Draft for Review and Comment

Report on the Independent Verification of the Mitigating Systems Performance Index (MSPI) Results for the Pilot Plants

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February 2004

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ACKNOWLEDGMENTS

The authors acknowledge the support and collaboration provided by our many colleagues at NRC, INEEL, and ISL. The research effort benefited from important discussions during the numerous public meetings on the MSPI, as well as with the ACRS. Patrick Baranowsky of NRC contributed substantially to many of the conceptual issues and technical ideas, and supported the overall project since its inception. The authors are especially grateful to Colleen Amoruso and Jennifer Jones (ISL) for production of the report.

LIST OF ACRONYMS

ACP	alternating current power
ACRS	Advisory Committee on Reactor Safeguards
AFW	auxiliary feedwater system
AOT	allowed outage time
AOV	air-operated valve
B	Birnbaum Importance
B&W	Babcock & Wilcox Reactor
CCF	common-cause failure
CCW	component cooling water system
CDE	Consolidated Data Entry program
CDF	core damage frequency
CNIP	constrained non-informative prior
CVCS	chemical and volume control system
DC	direct current
DCP	direct current power
DDP	diesel-driven pump
DRAA	Division of Risk Analysis and Applications
EAC	emergency alternating current power system
EB	empirical Bayes
EDG	emergency diesel generator
EPIX	Equipment Performance and Information Exchange
FTLR	failure to load and run
FTO/C	failure to open or close
FTR	failure to run
FTS	failure to start
FV	Fussell-Vesely Importance
HPCI	high pressure coolant injection system
HPCS	high pressure core spray system
HPI	high pressure injection (may include other high-head systems such as CVCS)
HPSI	high pressure safety injection system
HRS	heat removal system
IC	isolation condenser
ICCDP	incremental conditional core damage probability
INPO	Institute for Nuclear Power Operations
LER	Licensee Event Report
LOCA	loss of coolant accident
LOOP	loss of offsite power
MDP	motor-driven pump
MLE	Maximum Likelihood Estimate

MOV	motor-operated valve
MSPI	Mitigating System Performance Index
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
PCS	power conversion system
PI	performance indicator
PM	preventive maintenance
PORV	power-operated relief valve
PRA	probabilistic risk assessment
RADS	Reliability and Availability Database System
RAW	Risk Achievement Worth
RBPI	risk-based performance indicator
RCIC	reactor core isolation cooling system
RCP	reactor coolant pump
RES	Office of Nuclear Regulatory Research
RHR	residual heat removal system
ROP	Reactor Oversight Process
SBO	station blackout
SDP	Significance Determination Process
SGTR	steam generator tube rupture
SPAR	Standardized Plant Analysis – Risk
SSU	Safety System Unavailability
SWS	service water system
TDP	turbine-driven pump
TI	Temporary Instruction
TS	Technical Specifications
UA	Unavailability
UAI	Unavailability Index
UR	Unreliability
URI	Unreliability Index

EXECUTIVE SUMMARY

Overview

This report provides the results of the independent verification of the Mitigating Systems Performance Index (MSPI) for the pilot program that was initiated in the summer of 2002. The pilot consisted of a six-month data collection phase by twenty nuclear power plant units, followed by a ten-month analysis phase. The two main activities performed by the Office of Nuclear Regulatory Research (RES) during this pilot program included:

- Verification of the reasonableness and accuracy of inputs to the MSPI and results for the twenty plants in the pilot program
- Identification of technical issues arising from the formulation of the MSPI, and recommendations for improving the method.

The purpose of the MSPI is to "monitor the performance of selected systems based on their ability to perform risk-significant functions… ." RES has developed the MSPI to address several specific problems with the currently used performance indicators including: the use of fault exposure hours in the Safety System Unavailability (SSU), the omission of unreliability elements in the indicator, the use of mostly one-size-fits-all performance thresholds irrespective of risk-significance of the system, and the cascading of support system failures onto mitigating system unavailability. If and when implemented, the MSPI would replace the existing SSU Performance Indicators for mitigating systems in the Reactor Oversight Process (ROP). It may also replace or supplement the use of the Significance Determination Process (SDP) as applied to single failures within scope of the MSPI.

The MSPI builds upon the insights and findings developed in the Risk-Based Performance Indicators (RBPI) program in NUREG-1753 (Ref. 1). The MSPI approach separately quantifies the significance of changes in Unreliability (UR) and Unavailability (UA), but then rolls up these contributions into a single system-level indicator. The approach does this using a calculational algorithm based on Fussell-Vesely (FV) importance measures, thereby avoiding the need for ongoing manipulations of the entire risk model. As currently formulated, the MSPI of a system is a simplified and linearized approximation to the change in at-power, internal events core damage frequency (CDF) due to changes in reliability and availability of risk-significant elements of that system. The MSPI was extensively tested, evaluated, and reviewed during the pilot plant trial and evaluation period.

Results of the Independent Verification

The purpose of the MSPI verification effort was to obtain reasonable assurance of the adequacy of the inputs into the MSPI calculation, and reasonableness of pilot plant results. This was accomplished by assessing the individual inputs to the MSPI calculation on a plant-by-plant, system-by-system, and in many instances component-by-component basis. In addition, a comparison of MSPI results using the plant PRA models and the SPAR resolution models was performed. The detailed tasks performed in this activity included:

- Baseline data verification
- Current performance data verification
- Verification of FV/UA and FV/UR importance measures

- Electronic spreadsheet calculation verification
- Overall MSPI results verification.

In addition to the verification effort, analyses were performed to assess the sensitivity of MSPI results to differences between the licensees' PRA models and SPAR models. Finally, a comparison was made between MSPI results, SSU indications, and SDP findings as appropriate.

The major findings are as follows:

1. The generic failure rate values in Table 2 of NEI 99-02 Appendix F are not truly representative of 1995-1997 performance as supposed, and are not appropriate for use in the MSPI. An improved set of failure rates has been developed. (See Appendix C.)

2. The verification effort generally showed the pilot plant submittals for train-specific Unavailability baselines to be reasonable. However, the verification did identify several baseline UAs that were lower than the unplanned UA values, which is erroneous. More guidance and perhaps internal software checks are needed. Current UA results for the three-year period were tabulated and compared across plants and with baselines. No current UA entries were identified as outliers. (See Appendix A.)

3. The verification effort did identify pilot plant data entry errors. These errors included cases of double or "multiple counting" of failures or demands. The discovered errors were brought to the attention of the licensees, and most were corrected by the final data submittals in March 2003. (See Appendix A.)

4. The existing SPAR Rev. 3 models had been benchmarked against licensee models and were, in most cases, within a factor of 2 to 3 of licensee PRAs for core damage frequency. However, with regard to risk model importances at the component level, significant discrepancies were found between existing SPAR Rev. 3 models and the corresponding plant PRA models. A major effort to enhance the SPAR models was successful in identifying and resolving many issues related to component FVs. Using the geometric mean (over all monitored components at a plant) as the figure-of-merit, the SPAR resolution models agreed with the eleven unique plant PRA FV/URs within a factor of two on average. (See Appendix B.)

5. The MSPI calculations performed within the NEI spreadsheet were verified by comparing results from an independently developed spreadsheet. Results from both sets of spreadsheets agreed. (See Appendix A.)

6. Overall, the MSPI results from the pilot plant models and from the SPAR resolution models were found to be in very good agreement. In terms of color indications, the pilot plant model and SPAR resolution model results for the 4th Qtr 2002 are comparable if not identical depending on whether or not the frontstop is used or the effect of common-cause failure modeling is accounted for. Numerical results for MSPI values above the practical limit of significance (1E-7) generally agreed within a factor of three. (See Appendix A.)

7. The detailed analysis of the sensitivity of MSPI results to differences in the licensees' PRA models and the SPAR models demonstrated that these differences should be manageable. For all eleven unique PRA models, only three issues could have a

potentially large impact on MSPI results. The study found that significant differences in major model inputs such as system success criteria or initiating event frequencies are the primary source of significant quantitative differences, whereas factors of two to three differences in basic event probabilities have a much lesser effect on MSPI results. (See Appendix B.)

8. Recognizing that there are fundamental differences in approach between the MSPI, SDP, and SSU, a comparison was made of these three measures to determine whether there was overall congruence in the results for all seventy-seven component failures identified during the pilot program. It is concluded that the MSPI is a highly capable performance indicator that can differentiate risk significant changes in performance and addresses problems associated with the currently used performance indicators. The MSPI appears to consistently provide the best overall measure of integrated system performance, while minimizing both false positive and false negative likelihoods. (See Appendix I.)

Major Issues and Recommendations

In the course of the pilot program, a number of significant issues arose regarding the fundamental methodology of the MSPI as described in draft NEI 99-02. Resolution of these items first required a thorough understanding of how the issue affected MSPI results plant-by-plant, within the group of pilot plants, and across the industry as a whole. These issues relate to:

- The appropriateness of generic baseline reliability data.
- "Invalid" Indicators whereby one failure beyond normal expectation of performance results in exceeding the WHITE threshold.
- "Insensitive" Indicators whereby a very large number of similar component failures within a system would be necessary to reach the WHITE threshold.
- The recognition that an increase in unreliability increases delta CDF both through the independent failure contribution and through a common-cause failure contribution.
- The concern that because of the prescriptive rules for inclusion of components within the pilot program, some plants may need to monitor an inordinately large number of low risk significance valves.
- The concern that there is an inconsistency in the treatment of support system initiators for safety-related service water and component cooling water from plant-to-plant.

Six major recommendations to improve the MSPI as currently formulated in the draft NEI 99-02 guidance are made to address these issues:

RECOMMENDATION #1: Table 2 of Appendix F to NEI 99-02 should be revised to use industry failure rates derived for the period 1999-2001 (given in Table C.2 of this report) as surrogate for the period 1995-1997.

RECOMMENDATION #2: A "frontstop" as described in Appendix D of this report should be used as the means of addressing the Invalid Indicator issue. The frontstop would take the form of a risk cap of 5E-7 on the delta URI associated with the single most risk significant failure, so long as the delta URI is less than 1E-5. The frontstop would only be applied to the GREEN/WHITE threshold.

RECOMMENDATION #3: The variable backstop as described in Appendix E of this report should be employed as the means of addressing the Insensitive Indicator issue.

RECOMMENDATION #4: The Common-Cause Failure contribution to Fussell-Vesely Importance should be included in the MSPI formulation, as described in Appendix F of this report. Substantial guidance on the process for this inclusion should be provided in Appendix F to NEI 99-02.

RECOMMENDATION #5: The guidance in Appendix F to NEI 99-02 should be revised to allow the licensee the option of excluding low risk valves with Birnbaum importance measures (adjusted for common-cause effects) less than 1E-6/yr, as described in Appendix G of this report.

RECOMMENDATION #6: The guidance in Appendix F to NEI 99-02 should be revised to require the inclusion of the contribution of cooling water support system initiators to Fussell-Vesely importance, as described in Appendix H of this report.

Not all issues identified during the course of the pilot program have been resolved, but the above recommendations address the major *technica*l issues associated with the proposed MSPI formulation. Additional issues mostly related to the *implementation* of the MSPI, such as the need to apply the Significance Determination Process and the treatment of external events, continue to be addressed. Furthermore, the guidance in the draft Appendix F to NEI 99-02 as well as the NRC Inspection Manual will need to be modified to incorporate findings resulting from this research effort. Finally, prior to MSPI implementation, a process to identify and resolve potentially significant modeling differences between the licensee PRA models and SPAR models would be necessary. Developing such a process is beyond the scope of this report.

1. PURPOSE AND SCOPE

The purpose of this report is to provide the results of the independent verification of the Mitigating Systems Performance Index (MSPI) for the pilot. Pilot plant data was collected for six months starting in the September of 2002, and ending in February of 2003. This was followed by ten months of detailed analysis of the pilot results by the Office of Nuclear Regulatory Research (RES). The independent verification discussed in this report consists of a number of tasks performed by RES, and can be summarized as two major activities:

- Verification of the reasonableness and accuracy of inputs to the MSPI and results for the twenty plants in the pilot program
- Identification of technical issues arising from the formulation of the MSPI, and recommendations for improving the method.

The main body of this report provides an overview of the RES findings and results. The technical details can be found in the appendices to this report. Program and implementation issues associated with the MSPI are beyond the scope of this report, and will be addressed in separate assessments in conjunction with the Office of Nuclear Reactor Regulation (NRR).

2. BACKGROUND

The Reactor Oversight Process (ROP) currently uses performance indicators that quantify system unavailability. There are certain issues associated with these indicators, including (a) the use of generic thresholds, (b) the way in which fault exposure time associated with failure events affects the values of the current indicators, and (c) the method of cascading failures of cooling water support systems.

Phase 1 of the Risk-Based Performance Indicator (RBPI) Development program (Ref. 1) explored several possible enhancements to the ROP performance indicators. A key aspect of the Ref. 1 approach was the use of plant-specific models (the SPAR models) to assess the risk significance of changes in unreliability (UR) and unavailability (UA). Based on these models, it was possible to develop candidate RBPIs that separately quantify UR and UA within a common model framework. It was also possible to determine plant-specific thresholds for these indicators. These enhancements help to address the issues mentioned above for current ROP indicators. In the Phase 1 RBPI effort, these enhancements were shown to be generally feasible, although for some UR indicators, statistical uncertainty is an issue.

Although these candidate indicators displayed certain benefits compared to the performance indicators (PIs) currently in use, they also had certain drawbacks. In particular, implementing separate train-level UR and UA indicators leads to a substantial increase in the number of indicators. This increase in the number of indicators would raise concerns regarding their effect on the action matrix in the ROP, if implemented. In addition, including a larger number of indicators increases the likelihood that at least one indicator will give a false indication.

The MSPI builds upon the insights and findings developed in the RBPI program (improved quantification of UR, using plant-specific thresholds) while resolving the issues associated with proliferation of indicators. The MSPI approach separately quantifies the significance of changes in UR and UA, but then rolls up these contributions into a single system-level indicator. The MSPI approach does this using a simplified calculational approach based on importance measures, thereby avoiding the need for ongoing manipulations of the entire probabilistic risk

(PRA) model. This approach is quantitatively adequate until changes in UR and UA become very large, at which point the numerical inaccuracy does not matter, because licensee and regulatory attention has already become focused on these contributions.

3. CHARACTERIZATION OF MSPI's

3.1 Purpose of MSPI's

The purpose of the MSPI (NEI 99-02, Ref. 2) is to "monitor the performance of selected systems based on their ability to perform risk-significant functions… ." RES has developed the MSPI to address several specific problems with the currently used performance indicators including: the use of fault exposure hours in the Safety System Unavailability (SSU), the omission of unreliability elements in the indicator, the use of mostly one-size-fits-all performance thresholds irrespective of risk-significance of the system, and the cascading of support system failures onto mitigating system unavailability. If and when implemented, the MSPI would replace the existing SSU Performance Indicators for mitigating systems in the Reactor Oversight Process (ROP). It may also replace or supplement the use of the Significance Determination Process (SDP) as applied to single failures within scope of the MSPI.

3.2 Definition of MSPI's

As currently formulated, the MSPI of a system is a simplified and linearized approximation to the change in CDF due to changes in reliability and availability of risk-significant elements of that system. The calculation focuses on key components, and quantifies the change in CDF using a simple formula based on importance measures.

The MSPI is formulated as a sum of changes related to UA and changes related to UR:

$$MSPI = UAI + URI$$

Unavailability-Related Contributions

UAI , the UA-related contribution, is a sum of contributions from different trains:

$$UAI = \sum_{j=1}^{n} UAI_{tj} \qquad \text{(Equation 1)}$$

The summation runs over trains, and UAI_{tj} is the contribution of the jth train to the change in *CDF* due to changes in unavailability of this train.

If contributions to a given train's unavailability can be collected into a single PRA basic event having unavailability UA_t , then the change in *CDF* associated with a change in train UA can be written as (Ref. 2):

$$UAI_t = B(UA) * \Delta UA$$
$$UAI_t = B(UA) * \left(UA_t - UA_{BLt}\right)$$
$$UAI_t = CDF_p \left[\frac{FV_{UAp}}{UA_P}\right]\left(UA_t - UA_{BLt}\right),$$

where *B(UA)* is the Birnbaum importance for UA, FV_{UA} is the Fussell-Vesely importance for UA, and UA_{BLt} is the baseline unavailability. Items carrying a "p" subscript are understood to be calculated using the "P"RA values, while items on the right-hand side *not* carrying a "p" subscript (carrying instead a "t" subscript) are derived either from current operating data or from baseline data. In the NEI formulation, the "t" subscript just refers to "train." This formulation divorces the calculation of *B(UA)* from the calculation of ΔUA. In other words, *B(UA)* is independent of the value of *UA*. Given *B(UA)*, the terms whose difference yields ΔUA need only to be calculated on a mutually consistent basis - not necessarily consistently with the PRA - in order for the formula to yield a good estimate of the change in *CDF*. Of course, if *CDF* and *FV* are calculated and combined as above, then in order to yield *B(UA)* as desired, *CDF* and *FV* both need to be based on the same value of *UA* that appears in the denominator of the formula.

In practice, UA data are collected on a train basis. This avoids the potential for the overestimation of train unavailability that could result if individual components' unavailabilities were collected and summed as if they were independent. If one has separate terms in Equation 1 that can not be collected into a single basic event, then each element of the sum can still be calculated using the above approach.

<u>The Unreliability-Related Contribution</u>
The treatment of the UR-related contribution generally follows the above treatment of UAI. However, the elemental contributions to train unreliability need to be assessed separately, and partly as a result of this, there are additional considerations in URI.

The following quantity is used for the UR-related contribution:

$$URI = CDF_P \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj}),$$

where

the summation is over those active components and failure modes in the system that can by themselves fail a "train,"

CDF_p is the plant-specific internal events, at-power core damage frequency,

FV_{URc} is the component-specific Fussell-Vesely value for unreliability,

UR_{pc} is the plant-specific PRA value of component unreliability,

UR_{Bc} is the current estimate of ("Bayesian corrected") component unreliability for the previous 12 quarters,

UR_{BLc} is the historical baseline unreliability for the component.

Max refers to using the highest FV/UR from all the basic events (i.e. failure modes) for a given component (see Ref. 2). Note also that the current formulation considers only the internal events initiators, and does <u>not</u> include internal flooding events or external events initiators.

A Bayesian approach using the constrained non-informative prior (CNIP) is applied to the current estimate of component unreliability in the above formulation. The technical basis for the use of the CNIP is provided in Appendix J.

3.3 Benefits of MSPI's

Two key attributes of the MSPI include the consistent treatment of both unavailability and unreliability, and the implementation of plant-specific performance thresholds. The existing Safety System Unavailability (SSU) Performance Indicators account only for system unavailability, which is only half of the equation for overall system performance. Basic reliability theory recognizes that optimum system performance arises when the proper amount of preventive maintenance (PM) is applied: too little PM causes the unreliability term to become unacceptably high, while too much PM drives the unreliability term to near-zero but at the expense of too much down time. The implementation of plant-specific thresholds also acknowledges the large dissimilarities in design and operation of nuclear power plants, and sets the performance thresholds commensurate with the risk-significance of the varying systems, and number of component demands and failures.

More specifically, the major benefits of the MSPI include:

1. The MSPI's treat UR along the lines of the treatment of UR in NUREG-1753. This treatment is based on failure and demand counts rather than fault exposure time. The MSPI is intended to resolve certain issues associated with the way in which existing PI's treat fault exposure time, including the tendency of the T/2 fault exposure hours to over estimate risk significance in the current SSU.

2. MSPI's are simple to calculate *in comparison to complete PRA model requantification*. An MSPI requires only baseline performance parameters that go into the prior distributions for Bayesian updating, and a set of importance measures derived from a plant model. Once the importance measures are derived, manipulating the plant model is no longer necessary in order to quantify the MSPI. Given the above parameters, the MSPI can be quantified by hand calculation (although a spreadsheet, database, or computer program will normally be preferred).

3. The MSPI rolls up most equipment performance data into a single performance-related figure of merit for each system. Therefore, although the MSPI addresses both reliability and availability, and spans non-diverse trains within a given system, the number of different performance indices that would result from the various combinations is kept to a minimum.

4. The MSPI measures directly the performance of cooling water support systems (e.g. service water and component cooling water). There is no longer a need to have cooling water support system failures "cascading" onto mitigating systems as is the current practice with the SSU.

5. The MSPI can be a very good approximation to the change in CDF due to current performance, provided that changes in performance are not extremely large, and provided that current performance can be estimated accurately. If the changes in performance are large, the MSPI's correspondence to change in CDF loses numerical accuracy, but the MSPI still points up the existence of a large change.

3.4 Limitations of MSPI's

NEI 99-02 denotes some of the limitations of the MSPI as follows:

Due to the limitations of the index, the following conditions will rely upon the inspection process for evaluating performance issues:

1. Multiple concurrent failures of components including common-cause failures
2. Conditions not capable of being discovered during normal surveillance tests
3. Failures of non-active components such as piping and heat exchangers that are not accounted for in train unavailability.

Based upon the pilot program results, the treatment of these conditions under the inspection process is reasonable. No deletions or additions to the above list are recommended. During the pilot program, the possibility of having so-called "invalid indicators" defer to the inspection process was discussed. "Invalid indicators" are MSPIs having the property that just one failure above baseline during the observation period can cause the index to go "WHITE." According to Appendix F (Ref. 2),

> If, for any failure mode for any component in a system, the risk increase (ΔCDF) associated with the change in unreliability resulting from single failure is larger than 1.0×10^{-6}, then the performance index will be considered invalid for that system.

The recommended "frontstop" concept, if implemented as proposed in Section 6.2 and Appendix D below, could obviate the need to have invalid indicators defer to the inspection process as originally proposed.

There are a number of shortcomings to the MSPI. These include much greater licensee effort compared to the current SSUs in terms of up-front identification of system boundaries and components, assembly and adjustment (if necessary) of component risk measures, and data tabulation. Furthermore, quantification of the MSPI is not as transparent as the current SSUs. And the four limitations discussed above could result in duplication of effort and overlap with the SDP if implementation issues are not fully considered. Discussion and resolution of implementation issues are beyond the scope of this report, and will be addressed in separate assessments in conjunction with NRR.

4. DESCRIPTION OF PILOT PROGRAM

4.1 Objectives and Participants

At the onset of the pilot, there were three primary objectives:

1) Exercise the MSPI guidance
2) Perform validation and verification
3) Perform Temporary Instruction inspections.

The first objective was performed primarily by the licensees of the twenty nuclear power plant units in the pilot. With Ref. 2 as guidance, this activity included:

- Identifying risk significant functions for the six systems of interest
- Identifying success criteria
- Identifying data sources
- Identifying system boundaries
- Identifying active components to be monitored
- Tabulating Fussell-Vesely importance measures and basic event probabilities for all components to be monitored
- Collecting relevant unavailability and unreliability data
- Populating the pre-formatted NEI electronic worksheets
- Computing UAI, URI, and MSPI results on a quarterly basis, and submitting on-going results to the NRC on a monthly basis (for this pilot only)
- Identifying possible "Invalid Indicators"
- Assessing the reasonableness of results.

The second objective was a responsibility delegated to RES. It included a plant-by-plant performance data cross-comparison, use of SPAR models to validate importance measures, and identification and resolution of significant issues with the MSPI methodology. In order to reconcile significant differences between the plant PRA and the SPAR models, a major effort was undertaken to make further enhancements to the SPAR models that went beyond original anticipations of this pilot program. The results of all these activities performed by RES are the subject of this report.

Finally, the third major objective was to exercise Temporary Instruction inspections via TI 2515/149 (Ref. 4). This task was undertaken by the site Resident Inspectors/Senior Resident Inspectors and Region Senior Reactor Analysts. This activity included an item-by-item verification of many of the tasks performed by the licensees, although not on all systems on all plants. The reader is referred to Ref. 5 for a full description of inspection activities and findings.

As noted above, twenty nuclear power plant units participated in the pilot program. The list below identifies the Regions and plants in the pilot. The plants represent a reasonable cross-section of U.S. plant type, age and design, and reactor manufacturers. No Babcock & Wilcox (B&W) reactors were in the pilot. For complete vendor coverage, it would have been useful to include B&W plants. However, a more important consideration was the availability of internal events, level-1 at-power plant PRAs and the varied experience of the licensees' staffs to exercise the models. NEI has stated that, in this regard, the pilot participants were a reasonable representation of industry capabilities.

Region I	Region II	Region III	Region IV
Hope Creek	Surry 1 & 2	Braidwood 1 & 2	Palo Verde 1, 2 & 3
Limerick 1 & 2		Prairie Island 1 & 2	San Onofre 2 & 3
Millstone 2 & 3			South Texas 1 & 2
Salem 1 & 2			

4.2 Activities and Schedule

Public Meetings and Workshops were held in the first half of 2002 in order to set the stage for the initiation of the pilot in the second half of 2002. The three-day Workshop in Chicago in July, 2002 provided an opportunity to identify system boundaries and active components, attain familiarity with data reporting requirements, and resolve site-specific issues. On August 28, 2002, Regulatory Issue Summary 2002-14 was published, notifying addressees that NRC was starting a 6-month pilot program on September 1, 2002. Program Guidelines (Ref. 1) were issued and attached to NRC Regulatory Issue Summary 2002-14, Supplement 1 on September 30, 2002.

Licensees commenced the collection of data in September 2002. Monthly submittals of the NEI electronic worksheets were forwarded to NRC via e-mail beginning in October 2002. The final worksheets for the month of February, 2003 were submitted the following month, although several participants elected voluntarily to continue submittals for a short time thereafter. NRC issued Temporary Instruction 2515/149 in September 2002 (Ref. 4), and inspections of licensee MSPI submittals occurred through the late fall of 2002 and into the first quarter of 2003. Because of the incomplete state of some licensees' MSPI-related documentation, not all pilot plants received full inspection per the TI.

In January 2003, a Public Workshop was held to provide a mid-course assessment of the pilot, identify technical and process issues, and adjust the pilot program accordingly. A number of technical issues surfaced that would require resolution prior to full implementation of the MSPI. Over a period of six months, RES worked to fully assess the implications of the issues and to provide recommendations for their resolution. In May 2003, a White Paper on the MSPI methodology was issued for review and comment (Ref. 6). The White Paper provided background material for a briefing before the Advisory Committee on Reactor Safeguards (ACRS) Subcommittees on Reliability and PRA, and Plant Operations on July 8, 2003. The ACRS Subcommittees generally had no major concerns with the concept of the MSPI, or with the direction of the research.

On July 23, 2003, RES presented the details and technical basis for modifications to the MSPI methodology. Industry representatives held a workshop on August 20, 2003 to exercise the proposed changes to the MSPI methodology. RES and NRR staff observed the exercise.

In August 2003, the SPAR enhancement effort for the eleven unique SPAR models (all twenty nuclear units in the pilot) was completed. The results of this task are discussed below.

The pilot was completed in September 2003, but some analyses beyond the original scope continued for four more months. Additional issues mostly related to MSPI implementation continue to be addressed. Discussion and resolution of implementation issues are beyond the scope of this report.

5. RESULTS OF INDEPENDENT VERIFICATION

The purpose of the MSPI verification effort was to obtain reasonable assurance of the adequacy of the inputs into the MSPI calculation, and reasonableness of pilot plant results. This was accomplished by assessing the individual inputs to the MSPI calculation on a plant-by-plant, system-by-system, and in many instances component-by-component basis. In addition, a comparison of MSPI results using the plant PRA models and the SPAR resolution models was performed. The detailed tasks performed in this activity included:

- Baseline data verification
- Current performance data verification
- Verification of FV/UA and FV/UR importance measures
- Electronic spreadsheet calculation verification
- Overall MSPI results verification.

The pilot plant data submittals were reviewed to identify train-specific unavailability baselines. Results were tabulated by system and train type. The verification effort generally showed the pilot plant submittals to be reasonable. However, the verification did identify several baseline UAs that were lower than the unplanned UA values listed in Table 1 from Appendix F of draft NEI 99-02 (Ref. 2). Clearly, the sum of two positive values cannot be less than any individual value. The effort also identified situations where the average planned UA based on a three-year period could result in a baseline that is too high. This could arise if an unusually long planned train outage occurred in this baseline period. Additional guidance may be needed in this area.

The baseline failure rates of Table 2 from Appendix F of draft NEI 99-02 were also reassessed. These "generic" industry failure rates are common to all pilot plant submittals, and hence this task was not a verification of pilot plant data submittals *per se*. The reassessment of component failure rates led to a substantially expanded task on this topic. The basic conclusion is that the current values in Table 2 of NEI 99-02 Appendix F are not truly representative of 1995-1997 performance as supposed, and are not appropriate for use in the MSPI. Additional discussion is provided in Section 6.1 of this report and in Appendix C.

Current UA results for the three-year period were tabulated and compared across plants and with baselines. No current UA entries were identified as outliers. Pilot plant unreliability data also were compared with data searches of the Equipment Performance and Information Exchange (EPIX) using the NRC-developed Reliability and Availability Database System (RADS) software. In general, the results across the twenty pilot plants for the number of failures and demands (or hours) were found to be comparable to the results obtained from EPIX/RADS. But on a plant-specific basis, inconsistencies between EPIX data and MSPI data were found. Additionally, the verification effort did identify pilot plant data entry errors. These errors included cases of double or "multiple counting" of failures or demands. The discovered errors were brought to the attention of the licensees, and most were corrected by the final data submittals in March 2003.

Pilot plant FV/UA and FV/UR values were verified by comparing them with results obtained from SPAR models. The existing SPAR Rev. 3 models had been benchmarked against licensee models and were, in most cases, within a factor of 2 to 3 of licensee PRAs for core damage frequency. However, with regard to risk model importances at the component level, significant discrepancies were found between existing SPAR Rev. 3 models and the corresponding plant PRA models. Therefore, an additional SPAR enhancement effort was performed to help resolve these differences for the eleven SPAR models that cover the twenty pilot plants. The limited SPAR versus plant PRA resolution effort was successful in identifying and resolving many issues related to component FVs. Using the geometric mean (over all monitored components at a plant) as the figure-of-merit, the SPAR resolution models agreed with the eleven unique plant PRA FV/URs within a factor of two on average. Internal events CDF results also were comparable. However, significant differences were found to exist for certain components, especially those in the SWS and CCW where initiating event contributions to importance may be important. The results of this effort are discussed in detail in Appendix B.

With regard to FV/UA and FV/UR values submitted by the pilot participants, many instances were found where no FV/UR values were provided for components that otherwise would be monitored. These were, in general, low risk-significant components, but the basis for omission was not provided. Some inconsistencies in UA for standby versus normally running trains were found as well. In both these areas, additional guidance is warranted.

As part of the MSPI verification effort, the MSPI calculations performed within the NEI spreadsheet were verified by comparing results from an independently developed spreadsheet. Results from both sets of spreadsheets agreed.

The final step in the verification effort was to compare MSPI results from the pilot plant submittals and SPAR resolution models. Using similar performance data (previously verified) but different risk parameters (CDF, FV/UA, FV/UR) from SPAR and plant PRAs, the two sets of results were compared. In the process, some half-dozen data entry errors from the pilot plant spreadsheets had to be corrected.

Overall, the MSPI results from the pilot plant submittals and from the SPAR resolution models were found to be in very good agreement:

- In terms of color indications, the pilot plant model and SPAR resolution model results for the 4th Qtr 2002 are comparable if not identical depending on whether or not the frontstop is used or the effect of common-cause failure modeling is accounted for.
- For MSPI values above the practical limit of significance (1E-7), the SPAR resolution model numerical results generally agree with the pilot plant risk model results to within a factor of three.
- The pilot plant MSPI results indicated positive MSPIs for thirty-nine out of one hundred systems, compared to thirty-seven using the SPAR resolution risk model.

More details on this verification effort are provided in Appendix A to this report.

Because of concerns with the adequacy of plant PRAs for use in the MSPI, and because of significant differences in importance measures derived from the licensees' PRA models and the SPAR models, a detailed analysis was performed that went beyond the original scope of the pilot. The analysis investigated the effect of PRA model differences on the MSPI results, and is described in detail in Appendix B. The procedure involved first identifying major modeling differences between the licensees' PRA models and SPAR models, grouping the differences, creating "change sets" for the PRA computer code, requantifying the entire risk model, deriving new importance measures, and then assessing how the newly derived importances could affect the MSPI indications and numerical results.

The detailed analysis of the sensitivity of MSPI results to differences in PRA modeling demonstrated that these differences should be manageable. For all eleven unique PRA models, only three issues could have a potentially large impact on MSPI results. The study found that significant differences in major model inputs such as system success criteria or initiating event frequencies are the source of significant quantitative differences, whereas factors of two to three differences in basic event probabilities have a much lesser effect on MSPI results. However, prior to MSPI implementation, a process to identify and resolve potentially significant modeling differences would be necessary. Developing such a process is beyond the scope of this report.

Finally, while recognizing that there are fundamental differences in approach between the MSPI, SDP, and SSU, a comparison was made of these three measures to determine whether there was overall congruence in the results. In this regard, all seventy-seven failures over three years as reported in the MSPI program for all pilot plants were analyzed. The quarterly indication results for the MSPI that were measurably impacted by the failures were compared to the equivalent SSU performance indication as appropriate. When an SDP finding was available for the failure in question, these results were also compared. This detailed analysis can be found in Appendix I.

Of all three measures, it is concluded that the MSPI appears to consistently provide the best overall measure of integrated system performance, while minimizing both *false positive* and *false negative* likelihoods.

6. PROPOSED MODIFICATIONS TO MSPI METHODOLOGY

As a result of the pilot, a number of significant issues have arisen regarding the fundamental methodology of the MSPI as described in NEI 99-02 Rev 0. Resolution of these items first requires a thorough understanding of how the issue currently affects MSPI results plant-by-plant, within the group of pilot plants, and across the industry as a whole. Secondly, any proposed changes to the methodology must be assessed so as not to introduce unintended consequences. Thus, in assessing proposed changes to the methodology, every attempt has been made to compare results before and after the change whenever possible. In many cases, a direct quantification of the change (e.g. number of failures to the GREEN/WHITE threshold) could be derived. Two other techniques were often utilized: a) to compare 4th quarter 2002 MSPI results for the pilot plants with and without the proposed change, or b) to use numerical simulation whereby certain input parameters such as the number of component failures in a plant system within a three-year period were assumed to have a degree of randomness. The discussions below describe six major issues and proposed modifications to the MSPI methodology.

6.1 Baseline Performance Data

Table 2 of Appendix F to NEI 99-02 provides the generic industry failure rates as currently used in the MSPI. These failure rates, and the derived “a” and “b” values, are used for baseline component unreliabilities, and as priors for the Bayesian update of current performance. An important principle behind the selection of baseline generic data for the MSPI is that 1995-1997 industry performance has been deemed by NRC Policy to be acceptable. Contrary to this understanding, a closer review of the sources of reliability data in Table 2 identified the data to actually reflect 1970s, 1980s, and early 1990s performance. Failure rates in these time periods have been shown to be factors of 2 to 4 times greater than current rates. Higher failure rates would skew the baseline unreliability terms in the MSPI formulation to much higher values. This is turn could bias MSPI results in a more negative and non-conservative direction. Unfortunately, the sources of data for the period 1995-1997 are incomplete. A major data collection and analysis effort would be required to derive accurate 1995-1997 failure rates.

As discussed in Appendix C, good sources of data are available for the period 1999-2001. Comparison of the derived failure rates from the various sources indicates it is possible to determine failure rates with reasonable accuracy. Furthermore, statistical trend analyses of EPIX data, and LERs used in updated system reliability studies, indicate generally no significant trend from 1995 to 2001. Even if one were to nonetheless assume a trend, failure rates for 1999-2001 would be perhaps 20% less than those for 1995-1997, with wide scatter from one component failure rate type to the next. Finally, pilot plant 4th quarter 2002 MSPI results were calculated using both the 1999-2001 data, and rates extrapolated to 1996. While individual system MSPI numerical results varied from one case to the next, there was virtually no difference in GREEN and WHITE indications between these two data sets, across all MSPI systems and all pilot plants.

The overall conclusion is that reliability data for 1999-2001 are reasonably representative of 1995-1997 performance, and can be used with virtually no difference in results.

RECOMMENDATION #1: Table 2 of Appendix F to NEI 99-02 should be revised to use industry failure rates derived for the period 1999-2001 (given in Table C.2 of this report) as a surrogate for the period 1995-1997.

6.2 Use of Frontstop to Address Invalid Indicators

Some system indicators associated with the MSPI have significant "false positive" issues. That is, for statistical reasons, there is a significant probability of a plant system at baseline performance crossing over the GREEN/WHITE threshold. Within the MSPI pilot program, these indicators have been called "overly sensitive indicators" or, in the extreme case, "Invalid Indicators." "Invalid indicators" are MSPIs having the property that just one failure above baseline during the observation period can cause the index to go "WHITE." According to Appendix F of NEI 99-02 (Ref. 2),

> If, for any failure mode for any component in a system, the risk increase (ΔCDF) associated with the change in unreliability resulting from single failure is larger than 1.0×10^{-6}, then the performance index will be considered invalid for that system.

As discussed in detail in Appendix D, random failures that occur at a rate consistent with the industry performance are not indicative of a performance issue. One failure over a 3-year performance monitoring period, or one failure above the normal expectation, can be argued not to constitute a significant trend. Expected performance variation should not result in the crossing of a performance threshold.

Estimates based on pilot plant submittals are that some 17 to 24% of systems have at least one component failure mode (e.g. standby motor-driven pump fail-to-start) that could be considered an Invalid Indicator. There appears to be a strong correlation between high importance measure (Birnbaum in particular) and the likelihood of being an Invalid Indicator. The need to balance a high rate of correctly identifying degraded performance ("true positives") while minimizing "false positives" is the driver behind the "frontstop." Originally conceived as a firm limit on the minimum number of failures necessary for a component type to indicate WHITE, the concept evolved to become a "risk cap" on the single most risk significant failure within a system in the 3-year reporting period. The "risk cap" meets all of the desired characteristics of:

- Addressing Invalid Indicators (reducing the false positives)
- Being compatible with and not ignoring the Unavailability Index contribution
- Maintaining sensitivity (does not adversely impact the false negatives).

