State-of-the-Art Reactor Consequence Analyses (SOARCA)

October 6, 2010

Outline

- Background
- Objectives
- Approach
- Scenario Selection
- ACRS
- Mitigation
- Results
- Conclusions
- Peer Review
- Post Peer Review
- Uncertainty Study
- Risk Communication

J/9

Background

- Security assessments of reactor events indicated that radiological releases for scenarios representative of "typical and important severe accident scenarios" are delayed and smaller than that assumed in past safety/consequence studies (1982 Siting Study)
- Offsite health consequences predicted for security assessments were substantially smaller than 1982 Siting Study values
- Security assessments used our most advanced, integrated MELCOR code modeling of the plant. Phenomenological modeling based on extensive severe accident research. No substantial intentional bias towards conservatism.
  - Offsite consequences predicted using MACCS code

Background

- In 2005 timeframe Commission expressed interest in updating earlier published studies of offsite consequences of nuclear plant accidents based on insights from RES security assessments
  - Older reactor studies such as NUREG/CR-2239 (aka 1982 Sandia Siting Study)
  - More recent but out of date spent fuel pool studies such as NUREG/CR-6451 (1997) and NUREG-1738 (2001)
  - Earlier studies were believed to be excessively conservative in their technical assumptions and treatment
  - Earlier studies were used/misused by others to suggest risk associated with severe accidents was extremely large

Background

- Staff developed plan for State-of-the-Art Reactor Consequence Analyses, SECY 05-0233
  - Plan addressed all operating reactors using radiological source terms for 8 reactor/containment designs
    - Focus on the more likely, risk important scenarios. Realistic, best estimate analysis of accident progression, radiological source terms and offsite consequences.
    - Include all plant improvements/updates (e.g., EOPs, SAMGs, 10CFR50.44(hh))
    - More detailed site specific realistic EP (evacuation)
    - Alternate treatments of low dose effects. (LNT and dose threshold models)
  - Study of additional mitigation measures
  - Development of a computer model for accident progression and source term analysis for the NRC operations center

Official Use Only

5

Background

- Project anticipated and identified need for uncertainty analysis – separate but closely related study
- Project was coordinated among relevant NRC offices, technical review team composed of members from RES, NSIR, NRR, NRO.
- Senior management guidance through Steering Committee for policy related issues, risk communication
- Early public notice with feedback, RIC mtgs
- ACRS review
- Independent peer review

Official Use Only

6

Background

Early feedback and reviews

- Commission
  - Focus initially on 2 pilot plants , effective risk communication, current mitigation capabilities including security related enhancements
  - SRM April 14, 2006 approving plan
  - SRM April 2, 2007 limiting scope (to not more than 8 plants) and providing additional guidance
- ACRS
  - Concern over frequency truncation and adequacy of scenarios selected versus traditional PRA approach
    - Full scope PRA
  - Seismic initiators and EP treatment
  - Extremely large seismic events (SBO+LOCA + Containment failure)
- Other
  - Risk metric vs consequences

SOARCA Objective

- To develop a body of knowledge on the realistic outcomes of severe reactor accidents for 2 pilot plants
  - Incorporate plant improvements not reflected in earlier assessments (hardware, procedures, security related enhancements, emergency planning)
  - Incorporate state of the art modeling
  - Evaluate the benefits of recent improvements -10 CFR50.54(hh)
  - Enable the NRC to communicate severe accident aspects of nuclear safety to diverse stakeholders
  - Update the quantification of offsite consequences found in earlier publications such as NUREG/CR-2239 (1982 Siting Study)

Approach

- 4 technical elements of the study - scenario selection, mitigation measures, accident progression and radiological source terms, offsite consequences
- Study has adopted new approaches in many areas
  - Focus on "important" scenarios (CDF>10^{-6} /RY, 10^{-7} for bypass)
  - Realistic assessments and detailed analyses versus simplified and conservative treatments used in past PRA
  - Integrated, self consistent analyses
  - Incorporated recent phenomenological research
    - IRSN, PSI, NUPEC
  - Treatment of seismic impacts on EP
  - Range of health effects modeling (non LNT latent cancer modeling)

