# 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

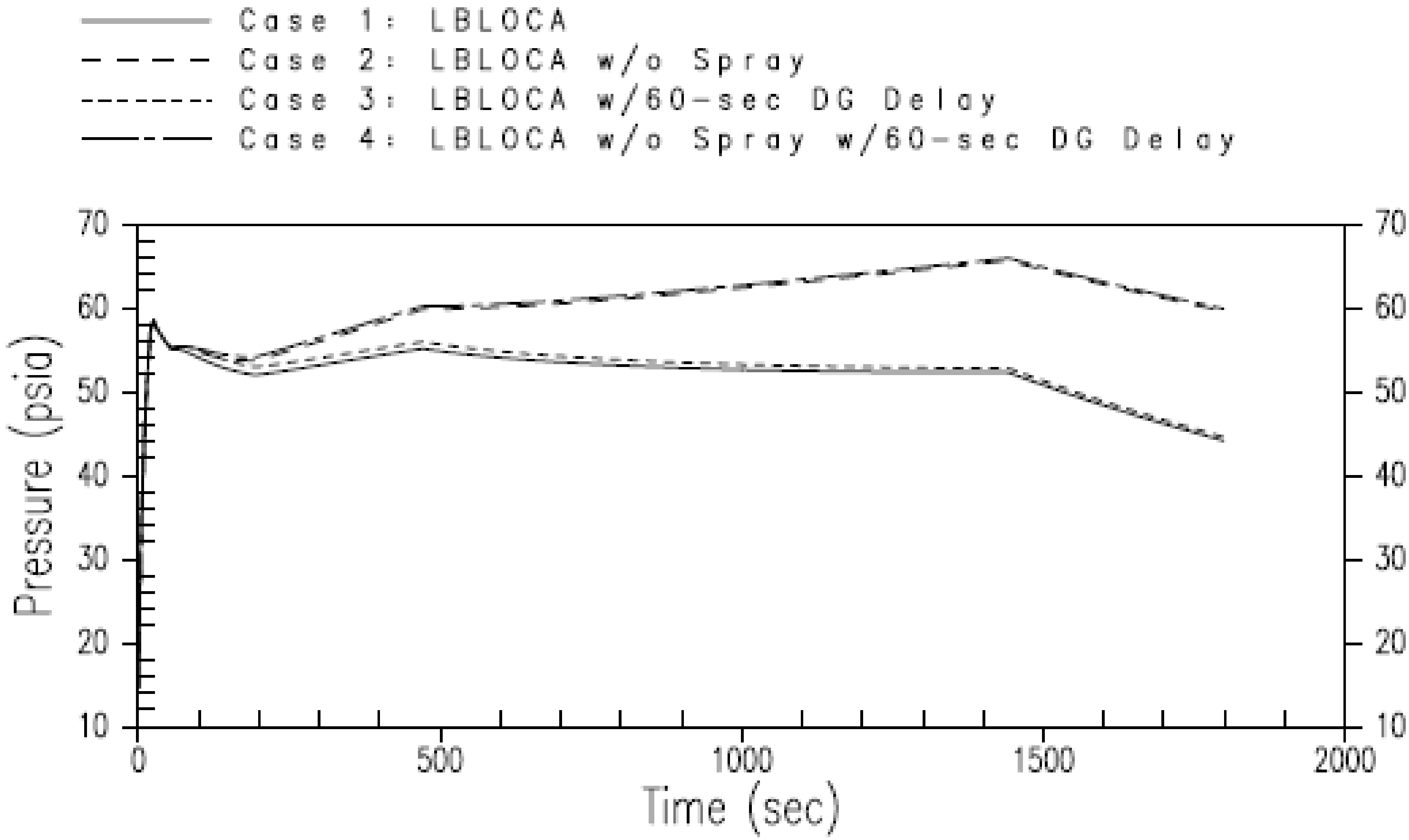
- RCS M&E Releases
  - DEPS; not DEHL
  - Current plant basis for DEPS releases
  - NOTRUMP accumulator line releases
  - WCOBRA/TRAC surge line releases

- Containment Analysis
  - Large dry containment design
  - GOTHIC model
  - With and without sprays

