Risk-Informing 10 CFR 50.46 and Large-Break LOCA DBA Status Briefing

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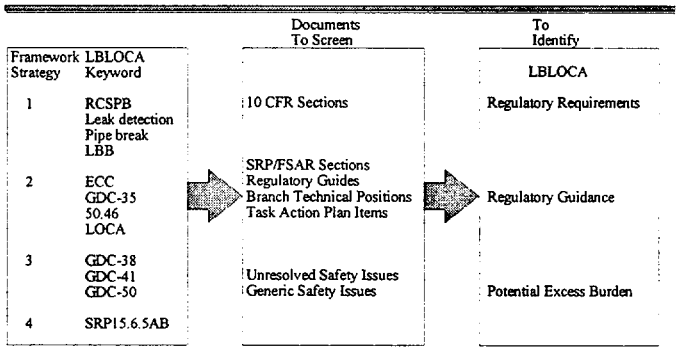
Development of Risk-Informed Options Based on Current Requirements

Identifying Existing LBLOCA Regulatory Requirements - Scope

- Requirements related to the terms
  - LOCA and ECC
  - as used in GDC- 35 and 10 CFR 50.46
- CFR requirements as opposed to regulatory guidance
- Primary requirements as opposed to cross references from other parts (e.g., Part 44)
- Specifically looking for existing requirements related to each of the four high-level defense-in-depth strategies
- Current list is preliminary

Identifying Existing LBLOCA Regulatory Requirements - Process



LBLOCA Requirements from Existing Regulations (Preliminary List)

Strategy 1 - Prevent Initiators

- 50.46(a)(1)(i) - Postulate spectrum of breaks
- GDC-14 - RCPB design, fabrication, erection, testing
- GDC-30 - RCPB quality
- GDC-31 - RCPB fracture prevention
- GDC-32 - RCPB inspection
- GDC-35 - RCPB leak detection

LBLOCA Requirements from Existing Regulations (Preliminary List)

Strategy 2 - Prevent core damage given initiator

- GDC-35 - Onsite or offsite electric power
- GDC-17 - System, component start times
- GDC-35 - Single failure criterion
- RG 1.124* - Equipment classification & seismic design
- GDC-35 - Abundant ECC capacity
- GDC-27 - Reactivity control
- GDC-35 - ECCS interfaces
- GDC-4 - Dynamic effects
- GDC-5 - Sharing

*Regulatory guidance

LBLOCA Requirements from Existing Regulations (Preliminary List)

Strategy 2 - Prevent Core Damage Given Initiator

- 50.46(a) - ECC Evaluation Model
  - Realistic with uncertainties quantified
  - Or Appendix K
  - Report significant changes or errors
- 50.46(b) - ECC Acceptance Criteria
  - Peak cladding T < 2200°F
  - Local oxidation < 17%
  - Global oxidation < 1%
  - Coolable geometry
  - Long term cooling
- GDC-36 - Inspection of ECCS
- GDC-37 - Testing of ECCS

LBLOCA Requirements from Existing Regulations (Preliminary List)

Strategy 3 - Contain radionuclides given core damage

- GDC-17, 35, 50 - Containment must "accomodate without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss of coolant accident."
- GDC-17, 35, 38, RG 1.52* - Containment heat removal
- GDC-17, 35, 41 - Containment atmospheric cleanup

*Regulatory guidance

LBLOCA Requirements from Existing Regulations (Preliminary List)

Strategy 4 - Protect public given core damage

- SRP 15.6.5* - Limit offsite doses to 10 CFR 100 guidelines
  - 300 rem thyroid
  - 25 rem whole body
  - 10 CFR 100 refers to "major accident hypothesized for purposes of site analysis or from considerations of possible accident events that would result in potential hazards not exceeded by those from any accident considered credible. Such accidents have generally been assumed to result in substantial meltdown of the core with subsequent release of appreciable quantities of fission products."
- Appendix E - Transmit ECC parameters via ERDS

*Regulatory guidance

LBLOCA Different Ways to Risk Inform

- Change Evaluation Models or Methods
  - Relax Appendix K conservatisms
    - Use current ANS decay-heat standard
    - Replace Baker-Just oxidation model
    - Etc.
    - Revised models would have to be approved
  - Make best-estimate analysis with uncertainty propagation less burdensome
    - Hybrid approaches (e.g. SECY-83-472)
    - Automate audit analyses
    - Use more efficient uncertainty analysis schemes
  - Treat break size and location probabilistically (propagate this uncertainty with others)

