Generic Safety Issue 191: Risk Informed Application at South Texas Project

Mary Anne Billings*[a], Kristin Kaspar[a], and Ernest John Lowry Kee[b]

[a] STP Nuclear Operating Company, Wadsworth, USA

[b] University of Illinois, Urbana-Champaign, USA

Abstract: Purpose of paper is to discuss risk-informed response to GSI-191, which NRC established in 1996 to address effects of debris accumulation on PWR sump performance during design-basis accidents. In response to GL 2004-02, STP replaced original strainers with 1880 ft^2 strainers. STP became pilot plant for risk-informed approach to close out GSI-191 and GL 2004-02. Key tenant was that safety benefit provided by containment insulation removal does not justify the radiation exposure. STP developed RoverD (risk over deterministic) methodology for the risk-informed approach. Breaks of all sizes and orientations were evaluated at RCS welds using detailed CAD modeling. Breaks that generate less than 191.78 lbm of fine fiber pass deterministic criteria. Breaks that generate more fine fiber are assumed to result in core damage. ΔCDF and ΔLERF were calculated based on summing LOCA frequencies of smallest breaks that generate greater than 191.78 lbm fine fiber; results were compared to RG 1.174 and were determined to be "very small." NRC approved STP's LAR in July 2017, eliminating need to replace fibrous insulation in both units and avoiding 176 REM exposure. Estimated cost savings is approximately $43 million. Risk-informed approach used for GSI-191 will help identify additional ways to risk-inform current regulations.

Keywords: GSI-191, Risk-informed application, cost savings.

1. INTRODUCTION

Following several incidents in Boiling Water Reactors (BWRs) where debris caused pump cavitation due to plugging of the RHR and containment vessel spray system pump strainers the NRC issued Bulletins 93-02 and 96-03. These two bulletins and follow-on supplements requested BWRs to remove temporary fibrous material and minimize potential for strainer clogging. Later, concerns were raised regarding potential debris plugging Pressurized Water Reactor (PWR) Emergency Core Cooling (ECCS) strainers in the unlikely event of a loss of coolant accident (LOCA). In 2001, the NRC issued Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance. The safety concerns resulted in NRC Generic Letter (GL) 2004-02 issued under 10CFR50.54(f) for review and as necessary, corrective actions to be taken by the PWR fleet to address the concerns raised in GSI-191. Plants like STP with large amounts of fibrous insulation in the reactor containment building (RCB) faced the greatest challenges addressing GL 2004-02.

Resolution of GSI-191 involves safety concerns related to potential clogging of the emergency core cooling (ECCS) sump strainers, potential clogging of fuel assemblies and debris build up on fuel pins, wear or plugging of the components of the ECCS and CSS, and upstream holdup of ECCS recirculation fluid [1,2,3]. The challenge at the strainers is that debris build up in the strainers causes increased head loss and potential loss of ECCS pump and containment spray (CSS) pump net positive suction head margin (NPSHM). The challenge in the core is primarily associated with cold leg breaks (CLBs) because debris bypassing the ECCS sump strainers can collect on the fuel assemblies reducing flow and increasing clad heat transfer resistance. Any of these effects can result in loss of the long-term cooling safety function required by 10 CFR 50.46.

In the initial response to GL 2004-02, STP replaced the original 56ft^2 ECCS sump screens with very large (1880 ft^2) ECCS sump screens and tested them to maximum assumed debris loads based on the

* mabillings@stpegs.com

state of knowledge at the time [4]. The replacement screens are designed to accommodate very large amounts of debris compared to the original screens. Although it was removed subsequent to testing, STP included Marinite (Calcium Silicate) insulation which is known to cause large head losses in the tests. A key assumption used in the test design is that the non-dimensional destruction zone of influence (ZOI) for unjacketed NUKON fiber insulation is 7D, where D is the break size. After completing the tests, the acceptable ZOI assumption was set to 17D, rendering the deterministic tests non-conservative for the fiber assumption [5]. Several NRC questions related to the testing and STP's resolution of GL 2004-02 were raised in late 2009 [6]. Although STP responded to these questions, some remained unanswered [7].

1.1. Risk-Informed Option Paths

In late 2010, the NRC Commissioners directed the staff to investigate closure options for GSI-191 to include risk-informed methods [8]. Based on its extensive experience in Probabilistic Risk Assessment (PRA) applications and risk management, STP proposed to pilot a risk-informed closure to GL 2004-02 [9]. In 2011, the NRC established pilot status to the proposed STP risk-informed methodology [10,11]. Based on STP's proposed approach [12] following the Commissioners' request for closure options, the NRC staff promulgated three paths to closure in 2012 including risk-informed methods [13]. The paths were (1) Compliance with 10 CFR 50.46 Based on Approved Models (2) Mitigative Measures and Alternative Methods Approach (3) Different Regulatory Treatment for Suction Strainer and In-Vessel Effects. Within Option 2, two paths were defined, (2a) Deterministic with potential to refine models (2b) Risk-Informed (STP) approach.

