

# Post Loss of Coolant Water Management Strategies to Optimize Long Term Core Cooling Availability

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NRC Meeting with Industry Regarding Water  
Management Post-Loss-Of-Coolant-Accident

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# Presentation Objective

- Provide an overview of analyses and evaluations of post-loss of coolant accident water management strategies to optimize the availability of long term core cooling to support GSI-191 resolution
  - Focuses on strategies to conserve RWST water inventory by changing the operation of containment sprays
    - Extends the time to switchover to sump recirculation phase of core cooling
    - Eliminates the need for sump recirculation for some loss of coolant accidents
  - Also includes strategies to minimize debris generation, transport and head loss on sump screens

## Preview of Summary and Conclusions

- Automatic spray initiation may be adverse to safety
- Elimination of automatic containment spray initiation makes sense as a water management strategy based on:
  - Risk reduction / safety increase
  - Increase margins to address future long term cooling / sump blockage issues
- Several changes in regulatory practice need to be completed to make elimination of automatic spray initiation a reality
  - Steamline break analysis methodology changes
  - Offsite / control room dose analysis methodology changes
  - Other plant specific issues

# Outline of Presentation

- Background
- Overview of Generic Studies in Response to NRC Bulletin 2003-1 (WCAP-16204)
- Overview of Generic Studies of Safety Benefits of Large Break LOCA Re-Definition (WOG-05-370)
- Summary of T&H Analyses of Containment Behavior
- Summary of Dose Analyses
- Summary of Risk Analyses
- Response to NRC Discussion Points
- Summary and Conclusions
- Future Direction

# Background

- Generic analyses have been performed for two related issues
  - Response to NRC Bulletin 2003-1 (WCAP-16204, Rev. 1)
    - Documents the results of a PWROG program to define generic EOP changes to address part of NRC Bulletin 2003-1
    - Summary of analyses and recommendations provided to NRC at January 22, 2004 meeting
    - Analyses only examined EOP changes that could be implemented without changes to plant license basis
  - PWROG initiative to define the safety benefits of LBLOCA Redefinition (WOG Letter 05-370)
    - Documents results of a PWROG program to define the safety benefits of large break LOCA break size re-definition
    - Provided to the NRC on August 16, 2005

## Background (continued)

- WCAP-16204 and LBLOCA Benefits Assessment addressed very specific issues but valuable insights were gained from these efforts that can be applied to current water management discussion

# WCAP-16204, Rev. 1

- Initiative examined a series of operator actions that could be beneficial to preventing sump blockage or mitigating the consequences of sump blockage
- Analyses and evaluations were performed to identify impacts of each candidate operator action
  - Time available for operator action
  - DBA LOCA analyses (core response)
  - DBA containment pressure / temperature
  - Sump chemistry
  - DBA dose analysis
  - Risk (PRA)
  - Plant licensing basis

# WCAP-16204 Candidate Operator Actions

## Summary of Strategies Examined in WCAP-16204, Rev. 1

1. Terminate spray after automatic initiation
2. Terminate spray for small LOCAs in ice condenser containments
3. Terminate one train of HHSI prior to sump recirculation
4. Terminate one train of HHSI after alignment for sump recirculation
5. Terminate one train of LHSI prior to alignment for sump recirculation
6. Establish one train of recirculation prior to switchover to sump recirculation
7. Continue HHSI with refilled RWST
8. Provide contingency actions for post-sump blockage
9. Provide more aggressive cooldown for small LOCA



# WCAP-16204 Limitations for Water Management

- Focused on strategies that could be implemented with no changes to the plant licensing basis
  - Termination of one train of spray was considered only after it could be verified that both trains were operating
- Strategies were evaluated based on a reference Westinghouse and CE NSSS design
  - Large dry containment plant was used as a reference
    - In some cases, separate analyses were performed for W and CE designs
  - There are significant plant-to-plant variations in key design features that may impact the strategy limitations and benefits

## WCAP-16204, Rev. 1 Recommendations

- Four candidate operator actions were considered generally applicable to all plants
  - Termination of one train of spray prior to sump recirculation
  - Termination of one train of HHSI after sump recirculation
  - Refill of RWST (after transfer to sump recirculation)
  - Response to loss of recirculation flow due to sump blockage
- The balance of the candidate operator actions could be implemented on a plant specific basis if it was the best trade-off to reduce the potential for, or the magnitude of, sump blockage
- Current regulatory positions prevented further consideration of mitigation strategies

