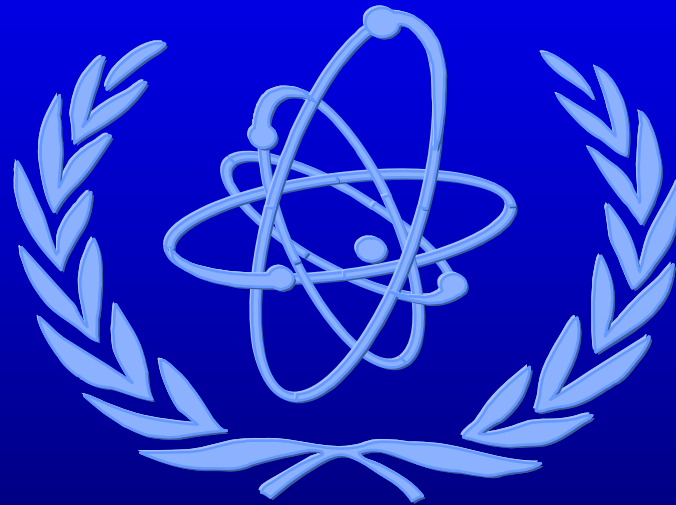


MODULE 7: **Containment Event Tree
Development & Quantification**



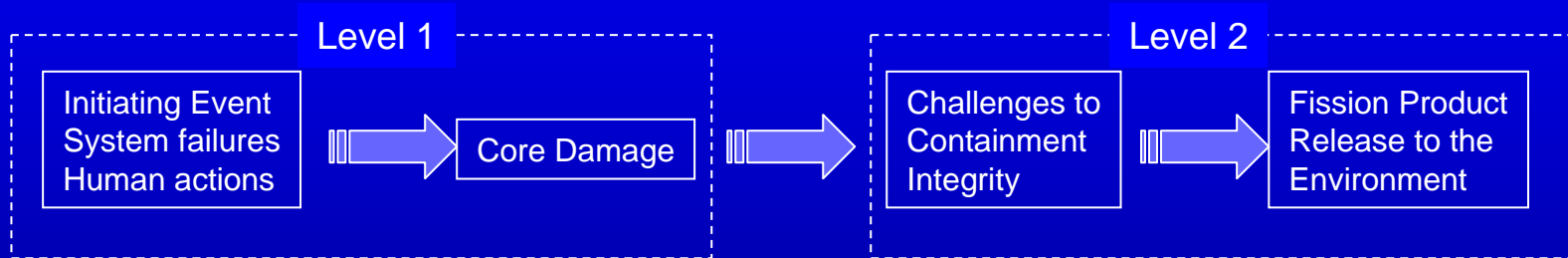
Outline of Discussion

- **What is a Containment Event Tree?**
 - **How does it differ from sequence ETs in a Level 1?**
 - **Alternative CET formats / approaches**
 - **Advantages & disadvantages**
 - **Selecting and appropriate format for your study**
 - **Methods & tools for CET Quantification**
-



What is a CET?

- A CET is a logical framework for estimating the range of consequences associated with a given accident sequence.

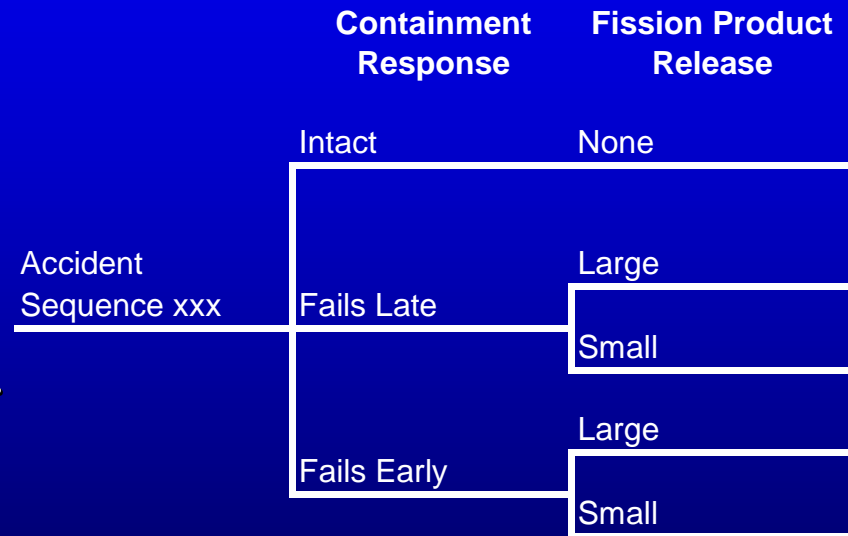


- A CET is a time-line of accident progression
 - It represents the sequence of events that could lead to failure of the containment pressure boundary and fission product release to the environment