1.2. Risk-Informed Pilot

STP partnered with other industry, academia, and national laboratories to establish an academically defensible technical basis to quantify the risk associated with the current STP containment design over 6 years time. STP guided technical approaches and tools under RG 1.174 that would accomplish both a full risk-informed approach and an alternative streamlined approach, Risk over Deterministic (RoverD), to address the risk associated with the concerns raised in GSI-191. By the end of the project the team consisted of: four universities - the University of Texas at Austin, Texas A&M University, the University of New Mexico, the University of Illinois at Urbana-Champaign; the Los Alamos National Lab; three industry consultants - ABS Consulting, Alion Science and Technology, KnF Consultants; and seven utilities - FP&L, WCNOC, Ameren Missouri, DCNPP, PG&E, SNC, and Exelon; were working on the pilot project. The technical team, led by STP, developed innovative risk-informed tools and methods including CASA Grande, the RoverD method, integrating uncertainty quantification results into a PRA, new Thermal-Hydraulic methods including three-dimensional core models, simplified deterministic models, directly coupled containment and RCS models, RUFF and FIDOE. STP Licensing developed necessary exemption requests, UFSAR and Technical Specification changes required for implementa-tion of a risk-informed application under RG 1.174. The tools, technical and licensing methods defined in the full risk-informed and RoverD approaches were detailed in STP application submittals. The ear-liest application and supplement in 2013 used the full risk-informed approach [14,15]. A revised sub-mittal in 2015 using the RoverD approach was approved in 2017 [16,17]. By the end of the project, STP had responded to just over 390 formal questions from the NRC [18].

2. PROJECT HISTORY, STEPS TO CLOSURE

The project history could be thought of as a three step process (1) Initial quantification (2) Full Risk-Informed Application (3) RoverD Supplement Application. Step (1), having the objective to assess feasibility of a risk-informed approach, was begun in 2010 and completed in 2011 [19]. Step (2), the full risk-informed approach continued the project about three years between 2012 and late 2014 and included the initial application and Supplements. Step (3) began in late 2014 and culminated with the RoverD methodology being accepted in STP's final supplement to the application. These steps are summarized in the following sections.

2.1. Step 1, Initial Quantification

In 2011, several crucial ideas and methods were developed and implemented into the full risk-informed methodology. A central idea used in the project was to ensure minimal changes to the STP PRA and a new concept in PRA technology was developed using uncertainty quantification (UQ) (from CASA Grande [20]) to supply conditional failure probabilities to the PRA. Figure 1 shows the conceptual process whereby distributions from simulation were supplied as conditional failure probabilities as split fractions or basic events to the PRA. A CAD model of the STP Reactor Containment Building (RCB) was developed with all insulation located on piping. The CAD model results were incorporated into CASA Grande. The deterministic transport logic trees, ZOIs for different insulation species, and partial break modeling (continuum model) described in NEI 04-07 were implemented in CASA Grande. The methods used in risk-informed in-service inspection to get LOCA frequencies for different break sizes was implemented in CASA Grande and methodology was developed to incorporate frequency estimates for different hypothesized break sizes.

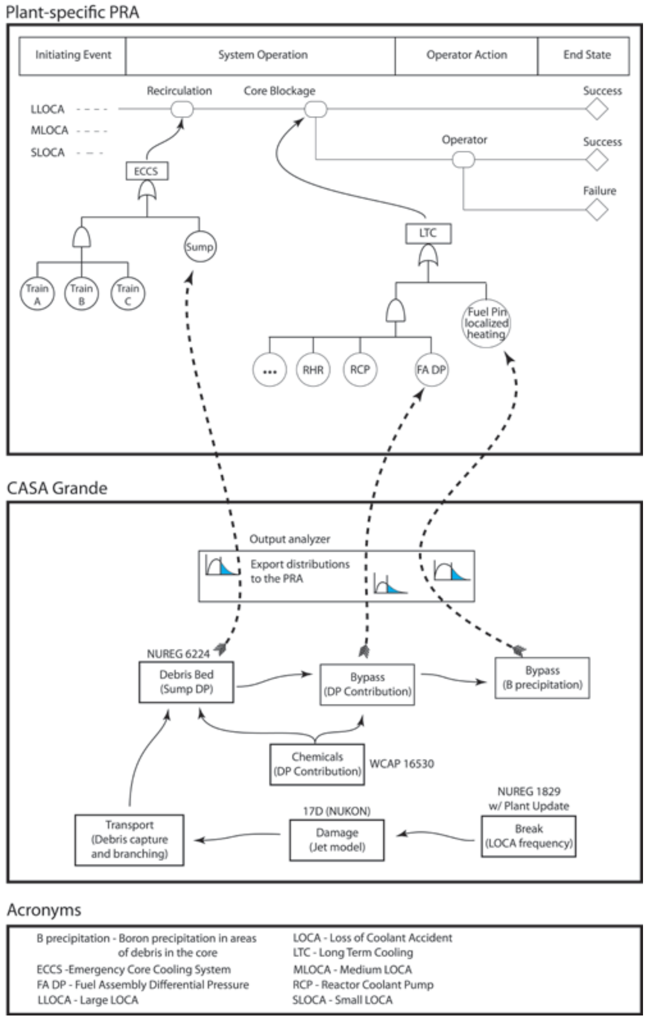

Figure 1. Conceptual design of the integrated UQ and PRA frameworks showing the physical UQ models and connections to the PRA used in the initial quantification.

Work began on a detailed thermal-hydraulic model that would be capable of best estimate analysis of RCS thermal-hydraulic response to small, medium and large hot leg and cold leg breaks. Split fractions were added to the PRA Medium and Large LOCA event trees for top events where ECCS/CSS pump configurations with success frequencies greater than 1E-09 through recirculation switchover were retained with others set to failure. The NEI 04-07 methodology was implemented in CASA Grande. CSS pumps, not normally important in Level 1 PRA for success were added because they play a role in NPSHM, debris accumulation timing and amounts on the strainers and core.

Late in 2011, approximately one year following start of the project, the STP team had quantified estimates for CDF and LERF using an initial full risk-informed methodology. Because most of the deterministic questions supporting the defense-in-depth and safety margin parts of RG 1.174 were developed for the initial response to GL 2004-02, STP was most concerned with the risk quantification part for making the feasibility determination for going forward with the risk-informed path. The initial quantification assumed chemical effects were negligible based on testing performed in 2006 [21]. The NRC staff was reluctant to accept results that ignored the effects of chemicals and the team began developing plans to perform chemical effects testing.