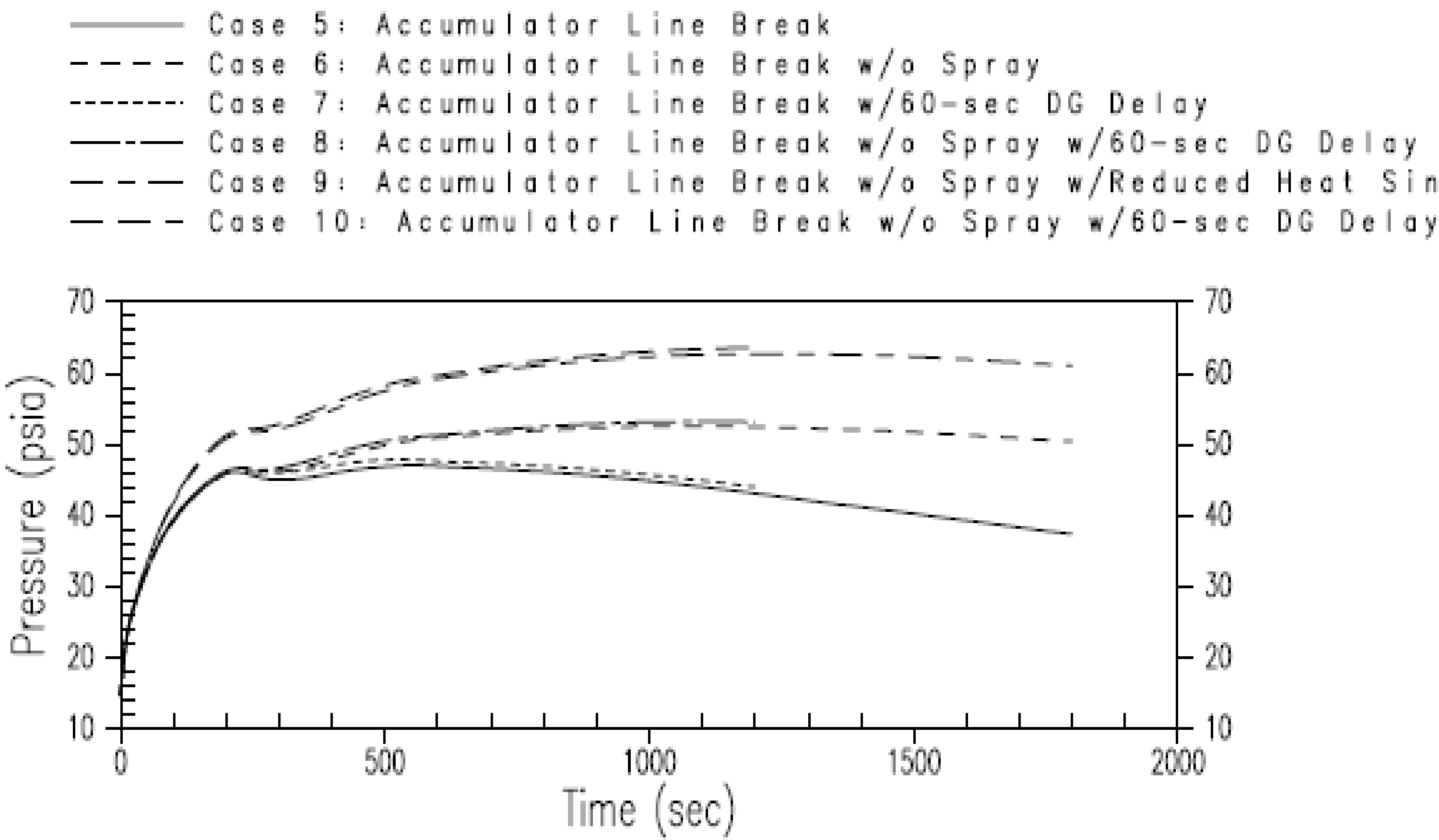
# LBLOCA Re-Definition T&H Analyses Results