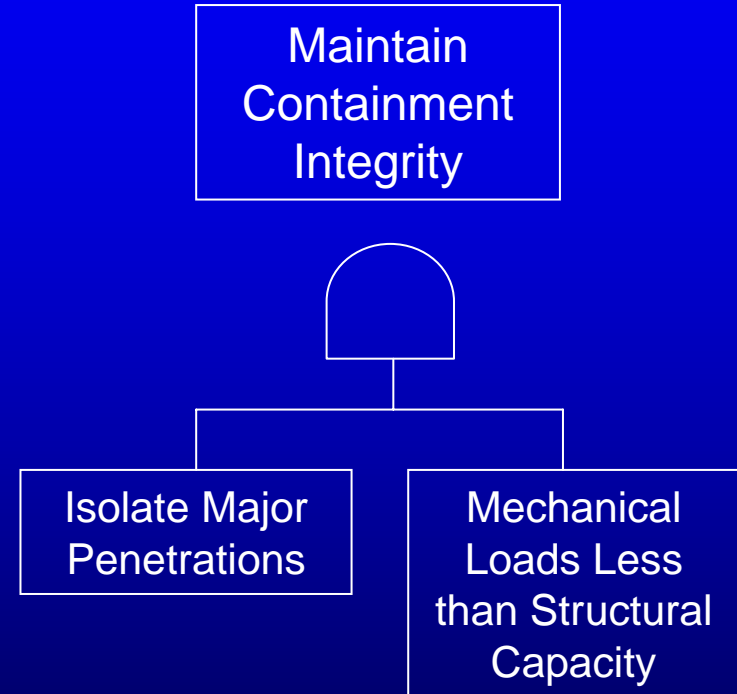
What is a CET? (2)

- It is a Probabilistic model.
 - It represents uncertainties in ability to predict accident progression
 - Particular assumptions regarding each uncertainty lead to different conclusions regarding plant response to the sequence
- Branch point probabilities typically NOT based on statistical analysis of “data”
 - Reflect confidence that one assumption is more likely to be correct than an alternative



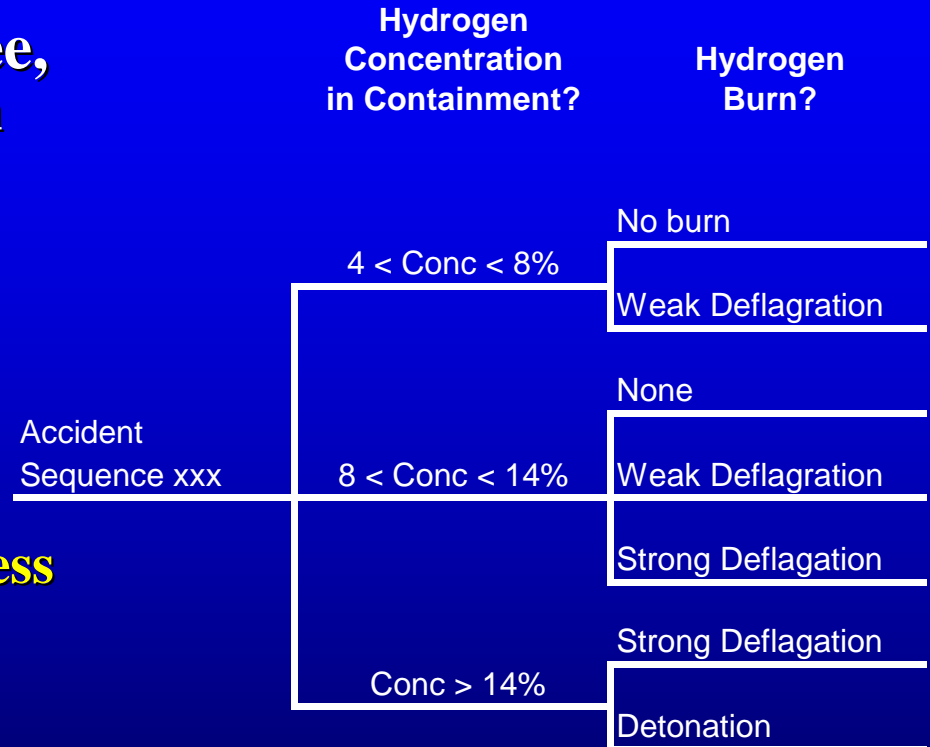
How Does a CET Compare to a Level 1 Sequence Event Tree?