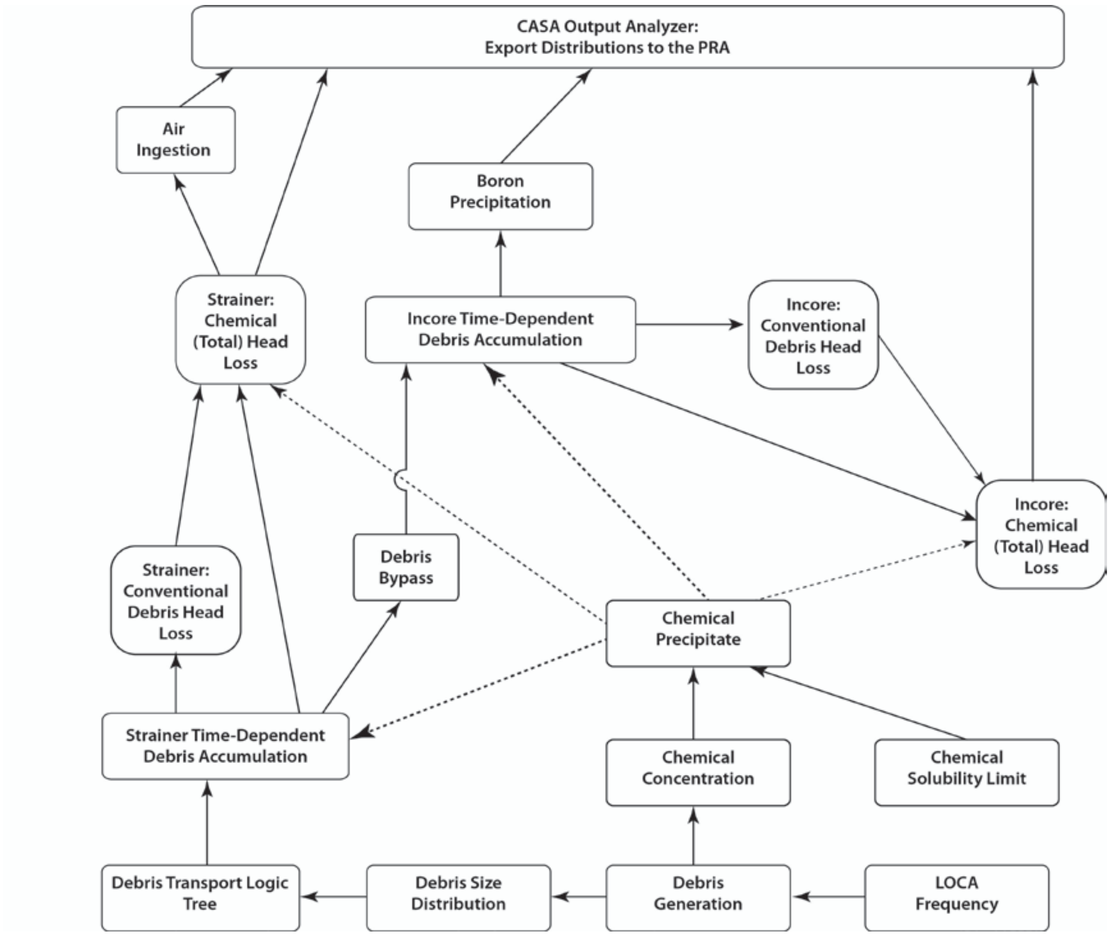

Figure 2. Models developed or expanded upon in the UQ for the full risk-informed method during Step 2. Causal connections among the models are shown with either dotted or solid lines to indicate "to/from" connections.

The initially quantified CDF was 4.96E-07 yr^{-1} and LERF was 3.10E-10 yr^{-1} indicating the project should continue with the risk-informed path. In the five years that followed, these numbers would remain essentially unchanged, ending at 1.5E-07 yr^{-1} and 3.75E-10 yr^{-1} in the final application.

2.2. Step 2, Full Risk-Informed Application

Step 2 started immediately following notification to the NRC of STP's intent to continue with the risk-informed path. Boron precipitation was added as another model in the UQ and several refinements were made to the existing models. Chemical effects were added and different types of debris were included in the generation and transport models. The models under development are shown in Figure 2 with causal connections. During 2012, the thermal-hydraulics model continued to be developed. New thermal-hydraulics models were developed that included a new method that used a two-dimensional downcomer, and lower and upper plena models in cylindrical coordinates connected to a three-dimensional core model that used Cartesian coordinates. The core model included channels for all 193 fuel assemblies with 21 cells each (4,053 cells). New results for core blockage scenarios showed that the limiting scenarios for full core and core barrel-baffle bypass blockage at sump switchover to recirculation mode were medium and large cold leg breaks [22]. This meant that hot leg breaks and small cold leg breaks could be eliminated from consideration for core blockage in the risk analysis. It was additionally shown that a single unblocked fuel assembly, either at the periphery or the center of the core provides sufficient cooling to keep peak cladding temperature (PCT) below 800 F. In addition, the RELAP5-3D RCS model was coupled to a MELCOR RCB model, a new method that relaxes the (uncoupled) M&E release method assumptions commonly used in industry analyses. During the LOCA blowdown phase, the RCS can reasonably assumed to be uncoupled from the RCB. However, this is the case after critical flow ceases and ECCS recirculation switchover starts.

