

ECCS Strainer Blockage: Overview of Activities

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Presentation Outline

- Three Main Periods for Addressing Post-Accident Long-Term Cooling Issues
 - Unresolved Safety Issue A-43 (1979 1985)
 - Boiling-Water Reactor ECCS Strainer
 Blockage Issue (1992 2001)
 - Generic Safety Issue 191, Pressurized-Water
 Reactor Sump Performance (1996 Present)
- Objective: Discuss NRC Activities and Lessons Learned from Each Period



Regulatory Guide 1.82, Revision 0

- Regulatory Guide (RG) 1.82, Revision 0, was issued in June 1974
- Purpose was to provide guidance for emergency core cooling system (ECCS) sump design
- Regulatory Positions addressing debris accumulation and filtration, structural adequacy, vortexing, and material degradation
- Recommended only half of available vertical screen area should be credited to account for partial screen blockage
 - Origin of the "50% blockage assumption"



Unresolved Safety Issue A-43

- Unresolved Safety Issue (USI) A-43 was opened in 1979 due to evolving staff concerns with strainer designs
- Variety of technical issues considered, including primarily:
 - Vortex formation and air ingestion
 - Sump screen blockage by debris
 - Ingestion of debris in pumps



USI A-43 Activities

- Significant analytical and experimental work completed, summarized in NUREG-0897
 - Debris generation testing and analytical modeling
 - Debris transport testing and nodal network analysis
 - Debris head loss testing and correlation development
 - Vortex testing and analysis
 - Pumping performance with ingested air and/or debris
 - Plant insulation surveys
 - Sample plant sump performance calculations
 - Probabilistic analysis
- In all, approximately a dozen NUREG reports written based on USI A-43 work

- Some reports still provide useful technical insights



USI A-43 Conclusions

- <u>Generic Letter (GL) 85-22</u> issued in 1985 to document closure of USI A-43
- Significant conclusions / outcomes:
 - A single generic solution for post-LOCA debris issues is not possible
 - The "50% blockage assumption" in RG 1.82, Rev. 0, was recognized to be usually non-conservative
 - RG 1.82 was updated to include revised technical information and a recommendation that plant-specific evaluations of sump performance be completed
- Generic backfitting of revised regulatory positions was not considered cost-justified
 - However, consideration of <u>RG 1.82, Rev. 1</u>, recommended for plants changing out insulation, etc.



BWR Strainer Issue – Operating Events

- In the early 1990s, operating events resulted in reconsideration of strainer blockage issue for BWRs
 - July 1992: Barsebäck
 - Inadvertent safety valve opening, strainer backflushing necessary
 - Reference: Information Notice (IN) 92-71
 - 1992 1993: Perry (two events)
 - Strainer deformation due to debris plugging in suppression pool cooling mode
 - References: <u>Bulletins 93-02</u> and <u>93-02 Supplement 1</u>, <u>IN 93-34</u> and <u>93-34 Supplement 1</u>
 - September 1995: Limerick
 - Inadvertent SRV opening, decreasing suction pressure for suppression pool cooling
 - References: <u>Bulletin 95-02</u>, <u>IN 95-47</u>
- Events apparently much less severe than largebreak LOCA, yet strainers were still challenged



BWR Strainer Issue – Actions Requested

- Due to safety significance, NRC issued several bulletins to request actions from BWR licensees concerning strainer blockage:
 - Bulletin 93-02
 - Requested removal of fibrous air filters or other temporary fiber sources
 - Bulletin 93-02, Supplement 1
 - Requested interim operator actions to reduce risk of debris blockage
 - Bulletin 95-02
 - Requested ECCS operability review, suppression pool cleaning, FME procedure review, etc.
 - Bulletin 96-03
 - Requested plant modifications to address debris blockage (i.e., installation of a larger passive strainer, an active strainer, or a backflush system)



BWR Strainer Issue – Operating Event Lessons

- Larger quantities of debris could reach the ECCS strainers than predicted using USI A-43 methods
- Fibrous debris beds can filter particulate
 - USI A-43 head loss correlations underpredicted head loss for fiber/particulate beds
 - Relatively small quantities of debris can form a "thin bed" resulting in significant strainer head loss
- Despite plant foreign material exclusion (FME) programs, significant foreign materials found in many plant containment buildings