- Top events are not built from “success criteria”; however, the general concept of safety functions applies.
 - **“Maintain Containment Integrity” and “Mitigate Fission Product Release” can be viewed as Critical Safety Functions**



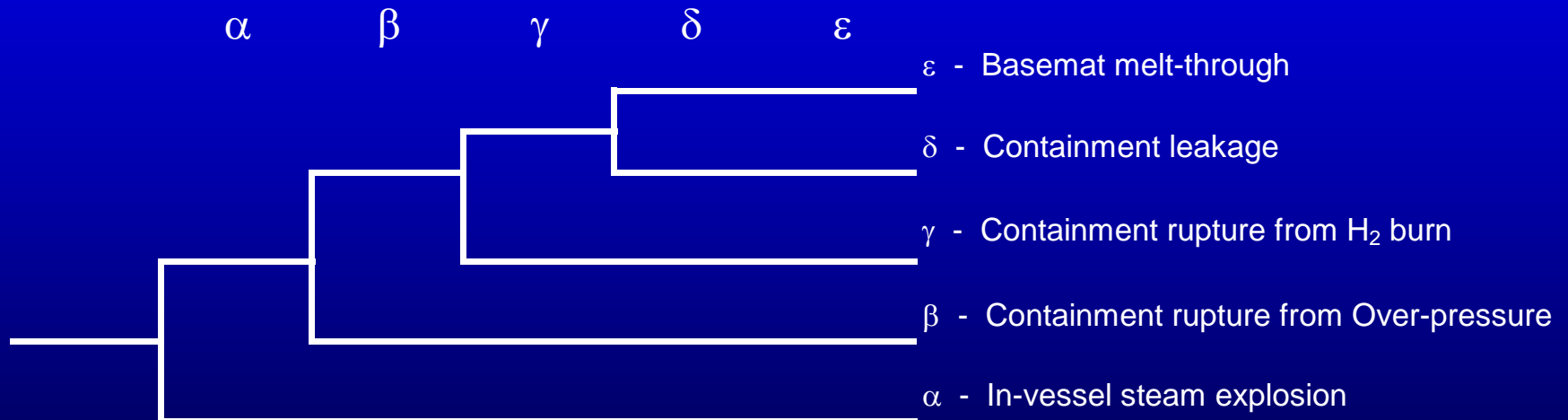
CET vs Level 1 Event Tree (2)

- Unlike the a Level 1 event tree, branch points in a CET often have more than two possible outcomes:
 - **Branch may not simply represent “success” or “failure” of an event**
 - **Often represent alternative conditions or physical process**
- **ALL branches represent sequences of interest**
 - **Quantification does not exclude “success” paths**



Genesis of the CET

- “Containment Failure Modes” formed the Top Events in CETs in the first reactor Level 2 PSA (WASH-1400):



WASH-1400 also Established Naming Conventions Still in Use Today

- **Linear combination of Accident Sequence and CET Outcome defined the conditions needed to estimate fission product source term.**
 - **Example:**
 - **Transient (T) with failure of power conversion system and SG secondary relief valve (M), aux feedwater (L), electric offsite and onsite ac power (B') - containment failure by overpressure.**
 - **Identified as TMLB' – γ .**
 - **Major weaknesses include:**
 - **Containment failure mode the only factor in determining source term**
 - **No structure to branch point probabilities**
 - **No mechanism for evaluating uncertainties**
-



Contemporary CET Formats

- **Three alternative approaches have evolved since WASH-1400:**
 - **Event tree / fault tree**
 - ❖ Extension of Level 1 modeling technology
 - **Small event tree / decomposition event tree**
 - ❖ Addresses major limitations of fault trees for Level 2 event quantification
 - **Large event tree**
 - ❖ Provides a single, consistent modeling framework for addressing the dependencies in severe accident uncertainties.
-