Because boric acid precipitation became a concern in 2013 added to the debris effects called out in GSI-191, an experimental facility was created to observe boric acid precipitation in a bench-top heated core simulator (PASTA facility) [23]. The experiments conducted showed that flow in the core is not appreciably impacted by precipitation even when highly concentrated (well beyond solubility limit concentrations) boric acid is present. Testing was performed to understand the effects of boric acid on transport properties of RCS coolant [24]. This testing showed that effects on the coolant viscosity in boric acid solutions buffered with Trisodium Phosphate or NaOH could be safely ignored in thermal-hydraulic LOCA calculations.

Full-scale and bench-scale testing for debris bypass through the ECCS sump screens was performed. Bench-scale tests showed that full-scale testing could be done using tap water [25]. Full-scale test data were fit to a function that gave filtration efficiency as a function of mass collected on the strainer [26]. These results, used in CASA Grande simulations for debris collection on the ECCS sump screens, showed that the debris buildup occurred over time rather than immediately. Time dependence was simulated solving mass conservation equations for the core (assuming 100% collection efficiency), the RCB floor pool, and the ECCS sump screens. Time-dependent debris collection was a new innovation in GSI-191 analysis.

Planning for integrated and separate effects testing for chemical effects began. By mid-2014, several integrated and separate effects (bench-top) tests had been completed. The integrated chemical effects tests simulated LOCAs and had representative amounts of materials including fiber and zinc and were run for 30 days. The tests continued to confirm earlier assumptions that chemical effects on screen head loss could be ignored. To demonstrate that chemicals could be formed in quantity in the apparatus, 10-day "extreme condition" tests were run to show that, under non-prototypical conditions, chemical precipitates could be formed. They additionally confirmed the accuracy of the chemical precipitate prediction models (primarily Visual MINTEQ) used for the test designs. Several new results were found related to the morphology of the chemical precipitates formed in-situ as opposed to those created ex-situ using industry test procedures [27,28]. Although the testing confirmed earlier results regarding chemical effects on debris bed head loss, chemical effects continued to be assumed in the CASA Grande simulations in Step 2.

Refinements were made to the CASA Grande model including the effect of robust barriers in the debris generation model. Although many structures are present that would block LOCA jets, only the presence of concrete walls was assumed. That is, other than concrete walls, pipes, components, beams, and supports were assumed to be "transparent" to the LOCA jets. In addition, at the end of 2012, the risk-informed ISI LOCA frequency model was abandoned in favor of a LOCA-Hybrid model that can support arbitrary "weights" at any location but return NUREG-1829 frequencies when all frequencies are summed [29]. In so doing, NRC staff concerns about using a new model for LOCA frequency were resolved although uncertainty regarding the appropriate model of aggregation and break characteristic persisted into Step 3.

By the end of 2014 the main issue unresolved in the full risk-informed method was inadequate bounding of uncertainties. The head loss developed in-core or on the ECCS sump strainers is a function of the type and amount of debris, the timing of arrival, and the flows through the strainer or core. The amount of testing required to develop a fully adequate understanding of the physics involved (with certainty) was truly vast. The NRC, working with industry over several years had arrived at a consensus model for bounding the uncertainties as opposed to using correlations. The consensus model requires very conservative assumptions about chemical amounts and morphologies, the amount and types of debris, timing of debris arrival, and conditions assumed for NPSHM calculation. The consensus models are intended to bound the known lack of epistemic understanding.

2.3. Step 3, RoverD Application

By end of summer of 2014, the team had answered many questions on the full risk-informed path but the NRC staff indicated that uncertainty regarding head loss correlations would be difficult to understand with the information available from the existing test database [30]. Questions continued about the use of NUREG-1829 break frequencies, completeness, key assumptions, and inclusion of boric acid precipitation. Sampling correlation between the conditional failure probabilities from the UQ and the PRA was raised as a cross-cutting issue in RAI responses. Results of the meetings with NRC staff held in 2014 indicated that resolving issues regarding uncertainties in the full risk-informed path would potentially delay the schedule for closure including a test campaign that could run for many years [31]. The team realized the path should be revisited and proposed the first concept for a path that came to be known as "RoverD" [32].

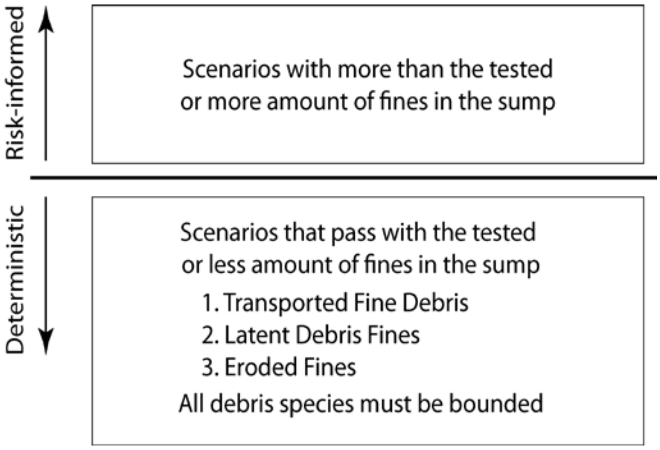

Figure 3. Concept of RoverD. If a scenario cannot meet deterministic criteria it is assigned to the category "risk-informed". Otherwise, the scenario is assumed as success.

