Status of Containment Accident Pressure (CAP) Analysis Activities and Path Forward Discussion

Monticello Nuclear Generating Plant

April 3, 2012

Purpose Statement

- Computational Fluid Dynamics (CFD) analysis is considered by the NRC staff as the cornerstone for the resolution of SECY 11-0014.
- After nearly one year, industry efforts have been unsuccessful in developing a CFD model that reflects the Monticello pump design (double suction vertical pump).
- The purpose of this meeting is to propose an alternative regulatory path to demonstrate adequate core and containment cooling is achieved without reliance on CFD analysis.

Agenda

- Background
  - SECY 11-0014 Overview
  - BWROG/Sulzer work
- Update Status of BWROG/Sulzer work
- Proposed Path Forward

Background

- SECY 11-0014 addressed a fundamental question that the ACRS has regarding CAP. Is defense in depth compromised because a plant must have an intact containment (1 fission product barrier) to achieve cooling (1 fission product barrier) of the reactor core?
- In the NRC Commissioners vote on SECY 11-0014 the philosophy that was endorsed stated:

  “The Commission, … defines defense in depth as "an element of the NRC's safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility". This definition does not state that the compensatory measures must be independent.”
- In addition, the SECY vote confirmed that reliance on CAP is not a safety issue. However, it directed that the NRC *“would use the improved guidance that resulted from ACRS recommendations to include margin and uncertainty determinations in CAP calculations.”*
- By selection of Option 1 of SECY 11-0014, the NRC Commission endorsed use of SECY 11-0014, Enclosure 1 which provides technical guidance on the use of CAP in reactor safety analyses.

Background

- SECY 11-0014, Enclosure 1, Guidance on Use of CAP, addresses the following:
  - **6.6.1 $NPSHr_{eff}$ –** For DBA, include uncertainty in the value of $NPSHr_{3\%}$ based on vendor testing and installed operation, including the effects of motor slip, suction piping configuration, air content, and wear ring leakage. For non-DBAs, $NPSHr_{3\%}$ without uncertainties may be used.
  - **6.6.2 Maximum Pump Flow Rate for the NPSHa Analysis -** maximum flow rate chosen for the NPSHa analysis should be greater than or equal to the flow rate assumed in the safety analyses that demonstrate adequate core and containment cooling.
  - **6.6.3 Conservative Containment Accident Pressure for Calculating NPSHa -** a 95/95 lower tolerance limit should be used to calculate the containment accident pressure used to determine the NPSHa.
  - **6.6.4 Assurance that Containment Integrity is not Compromised -** demonstrate conservatively that loss of containment integrity from containment venting, circuit issues associated with an Appendix R fire, or other causes cannot occur or that they would occur only after use of containment accident pressure is no longer needed.

Background

- SECY 11-0014, Enclosure 1 continued:
  - **6.6.5 Operator Actions -** Operator action to control containment accident pressure is acceptable. The NRC staff should approve any operator actions, and the appropriate plant procedures (e.g., emergency, abnormal) should include them.
  - **6.6.6 NPSHa less than NPSHr or NPSHr$_{eff}$ -** Operation in this mode is acceptable if appropriate tests are done to demonstrate that the pump will continue to perform its safety functions.
  - **6.6.7 Assurance of no Pre-existing leak -** licensees proposing to use containment accident pressure in determining NPSH margin should do the following:
    1. Determine the minimum containment leakage rate sufficient to lose the containment accident pressure needed for adequate NPSH margin.
    2. Propose a method to determine whether the actual containment leakage rate exceeds the leakage rate determined in (1) above.
    3. Propose a limit on the time interval that the plant operates when the actual containment leakage rate exceeds the leakage rate determined in (1) above.