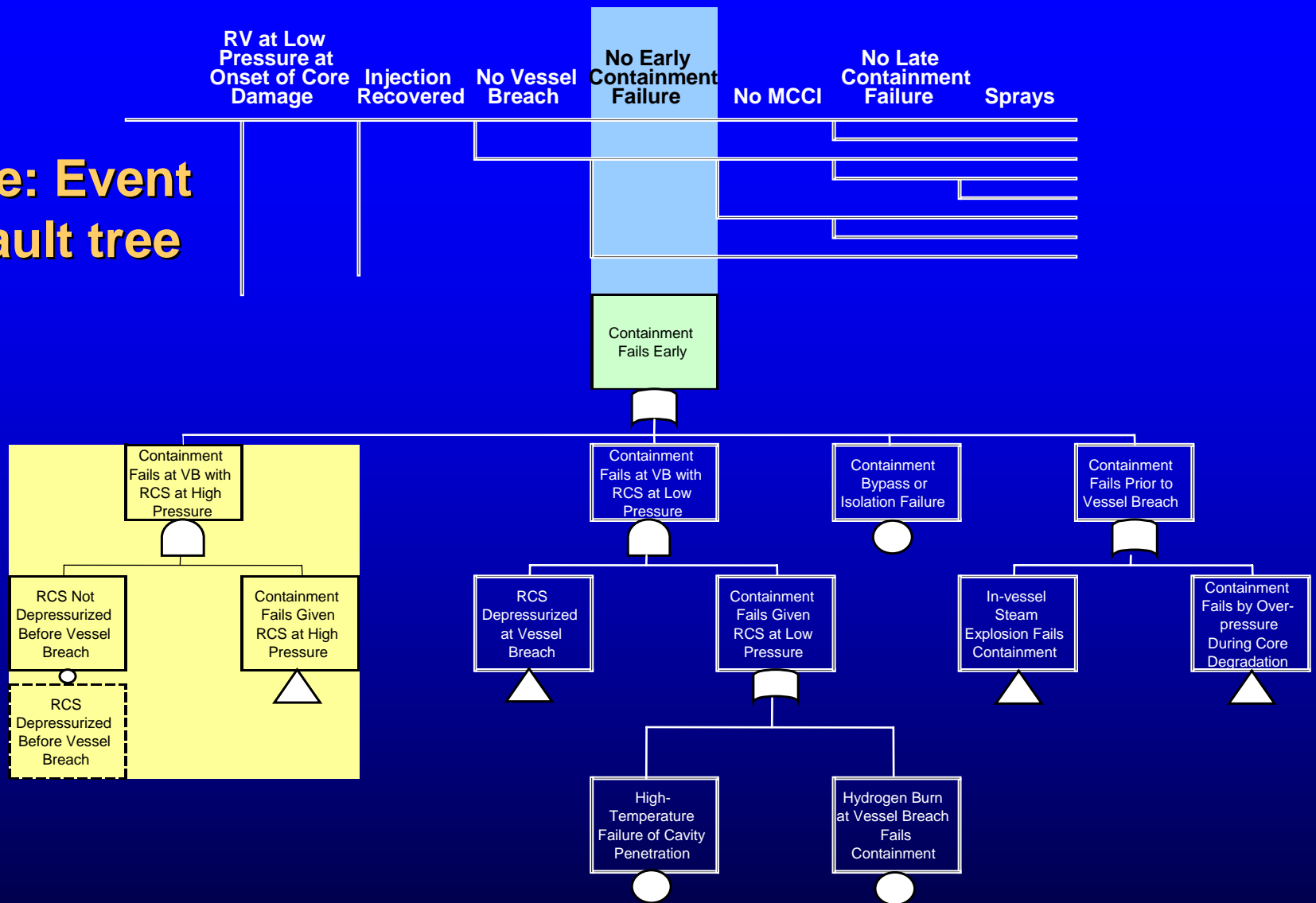


Approach 1: Event tree / Fault tree

- **Event tree represents major events that govern fission product source term**
- **Fault trees used to assemble combinations of accident conditions required to cause the event**



Example: Event tree - Fault tree



Advantages & Disadvantages of the Event tree / Fault tree Approach

- **Pro:**
 - **Small event trees are easier to draw and explain**
 - **Fault tree logic provides visual framework for identifying factors that contribute to major events**
 - **Allows directly coupling of Level 1 and Level 2 models**
 - **Con:**
 - **Logical dependencies among accident phenomena very difficult to model properly**
 - ❖ **Can demand extensive use of “not” logic or lists of “mutually-exclusive events” to prevent non-physical accident progression**
 - **Not possible to trace chronology of a particular accident scenario through the “CET”**
-