Furthermore, the risk cap approach is consistent with Reg Guide 1.177 (Ref. 3) regarding what constitutes an acceptable guideline for small risk increase owing to a permanent Technical Specification change.

The risk cap is the minimum of 5E-7 and the delta URI associated with the single most risk significant failure within a system in the 3-year reporting period. It applies only to the GREEN/WHITE threshold. By assigning a "risk cap" of 5E-7, the outcome has the attributes that:

- No single failure alone results in WHITE indication
- Two significant failures (each with a risk contribution > 5E-7) would very likely result in WHITE
- One significant failure with other less significant failures could result in GREEN/WHITE threshold being exceeded
- One significant failure with significant contribution from UAI could result in GREEN/WHITE threshold being exceeded
- A situation in which URI is near zero but UAI > 1E-6 would result in WHITE indication.

No other potential solutions to the Invalid Indicator issue that were considered met all of these desired characteristics. Many options added even greater complexity than the risk cap option.

In practice, the use of the risk cap would make the determination of which components constitute "Invalid Indicators" a moot point. The risk cap would always be applied to the delta URI associated with the single most risk significant failure, so long as the delta URI is less than 1E-5. Because of the concern with failures that could potentially result in greater than 1E-5 (i.e. YELLOW), and the much greater risk significance attached to YELLOW over WHITE, the risk cap would not be applied to the WHITE/YELLOW (or YELLOW/RED) threshold. Pilot plant results did not identify any such situations where a single failure resulted in delta URI greater than 1E-5. In fact, there were only a few components identified amongst the pilot plants where two failures could give delta URI greater than 1E-5. However, a single failure that gives delta URI greater than 1E-5 cannot be ruled out for the rest of the industry.

RECOMMENDATION #2: A "frontstop" as described in Appendix D of this report should be used as the means of addressing the Invalid Indicator issue. The frontstop would take the form of a risk cap of 5E-7 on the delta URI associated with the single most risk significant failure, so long as the delta URI is less than 1E-5. The frontstop would only be applied to the GREEN/WHITE threshold.

6.3 Use of Backstop to Address Insensitive Indicators

Although the systems selected for monitoring are relatively risk-significant at most plants, it may happen at some plants that the Birnbaum importances (B's) for specific system *trains* are relatively small numbers. This is due in part to the system selection process: an indicator defined for systems that are important at many plants, but not at all plants, may be *insensitive* at some plants. A low value of train B can also easily arise in highly redundant systems; failure of *individual* trains in a highly redundant system may not yield a high conditional CDF, even if failure of the entire system would do so. In such a case, a large number of failures is needed to produce a change in the MSPI greater than 1E-6.

Those components where a large number of failures are necessary before resulting in a change of CDF of 1E-6/yr have come to be called *Insensitive Indicators*. What constitutes a "large" number of failures can be subjective. For the sole purpose of identifying possible solutions to the Insensitive Indicator issue and performing sensitivity studies, a condition of > 20 failures was used in the original definition. By this measure, approximately 11% of the systems for the twenty plants in the pilot had all components within the system classified as Insensitive Indicators. The number of failures to WHITE for a component type was found to be correlated inversely with FV/UR, not unexpectedly. The RHR system was the system most likely to have an Insensitive Indicator, owing to its generally low risk-importance at power.

The occurrence of an unexpectedly large number of failures implies a performance issue that could well be cross-cutting (i.e., affecting other systems), and have a net effect on ΔCDF that is somehow not captured in the current calculations. Therefore, it is desirable to supplement the 1E-6 threshold criterion for entry into "WHITE" with another criterion. This criterion will be based on the statistical significance of the observed number of failures, relative to prior expectations. When a number of failures is observed larger than or equal to a specified "backstop" value, a WHITE will be declared, independently of the calculated change in the MSPI. As discussed in detail in Appendix E, the "backstop" threshold has been formulated to have the following properties:

- The false positive rate will be low. This criterion can be formulated to say that the conditional probability of declaring "WHITE," given normal performance, will be very low.
- Of all the positives that occur under baseline conditions, only very few are *false* positives.

In essence, the backstop should be invoked rarely in comparison to the calculated MSPI using the algorithm. (Numerical simulations have confirmed that the backstop has this property).

Conceptually, the "backstop" is a limit on the total number of failures, of all failure modes and of all components of one type in one system of a single nuclear power plant unit. Each system and type of component corresponds to a single backstop, with all failure modes combined. If the number of failures seen in the three-year performance period is equal to the backstop number or more, the system/component has reached or exceeded the backstop and is denoted "WHITE."

Two types of backstops were derived using the method in Appendix E. The first is a generic set of backstops by component type. In a three-year period, if the number of failures of similar components within a system (e.g. both EDGs) reached or exceeded the backstop, the system would be declared WHITE regardless of the calculated MSPI. This would ensure that the system would not remain GREEN despite a large number of failures. The second approach allows a variable backstop based on the "expected number of failures" of similar components in a system over a three-year period. The advantages of this approach are that the variable backstop allows for the variation in design configuration (number of components), testing frequency, and operation. Given the large variation of designs across the industry, the variable backstop approach is strongly urged.

With the "backstop" so defined, it is now possible to re-define what constitutes an "Insensitive" system. If all component failure modes within a system require more failures to WHITE using the 1E-6 criterion than the corresponding variable backstop counts, then that system is defined as "Insensitive." By this measure, approximately 33% of the one hundred systems for the twenty pilot plants would be deemed "Insensitive" (not including the adjustment for common cause).

RECOMMENDATION #3: The variable backstop as described in Appendix E of this report should be employed as the means of addressing the Insensitive Indicator issue.

6.4 Treatment of Common-Cause Contribution to Fussell-Vesely

The current draft industry guidance for MSPIs (Ref. 2) states that

> Some aspects of mitigating system performance cannot be adequately reflected or are specifically excluded from the performance indicators in this cornerstone. These aspects include ... the effect of common-cause failure...

The industry approach would relegate regulatory oversight of common-cause failure (CCF) potential entirely to inspection processes. Given a CCF-induced multiple failure, this would be analyzed under the SDP. But the current NEI program is not intended to address, before the fact, the existence of conditions that promote CCF. RES believes it is desirable to reflect the CDF significance of *all* performance changes that can validly be reflected in the MSPI, given the purpose of the MSPI and the character of the performance data and the available models.

Most CCF models represent the CCF contribution to risk as being essentially proportional to overall failure probability. In such models, if the measured UR increases and the proportionality constants are left alone, the assessed CCF contribution increases along with the independent failure contribution. This is how the RES effort has approached MSPI quantification: a change in UR increases delta CDF both through the independent failure contribution and through a CCF contribution. The current industry approach would not add the CCF contribution. For a given data set and a given model, the proposed RES staff approach therefore estimates a larger CDF change than does the industry approach. In many cases, this leads to substantially lower number-of-failures thresholds.

Because the purpose of the MSPI is to flag *potential* performance problems based on operating experience, it seems most reasonable to propagate changes in observed UR through the parametric CCF model, and include the change in CCF contribution in the assessed change in CDF. If there is an underlying performance issue causing a real increase in UR, it may well relate to CCF anyhow.

Appendix F provides a methodology for adjusting the MSPI Unreliability Index terms proposed by NEI to address the common-cause failure CCF contribution to these indices. Specifically, the appendix addresses the impact of a change in the independent failure probability on the CCF probability. The approach to address the CCF contribution provides a first-order mathematical approximation. It utilizes only one input beyond those already required by the MSPI, namely, the Fussell-Vesely (*FV*) importance value of the CCF event associated with each in-scope common-cause group. The increase in the URI term will vary depending on the common-cause importance of the component in question, the degree of coupling between total and common-cause failure rates, and the degree of redundancy of the component type.

Sensitivity studies described in Appendix F of this report indicate that the net effect of CCF on the increase in URIs could range from as low as 5% for low degrees of redundancy (e.g. 2-fold) and coupling, to an order-of-magnitude increase where the degree of redundancy is high (e.g. 4-fold) and the coupling is strong.

In a separate calculation for one particular failure mode for a highly redundant system at one pilot plant, the estimated number of failures-to-WHITE over a three-year period went from thirty-plus failures with no adjustment for CCF, to about five or six with CCF effects included.

Additional calculations were performed to estimate the impact of CCF on the issue of Invalid Indicators, as well as the number of WHITE indicators that might result from the long-term implementation of the program. The percentage of pilot plant systems having at least one component failure mode with Invalid Indication increased from 17% without CCF to 24% with the effect of CCF included. But the use of the “frontstop” would make the matter of Invalid Indicators moot. It would simply mean that the effect of CCF would be to apply the “frontstop” more often than if CCF were not considered.

Likewise, numerical simulation of the likely outcome of including CCF in the revised MSPI formulation was performed. The simulation indicates that there might be about one-third more WHITE indicators with CCF effects included compared to the case without CCF. RES does not believe this potential effect on the projected number of WHITE indicators to be unreasonable, given all of the limitations and approximations in the MSPI formulation. Moreover, the inclusion of CCF would substantially reduce the Insensitive Indicator issue, and minimize the need to rely on the performance-based “backstop.” Using the revised definition of an Insensitive system to be one where, for all components in the system, the number of failures to WHITE exceeds the “backstops,” the percentage of Insensitive systems for the pilot plants drops from 33% to 20% when common cause is considered.

Exercises performed by a number of pilot plant participants at the August 20, 2003 NEI workshop indicated that detailed guidance and training would be required to implement the proposed inclusion of Fussell-Vesely importances for CCF. The exercise also identified that in some instances the common-cause modeling includes a complicated coupling of pumps, motors, breakers, and other components. Dissection of the FV owing to common-cause into the various components was not a simple exercise. As a result, an alternative approach to address CCF has been provided in Appendix F. This option allows the use of generic multipliers on the FV from independent failures as an appropriate adjustment to account for the effect of CCF.

RECOMMENDATION #4: The Common-Cause Failure contribution to Fussell-Vesely Importance should be included in the MSPI formulation, as described in Appendix F of this report. Substantial guidance on the process for this inclusion should be provided in Appendix F to NEI 99-02.

6.5 Exclusion of Active Valves Based on Birnbaum Importance

Appendix F of NEI 99-02 provides clarifying notes as to the criteria for determining those components that are to be monitored in the MSPI. Specific guidance is provided on page F-9 of NEI 99-02 for valves, whether in series or parallel for multi-train systems. The guidance is prescriptive in nature and is intended to ensure to a first order of approximation that important valves within a system are included.

The expectation is that the number of valves to be monitored should not be far different from the number of pumps in the system, i.e. about twenty. However, the pilot identified that in some cases as many as forty-six valves would have to be monitored. This far exceeds expectations and can pose a large data collection burden, with no clear benefit in return.

Based on an analysis of all of the valves monitored by the twenty pilot plants, it is possible to exclude low importance valves without affecting the overall results of the MSPI. Birnbaum importance measure has been deemed to be appropriate since it is the measure directly used in the calculation of URI, and URI is the figure-of-merit of interest here. Analysis described in Appendix G shows a cutoff B value of 1E-6/yr to reduce burden significantly and still yield reasonably conservative results. ***The common-cause contribution to FV (and Birnbaum) must be added to the valve Birnbaums before the cutoff is applied.***

An important consideration is whether or not some minimum number of valves should remain in-scope regardless of their risk importance. There could be undesirable consequences of monitoring too few valves in MSPI. For one, the URI is more sensitive to failures of valves within a smaller population and more likely to result in a false WHITE for a small number of failures. Secondly, valves not monitored in the MSPI could be subject to the inspection process. Thirdly, as the plant PRA model changes owing to changes in plant design or equipment performance, it is likely that importance measures also change. It therefore seems reasonable to ensure a minimum number of valves are monitored by the MSPI, regardless of their risk significance.

RECOMMENDATION #5: The guidance in Appendix F to NEI 99-02 should be revised to allow the licensee the option of excluding low risk valves with Birnbaum importance measures (adjusted for common-cause effects) less than 1E-6/yr, as described in Appendix G of this report.

Appropriate cautions should be added regarding the potential negative consequences of having too few valves within a system. Also, the decision to use this option should be made at the beginning of the system boundary identification, and not changed unless a major PRA model revision causes significant movement of valve(s) Birnbaums above or below the cutoff.

6.6 Contribution of Support System Initiators to Fussell-Vesely Importance

Of the six systems within the scope of the MSPI, service water (SWS) and component cooling water (CCW) are the two systems that could serve in the two roles of both supporting other systems when called upon, and initiating a transient if the SWS or CCW system is lost entirely or is substantially degraded.

All PRA models provide risk measures such as Fussell-Vesely importance, Risk Achievement Worth (RAW), and Birnbaum importance from basic event probabilities for SWS and CCW components. However, while all the models include the component's contribution from the "support system" role of SWS and CCW, not all models include the contribution from the loss of SWS or CCW as an initiating event. This is because the initiating event frequencies used in some plant PRAs have been based on plant and/or industry experience, and use an explicit value for the frequency. The frequency may use a distribution with mean and variance, but the value that has been calculated is in some way separate from the linked PRA model. In other models, the PRA analyst may have chosen to link a loss of SWS initiator fault tree directly into the computer model of the PRA. Either approach is acceptable so long as it is based on valid equipment performance data, takes into account the potential for common mode failure based on plant-specific characteristics and design, and is generally consistent with industry operating experience.

All other things being equal, a plant PRA model that uses initiator fault trees explicitly for loss of SWS and/or CCW (where Importance of the initiating event components is accounted for) will result in higher Fussell-Vesely (FV) and Birnbaum risk measures for an associated basic event than a model that uses a point-estimate frequency. The difference between the two approaches would be a function of the importance of that initiator to the overall calculated CDF, as well as the importance of the particular component (and basic event) within the SWS or CCW system of interest. During the January 21, 2003 Workshop on the MSPI, a survey was taken of the pilot plant participants. Plant PRA models fell into three categories: a) those that used fault trees for loss of SWS and loss of CCW initiators that were directly linked in the PRA model, b) those that used fault trees and/or event trees outside of the linked PRA model to quantify the frequencies, which were entered manually into the PRA model no differently than a medium LOCA frequency would be, and c) those that used frequencies based on industry experience, updated with plant-specific data. Category “a” is the most prevalent, with about two-thirds of the pilot plants using this approach. These differences in approach clearly result in an inconsistency for the purpose of the MSPI; the MSPI methodology relies heavily on using calculated risk measures (FV divided by basic event probability) rather than (say) a re-quantification of the entire PRA model.

Sensitivity studies have been performed by some pilot plant analysts to identify the importance of including the contribution of support system initiators to the FV risk measure. Calculations were performed first by using the existing linked fault tree initiator models, and next with the fault tree initiator essentially turned off. Differences in FV using the two approaches can be expected to be strong functions of

- The importance of the initiator to overall CDF
- Importance of the component within the system
- System configuration and design
- Importance of recovery actions and success criteria.

At the lower end, the differences in calculated FV with and without initiator fault trees were shown to be less than one percent. At the upper end, differences as high as an order of magnitude in FV were seen for some components. The contribution of SWS and CCW components to FV both as initiators and mitigators need to be included if the full risk importance is to be properly accounted for.

Clearly, if the safety-related CCW and/or SWS systems to be monitored in the MSPI are strictly standby systems, then their loss cannot initiate a plant transient. The already-calculated FV values for the CCW/SWS components are proper and no further action is necessary.

Assuming that no initiator fault trees exist, it is possible to avoid the need to include the contribution of initiators to FV if all CCW/SWS components to be monitored in the MSPI have their Birnbaum (maximum for all failure modes) less than 1E-6/yr. Only if none of the above conditions are met is it necessary to account for the contribution of initiators to FV.

In the proposed resolution, licensees would be given two options. Those plant PRA models that do not use fault trees for loss of service water and/or loss of component cooling water could either a) add such fault trees and recalculate the FV importance measures, or b) use an approximation that adjusts the FV to account for the contribution in a way proportional to the importance of the system initiator to core damage frequency, and proportional to the importance of the component within the system, as described in Appendix H. This adjustment is shown to be conservative, yielding from zero to approximately 25% higher FV (based on regression analysis) than would be expected using an initiator fault tree. Given this potential conservatism in the approximation to adjust the FV, licensees may well choose to develop initiator fault trees for loss of service water and loss of component cooling water for the purpose of the MSPI.

RECOMMENDATION #6: The guidance in Appendix F to NEI 99-02 should be revised to require the inclusion of the contribution of cooling water support system initiators to Fussell-Vesely importance, as described in Appendix H of this report.

As discussed in Appendix H, one option to address this issue would be to add initiator fault trees for loss of SWS and loss of CCW. A second option would be to use an approximation that conservatively adjusts the FV to account for the contribution from support system initiators.

6.7 Additional Issues for Resolution

Finally, it should be noted that not all issues identified during the course of the pilot have been resolved. The above recommendations 1 through 6 address the major *technical* issues associated with the proposed MSPI formulation. Additional issues mostly related to the *implementation* of the MSPI, such as the need to apply the Significance Determination Process and the possible extension of the treatment to external events, continue to be addressed. Furthermore, the guidance in the draft Appendix F to NEI 99-02 as well as the NRC Inspection Manual will need to be expanded to incorporate findings resulting from this research effort.

7. REFERENCES

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APPENDIX A. SUMMARY OF MSPI VERIFICATION EFFORT

Appendix A
Summary of MSPI Verification Effort

A.1 Introduction

The Mitigating Systems Performance Index (MSPI) is a measure of change in core damage frequency (CDF) resulting from changes in mitigating system component unreliability performance and train unavailability. The MSPI is evaluated individually for five indicators comprised of six mitigating systems at each pilot plant. For each mitigating system, the MSPI equation is the following:

$$MSPI = \left(CDF_P\right)\left(\sum \frac{FV_P}{UR_P}\right)\left(UR_C - UR_B\right) + \left(CDF_P\right)\left(\sum \frac{FV_P}{UA_P}\right)\left(UA_C - UA_B\right) \quad \text{(Eq. A.1)}$$

where *MSPI* = *ΔCDF for the system (from changes in component UR and train UA)*
CDF_P = *internal events core damage frequency per calendar year (from plant PRA)*
FV_P = *Fussell-Vesely importance measure of the component or train (from plant PRA)*
UR_P = *component unreliability (from plant PRA)*
UR_C = *current component unreliability (Bayesian update using data from most recent three years)*
UR_B = *baseline component unreliability (Table 2 from Appendix F of draft NEI 99-02)*
UA_P = *train unavailability (from plant PRA)*
UA_C = *current train unavailability (data from most recent three years)*
UA_B = *baseline train unavailability (1999 – 2001 plant experience for planned and industry average for unplanned – Table 1 from Appendix F of draft NEI 99-02)*.

The first summation in Equation A.1 is over all monitored components within the system, while the second summation is over all trains within the system.

The MSPI calculation requires various inputs: monitored components within each monitored system, train UA_B's and component UR_B's, train and component performance during the rolling three-year data collection period (train UA_C, component failures, and associated demands or run hours), and risk model importance information (CDF_P, FV_P/UR_P, and FV_P/UA_P). Most of these inputs were addressed in the MSPI verification effort discussed in this appendix. However, inspection efforts covered the determination of monitored components and the collection of plant performance data, so those areas are not addressed here. Also, the risk model importance information is discussed in Appendix B, addressing the development of standardized plant analysis risk (SPAR) resolution models.

MSPI verification results presented in this appendix are based on the pilot plant data submittals dated March 21, 2003. However, several plants submitted corrected data in early April 2003. Also, modifications were made to Surry 1 and 2 in September 2003 to remove the internal flooding contribution to the model, consistent with the other pilot plants and the intent of the MSPI. Those corrections were included in the verification effort.

A.2 MSPI Baseline Data Verification

For train baseline unavailabilities, draft NEI 99-02 indicates that plant-specific and train-specific planned outages over a three-year period should be used to develop train-specific planned UA baselines. Unplanned UA baselines are industry-average values (over the period 1999 – 2001) listed in Table 1 from Appendix F of draft NEI 99-02. Unplanned and planned UAs are added to obtain the train-specific UA baselines. As part of the verification effort, the pilot plant data submittals were reviewed to identify train-specific UA baselines. Results were tabulated by system and train type. An example of the results of this effort is presented in Table A.1, covering the emergency AC power system. Several observations were noted based on this tabulation of UA baselines (which was performed for all five types of systems):

1. Several train baseline UAs were lower than the unplanned UA values listed in Table A.1 from Appendix F of draft NEI 99-02. According to the NEI guidelines, no train UAs should be lower than the values listed in that table.

2. Additional guidance is needed for cases where the baseline period for establishing UA planned includes an unusually long train outage (as might have occurred for emergency diesel generator B at Hope Creek, in Table A.1). In such cases, the resulting baseline may be too high, and results from the other trains may be more appropriate in terms of expected baseline performance.

3. The use of different UA baselines for similar trains within a system, especially if only a three-year period is used to establish the baseline, may imply differences between trains that do not actually exist.

4. Industry average results for UA planned baselines (using 1999 – 2001 data) may be more appropriate than plant-specific, train-specific results obtained over a three-year period.

For component baseline failure rates, values from Table 2 in Appendix F of draft NEI 99-02 are to be used. Appendix C addresses the applicability of those Table 2 baseline failure rates to the MSPI pilot program. The results of that comprehensive review are that a set of new failure rates (Year 2000) should be used based on industry performance during the period 1999 – 2001. The MSPI verification results in this appendix are based on use of the Year 2000 failure rates.

A.3 MSPI Current Performance Data Verification

Current UA results for the period July 1, 1999 through June 30, 2002 (3Q99 – 2Q02) for the twenty pilot plants were tabulated as shown in Table A.1. Results were compared across plants and with baselines to identify any suspect values. No current UA entries were identified as outliers.

To verify the pilot plant unreliability data, three-year results (3Q99 – 2Q02) were compared with data searches of the Equipment Performance and Information Exchange (EPIX) using the NRC-developed Reliability and Availability Database System (RADS) software. An example of the type of comparison made is presented in Table A.2 for the emergency AC power system, emergency diesel generator failure to start. In general, the results at the overall level (summation of all twenty pilot plants) for numbers of failures and demands (or hours) are comparable to the results obtained from EPIX/RADS. However, for individual plants, the failure counts may not agree (e.g., the pilot plant data indicate a failure, while EPIX/RADS do not, or vice versa). Also, the demand (or hour) totals may be significantly different. These plant-specific inconsistencies between EPIX data and MSPI data should be resolved at some point, especially if EPIX or the consolidated data entry (CDE) program is to be used in the future to submit data for the MSPI.

The comparison between pilot plant unreliability data and EPIX/RADS results identified several potential pilot plant data entry errors. An example of such errors was “multiple counting” of component demands, where component demands were summed over several components and then the sum was reported as the result for each individual component. (The NEI pilot plant data sheet would then again sum these values to obtain an overall demand total for the component type, resulting in multiple, incorrect counting of component demands.) Another example involved reporting of emergency diesel generator failures occurring during the load or run phase. One plant appeared to report failures during this phase as both failure to load/run (FTLR) and failure to run (FTR). Also, one plant appeared to report a single failure as occurring every quarter during the three-year period, thereby over counting the failures by a factor of 12. Most of the potential data entry errors were corrected in the March 21, 2003 pilot plant data submittals.

A.4 MSPI FV/UA and FV/UR Verification

Pilot plant FV/UA and FV/UR values were verified by comparing with results obtained from SPAR models. The existing SPAR Rev. 3 models had been benchmarked against licensee models and were, in most cases, within a factor of 2 to 3 of licensee PRAs for core damage frequency. However, with regard to risk model importances at the component level, significant discrepancies were found between existing SPAR Rev. 3 models and the corresponding plant PRA models. (There were often large differences between the SPAR Rev. 3 estimates for FV/UA and FV/UR and those from the pilot plant risk models.) Therefore, an additional SPAR enhancement effort was performed to help resolve these differences for the eleven SPAR models that cover the twenty pilot plants. The results of that effort are discussed in Appendix B, covering the development of SPAR resolution models. Using the SPAR resolution models, FV/UA and FV/UR comparisons with pilot plant risk model results usually agreed within a factor of three for the more risk-significant components (FV/UR or FV/UA > 1.0, or Birnbaum > 1.0E-5/year). However, several of the SPAR resolution models contain success criteria, basic event values, or initiating event frequencies (chosen to match the plant risk models) that would not be allowed under current SPAR development guidelines. These issues will need to be addressed before the SPAR resolution models can be issued as official SPAR models.

Several miscellaneous issues were identified with regard to FV/UR and FV/UA values. One is that a significant number of pilot plants did not list such values for some of their monitored components. It was not clear whether these components were not included in the risk model or these components were lost in the risk model truncation process. Guidelines might need to be developed to cover such instances. Another type of issue involves modeling of multiple-train systems with one or more trains normally running. In such cases, the risk models often assume certain trains are normally running and the others are standby. Then, train UA (from planned and unplanned outages) is included only for the standby train(s). Risk model FV/UA values obtained from such a model need to be modified to accurately reflect operations where any of the trains can be normally running (or standby). Such modifications were identified for two- and three-train systems, but additional guidance may be needed for other types of configurations. Note that these modifications to FV/UA values were made to the risk models during the MSPI verification process.

A.5 MSPI Spreadsheet Calculation Verification

As part of the MSPI verification effort, the MSPI calculations performed within the NEI spreadsheet (used by the pilot plants to report their data) were verified by comparing results from an independently developed spreadsheet. Results from both types of spreadsheets agreed.

A.6 MSPI Results Verification

The final step in verifying pilot plant MSPI results was a comparison of ∆CDF results with those obtained using SPAR resolution model results. For these comparisons, both approaches used the same pilot plant performance data (with several corrections listed below), the same baseline UA (pilot plant values) and UR (Year 2000 values recommended in Appendix C), and the same mission times (24 hours for all systems except the emergency diesel generators, and eight hours for the emergency diesel generators). However, the pilot plant MSPI results used the pilot plant risk model values for CDF, FV/UA, and FV/UR (with changes made by the plant during the SPAR enhancement efforts), while the SPAR MSPI results used SPAR resolution model values.

Several potential data corrections were included in this MSPI comparison:

1. Surry 2 EAC (FTR: 4 failures reduced to 0)

2. Salem 1 SWS (MDP FTS: 17 failures reduced to 1)

3. Millstone 3 HPSI (MDP FTR : 8080 hours reduced to 80.8)

4. Limerick 2 RHR (missing data filled in with Limerick 1 data)

5. Prairie Island 1 and 2 CCW (changed standby MDP to running MDP).

Because of the changes listed above (UR baselines, data corrections, mission times, FV/UA, and FV/UR), the pilot plant MSPI values listed in this appendix are different from those calculated in the March 21, 2003 pilot plant submittals. The changes were made to more accurately reflect current assumptions and methodologies.

Presented in Table A.3 are the MSPI results (∆CDF and performance color) for the three-year data period ending December 31, 2002 (4Q02), using the pilot plant risk models. Three MSPIs out of one hundred are greater than 1.0E-6/yr and are therefore WHITE. However, with the proposed frontstop, the Palo Verde 2 HRS and Salem 1 EAC MSPIs drop below 1.0E-6/yr and are GREEN. This leaves only one WHITE for the quarter, Braidwood 1 HRS. This MSPI is WHITE because of two diesel-driven pump failures to start and one failure to run over the three-year period.

Presented in Table A.4 are the same MSPIs for the same period, but calculated using the SPAR resolution model values for FV/UR, FV/UA, and CDF. Two of the one hundred MSPIs are WHITE using the SPAR resolution models. However, with the proposed frontstop, the Salem 1 EAC MSPI drops below 1.0E-6/yr and is GREEN. This leaves only one WHITE, Braidwood 1 HRS. Therefore, with the proposed frontstop, both the plant PRA and the SPAR resolution models indicate one WHITE, Braidwood 1 HRS. (Note that this result represents a snapshot of the MSPI for only one quarter during the pilot, and is not inclusive of all other possible WHITE indications during other quarters).

For MSPI values above 1.0E-7/year (the practical limit of significance), the SPAR resolution model results generally agree with the plant risk model results to within a factor of three. This is expected, because the SPAR resolution model development generally resulted in FV/UR and FV/UA values that were within a factor of three of the plant risk model results.

Overall, the plant risk model MSPI results (Table A.3) include thirty-nine positive ΔCDF entries and sixty-one negative values. Also, the average MSPI value is 6.63E-9/year, which is essentially neutral. In comparison, the SPAR resolution risk model MSPI results (Table A.4) include thirty-seven positive and sixty-three negative entries. The average MSPI value in the SPAR resolution model is -2.83E-8/year, also neutral.

A.7 Summary of MSPI Verification Effort

The MSPI verification effort involved the comparison of plant risk model parameters (FV/UR, FV/UA, and CDF) with corresponding SPAR risk model values. The verification effort also included comparison of MSPI ΔCDF results obtained from the two risk models. In general, the existing SPAR Rev. 3 models did not match the plant risk models with respect to the FV/UR, FV/UA, and CDF parameters. An additional SPAR enhancement effort was required in order to develop SPAR resolution models that produced FV/UR and FV/UA values within a factor of three of the plant risk model values. Given these SPAR resolution models, the MSPIs calculated are in general agreement with the plant risk model MSPI results. Specifically, for most MSPIs with a ΔCDF greater than 1.0E-7/year, the SPAR resolution model results generally agree with the plant risk model results within a factor of three.

Table A.1 MSPI Pilot Plant Emergency Diesel Generator UA Baselines and Current Performance Summary

Pilot Plant Data (3Q99 - 2Q02)
8/24/2003

Emergency AC (EAC) System

		UA Current Performance (3Q99 - 2Q02)					UA Train Baseline (1999 - 2001)						
Pilot Plant	# Trains	DGA	DGB	DGC	DGD		DGA	DGB	DGC	DGD	Site Current Average	Site Baseline Average	Comments
Braidwood 1	2.0000	0.0112	0.0124				0.0122	0.0122			0.0086	0.0122	
Braidwood 2	2.0000	0.0039	0.0069				0.0122	0.0122					
Hope Creek	4.0000	0.0093	0.0122	0.0110	0.0148		0.0107	0.0958	0.0132	0.0155	0.0118	0.0338	DGB baseline is much too high
Limerick 1	4.0000	0.0197	0.0129	0.0106	0.0134		0.0241	0.0154	0.0069	0.0098	0.0100	0.0119	
Limerick 2	4.0000	0.0032	0.0066	0.0044	0.0095		0.0116	0.0048	0.0119	0.0109			
Millstone 2	2.0000	0.0129	0.0120				0.0156	0.0149			0.0125	0.0153	
Millstone 3	2.0000	0.0090	0.0104				0.0130	0.0138					
Palo Verde 1	2.0000	0.0067	0.0087				0.0039	0.0050			0.0076	0.0049	
Palo Verde 2	2.0000	0.0124	0.0052				0.0083	0.0023					
Palo Verde 3	2.0000	0.0070	0.0057				0.0039	0.0059					
Prairie Island 1	2.0000	0.0099	0.0092				0.0195	0.0189			0.0136	0.0148	
Prairie Island 2	2.0000	0.0123	0.0231				0.0084	0.0126					
Salem 1	3.0000	0.0081	0.0126	0.0089			0.0090	0.0109	0.0086		0.0091	0.0093	
Salem 2	3.0000	0.0091	0.0083	0.0073			0.0091	0.0101	0.0082				
San Onofre 2	2.0000	0.0241	0.0193				0.0254	0.0234			0.0199	0.0189	
San Onofre 3	2.0000	0.0165	0.0194				0.0124	0.0144					
South Texas 1	3.0000	0.0178	0.0155	0.0172			0.0161	0.0160	0.0143		0.0171	0.0160	
South Texas 2	3.0000	0.0136	0.0138	0.0245			0.0164	0.0168	0.0166				
Surry 1	2.0000	0.0234	0.0250				0.0224	0.0167			0.0270	0.0224	
Surry 2	2.0000	0.0333	0.0261				0.0310	0.0194					
Average	Current	0.0130				Baseline	0.0149						
							0.0132	without Hope Creek DGB					

Table A.2 MSPI Pilot Plant Unreliability Data Comparison with EPIX/RADS for Emergency Diesel Generator Failure to Start

Comparison of Pilot Plant Data (3Q99 - 2Q02) with EPIX/RADS Data
6/10/2003
Pilot plant data as of 3/21/03. EPIX database including 4Q02, as accessed using RADS.

				Pilot Plant				EPIX/RADS			
System	Component	Failure Mode	Pilot Plant	# Components	# Failures	# Demands	# Hours	# Failures	# Demands	# Hours	Comments
EAC	EDG	FTS	Braidwood 1	2	1	116		1	87		
			Braidwood 2	2	0	123		0	112		
			Hope Creek	4	0	192		0	200		
			Limerick 1	4	0	227		0	198		EPIX estimate for test demands (12) is inaccurate. EPIX FTLR demands used.
			Limerick 2	4	0	201		0	198		EPIX estimate for test demands (12) is inaccurate. EPIX FTLR demands used.
			Millstone 2	2	0	106		0	92		EPIX estimate for test demands (41) is inaccurate. EPIX FTLR demands used.
			Millstone 3	2	0	77		0	92		EPIX estimate for test demands (23) is inaccurate. EPIX FTLR demands used.
			Palo Verde 1	2	1	72		0	149		
			Palo Verde 2	2	0	72		0	152		
			Palo Verde 3	2	1	72		0	152		
			Prairie Island 1	2	0	74		0	74		
			Prairie Island 2	2	2	92		1	95		
			Salem 1	3	0	216		0	212		
			Salem 2	3	0	216		0	246		
			San Onofre 2	2	0	72		0	72		
			San Onofre 3	2	0	72		0	72		
			South Texas 1	3	0	108		0	147		EPIX estimate for test demands (30) is inaccurate. EPIX FTLR demands used.
			South Texas 2	3	0	108		0	153		EPIX estimate for test demands (31) is inaccurate. EPIX FTLR demands used.
			Surry 1	1.5	1	159		2	98		Both plant data and EPIX include data from swing EDG.
			Surry 2	1.5	1	158		3	49		Plant data include data from swing EDG. EPIX does not include the swing EDG.
			Totals	49	7	2533		7	2650		
			Failure Rate (Jeffreys noninformative prior)			2.96E-03			2.83E-03		

Table A.3 Pilot Plant MSPI Results for the 4th Quarter 2002

Plant MSPI Results 4th Quarter 2002

Year 2000 Baselines, 8-hr EDG Mission Time

Licensees' Plant PRA Model	Mitigating System				
	EAC	HPI	HRS	RHR	SWS/CCW
Braidwood 1	-9.58E-08	4.39E-08	2.28E-06	1.51E-08	6.13E-08
Braidwood 2	-1.62E-07	-2.00E-08	1.22E-07	1.71E-07	6.99E-08
Hope Creek	-1.90E-07	5.61E-07	4.88E-07	-1.73E-09	-6.66E-08
Limerick 1	-5.90E-08	-5.90E-08	-6.68E-08	-3.95E-08	-1.87E-08
Limerick 2	-2.13E-07	-1.13E-07	-1.11E-07	-8.10E-08	2.24E-08
Millstone 2	-4.59E-07	-2.65E-07	-3.91E-07	3.75E-10	6.37E-07
Millstone 3	-4.67E-07	-2.63E-07	-8.78E-07	-8.18E-08	1.04E-07
Palo Verde 1	1.10E-07	2.42E-08	-5.37E-07	-8.30E-09	-8.00E-08
Palo Verde 2	-5.23E-08	1.35E-08	3.02E-06	-6.01E-09	-1.02E-07
Palo Verde 3	1.79E-07	2.38E-08	-3.59E-07	-4.01E-09	-1.49E-07
Prairie Island 1	-2.03E-07	-8.48E-09	-1.14E-07	-7.65E-08	3.76E-07
Prairie Island 2	3.62E-07	-1.03E-08	-1.90E-08	2.59E-08	2.89E-07
Salem 1	2.84E-06	-8.34E-09	-4.03E-07	-3.30E-07	1.57E-07
Salem 2	-3.17E-06	4.20E-08	-2.51E-07	-9.79E-08	6.33E-07
San Onofre 2	-2.29E-08	-1.47E-08	-8.42E-07	-2.42E-08	-9.06E-08
San Onofre 3	2.87E-09	-4.42E-07	-9.52E-07	-2.44E-08	-4.29E-07
South Texas 1	1.01E-07	-5.72E-08	-6.97E-07	4.58E-08	1.07E-08
South Texas 2	6.05E-08	2.02E-07	2.74E-07	5.22E-08	-1.67E-07
Surry 1	3.91E-07	-5.94E-09	-3.17E-08	-7.93E-09	1.97E-07
Surry 2	4.00E-07	-3.41E-09	-3.44E-08	-2.12E-10	1.92E-07

Note – With the proposed frontstop, the Palo Verde 2 HRS and Salem 1 EAC MSPIs become GREEN. However, Braidwood 1 HRS remains WHITE. Also, note that these results are a snapshot in time, representing the MSPI for 4Q2002 only.