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Background

- SECY 11-0014, Enclosure 1 continued:
  - **6.6.8 Maximum Erosion Zone -** The zone of maximum erosion rate should be considered to lie between NPSH margin ratios of 1.2 to 1.6. Realistic calculations should be used to determine the time within this band of NPSH ratio values.
  - **6.6.9 Estimate of NPSH Margin -** A realistic calculation of NPSHa should be performed to compare with the NPSHa determined from the Monte Carlo 95/95 calculation.
  - **6.6.10 Assurance of Pump Operability for Total Time Required -** The necessary mission time for a pump using containment accident pressure should include not only the duration of the accident when the NPSH margin may be limited, but any additional time needed for operation of the pump after recovery from the accident when the pump is needed to maintain the reactor or containment, or both, in a stable, cool condition but at a much greater NPSH margin. This additional time is usually taken as 30 days.
- NSPM has been working, independently and in conjunction with the BWROG, to address the issues in SECY 11-0014, Enclosure 1 on use of CAP since the NRC Commission approval of Option 1 of SECY 11-0014 (restarting the EPU reviews) in March 2011.

Background

- BWROG/Sulzer Work - Sulzer was contracted to perform CFD analyses in order to characterize the magnitude of several NPSHr uncertainties as compared to NPSHr vendor curves. The Sulzer study is divided into six tasks.
  - Task 1A – Determine pump baseline NPSH curve (benchmark)
  - Task 1B – Effect of Temperature
  - Task 1C – Effect of Inlet Geometry
  - Task 1D – Effect of Dissolved Gas
  - Task 1E – Effect of Mechanical Wear Ring Clearance
  - Task 1F – Combined effects of uncertainties
- The CFD (Task 1) is applied to:
  - The CVDS (3600 RPM double-suction) pumps used at all BWR sites except Cooper (based on Monticello pump).
  - The CVIC (1800 RPM single-suction) pumps used at many BWR sites (based on Browns Ferry and Peach Bottom pumps).

Background

- The BWROG/Sulzer project scope also includes the following tasks:
  - Task 2 - NPSHr changes due to pump speed changes
  - Task 3 - effects of pump operation with NPSHa < NPSHr
  - Task 4 - effects of extended pump operation (30 days) in the maximum erosion rate zone
  - Task 5 - effect of non-condensable gases on pump mechanical seal performance
  - Task 6 - NPSHr uncertainties related to pump test instrumentation

Background

- BWROG/Sulzer work addresses SECY 11-0014, Enclosure 1:

SECY Section	BWROG/Sulzer Scope
6.6.1	Tasks 1, 2, 5 and 6 address pump uncertainty and reliability issues.
6.6.6	Partially addressed by Tasks 3 and 5.
6.6.8	Task 4 addresses maximum erosion zone.
6.6.10	Task 3 addresses full mission time analysis assuming NPSHa < NPSHr. Task 4 includes full mission time (30 days) analysis with effects of operation in the maximum erosion zone.

- Remaining sections of SECY 11-0014 are being addressed independent of the BWROG/Sulzer work.

Update Status of BWROG/Sulzer work

- Sulzer performed 4 different steady-state CFD simulations (models) using ANSYS CFX in an attempt to produce a $NPSHr_{3\%}$ curve (Task 1A) for the CVDS pump. Each simulation could not reproduce the factory test results. The simulations included:
  - A full CFD model of the suction piping, pump, and volute/discharge.
  - A split-plane CFD model ("half-pump" model) to eliminate pump asymmetries from the full model.
  - A split-plane CFD model ("half-pump" model) with a "vaneless diffuser" to remove unsteady regions within volute.
  - A split-plane CFD model ("half-pump" model) with a "vaneless diffuser" to remove unsteady regions within volute and a stage grid interface to better handle the rotating and stationary elements of the pump.
- Sulzer also performed 1 transient CFD simulation case using ANSYS CFX for the CVDS pump, and demonstrated the ability to better predict the $NPSHr_{3\%}$ curve*. However, only 1 data point has been analyzed and the simulation could not reproduce the factory test results.

* **All data presented in this presentation is considered preliminary and is unverified.**

Update Status of BWROG/Sulzer work

- Recently Sulzer produced a transient CFD case using a different software (STAR-CCM+) for the CVDS pump. Only 1 data point has been analyzed and the simulation could not reproduce the factory test results.

