October 24, 2002

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SUBJECT: RESULTS OF THE SUSQUEHANNA STEAM ELECTRIC STATION UNITS 1 AND 2 SDP PHASE 2 NOTEBOOK BENCHMARKING VISIT

During August, 2002, NRC staff and a contractor visited the Pennsylvania Power and Light Company headquarters in Allentown, PA to compare the Susquehanna Steam Electric Station (SSES) Unit 1 and 2 Significance Determination Process (SDP) Phase 2 notebook and licensee's risk model results to ensure that the SDP notebook was generally conservative. The SSES PSA did not include external initiating events so no sensitivity studies were performed to assess the impact of these initiators on SDP color determinations. In addition, the results from analyses using the NRC's draft Revision 3i Standard Plant Analysis Risk (SPAR) model for SSES were also compared with the licensee's risk model. The results of the SPAR model benchmarking effort will be documented in next revision of the SPAR (revision 3) model documentation.

The benchmarking visit identified that there was poor correlation between the Phase 2 SDP Notebook and the licensee's PSA. The results indicate that the SSES SDP Phase 2 notebook was significantly more conservative in comparison to the licensee's PSA. This degree of poor correlation between notebook and PSA has not been experienced during any of the previous benchmarking visits. A summary of the results of the risk characterization of hypothetical findings by the SDP notebook are as follows.

0%	Underestimates Risk Significance
16%	Match Risk Significance
12.5%	Overestimates Risk Significance by 1 Order of Magnitude
27%	Overestimates Risk Significance by 2 Orders of Magnitude
12.5%	Overestimates Risk Significance by 3 Orders of Magnitude
32%	Unable to compare with licensee's PSA

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The benchmarking team noted several reasons why the notebook predicted greater significance than the PSA. The principle reasons for the differences were as follows:

- The yearly PSA core damage frequency for Susquehanna was a relatively low value of 3.46 E-7/reactor-year.

- The PSA definition of core damage was based on hydrogen generation from the cladding. Other PSAs assume core damage occurs when reactor water level is not maintained above the top of active fuel or 2/3 core height.

- The PSA did not carry containment failure prior to core damage forward to core damage. Traditionally, containment failure is carried forward to core damage because the location of the failure is unknown; and, the containment atmosphere is dumped into the reactor building, which is likely to fail substantial core damage prevention equipment. The SDP Phase 2 notebook assumes that the failure of containment will ultimately result in core damage.

- Accident sequences that involved successful containment venting were considered a success and not carried forward to core damage. Traditionally, plants with “soft” containment vent paths do not necessarily consider these sequences as success because the containment atmosphere is dumped into the reactor building at the point where the vent path ruptures, which is likely to fail substantial equipment necessary for reactor inventory makeup.

- The PSA assumed that the reactor water cleanup (RWCU) system was capable of removing decay heat from containment following an accident. This assumption is atypical for other BWR 4 PSAs reviewed during the benchmarking visits. This aspect of the licensee’s PSA was not reflected in the SDP Phase 2 notebook.

- The PSA modeled several of operator actions with essentially zero failure probability. In cases where the human error failure probabilities were considered unrealistically low, the SDP Phase 2 notebook used generic industry values in accordance with the notebook construction rules.

Attachment A describes the process and results of the comparison of the SSES SDP Phase 2 Notebook and the licensee’s PSA.

Attachments: As stated

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- The PSA assumed that the reactor water cleanup (RWCU) system was capable of removing decay heat from containment following an accident. This assumption is atypical for other BWR 4 PSAs reviewed during the benchmarking visits. This aspect of the licensee’s PSA was not reflected in the SDP Phase 2 notebook.
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Attachment A describes the process and results of the comparison of the SSES SDP Phase 2 Notebook and the licensee’s PSA.