Scenario Selection

- Approach
  - Focus on scenarios that are important to risk
  - Internal events
    - SPAR (level 1 PRA model) used to identify and quantify sequences
    - Confirmed and supplemented by comparisons with latest licensee PRAs
  - External events
    - NUREG-1150 used, supplemented by judgment from IPEEE and subsequent work

Scenarios – Peach Bottom

Scenario	Initiating event	Core damage frequency (per year)	Description of scenario
Long-term SBO (0.3 – 0.5g)	Seismic, fire, flooding	$3x10^{-6}$	Immediate loss of AC power and eventual loss of control of turbine driven systems due to battery exhaustion
Short-term SBO* (0.5 – 1.0g)	Seismic, fire, flooding	$3x10^{-7}$	Immediate loss of ac power and turbine driven systems (due to immediate loss of DC power)
Short term SBO w/ RCIC blackstart	Seismic, fire , flooding	$3x10^{-7}$	Immediate loss of ac and dc power, operators manually start RCIC (according to RCIC blackstart procedure)

* Below the screening criterion
Internal events $<10^{-6}$ and LOCA scenarios much lower
Bypass events are of very low frequency $<<10^{-7}$

11

Official Use Only

Scenarios – Surry

Scenario	Initiating event	Core damage frequency (per year)	Description of scenario
Long-term SBO (0.3 – 0.5g)	Seismic, fire, flooding	$2x10^{-5}$	Immediate loss of ac power, eventual loss of control of turbine-driven systems due to battery exhaustion
Short-term SBO (0.5 – 1.0g)	Seismic, fire, flooding	$2x10^{-6}$	Immediate loss of ac power and turbine-driven systems (due to failure of ECST)
Thermally induced steam generator tube rupture	Seismic, fire, flooding	$4x10^{-7}$	Immediate loss of ac power and turbine-driven systems, consequential tube rupture
Interfacing systems LOCA*	Random failure of 2 check valves	$3x10^{-8}$	Check valves in high-pressure system fail open causing low pressure piping outside containment to rupture, followed by operator error (to switchover/refill RWST)

* Below screening criterion

Official Use Only

12

ACRS Issues – Screening Criteria

- Letter dated February 22, 2008
- Concern over use of screening criteria
  - A priori CDF screening criteria can overlook many risk significant scenarios
  - Number of sequences and their aggregate contribution can increase at lower frequency
  - Does not provide a fully integrated evaluation of [total] risk
  - Level 3 PRAs should be performed
- In theory, concerns are reasonable, in practice, of lesser concern
  - Known designs with previous and current PRA
  - Potential vulnerabilities have long been identified – **what is needed is better and more rigorous and scrutable quantification of accident progression, radiological source term and offsite consequences**
  - SOARCA analyzes significant risk contributors (by comparison to NUREG-1150), not intended to capture total risk – not demonstrably true for existing PRA (e.g., security)

ACRS Issues – Screening Criteria

- ACRS comment on screening criteria does not reflect current imbalance between characterization of lower frequency internal events scenarios versus external events – what is an 10^{-8} (or lower) external event?
- SOARCA has indicated need for better external events PRA, especially seismic PRA
  - Dual unit SPAR models
  - Mechanistic fragility modeling
- Internal event LOCA scenarios were comfortably below the screening criteria
- Station blackout is a bounding surrogate for many transients
  - SOARCA added short term SBO to Peach Bottom analysis in response to ACRS concern (included originally for Surry)

ACRS Issues – Seismic Events

- ACRS commented that scenarios did not include a very large earthquake (>1.0 g) resulting in SBO + LOCA + Containment failure
  - Deferred to future evaluation – many technical issues requiring research
  - Requires assessment of non-nuclear risk

- ACRS concern that seismic events considered in SOARCA need to be addressed more comprehensively with consideration of impact on mitigation and EP
  - SOARCA project agrees – consistent, technically sound examination demands consideration of various seismic impacts
  - Mitigation measures assessment has factored in seismic impacts
  - EP modeling did not originally consider seismic impacts which may hinder EP implementation/execution
  - EP modeling has been extended based on assessment of seismic impact on EP infrastructure (communications, road network etc)

Mitigation Measures

- Early in the project (May 2007), staff visited Peach Bottom and Surry

- Conducted table-top exercises for each scenario
  - Participants included plant SROs and PRA analysts
  - NRC provided initial and boundary conditions and elicited how plant staff would respond