RoverD follows the concept shown in Figure 3. A break is analyzed to understand if it can meet deterministic criteria (consensus models) or not. If not, the scenario is assigned to a risk-informed category where the frequency of failure is assigned to core damage. The first concept for RoverD was to base the risk on the deterministic test described in Reference 4 and simply scale [see 33] the break size for the ZOI from the test to the ZOI recommended in Reference 5. Because several debris species could be generated in different amounts, STP recommended scaling based on fine fiber amounts. Fine fibers are the most easily transported fibrous debris and were used as a basis for fuel testing (for example, see Reference 1). STP proposed that any break sizes larger than the scaled size would be assigned to core damage and the frequency would be assigned to the NUREG-1829 frequency of the scaled break size.

Based on discussions held during and following the December meeting where RoverD was first introduced, a draft white paper was prepared outlining the RoverD path [34, Attachment 7]. The white paper showed how CASA Grande can be used in "deterministic mode" to transport each debris species to the sump using the transport logic recommended in Reference 5. Specialized models for break frequencies (Reference 34) and debris mass conservation [35] were developed and used to bound uncertainties for debris collection, bypass, and ECCS and CSS pump flows. A new methodology was introduced for break size evaluation shown in Figure 4. In the new method, a search performed by CASA Grande for the smallest break size at any location (Figure 4a) that would exceed the tested amount of debris species used in Reference 4 was set as the break size at that location for the purpose of determining break frequency (at the location). As shown in Figure 4b, some break sizes may be larger but produce less debris than that produced for the smallest break that just exceeds to the tested amount. However, assigning all such scenarios (which would, of course, have lower frequency of failure) to failure, the number of scenarios requiring evaluation is dramatically reduced. The technology requires a fine mesh search on break size and break diameter at each weld location in the CASA Grande model. In addition, beyond design basis evaluations were performed for single train ECCS/CSS operation using an assumed "quasi-tested" amount of fine fiber equal to ½ the amount tested in Reference 4. The RoverD method, by the assignment of scenarios to deterministic and risk-informed categories based on the smallest break size at any "failure location" substantially reduced the scenarios to be examined over the full risk-informed path. That is, in the full risk-informed path all break sizes and orientations at every location were potentially at risk. In the RoverD method, of the approximately 628 break locations, only 53 scenarios needed to be categorized for risk. All break sizes and orientations in the other locations (575)

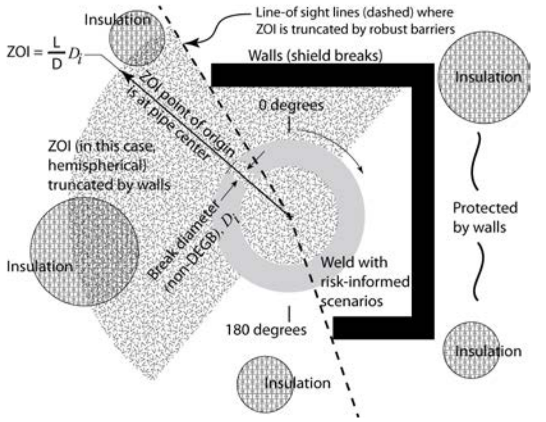

Figure 4a. Depending on the angle, break size, location of debris targets, and robust barrier locations, different amounts of debris will be formed.

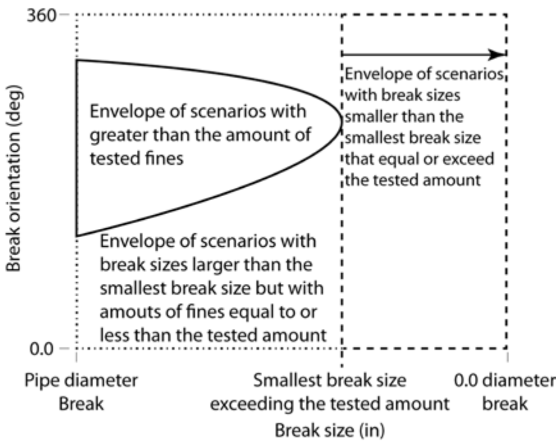

Figure 4b. Some break sizes larger and angles different than the smallest one producing more debris than tested may result in less debris. It is therefore "conservative" to use the smallest break size at any angle that just exceeds the tested amount.

Figure 4. Technology used to set the break size used to find LOCA frequency for risk-informed scenarios.

were deterministically successful in RoverD. In addition, the RoverD path uses un-weighted break frequency allocation from NUREG-1829 tables among locations referred to as "top-down" weighting as a conservative approximation (Reference 29). Uncertainty regarding break characteristics and expert elicitation aggregation was bounded by solving all quantiles and models given in NUREG-1829 in RUFF.

A critical element of the RoverD application became the use of RELAP5-3D as an evaluation model for deterministic evaluation of hot leg breaks. This was first identified following the submittal of the STP application Supplement 2 [36]. Each of the RELAP5-3D models for hot leg breaks and the steady state initialization was re-performed as Appendix B calculations under the STP Quality Assurance Program. The original RELAP5-3D/MELCOR coupled model was also used for demonstrating NPSHM with debris present. One of the deterministic requirements that must be met for ECCS sump operability is described in RG 1.82. This regulatory guide requires that a "conservative RCB pressure" should be used with a "conservative sump temperature" in evaluation of NPSHM if it is found that there is insufficient overpressure:

"For certain operating PWRs for which the design cannot be practicably altered, conformance with Regulatory Position 1.3.1.1 may not be possible. In these cases, no additional containment pressure should be included in the determination of available NPSH than is necessary to preclude pump cavitation. Calculation of available containment pressure and sump water temperature as a function of time should underestimate the expected containment pressure and overestimate the sump water temperature when determining available NPSH for this situation."