LBLOCA Different Ways to Risk Inform

- Change Acceptance Criteria
  - Replace high-temperature and oxidation limits with embrittlement criterion (Note: high-burnup fuel has more pre-existing oxidation)
  - Permit more core degredation but require containment integrity and long-term cooling
    - Perhaps require no molten relocation of core materials
    - But debris in recirculating coolant should not compromise long-term cooling

LBLOCA Different Ways to Risk Inform

- Change Design-basis Events
  - Relax simultaneous failure assumptions
    - Double-ended large break
    - Loss of offsite power
    - Failure of one emergency AC power train
  - Eliminate
    - Very large breaks as design-basis initiators for ECC
    - All large breaks as design-basis initiators for ECC
    - LBLOCA as DBA (ECC, containment, dynamic effects, etc.)
      - Framework currently implies frequency would have to be demonstrably less than 1e-6/yr
  - Risk-based definitions of AOOs and DBAs
    - Much broader scope than LBLOCA
    - Will consider for risk- informing single-failure criterion

LBLOCA
Why Consider So Many Ways?

- Some changes may prove generally applicable
  - Permits eliminating or replacing an existing requirement versus providing a risk-informed alternative
  - For example, relaxing conservative Appendix K assumptions
  - Plant-specific PRA not required
- Provide comprehensive justification for ultimately recommended approach
- Plant-type or plant-specific considerations may preclude eliminating all large breaks as design-basis initiators
  - Large break frequencies greater for BWRs
  - Design basis for new-plant ECC and Containment?

LBLOCA
Requirement Impact Matrix (Attachment A)

- Rows are existing LBLOCA regulatory requirements
- One column for each of eight indicated ways of risk informing LBLOCA requirements
- Table indicates the requirements potentially impacted for each of the 8 approaches
- Number of requirements to be risk-informed is much greater if LBLOCA is eliminated as a design-basis event for ECC and possibly containment

LBLOCA
Burden Impact Matrix (Attachment B)

- Rows are potential benefits of risk-informing (most suggested by Westinghouse Owner's Group)
- One column for each of eight indicated ways of risk informing existing LBLOCA requirements
- Table indicates the burdens potentially reduced for each of the 8 approaches
- Potential burden reduction is much greater if LBLOCA is eliminated as a design-basis accident for ECC and possibly containment

Development of Risk-Informed Options Based on the Defense-in-Depth Strategies

LBLOCA
Relevant History

- Earliest commercial reactors
  - Containment designed for double-ended guillotine break (DEGB) of largest pipe in RCS
  - ECC typically designed for rupture of largest pipe connected to RCS
- Mid-1960: China Syndrome led to ECCS task force, GDC- 35
- 1971-72: ECCS Rulemaking, 50.46 and Appendix K
- 1975: American Physical Society Review
- 1987: Leak before break applied for "dynamic effects"
- 1988: Realistic evaluation models, uncertainty propagation

Leak Before Break
Relevant History

- Generic Letter 84-04
  - acknowledged DEGB unlikely in primary loop piping
  - through-wall cracks would be detected before rupture
- Pipe whip restraints and jet impingement barriers
  - Make access for inservice inspection more difficult
  - Increase occupational exposures
  - Risk of damaging piping or equipment during removal and reinstallation
  - LBB used to justify removal in PWRs for hot, cold & crossover legs and some surge, accumulator, RHR, & RCS bypass lines
  - LBB also used to justify permanent shield over vessel annulus
- NUREG-1061 - staff should expedite rulemaking to address application of LBB to ECC, containment, & other ESFs

LBLOCA Relevant Data (NUREG/CR-5750)

- No reported medium or large NSSS pipe breaks in about 8000 worldwide reactor calendar years of operation
- Throughwall cracks
  - PWRs
    - Dominant mechanism is thermal fatigue
    - One large (8" pipe), four medium (2" to 6" pipes)
  - BWRs
    - Dominant mechanism is intergranular stress corrosion cracking (IGSCC)
    - Most in recirculation bypass lines and riser pipe welds
    - 34 in large U.S. pipes
    - One since IGSCC mitigation efforts began in mid-1980s
- Only 3 U.S. throughwall cracks discovered by leak detection systems while operating at power

Estimating Large-Pipe-Break LOCA Frequencies (NUREG/CR-5750)