- Developed timeline of operator actions
  - Includes all mitigation measures
    - Emergency Operations Procedures
    - Severe Accident Management Guidelines
    - 10 CFR 50.44 (hh) measures
    - Technical Support Center

- Staff concluded scenarios could reasonably be mitigated - resulting in prevention of core damage or delaying or reducing radiation release

10 CFR 50.54(hh) Measures

- Major effort by industry and NRC (2004 – 2008) to develop means to mitigate events involving loss of large areas of the plant due to fire and explosions
- Resulting requirements codified in 10 CFR 50.54(hh)
- New and diverse mitigation
  - Procedures for manually operating turbine-driven injection (RCIC, TD-AFW)
  - Portable diesel-driven pumps for injecting into RCS (BWR) and steam generators (PWR)
  - Alternative means to depressurize
  - Portable power supplies for critical indication

Mitigation Measures – Peach Bottom

Scenario	Mitigation		Result
	EOP/SAMG	10CFR50.54(hh)	
Long-term SBO (0.3 to 0.5 g)	Control RCIC and open SRV	1. Manual RCIC operation (black-run) 2. Portable diesel-driven pump (alternative, not needed)	No core damage
Short-term SBO (0.5 to 1.0 g)	Black-start RCIC	1. Manual RCIC operation (black-run) 2. Portable diesel-driven pump (alternative, not needed)	No core damage
Loss of vital AC bus E12	*Control RCIC and open SRV*	*Not needed, because CRDHS is operating.*	*No core damage*

Mitigation Measures – Surry

Scenario	Mitigation Measures		Result
	EOP/SAMG	10CFR50.54(hh)	
Long-term SBO (0.3 to 0.5 g)	Control TDAFW and initiate secondary cooldown	1. Manual TDAFW operation and primary injection with high-head portable diesel-driven pump 2. Low-head portable diesel-driven pump (alternative, not needed)	No core damage
Short-term SBO (0.5 to 1.0 g)	None	Containment spray at 8 hrs using low-head portable diesel- driven pump	Delay containment failure, reduce release
Short-term SBO with TISGTR (0.5 to 1.0 g)	None	Containment spray at 8 hrs using low-head portable diesel- driven pump	Delay containment failure, reduce release
ISLOCA	TSC, ample time	Not needed	No core damage
Spontaneous SGTR	TSC, ample time	Not needed	No core damage

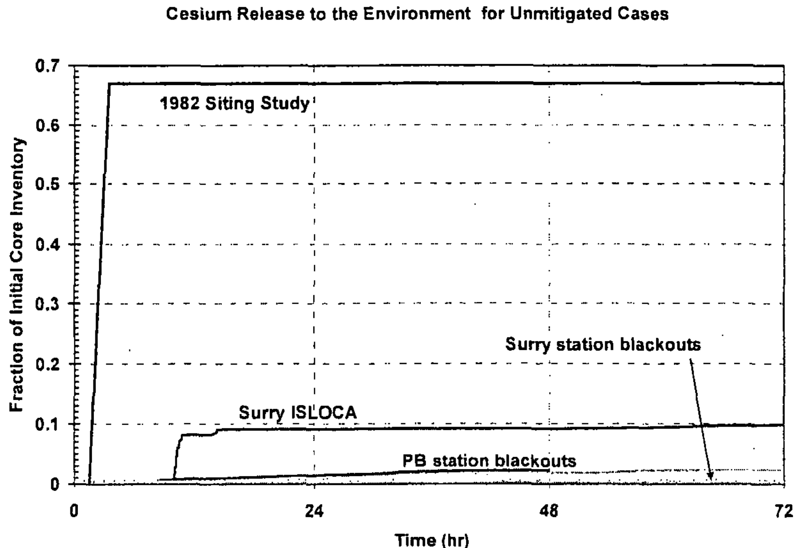
Official Use Only 19

Mitigation Measures

- Assessment of mitigation measures has received comment during the project
  - ACRS, SRA
  - Lack of quantitative HRA
  - However, procedures and training were inspected as part of security assessments with site specific evaluations prepared
- Follow-up site visits in June/August 2010 to explicitly address RCIC blackstart and run for STSBO and manual operation of TD-AFW, and to discuss fact check comments.
  - RCIC procedures
  - Conservatism in assumed PWR STSBO timeline (2hrs – 8hrs)
  - Walkdown and detailed review of procedures
- Staff concluded, following recent site visits, a greater likelihood of implementing mitigation