BWR Strainer Issue – Key Technical Work

- Significant testing and analysis completed by NRC and industry
- BWR Parametric Study, NUREG/CR-6224
- Debris generation testing with air jets
- Drywell Debris Transport Study, NUREG/CR-6369 (ML003728226)
- Head loss testing in vertical loop and for strainer modules
 - Vertical loop testing formed basis for NUREG/CR-6224 correlation
 - Correlation validated for shredded lowdensity fiberglass and iron oxide particulate
- <u>Regulatory Guide 1.82, Rev. 2</u>, issued to incorporate technical findings





BWR Strainer Issue – USNRC Utility Resolution Guidance

- In November 1996, BWR Owners' Group completed Utility Resolution Guidance (URG) report
 - Provided methodology for strainer analysis to BWR licensees
 - Key aspects of methodology included
 - Selection of limiting break
 - Debris generated by LOCA
 - Transport of debris to strainers
 - Debris head loss and pump NPSH estimation
- Staff completed safety evaluation for URG in August 1998



BWR Strainer Issue – Resolution

- Resolution of BWR ECCS Strainer Issue documented in October 2001 memorandum
- All BWR licensees installed significantly larger passive strainers
- Audits conducted to verify adequate implementation of URG guidance
- Technical report attached to October 2001 memorandum (ML012970246) summarizes BWR ECCS Strainer Issue and actions taken for resolution



Strainer Installation at Pilgrim Nuclear Power Plant

USNEC Generic Safety Issue 191 – Value for the Basivesses

- NRC staff recognized that updated findings for BWRs could be a concern for PWRs also
- Therefore, Generic Safety Issue (GSI) 191 was opened in September 1996 to reexamine adequacy of PWR sump performance



GSI-191 – Technical Assessment

- PWR Parametric Study (<u>NUREG/CR-6762</u>) demonstrated the potential for sump clogging
 - Parametric study used a mixture of generic parameters and plant-specific information from licensee surveys
- Associated probabilistic analysis (<u>NUREG/CR-6771</u>) demonstrated potential increase in core damage frequency due to sump blockage
- In September 2001, <u>technical assessment</u> was completed for generic issue
- Conclusion: Plant-specific analyses should be undertaken to ensure adequate sump performance for PWRs



GSI-191 – Regulatory Approach

- Address risk significance of post-LOCA debris in the near-term
 - Bulletin 2003-01 issued June 9, 2003

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sumpperformance/bulletin03-01-correspondence.html

- If regulatory compliance could not be assured, interim compensatory measures were requested to reduce potential risks associated with post-LOCA debris
- Risk benefit of operator recovery actions demonstrated in Los Alamos National Laboratory report (<u>LA-UR-02-7562</u>)
- Request plant-specific evaluation of sump strainer performance after development of detailed industry guidance through generic letter
 - Generic Letter 2004-02 issued September 13, 2004 http://www.nrc.gov/reactors/operating/ops-experience/pwr-sumpperformance/generic04-02-correspondence.html



GSI-191 – Technical Issues

- Although originally focused on loss of pump NPSH, GSI-191 expanded to encompass additional technical issues
 - Blockage and other adverse debris effects in systems downstream of the sump screen
 - Hold up of water at the refueling canal drain and other "chokepoints" upstream of sump screens
 - Failure modes for partially submerged screens
 - Strainer structural deformation or failure
- Emerging issue of chemical precipitation impact also later considered part of GSI-191



GSI-191 – Guidance Documents

- Guidance was developed to outline acceptable approaches for analyzing sump performance in response to GL 2004-02
 - RG 1.82, Rev. 3, was issued in November 2003
 - Updated to include recent findings from GSI-191 technical assessment
 - Nuclear Energy Institute (NEI) 02-01 was issued in September 2002
 - NEI 02-01 provided guidance for performing containment walkdowns to assess insulation, sump screen condition, latent debris, etc.
 - NRC staff provided comments on NEI 02-01 guidance

GSI-191 – U.S.NRC U.S.NRC From the Environment Count of the Environment Count of the Environment

- NEI 04-07 guidance report (ML041550661) and associated <u>NRC staff safety evaluation</u> (SE) were finalized in December 2004
 - Together, NEI 04-07 and SE provide a detailed methodology that is acceptable for sump evaluations
 - NEI 04-07 includes methodology for
 - Selecting limiting breaks
 - Debris generation
 - Debris characterization
 - Debris transport

- Latent debris
- Head loss
- Alternate break size
- Additional design considerations
- NEI 02-01 walkdown results are an input to analysis
- Essentially all U.S. PWR licensees are using this general approach to respond to GL 2004-02



