The Concept of Risk and its Role in Rational Decision Making on Nuclear Safety Issues

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Risks in Society

- **Hazard: A source of danger**
  - **Industrial facilities**
  - **Activities, e.g., driving a car**

- **Risk: The possibility that something bad or unpleasant (such as an injury or a loss) will happen**

- ***Uncertainty* is an integral part of risk**

- **Risk: Probability and adverse consequences**

Safety vs. Residual Risk

- **Safety is a continuum**
  - It is meaningless to call something safe or unsafe without further explanation
  - Claim: A plant is "safe" if it meets the regulations

- **The proper way is to speak of the *residual risk*.**
  - Example: In Japan, 5 people die in transportation accidents for every 100,000 residents every year
  - Therefore, the residual risk (frequency per year) is

$$\frac{5}{100{,}000} = 0.00005 \text{ a very small frequency}$$

- **This residual risk is "accepted" or "tolerated" by Japanese society**

Why do we tolerate Residual Risks?

- Because each facility or activity provides benefits

- For individual voluntary activities in which a person feels in control the residual risk may be relatively high (the risk in general aviation is about 1,000 times greater than that in commercial aviation)

- For industrial facilities, it is society through its representatives, government and regulatory agencies, that decides

- Risk-Benefit tradeoffs are rarely quantitative; benefit is much harder to quantify than risk

Managing Uncertainty in Nuclear Safety (1)

- **Traditional "conservative" approach**
  - **A bottom-up approach**
  - **A limited number of potential accidents is considered**
  - **Uncertainty is not quantified**
  - **Unquantified uncertainty is managed by conservatism via defense in depth and safety margins**

- ***Defense-in-Depth* is a safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility.**

- ***Safety Margin*: The imposed stress on a component or structure is maintained well below the onset of damage.**

Major Elements of Defense in Depth

Accident Prevention

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Safety Systems

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Containment

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Accident Management

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Emergency Plans

Managing Uncertainty in Nuclear Safety (2)

- **Probabilistic Risk Assessment**
  - ➢ **A top-down approach**
  - ➢ **Thousands of potential accident sequences are investigated**
  - ➢ **Uncertainty is quantified and managed**
  - ➢ **More realistic depiction of what can go wrong**

- **Probabilistic Risk Assessment (PRA) supports Risk Management by answering the questions:**
  - ➢ **What can go wrong? (thousands of accident sequences or scenarios)**
  - ➢ **How likely are these scenarios?**
  - ➢ **What are their consequences?**

Problems with the Traditional Approach

- There is no guidance as to how much defense in depth is sufficient (unreliable regulations)
- Qualitative approaches are used to ensure system reliability (the single-failure criterion) when more modern quantitative approaches exist
- Human performance is stylized (e.g., operators are assumed to take no action within, for example, 30 minutes of an accident's initiation)
- Difficult to reflect operating experience and modern understanding
- Industry-sponsored PRAs showed a variability in risk of plants that were licensed under the same regulations.

Reactor Safety Study Insights
(WASH-1400; 1975)

Prior Beliefs:

1. Protect against large loss-of-coolant accident (LOCA)
2. Core damage frequency (CDF) is low (about once every 100 million years, 10^{-8} per reactor year)
3. Consequences of accidents would be disastrous

Major Findings

1. Dominant contributors: Small LOCAs and Transients
2. CDF higher than earlier believed (best estimate: $5x10^{-5}$, once every 20,000 years; upper bound: $3x10^{-4}$ per reactor year, once every 3,333 years)
3. Consequences significantly smaller
4. Support systems and operator actions very important

Some Results from a PRA for a GEN II Plant

Core Damage Frequency (CDF): about 5 events per 100,000 years of operation

Initiator Contribution to CDF Total:

- **Internal Events (losses of coolant; transients): 56%**
- **External Events: 44%**
  - **Seismic Events 24%**
  - **Fires 18%**
  - **Other 2%**

Further Results

- Functional Internal-Event Sequences

<u>Contribution to CDF</u>

➢ Transients - Station Blackout/Seal LOCA	45%
➢ Transients - Loss of Support Systems/Seal LOCA	29%
➢ Transients - Loss of Feedwater/Feed & Bleed	12%
➢ LOCA - Injection/Recirculation Failure	7%
➢ ATWS - No Long Term Reactivity Control	6%
➢ ATWS - Reactor Vessel Overpressurization	2%

Regulatory Decision Making

- **Regulatory decision making (like any decision) should be based on the current state of knowledge and should be documented (clear and reliable regulations)**
  - ➢ **The current state of knowledge regarding design, operation, and regulation is key.**
  - ➢ **PRAs do not “predict” the future; they evaluate and assess future possibilities to inform the decision makers’ current state of knowledge.**
  - ➢ **Ignoring the results and insights from PRAs results in decisions not utilizing the complete state of knowledge.**

The Deliberation (NUREG-2150)