Official Use Only 20

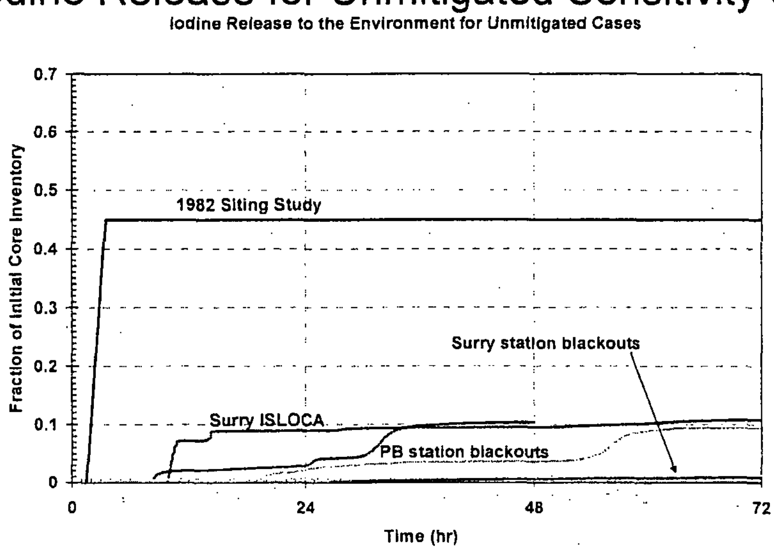
Cesium Release for Unmitigated Sensitivity Cases



Official Use Only

21

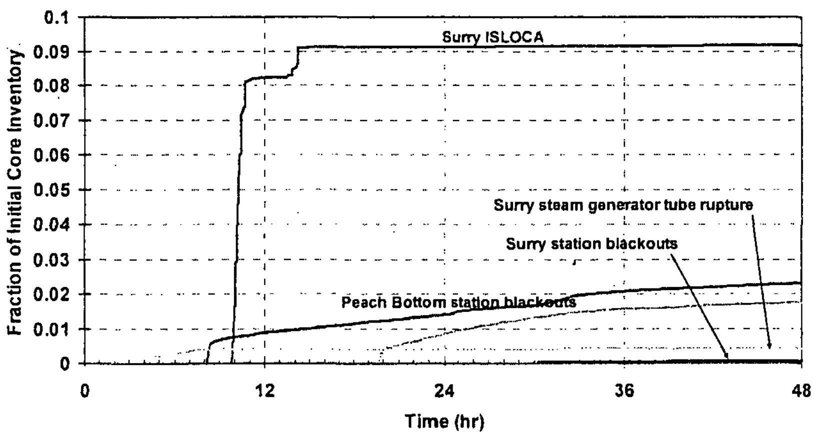
Iodine Release for Unmitigated Sensitivity Cases



Official Use Only

22

Cesium Release for Unmitigated Sensitivity Cases



Official Use Only

23

Key Accident Progression Timing Peach Bottom

Scenario	Time to start of core damage (hours)	Time to lower head failure (hours)	Time to start of release to environment (hours)	Evacuation start time (hrs)
Long-term SBO	10	20	20	2 ½ GE@ 45 min
Short-term SBO w/o RCIC blackstart	1	8	8	2 GE@ 15 min
Short term SBO w/RCIC blackstart -10 min	5	13	13	2
Short term SBO w/ RCIC blackstart -1hr	8*	17	17	2