Attachments: As stated
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Summary Report on Risk-Informed Benchmarking Trip to the Susquehanna Steam Electric Station (SSES) Units 1 & 2 (Aug. 20 - 22, 2002)

J. C. Higgins
Brookhaven National Laboratory

September 23, 2002

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1 Introduction

On August 20-22, 2002, the NRC conducted an SDP Benchmarking visit with PPL PSA staff in the Allentown, PA corporate office (Attachment 1 provides a list of participants). The purpose of this visit was to validate the underlying assumptions of the Revision 0, SDP Phase 2 Notebook. The validation was conducted by: soliciting comments from the licensee's PSA staff; reviewing differences between the underlying assumption of the notebook and the licensee's PSA; and comparing the safety significance of hypothetical inspection findings using both the notebook and PSA. The outcome of this SDP Benchmarking visit is the issuance of Revision 1 of the SDP notebook. The SDP notebook is used by inspectors to determine the safety significance of inspection findings.

The Susquehanna SDP Notebook was originally prepared in 2001. The notebook was updated in mid 2001 following a visit between the NRC and the licensee's PSA staff to gather additional information on the current PSA model for SSES. The Susquehanna notebook was reviewed prior to this benchmarking visit in order to identify potential changes that may be needed in order to address generic NRC changes for the Rev. 1 notebook update. These changes and questions were provided to the licensee prior to the benchmarking visit and are provided in Attachment 2.

2 Summary of Results from Benchmarking

The benchmarking visit identified that there was poor correlation between the Phase 2 SDP Notebook and the licensee's PSA. The results indicate that the Susquehanna SDP Phase 2 notebook was significantly more conservative in comparison to the licensee's PSA. This degree of poor correlation between notebook and PSA has not been experienced during any of the previous benchmarking visits. The comparison of the significance between the licensee's PSA and the SDP Phase 2 notebook for hypothetical inspection findings is provided in Table 1. A summary of the results of the risk characterization of hypothetical findings by the SDP notebook are as follows.

0% Underestimates Risk Significance
16% Match Risk Significance
12.5% Overestimates Risk Significance by 1 Order of Magnitude
27% Overestimates Risk Significance by 2 Orders of Magnitude
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The benchmarking team noted several reasons why the notebook predicted greater significance than the PSA. The principle reasons for the differences were as follows:

- The yearly PSA core damage frequency for Susquehanna was a relatively low value of 3.46 E-7/reactor-year.

- The PSA definition of core damage was based on hydrogen generation from the cladding. Other PSAs assume core damage occurs when reactor water level is not maintained above the top of active fuel or 2/3 core height. This assumption affects success criteria for mitigating systems. For example, as a result of this definition, the PSA credited the control rod drive pumps as being capable of fulfilling the high pressure injection function and to credit the reactor core isolation cooling pump following an inadvertent or stuck open relief valve. This assumption of the PSA was not reflected in the revision to the SDP Phase 2 notebook.

- The PSA did not carry containment failure prior to core damage forward to core damage. The licensee classified this as a containment failure end state that was only an input to the Level 2 PSA. Traditionally, containment failure is carried forward to core damage because the location of the failure is unknown; and, the containment atmosphere is dumped into the reactor building, which is likely to fail substantial core damage prevention equipment. The revision 1 SDP Phase 2 notebook assumes that the failure of containment will ultimately result in core damage.

- Accident sequences that involved successful containment venting were considered a success and not carried forward to core damage. Traditionally, plants with “soft” containment vent paths do not necessarily consider these sequences as success because the containment atmosphere is dumped into the reactor building at the point where the vent path ruptures, which is likely to fail substantial equipment necessary for reactor inventory makeup.

- The PSA assumes that the reactor water cleanup (RWCU) system was capable of removing decay heat from containment following an accident. This assumption is atypical for other BWR 4 PSAs reviewed during the benchmarking visits. This aspect of the licensee’s PSA was not reflected in the revision 1 SDP Phase 2 notebook.

- The PSA models several of operator actions with essentially zero failure probability. In cases where the human error failure probabilities were considered unrealistically low, the revision 1 SDP Phase 2 notebook used generic industry values in accordance with the notebook construction rules.

3 Modifications to SDP Worksheets

3.1 Benchmarking Details

Benchmarking Methodology

The licensee’s PSA information used during this benchmarking visit was based on the updated June 2002 version of the Susquehanna PSA (SSES-06014002 PM). This PSA had an internal events CDF of 4.32 E-7 events per operating cycle (15 operating months). This is equivalent to a CDF of about 3.46 E-7 events per reactor-year. The PSA did not include internal flooding or external events.