STP design requires this evaluation to be performed. Of course, using a thermal-hydraulic model of RCB response for low pressure (conservative) would result in a low estimate for sump temperature (non-conservative). STP took advantage of the coupled RELAP5-3D/MELCOR model to make an evaluation that assumes the containment pressure is governed by a "best estimate" pumping and heat exchanger configuration (all equipment operating) and a design basis calculation for sump temperature. The time-dependent pressure and temperature results were used in the evaluation of NPSHM [37, Attachment 1-4, Page 81 of 92].

The RoverD method makes possible setting limits on the amount of LOCA-generated debris allowed at any location in the RCB. It also provides an explicit list of welds for which exception from Federal Regulation 10CFR50.46(a)(1) and General Design Criteria 35, 38, and 41 is requested. Following submittal of Supplement 2, RAIs related to that submittal were received. These included erosion assumptions, thermal-hydraulic assumptions and modeling, effect of steam line and feed line breaks on risk, coating assumptions related to the thicknesses and location, assumptions about non-piping breaks, and the software quality assurance package for RUFF under the STP Appendix B program. However, the RoverD path ultimately resulted in eliminating many of the questions raised in the full risk-informed path. Of the over 300 original questions raised, roughly half of them became inapplicable (Reference 18) due primarily to narrowing the risk focus to a few scenarios.

Supplement 3 was submitted to the NRC in October, 2016 [37]. Supplement 3 includes Technical Specification Bases changes, Technical Specification Changes, and UFSAR changes. The Technical Specifications changes provide a 90-day ECCS and CSS AOT INOPERABILITY for debris-related issues. The debris must be related to any transportable debris created by a LOCA. That is, some blockage mechanism not related to LOCA-generated debris comes under the "normal" technical Specification AOTs.

3. SUMMARY & DISCUSSION

In April 2011, STP was granted Pilot status to resolve the issues raised in GSI-191 using a risk-informed approach. Over a period spanning almost exactly six years, December 2010 to October 2016, a team formed from academia, a national laboratory, and utility partners worked to develop a method to close GL 2004-02 at "high-fiber" plants. The NRC completed a safety evaluation for the STP license amendment on July 11, 2017 and this closed the issue for STP. The total project evolved in three basic steps, initial quantification, full risk-informed path, RoverD path. Why did the project evolve this way?

The basic project concept began at the University of Texas at Austin in a meeting with Prof. Elmira Popova. In this meeting, the idea of creating a UQ supplying PRA inputs on a full risk-informed path was developed. A central requirement was to minimize changes to the PRA model. It was recognized from the very start that major changes would be needed in the PRA model if the physical phenomena associated with the concerns raised in GSI-191 were to be directly included in the PRA. The second meeting was with Prof. Yassin Hassan at Texas A&M where the basic requirements for a robust thermal-hydraulics analysis were developed. Prof. Popova very quickly identified Dr. Bruce Letellier at LANL as someone with significant experience in GSI-191 who, in an extensive email, succinctly described the phenomenology and basic questions to be addressed in the UQ (1) able to initiate a break at an arbitrary location; execute a ZOI model, (2) execute a debris ablation model, (3) transport debris on the containment floor to the sump (containment spray to be included), (4) characterize the debris bed content and head loss, and (5) support implementation within a stochastic 'wrapper' for generating the initial conditions.

As the full risk-informed method continued to be developed and came under review, it became apparent that uncertainty (epistemology) was less fully understood than required to assure defense in depth and safety margin. Head loss correlations (1) required substantial support and (2) were not consensus models as required in Regulatory Guide 1.200. A full risk-informed path also requires that each successful scenario include a high confidence of success (pointing back to the requirements in Regulatory Guide 1.200). Modeling break frequency, a first-order effect on the risk estimate, lacked consensus. Completeness of boundary conditions, equipment configuration and feedback on the PRA is difficult to establish given the plant response under all possible equipment configurations and operational boundary conditions such as dependency of supply water temperature on seasonal variations.

The RoverD path by adopting consensus models and review of results under bounding conditions reduced the review burden and reduced future testing and analysis burden substantially. The enormous number of success scenarios needed to be examined went from effectively an infinite spectrum of scenarios to effectively none. This was accomplished by adopting deterministic results of testing that used consensus methods. Such consensus methods were developed and thoroughly examined to ensure they bound lack of knowledge in the state of affairs (the epistemic uncertainty). The technology used to find failures reduced the number of scenarios to a very few by bounding the break size at any location.

The GSI-19 Pilot Project contributed a significant body of knowledge to the phenomenology and technical approaches to challenging issues such as GSI-191 where lack of methods and technology inhibited progress to resolution. It demonstrated the effectiveness of teams of industry and academic institutions in this kind of endeavor.

Several documents have been cited in here however they represent only a small fraction of the documentation associated with the STP GSI-191 Pilot Project. The following SQL query can be used to find almost all the documents publicly available from the NRC ADAMS webpage (save the query to an ASCII-formatted file and use the WBA search option to load the query from the file):

(mode:sections,sections:(filters:(public-library:!t),options:(within-folder:(enable:!f,insubfolder:!f,path:")),properties_search_all:!(!(DocketNumber,starts,'05000498',")),properties_search_any:!(!('$title',contains,'(GSI)-191',"),!('$title',contains,GSI-191,"),!('$title',contains,MF2400,"),!(CaseReferenceNumber,contains,GSI-191,"),!(CaseReferenceNumber,contains,'GSI-191, Rev. 3',"))))

Many other documents are available in the academic literature as symposia or refereed journals. The acknowledgements show most of the authors of these other documents (for searches in Google Scholar, for instance).

4. CONCLUSION

On July 11, 2017, the NRC formally approved a license amendment adopting a risk-informed resolution to GSI-191. The approved license amendment eliminates the need to replace fibrous insulation in both STP units and avoids 176 rem of exposure. The cost saving is approximately $43 million.

