UNCERTAINTY

FACTORS OF UNCERTAINTY
- Randomness
- Phenomenological Ignorance
- Systematic Ignorance (Complexity, Sensitivity)
- Data Ignorance

IMPORTANT UNCERTAIN PHENOMENA
- Human Error
- Common Cause Failures
  - Internal
  - External
- Rare Events (e.g., Reactor Core Melt Progression)

TREATMENT OF UNCERTAINTY
- Statistical (via Standard Deviation)
- Sensitivity Analyses
- Subjective Probability Elicitation
- Research and Data Collection
- Assignment of Bias
IMPORTANT SOURCES OF PRA UNCERTAINTY

- INCOMPLETE PROBLEM STATEMENT
- MODELING APPROXIMATIONS
- SYSTEM BEHAVIOR SENSITIVITY
- PHENOMENOLOGICAL IGNORANCE, INCLUDING:
  - HUMAN BEHAVIOR
  - SEVERE ACCIDENT PHENOMENA
  - EARTHQUAKE SEVERITY
- COMMON-CAUSE FAILURE MODES
DATA SOURCES

• Generic Data Bases (those available are strongly safety-oriented; e.g., NPRDS/EPIX, NRC, GADS, . . .)

• Plant-Specific Data

• New Tests

• Subjective Judgment and Modeling
RISK MODEL OVERVIEW

RISK MODEL

PLANT MODEL

CONTAINMENT MODEL

SITE MODEL

SECTION 3

SECTION 4

(Not Included)

LEVEL I

LEVEL II

LEVEL III

RESULTS

Core Melt Sequences
Section 3.4.1.1

RESULTS

Containment Failure/Release Sequences
Section 3.4.1.2

RESULTS

Public Health Effects
(Not Included)

Courtesy of U.S. NRC.
INTEGRATED LEVEL 3 PRA FRAMEWORK

FRONT-END ANALYSIS

LEVEL 1

INTERNAL EVENTS
CORE DAMAGE
FREQUENCY
ANALYSIS

- EVENT TREES
- FAULT TREES
- FAILURE DATA
- FREQUENCIES

EXTERNAL EVENT
CORE DAMAGE
FREQUENCY
ANALYSIS

- RESOLUTION OF CORE VULNERABLE
SEQUENCES
- PLANT DAMAGE STATE DEFINITION

BACK-END ANALYSIS

LEVEL 2

ACCIDENT PROGRESSION EVENT TREE ANALYSIS

- PLANT DAMAGE STATE FREQUENCIES
- FRONT-END UNCERTAINTY ISSUES

SOURCE TERM ANALYSIS

- ACCIDENT PROGRESSION BIN FREQUENCIES
- CONTAINMENT UNCERTAINTY ISSUES

CONSEQUENCE ANALYSIS

- SOURCE TERM GROUPS
- SOURCE TERM ISSUES
- SOURCE TERM GROUP DEFINITION

LEVEL 3

RISK

FREQUENCY OF HEALTH & ECONOMIC CONSEQUENCES

Courtesy of U.S. NRC.
QUANTIFIED ATWS SEQUENCE EVENT TREE

ANTICIPATED TRANSIENT WITHOUT SCRAM

<table>
<thead>
<tr>
<th>LOSS OF MAIN FEED</th>
<th>RPS SCRAM</th>
<th>SAFETY VALVES OPEN</th>
<th>SAFETY VALVES CLOSE</th>
<th>MANUAL EMERGENCY BORON ADDITION</th>
<th>MANUAL ROD INSERTION</th>
<th>ALTERNATE BORON ADDITION</th>
<th>AUXILIARY FEEDWATER (SECONDARY COOLING)</th>
<th>OPERATOR ESTABLISHES FEED/BLEED</th>
<th>DECAY HEAT REMOVAL</th>
<th>CONSEQUENCE</th>
<th>PROB</th>
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</table>

1. 1.78

2. Failure Assumed

3. 4.6x10^-4

4. 2x10^-4

5. 9x10^-1

6. 9x10^-1

7. 10

8. 3x10^-4

9. 1.4x10^-4

10. OK

11. CD

12. 4x10^-13

13. 1x10^-1

14. 1x10^-1

15. 3x10^-4

16. 1.4x10^-4

17. OK

18. CD

19. 3x10^-11

20. 3x10^-14

21. 9x10^-1

22. OK

23. CD

24. 3x10^-14

25. 1.4x10^-4

26. OK

27. CD

28. 3x10^-11

29. 1x10^-1

30. OK

31. 3x10^-4

32. 2x10^-4

33. 6x10^-3

Small LOCA Due to Safety Valves Not Closing

Large LOCA Due to Safety Valves Not Opening

(Courtesy of U.S. NRC.)
PLANT MODEL OVERVIEW
(WITH IPE REPORT SECTION REFERENCES)

EVENT SEQUENCE MODEL

INITIATING EVENTS
SECTION 3.1.1

SUPPORT SYSTEM AVAILABILITY
SECTION 3.1.4

SYSTEM/OPERATOR RESPONSE
SECTION 3.1.2

CORE DAMAGE SEQUENCES
SECTION 3.4.1.1

HAZARD ANALYSIS
APPENDIX D

SYSTEMS ANALYSIS
SECTION 3.2, APP. E

OPERATOR ACTIONS
SECTION 3.3.3

DATA ANALYSIS

Courtesy of U.S. NRC.
CONTIBUTIONS TO CORE DAMAGE FREQUENCY
Accidents Grouped by Initiating Event

- Transients: 83%
- Loss of Support Systems: 39%
- General Transient: 19%
- LOCA: 8%
- ATWS: 9%

Courtesy of U.S. NRC.
CONTIBUTIONS TO CORE DAMAGE FREQUENCY
Accidents Grouped by Internal and External Initiating Event

INTERNAL EVENTS
55%

EXTERNAL EVENTS
45%

- Fire 24%
- Seismic 13%
- Flood 5%
- Other 3%

Courtesy of U.S. NRC.
CONTAINMENT PERFORMANCE RESULTS
(Conditional Failure Probability Given Core Damage)

Late Containment Failure**

65.4%

Early, Large Containment Failure/Bypass*

0.2%

Early, Small Containment Failure/Bypass

14.2%

Intact Containment

20.2%

* Equivalent to "unusually poor" containment performance, as defined in GL 88-20

**The containment failure probability of late containment failure is believed to be overestimated relative to containment intact. No credit has been taken for post-core melt recovery actions.

Courtesy of U.S. NRC.
CONTAINMENT FAILURE MODE CONTRIBUTIONS TO EARLY, LARGE CONTAINMENT FAILURES/BYPASS
("Unusually Poor" Containment Performance)

- Containment Isolation Failure: 58.7%
- Direct Containment Heating: 26.8%
- Induced Steam Generator Tube Rupture: 11.1%
- Other: 1.3%

Courtesy of U.S. NRC.