The team computed the break points in RAW values for the different SDP colors based upon a current PSA total internal events CDF of 3.46 E-7 events/reactor-year (which is equivalent to 4.32 events/ operating cycle). The team pre-selected components and human actions, as listed in Table 1, that would be evaluated for the effect of having the component or human action fail. The team developed the color corresponding to failure of each item. The latest revised version of the notebook was used to develop the color corresponding to failure of each item and compared that to the color that would be implied by the items RAW value from the PSA. Table 1 tabulates the results of the benchmarking of both the Rev. 0 and the modified Rev. 1 worksheets that are contained in the risk-informed inspection notebook for Susquehanna.

In developing the colors from the notebooks, the team evaluated all sequences in each worksheet that contained the item (component or human action). A number was obtained for each re-evaluated sequence. We then used a "counting rule" to cascade lower value sequences to higher value ones as follows. For example three sequences of value 8 (shorthand for an estimated sequence frequency of 1 E-8 events/reactor-year) were equivalent to one sequence of value 7. Likewise 3 sequences of value 7 (3-7s) were equivalent 1 sequence of value 6 (1-6). Also, 3-6s were equal to 1-5, and so on. Colors were developed as follows:

Sequences of value 7, 8, and higher	Green
Sequences of value 6	White
Sequences of value 5	Yellow
Sequences of value 4 or less	Red

When the above described counting rule was needed to obtain a color rather than a direct correlation from a sequence, Table 1 denotes that it was obtained "by the counting rule" or "bcr."

Non-conservative Benchmark Results

For this benchmarking there were no non-conservative results (where the licensee's PSA RAW value gives a color closer to red than the notebook).

Conservative Benchmark Results

As stated above, there were significant differences between several PSA assumptions and those used in the phase 2 SDP notebook. The team believes that these assumptions and techniques resulted in a lower value of CDF. As a result, more typical or generic assumptions and techniques were used for the notebook construction. As a result, the notebook for SSES provides higher colors (closer to red) than would be indicated by the licensee's PSA. Several components and human actions were identified that are 2 and even 3 orders of magnitude conservative compared to the SSES PSA. Specifically, there were seven items that were 3 orders of magnitude conservative, fourteen items that were 2 orders of magnitude conservative, and seven items that were 1 order of magnitude conservative.

The team examined the cutsets for several items that were significantly conservative to better understand the reasons for the conservatism. The following cutsets were reviewed:

Emergency Diesel Generators

EDG A & B were 3 orders conservative. The cutsets for EDG A were examined. The PSA only requires 1 EDG on a LOOP and SBO, where the notebook requires 2 (Item II.4 of Att. B). Also, the PSA credits CV and RWCU for CHR. The notebook does not credit RWCU. The PSA does not appear to model the dependency of CV on both EDGs A & B. Without both the A & B buses receiving AC power one cannot open the two series CV valves and cannot CV.

Turbine Building Closed Cooling Water Train

The TBCCW pump was 3 orders conservative. The notebook has a sequence: LOCCW - CHR with a credit of 5 (approximate frequency 1 E-5). The SSES PSA does not have any cutsets with the TBCCW pump that show in the base case using a truncation of 1 E-11. It is believed this is due to crediting RWCU for CHR and by assigning containment failure pre-core damage to a non-core-damage bin (i.e., only counted toward level II results).

Reactor Core Isolation Cooling Train

RCIC was 2 orders conservative. The cutsets RCIC for were examined. The notebook has two credit 6 (~ 1 E-6) sequences for RCIC, namely:

TPCS - HPI - DEP and
SORV - HPI - DEP.

Cutsets for these sequences do not appear near the top of list of RCIC cutsets. The reason is believed to be that the PSA credits operator action to inject with 2/2 CRD pumps at maximized flow for HPI. The notebook does not credit this since it depends on quick operator actions and on a relaxed definition of core damage.