Table A.4 SPAR Resolution MSPI Results for 4th Qtr 02

SPAR Resolution MSPI Results 4th Quarter 2002

Year 2000 Baselines, 8-hr EDG Mission Time

SPAR Resolution Model	Mitigating System				
	EAC	HPI	HRS	RHR	SWS/CCW
Braidwood 1	-1.57E-07	8.50E-08	2.58E-06	3.95E-11	4.09E-08
Braidwood 2	-2.49E-07	-1.86E-08	3.39E-07	1.41E-07	7.88E-08
Hope Creek	2.08E-07	7.54E-07	6.39E-07	2.46E-08	-1.81E-08
Limerick 1	-1.80E-07	-1.02E-07	-1.44E-07	-1.14E-07	-9.44E-09
Limerick 2	-2.20E-07	-1.01E-07	-1.24E-07	-1.22E-07	8.96E-09
Millstone 2	-1.63E-06	-2.59E-07	-1.07E-06	4.42E-07	4.16E-07
Millstone 3	-9.52E-08	-1.56E-07	-7.34E-07	-8.08E-08	-3.42E-08
Palo Verde 1	6.44E-08	8.09E-09	-5.37E-07	-3.08E-09	-1.36E-07
Palo Verde 2	-1.54E-07	3.38E-09	7.27E-07	-2.51E-09	-1.56E-07
Palo Verde 3	2.48E-07	1.13E-08	-3.54E-07	-2.65E-09	-1.75E-07
Prairie Island 1	-1.40E-07	5.82E-09	-8.93E-08	-5.68E-08	2.11E-07
Prairie Island 2	2.40E-07	-2.33E-09	-4.70E-08	9.82E-09	1.73E-07
Salem 1	4.13E-06	-9.34E-09	-1.01E-06	-2.07E-07	4.28E-07
Salem 2	-4.60E-06	4.19E-08	-3.89E-07	-8.20E-08	5.20E-07
San Onofre 2	-1.03E-07	-1.81E-09	-9.01E-07	-2.48E-08	-1.72E-08
San Onofre 3	-2.43E-08	-4.78E-07	-9.56E-07	-2.26E-08	-2.45E-07
South Texas 1	-2.50E-07	-7.72E-09	-4.41E-07	4.44E-09	1.67E-08
South Texas 2	-2.59E-07	1.34E-08	-8.95E-08	5.08E-09	-3.68E-08
Surry 1	6.59E-07	-1.76E-08	-3.01E-08	-3.86E-09	6.34E-07
Surry 2	4.98E-07	-9.28E-09	-2.59E-08	-4.47E-10	4.93E-07

Note – With the proposed frontstop, the Salem 1 EAC MSPI becomes GREEN. However, Braidwood 1 HRS remains WHITE. Also, note that these results are a snapshot in time, representing the MSPI results for 4Q2002 only.

APPENDIX B. SUMMARY OF SPAR ENHANCEMENT EFFORT

Appendix B
Summary of SPAR Enhancement Effort

B.1 Introduction

As part of the Mitigating Systems Performance Index (MSPI) pilot program, the standardized plant analysis risk (SPAR) models developed by the U.S. Nuclear Regulatory Commission (NRC) were used to verify the adequacy of plant probabilistic risk assessment (PRA) inputs to the MSPI. The MSPI is a measure of change in core damage frequency (CDF) resulting from changes in mitigating system component unreliability performance and train unavailability. The MSPI is evaluated individually for five indicators consisting of six mitigating systems at each pilot plant. For each mitigating system, the MSPI equation is the following:

$$MSPI = (CDF_P)\left(\sum \frac{FV_P}{UR_P}\right)(UR_C - UR_B) + (CDF_P)\left(\sum \frac{FV_P}{UA_P}\right)(UA_C - UA_B) \qquad \text{(Eq. B.1)}$$

where *MSPI* = *ΔCDF for the system (from changes in component UR and train UA)*
CDF_P = *internal events core damage frequency per calendar year (from plant PRA)*
FV_P = *Fussell-Vesely importance measure of the component or train (from plant PRA)*
UR_P = *component unreliability (from plant PRA)*
UR_C = *current component unreliability (Bayesian update using data from most recent three years)*
UR_B = *baseline component unreliability (Table 2 from Appendix F of draft NEI 99-02)*
UA_P = *train unavailability (from plant PRA)*
UA_C = *current train unavailability (data from most recent three years)*
UA_B = *baseline train unavailability (1999 – 2001 plant experience for planned and industry average for unplanned – Table 1 from Appendix F of draft NEI 99-02)*.

The first summation in Equation B.1 is over all monitored components within the system, while the second summation is over all trains within the system.

To verify the adequacy of plant PRA inputs to the MSPI, the plant PRA CDF, FV/URs, and FV/UAs were compared with corresponding values from the SPAR models. [The terms UR_C, UR_B, UA_C, and UA_B in Equation B.1 are independent of the plant PRA and were therefore covered under separate verification efforts.] Several types of SPAR model comparisons were made: SPAR Rev. 3 model as obtained from the SAPHIRE Users' Group website, SPAR resolution model, and SPAR resolution model but with selected basic event and initiating event values associated with various modeling issues (termed SPAR issues) changed back to the SPAR recommended values. Each plant's SPAR Rev. 3 importance measures that were used to generate MSPI inputs were compared with plant PRA results. Where significant differences were noted, modeling changes were identified that would resolve some of these differences. Modifications that were deemed within the SPAR development guidelines and additional modifications not within the SPAR development guidelines were added to obtain the SPAR resolution model. Examples of modifications not within the guidelines include basic event probabilities significantly different from the SPAR development guideline values, human error probabilities not derivable from the SPAR human error methodology, initiating event frequencies significantly different from SPAR development guidelines, and system success criteria that may not be appropriate. The impacts of these modeling issues on the SPAR resolution model results were also evaluated.

The SPAR Rev. 3 models represent an upgrade from the older SPAR Rev. 3i models. These upgrades were generated mainly using information obtained during plant visits as part of the Significance Determination Process (SDP) verification effort. (Additional basic event data upgrades were also part of this process.) However, when the resulting SPAR Rev. 3 models were first compared with plant PRA FV/UR values submitted as part of the MSPI pilot plant effort, significant differences were noted for many of the plants. (Wherever FV/UR is discussed, FV/UA is also included.) This was somewhat surprising, but previous SPAR upgrade efforts typically were not focused on importance measures for individual components. Therefore, additional effort was expended to identify and resolve the differences, and this effort led to the development of the SPAR resolution models.

Finally, many of the MSPI pilot plant PRA models include initiating event fault trees for loss of service water system (SWS) or component cooling water (CCW). When evaluating the importances of components within those two systems, many of those plant PRAs include importance contributions from the component to both the initiating event and the mitigating system. SPAR models do not presently include initiating event fault trees. Therefore, FV/UR comparisons for components within the SWS and CCW may be misleading. (In general, the SPAR FV/UR values should be lower than the plant values, because the SPAR results do not include importance resulting from the initiating event.)

B.2 SPAR Resolution Model Development and Comparison Process

The MSPI pilot program includes twenty commercial nuclear power plant units. However, because of similar units at some sites, eleven individual SPAR models cover these twenty units. (For example, the SPAR model for Braidwood covers each of the two units at that site.) For each of these eleven SPAR Rev. 3 models, a comparison spreadsheet was developed covering all of the monitored components for the plant in question. Table B.1 presents the spreadsheet developed for Braidwood Units 1 and 2. The plant PRA FV/URs were then listed for each monitored component. As a starting point, the SPAR Rev. 3 FV/URs were compared with the plant PRA values. This comparison is presented in Table B.1 as ratios of SPAR Rev. 3 value divided by plant PRA value. For these ratios, a value of 1.0 indicates agreement between the SPAR value and the plant PRA value.

To develop the final SPAR resolution model, plant PRA cut sets were compared with SPAR cut sets. Reasons for differences were identified and appropriate changes were then made to the SPAR Rev. 3 model and/or the plant PRA. (Note that this detailed comparison of cut sets at times led to changes in the plant PRA.) After several changes were made to the SPAR Rev. 3 model, a new comparison of FV/URs was made using the spreadsheet (under the SPAR resolution column). Although this process could be extended almost indefinitely, the SPAR resolution model development was truncated when most, if not all of the FV/UR ratios (for components with FV/URs > 0.1) lay between 0.3 and 3.0. The final SPAR resolution model results were then loaded into the spreadsheet and individual and summary comparison results generated. In Table B.1 the SPAR resolution FV/UR ratios are significantly closer to 1.0 than the SPAR Rev. 3 model results. For example, the auxiliary feedwater diesel-driven pump (SPAR event AFW-DDP-FR-1B) FV/UR ratio drops from 8.05 (8.05 times higher FV/UR than the plant PRA value) to 0.97. Also shown in the table are the geometric averages of ratios for components with FV/URs > 1.0 and within the range 1.0 to 0.1. Again, the geometric averages for the SPAR resolution model are much closer to 1.0 compared with the SPAR Rev. 3 results. Finally, the standard deviations of the FV/UR ratios within these two ranges are also shown.

As noted in Section B.1, the SPAR resolution models include some basic event values not typically allowed under the SPAR development guidelines. Therefore, the effects of these values on the SPAR resolution results were evaluated. Because many basic events can be involved, a standardized set of issue categories was developed. (These issue categories are listed in Table B.2 and discussed in more detail in Section B.4.) Basic event data changes were then grouped within these issue categories. As an example, Table B.3 shows the basic events grouped within each of the applicable issue categories for Braidwood. Note that the PORV issue in Table B.3 is not a basic event data change, but a model structure change involving the success criterion for the power-operated relief valves. The impact of each issue category on the SPAR resolution results was then determined by changing all of the basic events within the issue category back to SPAR recommended values and rerunning the SPAR model. Resulting Birnbaum ratios were then compared with the SPAR resolution results to determine how much of an impact that issue category had. Table B.2 presents the results of this type of sensitivity analysis for Braidwood. Note that Table B.2 uses Birnbaum importances, which are more informative because the Birnbaum importance incorporates not only the FV/UR portion of Equation B.1 but also the CDF factor. (The Birnbaum is just the CDF times the FV/UR.) When using Birnbaums, the component Birnbaum ranges of interest are > 1.0E-5/year and 1.0E-5 to 1.0E-6/year. A review of the SPAR issue results in Table B.2 indicates that the PORV success criterion (one-of-two for the SPAR resolution and plant PRA models, and two-of-two for the SPAR Rev. 3 model) most affects the Birnbaum results, especially for components with Birnbaums > 1.0E-5/year. However, modeling of DC power also has a significant impact.

To evaluate the potential impacts of these Birnbaum importances (from the various model runs) on actual MSPI ΔCDF results, two additional types of comparisons were performed. The first used actual pilot plant data for the period 2000 – 2002 (termed the 4Q2002 data set) to evaluate the UR_C and UA_C terms in Equation B.1. The system MSPIs were then calculated using Birnbaums obtained from each model run. Note that these MSPI calculations used the Year 2000 recommended baseline unreliability values discussed in Appendix C, and did not include the effects of common-cause modeling. Results from this type of comparison for Braidwood 1 and 2 are presented in Table B.4. (Results are presented for each unit in Table B.4 because the plant data – component failures and demands or hours and train unavailabilities – are different for each unit.) Note that the plant PRA and SPAR resolution MSPI colors agree – all GREEN except for the Unit 1 auxiliary feedwater system (HRS in the table) WHITE. In contrast, the SPAR Rev. 3 model predictions result in a Unit 1 HRS YELLOW and a Unit 2 HRS WHITE. Finally, changing the SPAR resolution PORV success criterion from one-of-two (the plant PRA criterion) to two-of-two (the SPAR recommended criterion) is the only issue category that results in color changes compared with the SPAR resolution (and plant PRA) results.

The MSPI comparisons using the 4Q2002 data set are highly dependent upon the actual system failures that occurred during that interval. For example, if the Braidwood 1 HRS had not experienced several diesel-driven pump failures, then the sensitivity of the MSPI to the PORV success criterion would not have been identified in the analysis presented in Table B.4. Therefore, a second type of MSPI ΔCDF comparison was also performed. This comparison postulates an additional component failure above the expected number of failures in the three-year period, with other component types and the train unavailabilities within the system postulated to be performing at their baseline conditions. This evaluation is performed separately for each component type and failure mode within a system. Results for Braidwood 1 are summarized in Table B.5. (Results for Braidwood 2 would be slightly different, because of differences in component demands and hours and train unavailabilities.)

Rather than a ratio (used in Tables B.1 and B.2), a difference factor is used as the measure of agreement in Table B.5. The difference factor is defined as the following:

$$\textit{Difference factor} = (\Delta MSPI_{SPAR} - \Delta MSPI_{Plant\ PRA})/1.0E\text{-}6/year \qquad \text{(Eq. B.2)}$$

The logic behind the difference factor is the desire to express SPAR model sensitivities in terms of absolute impacts on MSPI ∆CDF predictions. A ratio, as used in Tables B.1 and B.2, could be misleading. For example, if the plant PRA MSPI prediction were 1.0E-8/year, a ratio of three (SPAR MSPI prediction divided by plant PRA prediction) would indicate that the SPAR MSPI prediction is 3.0E-8/year, or higher than the plant result by 2.0E-8/year. However, if the plant PRA MSPI prediction were 1.0E-6/year, then a ratio of three indicates the SPAR MSPI prediction is 3.0E-6/year, or a difference of 2.0E-6/year. This second example is clearly much more important in terms of impacts on the MSPI, even though both examples have a ratio of three. Finally, the denominator of 1.0E-6/year in Equation B.2 is used to conveniently express results in terms of 1.0E-6/year units. For the two examples just discussed, the difference factors would be 0.02 and 2.0, respectively, clearly indicating the greater impact of the second example. For difference factor comparisons, a value of 0.0 indicates agreement between the SPAR and plant PRA results.

B.3 Summary of SPAR Resolution Model Results

Detailed results of the comparisons between the SPAR resolution model and the plant PRA results are presented in Tables B.1, B.2, B.4, and B.5 for Braidwood, as discussed in Section B.2. Similar tables were generated for the other ten SPAR models but are not presented in this appendix. However, summary statistics for each comparison are presented in Tables B.6 through B.8. Throughout the discussion of summary statistics in this section, it should be kept in mind that individual component results can vary significantly, even if the summary statistics indicate good overall agreement.

Table B.6 summarizes the CDF and Birnbaum comparisons. This table is a summary of the information presented in Table B.2 for Braidwood, but including all eleven SPAR models. The CDF ratios presented in the table are the SPAR model CDF divided by the plant PRA CDF. As indicated in the table, the SPAR Rev. 3 model CDF is an average of 1.63 times the corresponding plant PRA CDF. The worst agreement is for Braidwood, where the SPAR Rev. 3 CDF is 3.12 times the plant PRA CDF. However, the SPAR resolution models on average have a CDF 1.12 times higher than the corresponding plant PRA CDF. Also, the Braidwood ratio improves from 3.12 to 1.11.

In terms of component Birnbaum importances, Table B.6 presents summary statistics for two ranges of Birnbaums: > 1.0E-5/year, and 1.0E-5 to 1.0E-6/year. The Birnbaum ratios presented are the SPAR model component Birnbaum divided by the plant PRA Birnbaum (average of all monitored components for the plant). For the more important components (Birnbaum > 1.0E-5/y), the SPAR Rev. 3 models on average predict importances that are 0.66 times the plant PRA values. Also, the average standard deviation is 2.24. In contrast, the SPAR resolution models predict component Birnbaums that are 1.27 times the plant PRA values, with an average standard deviation of 1.01. Therefore, the SPAR resolution models result in improved component Birnbaum predictions (compared with plant PRA values) both in terms of the average ratio and the average standard deviation.

For components with Birnbaums in the range 1.0E-5 to 1.0E-6/year, the SPAR Rev. 3 models on average predict importances that are 1.08 times the plant PRA importances. The average standard deviation of these ratios is 3.14. In contrast, the SPAR resolution model average prediction is 1.35 times the plant PRA importance, with an average standard deviation of 1.99. For these less important components, the SPAR resolution models predict higher importances but the variability in predictions is reduced.

Table B.7 summarizes the MSPI comparison based on the 4Q2002 data set. This table is a summary of information presented in Table B.4 for Braidwood, but including the results from all twenty pilot plants. Shown in Table B.7 are the color comparisons (SPAR model versus plant PRA model) for the SPAR Rev. 3 and resolution models by system. Cases where the predictions do not agree are highlighted in the table. For the SPAR Rev. 3 models, three of the one hundred cases do not agree in MSPI color. In all three cases, the SPAR result is more severe (e.g., WHITE rather than GREEN, or YELLOW rather than WHITE). For the SPAR resolution models, only one of one hundred cases does not agree. Note that these comparisons do not include modifications to the MSPI predictions resulting from application of the proposed frontstop, backstop, or common-cause failure adjustments.

Finally, Table B.8 summarizes the MSPI comparisons based on the postulated additional failure above the baseline expected number of failures. This table is a summary of information presented in Table B.5 for Braidwood, but including all eleven SPAR models. Each difference factor entry in Table B.8 is an average of the results for the monitored components and failure modes for the plant in question. On average, the SPAR Rev. 3 models predict MSPIs (given one failure above the expected number of failures) that are 1.4E-7/year higher than the plant PRA predictions (a difference factor average of 0.14). However, the average of the standard deviations is 0.96, or 9.6E-7/year. This standard deviation is considered to be large. In comparison, the SPAR resolution models predict MSPIs that are an average 3.0E-8/y lower than the plant PRA predictions. However, the average standard deviation is much improved, from 0.96 (9.6E-7/y) to 0.26 (2.6E-7/year).

Difference factors summarized in Table B.8 provide some additional information concerning the SPAR resolution model development effort. In general, difference factors of 0.10 or smaller (impacts of 1.0E-7/year or smaller) indicate that differences between the SPAR model Birnbaums and the plant PRA Birnbaums do not significantly impact MSPI predictions. A review of summary information in Table B.8 indicates that on average the SPAR resolution effort for Limerick, Prairie Island, South Texas, and Surry had little impact on the MSPI predictions. For all of these plants, the SPAR Rev. 3 and SPAR resolution average difference factors and average standard deviations are small. However, a review of the Birnbaum comparison ratios in Table B.6 would not indicate that these SPAR resolution efforts had little impact. This reinforces the belief that the difference factor comparisons are the most meaningful in terms of evaluating SPAR models.

B.4 Summary of SPAR Model Issues

The following is a list of generic issues concerning the SPAR Rev. 3 models. This list was generated based on SPAR model development and comparison efforts before the SPAR resolution effort started. However, the SPAR resolution effort helped to reinforce the validity of the list.

Support System Initiating Event Fault Trees

Many plant PRAs model support system initiating events with fault trees that are then linked to the mitigating system fault trees when solving for sequence cut sets. This approach more correctly accounts for component importances (for those components in the affected systems) compared with the SPAR approach of using an initiating event frequency.

Initiating Event Frequencies

Differences in initiating event frequencies between the SPAR models and plant PRAs drive many of the differences observed in component importances. This is especially true for loss of SWS, CCW, and DC bus initiators, but is also true for other initiators. Present SPAR values are based mainly on industry average performance during the period 1987 – 1995. Industry performance has improved considerably since that period.

Reactor Coolant Pump (RCP) Seal Failure Modeling

The RCP seal failure modeling in SPAR, resulting from a loss of cooling differs from most plant PRAs. SPAR seal failure probabilities range from 0.7 to 0.08, while the plant PRAs often use 1.0 or a very low probability.

PORV Success Criterion during Feed and Bleed

Many plant PRAs require only one-of-two PORVs for success during feed and bleed. The SPAR models require two-of-two PORVs for success. This difference has a major impact on the Braidwood model results, and may significantly impact other plant models.

Loss of Offsite Power (LOOP) and Station Blackout (SBO) Modeling

Differences between plant PRAs and SPAR models with respect to LOOP and SBO include the following: preferential alignment of backup emergency power sources (assumed in order to simplify the models), modeling of dual unit LOOP, and offsite power recovery and emergency diesel generator mission time modeling. All of these can result in significant differences in component FVs.

Component Failure Rates

Significant differences can exist between plant PRA and SPAR component failure rates. The SPAR values are based mainly on published system study reports (1987 – 1993, 1995, or 1997, depending upon the study) and generic estimates (NUREG-1150, representing component performance before 1983). Again, significant performance improvement has occurred since the periods covered by these sources.

Steam Generator Tube Rupture (SGTR) Modeling

Significant differences between the plant PRA and SPAR models were noted with respect to the SGTR modeling. These differences are focused on the treatment of human actions in response to SGTR events including both the characterization of these actions and their values. For several plants these actions are dominant contributors and significantly impact the component FVs.

As noted in Section B.2, development of the SPAR resolution models included SPAR model changes not typically allowed under current development guidelines. Many of the changes fall under one or more of the SPAR generic issues listed above. An example of such changes for the Braidwood model is presented in Table B.3. Similar tables were prepared for the other ten SPAR resolution models. In order to systematically and efficiently evaluate the sensitivity of SPAR model Birnbaum results to these basic event changes, a standard set of SPAR issue categories was developed. This set of SPAR issue categories is listed below:

1. PORVs – power-operated relief valve success criterion

2. ACP – AC power, including LOOP frequency, LOOP recovery and emergency diesels

3. DCP – DC power

4. LOCAs - loss of coolant events, including reactor coolant pump seal leakage and stuck open relief valves

5. HPI – high-pressure coolant injection, including feed and bleed

6. HRS – decay heat removal (auxiliary feedwater or reactor core isolation cooling)

7. RHR – residual heat removal

8. SWS/CCW – service water or component cooling water systems, including initiating event frequencies

9. PCS – power conversion system

10. Misc. – other issues.

These ten SPAR issue categories are organized mainly by the system(s) affected. Other types of categories could have been chosen. For example, all human errors could have been grouped into a single category. Also, all initiating events could be included in a single category. The sensitivity effort described in this section covers only the system-related categorization scheme.

SPAR resolution model sensitivities to these issue categories were evaluated by replacing each basic event value (within a given issue category) with the SPAR Rev. 3 recommended value. New SPAR Birnbaums were then generated and their effects on MSPI predictions were determined. Summary results of this effort for all eleven SPAR resolution models are given in Tables B.9 and B.10, which present difference factor results assuming a single failure above the baseline expected number of failures. Table B.9 summarizes the average difference factor for each plant, while Table B.10 summarizes the standard deviation of the difference factor.

In Tables B.9 and B.10, the SPAR resolution model sensitivities to the SPAR issue categories can be classified based on three types of outcomes:

- Large impact – difference factor greater than 0.50 (5.0E-7/year), likely to result in an MSPI color change, given failures within a system

- Medium impact – difference factor between 0.10 and 0.50, with the potential to result in an MSPI color change given sufficient failures within a system

- Low impact – difference factor less than 0.10, unlikely to result in an MSPI color change.

In Tables B.9 and B.10, the large impact entries have been highlighted. Both tables indicate that the PORV success criterion issue has a large impact for Braidwood Units 1 and 2. The plant PRA assumes one-of-two PORVs is sufficient for feed and bleed, while the SPAR guideline requires two-of-two PORVs. However, this issue was not found to have a large or medium impact at any of the other applicable MSPI pilot plants.

Also, both tables indicate that LOCA issues have a large impact at Millstone 2. There are ten different basic (or initiating) event changes in the LOCA issue category for Millstone 2, covering initiating event frequencies, stuck open relief valve probabilities, and reactor coolant pump seal LOCA probability. Some values are higher for the SPAR Rev. 3 model and some are higher for the SPAR resolution model. Without reviewing each of the basic or initiating event changes individually, it is not clear which are driving the differences. Again, the LOCA issue category does not result in a large impact on MSPI predictions for the other pilot plants.

Finally, the SWS/CCW issue category has a large impact on MSPI predictions for Salem Units 1 and 2. In this case, the plant PRA has a loss of service water system initiating event frequency that is approximately 30 times lower than the SPAR Rev. 3 value. However, there are thirteen basic (or initiating) event changes in this issue category for Salem, so other events may also be contributing to the large impact. The SWS/CCW issue category does not result in a large impact on MSPI predictions for the other pilot plants.

Table B.11 summarizes the SPAR issue categories in terms of their impacts (large, medium, or small) on MSPI predictions. As discussed above, there are three cases where an issue category resulted in a large impact on MSPI predictions. Also, based on difference factor averages (Table B.9) or standard deviations (Table B.10), there are fifteen cases where an issue category resulted in a medium impact on MSPI prediction.

Table B.1 Comparison of SPAR Model FV/UR and FV/UA with Plant PRA Values (Braidwood 1)

Enhanced SPAR Model Development Results								
						Core Damage Frequency (note a)		
Plant Unit	Critical Hours (3Q99 - 2Q02)	Date				Plant PRA	SPAR Rev. 3.02	SPAR Resolution
Braidwood 1	25394	11/13/2003			Per Critical Hour		1.11E-08	3.96E-09
					Per Calendar Year	3.01E-05	9.40E-05	3.35E-05
					Plant Critical Operation Availability	?	0.97	0.97
					SPAR CDF/Plant CDF		3.12	1.11
Information from Plant MSPI Data Submittal Spreadsheet				SPAR Model		Plant PRA	FV/UR or FV/UA Ratio	
System	Component Type	Component Identifier	Component Description	SPAR Basic Event	Alternate Event	FV/UR or FV/UA (note b)	SPAR Rev. 3.02	SPAR Resolution/ Plant (note e)
HRS	MDP	1AF01PA	AF Pump 1A	AFW-MDP-FR-1A		16.60	0.33	0.36
HRS	Train (MDP)	AFA	Aux. Feedwater Train A (TM)	AFW-MDP-TM-1A		14.90	0.25	0.37
HRS	DDP	1AF01PB	AF Pump 1B	AFW-DDP-FR-1B		4.16	4.37	0.98
HRS	Train (DDP)	AFB	Aux. Feedwater Train B (TM)	AFW-DDP-TM-1B		2.91	8.05	0.97
RHR	MOV	1SI8811B	Charging Pump to Cold Leg Injection isol Valve	HPR-MOV-CC-8811B	HPR-MOV-CC-SMPB	1.83	0.10	0.73
RHR	MDP	1RH01PB	RH Pump 1B	RHR-MDP-FC-1B		1.82	0.14	0.85
RHR	Train (MDP)	RH1B	RH Pump 1B (TM)	RHR-MDP-TM-1B		1.76	0.08	0.67
CCW	MDP	1CC02PA	CC Pump 1A	CCW-MDP-FR-1A		1.57	0.07	0.23
RHR	MOV	1SI8811A	Charging Pump to Cold Leg Injection isol Valve	HPR-MOV-CC-8811A	HPR-MOV-CC-SMPA	1.11	0.16	0.48
RHR	MDP	1RH01PA	RH Pump 1A	RHR-MDP-FC-1A		1.04	0.24	0.70
RHR	Train (MDP)	RH1A	RH Pump 1A (TM)	RHR-MDP-TM-1A		1.02	0.12	0.37
HPI	MOV	1SI8804B	RH HX B to CV Pump suction isol valve	HPR-MOV-CC-RHRB		0.87	0.20	1.50
HPI	Train (MDP)	SIB	SI Pump Train 1B (TM)	HPI-MDP-TM-1B		0.84	0.00	0.01
EAC	EDG	DG1A	EDG 1A	EPS-DGN-FS-1A	EPS-DGN-FC-1A	0.83	0.61	1.32
HPI	MDP	1CV01PA	CV Pump 1A	CVC-MDP-FR-1A		0.67	0.10	0.80
HPI	MDP	1CV01PB	CV Pump 1B	CVC-MDP-FR-1B		0.67	0.01	0.20
EAC	Train (EDG)	DG1A	EDG 1A (TM)	EPS-DGN-TM-1A		0.66	0.52	0.98
SWS	MDP	1SX02PB	SX Pump 1B	ESW-MDP-FS-1B		0.63	0.56	1.27
SWS	Train (MDP)	SX1A	SX Pump 1A (TM)	ESW-MDP-TM-1A	ESW-MDP-TM-1B	0.21	0.48	1.35
SWS	Train (MDP)	SX1B	SX Pump 1B (TM)	ESW-MDP-TM-1B		0.21	0.48	1.35
EAC	EDG	DG1B	EDG 1B	EPS-DGN-FS-1B	EPS-DGN-FC-1B	0.40	0.60	1.90
CCW	MDP	1CC02PB	CC Pump 1B	CCW-MDP-FS-1B		0.26	0.06	0.41
SWS	MDP	1SX02PA	SX Pump 1A	ESW-MDP-FS-1A		0.17	1.26	5.02
EAC	Train (EDG)	DG1B	EDG 1B (TM)	EPS-DGN-TM-1B		0.14	0.76	2.34
HPI	MOV	1SI8801A	CV Pump to Cold Leg injection isol valve	CVC-MOV-CC-8801A		0.10	0.00	0.03
HPI	MOV	1SI8801B	CV Pump to Cold Leg injection isol valve	CVC-MOV-CC-8801B		0.10	0.02	0.68

Table B.1 Comparison of SPAR Model FV/UR and FV/UA with Plant PRA Values (Braidwood 1) (continued)

Enhanced SPAR Model Development Results								
						Core Damage Frequency (note a)		
Plant Unit	**Critical Hours (3Q99 - 2Q02)**	**Date**				**Plant PRA**	**SPAR Rev. 3.02**	**SPAR Resolution**
Braidwood 1	25394	11/13/2003			**Per Critical Hour**		1.11E-08	3.96E-09
					Per Calendar Year	3.01E-05	9.40E-05	3.35E-05
					Plant Critical Operation Availability	?	0.97	0.97
					SPAR CDF/Plant CDF		3.12	1.11
Information from Plant MSPI Data Submittal Spreadsheet				**SPAR Model**		**Plant PRA**	**FV/UR or FV/UA Ratio**	
System	**Component Type**	**Component Identifier**	**Component Description**	**SPAR Basic Event**	**Alternate Event**	**FV/UR or FV/UA (note b)**	**SPAR Rev. 3.02**	**SPAR Resolution/ Plant (note e)**
HPI	MDP	1SI01PA	SI Pump 1A	HPI-MDP-FS-1A	HPI-MDP-FC-1A	0.09	0.00	0.00
HPI	MDP	1SI01PB	SI Pump 1B	HPI-MDP-FS-1B	HPI-MDP-FC-1B	0.09	0.03	0.08
HPI	MOV	1CV8804A	RH HX A to CV Pump suction isol valve	HPR-MOV-CC-RHRA		0.06	2.70	8.14
HPI	MDP	SIA	SI Pump Train 1A (TM)	HPI-MDP-TM-1A		0.06	0.00	0.00
RHR	MOV	1CC9412A	CC water from RH HX isol Valve	CCW-MOV-CC-RHRA		0.05	1.62	5.23
RHR	MOV	1CC9412B	CC water from RH HX isol Valve	CCW-MOV-CC-RHRB		0.05	1.84	21.09
CCW	MOV	1SX007	Unit 1 CC HX Outlet MOV	ESW-MOV-CC-1SX007		0.05	0.34	1.98
HPI	MOV	1CV112C	VCT Outlet isol Valve	CVC-MOV-OO-112C		0.05	0.31	2.81
HPI	MOV	1CV112E	RWST to CV Pump Suction Valve	CVC-MOV-CC-112E		0.05	0.36	4.30
HPI	MOV	1CV112B	VCT Outlet isol Valve	CVC-MOV-OO-112B		0.03	0.42	3.44
HPI	MOV	1CV112D	RWST to CV Pump Suction Valve	CVC-MOV-CC-112D		0.03	0.42	3.48
HPI	Train (MDP)	CVB	CV Pump Train 1B (TM)	CVC-MDP-TM-1B		0.03	0.13	2.27
CCW	MOV	0SX007	Unit 0 CC HX Outlet MOV	ESW-MOV-CC-0SX007		0.03	0.42	2.19
HPI	Train (MDP)	CVA	CV Pump Train 1A (TM)	CVC-MDP-TM-1A	CVC-MDP-TM-1B	0.02	0.21	3.62
RHR	MOV	1RH8716A	RH HX Discharge Crosstie Valve	Not modeled		0.01	0.00	0.00
RHR	MOV	1RH8716B	RH HX Discharge Crosstie Valve	Not modeled		0.01	0.00	0.00
CCW	Train (MDP)	CC1A	CC Pump 1A (TM)	CCW-MDP-TM-1A	CCW-MDP-TM-1B	0.00	9.83	67.46
CCW	Train (MDP)	CC1B	CC Pump 1B (TM)	CCW-MDP-TM-1B		0.00	9.83	67.46
Note a - The plant PRA core damage frequency is for internal events without internal flooding.					**Plant FV/UR-A >= 1.00**			
Note b - Entries highlighted in gray are changes to the MSPI data submitted for the plant (3/21/03 submittal).					Geometric Mean		0.29	0.56
These are either changes made by the plant (PRA changes or other reasons) or changes judged by					Standard Deviation of Sample		2.58	0.26
the MSPI/SPAR analysts to be appropriate.					Variance of Sample		6.65	0.07
Note c - SPAR Rev. 3 model on website as of 6/15/03.					**1.00 > Plant FV/UR-A >= 0.10**			
Note d - SPAR Rev. 3 model with enhancements allowable under SPAR guidelines.					Geometric Mean		0.12	0.64
Note e - Similar to SPAR enhanced but with additional changes (not typically allowed) to better match					Standard Deviation of Sample		0.36	1.23
plant PRA results.					Variance of Sample		0.13	1.52

Table B.2 Comparison of SPAR Model Birnbaums with Plant PRA Values (Braidwood 1)

11/18/2003			Plant PRA	Birnbaum Ratio								
System	Component Type	Component Description	Birnbaum (1/y)	SPAR Resolution	SPAR Rev. 3	SPAR Issue PORVs	SPAR Issue DCP	SPAR Issue LOCAs	SPAR Issue HPI	SPAR Issue HRS	SPAR Issue SWS/CCW	SPAR Issue PCS
HRS	MDP	AF Pump 1A	5.00E-04	0.40	1.03	0.55	0.40	0.40	0.22	0.37	0.40	1.04
HRS	Train (MDP)	Aux. Feedwater Train A (TM)	4.48E-04	0.42	0.79	0.57	0.42	0.42	0.23	0.28	0.42	1.07
HRS	DDP	AF Pump 1B	1.25E-04	1.09	13.64	6.19	1.90	1.07	0.88	0.60	1.42	1.81
HRS	Train (DDP)	Aux. Feedwater Train B (TM)	8.76E-05	1.08	25.11	7.94	2.24	1.06	0.92	0.87	1.55	1.65
RHR	MOV	Charging Pump to Cold Leg Injection isol Valve	5.51E-05	0.82	0.32	0.34	1.96	0.82	0.82	0.64	0.82	0.83
RHR	MDP	RH Pump 1B	5.48E-05	0.94	0.44	0.46	2.10	0.94	0.94	0.77	0.94	0.95
RHR	Train (MDP)	RH Pump 1B (TM)	5.30E-05	0.75	0.24	0.26	1.94	0.75	0.75	0.58	0.75	0.76
CCW	MDP	CC Pump 1A	4.73E-05	0.26	0.21	0.25	0.35	0.14	0.26	0.24	0.26	0.26
RHR	MOV	Charging Pump to Cold Leg Injection isol Valve	3.34E-05	0.54	0.50	0.53	0.54	0.54	0.54	0.49	0.54	0.56
RHR	MDP	RH Pump 1A	3.13E-05	0.78	0.75	0.78	0.79	0.78	0.78	0.73	0.78	0.81
RHR	Train (MDP)	RH Pump 1A (TM)	3.07E-05	0.41	0.39	0.41	0.42	0.41	0.41	0.38	0.41	0.43
HPI	MOV	RH HX B to CV Pump suction isol valve	2.63E-05	1.67	0.62	0.67	4.06	1.66	1.66	1.30	1.67	1.69
HPI	Train (MDP)	SI Pump Train 1B (TM)	2.52E-05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
EAC	EDG	EDG 1A	2.51E-05	1.47	1.89	2.46	1.47	1.45	1.46	1.20	1.47	1.46
HPI	MDP	CV Pump 1A	2.00E-05	0.89	0.32	0.44	0.46	0.09	0.45	0.44	0.83	0.45
HPI	MDP	CV Pump 1B	2.00E-05	0.22	0.04	0.44	0.46	0.09	0.45	0.44	0.83	0.45
EAC	Train (EDG)	EDG 1A (TM)	1.97E-05	1.09	1.64	2.26	1.10	1.07	1.09	0.85	1.10	1.09
SWS	MDP	SX Pump 1B	1.88E-05	1.41	1.76	1.41	1.42	1.41	1.41	1.22	2.02	1.41
EAC	EDG	EDG 1B	1.21E-05	2.11	1.88	2.14	2.12	2.11	2.11	1.82	2.16	2.11
CCW	MDP	CC Pump 1B	7.86E-06	0.46	0.19	0.45	0.47	0.21	0.46	0.42	0.46	0.49
SWS	Train (MDP)	SX Pump 1A (TM)	6.20E-06	1.50	1.50	1.45	1.81	0.43	1.49	1.44	2.02	1.55
SWS	Train (MDP)	SX Pump 1B (TM)	6.20E-06	1.50	1.50	1.45	1.81	0.43	1.49	1.44	2.02	1.55
SWS	MDP	SX Pump 1A	5.03E-06	5.58	3.93	5.59	5.61	3.25	5.58	5.18	7.23	5.70
EAC	Train (EDG)	EDG 1B (TM)	4.27E-06	2.60	2.38	2.69	2.61	2.59	2.60	2.24	2.75	2.60
HPI	MOV	CV Pump to Cold Leg injection isol valve	3.10E-06	0.03	0.00	0.00	0.10	0.03	0.03	0.02	0.03	0.03
HPI	MOV	CV Pump to Cold Leg injection isol valve	3.10E-06	0.76	0.07	0.08	0.87	0.76	0.76	0.52	0.76	0.78
HPI	MDP	SI Pump 1A	2.57E-06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HPI	MDP	SI Pump 1B	2.57E-06	0.09	0.08	0.09	0.09	0.08	0.09	0.06	0.09	0.09
HPI	MOV	RH HX A to CV Pump suction isol valve	1.85E-06	9.05	8.41	9.02	9.15	9.04	9.04	8.19	9.04	9.48
HPI	MDP	SI Pump Train 1A (TM)	1.66E-06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RHR	MOV	CC water from RH HX isol Valve	1.54E-06	5.82	5.06	5.79	5.88	5.81	5.81	4.79	5.82	6.35
RHR	MOV	CC water from RH HX isol Valve	1.54E-06	23.46	5.73	6.43	64.57	23.45	23.42	17.22	23.44	23.87
CCW	MOV	Unit 1 CC HX Outlet MOV	1.44E-06	2.21	1.05	1.97	2.83	1.19	2.20	2.02	2.26	2.26
HPI	MOV	VCT Outlet isol Valve	1.39E-06	3.12	0.97	3.06	3.26	0.63	3.12	3.10	5.09	3.12
HPI	MOV	RWST to CV Pump Suction Valve	1.39E-06	4.78	1.13	3.27	5.03	2.26	4.78	4.25	6.75	4.83

Table B.2 Comparison of SPAR Model Birnbaums with Plant PRA Values (Braidwood 1) (continued)

Braidwood 1												
11/18/2003			**Plant PRA**	**Birnbaum Ratio**								
System	**Component Type**	**Component Description**	**Birnbaum (1/y)**	**SPAR Resolution**	**SPAR Rev. 3**	**SPAR Issue PORVs**	**SPAR Issue DCP**	**SPAR Issue LOCAs**	**SPAR Issue HPI**	**SPAR Issue HRS**	**SPAR Issue SWS/CCW**	**SPAR Issue PCS**
HPI	MOV	VCT Outlet isol Valve	9.12E-07	3.82	1.30	3.73	4.03	0.79	3.82	3.79	6.82	3.82
HPI	MOV	RWST to CV Pump Suction Valve	9.12E-07	3.87	1.31	3.75	4.08	0.82	3.86	3.81	6.86	3.87
HPI	Train (MDP)	CV Pump Train 1B (TM)	9.06E-07	2.53	0.42	1.26	2.99	1.60	2.53	2.09	2.93	2.56
CCW	MOV	Unit 0 CC HX Outlet MOV	9.03E-07	2.43	1.31	2.34	2.66	1.43	2.43	2.23	2.45	2.52
HPI	Train (MDP)	CV Pump Train 1A (TM)	5.69E-07	4.03	0.66	2.01	4.76	2.55	4.02	3.33	4.67	4.08
RHR	MOV	RH HX Discharge Crosstie Valve	3.43E-07									
RHR	MOV	RH HX Discharge Crosstie Valve	3.43E-07									
CCW	Train (MDP)	CC Pump 1A (TM)	2.46E-08	75.03	30.67	73.56	76.36	34.43	74.90	67.95	75.35	79.31
CCW	Train (MDP)	CC Pump 1B (TM)	2.46E-08	75.03	30.67	73.56	76.36	34.43	74.90	67.95	75.35	79.31
		Plant Birnbaum >= 1E-5/y										
		Geometric mean		0.61	0.64	0.68	0.81	0.50	0.56	0.50	0.69	0.72
		Standard deviation		0.53	6.04	2.06	0.98	0.57	0.54	0.43	0.59	0.56
		1E-5/y > Plant Birnbaum >= 1E-6/y										
		Geometric mean		0.67	0.36	0.39	0.81	0.43	0.67	0.56	0.75	0.69
		Standard deviation		5.67	2.43	2.70	15.21	5.77	5.66	4.28	5.72	5.79
		Core Damage Frequency (1/y)	3.01E-05	3.35E-05	9.40E-05	6.09E-05	3.79E-05	2.64E-05	3.17E-05	2.93E-05	6.76E-05	3.98E-05
		Ratio of SPAR CDF to Plant PRA CDF	N/A	1.11	3.12	2.02	1.26	0.88	1.05	0.97	2.25	1.32
Birnbaum ratio is SPAR Birnbaum divided by plant PRA Birnbaum.												