# **WOG Letter 05-370**

## **Safety Benefits of LBLOCA Re-Definition**

- One of the benefits examined was the potential for deleting automatic containment spray actuation using the transition break approach from the large break re-definition (50.46a rulemaking) initiative
- Analyses and evaluations were performed to identify the impact of deleting automatic containment spray actuation:
  - DBA containment pressure and temperature analysis
  - Offsite Dose Analysis
  - PRA analysis

## WOG Letter 05-370 T&H Analyses

- The T&H analyses were performed for a reference large dry containment design
  - Peak containment pressure for breaks up to the transition break size is less than design basis pressure
  - Peak containment pressure for breaks above the transition break size (i.e., a DEGB) could exceed the containment design pressure when analyzed with currently licensed analysis models
    - The use of more realistic models would likely result in peak containment pressures below the containment design basis for a larger population of plants
    - Substantial margin exists between design and ultimate pressure
  - Plants without safety grade fan coolers may have to manually initiate containment spray at a later time for containment heat removal

## WOG Letter 05-370 Dose Analyses

- The offsite dose analysis shows that doses would have a minimal increase ( $<10\%$ ) if spray is manually initiated within 45 minutes of the accident initiation
  - Analysis uses alternative Source Term from RG 1.183
- Other studies (not in WOG-05-370) show that some plants may be able to meet offsite dose limits without containment spray
  - Other plants would require additional credit for removal processes to meet dose limits
    - At least one plant has shown that spray recirculation is not needed to meet 30 day dose limits if spray is assumed initially

## WOG Letter 05-370 Dose Analyses (continued)

- Not actuating spray requires an alternate means of sump water pH control for iodine retention for NaOH plants
- No assessment performed for control room doses

# WOG Letter 05-370 Risk Assessment

- The PRA analyses were performed for several containment design classes
  - Large dry containments w/ and w/o fan coolers
  - Ice condenser containments
- PRA analyses credited
  - The impact of the increased time to switchover to ECC recirculation on the HRA analysis,
  - The potential for using normal shutdown cooling instead of sump recirculation for core cooling for break sizes less than 2 inch equivalent diameter
  - No credit for reduced sump blockage potential
- Quantified benefits are plant dependent and show a reduction in core damage frequency (ranging from ~10% to 1%)
  - Ice condenser containments and large dry containments with low containment spray setpoints would benefit the most

# LBLOCA Re-Definition T&H Analyses

- RCS M&E Releases
  - DEPS; not DEHL
  - Current plant basis for DEPS releases
  - NOTRUMP accumulator line releases
  - WCOBRA/TRAC surge line releases
- Containment Analysis
  - Large dry containment design
  - GOTHIC model
  - With and without sprays