Standby Liquid Control Pump Train

One SLC pump was 2 orders conservative. The cutsets for the SLC pump were examined. It was noted that for most of the ATWS sequences, SSES assumes success with 1/2 SLC pumps. This is not true for all ATWS sequences, so the notebook uses a success criterion of 2/2 pumps. Additionally, for most of the ATWS sequences for manual injection of SLC the PSA uses HEPs of about 1 E-9. The notebook provides a credit of 2 for SLC.

3.2 Specific Changes to the Rev-0 SDP Worksheet for SSES

A number of changes were made to the SSES worksheet. Refer to Attachment 2 for a detailed list of changes. These changes will be included in Revision 1 of the Susquehanna SDP notebook.

3.3 Generic Changes in IMC 0609 for Guidance to NRC inspectors

None.

3.4 Generic Changes to the SDP Notebooks

None.

4 Discussion on External Events

The licensee's updated PSA does not have an quantitative external events model.

5 References

3. June 2002 version of the Susquehanna PSA (SSES-06014002 PM)

4. Risk-informed Inspection Notebook for Susquehanna Steam Electric Station, Revision 1

Table 1: Comparison of Sensitivity Calculations Between Phase 2 SDP Worksheets and SSES RAW Values

(CDF = 3.46 E-7 events/ reactor-year; RAW splits - 3.89, 30, 290)
Truncation level 1 E-11

Item Out of Service	Rev. 0 SDP Work-sheets Color	SSES Basic Event	SSES RAW ratio	Color by SSES RAW	Mod. (Rev. 1) SDP Worksheets Color	Comments
Component						
HPCI	R	152-II-N-P204	7.45	W	Y	conservative by 1 order of magnitude
RCIC	R	150-I-N-P204	7.21	W	R_{bcr}	conservative 2 orders
PCS steam	-	%ISOMAN	1.5	G	Y	conservative 2 orders
PCS feed	-	%ISOMAN	1.5	G	G	
1 SRV fto	R_{bcr}	Not modeled	-	-	Y_{bcr}	
2 SRVs fto	R_{bcr}	Not modeled	-	-	Y	
1 SRV ftc	Y	183-N-N-RESET-PE	4.31	W	R	conservative 2 orders
LPCS pump A	G	151-I-A-P206	1.58	G	G	
RHR- pump A	Y	149-I-A-P202	1.02	G	Y	conservative 2 orders
RHR-pump B	Y	-	-	-	Y	

Item Out of Service	Rev. 0 SDP Work-sheets Color	SSES Basic Event	SSES RAW ratio	Color by SSES RAW	Mod. (Rev. 1) SDP Worksheets Color	Comments
RHR HX A	R	116-N-A-E205	1.0	G	R	conservative 3 orders
RHR HX B	R	116-N-B-E205	1.0	G	R	conservative 3 orders
1 CV valve	G	Not modeled	-	-	W	
1 DD Fire Pump	G	013-N-N-P511	1.0	G	G	
1 condensate pump	G	144-N-A-P102	1.0	G	G	
One SLC pump	G	153-N-A-P208	1.55	G	Y	conservative 2 orders
RPT 1 train	G	Not modeled	-	-	G	
RPT both trains	Y	Not modeled	-	-	Y	
EDG A	G	024DGR0G501A	2.2	G	R	conservative 3 orders
EDG B	G	024DGR0G501B	2.58	G	R	conservative 3 orders
EDG C	G	024DGR0G501C	2.63	G	Y_{bcr}	conservative 2 orders
OG503	G	002-N-N-0G503	2.91	G	G	
4160 AC A	R	104-N-N-A201	3.24	G	R	conservative 3 orders
4160 AC B	R	104-N-N-A202	2.59	G	R	conservative 3 orders
1 CRD pump	Y	155-N-A-P132	1.0	G	G	

