RISK INFORMED AND PERFORMANCE BASED INFLUENCES ON REACTOR DESIGN – PAST AND FUTURE

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PAST – FEDERAL LIABILITY CONCERNS

- Very early design recognized the uncertainty associated with accidents at nuclear power plants near population centers – Handled via barrier design and margins associated with those barriers (confinement and DID)
- Price-Anderson Act (1957) was to provide adequate funding in the event of a large nuclear plant accident
- This act prompted the initial evaluation of possible plant consequences in 1957
  - *Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants* (WASH-740)
- Report emphasis was on consequences of accidents, not frequency
- This oriented the industry toward consequence-based design bases, with the large break loss of coolant as the principle design basis accident

PAST – RESISTANCE TO QUANTIFICATION

- With the publication of WASH-740, the value of quantitative methods to assess the safety of nuclear power plants was advocated by many
- Introduction of new thinking – Probabilistic (evidence) versus Deterministic (rules)
- However, the latter was more familiar to design and utility personnel so resistance to PRA use remained firm, largely due to a lack of confidence in the technical ability to quantitatively evaluate the safety of large and complex facilities
- But the questions continued to be posed regarding the lack of a true assessment of reactor safety
- The next milestone was the *Reactor Safety Study: An Assessment of Accident Risks in U.S. Nuclear Power Plants* (WASH-1400) in 1975
- This was the first credible evaluation of the <u>risk</u> associated with use of nuclear powered generation of electricity

PAST – WASH-1400 AND TMI

- The WASH-1400 study challenged the existing mindset of consequence-based design
  - Placed the large break loss of coolant in a risk context with other potential hazards and associated consequences - not a major contributor to risk
  - More risk importance demonstrated for transients, small loss of coolants events, and human error
- Although it addressed the issue of measuring the true risk of nuclear power, attitudes toward it this revolutionary technology remained at “arms-length”
- This changed with TMI in 1979 where the series of events and failures leading to core damage was reflected in the WASH-1400 results

PAST – PUBLIC RISK

- The TMI accident, coupled with NRC siting study based on WASH-1400 results, raised concerns regarding the safety of nuclear power plants near population centers. Two plants stood out:
    - Zion (1981) near Chicago
    - Indian Point (1982) near New York City
- Evaluated using "full-scope" probabilistic risk assessments which demonstrated
    - Traced previous Oyster Creek PRA process (first utility-sponsored Level 3 PRA)
    - Proposed severe accident back-fits for these reactors had negligible impact on the overall risk of the plants to the public
    - Several low-cost changes to the plants were identified that, if implemented, would have a positive influence on plant risk
- With the publication of these studies, the use of PRA proved its value to quantitatively evaluate plant risks as well as design improvements that improve risk

PAST – RAPID EXPANSION

- The nexus created by WASH-1400, the TMI accident, and the Zion/Indian Point PRAs resulted in expansion of PRA in the nuclear power
  - ACRS Safety Goals/NRC Safety Goals Policy Statement
  - NUREG-1150 Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants
  - US (Seabrook, Browns Ferry), UK (Sizewell B), Canada (CANDU)
  - 10 CFR Part 52 – Requirement for new reactors to provide a PRA as part of licensing

Risk Management

- All these programs focused risk and vulnerabilities in safety design of existing large light water reactor designs

RISK MANAGEMENT

- Maximizes the value of risk and performance information
- Permits all potential hazards to be evaluated in a structured, integrated, and repeatable framework
  - During a seismic evaluation at a commercial plant, a physical interaction between adjacent buildings had the potential to collapse the control building. When coupled through the PRA with other potential earthquake effects (e.g., loss of offsite power), this interaction cascaded to a significant contributor to core damage. This scenario was mitigated with a relatively inexpensive structural modification.
  - During the external event evaluation at a research reactor, the building housing the off-site power switchgear and the on-site diesel generators was found vulnerable to high wind. The emergency cooling function for this reactor relies on DC-powered motors to maintain forced flow. Loss of the switchgear building meant battery charging capability was lost. Portable diesel generators were purchased and located offsite as emergency auxiliary power sources.