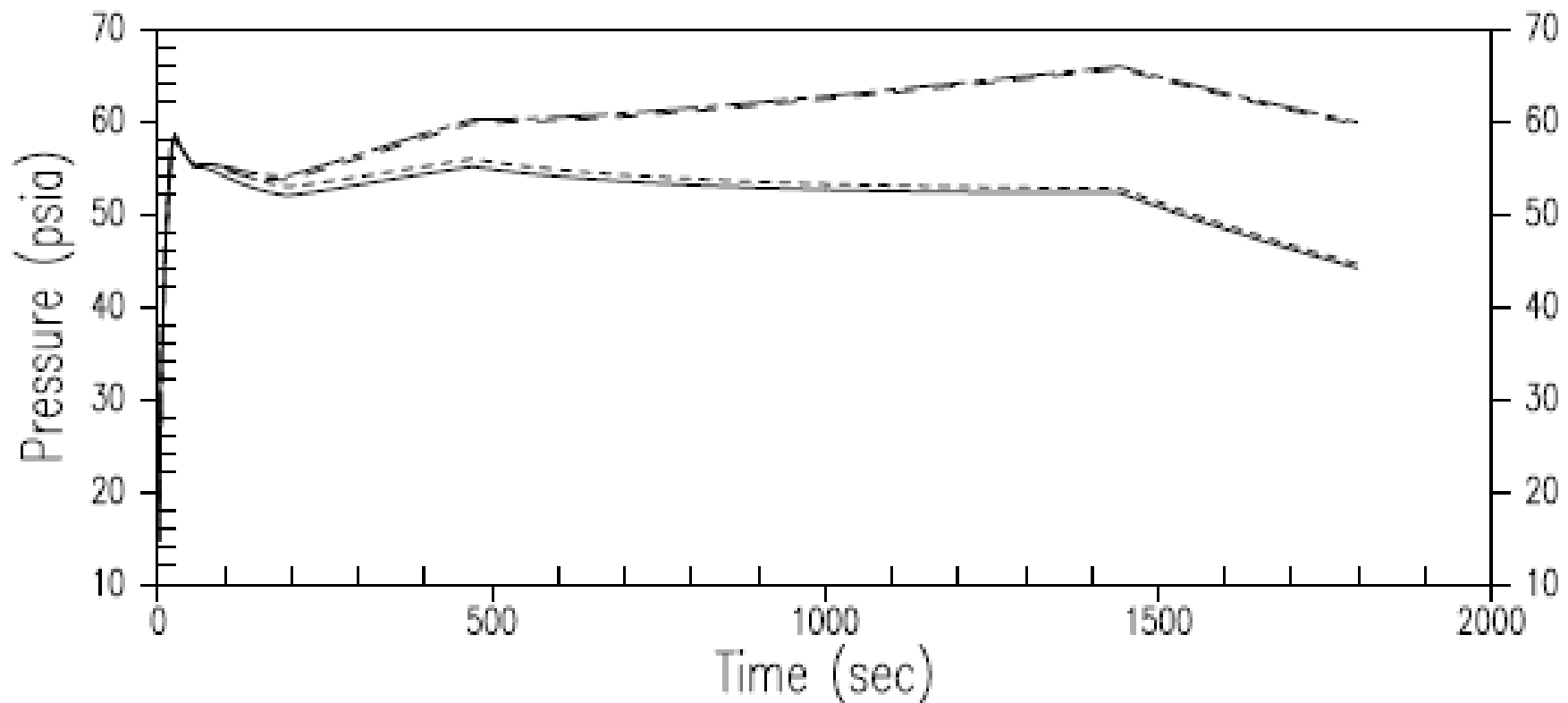


# LBLOCA Re-Definition T&H Analyses Results

Elimination of Spray in the Injection Phase			
Break	Sprays	Peak Ctmt Pressure (psia)	Time (sec)
DEPS (Base)	Y	58.5	25 *
DEPS	N	65.9	1440
Accumulator Line (Base)	Y	47.0	560
Accumulator Line	N	53.2	1110
Accumulator Line **	N	63.5	1199
Surge Line	Y	47.0	125 *
Surge Line	N	47.4	125 *
Surge Line **	N	51.9	155 *
* Blowdown Peak                      ** 50% Degraded Containment Heat Sink			