GSI-191 – Beyond NEI 04-07

- NEI 04-07 and SE do not cover all aspects of post-LOCA debris evaluation, including several major areas:
 - Chemical effects
 - Head loss testing methodology
 - Downstream effects
- Additional guidance was developed to address these areas
 - In some areas, additional research was performed to support guidance development



GSI-191 – Chemical Effects (1)

- Question on post-LOCA chemical precipitation raised by Advisory Committee on Reactor Safeguards in 2002
 - Basis was observation of gelatinous substance in Three Mile Island Unit 2 containment pool
- Integrated Chemical Effects Test (ICET) program examined 5 generic post-LOCA environments
 - Various pH buffers and material dissolution conditions
 - Evidence of precipitation observed for some tests
 - Head loss was not measured
- ICET results documented in <u>NUREG/CR-6914</u>
 - Detailed report comprises 6 volumes in total



GSI-191 – Chemical Effects (2)



ICET Tank



ICET Tank Coupon Rack



ICET Loop Schematic Diagram



Gel Removed From Tank After ICET 3



GSI-191 – Chemical Effects (3)

- Based on results of ICET program additional work was conducted to measure chemical precipitate head loss
- <u>NUREG/CR-6913</u> documents vertical loop head loss testing with chemical precipitates and other debris conducted at Argonne National Laboratory
- A number of additional technical letter reports discuss further head loss experiments conducted with chemical precipitates:

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sumpperformance/tech-references.html#tests

 Conclusion: Chemical precipitates can significantly increase measured head loss ANL Test Facility







GSI-191 – Chemical Effects (4)

- Industry has implemented several general approaches to model chemical effects for strainer head loss testing
 - WCAP-16530 approach to produce surrogates
 - Staff has accepted approach in <u>SE on WCAP-16530</u>
 - In-situ precipitation
 - Reasonable in concept
 - Potential challenges in controlling resulting precipitate characteristics
 - Representative environment to model dissolution and precipitation
 - Physical modeling is most similar to plant condition
 - Complex chemistry, potential challenges in measuring head loss impact
- Staff has prepared chemical effects review guidance dated March 28, 2008, to evaluate various industry approaches

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/techreferences.html#misc



GSI-191 – Head Loss Testing (1)

- NRC safety evaluation (SE) on NEI 04-07 guidance report recommended that plantspecific strainer testing be performed
 - NUREG/CR-6224 head loss correlation was not considered acceptable for strainer qualification due to a number of limitations
- However, guidance for performing acceptable tests was not provided in SE
- Industry did not obtain NRC acceptance of protocols prior to performing head loss tests



GSI-191 – Head Loss Testing (2)

- Between 2005 and 2008, NRC staff took roughly 20 trips to observe head loss testing at vendor facilities
- Objective was to ensure head loss test conditions are prototypical of plant post-LOCA conditions
- Observations on test protocols and results are typically documented in public trip reports: http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/tech-references.html#trip
- Insights from vendor testing observations were incorporated into staff head loss review guidance dated March 28, 2008

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sumpperformance/tech-references.html#misc

 Review guidance outlines head loss testing approaches considered acceptable by NRC staff



GSI-191 – Head Loss Testing (3)













Strainer Head Loss Testing Images



GSI-191 – Downstream Effects

- For GSI-191 review, downstream effects are categorized as either ex-vessel or in-vessel
 - Ex-vessel downstream effects considers impacts of post-LOCA debris on systems and components (excluding the reactor vessel) that handle sump fluid, for example
 - Erosion of pump bearings
 - Debris blockage at valves or instrument lines
 - In-vessel downstream effects considers impacts of post-LOCA debris in the reactor vessel, for example
 - Formation of debris bed on fuel assemblies
 - Localized debris accumulation on a fuel rod causing local heat-up



GSI-191 – Downstream Ex-Vessel

- Industry developed topical report WCAP-16406 to provide methodology for performing analysis of ex-vessel downstream effects
- Staff issued safety evaluation (SE) on WCAP-16406 in December 2007

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/regsguidance.html#five

PWR licensees are typically using this topical report for downstream evaluations



GSI-191 – Downstream In-Vessel

- In-vessel topical report WCAP-16793 was submitted to NRC in June 2007
- NRC staff completed draft SE in March 2008
- ACRS identified issues that had not been fully addressed by WCAP-16793
- Industry performing additional testing and analysis to address ACRS concerns and will resubmit revised topical report
- Staff will review revised report and issue final SE once outstanding issues have been addressed
- Staff is preparing generic communication to PWR licensees to outline path forward in this area