- Estimate through-wall crack frequency based on data
- Adjust downward for IGSCC mitigation (BWRs)
- Multiply by conservative estimate of probability of rupture given a through-wall crack based on
  - Technical review of information on fracture mechanics
  - Data on high-energy pipe failures and cracks
  - Assessments of pipe-break frequencies by others
  - $P_{R:TW}$ = max(2.5/diam(mm)), 0.01)

Estimated Mean Large-Pipe-Break LOCA Frequencies

	BWR	PWR
WASH-1400	3e-4/yr	3e-4/yr
NUREG-1150	1e-4/yr	5e-4/yr
NUREG/CR-5750	2e-5/yr	4e-6/yr
Bayesian	–	2e-6/yr

LBLOCA Quantitative Guidelines

- Quantitative guidelines are stated for mean values from full-scope PRAs (internal & external events, all modes of operation)
- For the plant
  - Core damage frequency, CDF < 10^{-4}/year
  - Conditional containment failure probability, CP-ECF < 0.1
  - Conditional probability of large late release, CP-LLR < 0.1
- For any specific initiator type, e.g., LBLOCA
  - $CDF_{LBLOCA} < 10^{-5}$/year
  - $LERF_{LBLOCA} < 10^{-6}$/year
  - $LLRF_{LBLOCA} < 10^{-6}$/year
- To eliminate RCS pipe breaks larger than a certain size as design-basis initiators their collective mean frequency should be demonstrably less than 10^{-6}/year

Illustration of a Possible Framework-Based Way to Risk Inform Existing LBLOCA Requirements (Attachment C)

- Rows denote risk-informed LBLOCA requirements
  - Simultaneous failures
  - Short-term cooling
  - Long-term cooling
  - Containment integrity
  - Plant risk measures (from full-scope PRA after risk-informed LBLOCA changes are implemented)
- Columns differ according to mean frequency of large pipe breaks
  - Large RCS breaks can all be lumped together or
  - Separated into 2 or 3 columns, hypothetical example:
    - $f_{LB} < 10^{-6}$/yr for >10" diameter RCS pipes
    - $f_{LB} = 5x10^{-6}$/yr for 6 to 10" diameter RCS pipes

Discussion Items

- If large RCS pipe break frequency can be demonstrated to be less than 10^{-6} /yr, LBLOCA may be eliminated as DBA. Then,
  - What should the DBA for ECC be?
  - What should the DBA for containment be?
- Would WOG be willing to provide written information regarding their list of potential benefits?
  - Brief explainations
  - Cost estimates (reflecting range of estimates received)
  - Extent of envisioned impact on USIs and GSIs

Attachment A

Very Preliminary LBLOCA Requirements Impact Matrix
(x - denotes requirement that would probably change)

Strategy		Regulations and Related Docs: 10 CFR	GDC	RG	SRP	Requirement	1 Relax Appendix K conservatisms	2 Make realistic evaluation model less burdensome	3 Treat break size & location probabilistically	4 Modify acceptance criteria	5 Relax simultaneous failure assumptions	6 Eliminate very large breaks as design-basis initiators for ECC	7 Eliminate all large breaks as design-basis initiators for ECC	8 Eliminate LBLOCA as design-basis initiator
1 Prevent Initiator	1	50.46a1i				Spectrum of breaks						x	x	x
	2		14			RCPB design, fabrication, erection, testing								
	3		30			RCPB quality								
	4		31			RCPB fracture prevention								
	5		32			RCPB inspection								
	6		35			RCPB leak detection								
	7		35		6.3	RCS-ECCS interface (ISLOCA Prevention)								
2 Prevent Core Damage	8		35			Electric Power: Offsite or Onsite					x		x	x
	9		17			Electric Power: Equipment Start Times					x	x	x	x
	10		35			Single Failure					x		x	x
	11		5			Sharing								
	12		35			System Interfaces								
	13		35	1.1		Capacity, NPSH							x	x
	14	50.46a1i				ECCS Evaluation Model: Realistic with uncertainties quantified		x	x				x	x
	15	50.46a1ii				ECCS Evaluation Model: Appendix K	x						x	x
	16	50.46b1	17,35			ECCS Acceptance Criteria: 1. Peak cladding T < 2200F				x			x	x
	17	50.46b2	17,35			ECCS Acceptance Criteria: 2. Local oxidation < 1%				x			x	x
	18	50.46b3	35			ECCS Acceptance Criteria: 3. Global oxidation < 17%				x			x	x
	19	50.46b4	17,35			ECCS Acceptance Criteria: 4. Coolable geometry							x	x
	20	50.46b5	17,35	1.82		ECCS Acceptance Criteria: 5. Long term cooling							x	x
	21			1.124		Equipment Classification & Seismic Design							x	x
	22		4			Dynamic effects						x	x	x
	23		27			Reactivity Control							x	x
	24		36			Inspection of ECCS								
	25		37			Testing of ECCS							x	x
	26			1.89		Equipment Qualification							x	x
	27	50.46a3				Reporting							x	x
3 Contain Core RN	28		17,35			Containment Integrity for LBLOCA								x
	29		17,35,38	1.52		Containment Heat Removal								x
	30		17,35,41			Containment Atmospheric Cleanup								x
4 Protect Offsite	31	100			15.6.5	Offsite Doses								x
	32	50.47,E				ECCS parameters to ERDS								