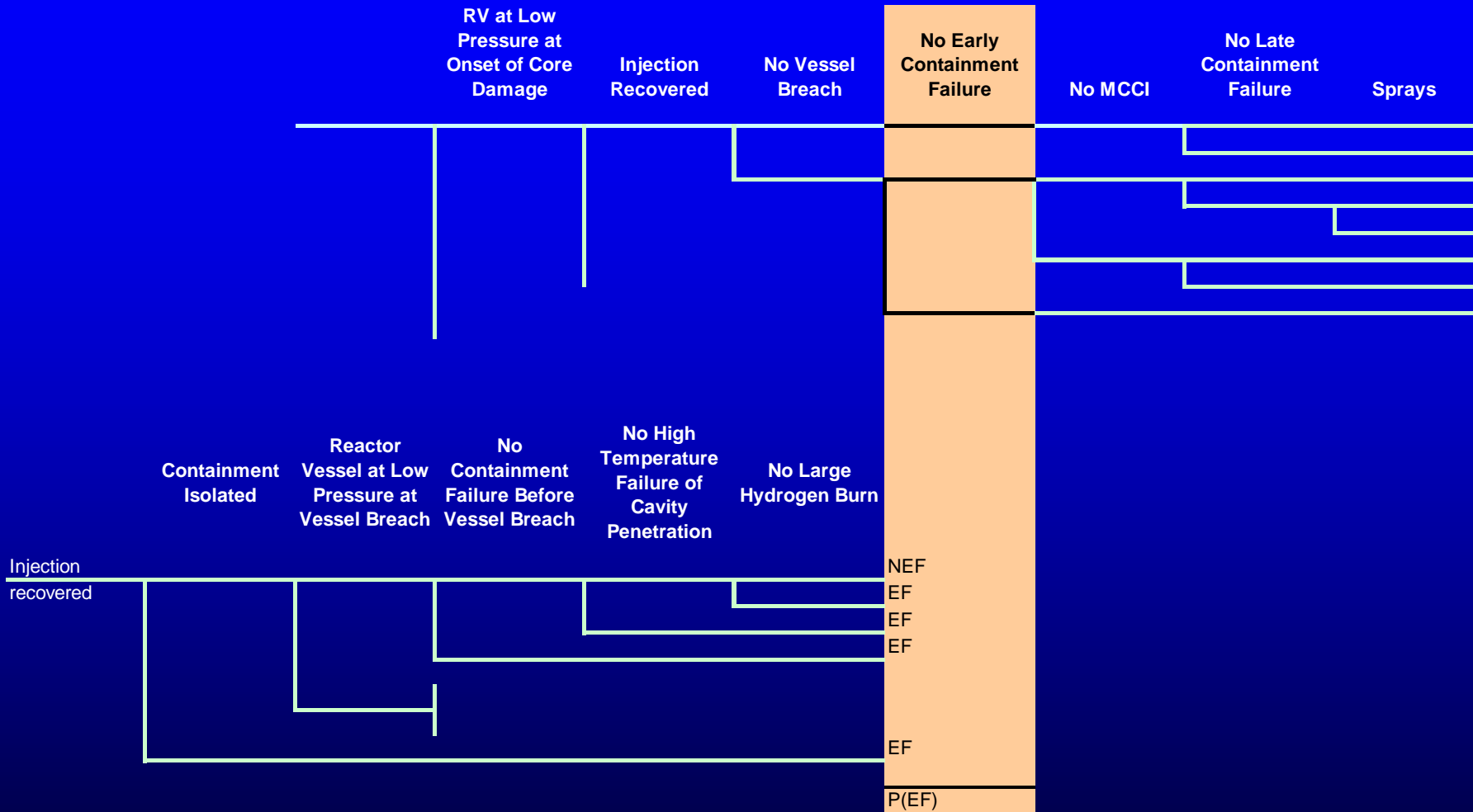


Approach 2: Event tree / Decomposition event tree

- Main event tree represents events that dominate fission product source term
- Main “event” is decomposed into multiple factors that determine whether the event would occur (e.g., phenomena, accident conditions, system or operator response)
 - **Factors are assembled in a chronological order**
- Outcomes of decomposition event tree are “rolled up” to define the split fraction for branches on the main event tree.



Example: Event tree / Decomposition event tree



Advantages & Disadvantages of the Decomposition Event Tree Approach

- **Pro:**
 - **Small main event tree is easy to draw and explain**
 - **Decomposition event trees provide rigorous logic structure to account for phenomena, system, and logical dependencies**
 - **Ability to trace accident chronology through CET**
 - **Source terms can be attached to a particular path through the CET**
 - **Con:**
 - **Requires careful attention to order in which events are placed**
 - **Some difficulty in assuring consistent treatment of event that may occur at various times in the accident sequence**
-



Approach 3: Large event tree

- CET is posed as a series of “questions” that have two or more answers
- Dependencies are addressed by referring back to the answers obtained from previous questions
- “Event” tree is not necessarily a graphical drawing – closer to a linked data base.