Update Status of BWROG/Sulzer work

- Progress on BWROG/Sulzer Tasks 2 - 6:
  - Task 2 is complete. The conclusion reached is that the ANSI 1.6 equation for speed-related NPSHr changes is valid for speed increases limited to ±3% from the nominal.
  - Task 3 is in review with the BWROG. The draft report shows, based on previous pump test experience, that a short period of operation with NPSHa < NPSHr does not adversely affect the pump mission time.
  - Task 4 is in final review with the BWROG. The draft report indicates significant cavitation erosion margin exists (~ 6,200 days = 17 years) even when operating in maximum erosion zone. A minimum service life of 30 days operation is assumed.
  - Task 5 has been reviewed by the BWROG and comments are being resolved by Sulzer. Independent methods confirm that mechanical seal performance is not impacted by non-condensable gas.
  - Task 6 is complete. The report shows that the NPSH uncertainties introduced by pump test instrumentation are small (< 1' NPSH at 4000 gpm).

Update Status of BWROG/Sulzer work

- The conclusion NSPM has reached based on the work completed over the past year is:
  - CFD modeling of the Monticello CVDS pump has not been successful to date. The failure of the steady-state model solution has been attributed to asymmetry in the fluid flow velocity and pressure in the pump impeller eye.
  - Evaluation of CFD modeling options for the Monticello CVDS pump continues using a transient solution; however, success is not assured.
  - CFD CVDS models may not be able to predict NPSHr uncertainties with the precision necessary to meet NRC objectives.
  - The results of non-CFD task reports indicate small changes in NPSHr for the parameters evaluated or negligible effects on pump performance and reliability.

Proposed Path Forward

- NSPM will apply the 21% uncertainty (used for Non-CAP plants) to the CVDS pumps for determining adequate margin for pump operation.
- Sulzer will perform a similarity analysis of the MNGP Core Spray pumps (also CVDS pumps) in relation to the MNGP RHR pumps (applicability of Tasks 2 – 6) and will demonstrate that these pumps also have adequate margin for pump operation.
- Using this approach NSPM will submit the following analyses to the NRC for approval:
  - the ECCS pump margin analyses using 21% uncertainty
  - the BWROG non-CFD related analyses to support pump NPSH uncertainty margins
  - the Core Spray similarity analysis
  - An analysis that demonstrates that negative NPSHr margins for a short time do not challenge ECCS performance or pump reliability
- In parallel NSPM will continue to stay engaged with, monitor and support the BWROG work regarding NPSH uncertainties for ECCS pumps.

Proposed Path Forward

- Use of 21% uncertainty for NPSHr results in negative margin for only 5 minutes of the 30 day DBA LOCA mission time.
- BWROG Task 3 will evaluate that NPSHa < $NPSHr_{3\%}$ is adequate to demonstrate pump performance and reliability for the 30 day DBA LOCA mission time.
- Current standard vendor testing to determine NSPH curves results in operation below $NPSHr_{3\%}$ curve for periods longer than 5 minutes and does not result in pump damage.
- Core is reflooded to 2/3 core height within the first 4 minutes of a DBA LOCA, prior to low NPSH margin. After core PCT excursion is mitigated, only 2700 gpm of Core Spray (CS) flow is required to cool core. Analysis will be provided to demonstrate CS pumps will supply this flow with substantial margin.
- Experts in hydraulic analysis are being utilized to review and provide direction on approaches being considered.

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Proposed Path Forward

Example Use of 21% Uncertainty (4000 gpm)