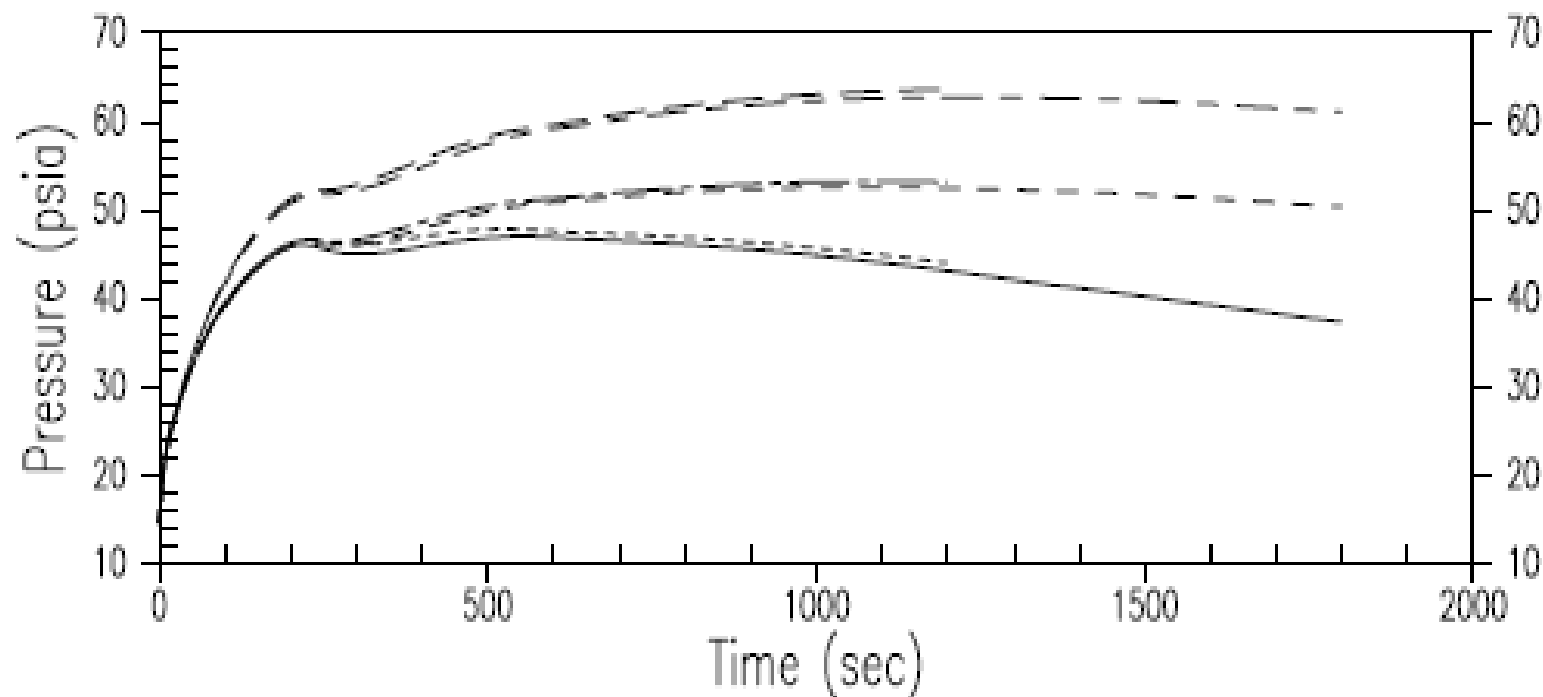
# LBLOCA Containment Response

- Case 1: LBLOCA
- - - Case 2: LBLOCA w/o Spray
- - - - Case 3: LBLOCA w/60-sec DG Delay
- - - - Case 4: LBLOCA w/o Spray w/60-sec DG Delay