Table B.3 List of Braidwood 1 SPAR Resolution Model Changes not Allowed Under SPAR Development Guidelines

SPAR Issue Category	Basic Event Affected or Description of Change	SPAR Enhanced Model Value or Description	Change
PORVs	PORV success criterion change for feed and bleed	2 of 2 PORVs required for feed and bleed	1 of 2 PORVs required for feed and bleed
DCP	IE-LDCA	2.4E-7/h	7.3E-8/h
	DCP-BDC-LP-1A	9.0E-5	9.0E-6
	DCP-BDC-LP-1B	9.0E-5	9.0E-6
	DCP-BDC-LP-2A	9.0E-5	9.0E-6
	DCP-BDC-LP-2B	9.0E-5	9.0E-6
LOCAs	RCS-MDP-LK-SEALS	1.9E-1	True
HPI	HPI-XHE-XM-FB2	1.6E-1	5.1E-1
HRS	AFW-MDP-FS-1A	2.8E-3 (*0.21 nonrecovery)	1.6E-3
	AFW-MDP-FR-1A	7.6E-4 (*0.75 nonrecovery)	3.2E-3
	AFW-MDP-TM-1A	1.1E-3	5.2E-3
	AFW-DDP-FS-1B	2.3E-2 (*0.25 nonrecovery)	1.3E-2
	AFW-PMP-CF-ALL	6.2E-8	3.3E-4
	AFW-XHE-XL-MDPFS	2.1E-1	True
	AFW-XHE-XL-MDPFR	7.5E-1	True
	AFW-XHE-XL-EDPFS	2.5E-1	True
	AFW-XHE-XL-EDPFR	7.5E-1	True
SWS/CCW	IE-LOESW	1.1E-7/h	6.0E-9/h
	ESW-MDP-FS-1A	3.0E-3	1.4E-3
	ESW-MDP-FS-1B	3.0E-3	1.4E-3
	ESW-MDP-FS-2A	3.0E-3	1.4E-3
	ESW-MDP-FS-2B	3.0E-3	1.4E-3
	ESW-MDP-TM-1A	9.8E-3	5.9E-3
	ESW-MDP-TM-1B	9.8E-3	5.9E-3
	ESW-MDP-TM-2B	9.8E-3	5.9E-3
PCS	MFW-SYS-UNAVAIL	1.0E-1	Ignore
	MFW-XHE-ERROR	1.0E-2	5.3E-3
	PCS-XHE-XO-SEC	2.0E-1	True
	PCS-XHE-XO-SECL	3.4E-1	True

Table B.4 Comparison of SPAR Model MSPI Predictions (4Q2002 Data Set) with Plant PRA Values (Braidwood 1)

MSPI Results for 4th Quarter 2002 Braidwood 1 12/19/2003											
System	Plant PRA Model	SPAR Resolution Model	SPAR Rev. 3 Model	SPAR Enhanced Model	SPAR Issue 1/2 PORVs	SPAR Issue DC Power	SPAR Issue LOCAs	SPAR Issue HPI	SPAR Issue HRS	SPAR Issue SWS/CCW	SPAR Issue PCS
EAC	-9.58E-08	-1.57E-07	-9.46E-08	-1.80E-07	-2.26E-07	-1.57E-07	-1.55E-07	-1.56E-07	-1.30E-07	-1.59E-07	-1.56E-07
HPI	4.39E-08	8.50E-08	2.85E-08	4.29E-08	5.27E-08	1.62E-07	7.60E-08	8.44E-08	7.08E-08	9.33E-08	8.63E-08
HRS	2.28E-06	2.58E-06	3.51E-05	3.77E-05	1.57E-05	4.69E-06	2.54E-06	2.13E-06	1.52E-06	3.43E-06	4.17E-06
RHR	1.51E-08	3.95E-11	-1.14E-08	-1.47E-08	-1.57E-08	3.91E-08	2.70E-10	2.83E-10	-3.21E-09	2.94E-10	-5.34E-10
SWS/CCW	6.13E-08	4.09E-08	-1.03E-08	4.97E-08	4.74E-08	1.42E-08	6.03E-08	4.24E-08	3.55E-08	4.81E-08	4.11E-08

MSPI Results for 4th Quarter 2002 Braidwood 2 12/19/2003											
System	Plant PRA Model	SPAR Resolution Model	SPAR Rev. 3 Model	SPAR Enhanced Model	SPAR Issue 1/2 PORVs	SPAR Issue DC Power	SPAR Issue LOCAs	SPAR Issue HPI	SPAR Issue HRS	SPAR Issue SWS/CCW	SPAR Issue PCS
EAC	-1.62E-07	-2.49E-07	-1.45E-07	-2.97E-07	-3.79E-07	-2.48E-07	-2.45E-07	-2.47E-07	-2.04E-07	-2.51E-07	-2.47E-07
HPI	-2.00E-08	-1.86E-08	-3.54E-09	-5.15E-09	-1.11E-08	-2.41E-08	-1.13E-08	-1.80E-08	-1.54E-08	-2.27E-08	-1.82E-08
HRS	1.22E-07	3.39E-07	7.05E-06	7.40E-06	2.76E-06	7.42E-07	3.32E-07	3.15E-07	2.02E-07	5.02E-07	4.25E-07
RHR	1.71E-07	1.41E-07	3.93E-08	8.17E-08	8.52E-08	2.73E-07	1.40E-07	1.40E-07	1.18E-07	1.40E-07	1.42E-07
SWS/CCW	6.99E-08	7.88E-08	-9.55E-09	7.05E-08	8.45E-08	5.21E-08	7.99E-08	7.98E-08	6.98E-08	9.10E-08	8.00E-08

Braidwood 2 results use the Braidwood 1 SPAR model importances and CDFs with Braidwood 2 failures, demands and operating hours.

Table B.5 Comparison of SPAR Model MSPI Difference Factors (Braidwood 1)

Braidwood 1															
11/18/2003			**1 Failure > Baseline**												
			Plant Results	**Difference Factor Comparisons**											
System	**Component**	**Failure Mode**	**Delta CDF (1/y)**	**SPAR Resolution**	**SPAR Rev. 3**	**SPAR Issue PORVs**	**SPAR Issue ACP**	**SPAR Issue DCP**	**SPAR Issue LOCAs**	**SPAR Issue HPI**	**SPAR Issue HRS**	**SPAR Issue RHR**	**SPAR Issue SWS/CCW**	**SPAR Issue PCS**	**SPAR Issue Misc**
EAC	EDG	FTS	1.91E-07	0.12	0.17	0.26		0.12	0.12	0.12	0.07		0.13	0.12	
		FTLR	1.66E-07	0.11	0.15	0.22		0.11	0.10	0.11	0.06		0.11	0.11	
		FTR	2.83E-07	0.19	0.25	0.38		0.19	0.18	0.19	0.11		0.19	0.19	
HPI	MDP	FTS	6.89E-08	-0.03	-0.06	-0.03		-0.03	-0.06	-0.03	-0.03		0.00	-0.03	
		FTR	8.71E-09	0.00	-0.01	0.00		0.00	-0.01	0.00	0.00		0.00	0.00	
	MDP Stby	FTS	3.50E-08	-0.03	-0.03	-0.03		-0.03	-0.03	-0.03	-0.03		-0.03	-0.03	
		FTR	3.15E-08	-0.03	-0.03	-0.03		-0.03	-0.03	-0.03	-0.03		-0.03	-0.03	
	MOV	FTO/C	6.04E-08	0.05	-0.01	0.01		0.13	0.03	0.05	0.03		0.06	0.05	
	AOV	FTO/C	1.07E-09	0.00	0.00	0.00		0.00	0.00	0.00	0.00		0.00	0.00	
HRS	MDP Stby	FTS	2.34E-06	-1.39	-0.08	-1.04		-1.39	-1.39	-1.82	-1.53		-1.39	0.11	
		FTR	1.83E-06	-1.09	-0.09	-0.81		-1.09	-1.09	-1.42	-1.20		-1.08	0.09	
	DDP	FTS	1.10E-06	0.09	15.37	5.94		1.03	0.08	-0.12	-0.41		0.48	0.87	
		FTR	1.30E-06	0.11	17.93	6.99		1.21	0.09	-0.14	-0.49		0.56	1.03	
	MOV	FTO/C	3.80E-07	-0.18	1.43	0.29		-0.11	-0.18	-0.25	-0.24		-0.15	0.06	
	AOV	FTO/C	3.80E-07	-0.18	1.43	0.29		-0.11	-0.18	-0.25	-0.24		-0.15	0.06	
RHR	MDP Stby	FTS	3.17E-07	-0.05	-0.16	-0.15		0.18	-0.05	-0.05	-0.09		-0.05	-0.05	
		FTR	2.48E-07	-0.04	-0.13	-0.12		0.14	-0.04	-0.04	-0.08		-0.04	-0.04	
	MOV	FTO/C	1.60E-07	-0.01	-0.09	-0.08		0.18	-0.01	-0.01	-0.04		-0.01	0.00	
SWS	MDP	FTS	3.37E-08	0.04	0.03	0.05		0.06	0.02	0.05	0.04		0.08	0.05	
		FTR	1.25E-08	0.01	0.01	0.02		0.03	0.00	0.02	0.02		0.03	0.02	
CCW	MDP	FTS	6.95E-08	-0.05	-0.05	-0.05		-0.04	-0.06	-0.05	-0.05		-0.05	-0.05	
		FTR	8.55E-09	0.00	-0.01	0.00		0.00	-0.01	0.00	0.00		0.00	0.00	
	MOV	FTO/C	3.25E-09	0.01	0.00	0.01		0.01	0.00	0.01	0.01		0.01	0.01	
Difference factor average				-0.10	1.57	0.53		0.02	-0.11	-0.16	-0.18		-0.06	0.11	
Difference factor standard deviation				0.37	4.79	1.91		0.52	0.37	0.47	0.40		0.41	0.27	
Difference factor = (delta CDF,SPAR - delta CDF, Plant)/(1E-6/y)															

Table B.6 Summary of SPAR Model CDFs and Birnbaums with Plant PRA Values

	CDF Comparison		Birnbaum Comparison (Components with Birnbaum > 1.0E-5/y)				Birnbaum Comparison (Components with Birnbaum in range 1.0E-5/y to 1.0E-6/y)			
	CDF(SPAR)/ CDF(Plant PRA)		Birnbaum(SPAR)/ Birnbaum(Plant PRA) (Geometric Average of Components)		Birnbaum(SPAR)/ Birnbaum(Plant PRA) (Standard Deviation of Components)		Birnbaum(SPAR)/ Birnbaum(Plant PRA) (Geometric Average of Components)		Birnbaum(SPAR)/ Birnbaum(Plant PRA) (Standard Deviation of Components)	
Plant	SPAR Revision 3	SPAR Resolution	SPAR Revision 3	SPAR Resolution	SPAR Revision 3	SPAR Resolution	SPAR Revision 3	SPAR Resolution	SPAR Revision 3	SPAR Resolution
Braidwood 1	3.12	1.11	0.64	0.61	6.04	0.53	0.36	0.67	2.43	5.67
Hope Creek	1.89	1.39	1.12	1.40	0.92	0.12	3.35	1.67	2.98	2.52
Limerick 1	2.22	1.12	3.52	1.49	3.21	1.19	3.18	1.75	3.14	1.09
Millstone 2	0.60	1.30	0.04	1.20	0.90	1.34	0.02	6.87	6.09	Undefined
Millstone 3	2.06	0.86	0.12	0.38	3.16	2.05	0.05	0.17	0.03	0.37
Palo Verde 1	1.28	0.88	0.67	0.78	2.26	0.52	3.21	0.99	4.04	0.66
Prairie Island 1	0.60	0.67	0.60	0.65	0.42	0.15	0.36	0.55	0.76	1.18
Salem 1	1.68	0.97	0.23	0.98	1.32	1.64	0.05	0.45	2.64	3.45
San Onofre 2	1.84	1.34	0.24	0.82	4.52	0.94	0.05	0.73	8.00	1.93
South Texas 1	1.27	1.21	0.12	0.37	0.33	0.69	0.13	0.35	0.19	0.66
Surry 1	1.33	1.44	0.01	5.28	1.60	1.90	1.09	0.61	7.15	2.40
Average	1.63	1.12	0.66	1.27	2.24	1.01	1.08	1.35	3.14	1.99
For the CDF and Birnbaum (geometric average of components) comparisons, a value of 1.00 indicates agreement between the SPAR and plant PRA results. If the value is > 1.00, then the SPAR value is higher than the plant PRA value.For the standard deviation comparisons, a value of 0.00 indicates agreement between the SPAR and plant PRA results.										

Table B.7 Summary of SPAR Model MSPI Color Predictions (4Q2002 Data Set) versus Plant PRA Colors

	MSPI Color Summary by SPAR Model and System (4Q2002 Data Set)									
	SPAR Rev. 3					SPAR Resolution				
Plant	**EAC**	**HPI**	**HRS**	**RHR**	**SWS/CCW**	**EAC**	**HPI**	**HRS**	**RHR**	**SWS/CCW**
Braidwood 1	G/G	G/G	Y/W	G/G	G/G	G/G	G/G	W/W	G/G	G/G
Braidwood 2	G/G	G/G	W/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Hope Creek	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Limerick 1	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Limerick 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Millstone 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Millstone 3	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Palo Verde 1	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Palo Verde 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/W	G/G	G/G
Palo Verde 3	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Prairie Island 1	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Prairie Island 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Salem 1	W/W	G/G	G/G	G/G	G/G	W/W	G/G	G/G	G/G	G/G
Salem 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
San Onofre 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
San Onofre 3	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
South Texas 1	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
South Texas 2	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Surry 1	W/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G
Surry 2	W/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G	G/G

Note - Each entry (e.g., G/W) indicates the system color predicted by the SPAR model and then the color from the plant PRA model. Cases where the colors do not agree are highlighted. Results do not include the frontstop, backstop, or application of CCF multipliers.

Table B.8 Summary of SPAR Model MSPI Difference Factor Predictions

	Difference Factor Comparison (MSPI Delta CDF with 1 Failure Above Baseline)			
	Difference Factor (Arithmetic Average of Component Failure Modes)		Difference Factor (Standard Deviation of Component Failure Modes)	
Plant	**SPAR Revision 3**	**SPAR Resolution**	**SPAR Revision 3**	**SPAR Resolution**
Braidwood 1	1.57	-0.10	4.79	0.37
Hope Creek	-0.08	0.10	0.54	0.12
Limerick 1	0.10	0.04	0.09	0.06
Millstone 2	-0.67	-0.20	0.95	0.59
Millstone 3	0.53	-0.07	1.21	0.24
Palo Verde 1	-0.09	-0.18	1.09	0.58
Prairie Island 1	-0.06	-0.05	0.09	0.04
Salem 1	-0.21	0.14	0.63	0.53
San Onofre 2	0.42	0.02	0.96	0.25
South Texas 1	-0.09	-0.03	0.08	0.07
Surry 1	0.10	0.03	0.15	0.06
Average	0.14	-0.03	0.96	0.26
For the difference factor (arithmetic average of component failure modes) comparisons, a value of 0.00 indicates agreement between the SPAR and plant PRA results. If the difference factor value is > 0.00, then the SPAR MSPI value is higher than the plant PRA value. For the standard deviation comparisons, a value of 0.00 indicates agreement between the SPAR and plant PRA results.				

Table B.9 Summary of SPAR Model MSPI Difference Factor Predictions (Means) for SPAR Issue Categories

	MSPI Difference Factor Summary (Average of All Monitored Component Failure Modes within a Plant)											
Plant	SPAR Rev. 3	SPAR Resolution	SPAR Issue PORVs	SPAR Issue ACP	SPAR Issue DCP	SPAR Issue LOCAs	SPAR Issue HPI	SPAR Issue HRS	SPAR Issue RHR	SPAR Issue SWS/CCW	SPAR Issue PCS	SPAR Issue Misc.
Braidwood 1	1.57	-0.10	0.53		0.02	-0.11	-0.16	-0.18		-0.06	0.11	
Hope Creek	-0.08	0.10		0.40		0.11	-0.05	0.18	0.10	0.25	0.35	0.27
Limerick 1	0.10	0.04		0.05			0.01	0.01	0.04	0.04	0.17	0.05
Millstone 2	-0.67	-0.20		-0.21	-0.19	9.62	-0.27	-0.27		-0.44	-0.20	
Millstone 3	0.53	-0.07		0.16	-0.02	-0.07	-0.18	-0.23	-0.07	-0.07	-0.25	-0.09
Palo Verde 1	-0.09	-0.18			-0.20	-0.16	-0.17	0.05		-0.14		
Prairie Island 1	-0.06	-0.05		-0.07	-0.05	-0.07	-0.05	-0.07	-0.04	-0.02		-0.06
Salem 1	-0.21	0.14		-0.13		0.10	0.14			0.72		0.15
San Onofre 2	0.42	0.02		0.04		-0.05	0.02	0.00		0.00		0.02
South Texas 1	-0.09	-0.03		-0.02		-0.03	-0.03	-0.03			-0.03	
Surry 1	0.10	0.03		0.07	0.04	0.02		0.04		0.03		

The difference factor is defined as (delta CDF, SPAR - delta CDF,plant PRA)/1.0E-6/y. Results for each plant represent averages of the difference factors calculated for each of the monitored component failure modes.

SPAR issue values highlighted in grey indicate cases where the issue results in an average difference factor that is +/- 0.50 worse than the SPAR resolution result.

A difference factor of 0.00 represents agreement between the SPAR and plant PRA results. If the value is > 0.00, then the SPAR delta CDF prediction is higher than the plant PRA prediction. If the value is < 0.00, then the SPAR delta CDF prediction is lower.

Table B.10 Summary of SPAR Model MSPI Difference Factor Predictions (Standard Deviations) for SPAR Issue Categories

	MSPI Difference Factor Summary (Standard Deviation of All Monitored Component Failure Modes within a Plant)											
Plant	**SPAR Rev. 3**	**SPAR Resolution**	**SPAR Issue PORVs**	**SPAR Issue ACP**	**SPAR Issue DCP**	**SPAR Issue LOCAs**	**SPAR Issue HPI**	**SPAR Issue HRS**	**SPAR Issue RHR**	**SPAR Issue SWS/CCW**	**SPAR Issue PCS**	**SPAR Issue Misc.**
Braidwood 1	4.79	0.37	1.91		0.52	0.37	0.47	0.40		0.41	0.27	
Hope Creek	0.54	0.12		0.47		0.16	0.60	0.19	0.12	0.37	0.54	0.35
Limerick 1	0.09	0.06		0.06			0.04	0.04	0.06	0.06	0.25	0.07
Millstone 2	0.95	0.59		0.57	0.60	16.77	0.63	0.57		0.76	0.59	
Millstone 3	1.21	0.24		0.35	0.35	0.25	0.21	0.28	0.24	0.24	0.20	0.23
Palo Verde 1	1.09	0.58			0.59	0.58	0.58	0.79		0.58		
Prairie Island 1	0.09	0.04		0.06	0.04	0.05	0.05	0.08	0.05	0.07		0.05
Salem 1	0.63	0.53		0.58		0.55	0.53			1.85		0.52
San Onofre 2	0.96	0.25		0.28		0.30	0.25	0.23		0.26		0.25
South Texas 1	0.08	0.07		0.09		0.07	0.06	0.07			0.07	
Surry 1	0.15	0.06		0.14	0.11	0.09		0.11		0.07		

The difference factor is defined as (delta CDF, SPAR - delta CDF,plant PRA)/1.0E-6/y. Results for each plant represent difference factor standard deviations calculated from results for each of the monitored component failure modes.

SPAR issue values highlighted in grey indicate cases where the issue results in a difference factor standard deviation that is 0.50 worse than the SPAR resolution result.

A difference factor standard deviation of 0.00 indicates agreement between the SPAR and plant PRA results. The standard deviation can only be >= 0.00. A higher value indicates a poorer match of SPAR delta CDF predictions with plant PRA predictions.

Table B.11 Summary of SPAR Model Issue Category Impacts on MSPI Predictions

	SPAR Model Issue Category Impact on MSPI Prediction (1 Failure Above Baseline)									
Potential Impact on MSPI Prediction	**SPAR Issue PORVs**	**SPAR Issue ACP**	**SPAR Issue DCP**	**SPAR Issue LOCAs**	**SPAR Issue HPI**	**SPAR Issue HRS**	**SPAR Issue RHR**	**SPAR Issue SWS/CCW**	**SPAR Issue PCS**	**SPAR Issue Misc.**
Large (>5.0E-7/y)	Braidwood			Millstone 2				Salem		
Medium (1.0E-7/y to 5.0E-7/y)		Hope Creek Millstone 3 Salem	Braidwood		Hope Creek Millstone 3	Millstone 3 Palo Verde		Hope Creek Millstone 2	Braidwood Hope Creek Limerick Millstone 3	Hope Creek
Small (<1.0E-7/y)	All others	All others	All others	All others	All others	All others	All	All others	All others	All others

APPENDIX C. TECHNICAL BASIS FOR REVISED BASELINE COMPONENT FAILURE RATES

Appendix C
Technical Basis for Revised Baseline Component Failure Rates

C.1 Summary

The Mitigating Systems Performance Index (MSPI) pilot program investigated whether component performance during the period 1995 – 1997 is significantly different from performance during the period 1999 – 2001, and whether or not performance data from 1999 - 2001 should be used in lieu of Table 2 baselines of NEI 99-02 (shown below in Table C.1). To investigate these issues, two data sources were reviewed: Equipment Performance and Information Exchange (EPIX), and Licensee Event Reports (LERs) used in the updated system studies. Statistical trend analyses of each of these data sources indicate no significant trends over the period 1995 – 2001, except for the auxiliary feedwater system diesel-driven pump failure to run (FTR) rate, which has an increasing rate with time.

Ignoring the statistical evidence of essentially no trends, if component failure mode data are fitted to trend curves, then the geometric average of the ratios of 1996 estimate to 2000 estimate for the component failure modes is 1.25 using the EPIX data and 1.18 using the updated system study (LER) data. This composite result indicates that 1996 performance may be approximately 18% to 25% worse than 2000 performance. Therefore, this composite metric also indicates little difference between 1996 and 2000 component performance.

The Year 2000 baselines proposed by the Nuclear Regulatory Commission (NRC) for use in the MSPI pilot program (Table C.2) appear to be approximately 16% high (overall for the 16 component failure modes used in the MSPI) when compared with actual pilot plant performance for the period July 1999 through June 2002. The apparent 16% higher values compensate for most of the potential 18 to 25% difference between 1996 and 2000 performance. The fact that all these performances are so close also gives reasonable confidence in the appropriateness of the revised Year 2000 failure rates.

The existing Table 2 baselines in draft NEI 99-02 are not representative of component performance for the period 1995 – 1997. The sources used to develop the existing Table 2 are more representative of component performance around 1990 or 1991 (or earlier).

Therefore, the Year 2000 baselines are recommended for use in the MSPI pilot program because of the following:

- The existing Table 2 baselines are representative of component performance around 1990 or 1991 (or earlier), not for the period 1995 – 1997.

- There appears to be little or no trend in component performance over the period 1995 – 2001.

- The Year 2000 baselines were all generated using a single consistent set of industry data matching the types of data to be reported in the MSPI pilot program.

- The Year 2000 baselines appear to be 16% high compared with current performance. Therefore, the apparent 16% higher values compensate for most of the potential 18 to 25% difference between 1996 and 2000 performance.

- Using Year 2000 baselines is consistent with the MSPI train unavailability baselines, which were also generated from data for the period 1999 – 2001.

C.2 Introduction

Component baseline failure rates for the MSPI pilot program are presented in Table 2 in Appendix F of the draft NEI 99-02 report. Those baseline failure rates were generated by the NRC in early 2002. At that time, the most appropriate published sources for component baseline failure rates were judged to be the system studies (NUREG/CR-5500 series) published in the late 1990s and the generic database developed for the NUREG-1150 studies (NUREG/CR-4550, Vol. 1). The desire was to generate component baseline failure rates representative of industry performance over the period 1995 – 1997. However, the available published sources were more representative of industry performance around approximately 1990 or 1991. Therefore, the existing Table 2 values are representative of industry performance around 1990 or 1991, and not for the period 1995 – 1997.

Follow-on work in support of the MSPI pilot program included an update to the Table 2 component baseline failure rates, to reflect industry performance during the period 1999 – 2001. The source for the updated Table 2 values, termed the Year 2000 baselines, was primarily the journal article "Historical Perspective on Failure Rates for US Commercial Reactor Components" (S. A. Eide, *Reliability Engineering and System Safety*, Vol. 80, 2003, pp. 123 – 132). Baseline failure rates in that journal article for the period 1999 – 2001 were obtained from the EPIX database maintained by the Institute for Nuclear Power Operations (INPO). The EPIX data were reviewed and evaluated using the Reliability and Availability Database System (RADS) software developed by the NRC.

To complete the component baseline failure rate work for the MSPI pilot program, equipment performance over the period 1995 through 2001 is to be investigated, to discern whether significant differences exist between the period 1995 – 1997 and 1999 – 2001. If significant differences do exist, then a new set of baselines should be established for the period 1995 – 1997. A decision would then be made whether to use the 1995 – 1997 baselines or the Year 2000 baselines.

C.3 Existing Table 2 Baselines

The existing Table 2 component baseline failure rates are presented in Table C.1. Several issues need to be kept in mind when reviewing the existing Table 2 mean failure probabilities and rates:

- The failure to start (FTS) probabilities, except for the EDGs, include failures to run that occur within the first hour of operation. This "expanded" definition of FTS was recommended by the NRC to help reduce the number of FTR events. (Such events typically have a greater chance of resulting in a change in core damage frequency greater than 1.0E-6/y, given just one failure.) Also, this approach is generally consistent with the approach used in the NRC component studies (NUREG-1715 series). To identify such events within the system studies, the individual failure reports were reviewed to determine which FTR events were placed into the FTS category and which remained in the FTR category. Note that this effort was time intensive.

- FTR rates apply only after the first hour of operation.

- Failure probabilities and rates reflect nonrecovery probabilities identified in the system studies. For example, the EDG FTS probability in the existing Table 2 is the product of FTS and failure to recover from FTS. The nonrecovery probabilities range from 0.88 to 0.083, with an average of approximately 0.5. Nonrecovery probabilities were included when generating the existing Table 2 baselines for two reasons: it was not clear at that time whether all failures would be reported (or just those that were not recovered), and it was judged that the system study results were too high if nonrecovery was not included, compared with more recent industry performance. Note that the MSPI guidelines for data reporting instruct the plants to report all failures, not just those that could not be recovered within minutes from the control room (without any actual repair activities).

- For several of the component failure modes (MOV FTO/C, MDP Standby FTS, MDP Standby FTR, TDP Standby HPCI/RCIC FTS, and TDP Standby FTR), data from several different system studies were combined to obtain the values in the existing Table 2.

- The component boundaries in the system studies are generally broader than those in the MSPI. In August 2002 the system study failure events used to generate the existing Table 2 values were reviewed to identify events outside the component boundaries specified in draft NEI 99-02. (Typically, up to 20% of the FTS events were eliminated, while up to 100% of the FTR events were eliminated, depending upon the component.) These changes were never incorporated into the existing Table 2, mainly because the focus turned to development of the Year 2000 baselines.

- Component baseline failure probabilities and rates are representative of industry performance around 1990 or 1991 (or earlier, in some cases).

- Eleven of sixteen component failure mode baselines were derived from the system studies, while five were obtained from the older NUREG-1150 generic database.

- Given the mean failure probabilities and rates, “a” and “b” parameters for beta or gamma prior distributions are generated assuming a constrained noninformative prior.

C.4 Year 2000 Baselines

As explained in the introduction, the Year 2000 baseline failure probabilities and rates (see Table C.2) were obtained from the journal article “Historical Perspective on Failure Rates in US Commercial Reactor Components” (S. A. Eide, *Reliability Engineering and System Safety*, Vol. 80, 2003, pp. 123 – 132). Baseline failure rates in that journal article for the period 1999 – 2001 were obtained from the EPIX database maintained by INPO. In general, the recommended values in Table 2 of the journal article were used directly. However, for pump FTS including the first hour of operation, the FTS value in the journal article was combined with the FTR rate specific for the first hour of operation (multiplied by one hour) to obtain the FTS value for the Year 2000 baselines. (The journal article subdivided FTR for standby components into two periods: the first hour of operation, and operation beyond the first hour of operation. In general, a factor of approximately 15 difference was observed between the two failure rates, with the first hour of operation having the higher FTR value.) Also, the FTR rates (following the first hour of operation) in the journal article could then be used directly for Year 2000 FTR baselines.

The journal article did not cover circuit breakers. A separate EPIX/RADS search was performed to determine the mean failure probability for this component. Therefore, all of the component failure mode Year 2000 baselines were generated from the same data source using the same methodology.

Table C.1 Existing Table 2 of NEI 99-02 Component Baseline Failure Rates and Sources

Component	Failure Mode	Applicable MSPI Systems	Mean Failure Probability or Rate	Source	Data Period	Midpoint of Data Period
MOV	FTO/C	All	2.1E-3/d	NUREG/CR-5500, Vol. 4,7,8,9	1987 – 1997	1992
AOV	FTO/C	All	2.0E-3/d	NUREG/CR-4550, Vol. 1	1970 – 1983	1977
MDP Standby	FTS [a]	HPI, HPCS, AFW, RHR, SWS, CCW	2.1E-3/d	NUREG/CR-5500, Vol. 1,8,9	1987 – 1995	1991
	FTR [b]	HPI, HPCS, AFW, RHR, SWS, CCW	1.0E-4/h	NUREG/CR-5500, Vol. 1,8,9	1987 – 1995	1991
MDP Running or Alternating	FTS [a]	HPI (CVCS), SWS, CCW	3.0E-3/d	NUREG/CR-4550, Vol. 1	1970 – 1983	1977
	FTR [b]	HPI (CVCS), SWS, CCW	3.0E-5/h	NUREG/CR-4550, Vol. 1	1970 – 1983	1977
TDP Standby, AFW	FTS [a]	AFW	1.9E-2/d	NUREG/CR-5500, Vol. 1	1987 – 1995	1991
	FTR [b]	AFW	1.6E-3/h	NUREG/CR-5500, Vol. 1,4,7	1987 – 1995	1991
TDP Standby, HPCI/RCIC	FTS [a]	HPCI, RCIC	2.7E-2/d	NUREG/CR-5500, Vol. 4,7	1987 – 1993	1990
	FTR [b]	HPCI, RCIC	1.6E-3/h	NUREG/CR-5500, Vol. 1,4,7	1987 – 1995	1991
DDP Standby	FTS [a]	AFW, SWS	1.9E-2/d	NUREG/CR-5500, Vol. 1	1987 – 1995	1991
	FTR [b]	AFW, SWS	8.0E-4/h	NUREG/CR-4550, Vol. 1	1970 – 1983	1977
EDG Standby	FTS	EAC	1.1E-2/d	NUREG/CR-5500, Vol. 5	1987 – 1993	1990
	FTLR [c]	EAC	1.7E-3/d [c]	NUREG/CR-5500, Vol. 5	1987 – 1993	1990
	FTR [b]	EAC	2.3E-4/h	NUREG/CR-5500, Vol. 5	1987 – 1993	1990
Circuit Breaker	FTO/C	EAC	3.0E-3/d	NUREG/CR-4550, Vol. 1	1970 – 1983	1977

Acronyms: AFW (auxiliary feedwater system), AOV (air-operated valve), CCW (component cooling water system), CVCS (chemical and volume control system), DDP (diesel-driven pump), EAC (emergency AC power system), EDG (emergency diesel generator), FTLR (fail to load and run for 1h), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPCI (high-pressure coolant injection system), HPCS (high-pressure core spray), HPI (high-pressure safety injection system), RCIC (reactor core isolation cooling system), RHR (residual heat removal system), SWS (service water system).

Notes:
a. FTS includes FTR events that occur within the first hour of operation.
b. FTR applies to continued operation after successful start and operation for the first hour.
c. The system study did not address the FTLR failure mode. A value was obtained by multiplying the FTR rate for 0 to 0.5h by 0.5h, doing the same to the FTR rate for 0.5 to 14h, and adding the two results (to cover 1h of operation). This approximation probably underestimates the FTLR probability, while overestimating the FTS probability.

Since the journal article was published, the Year 2000 baselines have been compared with results from the MSPI pilot plant data submittals (July 1999 through June 2002). That comparison is presented in Table C.3. In general, the agreement is good, keeping in mind that the MSPI pilot program includes only 20 plants, compared with 103 plants in the EPIX database. The existing Table 2 values are also listed in Table C.3 for comparison purposes.

Another related comparison was made using the pilot plant data. Over the period July 1999 – June 2002, the pilot plants experienced 72 failures in components covered by the MSPI pilot program. Using the reported demands and hours, the Year 2000 baselines predict 83.5 failures. Therefore, overall, the Year 2000 baselines appear to be high by approximately 16%, compared with the actual pilot plant performance.

In contrast to the Year 2000 expected failures (83.5), the expected number of failures using the existing Table 2 baselines is 176.9, compared with the actual number of failures, 72. Therefore, the Year 2000 baselines are much closer to pilot plant performance than are the existing Table 2 baselines.

Table C.2 Year 2000 Component Baseline Failure Rates and Sources

Component	Failure Mode	Applicable MSPI Systems	Mean Failure Probability or Rate	Constrained Noninformative Prior Parameters		Source	Data Period	Midpoint of Data Period
				a	b			
MOV	FTO/C	All	7.0E-4/d	0.499	712.0	EPIX/RADS	1999 – 2001	2000
AOV	FTO/C	All	1.0E-3/d	0.498	498.0	EPIX/RADS	1999 – 2001	2000
MDP Standby	FTS [a]	HPI, HPCS, AFW, RHR, SWS, CCW	1.9E-3/d	0.497	261.0	EPIX/RADS	1999 – 2001	2000
	FTR [b]	HPI, HPCS, AFW, RHR, SWS, CCW	5.0E-5/h	0.500	10000.0	EPIX/RADS	1999 – 2001	2000
MDP Running or Alternating	FTS [a]	HPI (CVCS), SWS, CCW	1.0E-3/d	0.498	498.0	EPIX/RADS	1999 – 2001	2000
	FTR [b]	HPI (CVCS), SWS, CCW	5.0E-6/h	0.500	100000.0	EPIX/RADS	1999 – 2001	2000
TDP Standby, AFW	FTS [a]	AFW	9.0E-3/d	0.485	53.3	EPIX/RADS	1999 – 2001	2000
	FTR [b]	AFW	2.0E-4/h	0.500	2500.0	EPIX/RADS	1999 – 2001	2000
TDP Standby, HPCI/RCIC	FTS [a]	HPCI, RCIC	1.3E-2/d	0.478	36.3	EPIX/RADS	1999 – 2001	2000
	FTR [b]	HPCI, RCIC	2.0E-4/h	0.500	2500.0	EPIX/RADS	1999 – 2001	2000
DDP Standby	FTS [a]	AFW, SWS	1.2E-2/d	0.480	39.5	EPIX/RADS	1999 – 2001	2000
	FTR [b]	AFW, SWS	2.0E-4/h	0.500	2500.0	EPIX/RADS	1999 – 2001	2000
EDG Standby	FTS	EAC	5.0E-3/d	0.492	97.9	EPIX/RADS	1999 – 2001	2000
	FTLR	EAC	3.0E-3/d	0.495	164.0	EPIX/RADS	1999 – 2001	2000
	FTR [b]	EAC	8.0E-4/h	0.500	625.0	EPIX/RADS	1999 – 2001	2000
Circuit Breaker	FTO/C	EAC	8.0E-4/d	0.499	623.0	EPIX/RADS	1999 – 2001	2000

a. FTS includes FTR events that occur within the first hour of operation.
b. FTR applies to continued operation after successful start and operation for the first hour.