Official Use Only

24

Key Accident Progression Timing for Unmitigated Sensitivity Cases – Surry

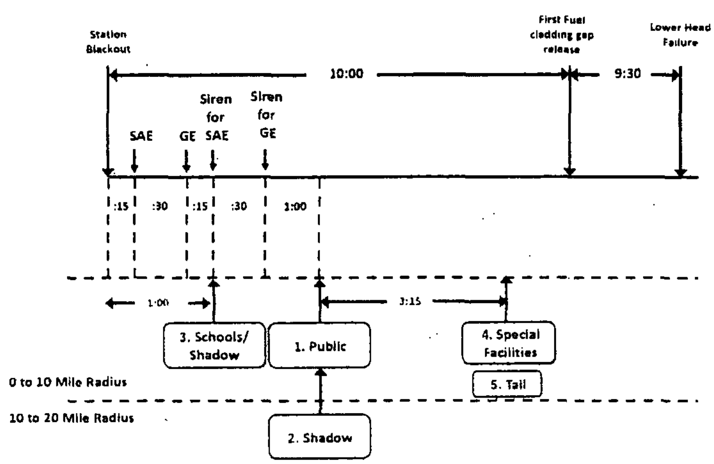
Scenario	Time to start of core damage (hours)	Time to lower head failure (hours)	Time to start of release to environment (hours)	Evacuation start time (hours)
Long-term SBO	16	21	45	3 ¾ GE@ 2
Short-term SBO	3	7	25	3 ¾
Thermally induced steam generator tube rupture	3	7 ½	3 ½	3 ¾
Interfacing systems LOCA	9	15	10	3

Official Use Only

25

Peach Bottom

Unmitigated LTSBO Emergency Response Timeline

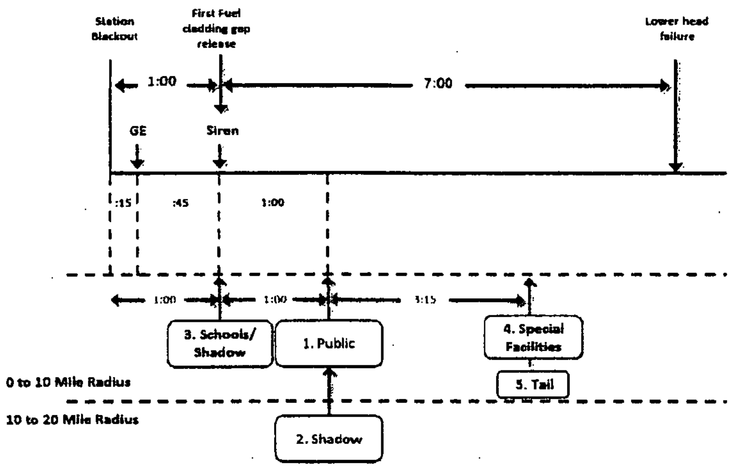


Official Use Only

26

Peach Bottom

STSBO without RCIC Blackstart
Emergency Response Timeline

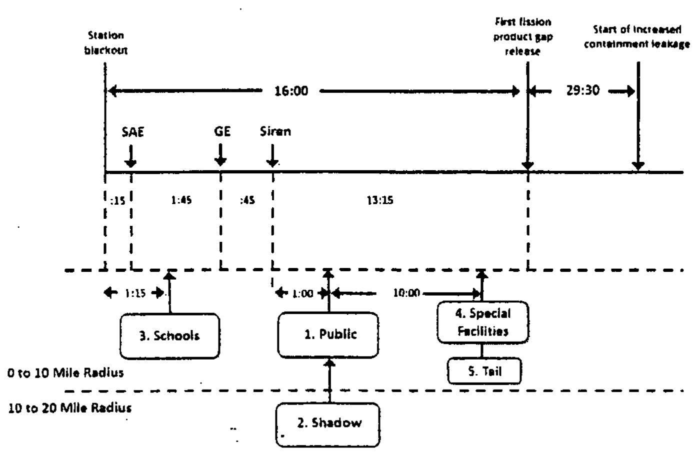


Official Use Only

27

Surry

Unmitigated LTSBO Emergency Response Timeline



Official Use Only

28

Offsite Consequences

- More detailed modeling of plume release and azimuthal sectors
- Scenario specific Emergency Action Levels based on site procedures for Site Area Emergency and General Emergency
- Detailed evacuation and relocation modeling
  - Reflect ETEs and road networks at Surry and Peach Bottom
  - Treatment of multiple population groups
- Site-specific population and weather data

Official Use Only

29

Offsite Consequences (cont)

- Range of truncation dose rates for latent cancer fatality prediction
  - SRM approved staff's recommendation to use LNT and 10 mrem/year
  - Also performed sensitivities at background (620 mrem/year) and HPS position paper (5 rem/year with a 10 rem lifetime cap)
- Sensitivities
  - Potential evacuation impacts from earthquake (ACRS)
    - Loss of bridges, traffic signals, delay in notification
  - Potential evacuation of areas outside of EPZ