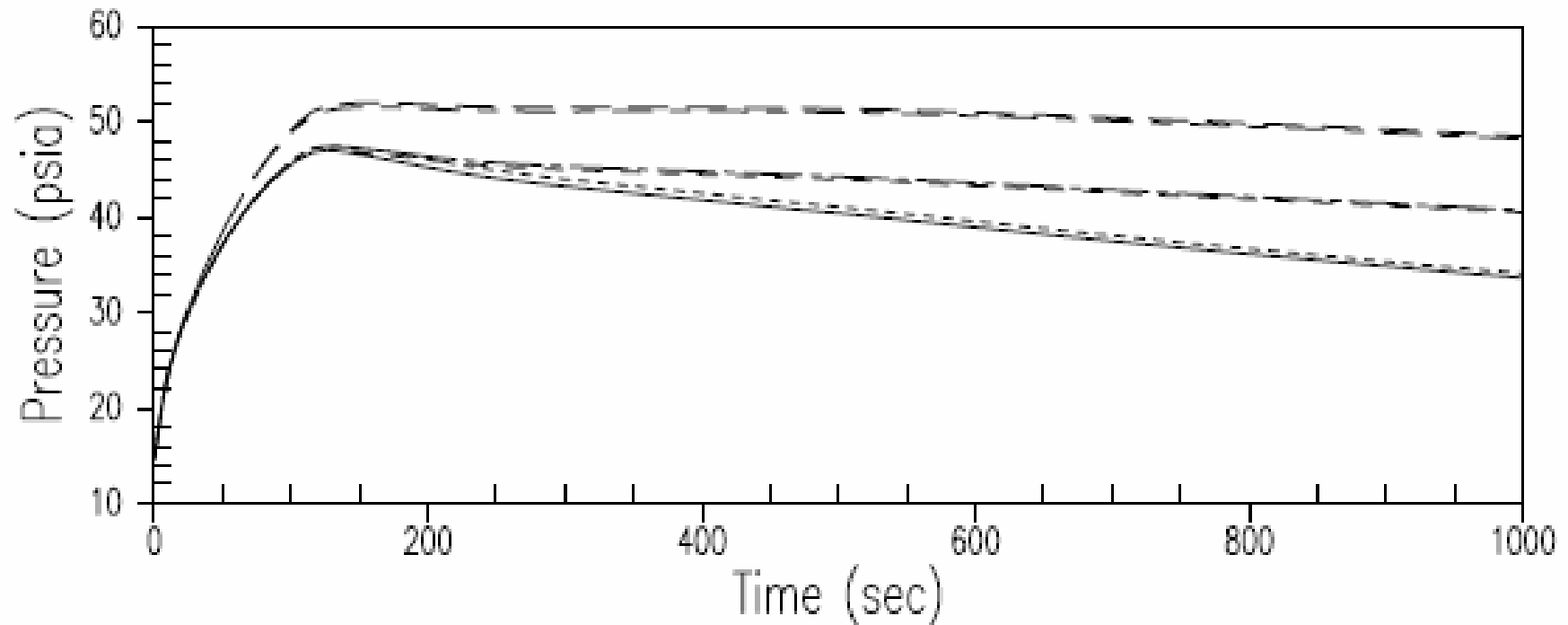
# Accumulator Line Break Pressure

- Case 5: Accumulator Line Break
- - - - Case 6: Accumulator Line Break w/o Spray
- · - · Case 7: Accumulator Line Break w/60-sec DG Delay
- - - - Case 8: Accumulator Line Break w/o Spray w/60-sec DG Delay
- - - - Case 9: Accumulator Line Break w/o Spray w/Reduced Heat Sin
- - - - Case 10: Accumulator Line Break w/o Spray w/60-sec DG Delay



# Surge Line Break Containment Response

- Case 11: Base
- - - - Case 12: Base w/o Spray
- - - - Case 13: Base w/50 sec EDG Delay
- · — · Case 14: Case 12 w/50 sec EDG Delay
- - - - Case 15: Case 12 w/50% Heat Sink Reduction
- · - · Case 16: Case 15 w/50 sec EDG Delay



# LBLOCA Re-Definition T&H Analysis

## Conclusions

- Typical 4-loop Westinghouse NSSS design with a dry containment
  - Calculated pressures are less than design pressure
  - DEPS remains bounding
  - No second peak for surge line breaks
  - Results are plant dependent
  - Sensitivity of reduced containment mixing without sprays addressed by assuming 50% degradation of containment heat sink surface area

# LBLOCA Re-Definition T&H Analysis Insights

- Removal of automatic spray injection is feasible for large dry containment
- Other designs unique
  - Ice condenser containments
    - No fan coolers for long term heat removal
    - Spray recirculation may be required after ice depletion
  - Subatmospheric containments
    - No safety grade fan coolers
    - Recirculation spray cools sump
  - Other large dry containment designs
    - A few do not have safety grade fan coolers
- Some designs use spray recirculation to cool the sump

## WCAP-16204 T&H Analyses

- Strategies chosen based on ability to continue to meet regulatory requirements
- A candidate action modeled terminating one train of containment spray in the injection phase
  - Double ended break
  - Operator stopped one train of spray at 10 minutes after verifying that both trains were operational
  - Smart single failure loss of remaining spray pump at termination of other train
- Idle spray pump assumed to be restarted in 10 minutes

## WCAP-16204 T&H Analyses Conclusions

- No change in peak containment pressure for limiting case
- 10 minute operator action to re-establish one train of spray was timely to prevent peak pressure from exceeding design pressure
  - Available time is dependent on fan cooler capacity, which is plant dependent
- Change in ECC recirculation switchover time was minimal



## WCAP16204 T&H Analyses Conclusions (continued)

- Time to recirculation would be more positively impacted (longer time to recirc) for smaller break sizes
- At recirculation, one idle spray pump can reduce flow through the sump screens by 15 to 35%