Table C.3 Year 2000 Baseline Comparison with Pilot Plant Data

Component	Failure Mode	Applicable MSPI Systems	Year 2000 Mean Failure Probability or Rate	Pilot Plant Data Mean Failure Probability or Rate (3Q1999 – 2Q2002)	Existing Table 2 Mean Failure Probability or Rate
MOV	FTO/C	All	7.0E-4/d	1.4E-3/d	2.1E-3/d
AOV	FTO/C	All	1.0E-3/d	6.3E-4/d	2.0E-3/d
MDP Standby	FTS [a]	HPI, HPCS, AFW, RHR, SWS, CCW	1.9E-3/d	4.4E-4/d	2.1E-3/d
	FTR [b]	HPI, HPCS, AFW, RHR, SWS, CCW	5.0E-5/h	3.0E-5/h	1.0E-4/h
MDP Running or Alternating	FTS [a]	HPI (CVCS), SWS, CCW	1.0E-3/d	5.0E-4/d	3.0E-3/d
	FTR [b]	HPI (CVCS), SWS, CCW	5.0E-6/h	1.2E-5/h	3.0E-5/h
TDP Standby, AFW	FTS [a]	AFW	9.0E-3/d	2.8E-3/d	1.9E-2/d
	FTR [b]	AFW	2.0E-4/h	<2.4E-4/h [c]	1.6E-3/h
TDP Standby, HPCI/RCIC	FTS [a]	HPCI, RCIC	1.3E-2/d	<4.7E-3/d [c]	2.7E-2/d
	FTR [b]	HPCI, RCIC	2.0E-4/h	<2.4E-4/h [c]	1.6E-3/h
DDP Standby	FTS [a]	AFW, SWS	1.2E-2/d	2.1E-2/d	1.9E-2/d
	FTR [b]	AFW, SWS	2.0E-4/h	4.8E-3/h	8.0E-4/h
EDG Standby	FTS	EAC	5.0E-3/d	3.1E-3/d	1.1E-2/d
	FTLR	EAC	3.0E-3/d	3.4E-3/d	1.7E-3/d
	FTR [b]	EAC	8.0E-4/h	5.8E-4/h	2.3E-4/h
Circuit Breaker	FTO/C	EAC	8.0E-4/d	No data	3.0E-3/d

a. FTS includes FTR events that occur within the first hour of operation.
b. FTR applies to continued operation after successful start and operation for the first hour.
c. No failures and limited demands or hours, so this value probably overestimates the actual failure probability or rate.

C.5 Equipment Performance Trends over the Period 1995 - 2001

There are two main sources of data available to the NRC that can be used to investigate equipment performance trends over the period 1995 - 2001: EPIX data, and LERs used in the system studies. Both sources of data have shortcomings for this effort. For example, the EPIX data cover the period 1997 – present. EPIX data are not available for 1995 and 1996. Also, the LERs cover mainly component failures occurring during unplanned demands (and cyclic tests performed approximately every 18 months), while the MSPI pilot program focuses heavily on failures during monthly or quarterly testing. Both types of data are analyzed in this section.

The available EPIX data for the period 1997 – 2002 were analyzed for trends with time using the RADS software. The analysis included a test for whether a trend actually exists (p-value determination) and the fitting of the yearly data to a curve. For demand-related failures, the RADS curve fit is of the form:

$$\frac{P}{1-P} = e^{X+Yt}$$

where P = component failure mode probability for a given year
X = constant
Y = constant
t = integer representing the year, with 1997 represented by 1, 1998 by 2, etc.

For failures to run, the RADS curve fit is of the form:

$$\lambda = e^{X+Yt}$$

where λ = component failure to run rate (1/h) for a given year.

The EPIX data were not reviewed to eliminate failures outside the component boundaries specified in draft NEI 99-02. Also, FTR data were not reviewed in detail to segregate FTR (<1h) from FTR (>1h). (This effort would be resource intensive.)

Shown in Table C.4 are the p-values from the trend analyses. The smaller the p-value, the more certain the analysis is that there is a trend in P (or λ) with time. Typically in statistical analyses, a p-value of less than 0.05 is used to declare that there is a significant trend with time. With larger p-values, the data are typically processed using a no-trend (homogeneous data) assumption to generate component failure probabilities. (This approach was used in the NRC system studies and initiating event studies.) Using the p-value < 0.05 criterion to declare a trend with time, only the DDP FTS has a trend. The other fifteen component failure modes have no trends. Even using a more relaxed criterion of p-value < 0.20, only four of sixteen component failure modes have trends. An example trend plot from RADS is presented in Figure C.1.

The other type of trend comparison was to use the trend analyses to compare curve fit values for 1996 (midpoint of the period 1995 – 1997) with those for 2000 (midpoint of the period 1999 – 2001). To extrapolate a value for 1996, t was set to 0 in the trend equations. The ratios P_{1996}/P_{2000} (for FTO/C, FTS, and FTLR) and $\lambda_{1996}/\lambda_{2000}$ (for FTR) are summarized in Table C.4. The ratios range from a high of 2.02 to a low of 0.36, and the geometric average is 1.25. Again, this composite metric indicates only a potentially small change (25%) in component performance between 1996 and 2000.

Updated system study (NUREG/CR-5500 series) data are available for the period 1987 – 2001. These updated studies cover AFW, HPI, HPCI, HPCS, RCIC, and IC (isolation condenser). Note that the earlier system studies also included EAC (EDGs), but that study (1987 – 1993 data) has not been updated through 2001 because plants no longer report EDG data under RG 1.108. Therefore, the updated system studies do not cover EAC (EDGs), RHR, SWS, or CCW.

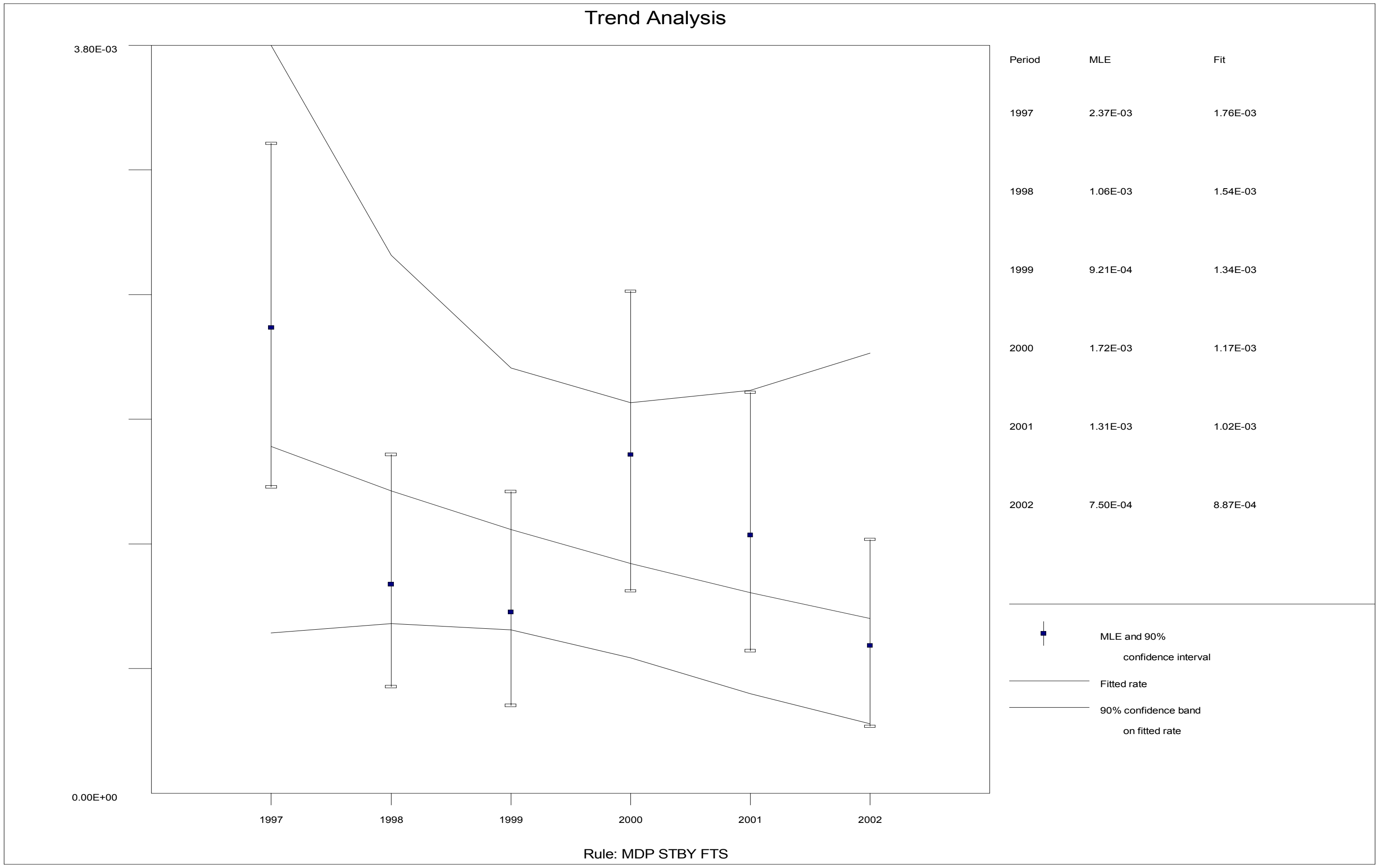

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Figure C.1 EPIX MDP (standby) FTS Data Trend Plot (p-value = 0.24)

Table C.4 Year 2000 Baseline Comparison with Pilot Plant Data

Component	Failure Mode	Applicable MSPI Systems	Ratio of Mean Failure Probability or Rate (1996/2000)	Trend Analysis P-Value	Trend Exists? (p-value < 0.05)
MOV	FTO/C	All	2.02	0.07	No
AOV	FTO/C	All	1.74	0.26	No
MDP Standby	FTS	HPI, HPCS, AFW, RHR, SWS, CCW	1.51	0.24	No
	FTR	HPI, HPCS, AFW, RHR, SWS, CCW	1.64	0.33	No
MDP Running or Alternating	FTS	HPI (CVCS), SWS, CCW	1.22	0.53	No
	FTR	HPI (CVCS), SWS, CCW	1.47	0.13	No
TDP Standby, AFW	FTS	AFW	1.96	0.19	No
	FTR	AFW	1.34	0.69	No
TDP Standby, HPCI/RCIC	FTS	HPCI, RCIC	1.76	0.34	No
	FTR	HPCI, RCIC	1.34	0.69	No
DDP Standby	FTS	AFW, SWS	0.36	0.03	Yes
	FTR	AFW, SWS	0.99	0.40	No
EDG Standby	FTS	EAC	1.19	0.51	No
	FTLR	EAC	1.18	0.91 or 0.45	No
	FTR	EAC	0.57	0.48	No
Circuit Breaker	FTO/C	EAC	1.40	0.45	No
Summary		Geometric Average	1.25		15 of 16 component failure modes have no significant trend

The updated system study data were combined across studies similar to the process used to generate the existing Table 2 baselines. However, the data were not reviewed to identify FTR events that occurred within the first hour of operation (to place such events into FTS), and to identify failures outside the MSPI component boundaries. (This effort would be resource intensive.)

The combined system study data were plotted versus year, and the results were analyzed for trends. An example trend plot is presented in Figure C.2. Shown in Table C.5 are the p-values from the trend analyses. Using the p-value < 0.05 criterion to declare a trend with time, none of the nine component failure modes covered by the system studies have a significant trend. Using the more relaxed criterion of p-value < 0.20, one of nine component failure modes has a trend.

The other type of trend comparison made was to use the trend analyses to compare curve fit values for 1996 with those for 2000. The ratios P_{1996}/P_{2000} (for FTO/C, FTS, and FTLR) and $\lambda_{1996}/\lambda_{2000}$ (for FTR) are summarized in Table C.5. The ratios range from a high of 2.04 to a low of 0.95, and the geometric average is 1.18. Again, this composite metric indicates only a potentially small change (18%) in component performance between 1996 and 2000.

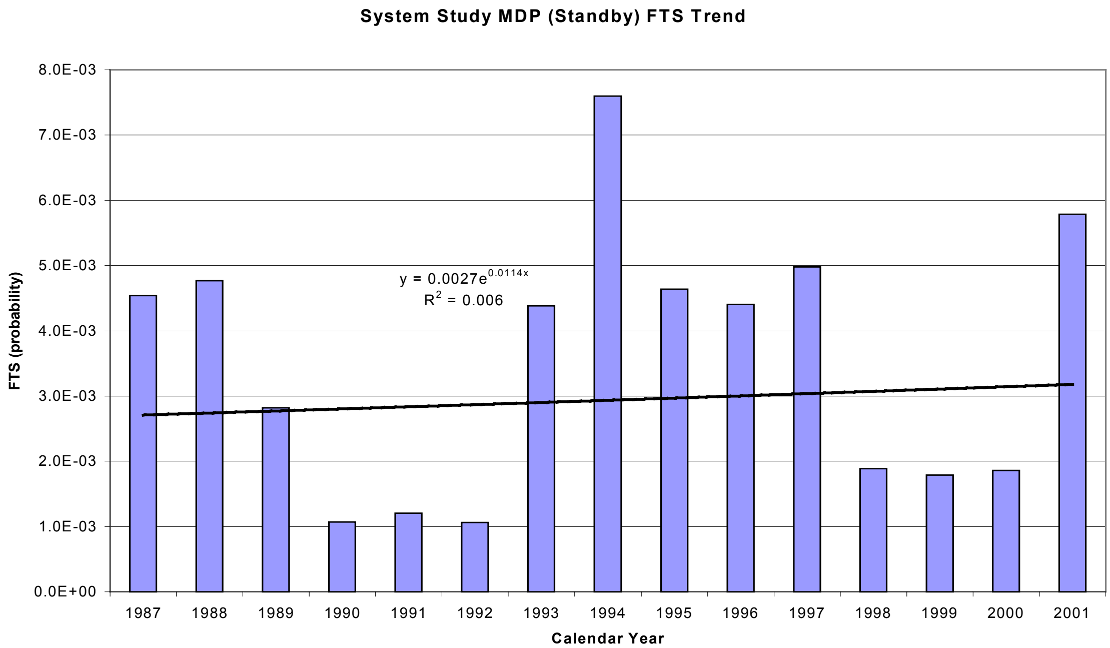

Figure C.2 System Study MDP (standby) FTS Data Trend Plot (p-value = 0.82)

Table C.5 Updated System Study Data Trend Analysis and Comparison (1996 vs. 2000)

Component	Failure Mode	Applicable MSPI Systems	Ratio of Mean Failure Probability or Rate (1996/2000)	Trend Analysis P-Value	Trend Exists? (p-value < 0.05)
MOV	FTO/C	All	0.95	Too few failures to detect a trend	No
AOV	FTO/C	All	No data		
MDP Standby	FTS	HPI, HPCS, AFW, RHR, SWS, CCW	0.96	0.82	No
	FTR	HPI, HPCS, AFW, RHR, SWS, CCW	0.95	Too few failures to detect a trend	No
MDP Running or Alternating	FTS	HPI (CVCS), SWS, CCW	No data		
	FTR	HPI (CVCS), SWS, CCW	No data		
TDP Standby, AFW	FTS	AFW	1.11	0.55	No
	FTR	AFW	1.40	0.39	No
TDP Standby, HPCI/RCIC	FTS	HPCI, RCIC	2.04	0.12	No
	FTR	HPCI, RCIC	1.40	0.39	No
DDP Standby	FTS	AFW, SWS	0.95	Too few failures to detect a trend	No
	FTR	AFW, SWS	0.95	Too few failures to detect a trend	No
EDG Standby	FTS	EAC	No data		
	FTLR	EAC	No data		
	FTR	EAC	No data		
Circuit Breaker	FTO/C	EAC	No data		
Summary		Geometric Average	1.18		9 of 9 component failure modes have no significant trend

APPENDIX D. TECHNICAL BASIS FOR THE FRONTSTOP TO ADDRESS INVALID INDICATORS

Appendix D
Technical Basis for the Frontstop to Address Invalid Indicators

D.1 Introduction

Some indicators associated with the Mitigating Systems Performance Index (MSPI) proposed by the Nuclear Energy Institute (NEI) (Ref. D.1) have significant "false positive" issues. That is, for statistical reasons, there is a significant probability of a plant system at baseline performance crossing over the GREEN/WHITE threshold. Within the MSPI pilot program, these indicators have been called "overly sensitive indicators" or, in the extreme case, "Invalid Indicators." These designations were given because a small performance change induces a relatively large change in core damage frequency (CDF) and, in the extreme case, this over sensitivity prevents the indicator from being effective. This appendix provides a proposed solution for addressing this issue through the use of a "frontstop."

D.1.1 Frontstop Concept

As defined within the context of the MSPI pilot program, a frontstop is a supplementary set of requirements or adjustments that must be satisfied prior assigning a "WHITE." These adjustments are designed to ameliorate the indicator's sensitivity, a sensitivity that is, in part, due to the basic simplified approach of the MSPI framework.

A frontstop could be a minimum number of failures, or a fixed or variable risk threshold. Adjustments to the input parameters such as limiting the risk contribution associated with failures could also be used to accomplish the same result. Limiting the risk contribution associated with failures is the approach used for the proposed frontstop.

D.1.2 Sensitive Indicator Issue

Sensitive indicators have a significant probability of exceeding a performance threshold as a result of statistical fluctuations, even if performance is at baseline. An extreme example is an indicator that crosses a threshold as a result of a single failure within an observation period. Ref. D.1 states:

> *"The performance index relies on the existing testing programs as the source of the data that is input to the calculations. Thus, the number of demands in the monitoring period is based on the frequency of testing required by the current test programs. In most cases this will provide a sufficient number of demands to result in a valid statistical result. However, in some cases, the number of demands will be insufficient to resolve the change in the performance index ($1.0x10^{-6}$) that corresponds to movement from a green performance to a white performance level. In these cases, one failure is the difference between baseline performance and performance in the white performance band. The performance index is not suitable for monitoring such systems and monitoring is performed through the inspection process."*

The NEI guidance refers to indicators that cross a threshold on a single failure as "Invalid Indicators." There are also valid sensitive indicators; indicators that maintain acceptable performance for all single failures but cross a performance threshold as a result of what could be referred to as expected performance variations.

The issue with both sensitive and invalid indicators is “false positives.” Random failures that occur at a rate consistent with the industry performance are not indicative of a performance issue. However, due to limitations associated with the MSPI framework, these random failures could result in challenging the WHITE threshold. These limitations are primarily associated with the data collection duration and the data update process. The collection duration and data update process were designed to achieve an indicator that would minimize the failure to detect degraded performance (false negatives). This balance between preventing the failure to identify degraded performance while not falsely identifying performance as degraded is the driver behind the frontstop. The MSPI is sensitive to changes in equipment reliability to minimize false negatives, and therefore requires some adjustment to prevent false positives.

D.1.3 MSPI Equation

The MSPI is the sum of the unreliability index (URI) and the unavailability index (UAI). The sensitive indicator issue is mainly focused on the URI. However, it is important to understand how the UAI index contributes to ensure that the design of the frontstop works with both indices.

D.1.3.1 MSPI System Unreliability Index (URI)

Equation 3 of Ref. D.1 defines the System Unreliability Index (URI) and is reproduced below. This equation is examined in this appendix since its structure is key to the design of the frontstop.

$$URI = CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj}) \qquad \textit{(NEI 99-02 Equation 3)}$$

where the summation is over the number of active components (*m*) in the system, and:

CDF_p is the plant-specific internal events, at power, core damage frequency,

FV_{Urc} is the component-specific Fussell-Vesely value for unreliability,

UR_{Pc} is the plant-specific PRA value of component unreliability,

UR_{Bc} is the Bayesian corrected component unreliability for the previous 12 quarters, and

UR_{BLc} is the historical industry baseline calculated from unreliability mean values for each monitored component in the system.

By examining Equation 3, it can be seen that there are three factors that contribute to the sensitivity of performance indices:

- Sensitivity to Changes in Unreliability (ΔUR)
- High Fussell-Vesely Importance (FV/UR)
- High CDF.

Each of these issues is examined below.

(Note that the product of CDF*(FV/UR) is equivalent to the Birnbaum Importance Measure; this measure is referred to later in this appendix and is described in Ref. D.2.)

D.1.3.1.1 Sensitivity to Changes in Unreliability (ΔUR)

For highly reliable components, a single failure can cause a large change in unreliability. Several solutions have been investigated in an attempt to reduce or eliminate this sensitivity. These include pooling data, merging failure modes, and modifying the data update process. Improvements in the pooling of data and the treatment of failure modes have been incorporated into the MSPI framework. Although the proposed frontstop benefits from these improvements, it does not directly include these elements in its design. The solutions to sensitive data updates are discussed below.

Pooling Data

Pooling data of similar components when updating the reliability performance is a technique advocated in Ref. D.1. This reference uses the following equations to calculate component unreliability.

$$UR_{Bc} = P_D + \lambda T_m \qquad \text{(NEI 99-02 Equation 4)}$$

where:

- P_D is the component failure on demand probability calculated based on data collected during the previous 12 quarters,
- λ is the component failure rate (per hour) for failure to run calculated based on data collected during the previous 12 quarters, and
- T_m is the risk-significant mission time for the component based on plant-specific PRA model assumptions.

$$P_D = \frac{(N_d + a)}{(a + b + D)} \qquad \text{(NEI 99-02 Equation 5)}$$

where:

- N_d is the total number of failures on demand during the previous 12 quarters,
- D is the total number of demands during the previous 12,

and

a and *b* are parameters of the industry prior, derived from industry experience.

$$\lambda = \frac{(N_r + a)}{(T_r + b)} \qquad \text{(NEI 99-02 Equation 6)}$$

where:

N_r is the total number of failures to run during the previous 12 quarters,

T_r is the total number of run hours during the previous 12 quarters.

As can be seen from Equations 5 and 6 above, if the number of demands or run hours is increased, then the impact of a single failure is reduced. For highly reliable components, the expectation is that the improvements in demand and run hours, due to data pooling, far outweigh the increase in failures due to the increased number of components that are monitored.

The application of data pooling is limited in that it requires the monitored components to be within a group of similar components and requires them to have significant demands and/or run hours to fully resolve the sensitive indicator issue. For a small pool of high-Birnbaum components, pooling data does not resolve the issue.

Merging Failure Modes for Turbine and Diesel-Driven Components

In addition to pooling data from similar components, data can be pooled by consolidating the various failure modes for a given component. This is only achievable if an appropriate unit for the reliability data can be determined. The failure mode merging technique works for turbine and diesel-driven components.

For turbine and diesel-driven components, extended run times (greater than one hour) are not typical, and the number of starts and the number of run hours are nearly equivalent. Since the historical failure rates are based on the failure to start and the failure to run, the combined failure rate is the sum of these failures. This assumes that the typical run duration is one hour.

The merging of the failure modes for turbine and diesel-driven components has been incorporated into the MSPI framework. The need for the frontstop is reduced due to the reduced sensitivity of these components.

Data Update

The NEI MSPI methodology uses a posterior mean from updating a constrained noninformative prior (CNIP). See Ref. D.3 for a discussion of the CNIP. The following two alternative approaches have been investigated to address both invalid and insensitive indicators:

Base the decision on percentiles of the posterior distribution rather than on the posterior mean.
Use a different prior, a mixture of two simple distributions corresponding to “normal” and “degraded” states, respectively.

These approaches are discussed in detail in Ref. D.4.

Limited benefit was seen in the use of percentiles due to the nondiscriminatory nature of this approach. That is, both sensitive and insensitive indicators are impacted. Although sensitive indicator performance is improved, less sensitive indicators are made even less sensitive.

The use of a mixture prior showed good results for both sensitive and insensitive indicators. However, this method results in added complexity in both communicating the concept and in the implementation of the methodology. It is not immediately practical to implement the mixture prior. For now, approaches that improve the data updating processes are not considered in the development of the frontstop.

D.1.3.1.2 High Fussell-Vesely Importance

As can be seen from Equation 3, component importance, normalized by dividing the importance by the unreliability, ${}^{FV}/_{UR}$, is a direct multiplier used for the determination of the change in risk due to a change in performance. Those components with high ${}^{FV}/_{UR}$ values are likely to be more sensitive to small changes in performance. The impact of the ${}^{FV}/_{UR}$ value is considered in the frontstop.

D.1.3.1.3 High CDF

CDF is a direct multiplier used for the determination of the change in risk due to a change in performance. Therefore, plants with a higher calculated CDF will have greater sensitivity to small changes. The influence of the calculated CDF is considered in the frontstop.

D.1.3.2 MSPI Unavailability Index (UAI)

The UAI uses a similar equation to that of the URI and can also be found in Ref. D.1. However, of interest to the frontstop design, is the development of the UAI's baseline unavailability. This baseline unavailability has two elements: planned and unplanned. Each element is derived from a different data source. The planned unavailability is the actual, plant-specific three-year total planned unavailability for an in-scope train for the years 1999 through 2001. The baseline unplanned unavailability is the historical industry average for unplanned unavailability for the years 1999 through 2001. Basing planned unavailability on plant-specific practices is of interest since it directly relates current maintenance practices at the monitored plant to the baseline. Plants that maintain these practices should not challenge the MSPI due to planned maintenance. However, changes in maintenance practices, especially due to the implementation of risk-informed allowed outage time (AOT) extensions, could impact the actual planned maintenance and may challenge the MSPI indicator. The impact of planned maintenance is further discussed in Section D.4.

D.2 Desired Frontstop Characteristics

A fundamental objective of the MSPIs is to monitor system performance so that declining performance is identified before it becomes unacceptable. Although the frontstop supports this objective, its focus is narrower. If the framework of the frontstop is appropriately constructed, then changes that are within a band of acceptable performance, including single failures, would not result in exceeding an action threshold. However, declining performance would be identified.

In order to achieve this fundamental objective, the following characteristics are considered critical for an effective frontstop:

- Addresses Invalid Indicators (reduce the false positives)
- Compatible with Unavailability
- Sensitivity is Maintained (does not adversely impact the false negatives).

Each of these characteristics is discussed below.

D.2.1 Addresses Invalid Indicator

An important characteristic is that no single failure results in WHITE, that is makes URI>1E-6. If invalid indicators are not eliminated, there is a potential that a separate monitoring process, such as inspections, would be required. Implementing such a process would directly challenge the ability to work within the MSPI framework; a desirable attribute for a successful monitoring program.

D.2.2 Compatible with Unavailability

An effective frontstop should be able to appropriately address a change in performance that results from a failure in light of any prior performance, whether at baseline or at some other state. This is especially true for how the frontstop relates to unavailability. Both the URI and UAI indices are impacted by failures. The URI contribution increases due to the updated failure rate while the UAI contribution increases due to the repair time required to return the failed component to service. In addition, both indices will reflect the system's performance prior to a failure. The frontstop must be able to address the interaction between unreliability and unavailability. It can not prevent the indicator from going WHITE if URI is near zero and UAI is greater than 1E-6.

D.2.3 Indicator Sensitivity is Maintained

The structure selected for the frontstop must maintain the MSPI's ability to identify degraded performance. The following criteria are considered to represent degraded performance:

- Two significant failures (each with a risk contribution > 5E-7)
- One significant failure with other less significant failures could result in GREEN/WHITE threshold being exceeded
- One significant failure with significant contribution from UAI could result in GREEN/WHITE threshold being exceeded.

D.3 Proposed MSPI Frontstop

The proposed MSPI frontstop places a cap on the URI contribution for the most significant failure in any 12-quarter reporting period at 5E-7. This risk cap ensures that two significant failures, i.e. failures contributing >5E-7 to the URI, result in WHITE. It also ensures no invalid indicators, with some restrictions. Indicators that have a 5E-7 failure contribution with >5E-7 UAI will result in WHITE. Indicators that have a significant contribution from either URI or UAI, or both, prior to a significant failure may result in WHITE.

D.3.1 MSPI Frontstop URI Risk Cap of 5E-7

For the risk cap to be effective, its value needs to be less than 1E-6 to prevent invalid indicators, and equal to or greater than 5E-7 to maintain the MSPI sensitivity as discussed in Section D.2.3. Within this range, a risk cap of 5E-7 is recommended for consistency with the current NRC position for a small quantitative impact for a single technical specification (TS) change.

RG 1.177, "An approach for Plant-Specific, Risk-Informed Decision-making: Technical Specifications" (Ref. D.5), includes an acceptance guideline for a small quantitative impact on plant risk due to a permanent TS change. It uses the metric of incremental conditional core damage probability (ICCDP).

ICCDP = [(the conditional CDF with the subject equipment out of service) – (baseline CDF with nominal expected equipment unavailabilities)] x (duration of single AOT under consideration)

RG 1.177 states "An ICCDP of less than 5E-7 is considered small for a single TS AOT change." The ICCDP is very similar to the UAI calculation in that it evaluates the change in unavailability from the baseline to determine risk. Capping the MSPI risk associated with the most significant failure at 5E-7 leaves a nominal 5E-7 (assuming performance is at baseline) for the unavailability associated with the failure. That is, the repair activities associated with this significant failure could result in an UAI contribution of 5E-7 without exceeding the WHITE threshold. A higher risk cap, greater than 5E-7, would reduce the UAI margin for returning failed components to service. A lower margin could create a conflict between the MSPI and risk-informed AOT extensions. Such a conflict would occur if a licensee had received a risk-informed AOT extension allowing a one-time entry into a TS action statement based, in part, on the 5E-7 guideline but had a more restricted MSPI limit. This leads to the question: Is the governing limit, the approved AOT extension or the MSPI? Conforming the proposed risk cap to RG1.177 ensures that when the licensee's performance is at baseline, the risk margins for risk-informed AOT extensions and the MSPI frontstop are consistent.

Note that RG 1.177 guidelines are intended for comparison with a full-scope (including internal events, external events, full power, low power and shutdown) assessment of the change in risk metric. Since the MSPIs only address internal events, the risk margin for unavailability is somewhat greater than it would be if a full scope PRA was considered.

D.3.2 MSPI Frontstop UAI Unaffected

The UAI contribution is unaffected by the proposed frontstop. Its value is added to the frontstop-adjusted URI value to obtain the resulting MSPI value. Since the GREEN/WHITE threshold is 1E-6 and the URI risk cap is 5E-7, there remains an approximate risk margin of 5E-7, potentially less if previous performance is above baseline and more if performance is below baseline, to execute the repair activities. As stated in Section D.3.1, this is consistent with RG 1.177.

D.3.3 Indicator Sensitivity – White/Yellow Threshold

The proposed frontstop only applies to the GREEN/WHITE threshold. If the calculated risk, without the frontstop adjustment, exceeds the WHITE/YELLOW threshold of 1E-5, then the adjustment is not applied. This approach maintains the basic criterion of the WHITE/YELLOW threshold.

D.4 Changes in Baseline UA

As discussed above, the MSPI frontstop does not limit the unavailability index for a given failure. Since the unavailability margin for repairs is directly impacted by the prior performance, it is important to ensure that planned unavailability is consistent with approved maintenance practices. This point is emphasized due to the changing nature of planned maintenance practices and the baselining of these practices to plant-specific data. A key planned unavailability change agent is risk-informed AOT extensions. Implementation of a risk-informed AOT extension could significantly change the plant-specific unavailability baseline. If the MSPI planned unavailability baseline were significantly different from the unavailability that results from an approved AOT extension, then the licensee would be forced to manage potentially conflicting expectations. It is therefore recommended that as part of the implementation of the proposed frontstop, adjustments to the baseline unavailability for planned unavailability be allowed for NRC-approved risk-informed changes.

D.5 Assessment of the Proposed Frontstop

This section evaluates the performance of the proposed frontstop with respect to the desired critical characteristic discussed in Section D.2.

Addresses Systems with Invalid Indicators

By limiting the risk of the most significant failure to 5E-7, an additional 5E-7 remains for the sum of past performance plus repair unavailability. If past performance is at baseline, then a total of 5E-7 is available for the risk associated with repair. Only if the repair unavailability is excessive or previous performance provides limited repair opportunity will a single failure result in exceeding the GREEN/WHITE threshold.

Compatible with Unavailability

Using a risk cap, as opposed to limiting the number of failures, gives the ability to directly interface the unreliability frontstop with unavailability. The limit on URI does not reduce the sensitivity of the MSPI to unavailability, it only reduces its sensitivity to a single risk significant failure. If an indicator has a near-zero URI, and UAI is greater than 1E-6, the indicator will be WHITE (or higher).

Indicator Sensitivity is Maintained

With a limit of 5E-7 on the most significant failure, a second significant failure of 5E-7 or greater will result in at least a WHITE indicator. Other combinations of a 5E-7 failure and lesser failures or unavailability greater than baseline would result in WHITE when the other failures and unavailability have a value that is greater than 5E-7. The sensitivity of an indicator that has a value greater than 1E-5, the WHITE/YELLOW threshold, is not affected by the frontstop. The proposed frontstop applies only to the GREEN/WHITE threshold.

D.6 Examples Using the Proposed Frontstop

The following cases are sample applications of the proposed frontstop.

D.6.1 Case 1

Scenario

A plant experiences a start failure of an Auxiliary Feedwater motor-driven pump. Prior to the failure, the UAI = 1E-7. The delta URI associated with the start failure is 4E-6. No other failures have occurred during this reporting period yielding an URI baseline of zero (this is a simplification since baseline could be below zero). The UAI contribution resulting from the repair unavailability is 2E-7.

MSPI Calculation

Without the frontstop, the MSPI would be an invalid WHITE (sometimes denoted “GRAY”) with a resulting value of 4.3E-6. With the frontstop, the failure is limited to delta URI of 5E-7 (the risk cap) that is added to the previous UAI of 1E-7 and the repair contribution to UAI of 2E-7. This results in a total MSPI of 8E-7 (GREEN).

D.6.2 Case 2

Scenario

A plant experiences a start failure of an Auxiliary Feedwater motor-driven pump. Two previous failures have occurred during this reporting period. One was on this same pump and a second was on a motor-operated valve failing to open on demand. The delta URI associated with the start failures is 4E-6 each. The delta URI of the MOV failure is 1E-7. The previous UAI, which includes the first two failures, is 2E-7. The delta UAI resulting from the repair of the current failure is 2E-7.

MSPI Calculation

Without the frontstop, the MSPI would be the sum of the two AFW pump failures, 8E-6, plus the MOV failure for a total URI of 8.1E-6. UAI would sum to 4E-7 and the total MSPI would be 8.5E-6 (WHITE). With the frontstop, the most significant failure is reduced to a delta URI of 5E-7. Since there are two failures of equal risk, one of these two is reduced by the risk cap. This results in an URI of 5E-7 + 4E-6 + 1E-7 = 4.6E-6. This is added to the UAI, which is unchanged at 4E-7, for a total MSPI of 5E-6 (WHITE). In this case, the resulting color is unchanged by the frontstop when it is applied due to the presence of two significant failures.

D.6.3 Case 3

Scenario

A plant experiences a start failure of an Auxiliary Feedwater motor-driven pump. Two previous start failures have occurred during this 12-quarter reporting period on the same pump. The delta URI associated with the start failures is 4E-6 each. The previous UAI, which includes the first two failures, is 2E-7. The delta UAI resulting from the repair of the current failure is 2E-7.

MSPI Calculation

Without the Frontstop, the sum of the three AFW pump failures results in delta URI of 1.2E-5. The unavailability contribution (UAI) is 4E-7. This yields a total MSPI of 1.24E-5 (YELLOW). Since the frontstop only applies to the GREEN/WHITE threshold, the resulting MSPI would remain at 1.24E-5 (YELLOW) as first calculated without the frontstop.

D.7 References

D.1 Nuclear Energy Institute (NEI). NEI 99-02 (Draft Report), "Regulatory Assessment Performance Indicator Guideline," Section 2.2 ("Mitigating Systems Performance Index") and Appendix F ("Methodologies for Computing the Unavailability Index, the Unreliability Index, and Determining Performance Index Validity"). NEI: Washington, D.C. 2002.

D.2 NRC Interoffice Memorandum from Scott F. Newberry (RES/DRAA) to John A. Zwolinski (NRR), "Request for Review of Mitigating Systems Performance Indices White Paper, Adams Accession Numbers ML031350208 and ML031360121, May 12, 2003.

D.3 C. L. Atwood, "Constrained Noninformative Priors in Risk Assessment," Reliability Engineering and System Safety, Vol. 53, No 1, pp 37-46, 2003.

D.4 C. L. Atwood, "Improving Invalid and Insensitive Indicators: Approaches and Examples" (draft), 2003.

D.5 Regulatory Guide 1.177, "An Approach for Plant-Specific, Risk-Informed Decision-making: Technical Specifications," August 1998.

APPENDIX E. TECHNICAL BASIS FOR THE BACKSTOP TO ADDRESS INSENSITIVE INDICATORS

Appendix E
Technical Basis for the Backstop to Address Insensitive Indicators

E.1 Introduction

Although the systems selected for monitoring are relatively risk-significant at most plants, it may happen at some plants that the Birnbaum measures (B's) for specific system *trains* are relatively small numbers. This is due in part to the system selection process: an indicator defined for systems that are important at many plants, but not at all plants, may be *insensitive* at some plants. A low value of train B can also easily arise in highly redundant systems; failure of *individual* trains in a highly redundant system may not yield a high conditional CDF, even if failure of the entire system would do so. In such a case, the number of failures needed to produce a change in the MSPI greater than 1E-6 is large. This makes it possible for many failures to occur in a system having apparent regulatory significance, with the performance index still falling short of the WHITE performance band threshold.