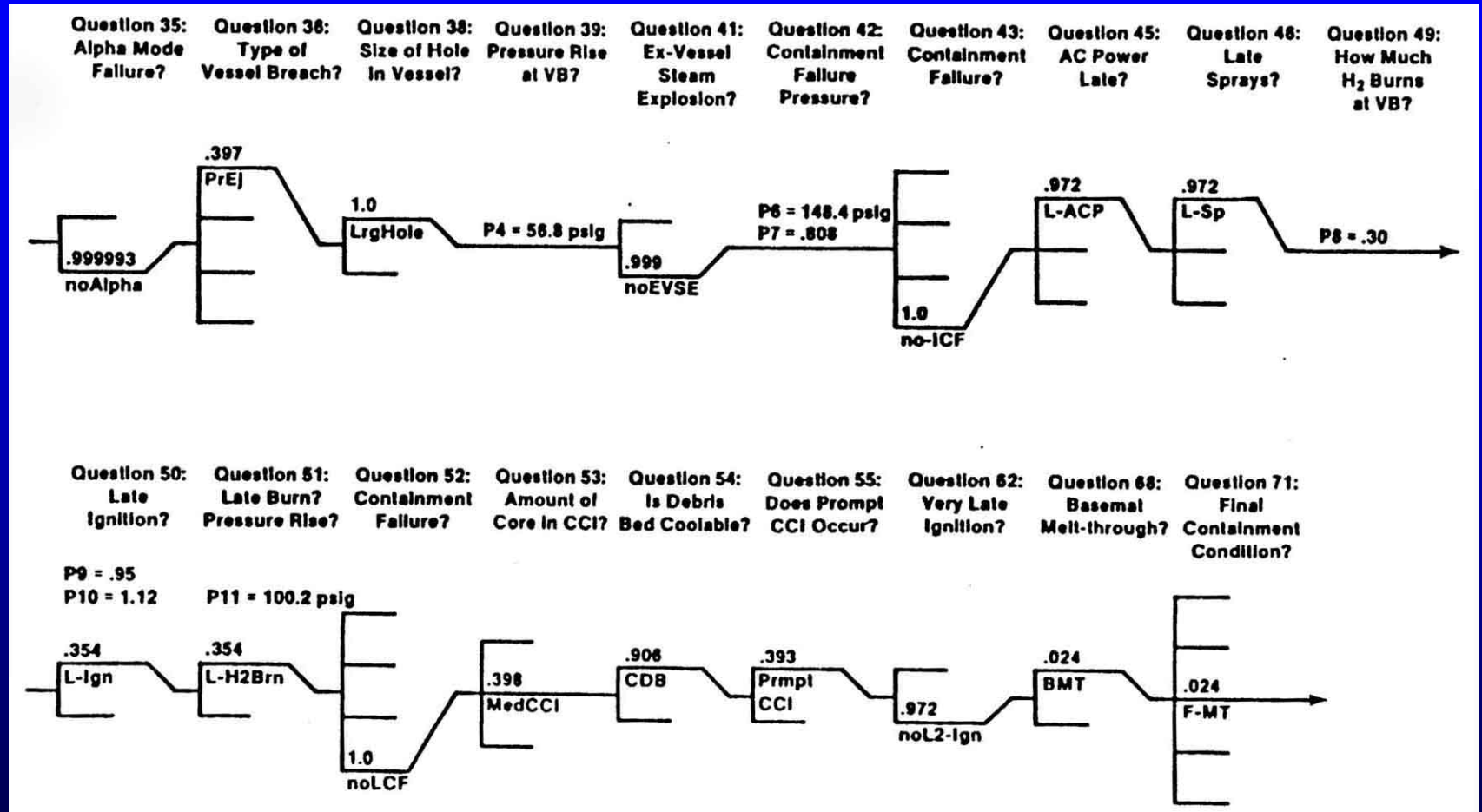


Example: Large event tree (1)

- **Example PWR questions:**
 - **(1) Is ac power available after the initiating event?**
 - **(2) What is the level of containment leakage or isolation failure?**
 -
 - **(18) Is there containment heat removal during core degradation?**
 - **(20) What is the containment pressure before vessel breach?**
 - **(27) What is the mode of vessel breach?**
 -
 - **(41) How much water is injected into the containment prior to vessel breach?**
 - **(42) Do core-concrete interactions occur after vessel breach?**
-