## Radiological Dose Analyses

- WCAP-16204 analyses conclude that there is little impact on offsite dose of a 10 minute period with no spray when using the alternative source term (RG 1.183) methodology

## Radiological Dose Analyses

- WOG-05-370 analyses show that spray is only required for radiological impacts if core melting occurs
  - Some plants may not need spray using alternative source term
  - Actuation of spray on diagnosis of high containment radiation levels would still permit dose limits to be met
    - Delay in spray actuation for a core melt accident of up to 45 minutes can be accommodated using alternative source term
    - If spray is not credited, control room doses may not meet current regulatory guidance, even if alternative source term is used
- For design basis accidents with successful core cooling, dose limits can be met without spray for up to 100% clad damage using alternative source term

# Risk Assessment Considerations

- Risk impacts of containment spray can be modeled in two ways:
  - CDF reduction due to longer times to ECC switchover
  - CDF reduction due to lower potential for failure of recirculation cooling due to debris
- WCAP-16204, Rev. 1 risk assessment was qualitative and included both considerations
- WOG-05-370 risk assessment was based only on risk reduction due to increased time to sump recirculation

# Risk Assessment Insights

- Risk benefits are plant dependent and can be characterized by several key features
  - Contribution of small, medium and large LOCAs to the overall risk profile
  - Operator actions to transfer to sump recirculation (manual, semi-automatic or completely automatic)
  - Availability of safety grade fan coolers
  - Containment spray setpoint in relation to small LOCA containment pressures

## Risk Assessment Conclusions

- Risk benefits from delaying sump recirculation can vary from 10% to 1% reduction in CDF
  - Risk reduction is greatest for ice condenser plants and plants with safety grade fan coolers and low containment spray setpoints
    - Spray normally actuates for small LOCAs and significantly shortens the time for sump recirculation
  - Risk reduction is lowest for plants with low contribution to risk from LOCAs
- Risk benefits for LERF are negligible because LERF is dominated by containment bypass sequences

# Question 1: Is reducing containment spray flow a net risk benefit?

- Yes. From a core damage risk perspective, there is no downside to reducing containment spray flow when analyzed using realistic models and acceptance criteria
  - PRA model will always predict a reduction in CDF
    - CDF reduction varies from 10% to 1%, depending on plant design features and risk profile
    - LERF reduction is negligible because LERF is dominated by containment bypass
      - Small increases in containment peak pressure do not impact LERF due to large containment capability margins

## **Question 1: Is reducing containment spray flow a net risk benefit? (continued)**

- Yes. From a qualitative perspective, there is no downside to reducing containment spray flow
  - Reduced debris generation and reduced debris transport
    - Increases available NPSH margin
    - Increases containment water levels
  - Increased margin on emergency diesel loading



## Question 1: Is reducing containment spray flow a net risk benefit? (continued)

- Some margins to deterministic licensing basis criteria may be reduced if the present mode of spray operation is changed
  - Licensing basis margins that may be reduced (e.g., margin to containment design pressure) are very conservative and do not realistically impact overall safety
  - Margin reductions for main steam line break and radionuclide releases can be minimized by manual spray actuation
- Overall risk is reduced even though the consequences of some low frequency events may increase slightly

## Question 2: What changes to reduce containment spray flow are considered?

Strategy	Benefits
Eliminate automatic spray initiation	Eliminates competition for RWST water Decreases debris generation Decreases debris transport
Raise containment spray setpoint	Eliminates competition for RWST water for LOCAs < DEGB Decreases debris generation for LOCAs < DEGB <i>Does not help DEGB which is the largest debris generation</i>
Eliminate containment spray recirculation	Decreases debris transport Decreases head loss through sump screens <i>Does not help conserve RWST water or debris generation</i> <i>May be the only heat removal option for some plants</i>
Stop one Train of Spray or Decrease Spray Flow	Decreases competition for RWST water <i>Does not help debris generation</i>
<b>Elimination of automatic spray actuation offers the most benefits</b>	

### **Question 3: To what extent are benefits of spray eliminations plant specific?**

- Risk benefits due to extended time to sump recirculation are plant dependent and can be characterized by several key plant features
  - Contribution of small, medium and large LOCAs to the overall risk profile
  - Operator actions to transfer to sump recirculation (manual, semi-automatic or completely automatic)

