- ◆ In many cases, however, the contribution of the random portion of phenomena in the APET branching is not so much (**when compared to the impact of physical & modeling uncertainties assessed for a specific PDS**).
- ◆ The use of a more detailed PDS/APET seems to be a good solution to less consider the impact of randomness in phenomena from the various points of view (e.g., **difficulty in clearly defining the randomness of phenomena and probabilistically modeling it**).

Concluding Remarks

- ◆ In Level 2 PSA, a formal separation between aleatory & epistemic portion of uncertainty should be kept. For example, the APET branch probabilities themselves are already an expression of uncertainty about the possibility of the branch event. So, uncertainty about these probabilities should be avoided (an additional uncertainty about the uncertainty ?).
- ◆ From the aforementioned viewpoints, a guidance for formally handling uncertainty sources that would be employed in Level 2 APET has been provided (particularly with their characterization, propagation, interpretation, and impact on the RI-DM process).
- ◆ Finally, a formulation has been given for the question on how to propagate consistently the two types of uncertainties characterizing Level 1 and 2 events into an integrated uncertainty addressing the Level 2 risk results.

For example, an epistemic uncertainty on the Level 2 aleatory quantities (LERF or LLRF, STC frequencies).

Thank you for
your attention

新時代の動力
韓国電力研究50周年記念
朴正熙