21% Uncertainty	4.62’	Total uncertainty applied to MNGP RHR pump to be assumed at 4000 gpm based on NPSHr.
Task 1B, Temperature	Not Used	Positive effect and will not be used, Budris Technical Report on Task #4 Findings (ML093510164) suggests benefit of 3% or 0.67’.
Task 1C, Piping Geometry	2.2’	Budris recommends 0% - 10% uncertainty in Technical Report on Task #4 Findings (ML093510164).
Task 1D, Dissolved Gas	1.1’	Budris recommends 0% - 5% uncertainty in Technical Report on Task #4 Findings (ML093510164).
Task 1E, Wear Ring Clearance	Not Used	Not significant as long as the pump meets ASME Section XI In-service Testing Limits, not listed in Budris’ recommended uncertainties.
Task 2, Speed	$\pm$ 0.88’	Task 2 report applied to MNGP RHR pump based on speed assumed in MNGP TS 3.8.1 Surveillance Requirement (2% fast). Appropriate to treat as random uncertainty (square root sum of the squares – SRSS) with other issues.
Task 6, Vendor Test Instrument	$\pm$ 0.98’	Task 6 report applied to MNGP RHR pump. Appropriate to treat as random uncertainty (SRSS) with other issues.
Total uncertainty	4.62’	This is 21% using SRSS

Proposed Path Forward

- Compliance with SECY 11-0014 demonstrated by:

SECY Section	How Complying
6.6.1 $NPSHr_{eff}$	Develop 21% uncertainty analysis – includes Task 2, Task 5 and Task 6 from BWROG work to justify low uncertainties and robustness of pumps. Does not include wear ring leakage uncertainty based on successful ASME (IST) pump testing.
6.6.2 Pump Flow Rate	Flow rate assumed in the EPU safety analyses demonstrates adequate core and containment cooling. No change in EPU analysis for NPSHa is anticipated.
6.6.3 Conservative Containment Press	95/95 Monte Carlo Analysis – MNGP results shown in NEDC - 33347P, Containment Overpressure Credit for NPSH or use of license basis deterministic analysis.
6.6.4 Containment Integrity	Demonstrate containment is not compromised in DBA LOCA. For Appendix R events - will demonstrate that any containment leakage will not result in loss of core cooling capability.
6.6.5 Operator Actions	No new operator actions are required. For beyond-design-basis containment failure operator actions can be added (e.g. raise torus water level) to enhance EOP response if inadequate NPSH is detected.

Proposed Path Forward

- Compliance with SECY 11-0014 demonstrated by:

SECY Section	How Complying
6.6.6 NPSHa < NPSHr	No testing required - Analysis to demonstrate ECCS pumps will run for full mission time included in 6.6.10, Task 3 and Task 5 from BWROG work supports operation when NPSHa < NPSHr.
6.6.7 No Pre-existing Leak	Will demonstrate: (1) sufficient margin in results from 6.6.4, (2) minimum containment leakage that will provide sufficient CAP, (3) surveillance test that can detect leakage $<L_a$ using nominal instrument indications and existing TS limits, and (4) enhanced online monitoring of containment leakage.
6.6.8 Max Erosion Zone	Task 4 from BWROG work determines effects of operation in the maximum erosion zone.
6.6.9 NPSH Margin	Use 95/95 Monte Carlo analysis to compare with NPSHa – NRC has said that "realistic" analysis may be eliminated.
6.6.10 Mission Time	Task 3 and Task 4 from BWROG work and CS pump similarity analysis provide basis for pump performance for full 30 day mission time.