### Question 3: To what extent are benefits of spray eliminations plant specific (continued)?

- Plant specific features that impact risk benefits (continued)
  - Availability of safety grade fan coolers
    - Eliminates the need for spray in either injection or recirculation
  - Containment spray setpoint in relation to small LOCA containment pressures
    - Small LOCAs and loss of feedwater “bleed and feed” scenarios can result in containment pressures in the range of 10 to 15 psig for plants with fan coolers
    - Plants with low spray setpoints (e.g., in the range of 5 to 10 psig) would benefit most
- **The majority of the plants would likely see a reduction in CDF of 2 to 5% based on extending the time to recirculation**

## **Question 4: What are the regulatory impediments to elimination of spray automatic initiation?**

- Regulatory impediments include:
  - Containment design pressure and temperature
  - Radiological dose (both offsite and control room)
  - Equipment qualification
  - Operator actions
  - NRC approval of License Amendment Requests

## **Question 4: What are the regulatory impediments to elimination of spray automatic initiation?**

- Main steam line break peak pressure requirement and Main steam line break temperature profile
  - More realistic analysis models and assumptions; examples include
    - Credit for manual operation of spray for MSLB symptoms
    - Time for operator action to manually initiate spray
    - More realistic credit for heat sinks
    - Containment design pressure vs. ultimate capability
    - More realistic credit for thermal lag of equipment in EQ space

## Question 4: What impediments to elimination of spray automatic initiation (continued)?

- Offsite and control room dose requirements
  - More realistic analysis models and assumptions; examples include
    - Credit for manual operation of spray for high containment radiation conditions
    - Time for operator action to manually initiate spray
    - Iodine re-evolution from the sump prior to effective pH control
    - More realistic credit for sedimentation of aerosol fission products in containment

## **Question 4: What impediments to elimination of spray automatic initiation (continued)?**

- NRC approval of License Amendment Requests
  - Licensees need to know that approvals can be timely and predictable
    - Regulatory approval of implementation of alternative Source Term was considered to be burdensome
    - Consistent application of reasonable assurance criterion



## Question 5: Is removing automatic spray initiation viable?

- For large dry containment plants– **YES**
- For ice condenser plants – **YES**
- For subatmospheric containment plants – **Maybe**

## **Question 6: What other water management considerations should be under consideration?**

- Shutdown of one train of safety injection after both trains are verified as operational
  - Decreases rate of RWST usage
  - Symptom based procedures would enable timely start of idle train if needed
- Transfer of only a single train of ECC to recirculation
  - Decreases sump screen head loss
  - Two train operation is only required because of single failure criteria
  - Two operating trains increase potential for loss of all pumps (cavitation) if sump blockage (or other events) occurs
  - Two operating trains increase “fail to run” failure of recirculation in the long term

## **Question 6: What other water management considerations (continued)?**

- Transfer to spray recirculation – if required, use only a single train
  - Same reasons as ECC sump recirculation
- Decrease spray flow rates
  - Some benefit for RWST depletion and sump screen head loss
  - May be viable for plants requiring containment heat removal with sprays
  - Requires plant modifications to throttle spray flow

# Summary and Conclusions

- Elimination of automatic containment spray initiation makes sense as a water management strategy based on:
  - Risk reduction
  - Increase margins to sump blockage
- Automatic spray initiation may be adverse to safety
  - While offsite and control room doses for the low probability design basis sequences are predicted to increase slightly if automatic spray initiation is eliminated, the overall “risk” will decrease
- Several impediments need to be addressed to make elimination of automatic spray initiation a reality
  - Containment design pressure and temperature
  - Radiological dose (both offsite and control room)
  - Equipment qualification
  - Operator actions
  - NRC approval of License Amendment Requests

## Future Direction

- Changes in approved methodologies may be enough to provide the opportunity to replace automatic spray initiation with a manual action
  - Removal of undue conservatism from methodologies (e.g., SRPs and Reg. Guides) does not require rulemaking
  - The methodology changes are required to address issues related to
    - EQ
    - MSLB
    - Dose
    - Containment Pressure