This is undesirable from both technical and outside stakeholders' points of view. From an outsider perspective, an indicator scheme appears deficient if large numbers of failures do not warrant a "WHITE" response. Moreover, absent a comprehensive model relating licensee performance to different kinds of indications, it is difficult to conclude on purely technical grounds that such performance excursions are risk-insignificant, even if they arise in low-B trains. Examples of this are the following. First, the occurrence of an unexpectedly large number of failures implies a performance issue that could well be cross-cutting (i.e., affecting other systems), and have a net effect on ΔCDF that is somehow not captured in the current calculations. Second, a performance issue causing a large number of failures could easily alter the effective common-cause failure (CCF) parameters. The current approach of NEI 99-02 Appendix F (Ref. E.1) does not explicitly update the effective CCF parameters, so the risk significance of a performance issue affecting the CCF parameters can be understated by the current calculational approach.

Therefore, it is desirable to supplement the 1E-6 threshold criterion for entry into "WHITE" with another criterion. This criterion will be based on the statistical significance of the observed number of failures, relative to prior expectations. When a number of failures is observed larger than or equal to a specified "backstop" value, a WHITE will be declared, independently of the calculated change in the MSPI.

When evaluating a backstop, it must be recognized that baseline conditions include both normal performance and degraded performance, with normal performance occurring in the vast majority of the cases. A "positive" indicator consists of a failure count at or above the backstop. It is a "false positive" if the underlying performance is normal (with the many failures having been just the result of coincidence), and a "true positive" if the underlying performance is degraded. The backstop threshold will be formulated to have the following properties:

- The false positive rate will be low. This criterion can be formulated to say that the conditional probability of declaring "WHITE," given normal performance, will be very low (actual cutoff probability determined below). This is the classical notion of hypothesis testing, based on the consistency of the data with "normal" performance.

- Of all the positives that occur under baseline conditions, only very few are *false* positives. This criterion involves both the probability of false positives and the probability of true positives, under the *a priori* baseline conditions. Thus, a “WHITE” will be declared only when the number of observed failures leaves little room for doubt regarding the existence of a performance issue.

These two objectives can be satisfied by adjusting the backstop threshold to correspond to the smallest possible number of failures, consistent with achieving the desired low false positive rate. This is discussed below.

Because the “backstop” is intended to address failures that are in some sense repetitive, comparison with the intent of the Maintenance Rule is natural. There is one key similarity between the Maintenance Rule and the MSPI with backstop: an unexpectedly high number of failures triggers corrective action. The intent of the present MSPI backstop development is to formulate backstops that envelop licensee goals under Maintenance Rule implementation. That is, licensees will ordinarily trip their own Maintenance Rule goals before they trip the backstop. At some plants, it may be possible for a peculiar sequence of failures to trip the MSPI backstop first. However, since the MSPI backstop will be designed with a low false positive rate, this is not necessarily undesirable; it may signal a performance issue that is real enough, despite having gotten past the Maintenance Rule criterion.

The effect of the “frontstop” and “backstop” on the decision rule for declaring “WHITE” is illustrated in Figure E.1 below.

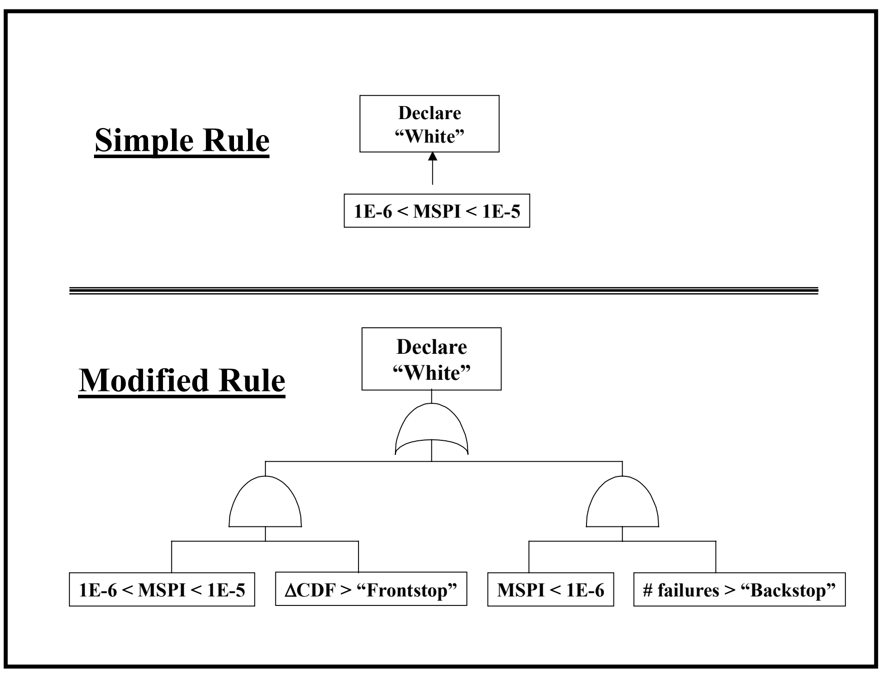

Figure E.1 Decision Rule for Declaring WHITE with Backstop

E.2 Parameter Distributions

Conceptually, the “backstop” is a limit on the total number of failures, of all failure modes and of all components of one type in one system of a single nuclear power plant unit. Each system and type of component corresponds to a single backstop, with all failure modes combined. If the number of failures seen in the three-year performance period is equal to the backstop number or more, the system/component has reached or exceeded the backstop and is denoted “WHITE.” The details of this definition are given below.

The criteria defining the backstop are based on probabilities. These probabilities are predicated on a realistic belief about the possible values of the failure parameters, recognizing that a single parameter will be somewhat different at different plants and in different time periods. Each parameter was assigned a distribution, reflecting belief about the values that the parameter could actually take at various plants in various three-year periods. The distribution was developed as follows.

The data were collected for the following systems/components/failure-modes:

Air-operated valves	Failure to operate
Circuit breakers	Failure to open or close
EDG circuit breakers	Failure to close
Emergency diesel generators	Failure to load and run
Emergency diesel generators	Failure to run
Emergency diesel generators	Failure to start
Motor-driven pumps, norm. running	Failure to run
Motor-driven pumps, norm. running	Failure to start
Motor-driven pumps, standby	Failure to run
Motor-driven pumps, standby	Failure to start
Motor-operated valves	Failure to operate
Turbine-driven pumps, AFW	Failure to start
Turbine-driven pumps, all	Failure to run
Turbine-driven pumps, HPCI/RCIC	Failure to start

Diesel-driven pumps were not considered here, because they are present at very few plants. For each system/component/failure-mode, the data were collected separately in two three-year periods, 1997-1999 and 2000-2002. The reason for using three-year periods is that the MSPI pilot program will look at three-year windows of data. Therefore, it is most relevant to use comparable windows of data in the analysis here.

For each system/component/failure-mode/data-period, the empirical Bayes (EB) distribution was found, modeling between-plant variation in either p (for failure to start, failure to load and run, or failure to open or close) or λ (for failure to run). The plant-specific means were tabulated. Each plant-specific mean is a “best estimate” of the parameter at the plant during the three-year period. In particular, it is better than the maximum likelihood estimate (MLE) using the plant-specific data, because plants with few demands or few exposure hours do not have as great a volatility in their EB posterior means as in the MLEs.

For each system/component/failure-mode/data-period, the empirical Bayes means were rescaled by dividing them by the industry mean. This put all the parameters on the same scale, with mean 1. For two system/component/failure-mode/data-periods, the empirical Bayes distribution was degenerate, showing no between-plant variability. For these two cases, every plant-specific parameter was assigned a rescaled value of 1.

Plots were examined, and no correlations were evident. That is, for any system/component/failure-mode, a plant that was high in one three-year period did not show a tendency to be high in the other three-year period. Also no plant seemed to be consistently high for more than one system/component/failure-mode. Therefore, the results for different system/component/failure-mode/data-periods were treated as independent of each other.

The rescaled plant-specific means were pooled into a single data set, with 2388 values. The smallest value was 0.016 and the largest value was 24.05. At this point, the distinction between *p*s, having beta distributions, and λs, having gamma distributions, was ignored. This is not unreasonable, because a beta distribution with small mean is approximately a gamma distribution.

The values were ordered from smallest to largest, and the empirical cumulative distribution was plotted. This is shown in Figure E.2.

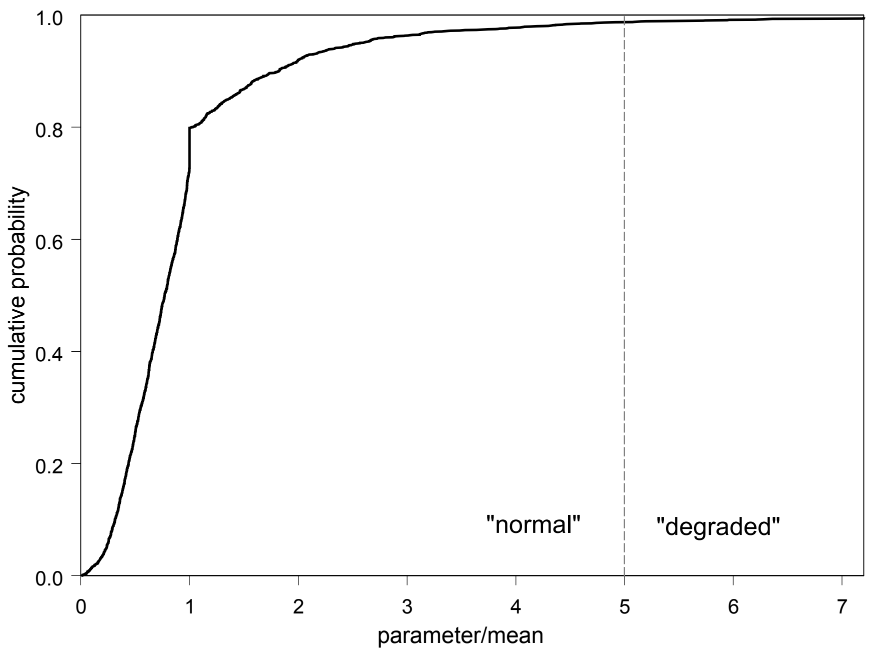

Figure E.2 Empirical Distribution of Rescaled Plant-Specific Parameters

A little bump can be seen corresponding to the cases when the EB distribution was degenerate and the rescaled plant-specific means were set to exactly 1. That bump is an artifact of the EB methodology.

Each parameter was assigned a generic probability distribution based on this distribution. That is, each parameter has an industry mean, obtained from industry experience in 1997-2002. For any particular parameter, the distribution in Figure E.2 was rescaled so that its mean was the industry mean of the parameter. The resulting distribution was used for the parameter.

E.3 Positives, False and True

Parameter values less than 5 times the industry mean were considered “normal”. Values more than 5 times the industry mean were considered “degraded”. This dichotomy into good and degraded is shown in Figure E.2. There were 30 “degraded” points in the distribution of 2388 points. Therefore, without seeing data, one can set *a priori* Pr(parameter is degraded) = 30/2388 = 0.0126 — any parameter is probably normal almost all of the time at almost all of the plants.

Suppose that some candidate value has been nominated as a backstop, for some system and component type. If the observed failure count equals the backstop or more, call this a “positive”. For example with a pump, the total count of failures to start and failure to run would be compared with the backstop limit. A “false positive” is a case when all the corresponding parameters (p_{FTS} and λ_{FTR} in the example) are normal yet the count equals the backstop or higher. A “true positive” is a case when at least one of the parameters is degraded and the count equals the backstop or more.

Pr(false positive) therefore is the probability that two things occur: all the parameters are normal and the data count is as high as the backstop or higher.

Pr(false positive) = Pr(parameters normal)$\times$Pr(backstop exceeded | parameters normal).

The second factor on the right-hand side is the conditional probability, given that the parameters are normal. In classical hypothesis testing, only this conditional probability is considered. However, the value of Pr(parameters normal) is treated as known in the present work — for example, it is $(1 - 0.0126)^2$ for two parameters each having distributions based on Figure E.2. Therefore, any criterion based on the unconditional Pr(false positive) is equivalent to a criterion in terms of the conditional probability.

E.4 Precise Definition of Backstop

The backstop was chosen to be the smallest number such that:

1. Pr(false positive) $\leq$ = 0.01
2. Pr(false positive)/Pr(positive) $\equiv$ fraction of positives that are false $\leq$ 5%.

Thus, the backstop is defined to ensure that false positives are very rare, and if a positive occurs it is very probably a true positive. By the last paragraph of the previous section, the first condition can be re-expressed in terms of Pr(backstop exceeded | normal parameters), the conditional probability that is used in hypothesis testing. The second condition was the more difficult condition to fulfill, and governed the value of the backstop limit in every case.

The calculations depend on the assumed distribution for the parameters and on the number of demands or the running time for the components in the particular system in a three-year period at the plant. If two otherwise-identical plants have different demands counts and run-times, the one with more demands and run hours may have a higher backstop limit.

E.5 Calculation Method

Because the underlying probability distribution of the parameter values (Figure E.2) was discrete, and the number of failures is a discrete distribution (Poisson or binomial) depending on the parameter value and on the total demand count or run time, all the calculations could be performed in a spreadsheet. In the pump example, the equations are as follows:

First,
Pr(*x* failures to start and *p* normal) = Σ_i Pr(*x* failures to start | p_i) Pr(p_i),
where the probability distribution of *X* is binomial, the distribution of *p* is based on Figure E.2, and the sum is over all *i* in the "normal" part of Figure E.2.

Similarly,
Pr(*y* failures to run and λ normal) = Σ_i Pr(*y* failures to run | λ_j) Pr(λ_j),
where the conditional distribution of *Y* is Poisson, and the distribution of λ is based on Figure E.2.

The probability of *z* failures when both parameters are normal is given as follows:
Pr(*z* failures and both parameters normal)

$$= \sum_{x=0}^{z} \Pr(x \text{ failures to start and } p \text{ normal}) \Pr(z - x \text{ failures to run and } \lambda \text{ normal}) .$$

Finally, for a candidate backstop *b*, the probability of a false positive is

$$\Pr(\text{false positive}) = 1 - \sum_{z=0}^{b-1} \Pr(z \text{ failures and both parameters normal}) .$$

The calculations are all based on equations such as these. For each candidate value of the backstop, the probability of a false positive and the fraction of positives that are false were calculated. The value selected as the backstop was the smallest candidate backstop satisfying constraints 1 and 2 above.

E.6 Backstop Values

The backstops were first calculated on a system basis for the major components at all twenty pilot plants. Mean values and standard deviations were next generated based on similar component types. Table E.1 below gives the backstops if generic values were to be used. The standard deviations are shown for information only, and provide a measure of how much plant-to-plant variability there is.

Table E.1 Generic Backstops

Component	mean	st dev
AOV	5	0.9
DDP	13	4.5
EDG	9	1.7
MDP	7	1.4
MDP Stby	6	2.7
MOV	5	1.1
TDP	6	1.0

The expected number of failures based on the number of demands and run hours for each component type within a system for all pilot plants can be derived. The expected failure count is

$$pD + \lambda t$$

where p = Pr(failure on demand), D = number of demands, λ = rate of failure to run, and t = number of run hours. When generic failure rates were used, a strong correlation was observed between backstop and expected number of failures, for each component type.

One could also plot the backstop versus expected failure count for *all* component types on a common graph, and still observe a strong correlation. Figure E.3 below shows this correlation. In practice, calculated values using the linear regression expression would be rounded up or down to the nearest integer. For example, assume a particular plant had two similar standby motor-driven auxiliary feedwater pumps. Use of the total number of start and run hours over a three-year period, in combination with the revised generic mean failure rates (Table C.2), would allow the derivation of the expected number of failures for the two pumps. The equation in Figure E.3 would yield a number *y* which, after being rounded to the nearest integer, would be the backstop for the two pumps. This process could be applied to all similar components within a system, for all systems in the MSPI. The advantage of Figure E.3 over Table E.1 is that the variable backstop allows for the variation in design configuration (number of components), testing frequency, and operation.

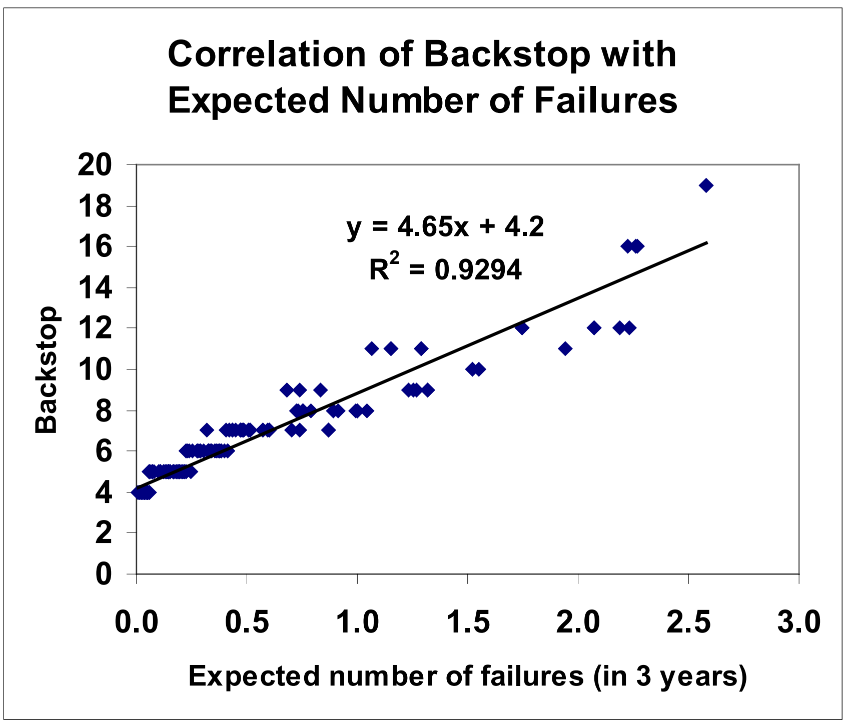

Figure E.3 Variable Backstop

E.7 References

E.1 Nuclear Energy Institute (NEI). NEI 99-02 (Draft Report), "Regulatory Assessment Performance Indicator Guideline," Section 2.2 ("Mitigating Systems Performance Index") and Appendix F ("Methodologies for Computing the Unavailability Index, the Unreliability Index, and Determining Performance Index Validity"). NEI: Washington, D.C. 2002.

APPENDIX F. TECHNICAL BASIS FOR TREATMENT OF COMMON-CAUSE FAILURE CONTRIBUTION TO FUSSELL-VESELY IMPORTANCE

Appendix F
Technical Basis for Treatment of Common-Cause Failure Contribution to Fussell-Vesely Importance

F.1 Introduction

This appendix provides a methodology for adjusting the Mitigating Systems Performance Index (MSPI) Unreliability Index terms proposed by NEI (Ref. F.1) to address the common-cause failure (CCF) contribution to these indices. Specifically, it addresses the impact of a change in the independent failure probability on the CCF probability. It does not address the impact of changes in the CCF parameters.

The current NEI proposal is to account only for "independent" failures in the MSPI. The NEI-proposed approach would not account for the contribution to common cause due to a change in total reliability.

The present approach to address the CCF contribution provides a first order mathematical approximation. It requires one input beyond those already required by the MSPI, namely, the Fussell-Vesely (*FV*) importance value of the CCF event associated with each in-scope common-cause group.

Conceptually, the use of the *FV* as a factor to adjust the MSPI for common cause appears reasonable. This factor directly addresses the importance of the common-cause contribution. However, two other factors need to be considered. These are the degree of redundancy and the degree of common-cause coupling. Both of these issues are also addressed by this approach through the $FV_{(CommonCause)}/UR_{(Independent)}$ ratio (*UR* refers to component unreliability) inherent in the MSPI equation. This is described in detail later in this appendix.

Note that this common-cause adjustment only addresses the impact of changing the independent failure rate on common-cause failure rate in PRA models, and hence on the MSPI. It does not attempt to address the conditional risk associated with a multiple-failure event due to common cause. The current program position is that while total failure counts would go into the MSPI, multiple-failure events *per se* would be addressed through the inspection process.

F.2 Methodology

This section develops the methodology for applying common cause to the MSPI.

F.2.1 MSPI System Unreliability Index (*URI*)

Equation 3 of Reference F.1 defines the system Unreliability Index (*URI*) and is reproduced below. This equation is modified later in this appendix to reflect the impact of common cause on CDF.

$$URI = CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj}) , \qquad \textit{(NEI 99-02 Equation 3)}$$

where the summation is over the number of active components (*m*) in the system, and:

CDF_p is the plant-specific internal events, at power, core damage frequency,

FV_{URc} is the component-specific Fussell-Vesely value for unreliability,

UR_{Pc} is the plant-specific PRA value of component unreliability,

UR_{Bc} is the Bayesian corrected component unreliability for the previous 12 quarters, and

UR_{BLc} is the historical industry baseline calculated from unreliability mean values for each monitored component in the system.

F.2.2 Common-Cause Models

In order to clarify the relationship between independent failure probability and common-cause probability, a brief discussion of common-cause models is provided.

The Beta Factor, Multiple Greek Letter, and Alpha Factor models are typically used to quantify common-cause failure probabilities. These are “parameter” models: they use parameters based on ratios of common-cause failures to total failures from one source of data and a total failure probability from another source (Ref. F.2). It is this model structure that results in the change in common-cause failure probability for a given change in total failure probability. Although it is recognized that both the common-cause ratios and the total failure probability change with new data, the current proposal for MSPI does not attempt to quantify changes in the CCF model parameters. In effect, the common-cause ratios are considered constant over the limited range for which the independent failure rate changes are evaluated.

Within the Alpha Factor Model, the following relationship exists between the total and independent failure probabilities:

$$UR_{Independent} = \alpha_1 \times UR_{Total} \qquad \textit{(Equation F.1)}$$

where

α_k = fraction of the total frequency of failure events that occur in the system and involve the failure of *k* components due to a common cause.

There is a similar relation between the total and common-cause failure probabilities. This relationship can be simple, like that for a two component common-cause group:

$$UR_{CommonCause} = \alpha_2 \times UR_{Total} . \qquad \textit{(Equation F.2)}$$

Or it can be significantly more complicated, like that for a four component common-cause group where one of four must operate:

$$UR_{CommonCause} = \left(\tfrac{1}{3} \alpha_2{}^2 UR_{Total} + \tfrac{4}{3} \alpha_1 \alpha_3 UR_{Total} + 2\alpha_1 \alpha_2 UR_{Total} + \alpha_4 \right) \times UR_{Total} \qquad \textit{(Equation F.3)}$$

The more complex relationships like that above are the reason that a first order approximation is needed for MSPI purposes. Without this approximation, the equation fragment that is multiplied with UR_{Total} would be also dependent on UR_{Total}. Since UR_{Total} is typically much smaller than the common-cause coupling factor, α_4 in this case, simplifying this equation to a form that is first-order in UR introduces minimal error.

$$UR_{CommonCause} \approx \alpha_4 \times UR_{Total} \quad \text{(Equation F.4)}$$

This can be generically represented by the following equation:

$$UR_{CommonCause} \approx \alpha_{CCF} \times UR_{Total} \quad \text{(Equation F.5)}$$

The generic form of this equation reflects the reparametrization form of the typical common-cause model and clearly shows the dependence of common cause on the total failure probability.

F.2.3 Component Unreliability (*UR*)

The NEI document defines UR_{pc} as the plant-specific PRA value of component unreliability. Typically, the failure rate used in the PRAs includes both independent and common-cause failures. That is, failures are not evaluated and screened due to their association with a common-cause event. The assumption is that UR_{pc} represents the total failure rate as opposed to the independent failure rate. In practice, the difference between these two values is small since most failures are independent. This clarification is necessary in order to establish an effective framework that addresses both independent and common-cause impacts.

F.2.4 URI Equation with Common Cause

Given the assumption that there is a change in both independent and common-cause failure probabilities as the result of a change in the total failure probability, the *URI* equation can be re-written as follows:

$$URI_{Total} = URI_{Independent} + URI_{CommonCause} \quad \text{(Equation F.6)}$$

Since the NEI *URI* equation assumes that a change in component reliability has only an independent impact, one can equate the $URI_{Independent}$ with the current NEI *URI* equation. As noted above, this is slightly conservative in that the change on component unreliability includes both independent and common-cause failures. However, the more significant issue is the FV value used in the equation and this reflects only the independent impact. The common-cause impact is addressed by the second term in the above equation, $URI_{CommonCause}$.

Using Equation F.6 above, and NEI Equation 3, the following *URI* equation can be developed.

$$URI_{CCGroup} = CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj}) + CDF_p \left[\frac{FV_{URc(CommonCause)}}{UR_{pc(CommonCause)}} \right]_{\max} (UR_{bc(CommonCause)} - UR_{BLc(CommonCause)}) \qquad \text{(Equation F.7)}$$

For simplicity, this equation represents the components associated with a single common-cause group. This avoids having additional nomenclature to associate the common-cause group with its independent failures. Substituting α_{CCF} UR_{Total} for $UR_{CommonCause}$ from Equation F.5 yields the following:

$$URI_{CCGroup} = CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj}) + CDF_p \left[\frac{FV_{URc(CommonCause)}}{UR_{pc(CommonCause)}} \right]_{\max} (\alpha_{CCF} UR_{Bcj} - \alpha_{CCF} UR_{BLcj}) \qquad \text{(Equation F.8)}$$

Note that since the components within a common-cause group are *a priori* similar, their failure data are pooled in accordance with NEI (and NRC) guidance. This results in the same *ΔUR* being used for each component. This also results in the same *ΔUR* being used for the common-cause contribution, although this change is modified by the α_{CCF} factor. It can also be seen that the magnitude of the change in common cause is significantly less due to the presence of the α_{CCF} factor. This factor carries the knowledge of the degree of common-cause coupling and the degree of redundancy. The overall change in common-cause unreliability increases with increased coupling and decreases with increased redundancy. Therefore, all three common-cause characteristics are addressed: importance by the use of *FV*, as well as coupling and redundancy by use of the α_{CCF} factor.

Equation F.8 can be rewritten are follows:

$$URI_{CCGroup} = CDF_p \left(\sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} + \left[\frac{\alpha_{CCF} FV_{URc(CommonCause)}}{UR_{pc(CommonCause)}} \right]_{\max} \right) (UR_{Bcj} - UR_{BLcj}) \qquad \text{(Equation F.9)}$$

Using a modified version of Equation F.5, $UR_{(CommonCause)}$ can be substituted out of the equation.

$$UR_{(Independent)} = {}^{1}\!/_{\alpha_{CCF}} \times UR_{(CommonCause)} \qquad \text{(Equation F.10)}$$

This results in a new *URI* equation that only requires addition of the common-cause *FV* value as shown below.

$$URI_{CCGroup} = CDF_p \left(\frac{\sum_{j=1}^{m} FV_{URcj} + FV_{URc(CommonCause)}}{UR_{pc}} \right)_{\max} (UR_{Bcj} - UR_{BLcj}) \qquad \textit{(Equation F.11)}$$

This equation represents the *URI* for a given common-cause group. It can be generically represented by the following:

$$URI_{Total} = CDF_p \sum_{i=1}^{n} \left(\frac{\sum_{j=1}^{r} FV_{URcj} + FV_{URc(CommonCause)i}}{UR_{pc}} \right)_{\max} (UR_{Bcj} - UR_{BLcj}) \qquad \textit{(Equation F.12)}$$

$$+ CDF_p \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj})$$

where:

I indexes common-cause groups,

n represents the number of in-scope common-cause groups,

m represents the number of independent components (not associated with a common-cause group),

j indexes components within a common-cause group,

r represents the number of components within a given common-cause group.

The two parts of this equation are necessary to address both components associated with a common-cause group and components that are unique and independent of any common-cause group.

F.2.5 Example

As an example, consider a common-cause group of two emergency diesel generators. This would result in the following equation:

$$URI_{TOTAL} = CDF_p \left(\frac{FV_{UR(EDG1)} + FV_{UR(EDG2)} + FV_{UR(EDGCommonCause)}}{UR_{pc}} \right) \times \left(UR_{Bc(EDG)} - UR_{BLc(EDG)} \right)$$

Substituting values from the Palo Verde enhanced SPAR model this equation becomes:

$$URI_{TOTAL} = 1.2E-5 \times \left(\frac{1.7E-02 + 2.3E-02 + 1.1E-02}{1.5E-02} \right) \times \left(UR_{Bc(EDG)} - UR_{BLc(EDG)} \right)$$

$$URI_{TOTAL} = 4.1E-05 \times \left(UR_{Bc(EDG)} - UR_{BLc(EDG)} \right)$$

This can be compared to the *URI* equation that only considers independent failures by removing the common-cause *FV*.

$$URI_{Independent} = 3.2E-05 \times \left(UR_{Bc(EDG)} - UR_{BLc(EDG)} \right)$$

In this case, there is a 30% increase in the *ΔUR* multiplier. This increase will vary depending on the common-cause importance, the degree of coupling and the degree of redundancy. Additional examples are shown below.

Table F.1 Examples of the Effect of Common Cause

Indicator	Plant	Component	Redundancy	UR	Sum of Component FV	CCF FV	Increase
RHR	Millstone 2	MDP Cntmt Spray	2	5.46E-03 (FTS)	1.21E-04	5.05E-06	5%
SWS	S. Texas	Pumps	3	1.32E-04 (FTR)	3.1E-03	1.9E-04	6%
EAC	Millstone 2	EDGs	2	8.02E-03 (FTS)	7.09E-03	7.58E-04	11%
EAC	S. Texas	EDG	2	8.26E-03 (FTLR)	4.09E-02	1.57E-01	17%
EAC	S. Texas	EDGs	3	3.17E-02 (FTR)	1.57E-01	2.6E-02	17%
EAC	Palo Verde (Enhanced SPAR)	EDGs	2	1.5E-02 (FTR)	4.0E-02	1.1E-02	30%
HPI	Millstone 2	MDP	3	3.36E-03 (FTS)	5.61E-02	2.07E-02	37%
SWS	Hope Creek	MDPs	4	5.47E-04 (FTR)	4.33E-03	7.53E-03	63%
EAC	Hope Creek	EDGs	4	6.83E-03 (FTR)	6.13E-03	3.94E-02	146%
EAC	Limerick	EDGs	4	1.19E-02 (FTR)	2.57E-02	2.40E-01	930%

As stated in the introduction, this equation does not capture the change in reliability resulting from a common-cause induced, multiple failure event. Such an equation would require that $FV_{UR(EDGCommonCause)}$ be divided by the *UR* for the common-cause basic event, a much smaller number that is reduced by the α_{CCF} factor. In addition, the change in *UR* would need to reflect the change in the coupling factor as well as the change in the independent failure likelihood.

F.2.6 Truncation

The truncation limit used during model quantification could have a significant impact on this approach for adjusting the MSPI equation to address common cause. Due to the low common-cause failure probabilities when compared with the independent failure probabilities, there is a greater risk that a significant number of common-cause cutsets or sequences will be truncated at a given truncation level. This results in lower common-cause FV values, and therefore, an underestimation of the common-cause impact. This needs to be considered when the importance of the CCF basic event is determined.

F.3 Process for Evaluating CCF Contribution to MSPI

The process for evaluating the CCF contribution to the MSPI is described below. This process addresses the various means by which common cause is treated in PRA models. The premise of this process is that the observed failure data relate to total failure probability. When total failure probability increases, so too does CCF probability, as implied by the parametric models commonly used. The risk significance of declining reliability performance is therefore affected by the risk significance of CCF. A flowchart of the overall process is shown in Figure F.1.

Step 1: For each component, determine whether it is within one or more CCF groups.

Common cause should be considered for components of similar design, operation, maintenance practices or environment. In accordance with the NEI guidance, demands and failures for similar components within each system are summed. Components that have been grouped for this purpose should be considered for common cause.

Step 2: For each common-cause group, determine the failure mode used for the maximum FV/UR.

The MSPI process only uses the failure mode with the maximum FV/UR for components within scope. The CCF associated with the failure mode is used to represent the impact of common cause on the MSPI.

Steps 3 and 3.1: Identify the associated CCF events within the PRA

For the identified failure mode, the associated CCF events that are modeled within the site-specific PRA should be identified. If there are no CCF events, then the appropriate event(s) should be added to the PRA. Alternatively, the lack of common-cause modeling should be justified and documented.

Step 4: Determine the modeling approach

PRA practitioners use a variety of techniques to apply CCF to fault-tree and event-tree models. The capability or limitations of the PRA software used for the models sometime drive these techniques. Several different modeling approaches are discussed below. The overriding principle of all these approaches is to identify the total risk contribution from both independent and common-cause failures for each in-scope MSPI component.

Step 4.1: Single Event

Often, CCF is modeled as a single event that addresses all the combinations of the failures with exception of independent failures failing with other independent failures. These independent failures are modeled as separate basic events. For example, consider a system with three redundant components. In a “single event” CCF model, there would be one basic event for each single failure and a basic event for the common-cause failures. This common-cause basic event corresponds to the common-cause failure of all three components as well as combinations of the common-cause failure of two components and the independent failure of the third.

The recommended treatment for a “single event” common-cause model is simply to add the FV of this single event to the independent FV values within the MSPI equation.

Step 4.2: Split Event

Sometimes the common-cause failure of components is addressed at the sub-component level. For example, common cause for a motor-drive pump can be considered for the motor and for the pump. This may be appropriate in that the motor-driven pump could be in a three-pump system with two motor-driven and one turbine-driven pumps. The pumps may be of similar design and may have the same suction source. Therefore the pumps would be in a three component common-cause group and the motors in a group of two.

For the MSPIs, a key objective is to capture the change in CCF probability when the associated total failure rate changes. Failures associated with the driver are typically more dynamic than those associated with the pump. Therefore, the recommended treatment for a "split event" is to use the sub-component FV associated with the highest CCF probability. In the case of the above example, this would be the CCF associated with the motor. This is also consistent with the component grouping used in the MSPIs.

Step 4.3: Multiple Events

Some PRA practitioners and/or PRA software use multiple events to model the impact of CCF. For example, consider a system with three redundant components (and a 1 of 3 success criterion). In a "multiple events" CCF model, there would be a basic event for each single failure, three events, and several events for the common-cause failures. These events would include a basic event for the common-cause failure of all three components and additional basic events for each combination of the common-cause failure of two components and the independent failure of the third. For this example there are a total of four common-cause basic events. However, the number of combinations varies with the success criteria and the degree of redundancy within a given system.

The recommended treatment of "multiple events" is to either use a group FV (if available) to obtain the total FV for all of the common-cause events or, if the group FV cannot be evaluated, to simply add the FVs. The simple addition of the FVs could result in some double counting (over-estimation) in the rare case where multiple common-cause basic events for the same common-cause group appear in the same cutset.

Step 4.4: Combined Events

The "combined events" approach addresses the consolidation of failures modes (e.g., fail-to-start and fail-to-run) into a single common-cause basic event. The combined event can either be separated (site-specific PRA model is updated) or estimated.

The following approach can be used to estimate the CCF FV. Cutsets that contain combined events are typically similar to those that contain separate events in that the other failure events in these cutsets are the same. This results in the following relationship:

$$\frac{FV_{FTS}}{UR_{FTS}} \cong \frac{FV_{FTR}}{UR_{FTR}} \cong \frac{FV_{Combined}}{UR_{Combined}}$$

Therefore, the FV for the failure mode of interest can be obtained by determining its contribution to the combined UR CCF value and then multiplying this value by the FV/UR combined value. For example, if failure-to-start is the failure mode of interest, then FV_{FTS} would be determined as follows:

$$FV_{FTS} = \frac{FV_{Combined}}{UR_{Combined}} \times UR_{FTS}$$

where UR_{FTS} is the portion of $UR_{Combined}$ associated with the failure to start. Note that UR_{FTS} would be determined based on the examination of the bases for $UR_{Combined}$ in order to determine that portion of the combined event that is associated with the failure to start.

Step 4.5: Conditional Split Fractions

Conditional split fractions are sometimes used in the large event tree methodology to model the CCF impact of redundant trains that are represented by separate top events. The CCF importance may be able to be derived by one of the methods described above or may require other techniques. If other techniques are used, their objective should be to achieve the appropriate CCF contribution similar to the methods above.

Step 4.6: Other

In addition to the above CCF approaches, there may be other unique applications of CCF within PRA models or combinations of the above methods. If other techniques are used, approaches analogous to the above should be applicable. The objective is to reflect the appropriate CCF contribution to each component's FV/UR, as in the methods above.

Step 5: Determine the CCF FV

Based on the above modeling approaches, determine the CCF FV for each identified common-cause group.

Step 6: Add CCF FV to the independent FV values

Add the CCF FV for each common-cause group to the associated independent FV.