Item Out of Service	Rev. 0 SDP Work-sheets Color	SSES Basic Event	SSES RAW ratio	Color by SSES RAW	Mod. (Rev. 1) SDP Worksheets Color	Comments
2 CRD pumps	Y	-	1.11	G	Y	conservative 2 orders
IA compressor	-	118-N-A-K107	1.0	G	Y	conservative 2 orders
CIG flow path	-	125-N-–12605	1.36	G	Y	conservative 2 orders
1 ESW-pump	-	054-N-A-P504	1.49	G	Y	conservative 2 orders
2 ESW-pumps	-	A & C	4.01	W	R	conservative 2 orders
RHRSW pump A	-	116-N-A-P506	1.35	G	Y	conservative 2 orders
RHRSW pump B	-	116-N-B-P506	1.38	G	Y	conservative 2 orders
RBCCW pump	-	114-N-A-P210	1.0	G	G	
TBCCW pump	-	115-N-A-P103	1.06	G	R	conservative 3 orders
DC-Div A panel	R	102-I-A-D614	59.4	Y	R_{bcr}	conservative 1 order
DC-Div B panel	R	102-II-B-D624	65.6	Y	R_{bcr}	conservative 1 order
DC Battery A	R	102BTR1D610	43.9	Y	R	conservative 1 order
DC Battery B	R	102BTR1D620	15.3	W	R	conservative 2 orders
DC Charger A	R	102-I-A-D613	2.89	G	W	conservative 1 order
DC Charger B	R	102-I-A-D623	3.05	G	W	conservative 1 order

Item Out of Service	Rev. 0 SDP Work-sheets Color	SSES Basic Event	SSES RAW ratio	Color by SSES RAW	Mod. (Rev. 1) SDP Worksheets Color	Comments
1 SP vac. bkr	W	Not modeled	-	-	Y	
2 SP vac. bkrs	R	Not modeled	-	-	R	
Operator Actions						
PCS	W	-	-	-	W	
Injection with CRD	Y	-	-	-	Y	
DEP / ATWS	W	-	-	-	W	
RPV inj with RHRSW	G	-	-	-	G	
CHR w/ RWCU blowdown	Y	Not modeled	-	-	G	
RPV inj with DD fire pump	W_{bcr}	-	-	-	G	
Inject with condensate pump	G	-	-	-	W	
OG503	G	002-N-N-BMS-O	2.9	G	G	

Item Out of Service	Rev. 0 SDP Work-sheets Color	SSES Basic Event	SSES RAW ratio	Color by SSES RAW	Mod. (Rev. 1) SDP Worksheets Color	Comments
SLC	Y	-	-	-	Y	
Overfill on ATWS	W	144-N-N-LRPBE-O	1.7	G	W	conservative 1 order
CV	W	Not modeled	-	-	R	
RLOOP1	G	-	1.0	G	G	
RLOOP4	-	-	-	-	W	
RLOOP12	W	-	2.47	G	Y	conservative 2 orders

Table 1 Notes:

1. SSES RAW for internal events, average maintenance case.
2. The Delta CDF used in RAW value calculations represented the change in CDF due to the component being out of service for 1 year.
3. The subscript bcr means “by counting rule.”
4. For a component such as a pump, we examined the RAW values for the basic events both for “failure to start” and “failure to run,” and either selected the highest (more conservative) value here, or used a synthesized RAW value separated calculated by the licensee that included all failure modes. Where the basic event column indicates “System,” the licensee calculated a system RAW by setting all the appropriate system events to true (or failed) and resolving the model to obtain the new higher CDF.
5. For those items where the basic event column is noted as “not modeled”, the PSA did not separately model the item and so a PSA RAW value was not available. For those items where the basic event column has a dash (-), an appropriate basic event could not be identified (for a variety of different reasons) or the RAW could not readily be determined.

6. When comparing the modified SDP worksheet color to the color by SSES RAW, we found many that were conservative. Each color of conservatism represents approximately one order of magnitude in delta CDF. In the comments column, we indicate how by many orders of magnitude the item is conservative.
7. We did not have sufficient information about several systems to be able to benchmark all of the selected items using the Rev. 0 SDP notebook before the benchmarking visit.
8. Items that were 3 orders of magnitude conservative were: RHR HXs A & B, EDGs A & B, 4160 VAC buses A & B, TBCCW pump.
9. Items that were 2 orders of magnitude conservative were: RCIC, PCS steam, 1 SRV ftc, RHR pump A, one SLC pump, EDG C, 2 CRD pumps, one IA compressor, CIG, 1 or 2 ESW pumps, RHR SW pump A or B, DC battery B, RLOOP12.
10. Items that were 1 order of magnitude conservative were: HPCI, DC panels for Div. A or B, DC battery A, DC chargers A or B, Overfill on ATWS.