A key project conclusion is that the safety benefit provided by containment insulation removal as the recommended GSI-191 closure path, does not justify the required worker radiation exposure and significant resource expenditures.

The project results demonstrate the viability of a risk-informed closure path to GSI-191.

These results provide confidence that the issues associated with fibrous insulation in STP’s RCB will be further shown to be non-risk significant with adequate defense-in-depth and safety margins.

The resulting framework provides STP the flexibility to address current issues as well as future issues on a risk-informed basis. STP’s approach is easily transferred to other utilities.

Beyond resolving the GSI-191 issue, the methods developed in the pilot project can be extended to efficiently and safely resolve other nuclear safety issues to include Fukushima-related issues, seismic issues, and fire protection issues.

Acknowledgements

S. Blossom was the STPNOC project manager and provided funding support through STPNOC. Alion Science and Technology work was funded by STPNOC contract BO4461, Rev. 5. The University of Texas at Austin (UT Austin) work was funded by STPNOC grant BO4425. Two phase jet models were done by E. Schneider. E. Popova developed the top-down frequency allocation method at UT Austin. Reduction of CASA Grande results was performed by J. Tejada at UT Austin. N. Ogden reduced strainer bypass data at UT Austin. Work at the University of Illinois at Urbana-Champaign was funded under STPNOC grant BO5270. Implementation of RoverD was supported by D. Johnson and D. Wakefield at ABS Consulting under STPNOC contracts BO5760 and BO4461. Texas A&M University work was funded by STPNOC grant B04422. Work at YK.risk, LLC, was funded by STPNOC contract BO5657.

Thanks to the NRC staff for critical review of the STP applications. Drew Richards (STPNOC) created the SQL query for ADAMS documents in Section 3 of this article.

References

[1] T. S. Andreychek, S. L. Baier, K. F. McNamee, W. A. Byers, R. B. Sisk, K. J. Barber, D. Mitchell, D. P. Crane, D. J. Fink, M. E. Nissley, G. Wissinger, B. G. Lockamon, H. Dergel, P. A. Sherburne, V. Hatman, and T. D. Croyle, *"WCAP-16793-NP, Revision 2, Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid,"* Westinghouse, 2011, Cranberry Township.

[2] Yu Jung Choi, Sang Won Lee, and Hyeong Taek Kim. *"Preliminary Evaluation of Long-Term Cooling Considering Chemical Precipitation and Subsequent Impact on the Recirculating Fluid",* Proceedings of the KNS Autumn Meeting, pp. 1CD-ROM, (2010).

[3] D. V. Rao and Francisco Javier Souto, "*NUREG/CR-6367; SEA 95-554-06-A: 8, Experimental study of head loss and filtration for LOCA debris*", Nuclear Regulatory Commission, 1996, Washington, DC.

[4] M. Bost and J. Raymond, *"AREVA NP Document 66-9088089-000, 0415-010007WN, Rev. A, South Texas Project Test Report for ECCS Strainer Testing,"* AREVA, 2008, Charlotte.

[5] NEI. *"NEI 04-07 Pressurized Water Reactor Sump Performance Evaluation Methodology, Revision 0,"* NEI, 2004, Washington, DC.

[6] USNRC, *"Request for Additional Information for Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,""* ML093410607, USNRC, 2009, Washington, DC.

[7] USNRC, *"Summary of September 13, 2010, Category 1 Meeting, Via Conference Call, With STP Nuclear Operating Company Discussion of Draft Responses to Request for Additional Information for Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors,""* ML102810345, USNRC, 2010, Washington, DC.

[8] Annette L. Vietti-Cook. *"Staff Requirements – SECY-10-0113 – Closure Options for Generic Safety Issue-191, Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance,"* 2010-0113SRM, USNRC, Washington, DC, 2010.

[9] Edward Halpin, *"South Texas Project Units 1 and 2 Letter to NRC Commissioners Regarding GSI-1 91 Status,"* STP NOC-AE-10002625, ML103481027, USNRC, Washington, DC, 2010.

[10] A. W. Harrison, *"South Texas Project Units 1 and 2 Docket Nos. STN 50-498, STN 50-499 Request for Fee Waiver as Risk Informed Pilot Plant,"* NOC-AE-11002650, ML110670533, USNRC, 2011, Washington, DC.

[11] M. Brown, *"Grant of pilot project status. Letter from J.E. Dyer to A. W. Harrison,"* ML111050388, USNRC, 2011, Washington, DC.

[12] C. R. Grantom, *"Licensee Slides from 2/22/2011 Public Meeting with STP Nuclear Operating Company,"* ML110550395, USNRC, 2011, Washington, DC.

[13] USNRC, *"Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance, Letter (SECY) 12-0093,"* USNRC, 2012, Washington, DC.

[14] John W. Crenshaw, "STP Pilot Submittal and Request for Exemption for a Risk-Informed Approach to Resolve Generic Safety Issue (GSI)-191," NOC-AE-13002954, ML13043A013, USNRC, 2013, Washington, DC.

[15] David W. Rencurrel, *"Revised STP Pilot Submittal and Request for Exemption and License Amendment for a Risk-Informed Approach to Resolve Generic Safety Issue (GSI)-191,"* NOC-AE-1300298, ML13175A211, USNRC, 2013, Washington, DC.

[16] Gerald Powell, *"Supplement 2 to STP Pilot Submittal and Requests for Exemptions and License Amendment for a Risk-Informed Approach to Address Generic Safety Issue (GSI)-1 91 and Respond to Generic Letter (GL) 2004-02,"* NOC-AE-15003241, ML15246A126, USNRC, 2015, Washington, DC.