Example: Large event tree (2)



Advantages & Disadvantages of the Large Event Tree Approach

- **Pro:**
 - **Ability to trace accident chronology through CET**
 - **Strong link to calculation performed with severe accident computer codes**
 - ❖ **Format (series of questions) consistent with process of selecting modeling assumptions and sequence of calculated events**
 - **“Events” can be extended to include values of parameters (e.g., H₂ concentration), that can change with time**
 - **Very amenable to detailed uncertainty analysis**
 - **Con:**
 - **Studying CET to confirm logical relationships is tedious**
 - ❖ **Requires analysis rather than visual inspection**
 - **Difficult to explain modeling details to others**
 - **Requires special tools for build/solve model**
-



Selecting an Appropriate CET Structure or Method Depends on Many Factors

- **Study Objectives**
 - **What questions are to be answered?**
 - **Is a quantitative uncertainty analysis needed?**
 - **Require / Desired Level of Detail**
 - **Are quantitative results important?**
 - **Extent to which “reference plant” analysis will be used rather than plant-specific study**
 - **Available resources**
 - **Experience and subjective preferences of the analysis team**
-



CET Quantification (1)

- Some events can be quantified using traditional systems analysis techniques
 - **Probability containment sprays start/run on demand**
 - **Probability operators manually open containment filtered vent**
 - Dependencies with Level 1 systems analysis must be carried forward in Level 1-2 interface
 - **Support system failures**
 - **Prior operator performance**
-



CET Quantification (2)

- However, most basic events cannot be quantified by familiar statistical analysis of randomly occurring events
 - **Fundamental nature of uncertainty is NOT stochastic (random) behavior of the ‘system’**
 - **Probability represents analysts’ degree of confidence that a particular outcome is correct (Baysian analysis)**
 - ❖ Evidence may point to one outcome over another
 - ❖ Often, available evidence leads to conflicting conclusions
 - Many events are quantified using engineering judgment
 - **Several procedures have been followed in various studies to add discipline to this process**
-



Consistent Rules for Subjective Judgment of Uncertain Events (1)

Probability Value	Description	Amount and Quality of Information Required to Support the Probability
0.999	ALMOST CERTAIN	Detailed analysis has been performed which includes all phenomena identified as relevant and has been subjected to independent review. At least one other individual who has analyzed the situation [other than the analyst and reviewer(s)] agrees that the outcome is almost certain. Separate analysis exists that supports this outcome. Consideration of all identified uncertainties has been made and none has been found to have a credible effect on the outcome.
0.99	EXTREMELY LIKELY	Either detailed analysis has been performed and subjected to independent review or a significant body of directly applicable experimental data published in the technical literature, support this position. The indicated outcome is obtained for all credible assumptions as to the values of parameters in supporting analysis. Arguments against this position are not supported by either analysis or data.
0.9	LIKELY	Either it is supported by analysis or the preponderance of experimental evidence points to this result. Arguments against this position are apparently flawed and the technical basis for disagreement with the counter argument has been established. Alternatively, no analysis has been performed but there is general agreement between two or more independent individuals knowledgeable of the situation that the indicated outcome is appropriate.



Consistent Rules for Subjective Judgment of Uncertain Events (2)

0.5	FULLY POSSIBLE	Either no analysis has been performed or existing analysis is inconclusive. Inconclusive analysis includes that for which no concurrence from an independent party can be gained. Experimental data do not clearly indicate this outcome to be more likely or experiments are obviously not directly pertinent.
0.1	UNLIKELY	It cannot be supported by incontrovertible analysis or a preponderance of data. It is, however, a credible outcome when attendant uncertainties are considered.
1.0E-2	EXTREMELY UNLIKELY	Uncertainties in the available analysis that show the outcome not to occur can be identified. Consideration of these uncertainties might lead to this outcome but no analytical or experimental support can be found.
1.0E-3	ALMOST IMPOSSIBLE	It has credibility only if a number of unsupported (but not demonstrably incorrect) assumptions are made. No analysis is available to support this result event when relevant uncertainties in the parameters of the analysis are considered.