GSI-191 –

GL 2004-02 Review Activities

- Audits
 - Two pilot audits completed
 - Nine full-scope audits completed
 - Staff planning three chemical effects audits
 - Completed audit reports on NRC sumps website http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/tech-references.html#audit
- Detailed GL 2004-02 Response Reviews
 - September 2005 responses
 - Supplemental responses from February 2008
 - Additional supplemental responses
 <u>http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/generic04-02-correspondence.html</u>
- Inspections to verify implementation of plant corrective actions



Planned Revision of **Regulatory Guidance** Regulatory Guide (RG) 1.82

- Provides regulatory guidance on ECCS strainer design for operating reactors and new reactor applications
- Currently plan to complete draft Revision 4 of RG 1.82 in June 2009
- Standard Review Plan, Section 6.2.2
 - Contains review criteria for NRC staff for ECCS strainer performance
 - Currently plan to undertake Standard Review Plan update after closure of GL 2004-02 supplemental response reviews



GSI-191 -

Additional Technical Reports

- A number of additional technical reports describing GSI-191 research have been completed, covering a number of subject areas including:
 - Head loss testing
 - Head loss correlation development
 - Debris transport to the sump strainer
 - Chemical effects
 - Characterization of latent debris
- <u>NUREG/CR-6808</u> provides a broad overview of state of knowledge for post-LOCA debris in 2003
- Reports are available on NRC sump website <u>http://www.nrc.gov/reactors/operating/ops-experience/pwr-sump-performance/tech-references.html</u>



GSI-191 – Impact on BWRs?

- GSI-191 resolution efforts improved state of knowledge for ECCS strainer performance issues
- New information raised questions on previous BWR resolution
 - Some issues were not considered during BWR issue resolution, for example
 - Downstream effects
 - Chemical effects
 - Other issues were considered but resolution was not consistent with PWR approach, for example
 - Head loss testing protocols
 - Zone of influence for pipe ruptures



BWR Scoping Study

- NRC contracted with Pacific Northwest National Laboratory to evaluate discrepancies between methodology used for resolution of strainer performance issues for BWRs and PWRs
- NUREG/CR report with recommendations expected to be complete in Spring 2009



BWR Owners' Group Activities

- In parallel with NRC scoping study, BWR Owners' Group has begun analyzing discrepancies between BWR and PWR resolution approaches
- Purpose is to ensure adequacy of BWR resolution in light of new information
- BWR Owners' Group developed 3-year schedule to complete all aspects of evaluation
- Regular discussions planned with NRC staff



Conclusion

- The NRC and industry have undertaken significant efforts to ensure the adequacy of ECCS strainers
 - USI A-43
 - BWR Strainer Issue
 - Generic Safety Issue 191
 - Study of BWR/PWR Resolution Discrepancies
- Completion of GSI-191 activities and any follow-on work identified for BWRs will provide reasonable assurance of adequate ECCS strainer performance for U.S. nuclear reactors



Postscript – New Reactor Designs

- NRC staff is presently performing design certification reviews for a number of new reactor applications:
 - * Advanced Passive 1000 (AP1000)
 - U.S. Evolutionary Power Reactor (U.S. EPR)
 - U.S. Advanced Pressurized-Water Reactor (US-APWR)
 - Economic Simplified Boiling-Water Reactor (ESBWR)
- Staff is considering current state of knowledge regarding ECCS strainer performance in reviewing adequacy of design applications for new reactors

* Design Certification Amendment Review



Access to NRC Documents

- Documents generated by NRC are typically publicly available
- Many public documents associated with GSI-191 may be found on the NRC's PWR Sump Performance Website:

http://www.nrc.gov/reactors/operating/ops-experience/pwr-sumpperformance.html

 Public documents not posted on sump website are available online through our ADAMS document management system: http://www.nrc.gov/reading-rm/adams/web-based.html



Abbreviations

- ACRS Advisory Committee on Reactor Safeguards
- BWR boiling water reactor
- ECCS emergency core cooling system
- FME foreign material exclusion
- GL generic letter
- GSI-191 Generic Safety Issue 191
- ICET integrated chemical effects test
- IN Information Notice
- LOCA loss-of-coolant accident
- NEI Nuclear Energy Institute
- NPSH net positive suction head
- NRC U.S. Nuclear Regulatory Commission
- PWR pressurized-water reactor
- RG Regulatory Guide
- SE safety evaluation
- URG Utility Resolution Guidance
- USI A-43 Unresolved Safety Issue A-43