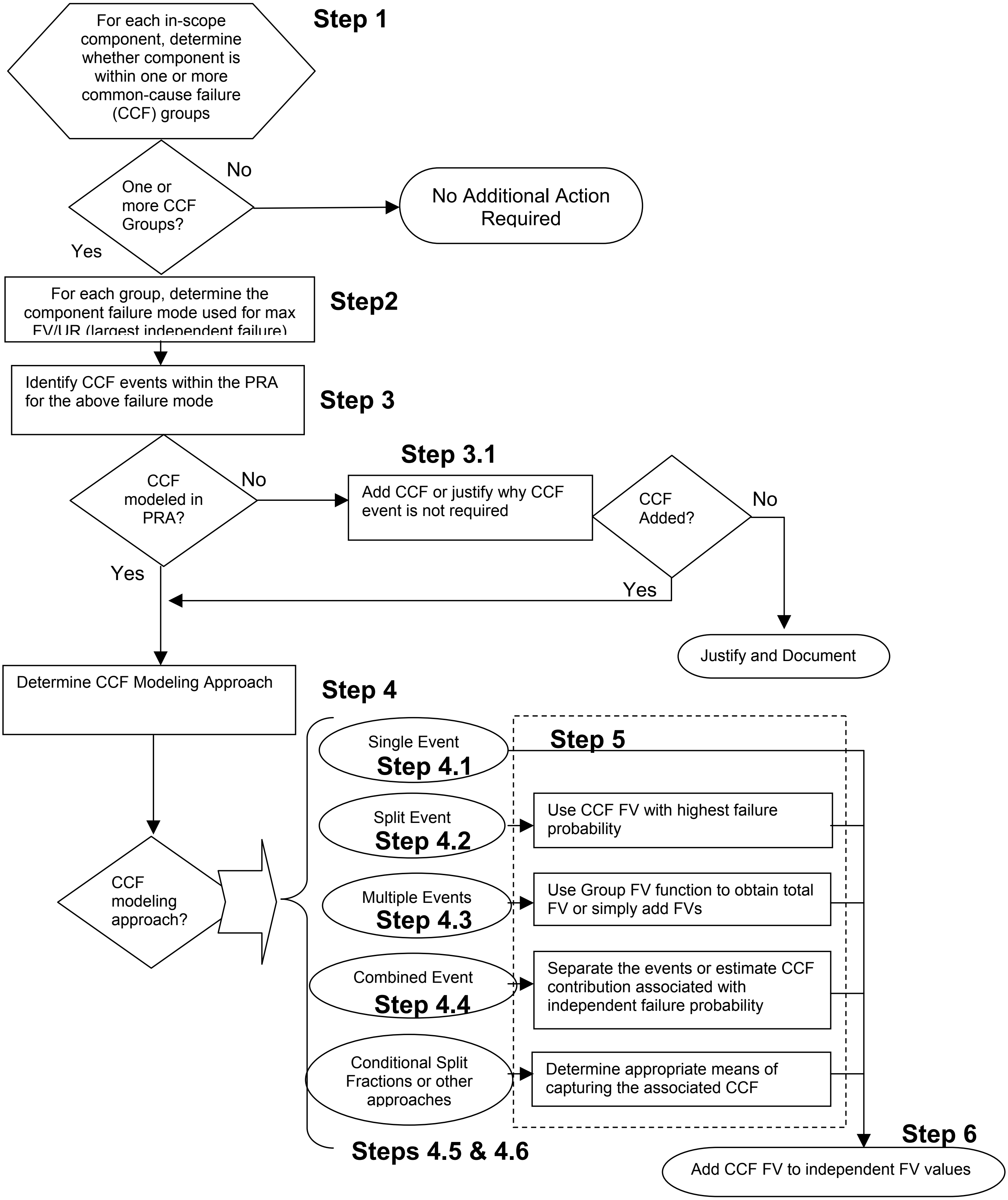

Figure F.1 Evaluation of Common-Cause Failure Contribution to MSPIs

F.4 Alternate Approach Using Generic Multipliers on FV

Exercises performed by a number of pilot plant participants at the August 20, 2003 NEI workshop indicated that detailed guidance and training would be required to implement the proposed inclusion of Fussell-Vesely importances for CCF as described above. The exercise also identified that in some instances the common-cause modeling includes a complicated coupling of pumps, motors, breakers, and other components. Dissection of the FV owing to common-cause into the various components was not a simple exercise. As a result, an alternative approach to address CCF is provided in this section. This option allows the use of generic multipliers on the FV from independent failures as an appropriate adjustment to account for the effect of CCF.

One simple way to incorporate the impacts of CCF modeling on component Fussell-Vesely importance measures is to apply a CCF multiplier to the importance measure. For a system with two parallel components and system success defined as success of either of the components, the risk model includes three events: independent failure of component 1, independent failure of component 2, and CCF of components 1 and 2. Each of these events has an associated Fussell-Vesely importance factor (FV_1, FV_2, and $FV_{12,CCF}$). To determine the CCF multiplier for a particular component type in a particular system, the Fussell-Vesely importances of all three events are summed and divided by the sum of the Fussell-Vesely importances of the two independent failure events. In equation form, the CCF multiplier is the following:

$$\textit{CCF multiplier} = (FV_1 + FV_2 + FV_{12,CCF})/(FV_1 + FV_2)$$

This *CCF multiplier* then can be applied to each of the independent failure event Fussell-Vesely importances. In the example above, FV_1 would be replaced by FV_1**CCF multiplier*, and FV_2 would be replaced by FV_2**CCF multiplier*. This is valid even if the importances of the two components are not equal. For a system with n components, the CCF multiplier would be determined similar to above, but with “$FV_1 + FV_2$” replaced by “$FV_1 + \ldots + FV_n$”.

To develop a set of recommended generic CCF multipliers, a two-step process was used. First, the eleven Standardized Plant Analysis Risk (SPAR) resolution models (covering the twenty pilot plants) were used to identify system/component/failure mode CCF multipliers for each model. Results of that effort are presented in Table F.2. Blanks in the table indicate that either the plant has only one such component (and CCF is therefore not applicable) or the SPAR model did not include a CCF event for such components. In a few cases, the data sets were augmented with data from non-pilot plants for better sampling. Then the results in Table F.2 were analyzed to generate a limited set of recommended generic CCF multipliers believed to be applicable to all plants. The recommended generic CCF multipliers are presented in Tables F.3 and F.4. (Table F.4 lists the results by pilot plant rather than by number of components and success criterion.)

The reduced set of recommended generic CCF multipliers in Table F.3 was generated by reviewing the individual plant results in Table F.2. Each table entry was characterized by the number of components modeled, the system success criterion, and other factors such as the availability of backup systems to perform the same function. Then this information was used to group plants with similar CCF multipliers, and a geometric average from those plants was used as the recommended generic CCF multiplier. Also, these multipliers were rounded to 1.25, 1.50, 2.0, 3.0, or 5.0. Finally, for pumps and emergency diesel generators, results for failure-to-start, failure-to-load/run, and failure-to-run were combined to obtain results applicable to all failure modes.

Sensitivity studies were performed to assess the effect of generic CCF multipliers on overall MSPI results. The results of these studies were compared to the MSPI values generated for the one hundred systems as shown in Tables A.3 and A.4 for 4th quarter 2002.

On a case-by-case basis, the effect of using generic CCF multipliers could be to either *increase* or *decrease* the MSPI results depending on system performance. The CCF multiplier has the effect of increasing the Birnbaum value or coefficient as shown in Equation F.9, for example. If component reliability is worse than baseline, its contribution to URI would be positive, and the larger coefficient resulting from the adjustment for CCF would tend to make these terms more positive. Likewise, terms where performance is better than baseline (negative), would become more negative. In the aggregate, systems with lower MSPI because of the CCF effect would be balanced by systems with higher MSPI owing to CCF.

But in general, the use of generic CCF multipliers is found to increase the number of WHITE MSPI indications, especially where the system MSPI without CCF is a high GREEN and on the margin of the GREEN/WHITE threshold. The results are consistent with numerical simulation that indicates the inclusion of CCF could result in about one-third more WHITE indicators than without accounting for CCF.

F.5 References

F.1 Nuclear Energy Institute (NEI). NEI 99-02 (Draft Report), “Regulatory Assessment Performance Indicator Guideline,” Section 2.2 (“Mitigating System Performance Index”) and Appendix F (“Methodologies for Computing the Unavailability Index, the Unreliability Index, and Determining Performance Index Validity”). NEI: Washington, D.C. 2002.

F.2 A. Mosleh, et al., NUREG/CR-5485, Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment, November 1998.

Table F.2 CCF Multipliers from SPAR Resolution Models

System	Component	Failure Mode	Braidwood	Hope Creek	Limerick	Millstone 2	Millstone 3	Palo Verde	Prairie Island	Salem	San Onofre	South Texas	Surry		Geometric Average
EAC	EDG	FTS	1.41	1.84	6.93	1.11	1.06	1.21	1.11	1.10	1.22	2.31	1.06		1.51
		FTLR													
		FTR	1.51	1.28	1.00	1.11	1.08	1.27	1.14	1.14	1.29	1.97	1.07		1.24
	AOV	FTO/C							1.10						1.10
HPI	MDP Running	FTS	1.12				1.00			1.50			1.25		1.20
		FTR	2.41				1.21			1.23			8.76		2.37
	MDP Standby	FTS	1.18			1.02	1.31	5.88	6.04	3.22	1.27	8.88			2.59
		FTR	1.78			1.00	1.15	3.93	3.38	2.05	1.27	10.72			2.29
	MOV	FTO/C	2.11			1.55	1.04	1.36	1.43	1.26	1.50	1.90	5.50		1.72
	AOV	FTO/C													
HRS	MDP Standby	FTS				1.05	1.74	1.85		2.11	1.00	6.02	1.69		1.84
		FTR				1.00	2.07	1.00		1.15	1.00	2.55	1.09		1.31
	TDP	FTS													
		FTR													
	DDP	FTS													
		FTR													
	MOV	FTO/C									1.01	1.81	7.55		2.40
	AOV	FTO/C				5.74				1.01					2.41
RHR	MDP Standby	FTS	1.61	1.65	1.00	2.40	2.97	1.59	1.13	1.56	1.11	1.56	3.50		1.69
		FTR	1.61	1.29	1.00	2.40	1.90	1.36	1.06	1.27	1.11	1.67	2.17		1.47
	MOV	FTO/C	1.22	2.07	1.01	2.03	1.36	1.31	1.54	1.18	1.50	1.90	14.30		1.81
	AOV	FTO/C													
SWS	MDP Running	FTS	1.33	1.92		1.11	1.24			3.46	2.38	1.82	1.26		1.69
		FTR	7.97	4.39		1.18	51.72			4.81	2.38	20.67	4.21		6.17
	MDP Standby	FTS			1.00			1.14							1.07
		FTR			4.14			1.06							2.10
	DDP	FTS							1.25				1.00		1.12
		FTR							1.80				1.00		1.34
	MOV	FTO/C					1.24					6.31	1.13		2.07
	AOV	FTO/C				1.09					1.07				1.08
CCW	MDP Running	FTS	1.30			1.24			1.07	1.49	1.39	1.93	1.10		1.34
		FTR	1.76			1.15			1.69	1.94	1.39	6.67	1.43		1.90
	MDP Standby	FTS						2.59							2.59
		FTR						1.98							1.98
	MOV	FTO/C													
	AOV	FTO/C				1.54						3.28			2.24
													All MOVs		1.86
			1.00 = Truncated (or calculated) CCF										All AOVs		1.68
			Blank = single component, components don't exist, or components and/or CCF not modeled										All MDPs Running		2.17
													All MDPs Standby		1.79
													All EDGs		1.37

Acronyms: AOV (air-operated valve), CCF (common-cause failure), CCW (component cooling water), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), FTLR (fail to load and run for 1 hour), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), RHR (residual heat removal system), SWS (service water system), TDP (turbine-driven pump)

Table F.3 Recommended Generic CCF Multipliers

		Generic CCF Multiplier					
System	**Component**	**1.25**	**1.50**	**2.00**	**3.00**	**5.00**	**Comments**
EAC	EDG	2 EDGs (1/2) or 3 EDGs (2/3)	4 EDGs (1/4) with other diverse sources of power	3 EDGs (1/3)		4 EDGs (1/4) and no diverse sources of power	4 EDG case (with no diverse sources of power) includes information from SPAR Rev. 3 models for Browns Ferry 3 and Fitzpatrick.
HPI	MDP Running		With SI and CVC		With only CVC		
	MDP Standby		With SI and CVC		With only SI		
HRS	MDP Standby	2 MDPs (1/2)			3 MDPs (1/3)		
	TDP	2 TDPs and 1 MDP			3 TDPs and no MDPs		Information from SPAR Rev. 3 models for Calvert Cliffs, Davis Besse and Turkey Point used.
RHR	MDP Standby		All				
SWS	MDP Running				All		
	MDP Standby		All				
	DDP	All					
CCW	MDP Running		All				
	MDP Standby			All			
All	MOV			All			
All	AOV		All				

Note - Success criterion indicated in parentheses.

Note - Generic CCF multipliers obtained from SPAR resolution model results for 11 pilot plants, unless otherwise indicated.

Acronyms: AOV (air-operated valve), CCF (common-cause failure), CCW (component cooling water), CVC (chemical and volume control system), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), RHR (residual heat removal system), SI (safety injection system), SWS (service water system), TDP (turbine-driven pump)

Table F.4 Recommended Generic CCF Multipliers by Pilot Plant

		Generic CCF Multiplier					
System	**Component**	**1.25**	**1.50**	**2.00**	**3.00**	**5.00**	**Comments**
EAC	EDG	Braidwood Millstone 2 Millstone 3 Palo Verde Prairie Island Salem San Onofre Surry	Hope Creek	South Texas		Limerick	4 EDG case (with no diverse sources of power) includes information from SPAR Rev. 3 models for Browns Ferry 3 and Fitzpatrick.
HPI	MDP Running		Braidwood Millstone 3 Salem		Surry		
	MDP Standby		Braidwood Millstone 3 Salem		Millstone 2 Palo Verde Prairie Island San Onofre South Texas		
HRS	MDP Standby	Millstone 2 Millstone 3 Palo Verde Salem San Onofre Surry			South Texas		
	TDP	No MSPI pilot plants			No MSPI pilot plants		Information from SPAR Rev. 3 models for Calvert Cliffs, Davis Besse and Turkey Point used.
RHR	MDP Standby		All				
SWS	MDP Running				All		
	MDP Standby		All				
	DDP	All					
CCW	MDP Running		All				
	MDP Standby			All			
All	MOV			All			
All	AOV		All				
Note - Success criterion indicated in parentheses.							
Note - Generic CCF multipliers obtained from SPAR resolution model results for 11 pilot plants, unless otherwise indicated.							
Acronyms: AOV (air-operated valve), CCF (common-cause failure), CCW (component cooling water), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), MSPI (mitigating systems performance index), RHR (residual heat removal system), SWS (service water system), TDP (turbine-driven pump)							

APPENDIX G. TECHNICAL BASIS FOR EXCLUDING ACTIVE VALVES BASED ON BIRNBAUM IMPORTANCE

Appendix G
Technical Basis for Excluding Active Valves Based on Birnbaum Importance

G.1 Background

Appendix F of Draft NEI 99-02 MSPI Rev 0 provides clarifying notes as to the criteria for determining those components that should be monitored. For example, all pumps and diesel-generators are included in the performance index. Specific guidance is provided on page F-9 for valves, whether in series or parallel for multi-train systems. The guidance is prescriptive in nature and is intended to ensure to a first order of approximation that important valves within a system are included.

The expectation is that the number of valves to be monitored should not be too different from the number of pumps in the system. Thus, in a three-train system consisting of three pumps, one should expect the number of valves to be monitored to be on the order of two to six. Certainly ten or more valves to be monitored within a system should be the rare exception.

For the twenty pilot plants in the program, the average number of components for all six systems combined has been found to be fewer than fifty, comprised of:

- About 16 pumps
- About 24 valves
- From 2 to 4 emergency diesel-generators
- The occasional circuit breaker for electrical cross-tie.

The above counts meet general expectations. However, there are instances where, for several reasons, the number of valves to be monitored in total has been determined to be as high as forty-six. This far exceeds expectations and can pose a large data collection burden, with no clear benefit in return.

G.2 Birnbaum Cutoff for Excluding Valves

Based on an analysis of all of the valves monitored by the twenty pilot plants, it is possible to exclude low importance valves without affecting the overall results of the MSPI. The analysis considered both FV/UR and Birnbaum (CDF * FV/UR) as possible criterion for excluding active valves from the MSPI. Birnbaum has been deemed to be more appropriate since it is the measure directly used in the calculation of URI, and URI is the figure-of-merit of interest here.

Figure G.1 shows the average number of active valves (mainly air-operated and motor-operated) per nuclear unit that would be monitored as a function of possible cutoff in Birnbaum, based on pilot plant results. Lowest and highest valve counts are also shown for comparison. As the Birnbaum increases, there is a large initial drop in the average valve count, owing to a clustering of low importance valves. The plot flattens out considerably after 1E-6/yr or so. Clearly, there is diminishing return after about 1E-6/yr.

Figure G.2 shows the potential unaccounted for delta URI that could arise from the exclusion of low importance valves from the MSPI. The analysis is conservative because it assumes that the excluded valves in question each could have had three failures over three years. The potentially unaccounted for delta URI plot remains flat for the “average” case through 1E-6/yr, before increasing slowly thereafter. The unaccounted for delta URI for the highest valve count plant is only about 1E-7/yr at a Birnbaum of 1E-6/yr. This unaccounted for delta URI is only 10% of the value necessary to turn the indicator for the system WHITE. And this assessment is still somewhat conservative because not all valves that would be excluded would necessarily be in the same system.

In consideration of the benefits to be gained by excluding low risk valves, and the insignificant impact on MSPI results, the exclusion of active valves with Birnbaum of less than 1E-6/yr is appropriate. ***Based on the discussion below, the common-cause contribution to FV (and Birnbaum) must be added to the valve Birnbaums before the cutoff is applied.***

G.3 Other Considerations

Appendix F discusses the need to include the common-cause contribution to FV in the overall approach to the MSPI. Since Figure G.1 does *not* include the adjustment to valve Birnbaums owing to common cause, the potential benefit in terms of the number of valves excluded from scope could be somewhat less than shown. The effect of including the adjustment to FV for common cause would be to shift the three plots in Figure G.1 to the right. Without having available the FV due to common cause from the plant PRA for all the pilot plant valves, the exact effect can not be ascertained. If the option of using *generic multipliers* as discussed in Appendix F were used, then the impact could be estimated. For motor-operated valves, a generic multiplier of 2.0 has been recommended. This would effectively reduce the unadjusted Birnbaum cutoff (i.e. without common cause) from 1E-6/yr to 5E-7/yr. Figure G.1 shows that using a Birnbaum cutoff of 1E-6/yr reduces the average number of valves per plant from 24 to about 17. If common cause using the generic multiplier is included, this average is estimated to be 18 instead.

Another important consideration is whether or not some minimum number of valves should remain in-scope regardless of their risk importance. *Any valves that meet the cutoff criterion of 1E-6/yr on Birnbaum (including common cause) do not impact URI in any way.* But there could be undesirable consequences of monitoring too few valves in MSPI. For one, the more valves that are monitored, the larger the pool of similar valves and the higher the number of demands. If a larger population is considered, the URI is less sensitive to small numbers of failures of valves, and less likely to result in a false WHITE for a small (statistically not unlikely) number of failures. Secondly, valves not monitored in the MSPI could be subject to the inspection process. Thirdly, as the plant PRA model changes owing to changes in plant design or equipment performance, it is likely that importance measures also change. A valve with a Birnbaum just under the 1E-6/yr cutoff probably should be included because of its potential to meet the criterion at some future point. It therefore seems reasonable to ensure a minimum number of valves are monitored by the MSPI, regardless of their risk significance.

The next logical question would be to ask whether such a cutoff could be applied to components other than valves. Analysis was performed for pumps in a way similar to valves. A case could have been made to exclude some pumps based strictly on risk. However, since the pumps are at the core of the system reliability, it would be inconsistent with the intent of the MSPI to exclude pumps from monitoring.

G.4 Process

The approach to address the option regarding which valves to monitor in the MSPI should proceed as follows:

(1) Identify all active valves that meet the prescriptive criteria per NEI 99-02.
(2) Calculate the independent Fussell-Vesely (FV) importance for all valves in (1).
(3) Calculate the common-cause contribution to FV for all valves in (1) per Appendix F in this report. Apportion the FV due to common cause and add them to FV for independent failures. (For example, if FV_{ccf} were 0.02 for a two-valve configuration, 0.01 would be added to the FV for each independent failure).
(4) Calculate the Birnbaum (= CDF * FV/UR) for all valves. (If the option to use generic multipliers for common cause is invoked, the effective Birnbaum cutoff would be the unadjusted B divided by the generic multiplier, rather than 1E-6/yr).
(5) Identify which valves are required to be monitored (B > 1E-6/yr), and those that are optional (B < 1E-6/yr).
(6) Based on a consideration of the (a) potential data collection burden if the list of valves is large, (b) the desirability of having a large enough pool of valves, and (c) the margin of valves from the 1E-6/yr cutoff: clearly identify the list of valves that are to be monitored for the duration of the indicator.

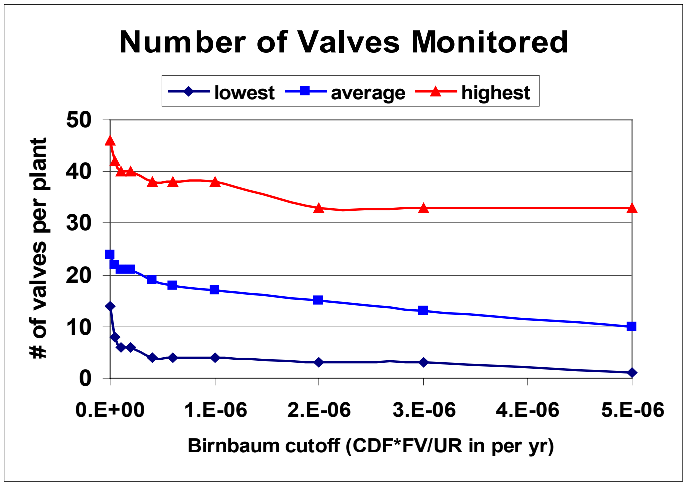

Figure G.1 Average Number of Values Monitored

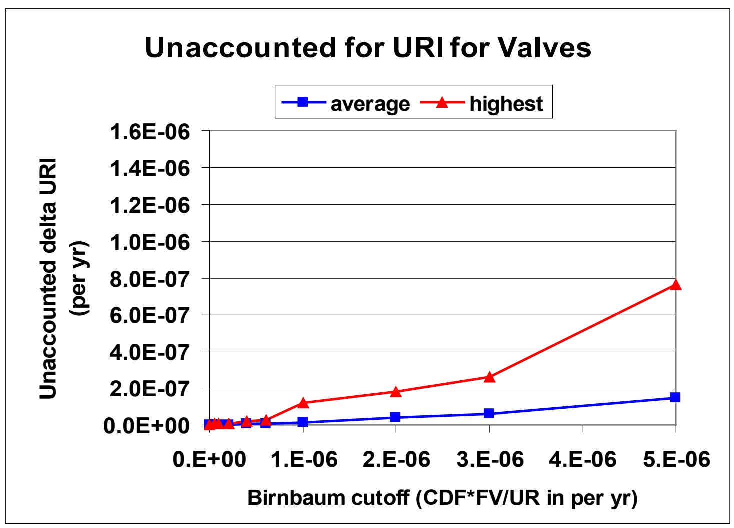

Figure G.2 Estimate of Unaccounted for URI for Valves

APPENDIX H. TECHNICAL BASIS FOR INCLUDING THE CONTRIBUTION OF SUPPORT SYSTEM INITIATORS TO FUSSELL-VESELY IMPORTANCE

Appendix H
Technical Basis for Including the Contribution of Support System Initiators to Fussell-Vesely Importance

H.1 Background

The MSPI is calculated for five indicators consisting of six systems. Two of the six systems, component cooling water and service water, are to be combined into one indicator called the "cooling water support system." A primary reason for combining these systems into one indicator is owing to the large variability in design from plant-to-plant. For the majority of nuclear plants, the cooling water systems provide cooling to secondary and auxiliary systems such as the turbine-generator, as well as to safety systems such as the emergency diesel-generators and residual heat removal heat exchangers. However, in a number of plants, cooling water systems have been separated into those that provide cooling strictly to non-safety components and those that cool only safety systems. Still other plants utilize safety-related service water to directly cool safety-related systems, and do not have the intermediate safety-related component cooling water system. In the MSPI, only those cooling water support systems that have some safety-related function are to be included.

Support systems such as service water contribute to a plant PRA model in two ways. First, the service water system provides a "support" role whereby it cools other support systems such as emergency diesel generators or even "frontline" systems, depending on the design. These are modeled appropriately in the PRA through the use of linked fault trees or large event trees. Second, if the loss of the cooling water system such as service water could also result in a plant transient, automatic scram, or is likely to lead to a manual scram, then that system is also modeled as a potential initiating event in the PRA. Thus, a component such as a service water pump could impact the overall plant PRA results because a) of its function in cooling needed equipment *following* a transient, and b) through the potential to *initiate* a plant transient. Of all the systems within scope of the MSPI, service water system (SWS) and component cooling water (CCW) are the two systems that could serve in these two roles of both supporting other systems when called upon, and initiating a transient if the SWS or CCW system is lost entirely or is substantially degraded.

The plant PRA models calculate various risk measures such as Fussell-Vesely importance, Risk Achievement Worth (RAW), and Birnbaum importance from basic event probabilities. All PRA models can provide such risk measures for SWS and CCW components of interest in the MSPI. However, while all the models include the component's contribution from the "support system" role of SWS and CCW, not all models include the contribution to the importance measures from the loss of SWS or CCW as an initiating event. This is because the initiating event frequencies used in some plant PRA have been based on plant and/or industry experience, and use an explicit value for the frequency. The frequency may use a distribution with mean and variance, but the value has been calculated is some way separate from the linked PRA model. In other models, the PRA analyst may have chosen to link a loss of SWS initiator fault tree directly into the computer model of the PRA. This is a matter of practice and convenience that is left to the discretion of the analyst. The Standardized Plant Analysis Risk (SPAR) models, for example, use initiating event frequencies for loss of SWS and loss of CCW that are based largely on industry experience. SPAR does not use fault trees for these initiators, but could be changed to do so. Either approach is acceptable so long as it is based on valid equipment performance data, takes into account the potential for common mode failure based on plant-specific characteristics and design, properly conditions mitigating system failure on initiating event characteristics, and is generally consistent with industry operating experience.

H.2 Contribution to Fussell-Vesely Importance Measure

All other things being equal, a plant PRA model that uses initiator fault trees explicitly for loss of SWS and/or CCW (where Importance of the initiating event components is accounted for) will result in higher Fussell-Vesely (FV) and Birnbaum risk measures for an associated basic event than a model that uses a point-estimate frequency. The difference between the two approaches would be a function of the importance of that initiator to the overall calculated core damage frequency (CDF), as well as the importance of the particular component (and basic event) within the SWS or CCW system of interest. During the January 21, 2003 Workshop on the MSPI, a survey was taken of the pilot plant participants. Plant PRA models fell into three categories: a) those that used fault trees for loss of SWS and loss of CCW initiators that were directly linked in the PRA model, b) those that used fault trees and/or event trees outside of the linked PRA model to quantify the frequencies, which were entered manually into the PRA model no differently than a medium LOCA frequency would be, and c) those that used frequencies based on industry experience, updated with plant-specific data. Category "a" is the most prevalent, with about two-thirds of the pilot plants using this approach. These differences in approach clearly result in an inconsistency for the purpose of the MSPI; the MSPI methodology relies heavily on using calculated risk measures (FV divided by basic event probability) rather than (say) a re-quantification of the entire PRA model.

Given this inconsistency, there are three options for consideration:

(1) For those plant PRAs that have used linked SWS and CCW initiator fault trees, require that they substitute point-estimate frequencies in lieu of using the linked trees.
(2) For those plant PRAs that have used point-estimate frequencies for loss of SWS and CCW, ensure that they account for the contribution of the SWS and CCW initiators in the FV computation for the components within scope of the MSPI.
(3) Ignore the inconsistent approaches.

Sensitivity studies have been performed by some pilot plant analysts to identify the importance of including the contribution of support system initiators to the FV risk measure. Calculations were performed first by using the existing linked fault tree initiator models, and next with the fault tree initiator essentially turned off. Differences in FV using the two approaches can be expected to be strong functions of

- The importance of the initiator to overall CDF
- Importance of the component within the system
- System configuration and design
- Importance of recovery actions and success criteria.

At the lower end, the differences in calculated FV with and without initiator fault trees were shown to be less than one percent. At the upper end, differences as high as an order of magnitude in FV were seen for some components. Clearly, the potentially significant contribution of support system initiators to FV rules out options "1" and "3". The only viable option is "2", that is, to account for the contribution of the support system initiator to FV. Some have argued that in a mitigating system performance index, these contributions of initiators should not be included at all. But the loss SWS or CCW initiators cascading to core damage also implies that these components would not have been available to support their mitigation function as well. The contribution of SWS and CCW components to FV, both as initiators and mitigators, need to be included if the full risk importance is to be properly accounted for.

H.3 Process to Account for Support System Initiators

Figure H.1 shows the process to account for the contribution of support system initiators to FV. Clearly, if the safety-related CCW and/or SWS systems to be monitored in the MSPI are strictly standby systems, then their loss can not initiate a plant transient. The calculated FV values for the CCW/SWS components are proper and no further action is necessary.

In the second diamond, if initiator fault trees are being used, then the contribution of initiators to FV is accounted for. ***However, it is critical that the same basic event ID is used both in the support system modeling and in the initiator fault tree.*** FV importance is calculated on a *basic event* level, and the use of different IDs would result in the full contribution of a failure mode to FV not being captured. This would necessitate adding the contributions manually.

If different basic event probabilities UR_c and UR_{ie} are used because of different mission times for the same component failure mode, addition of the FV for the support system aspect to the FV contribution from the initiator fault tree would give consistent and correct results. In theory, it is the Birnbaums (= CDF * FV/UR) that are directly additive. But in the fundamental expression for URI shown below, if UR is proportional to the mission time via a fail-to-run expression λT, then the increase in the denominator is cancelled by the increase in the term in the parenthesis. Birnbaum is preserved by adding the FV values in this situation.

$$URI = CDF_P \sum_{j=1}^{m} \left[\frac{FV_{URcj}}{UR_{pcj}} \right]_{\max} (UR_{Bcj} - UR_{BLcj})$$

Assuming that no initiator fault trees exist, it is possible to avoid the need to include the contribution of initiators to FV, as shown in the third diamond of Figure H.1. Analysis of pumps and valves indicate that a component with a Birnbaum of 1E-6/yr typically contributes of the order of 1E-9 to 1E-8/yr to delta URI. Even if the inclusion of the contribution of the initiator to FV could increase the Birnbaum and hence delta URI by an order of magnitude, it still would make the component a relatively insignificant contributor to the overall system MSPI. Hence, if all CCW/SWS components to be monitored in the MSPI have their Birnbaum (maximum for all failure modes) less than 1E-6/yr, then it is not necessary to take further action. Only if none of the above conditions are met is it necessary to account for the contribution of initiators to FV.

In the proposed resolution (the rectangle of Figure H.1), licensees would be given two options. Those plant PRA models that do not use fault trees for loss of service water and/or loss of component cooling water could either a) add such fault trees and recalculate the FV importance measures, or b) use an approximation that adjusts the FV to account for the contribution in a way proportional to the importance of the system initiator to core damage frequency, and proportional to the importance of the component within the system. Presumably, if numerous components within CCW and/or SWS are impacted, creating new initiator fault trees may well be the preferred way to proceed. In this process, care must be taken to account for all basic events associated with a component since the identifiers for these events could be different between the initiating event fault tree and the mitigating system fault tree. The fault trees would have to adequately include the potential contribution from common-cause events, as seen through industry operating experience.

H.4 Alternate Approach to Calculate FV for Support System Initiators

Now presume that only two components in all of the CCW or SWS system are shown to have Birnbaums greater than 1E-6/yr. Why should it be necessary to create entirely new initiator fault trees when most of the components would have no impact on the calculated system URI (and MSPI)? Since the MSPI algorithm relies only on inputted FV/UR, an adjustment to two FVs is all that is called for. As discussed above, the adjustment is based on

- the proportionality of the importance of the system initiator to CDF, and
- the proportionality of the importance of the component to the system.

Mathematically,

- Let FV_{ie} be the Fussell-Vesely contribution for the initiating event in question (e.g. loss of service water).
- Let FV_{sc} be the Fussell-Vesely *within the system fault tree only* for component c (i.e. the ratio of the sum of the cut sets contribution in which that component appears to the overall system failure probability).
- Let FV_c be the Fussell-Vesely for CDF for component c as calculated from the PRA Model. This does not include any contribution from initiating events.

The adjusted FV to include in the MSPI is then

$$FV_c + [FV_{ie} * FV_{sc}] \qquad \text{(eq. H.1)}$$

To assess the accuracy of this approximation, several licensees compared the adjusted FV for a dozen or so SWS and CCW components to the correct FV as computed within the PRA model. The results are provided Figure H.2. This adjustment is shown to be conservative, yielding from zero to approximately 25% higher FV (based on regression analysis) than would be expected using an initiator fault tree. These differences in results arise because of differences in success criteria and recovery actions in the initiator tree, whereas less credit is often given in the support system fault tree model. Hence the approach is conservative. Given this potential conservatism in the approximation to adjust the FV, licensees may well choose to develop initiator fault trees for loss of service water and loss of component cooling water for the purpose of the MSPI.

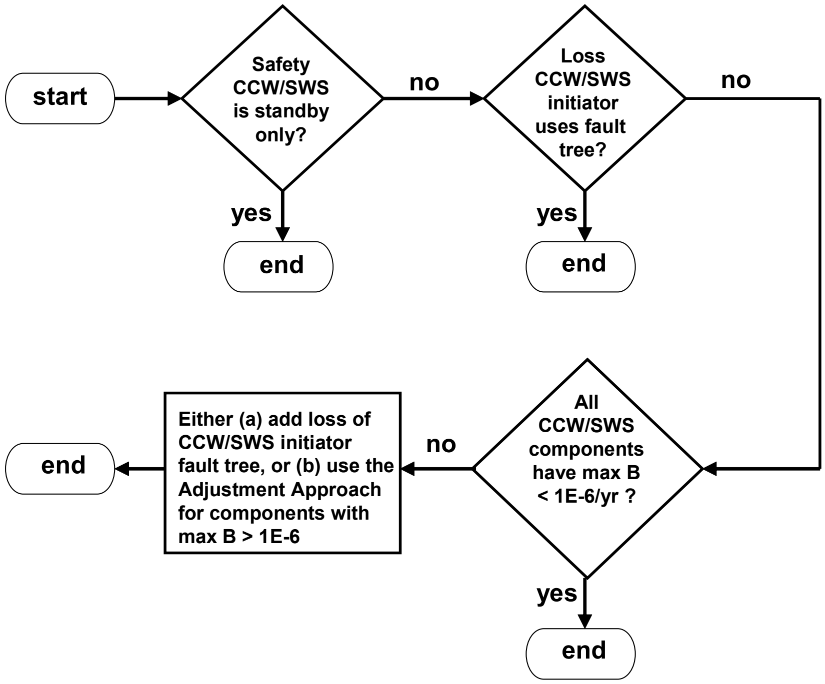

Figure H.1 Flow Chart for Support System Initiators

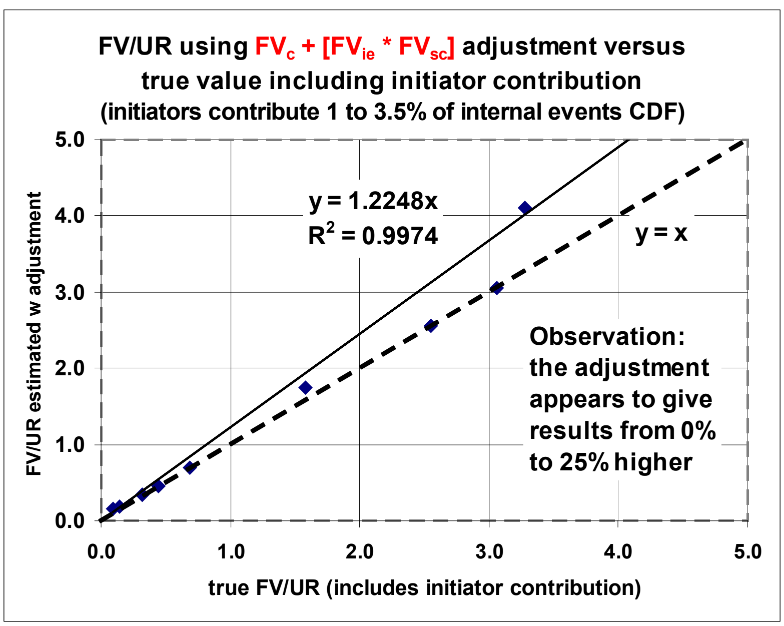

Figure H.2 Comparison of Approximation to Exact Solution

APPENDIX I. MSPI/SSU/SDP BENCHMARK

Appendix I
MSPI/SSU/SDP Benchmark

I.1 Introduction

To assess the characteristics of the Mitigating Systems Performance Index (MSPI), comparisons were made with corresponding Reactor Oversight Process (ROP) Safety System Unavailability (SSU) indicators and Significance Determination Process (SDP) evaluations to the extent possible. The limitations of this comparison are recognized in that the MSPI and SSU indicators are based on aggregate quarterly measures using rolling three-year base periods, whereas the SDP evaluations are for single events. The comparisons focus on the performance color predictions (GREEN, WHITE, YELLOW, or RED) from each of these different measures. Two different comparisons were made:

- MSPI indicators for each of the component failures identified in the MSPI pilot program over the period 2000 – 2002 (and corresponding SSU and SDP results)

- SSU and SDP mitigating system non-GREEN evaluations over the period 2000 – 2002 (and corresponding MSPI results).

I.2 Sources of Information

For the MSPI data and results, spreadsheets based on an NEI template were submitted by each of the MSPI pilot plants. There were a total of seventy-seven component failures over the period 2000 – 2002 for monitored components at the twenty pilot plants. The spreadsheets automatically calculate the MSPI delta core damage frequency (ΔCDF) results for each system, given the component performance data and train unavailability data over a three-year period. These calculations use the plant CDF and component and train Fussell-Vesely importance measures obtained from the plant probabilistic risk assessment (PRA) model. However, the component unreliability baselines built into the spreadsheets were replaced by the "Year 2000" baselines recommended in Appendix C of this report.

SSU performance indicator results were obtained from the Nuclear Regulatory Commission (NRC) website (Ref. I.1) under the "Historical Performance for Previous Quarters" page. This included both train unavailability data and the resulting color.