RISK MANAGEMENT

- Integrates all hazards and resulting consequences onto a "level playing field" allowing competent decisions to manage the various contributors to risk

At a proposed commercial plant, PRA methods were used as part of the design process

System(s) or Operator Action	Percent Reduction in Core Damage Frequency if the Individual System (or Operator Action) Failure Frequency Could Be Reduced to Zero			
	First Iteration	Second Iteration	Third Iteration	Fourth Iteration
1. Electric Power	11	65	43	52
2. Auxiliary Feedwater	9	11	11	31
3. Two Trains of Electric Power Recovered				21
4. Low Pressure Injection / Decay Heat Removal	4	3	8	19
5. Failure to Reclose PORV / PSVs		5	20	17
6. ESFAS / ECCAS			14	15
7. High Pressure Injection Systems	3	9	15	14
8. Operator Recovery of Electric Power During Station Blackout		50	14	14
9. Sump Recirculation Water Source				11
10. Component Cooling Water			3	8
11. Throttle HPI Flow (Operator Action)			1	4
12. Failure of Main Steam Safety Valve to Reclose			1	4
13. Service Water	32	<1	10	4
14. Safeguards Chilled Water	20	8	13	1
15. BWST Suction Valve				1
16. Containment Isolation			1	
Relative Core Melt Frequency	1.00	0.30	0.10	0.06

RISK MANAGEMENT

- Reveals hidden risks in what seems obvious
  - Safety design free from common cause failure would indicate a strategy of complete separation of important safety trains. However, the evaluation of a proposed design found while such a design philosophy protected from rare events, it actually reduced safety as it removed the potential for cross connections of one train to bypass failed equipment in the other, the latter being a more likely situation.
  - At a research reactor, vessel nozzle embrittlement was of significant concern. Modifications were made to ensure primary pressure relief in the event of low primary temperature to mitigate this concern. However, the results of the PRA revealed this particular design resulted in the creation of a potential loss of coolant accident that was much more significant to risk than the original design preventing a vessel embrittlement challenge. The system was redesigned to give priority to mitigation of the loss of coolant event.

RISK MANAGEMENT

- Performance-based aspects of risk management
  - “Performance” relies on measurable outcomes to determine acceptability of system performance when compared to established criteria for acceptance.
  - Performance metrics may be implemented under a deterministic design process such as valve closure speeds, pump pressures, or HVAC flows.
  - When introduced in a risk management process, the metrics of performance may be directly associated with the risk results, such as establish minimum reliability performance for important systems.
  - Risk informed, performance based have been present in the nuclear power industry since 1991 through the Maintenance Rule (10CFR50.65)

RISK MANAGEMENT

- Uncertainty is a direct input to the risk management decision process
  - Because our knowledge is never perfect, decisions made without consideration of uncertainty will be flawed
  - This is core to Risk-Informed vs Risk-Based (latter being more problematic due to reality of uncertainty)
  - Deterministic margin used as surrogate to uncertainty
  - Much more powerful in risk management decisions to specifically address uncertainty instead of handling through surrogates
  - Using “probability of frequency” allows uncertainty to be addressed for any topic where the degree of available knowledge has bearing on the evaluation of options and decisions

Statistics is the science of handling data; probability is the science of handling the lack of data.

Stan Kaplan

RISK MANAGEMENT

- Application to advanced reactors
  - New reactor technologies do not fit neatly in existing power reactor regulatory framework
  - Cross-cutting technology-neutral framework standards under development and to be extended with technology-specific standards
  - Applications of risk-informed and performance-based mindset
    - Scenario-based PRA analysis provides information on both failures (risk contributions) and successes (risk mitigations)
    - Uncertainty of technology and research is part of design options evaluation
    - The engineering discipline of Systems Engineering is endorsed
    - Defense in depth is evaluated in a performance metric framework

CONCLUSIONS

- A formal PRA evaluation is not necessary to achieve significance risk management information
- Uncertainty is essential to an risk management design process that is efficient and minimizes design rework
- Discussions on “how safe is safe enough” are enabled by quantification of defense in depth using risk informed and performance based metrics (including uncertainty)
- Balance/Blended deterministic and risk thinking is the goal of an efficient and effective design process