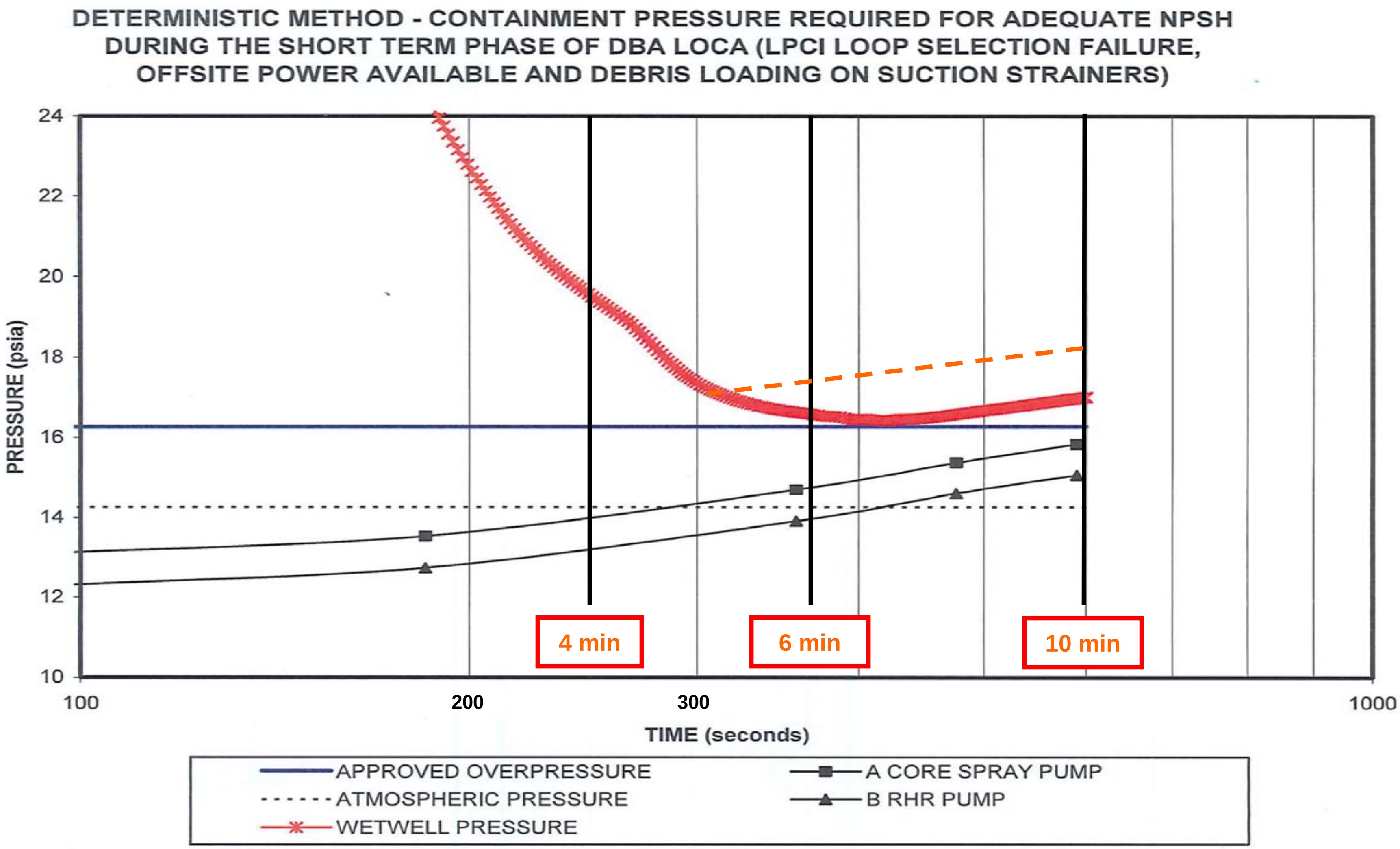
Proposed Path Forward

Basis for Proposed Approach

- Adequate core cooling is demonstrated by meeting SECY 11-0014, Enclosure 1 criteria as described.
- Use of CAP results in a “very small” increase in CDF as defined by RG 1.174*
- Use of CAP does not challenge the accepted definition of defense-in-depth.
- Online monitoring for containment integrity.
- Enhance the procedural response to mitigate inadequate NPSH under beyond-design-basis containment failure conditions.
- Provide training to increase Operator awareness and sensitivity to NPSH concerns, that includes pump NPSH monitoring and containment integrity monitoring.
- Emergency Operations Procedures provide alternate methods to cool the core.