Table 2: Comparative Summary of the Benchmarking Results

	Rev. 0 SDP Worksheets		Rev. 1 SDP Worksheets, as Modified	
	Number of Cases	**Percentage**	**Number of Cases**	**Percentage**
SDP: Non-Conservative	0	0	0	0
SDP: Conservative	18	64	**29**	**52**
by one order			7	12.5
by two orders			15	27
by three orders			7	12.5
SDP: Matched	10	36	**9**	**16**
RAW values not available			18	32
Total	28	100	56	100

Table 2 Notes:

1. In addition to the 38 items that were benchmarked against the licensee's RAW value, the team also determined the color by the notebook for an additional 18 items for which RAW values were not available.

2. The notes to Table 1 provide the specific components and operator actions that were conservative.

List of Participants

Pete Wilson	NRC/NRR
Gene Cobey	NRC/Region I
Jim Trapp	NRC/Region I
John Richmond	NRC/Region I
James Higgins	BNL
Bob Buell	INEEL
Mike Adelizzi	SSES
Kevin Brinkman	SSES
Lonnie Crawford	SSES
Frank Czysz	SSES
Chet Lehmann	SSES
Mike Crowthers	SSES

Questions and Changes to Notebook

Questions Provided to Licensee

1 Obtain updated PSA info, including: date of new PSA information, IE frequencies, HEPs, truncation level, CDF, and % contributions.
2 Obtain RAW values for all those components and operator actions listed in Table 1 herein.
3 Obtain CDF for internal flooding and external events (If available).
4 What is the total PSA IE frequency for those transients that involve a loss of the Power Conversion System (PCS)?
5 Confirm support systems for PCS (steam cycle and feed cycle) in Table 2.
6 Need information on HVAC requirements, as credited in PSA.
7 Need information on fire pumps credited in PSA for late injection.
8 What is the capacity of the “DA” tank for the EDGs and how long can the EDGs can run on a full DA tank with no makeup from the fuel oil transfer pumps?
9 What is the credited time for batteries on an SBO?
10 Do you have a dedicated DC supply (with battery and charger) for switchgear/circuit breaker operation?
11 Can the battery chargers supply the safety loads without the batteries?
12 What is the equivalent size break to an SORV? Discuss IORV and SORV? Is worksheet good for both?
13 Do you credit the stuck open SRV for DEP on an SORV event?
14 Do we need to add worksheets for: Loss of SW, Loss of IA, and LOOP with failure of one EDG (LEAC)?
15 On ATWS, can you use condensate pumps for an ATWS induced by an MSIV-closure transient?

Notebook Changes Prior to Onsite Visit

3. Changed credit for CRD as part of early HPI from 2 to 1.
4. Dropped credit for CRD as part of early HPI from the SORV worksheet.
5. Dropped credit for PCS from the SORV worksheet.
6. Editorial changes.
7. Added base case credits to the worksheet sequences.

Changes Made During Benchmarking Visit

3. Added worksheet and event tree for a Loss of 4160 VAC Bus A (LOAC).
4. Added worksheet for Loss of Instrument Air (LOIA).
5. Dropped the LODCA worksheet.
6. Moved SLOCA to Row III of Table 1 and added LOAC & LOIA to Table 1.
7. Updated systems information in Table 2.
8. Moved credit for CRD pumps from HPI to LI in most all worksheets.
9. Changed the requirement for LPCS to 2/2 pumps in 1/2 trains.
10. Changed DEP from an operator action to multi-train system with automatic ADS.
11. Dropped credit for RWCU as a method of CHR.
12. Updated the credit for number of RHR SW pumps to match the site arrangement of the RHR SW pumps. Also moved credit for injection with RHR SW cross-tie from LPI to LI.
13. Updated the mitigation capability in LI in most all worksheets to ensure consistency.
14. Completely revised the LOOP event tree and worksheet to address the dual unit. LOOP and the electrical arrangement of equipment between the units.
15. Changed SLC on ATWS to 2/2 pumps.
16. On the LODCB and LOAC worksheets, added credit for operator action to cross-tie IA to CIG.