Official Use Only

30

Offsite Consequences Peach Bottom – Unmitigated Cases

Scenario	CDF per R-Y	LNT – Conditional Individual LCF risk (0 -10 miles)	LNT – Individual LCF risk per R-Y* (0 -10 miles)
Long Term SBO	3×10^{-6}	2×10^{-4}	6×10^{-10}
Short Term SBO w/o RCIC blackstart	3×10^{-7}	2×10^{-4}	7×10^{-11}
Short Term SBO w/ RCIC blackstart @ 10 min	3×10^{-7}	2×10^{-4}	7×10^{-11}

*U.S. average individual risk of a cancer fatality: 2×10^{-3} / year

Official Use Only

31

Offsite Consequences Surry – Unmitigated Cases

Scenario	CDF per R-Y	LNT – Conditional Individual LCF risk (0 -10 miles)	LNT - Individual LCF risk per R-Y (0 -10 miles)*
LTSBO	2×10^{-5}	5×10^{-5}	7×10^{-10}
STSBO	2×10^{-6}	9×10^{-5}	1×10^{-10}
STSBO / TISGTR	4×10^{-7}	3×10^{-4}	1×10^{-10}
ISLOCA	3×10^{-8}	8×10^{-4}	2×10^{-11}

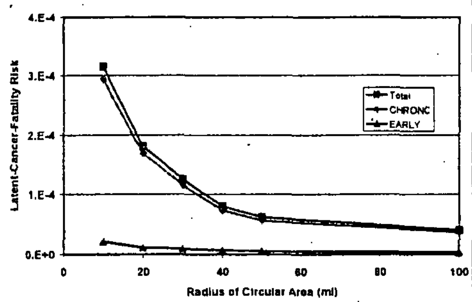
*U.S. average individual risk of a cancer fatality: 2×10^{-3} / year

Official Use Only

32

Conditional, Mean, LNT, LCF Risks by Phase for Unmitigated STSBO with TISGTR (CDF = $4 \cdot 10^{-7}$/yr)

- Emergency phase (EARLY)
  - Risks diminish monotonically with radius.
- Long-term phase (CHRONC)
  - Risks are controlled by habitability criterion (4 rem in 5 yr)
  - Risks diminish monotonically with radius
- Total risk is dominated by long-term phase.



Conclusions

- Mitigation is likely. Implementation of mitigation measures will either prevent core damage, or delay or reduce radiation release. Confirmation of benefit with MELCOR analysis.
  - PRA needs to address mitigation in a more realistic fashion (e.g., HRA)
  - Major new insights on level 1 CDF contributors (CRD, SGTR)
  - Major new insights on level 2/3 contributors (SBO-TISGTR, ISLOCA)
  - Insight on EALs revealed
- For cases assumed to proceed to radiological release:
  - Accidents progress more slowly and result in smaller and delayed radiological releases than previously assumed/predicted
  - Because fission product releases are delayed and substantially smaller, offsite consequences are smaller than previously predicted
  - Individual early fatality risk is essentially zero; No LERF Contributors

Conclusions (cont)

- Individual latent cancer fatality risk within the EPZ is very low
  - Thousands of times lower than the NRC safety goal and millions of times lower than other cancer risks (assuming LNT)
  - Generally dominated by long term exposure to small annual doses (return criteria and LNT)
  - Non LNT models predict risk is even lower (factor of 3 – 100)
- Bypass events do not pose higher risk
- Explicit consideration of seismic impacts on EP had no significant impact on predicted risk
- Dominance of external events suggests need for PRA focus and seismic research

Official Use Only

35

Peer Review

- Assess SOARCA approach, methods, results and conclusions to ensure study is best estimate and technically sound
- Broad array of content experts, series of meetings, draft documents
  - Last mtg on 3/2/10
  - Comments have been received in all major technical areas
- Major areas of uncertainty for peer review have been addressed by sensitivity studies and/or text
  - Severe accident modeling
  - EP
  - Health effects due to low doses
- Individual draft peer reviewer letter reports received May