*** NRC staff presentation to ACRS found in ML101830190**

Design Basis Accident (DBA) Loss of Coolant Accident with 3% NPSHR Curves (LOCA)



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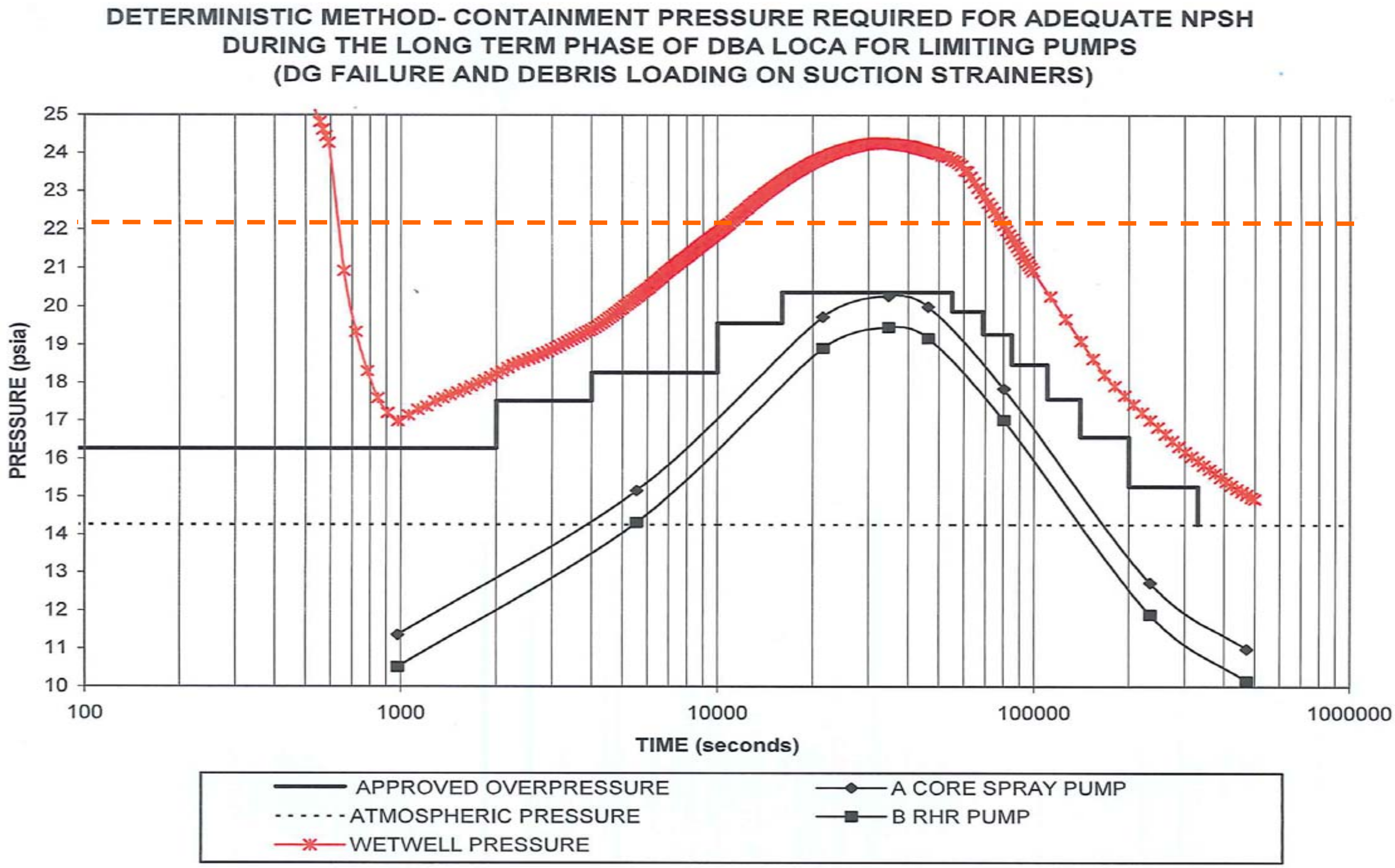

Proposed Path Forward

- Current Proposed Schedule:

Date	Deliverables
May 2012	21% Uncertainty analysis complete
June 2012	BWROG Task Reports complete
July 2012	Revised ECCS analysis complete
August 2012	CS Pump similarity analysis complete
September 2012	Provide CAP Submittal to NRC
March 2013	NRC Draft Safety Evaluation
April 2013	ACRS EPU subcommittee review
May 2013	ACRS full committee review
June 2013	NRC issues EPU License Amendment

Discussion