| 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 | | |

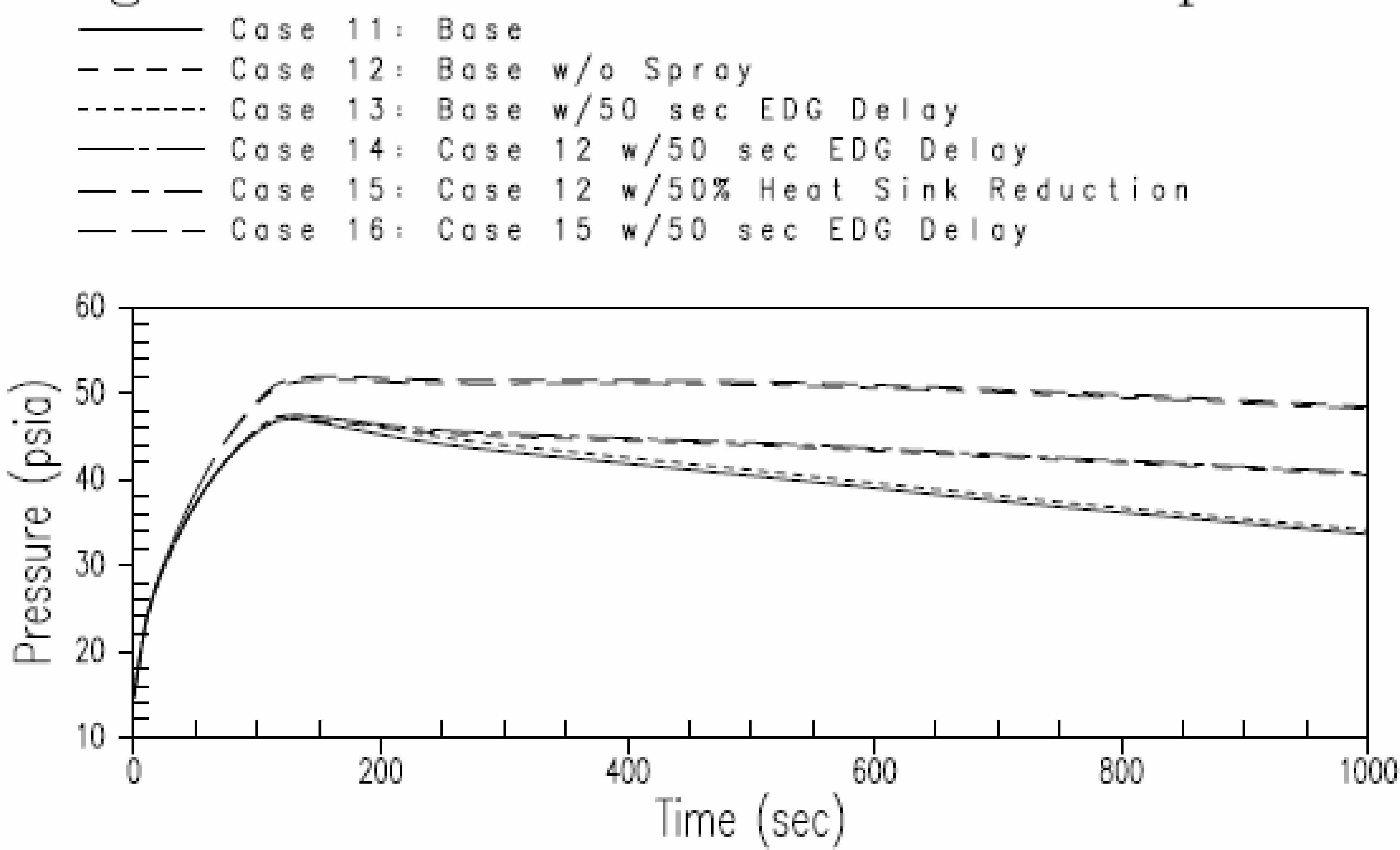
# LBLOCA Containment Response



# Accumulator Line Break Pressure



# Surge Line Break Containment Response



# 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<br>Decreases debris generation<br>Decreases debris transport |
| Raise containment spray setpoint | Eliminates competition for RWST water for LOCAs < DEGB<br>Decreases debris generation for LOCAs < DEGB<br>*Does not help DEGB which is the largest debris generation* |
| Eliminate containment spray recirculation | Decreases debris transport<br>Decreases head loss through sump screens<br>*Does not help conserve RWST water or debris generation*<br>*May be the only heat removal option for some plants* |
| Stop one Train of Spray or Decrease Spray Flow | Decreases competition for RWST water<br>*Does not help debris generation* |

**Elimination of automatic spray actuation offers the most benefits**

# 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