Official Use Only

36

Peer Review

- In general, the findings of the peer reviewers (with one exception) were quite positive with respect to the project meeting its stated objectives.
  - E.g. "*The SOARCA has evaluated the scenarios which are the major contributors to risk.*", "*...SOARCA accident progression analysis represents an advancement of the state-of-the-art in severe accident analyses.*"
- Six (out of 9) peer reviewers offered the recommendation for extension of SOARCA level analysis to different NPP types with different containment designs and further noted a preference for such analysis over a full scope level 3 PRA
  - Noted more generic insights from SOARCA type analyses
  - Provides a mechanism for establishing acceptance criteria for analytical methods, re: severe accident modeling

Official Use Only

37

Post Peer Review

- Large effort devoted to resolving internal staff comments and revising/updating documentation
  - Likelihood of mitigation
  - Comparison with and characterization of past studies
  - Characterization of SOARCA findings
- Subsequent to last peer review mtg, updates to analyses identified, and initiated
  - Refinement of best estimate (BWR - SRV failure)
  - Addition of new BWR cases with RCIC blackstart – follow-up to fact check, plant walk-down (June 2010)
  - Error discovered (upon further examination of peer review comment) (PWR – hydrogen combustion)
  - Fact check review (PWR – ECST failure) (PWR – ISLOCA radiation release pathway/deposition)

Official Use Only

38

Post Peer Review - BWR issues

- BWR offsite consequence analyses need to be revised to address new (more realistic) SRV failure model – not likely to alter findings (revised radiological releases are smaller)
  - New and additional sensitivity analyses strengthen previous argument and provide additional insight to uncertainty study
- BWR offsite consequence analyses need to be added to address 1 hr RCIC blackstart for STSBO – more realistic.(confirmed by fact check)
  - New analyses likely to yield lower consequences, radiological releases are smaller, more delayed than case with 10 min RCIC blackstart
  - Likelihood of no RCIC blackstart case judged to be smaller as a result of recent plant walkdown

Post Peer Review – PWR hydrogen issue

- Mitigation by the use of PWR containment sprays during a severe accident has been a longstanding concern in SAMGs, particularly for SBO events - caution because of increased potential for sprays to create a highly combustible mixture
- In examining sensitivity cases of mitigated STSBO run to address peer review comments, error was discovered in hydrogen combustion info presented to peer review committee. Further analysis performed.
  - Combustion of hydrogen may lead to increased leakage
  - Possibility of detonation (judged small)
  - Conservative sensitivity studies do not result in larger releases but do lead to higher potential for earlier containment failure
- Further examination of SAMG guidelines raises doubt whether this mitigation may be taken as assumed in SOARCA

Post Peer Review – PWR Fact check

- Fact check revealed 2 issues
  - Recent site specific seismic study for Surry indicated vulnerability of ECST for 0.4 g earthquake, (currently credited in LTSBO)
  - Pathway of radiation release for ISLOCA has been altered by the use of fire barrier foam (blocking passageway between Safeguards bldg and Auxiliary bldg). Confirmed during recent walkdown.
- Additional analyses underway, clarification sought from Surry on additional strategies
  - ECMT is highly robust and would be used as source of water
  - Diesel driven pump connection to fire water piping
  - Alternative pathways for radiation release
  - Awaiting feedback from licensee

Uncertainty Study

- Proper emphasis on more realistic analyses also draws attention to the need to characterize uncertainty
- Uncertainty in level 3 PRA has traditionally considered uncertainty in offsite consequences due to weather.
- The detailed, integrated accident progression, source term and offsite consequence analyses should be accompanied by a similarly detailed, integrated consideration of uncertainty in modeling.
  - Perception of uncertainty, in part, drives the need
  - Parameter uncertainty
  - Elements of epistemic and aleatory uncertainty
- Demonstration of integrated uncertainty study to be performed for a suitable candidate scenario. Methodology, parameter list and distributions to be peer reviewed. Primary focus on confirmation of relationship of "best estimate" to the mean value of uncertainty study.

Risk Communication

- Major element of project reflecting Commission interest
- Latest risk communication principles for a diverse audience
- Communication Plan and Information Booklet developed by communications specialists in OPA, EDO, RES (with technical content expert input from all Offices)
- Tested with Region IV staff
- Additional tools
  - Website
  - Press releases/briefing
  - Public mtgs