[17] Lisa M. Regner, *"Issuance Of Amendments Re: Changes to Design Basis Accident Analysis Using a Risk- Informed Methodology to Account for Debris in Containment,"* ML17038A223, USNRC, 2017, Washington, DC.
[18] James Connolly, *"Applicability of Application Supplement 1 Correspondence to Supplement 2 to STP Risk-Informed GSl-191 Licensing Application,"* NOC-AE-16003369, ML16176A148, USNRC, 2016, Washington, DC.
[19] John W. Crenshaw, *"Summary of the South Texas Project Risk-Informed Approach to Resolve Generic Safety Issue (GSI-191),"* USNRC, NOC-AE-12002784, ML12023A056, 2012 Washington, DC.
[20] Alion Science & Technology, *"CASA Grande Theory Manual,"* ALION-SPP ALION-I009-10, STP STI 34179370, Alion Science & Technology, 2015, Albuquerque.
[21] J. Dallman, B. Letellier, J. Garcia, J. Madrid, W. Roesch, D. Chen, K. Howe, L. Archuleta, F. Sciacca, and B. P. Jain, *"NUREG/CR-6914, Integrated Chemical Effects Test Project: Consolidated Data Report,"* Los Alamos National Laboratory, 2006, Los Alamos.
[22] Rodolfo Vaghetto and Yassin A. Hassan. *"Study of debris-generated core blockage scenarios during loss of coolant accidents using RELAP5-3D"*, Nuclear Engineering and Design, 261, pp. 144-155, (2013).
[23] Rodolfo Vaghetto, Mason Childs, Ernie Kee, and Yassin A. Hassan. *"Observations and measurements of boric acid precipitation scenarios"*, Progress in Nuclear Energy, 91, pp. 302-309, (2016).
[24] Yassin A. Hassan, Serdar Osturk, and Saya Lee. *"Rheological characterization of buffered boric acid aqueous solutions in light water reactors"*, Progress in Nuclear Energy, 85, pp. 239-253, (2015).
[25] Saya Lee, Rodolfo Vaghetto, and Yassin A. Hassan, *"Bench Top Screen Penetration Test (Water Type Sensitivity Analysis), Report Revision 2.0,"* Texas A&M University, 2012, College Station.
[26] Nicole Ogden, David Morton, and Jeremy Tejada, *"South Texas Project Risk-Informed GSI-191 Evaluation: Filtration as a Function of Debris Mass on the Strainer: Fitting a Parametric Physics-Based Model, Technical report, STP–RIGSI191–V03.06,"* The University of Texas at Austin, 2013, Austin.
[27] Gerald T. Powell, *"Submittal of Chemical Effects Test Reports,"* NOC-AE-14003075, ML14072A076, USNRC, 2014, Washington, DC.
[28] Kerry J. Howe, Lana Mitchell, Seung-Jun Kim, Edward D. Blandford, and Ernest J. Kee. *"Corrosion and solubility in a TSP-buffered chemical environment following a loss of coolant accident: Part 1 – Aluminum,"* Nuclear Engineering and Design, 292, pp. 296 – 305, (2015).
[29] Y-A. Pan, E. Popova, and D. P. Morton, *"South Texas Project Risk-Informed GSI-191 Evaluation, Volume 3, Modeling and Sampling LOCA Frequency and Break Size. Technical report, STP–RIGSI191–V03.02, Revision 4,"* The University of Texas at Austin, 2013, Austin.
[30] USNRC, *"Summary of August 20, 2014, Public Meeting with STP Nuclear Operating Company to Discuss the License Amendment and Exemption Requests to Use a Risk-Informed Approach to the Resolution of GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance,""* ML14269A002, USNRC, 2014, Washington, DC.
[31] USNRC, *"Summary of November 6, 2014, Public Meeting with STP Nuclear Operating Company to Discuss the License Amendment and Exemption Requests to Use a Risk-Informed Approach to the Resolution of GSI-191, "Assessment of Debris Accumulation on PWR Sump Performance,""* ML14323A576, USNRC, 2014, Washington, DC.
[32] Albon Harrison, *"Fwd: Ernie's slides, Letter from A. W. Harrison to B. Singal, F. Lyon,"* ML14349A790, USNRC, 2014, Washington, DC.
[33] Gerald T. Powell, *"Description of Revised Risk-Informed Methodology and Responses to Round 2 Requests for Additional Information Regarding STP Risk-Informed GSI-191 Licensing Application,"* NOC-AE-15003220, ML15091A440, USNRC, 2015, Washington, DC.
[34] Alexander Zolan, John Hasenbein, and Jeremy Tejada, *"Risk Unifying Frequency Functional, Technical Report 2015-003, STP STI 34164176,"* The University of Texas at Austin, 2015, Austin.

[35] Alexander Zolan, John Hasenbein, and Jeremy Tejada, *"Fiber Diffusion Operations Engine, Technical Report 2015-002, STP STI 34164169,"* The University of Texas at Austin, 2015, Austin.
[36] Gerald T. Powell, *"Supplement 2 to STP Pilot Submittal and Requests for Exemptions and License Amendment for a Risk-Informed Approach to Address Generic Safety Issue (GSI)-191 and Respond to Generic Letter (GL) 2004-02,"* NOC-AE-15003241, ML15246A126, USNRC, 2015, Washington, DC.
[37] James Connolly, *"Supplement 3 to Revised STP Pilot Submittal and Requests for Exemptions and License Amendment for a Risk-Informed Approach to Address Generic Safety Issue (GSI)-191 and Respond to Generic Letter (GL) 2004-02,"* NOC-AE-16003401, ML16302A015, USNRC, 2016, Washington, DC.