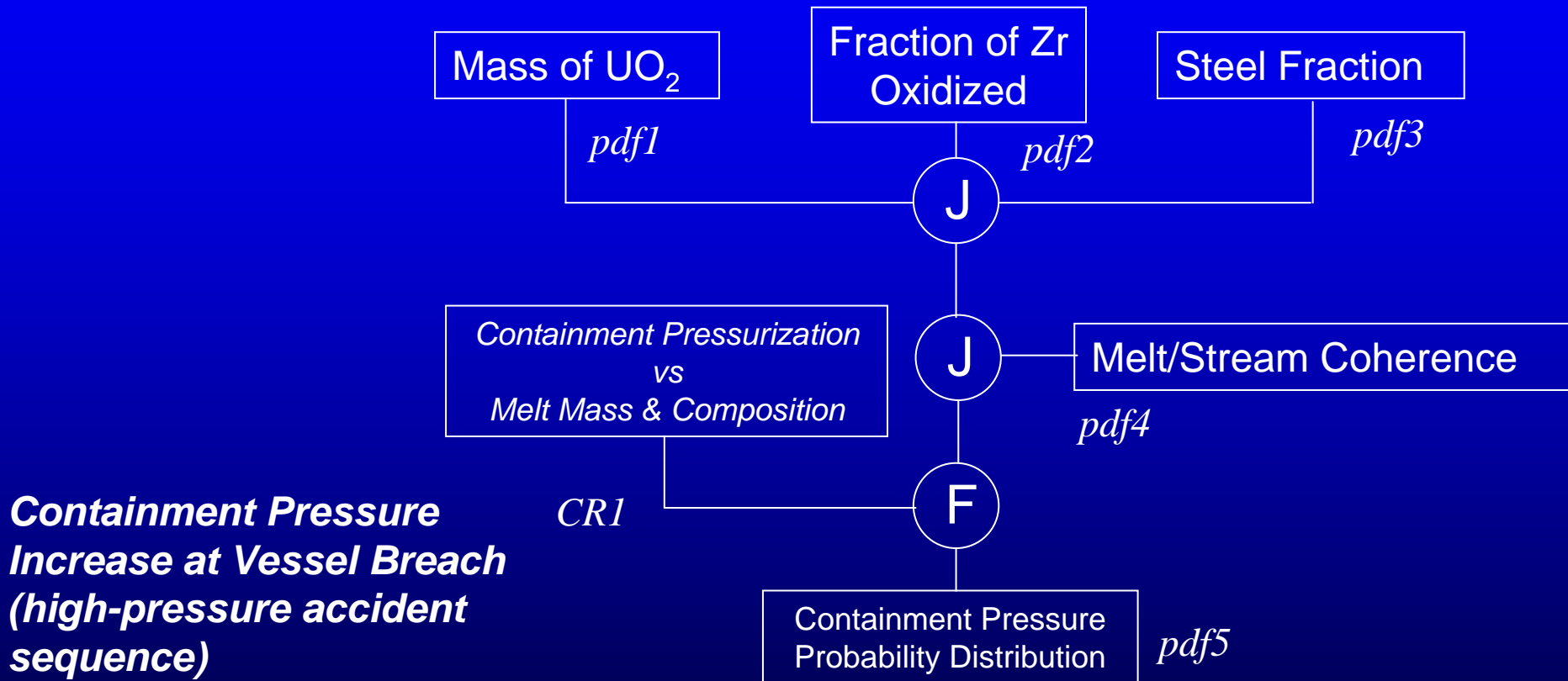
A Structured Method for Evaluating Particularly Complex Events

- **Risk-Oriented Accident Analysis Methodology (ROAAM)**
 - **Developed to address the interdependencies of ‘state-of-knowledge’ uncertainties in complex severe accident issues**
 - **Decomposes a complex issue into specific technical topics that can be quantified**
 - **Probability Distribution Functions (PDF) are developed for each topic to represent uncertainty in that component of the problem**
 - **Causal Relations (CR) are defined to capture the relationship between parameters that influence conditions for which the PDFs are valid**
-



Example Application of ROAAM

[Theofanous, NUREG/CR-6075, (1994)]



Containment Pressure Increase at Vessel Breach (high-pressure accident sequence)



Summary

- A CET is a Probabilistic Logic Framework for estimating the range of consequences associated with a given accident sequence.
 - Several formats have been successfully used in past studies
 - No single format is “best” ... each can be made to work.
 - Each format has advantages and disadvantages that must be weighted before starting
 - Quantification of a CET requires knowledge of a wide range of information
 - Chronology and interdependencies of severe accident events
 - Plant-specific computer code calculations
 - Key findings of experimental studies of complex phenomena
 - → CET development is a GROUP effort
-