Attachment B

Very Preliminary LBLOCA PWR-Burden Impact Matrix

	Possible Ways to Risk-Inform Existing LBLOCA Regulatory Requirements							
	1	2	3	4	5	6	7	8
Potential Benefits of Risk-Informing LBLOCA Regulatory Requirements	**Relax Appendix K Assumptions**	**Reduce Burden w/ Realistic Models**	**Propagate Uncertainty in Break Size & Loc**	**Modify Acceptance Criteria**	**Relax Simultaneous Failure Assumptions**	**Eliminate Very Large Breaks from DB for ECC**	**Eliminate All Large Breaks from DB for ECC**	**Eliminate LBLOCA as DBA**
Reduce Scope of Regulatory Issues			?	?	M	?	H	H
Diesel Generator Start Times			?	?	H	?	H	H
Accumulator Tech Specs			?	?		?	H	H
Analytic/Maintenance Costs for Post-LOCA Control Rod Insertion			?			?	H	H
Analytic/Maintenance Costs for Post-LOCA Hot Leg Switchover				?			?	H
Peaking Factor Increases		?	?	?	?	?	H	H
Power Uprates		?	?	?	?	?	H	H
Reactor Vessel Internals (Barrel Baffle Bolts)			?			?	H	H
High-Burnup Fuel	?	?	?	?	?	?	M	M

Symbols:
? Potential impact, magnitude unknown
M Moderate impact
H High impact

Attachment C

Very Preliminary Illustration of a Possible Composite Way to Risk-Inform LBLOCA Requirements

Frequency of large RCS pipe break	$f_{LB} < 10^{-6}$/yr	10^{-6}/yr $\leq f_{LB} < 10^{-5}$/yr	10^{-5}/yr $\leq f_{LB}$
LOP & Single Failures	No Regulatory Requirement	No Regulatory Requirement	Consider system/train failures with probability[a,b] $P_F \geq (10^{-6}/yr)/f_{LB}$
Short-term Cooling	No Regulatory Requirement	Criteria to assure coolable in-vessel debris[c]	Current ECC Acceptance Criteria 1-4
Long-term Cooling	No Regulatory Requirement	Current ECC Acceptance Criterion 5[c]	Current ECC Acceptance Criterion 5
Containment Integrity	No Regulatory Requirement	Demonstrate[a] $CP\text{-}ECF_{LB} < 0.1$ $CP\text{-}LLR_{LB} < 0.1$	Containment Integrity Required as per Current Regulations
Plant Risk Measures	Demonstrate[a,d] $CDF < 10^{-4}$/yr CP-ECF < 0.1 CP-LLR < 0.1	Demonstrate[a,d] $CDF < 10^{-4}$/yr CP-ECF < 0.1 CP-LLR < 0.1	Demonstrate[a,d] $CDF < 10^{-4}$/yr CP-ECF < 0.1 CP-LLR < 0.1

NOTES:

a All quantitative comparisons are to mean values from full-scope PRAs

b Example: Suppose $f_{LB} = 2x10^{-5}$ and the probability of loss of offsite power given a large RCS break is 0.02. LOP need not be postulated as part of a design-basis LBLOCA because P_f = 0.02 is less than $(10^{-6}/yr)/(2x10^{-5}/yr) = 0.05$.

c The impact of suspended debris on long-term cooling must be considered.

d Mean CDF and CCFP should satisfy these quantitative objectives considering all LBLOCA-related changes.