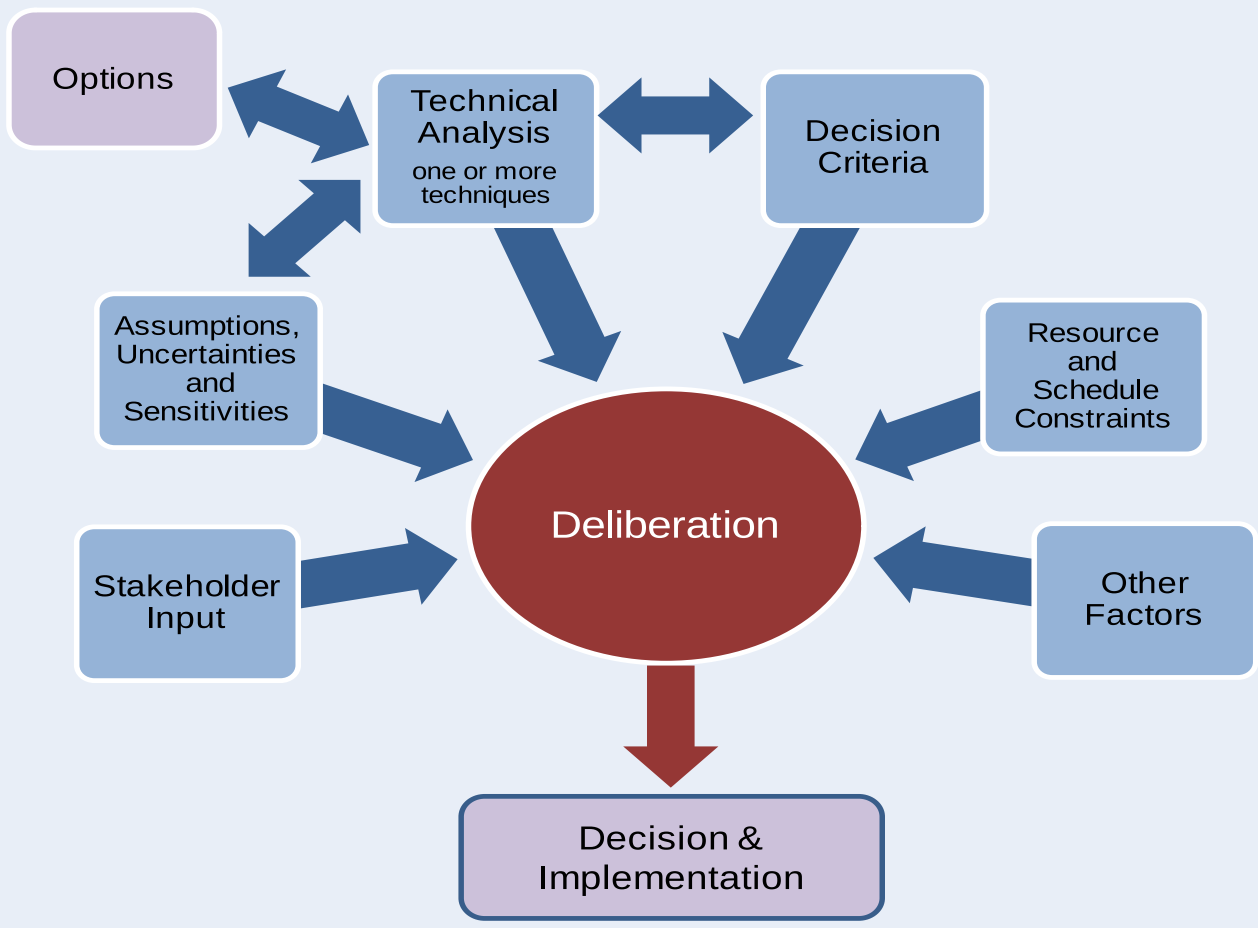

Figure 3-2 Deliberations

U.S. Quantitative Health Objectives, 1986 (Residual Risk Goals)

- **Early and latent cancer mortality risks to an individual living near the plant should not exceed 0.1 percent of the background accident or cancer mortality risk, approximately**

5×10^{-7}/year for early death and

2×10^{-6}/year for death from cancer

- ❖ **The prompt fatality goal applies to an average individual living in the region between the site boundary and 1 mile beyond this boundary.**
- ❖ **The latent cancer fatality goal applies to an average individual living in the region between the site boundary and 10 miles beyond this boundary.**

Risk-Informed Framework

Traditional "Deterministic" Approach

- Unquantified probabilities
- Design-basis accidents
- Defense in depth
- Can impose unnecessary regulatory burden
- Incomplete

Risk-Informed Approach

- Combination of traditional and risk-based approaches through a deliberative process

Risk-Based Approach

- Quantified probabilities
- Thousands of accident sequences
- Realistic
- Incomplete

Risk-informed Regulation

"A risk-informed approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety."

[Commission's White Paper, USNRC, 1999]

Confidence Building

- Industry-sponsored PRAs for Zion and Indian Point NPPs
  - Reviewed extensively by the USNRC
  - Identified the significance of earthquakes and fires
  - Failure modes with easy fixes identified
- Early applications of risk-informed decision making
  - South Texas Project Experience
  - Allowed Outage Times extended from 3 days to 14 days for emergency AC power and 7 days for Essential Cooling Water and Essential Chilled Water systems.
  - Actual experience: Less than 5 days.
- PRA standards

Major Successes

- **Maintenance Rule**
  - Objective - Structures, systems and components (SSCs) important to safety of nuclear power plants shall be maintained so that they will perform their intended function when required.
  - PRA identifies SSCs important to safety
- **Reactor Oversight Process**
  - Regulatory and industry response to “violations” is commensurate to their risk significance
- **Risk-informed In-service Inspection**
  - Focused on risk significant piping segments
  - Reduces cost and man-rem to workers
- **Fire Protection Rule**
  - Realistic assessment of fire risks

Concluding Remarks

- **The question of what is acceptable or tolerable risk cannot be avoided**
- **Decision making regarding reactor safety issues must be based on the totality of available information**
- **Too many people focus on the P of PRA. It's the accident scenarios that provide the most benefit.**
- **Risk insights have been used successfully to focus attention (industry and regulators) on what is important to safety**