Finally, SDP evaluation information was obtained from two sources. To identify SDP evaluations related to the MSPI component failures, the same NRC website was used. Under the "Historical Performance for Previous Quarters" page, individual plant inspection findings by quarter were reviewed. These findings listed corresponding inspection report numbers. Then the "List of Inspection Reports" page was used to obtain actual inspection reports. These reports were reviewed to see if SDP evaluation results were referenced. Also, to identify the SDP non-GREEN findings over the period 2000 – 2002, previous work performed in Ref. I.2 was used. Table 1 from that report listed the SDP WHITE findings.

I.3 MSPI Component Failure Comparison

The MSPI covers six mitigating systems and five indicators: emergency ac power (EAC), high-pressure injection (HPI), heat removal system (HRS), residual heat removal (RHR), and service water system/component cooling water (SWS/CCW). Within each of these systems, a subset of components is included within the scope of the MSPI, and performance of these components is tracked and reported quarterly. For the period 2000 – 2002 (termed the 4Q2002 data period), the twenty MSPI pilot plants identified seventy-seven failures of monitored components. These failures are listed in Table I.1, along with the quarter in which the failure occurred.

For each MSPI component failure in Table I.1, a corresponding MSPI ΔCDF was determined using the NEI spreadsheet (with the "Year 2000" baselines). The MSPI methodology uses a rolling three-year period of data in its calculation routine. This implies that if a failure occurred in 4Q2000, then data over the period 1998 – 2000 would normally be used. However, data before 3Q1999 are not available within the spreadsheets. Therefore, for consistency, all of the MSPI calculations presented in Table I.1 were performed using data over the period 2000 – 2002 (4Q2002 results). These data include monitored component performance (failures and demands or hours) and train unavailability hours and required (i.e. reactor critical) hours.

If a system includes more than one failure, then the failures are listed chronologically by quarter in Table I.1. The MSPI calculation for a given system includes all of the component failures down to the one in question. As an example, consider Braidwood 1 HRS in Table I.1. The MSPI calculation for the first failure (DDP FTR, 2Q2001) includes only that failure. However, the MSPI calculation for the second failure (DDP FTS, 4Q2001) includes both failures. Finally, the MSPI calculation for the third failure (DDP FTS, 1Q2002) includes all three failures. This calculation approach mimics the MSPI calculations performed on a quarterly basis, except that for the other components (all with no failures) and trains within the system, the performance data are always based on 2000 – 2002, rather than on a rolling three-year period.

A special case for multiple component failures in the same system involves several failures occurring within a single quarter. In that case, the MSPI calculation for each of those failures includes all of the failures occurring within that quarter (and also system failures occurring before that quarter). That situation occurs for Hope Creek EAC for 4Q2002, where two EDG FTSs occurred. The MSPI calculation for each of those two failures includes both EDG FTSs within that quarter, plus the four EDG failures occurring before 4Q2002. Because of several cases with multiple failures within one quarter, the seventy-seven MSPI failures actually correspond to sixty-four MSPI quarterly indicators.

Finally, there is the potential for a component failure to result in a GREEN MSPI for the quarter in which the failure occurred, and yet result in a WHITE in a succeeding quarter (with no additional component failures) because of larger than expected train unavailability. This is observed with the Hope Creek HPI MOV FTO/C event in 2Q2001. The MSPI for that quarter and successive quarters up through 2Q2002 is GREEN. However, the indication for the next quarter, 3Q2002, results in a WHITE because of a relatively large train unavailability outage during 3Q2002. Although this type of multiple quarter MSPI calculation was not performed formally for all of the seventy-seven MSPI failures, the failures with large unreliability contributions to the MSPI were reviewed to identify quarters with large unavailability contributions. No cases other than the Hope Creek HPI indicator were identified.

MSPI results (ΔCDF and color) for the seventy-seven component failures are presented in Table I.1. Eight of the seventy-seven cases result in a WHITE indication (including the Hope Creek HPI failure discussed previously), while the remaining sixty-nine are GREEN. In terms of the more meaningful MSPI quarterly indicators, five of the sixty-four quarterly evaluations are WHITE, while fifty-nine are GREEN.

If the proposed *frontstop* outlined in Appendix D of this report were applied, then only two failures (out of seventy-seven) result in a WHITE color – Braidwood 1 HRS (DDP FTS, 1Q2002) and Hope Creek HPI (MOV FTO/C 2Q2002 but evaluated through 3Q2002). The other six failures with WHITE indications revert to GREEN. In terms of MSPI quarterly calculations, only two of sixty-four are WHITE.

Table I.1 also shows the corresponding SSU results, in terms of the unplanned outage and fault exposure times, the unavailability value (expressed as a percent), and the color. Because the SSU does not include SWS/CCW, the SSU results are listed as "N/A" for MSPI failures occurring within these systems. There are a total of fifty-five SSU entries in Table I.1 not labeled as "N/A" (counting only one entry for the Hope Creek HPI event). Of these fifty-five entries, nine are WHITE and forty-six are GREEN. These fifty-five entries correspond with forty-seven quarterly indicators, again because of multiple failures occurring within a single quarter. Of the forty-seven quarterly indicators, eight are WHITE and thirty-nine are GREEN.

Of the fifty-five MSPI component failures not occurring in SWS/CCW, there are seven cases where the MSPI calculation is GREEN while the SSU is WHITE. Also, there are six cases where the MSPI calculation is WHITE while the SSU is GREEN. In terms of the sixty-four MSPI quarterly indicators, there are six cases where the MSPI value is GREEN while the SSU is WHITE, and three cases where the MSPI is WHITE while the SSU is GREEN.

Note that if the proposed frontstop were applied, then there are eight cases where the MSPI calculation is GREEN while the SSU is WHITE. Also, there is one case where the MSPI is WHITE and the SSU is GREEN. In terms of the sixty-four MSPI quarterly indicators, there are seven cases where the MSPI evaluation is GREEN while the SSU is WHITE, and one case where the MSPI is WHITE and the SSU is GREEN.

Finally, Table I.1 shows the corresponding SDP evaluation results that were reported in inspection reports. Of the seventy-seven MSPI failures, SDP evaluations mentioned in the inspection reports covered sixteen of the failures. Of these sixteen, two are WHITE. This indicates that overall the SDP methodology resulted in two WHITES and seventy-five GREENS or no SDP finding for the seventy-seven MSPI failures. This is in comparison to the MSPI calculations, in which eight of seventy-seven are WHITE. If the front stop is applied, then the MSPI calculations result in two WHITES out of seventy-seven MSPI failures.

Comparing individual component failure results, there is one failure where the MSPI is GREEN while the SDP is WHITE (Millstone 2 HRS). Also, there are seven failures where the MSPI is WHITE and the SDP is GREEN (or no SDP finding). If the frontstop is applied, then there are two failures where the MSPI is GREEN and the SDP is WHITE (Millstone 2 HRS and Salem 1 EAC, EDG FTR, 3Q2002), and there are two failures where the MSPI is WHITE and the SDP is GREEN or there is no SDP finding (Braidwood 1 HRS, DDP FTS, 1Q2002 and Hope Creek HPI, MOV FTO/C, 2Q2002 but also evaluated for 3Q2002).

Finally, the MSPI results in Table I.1 were reviewed to determine whether any color changes might occur if the proposed common-cause failure (CCF) adjustments to component Fussell-Vesely importances were used. These adjustments are discussed in Appendix F of this report. Including CCF adjustments could change the numerical results in Table I.1, and the quarter in which some indicators become WHITE. But only in one case might the inclusion of CCF affect the overall color outcome (Surry-1 SWS/CCW may become WHITE), and here the case is borderline and dependent on the PRA model used and the CCF method applied.

I.4 SSU and SDP Whites Comparison

The other comparison covers SSU and SDP WHITES identified over the period 2000 – 2002 for the six MSPI systems within the twenty MSPI pilot plants. Only one SSU WHITE during the period 2000-2002 is not listed in Table I.1. That SSU is listed in Table I.2. The SSU WHITE at Millstone-2 for HPI (3Q2000) was the result of a component condition identified during periodic testing. However, an actual failure did not occur during testing. Therefore, the MSPI is not applicable for this event. The SDP evaluation for this event resulted in GREEN, as noted in Table I.2.

As indicated in Section I.2, the SDP WHITES were identified in Ref. I.2. However, that report did not include the Salem 1 EAC EDG FTR event, which was finally classified as an SDP WHITE in May of 2003. This event is included in the comparison for completeness. Overall, there were six SDP WHITES identified. Two are listed in Table I.1. However, four of these SDPs cover component failures or discovered conditions that are outside the scope of the MSPI. These four events are listed in Table I.2. For these events, the SDP evaluations would be used for assessing their safety significance per the guidelines. Of the remaining two events (listed in Table I.1), the MSPI results without the frontstop are WHITE (agreeing with the SDP) for the Salem 1 EAC EDG FTR event and GREEN for the other (Millstone 2 HRS). With the frontstop applied, both of the MSPI results are GREEN.

For the SSU, two of the six events are not applicable because they cover the SWS/CCW (not explicitly within the scope of the SSU). Of the remaining four events, the SSU results include two WHITES (agreeing with the SDP) and two GREENS.

I.5 Summary of Comparisons

Seventy-seven MSPI component failures occurred during the period 2000 – 2002, corresponding to sixty-four quarterly MSPI indicators (because of multiple failures occurring within a single quarter). For these seventy-seven failures, the MSPI calculations result in eight WHITES and sixty-nine GREENS. If the proposed frontstop were used, then there are two WHITES and seventy-five GREENS. In terms of the sixty-four quarterly MSPI indicators, five result in WHITE, while fifty-nine are GREEN. With the proposed frontstop, two are WHITE and sixty-two are GREEN. *However, because some WHITE MSPI indicators remain so for more than one quarter, the number of unique WHITE MSPI indicators for the twenty pilot plants over the three years is four without the frontstop and two with the frontstop.* The unique number of WHITES is important to note because increased regulatory attention would probably occur only once for consecutive quarterly WHITE indicators on the same system.

For the SSU, fifty-five of the MSPI component failures are applicable (excluding SWS/CCW failures). The SSU results for these fifty-five failures include nine WHITES and forty-six GREENS. In terms of quarterly indicators, there are eight WHITES and thirty-nine GREENS. *Because some WHITE indicators remain so through several consecutive quarters, the number of unique WHITE SSU indicators is five.*

Finally, corresponding SDP evaluations indicate two WHITES and seventy-five GREENS (or no SDP findings) for the seventy-seven MSPI component failures. Similarly, the MSPI results indicate two WHITES and seventy-five GREENS or no SDP findings (with the proposed frontstop). But the MSPI WHITES are for Braidwood 1 HRS and Hope Creek HPI, while the two SDP WHITES are for Millstone 2 HRS and Salem 1 EAC.

I.6 Analysis of Results

This section provides a detailed analysis of the WHITE indications, as well as near-WHITE and GREEN MSPI indications where there were a significant number of component failures.

Braidwood-1 HRS

From the 2nd quarter of 2001 through the 1st quarter of 2002, there were three failures of the diesel-driven AFW pump (DDP). Analysis indicates that given the number of demands and run-hours over the three-year measurement interval, the expected number of failures of the DDP is approximately 1. The MSPI was GREEN for the first failure. The second failure indicated WHITE absent the use of the frontstop, but with the frontstop would be GREEN. This is consistent with the discussion in Section 6.2 and Appendix D whereby one failure more than baseline or expectation should not result in WHITE indication (N to N+1 issue). The third failure resulted in WHITE indication regardless whether or not the frontstop was applied. During and shortly after this time frame, UAI contribution was significant, of the order of 3E-7 to 7E-7. Thus, the WHITE MSPI indication resulted from a combination of multiple failures and large unavailability some of which accompanied those failures. It is concluded that this WHITE indication is valid, and that the MSPI performed as intended.

The SSU indicated WHITE owing to the use of a large fault exposure time of 335.8 hours as a surrogate for not directly accounting for reliability. The corresponding average system unavailability of 2.3% exceeded the generic threshold of 2.0%, thus accounting for the WHITE. It should be noted that the generic threshold of 2.0% does not recognize the fact that the Braidwood design has only two AFW pumps, compared to many other PWR designs with three, thus making the risk-importance of the pumps at Braidwood relatively higher.

The April 29, 2002 inspection report referred to one finding of “very low safety significance (Green)” because the licensee failed to identify the cause and prevent recurrence from a previous failure.

It is concluded that for this case, the MSPI approach provides the best overall measure of system performance. Both unavailability and unreliability contribute to the measure. The GREEN/WHITE threshold is exceeded based on consideration of plant-specific design features and performance, such as the relative risk-importance of the diesel-driven AFW pump in the licensee’s PRA. The frontstop behaved as intended, and because indication did not turn WHITE until three failures had occurred, the likelihood of *false positive* is low.

Hope Creek EAC

From the 2nd quarter of 2000 through the 4th quarter of 2002, there were six failures of the emergency diesel generators (EDGs) at Hope Creek. The plant design consists of four EDGs plus a back-up gas turbine generator, and thus the relative risk-importance of an EDG failure is low. Analysis indicates that the expected number of failures (with Bayesian updating of failure rates) in the three-year time frame for this system given the number of demands and run-hours to be about 2. The MSPI indication for this period is GREEN regardless of frontstop, with UAI of the order of -5E-7 owing to better-than-baseline unavailability, and the URI varying from 1 to 3 E-7. Sensitivity studies using the recommended generic common-cause failure (CCF) multiplier of 1.5 per Appendix F for this design configuration indicate that the inclusion of CCF would not change the color indication.

The SSU is also GREEN in this time frame. The average train unavailability reached 1.9%. The SSU does not account for the plant-specific design configuration in so far as the GREEN/WHITE threshold. The threshold is 2.5% regardless of whether there are 2 EDGs or 4 EDGs plus diverse backup power. Thus the MSPI approach is preferred in this regard. The SDP evaluations also indicated GREEN.

It is concluded that the MSPI, SSU, and SDP indication results are in congruence. Because the MSPI specifically accounts for a) unreliability and unavailability contribution to overall risk, and b) plant-specific design features including the number and relative risk-importance of the emergency and back-up power supplies, the MSPI provides the best overall measure of integrated system performance.

Hope Creek HPI

From 3rd quarter 2000 through 2nd quarter of 2001, there were three MOV failures on the high pressure coolant injection (HPCI) system compared to an expected number of failures much less than 1. These failures corresponded to URI of the order of 8E-7. In the 3rd quarter of 2002, about 92 hours of train unavailability along with unavailability from previous quarters was sufficient to result in UAI above 2E-7, thus placing the overall MSPI just above 1E-6 (WHITE).

The SSU on the other hand peaked at about 1.7%, quite distant from the generic BWR HPCI GREEN/WHITE threshold of 4%. The fact that there was no large fault exposure hours contributing to the SSU measurement explains the GREEN SSU indication. Indeed, analysis of all the WHITE SSUs for the MSPI pilot plants indicate it is always the case that large fault exposure times are the main reasons why indication is WHITE. Finally, there were no SDP evaluations associated with these MOV failures.

It is concluded that for this case, the MSPI approach provides the best overall measure of system performance. Both unavailability and unreliability contribute to the measure. The GREEN/WHITE threshold is exceeded based on consideration of plant-specific design features and performance, such as the relative risk-importance of the HPCI MOVs. There is sufficient margin between the actual number of failures in the system (three) and expected number (a fraction of one) to conclude that there is low likelihood that this particular positive indication is a *false positive* indication. Moreover, the SSU approach failed to account for the reliability contribution to system performance – a significant deficiency in the approach. Apparently, because the MOV failures were not deemed to be the result of a licensee performance deficiency, no SDP evaluation was performed. Since it is believed that the MSPI result is a valid signal of a licensee performance issue that was identified by neither the SDP (no apparent performance issue) nor the SSU (not much fault exposure time), this appears to be an instance of *false negative* on the part of the current ROP approach.

Millstone-2 HRS

On September 20, 2000 the turbine-driven AFW pump (TDP) failed during the normal surveillance test. The MSPI indicated that the unavailabilities of the three trains of AFW during the three-year interval of the pilot were much better than baseline for the two motor-driven pump (MDP) trains, and about baseline for the TDP. The expected number of failures of components within the system would have been about 1 over the three years of the pilot. That is, reliability was about at-baseline on average. The net result is an MSPI value of the order of -4E-7 (GREEN). This negative value is exactly as intended, allowing the risk-weighted contribution of better-than-baseline performance of the MDPs to more than offset the near-baseline performance of the TDP in the overall measure of system performance.

The SSU for this quarter was 2.7%, i.e. above the generic 2.0% GREEN/WHITE threshold. The SSU had jumped from 0.4% in the previous quarter to 2.7% owing to over 670 hours of assumed fault exposure time associated with the TDP failure. Since the SSU does not directly account for reliability, fault exposure time is used as a surrogate. In this case, the application of the large fault exposure time in conjunction with a generic, non-risk informed GREEN/WHITE threshold results in WHITE indication. The discussion above describes how the MSPI for this system found the MDP trains to have better than baseline unavailability, and the TDP train to be about at baseline. The baseline unavailabilities are based on industry average unplanned unavailability from ROP data for 1999 through 2001. The planned unavailabilities are based on plant-specific values for period 1999 through 2001. A review of the baseline unavailabilities for Millstone-2 indicates that while they are higher than industry average, they are within the range of the norm (less than one standard deviation). If so, then it can not be concluded that the average AFW system unavailability for Millstone-2 is indicative of degraded performance. The SSU WHITE indication is the result of not appropriately accounting for reliability, inappropriate use of fault exposure time as a surrogate for reliability, and the use of a generic, non-risk informed threshold.

The SDP evaluation for the TDP failure in question was identified as WHITE. This came about from an originally assumed T/2 fault exposure time of 14 days. (The fault exposure time was later revised in the SSU to a full T or 28 days when the cause of the failure was identified). As a measure of overall system performance, can a single failure of the TDP in the three-year period be indicative of degraded system performance? Viewed from a different perspective, there were fifty-two TDP start demands in the three-year measurement period of the pilot. Assuming an industry-averaged failure-to-start rate of 9E-3 per demand, the expected number of failures of the pump would have been 0.47. The one failure of the TDP is not inconsistent with this expectation. Assuming a constant rate of pump testing and operation, the mean-time-to-failure of the TDP would have been about six years. The last functional failure of the TDP was over a decade ago (1989). Thus, even accounting for the extended plant shutdown in the late 1990s, the TDP reliability performance is consistent with industry norm.

It is concluded that for this case, the MSPI approach provides the best overall measure of integrated system performance. Both unavailability and unreliability contribute to the measure commensurate with the relative risk-importance of these two elements. System unavailability is within the norm, and the reliability of the TDP is consistent with the industry norm as well when measured over a time period consistent with most PRA models. Given a single failure, the likelihood that the MSPI is giving *false negative* indication is low. Rather, the inappropriate use of fault exposure time in the SSU as a surrogate for reliability, and the small time window of observation regarding the performance of the TDP in the SDP, are the primary reasons why SDP and SSU appear to give *false positive* indication from an integrated system performance perspective.

<u>Palo Verde-2 HRS</u>
In the 4th quarter of 2000, there was a single failure of the motor-driven AFW pump to start. Because of the high risk-importance of the pump, the MSPI without the backstop was calculated to be about 3E-6 (WHITE). The UAI contribution during the period of the pilot (calendar year 2002) varied between about 2E-7 and 5E-7. The application of the frontstop reduced the overall MSPI to about 4E-7 (GREEN) in the 4th quarter 2002, absent any inclusion of CCF effects. A sensitivity study indicated that the inclusion of CCF would not change the color indication. Should a second failure occur within the AFW system in the three-year interval, the MSPI would very likely become WHITE (hence, a designation of near-WHITE). This is exactly as intended,

based on the principle that because of the high likelihood of *false positive* indication, a single failure of a component in a three-year interval, all other parameters at baseline, should not result in WHITE indication. In fact, the expected number of failures within the AFW system given the number of demands and run-hours in the three-year interval is about 0.4, so an actual single failure would not be representative of degraded system performance.

The SSU for AFW was 0.5% (GREEN), with no fault exposure hours. This is distant from the 2.0% generic GREEN/WHITE threshold. There was no documented SDP evaluation.

It is concluded that for this case, the MSPI approach provides the best overall measure of system performance. Both unavailability and unreliability contribute to the measure. The frontstop performed as intended by minimizing the likelihood of *false positive.* One additional failure within the system over three years, or additional system unavailability beyond baseline, could potentially result in WHITE indication. Because the MSPI (with the frontstop) and the SSU results were both GREEN, and because the one actual failure is consistent with the expected number, it is judged that the likelihood of a *false negative* on the part of the MSPI in this case is low.

<u>Palo Verde-3 HPI</u>
From 1st quarter 2000 through 4th quarter of 2001, there were two MOV failures in the high pressure safety injection system. System unavailability in this time frame was near baseline. The expected number of failures of components in the system in the three-year interval is about 0.3. But because these valves had relatively low risk-importance (factors of five to ten lower than the pumps), the MSPI remained far below the GREEN/WHITE threshold, as expected.

The SSU in the first quarter of 2000 when the first MOV failure occurred was 3.0% (WHITE), double the generic threshold of 1.5%. All of this can be attributed to an assumed T/2 fault exposure time of 984.14 hours owing to quarterly surveillance. It should be noted that because of issues associated with the use of T/2 fault exposure time as a surrogate for reliability, the use of T/2 in the SSU was discontinued in January 2002. Thus, had this MOV failure occurred some two years later, indication would have been GREEN rather than WHITE.

A supplemental inspection resulted from the PI, but there were no SDP evaluations associated with the two MOV failures.

It is concluded that for this case, the MSPI approach provides the best overall measure of system performance. Both unavailability and unreliability are accounted for. Unavailability of the system was near baseline. The two MOV failures were of low-risk importance, and the MSPI properly accounted for this plant-specific feature in the calculation. On the other hand, the SSU only resulted in WHITE indication because of the use of T/2 fault exposure time, a practice that was later discontinued.

<u>Salem-1 EAC</u>
During the 3rd quarter of 2002, there were four failures of the emergency diesel generators (EDG). Three of the failures were classified as failures-to-load/run (failure in less than one hour of running after successful start), and one as failure-to-run (run failure beyond one hour). Without the frontstop, the MSPI was calculated to be about 3E-6 (WHITE). With the frontstop, the MSPI was around 8E-7, or near-WHITE. Inclusion of CCF would not significantly alter these results. The expected number of failures (N) is calculated to be about 2.3. Sensitivity studies indicate that the MSPI would become WHITE either on a) one additional EDG failure (of any mode) through the 2nd quarter of 2005, or b) a total of about 40 hours of additional EDG

unavailability in the three-year measurement period along with the four actual failures. In addition, the MSPI is found to be somewhat sensitive to the mode of failure of the emergency diesel generators. A sensitivity study found that had one of the failures been a failure-to-run rather than a failure-to-load/run, the MSPI would have been WHITE with or without the frontstop. Hence, the MSPI could become WHITE on four failures with additional unavailability or a different set of failure modes, or five failures at most. This is not inconsistent with the N to N+1 principle but does illustrate the importance of classifying the failure mode. The frontstop generally had the intended effect of precluding WHITE indication on one failure more than baseline (N+1), while N+2 failures likely would indicate WHITE except for some unique combination of failure modes, whereby it would be WHITE just under N+3.

The SSU for this quarter was 1.5% (GREEN), compared to the generic GREEN/WHITE threshold of 2.5%. It should be noted that the fault exposure time of about 88 hours in the SSU was relatively low. On the other hand, the SDP evaluation associated with the September 13, 2002 failure of the turbocharger resulted in WHITE indication based on 283 hours of fault exposure time.

The results for this case amplify the differences in approach between the three measures. On one hand, the failure to properly account for unreliability resulted in underestimating the risk-impact of the EDG outages and a GREEN performance indication on the part of the SSU. On the other hand, the WHITE SDP evaluation was based on the risk impact of a single EDG failure event with a 12-day estimated fault exposure time. It should be noted that twelve days is less than the Allowed Outage Time of 14 days in the Technical Specifications for emergency diesel generators for several nuclear power plants. If nothing else, this seeming contradiction demonstrates the issues associated with using a short time horizon for component unavailability or fault exposure time in the SDP in contrast to risk assessments that use a longer time horizon to dampen the volatility associated with a single outage or event. In this regard, it is judged that the MSPI best accounted for the unreliability and unavailability contributions to system performance through the use of a three-year period that is better-suited to minimizing *false positive* and *false negative* indication.

San Onofre-2 SWS/CCW

From 1st quarter 2001 through 4th quarter 2002, there were six failures of the motor-driven salt water (service water) pumps. The MSPI for this system was near baseline owing to the balancing of unreliability and unavailability. However, the “backstop” for this component based on the plant-specific number of demands and run-hours, and the use of generic industry failure rates, is 7. Thus, the MSPI is a near-WHITE. One additional failure over the three-year performance measurement period would result in WHITE indication. This is as intended, and illustrates the application of the “backstop” concept in identifying statistically-significant departure of component performance from the industry norm.

There is no equivalent SSU because the cooling water support systems are not part of the current ROP. The service water cooling pump failures did not cascade sufficiently so as to cause WHITE indication. There were no SDP evaluations reported for these failures.

It is concluded that for this case, the MSPI approach provides the best overall measure of integrated system performance. Both unavailability and unreliability contribute to the measure commensurate with the relative risk-importance of these two elements. The “backstop” in this case was nearly invoked, and is appropriate for indicating statistically-significant departure from the norm.

Additional SSU WHITE Indicators

In addition to the WHITE SSU indicators discussed above, there were three other cases for which the MSPIs were GREEN, and the SDP evaluations were either GREEN or there were no SDP findings:

- Surry-1 EAC: Four failures of the EDGs between 3rd quarter 2000 and 4th quarter 2002. Fault exposure time was 238 hours. SDP evaluation was GREEN.
- Surry-2 EAC: Five failures of the EDGs between 3rd quarter 2000 and 4th quarter 2001 (some of the failures are common to Surry-1). Fault exposure time was 336 hours. SDP evaluation was GREEN.

These WHITE indicators were the result of the inappropriate use of fault exposure time as a surrogate for unreliability in the SSU. It is concluded that the MSPI approach provides the best overall measure of integrated system performance. Both unavailability and unreliability contribute to the measure commensurate with the relative risk-importance of these two elements.

Additional Non-GREEN Indicators Out-of-Scope of MSPI

Table I.2 identifies additional non-GREEN SSU or SDP evaluations:

- Millstone-2 HPI: Failure of the motor-driven pump in the 3rd quarter of 2000. Fault exposure time was 654 hours. SDP evaluation was GREEN.
- Prairie Island-1 and 2 SWS/CCW: In the 4th quarter of 2000, the pumps were declared inoperable because of a design condition with non-safety related power supply to the back-flush system for cooling and lubrication. The SDP evaluation was WHITE.
- Surry-1 and 2 EAC: In the 2nd quarter of 2001, a degraded condition was identified on the EDGs whereby failed piston rings would have caused the diesel not to meet its mission time. The SSU was WHITE on Unit 2 owing to over 500 hours of fault exposure time. The initial SDP evaluation was WHITE, although a revised assessment of the fault exposure time may indicate YELLOW.

None of these cases were within the scope of the MSPI. The guidelines states that "conditions not capable of being discovered during normal surveillance tests" are not within scope of the MSPI, and the inspection process would be applicable. Thus, the WHITE findings for Prairie Island, and the WHITE (possibly YELLOW) results for both Surry units would remain in effect.

Summary

The MSPI, SSU, and SDP use three fundamentally different approaches. The MSPI measures statistically valid risk-informed performance of systems. It accounts for both unreliability and unavailability over a three-year interval. Extensive research has shown that such an interval best minimizes the probability of *false positive* and *false negative* indication. The SSU directly accounts for unavailability averaged over three years, while indirectly attempting to address unreliability through the use of fault exposure time. The use of T/2 fault exposure time was discontinued two years ago because it contributed to arguably *false positive* indications. The SDP, on the other hand, quantifies short-term peak contributions to annual cumulative risk. This is intended to capture excessive risk contributions resulting from performance that is degraded from baseline values.

Recognizing that there are fundamental differences in approach between the MSPI, SDP, and SSU, a comparison was made of these three measures to determine whether there was overall congruence in the results. In this regard, seventy-seven failures over three years as reported in the MSPI program for all pilot plants were analyzed. The quarterly indication results for the MSPI that were measurably impacted by the failures were compared to the equivalent SSU performance indication as appropriate. When an SDP finding was available for the failure in question, these results were also compared. Not surprisingly, the MSPI, SSU and SDP measures were found to be in agreement the vast majority of the time for non-risk significant failures. However, results for non-GREEN findings and indications were mixed.

Four of the five WHITE or near-WHITE MSPI indications discussed above involved multiple failures and substantial unavailability contribution that, in combination, provided a high degree of confidence that system performance was at or near the point of degradation. A fifth near-WHITE was the result of multiple failures approaching the backstop, indicating pump performance bordered on statistically significant departure from industry norm.

All of the SSU non-GREEN indications were driven almost entirely by the use of fault exposure time as a surrogate for a valid reliability calculation. In one case, the indicator had turned WHITE on T/2 fault exposure time before that approach was discontinued, otherwise it would have indicated GREEN.

Of the WHITE SDP evaluations, one involved a single failure corresponding to a mean-time-to-failure based on historical performance no different than the industry norm - a high likelihood of *false positive* indication. The other was on a system for which the SSU indicated WHITE and the MSPI indicated a near-WHITE measure, thus possibly valid indication. But it should be noted that the fault exposure time used in the SDP risk calculation was no different than the Allowed Outage Time for the same component at many other plants. Several other non-GREEN SDP evaluations were on conditions which are out-of-scope of the MSPI, and the proposed process would default to the current inspection process and the non-GREEN findings would be applied.

Of all three measures, it is concluded that the MSPI appears to consistently provide the best overall measure of integrated system performance, while minimizing both *false positive* and *false negative* likelihoods.

I.7 References

I.1 U.S. Nuclear Regulatory Commission, http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/index.html .

I.2 J. R. Houghton and M. R. Harper, Operating Experience Risk Analysis Branch, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, “ROP Baseline Inspection Findings Summary, SDP, ASP, and Current PI Comparison for Applicability to MSPI,” July 2003

Table I.1 MSPI/SSU/SDP Comparison for MSPI Failures

Plant	System	Failure	Date	MSPI		SSU				SDP		Comments
				Delta CDF (1/y) (4Q2002 Data) (note 1)	Color (note 2)	Unplanned Outage Time (h)	Fault Exposure Time (h)	Result	Color	Failure Mentioned in Inspection Report?	SDP Color Indicated in Inspection Report (note 3)	
Braidwood 1	EAC	EDG FTS	1Q2000	-9.60E-08	Green	18.3	7.4	0.40%	Green	None		
	HPI	MOV FTO/C	3Q2001	4.39E-08	Green	35.2	0	0.60%	Green	2001010	Green	SDP result from Phase 2 analysis.
	HRS	DDP FTR	2Q2001	3.84E-07	Green	0	155.9	1.50%	Green	None		MSPI using 1 FTR
		DDP FTS	4Q2001	1.33E-06	White (Green)	0	335.8	2.30%	White	2002004	Green	MSPI using 1 FTR and 1 FTS. SDP result from Phase 1 analysis.
		DDP FTS	1Q2002	2.28E-06	White	68.6	0	2.50%	White	2002004	Green	MSPI using 1 FTR and 2 FTS. SDP result from Phase 1 analysis.
Braidwood 2	EAC	EDG FTLR	1Q2002	-1.63E-07	Green	11.7	0	0.30%	Green	2002007	Green	SDP result from Phase 1 analysis.
	HPI	AOV FTO/C	2Q2001	-2.00E-08	Green	0	0	0.80%	Green	None		
	HRS	DDP FTR	4Q2000	1.22E-07	Green	0	8.7	0.50%	Green	None		
	RHR	MDP FTR	4Q2001	1.71E-07	Green	0	0	0.60%	Green	2001013	Green	Event occurred during process of placing shutdown cooling in service. SDP result from Phase 1 analysis.
Hope Creek	EAC	EDG FTR	2Q2000	-5.23E-07	Green	11.2	336	1.40%	Green	2001012?	Green	MSPI using 1 FTR. MSPI UA contribution is -4.87E-7. SDP is from Phase 1 analysis.
		EDG FTR	4Q2001	-4.44E-07	Green	36.3	335.5	1.80%	Green	None		MSPI using 2 FTR. MSPI UA contribution is -4.87E-7.
		EDG FTR	1Q2002	-3.66E-07	Green	9.2	0	1.80%	Green	2001012	Green	MSPI using 3 FTR. MSPI UA contribution is -4.87E-7. SDP result from Phase 1 analysis.
		EDG FTR	3Q2002	-2.87E-07	Green	35.3	0	1.90%	Green	None		
		EDG FTS	4Q2002	-1.90E-07	Green	38.7	0	1.90%	Green	None		MSPI using 4 FTR and 2 FTS. MSPI UA contribution is -4.87E-7.
		EDG FTS	4Q2002	-1.90E-07	Green	40.7	0	1.90%	Green	None		MSPI using 4 FTR and 2 FTS. MSPI UA contribution is -4.87E-7.
	HPI	MOV FTO/C	3Q2000	-3.18E-07	Green	22.7	1.3	1.10%	Green	None		MSPI using 1 MOV FTO/C. MSPI UA contribution is -2.81E-7.
		MOV FTO/C	1Q2001	1.22E-07	Green	0	0	1.00%	Green	None		MSPI using 2 MOV FTO/C. MSPI UA contribution is -2.81E-7.
		MOV FTO/C	2Q2001	5.61E-07	Green	0	0	0.70%	Green	None		MSPI using 3 MOV FTO/C. MSPI UA contribution is -2.81E-7.
		(Note 4)	3Q2002	1.05E-06	White (Note 4)	0	0	1.70%	Green	None		MSPI using 3 MOV FTO/C. MSPI UA contribution (3Q2002 data) is 2.1E-7/y.
	HRS	TDP FTS	4Q2002	1.22E-07	Green	0	0	1.50%	Green	None		
	RHR	MOV FTO/C	1Q2000	1.71E-07	Green	14.2	0	1.10%	Green	2000007	Green	Event occurred while supporting HPCI and RCIC surveillances during startup. SDP result from Phase 1 (?) analysis.
	SWS/CCW	MDP FTR	1Q2001	4.32E-08	Green	N/A	N/A	N/A	N/A	2002002	Green	SDP result from Phase 1 (?) analysis.
Millstone 2	HPI	MOV FTO/C	1Q2000	-2.65E-07	Green	0	0	0.40%	Green	None		This failure is also listed under RHR MOV FTO/C. ROP UA hours listed under RHR.
	HRS	TDP FTS	3Q2000	-3.91E-07	Green	30.75	677.5	2.70%	White	2000011	White	SDP result from Phase 2 and Phase 3 analysis. 14-day outage assumed.
	RHR	MOV FTO/C	1Q2000	3.75E-10	Green	11.06	0	0.20%	Green	None		
	SWS/CCW	AOV FTO/C	4Q2002	3.13E-07	Green	N/A	N/A	N/A	N/A	None		
Millstone 3	HPI	MDP FTR	3Q2002	-2.62E-07	Green	0.03	0	1.10%	Green	None		MSPI using 2 MDP FTR.
		MDP FTR	3Q2002	-2.62E-07	Green	7.3	0	1.10%	Green	None		MSPI using 2 MDP FTR.
	SWS/CCW	MDP FTS	2Q2000	1.04E-07	Green	N/A	N/A	N/A	N/A	None		

Note 1 - For system failures occurring within a single quarter, the MSPI evaluation includes all of the failures within the quarter (plus any previous failures).

Note 2 - If the proposed front stop is applied and the resulting color is different, then the color using the front stop is presented in parentheses.

Note 3 - If blank, there was no identified performance deficiency requiring an SDP.

Note 4 - This row was added to show that the MSPI is white using 3Q2002 data (rolling 3-year period), because of a relatively large unavailability during 3Q2002. However, the MSPI returns to green the next quarter, when the 4Q2002 data are used.

Acronyms: AOV (air-operated valve), CDF (core damage frequency), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), FTLR (fail to load and run for 1 hour), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), MSPI (mitigating systems performance index), RHR (residual heat removal system), ROP (reactor oversight process), SDP (significance determination process), SSU (safety system unavailability), SWS/CCW (service water system/component cooling water system), UA (unavailability)

Table I.1 MSPI/SSU/SDP Comparison for MSPI Failures (continued)

Plant	System	Failure	Date	MSPI		SSU				SDP		Comments
				Delta CDF (1/y) (4Q2002 Data) (note 1)	Color (note 2)	Unplanned Outage Time (h)	Fault Exposure Time (h)	Result	Color	Failure Mentioned in Inspection Report?	SDP Color Indicated in Inspection Report (note 3)	
Palo Verde 1	EAC	EDG FTS	2Q2002	1.10E-07	Green	27.92	15.82	0.70%	Green	None		
	HPI	MOV FTO/C	1Q2000	1.90E-09	Green	0	0	1.10%	Green	None		MSPI using 1 MOV FTO/C.
		MOV FTO/C	4Q2000	2.42E-08	Green	0	0	1.10%	Green	None		MSPI using 2 MOV FTO/C.
Palo Verde 2	HPI	MOV FTO/C	4Q2000	1.35E-08	Green	0	29.57	1.10%	Green	None		
	HRS	MDP FTS	4Q2000	3.02E-06	White (Green)	13.97	0	0.50%	Green	None		
Palo Verde 3	EAC	EDG FTR	2Q2000	8.89E-08	Green	0	0	0.50%	Green	2001004	Green	MSPI using 1 EDG FTR. SDP results from Phase 1 (?) analysis.
		EDG FTS	3Q2001	1.79E-07	Green	54.97	312.1	1.30%	Green	2001005		MSPI using 1 EDG FTR and 1 EDG FTS. Failure listed in inspection report (2001005) but no mention of SDP evaluation.
	HPI	MOV FTO/C	1Q2000	1.36E-09	Green	11.47	984.14	3.00%	White	None		MSPI using 1 MOV FTO/C. Supplemental inspection (2000012) conducted because ROP indicator changed to white. No mention of SDP evaluation.
		MOV FTO/C	4Q2001	2.38E-08	Green	0	0	0.80%	Green	None		MSPI using 2 MOV FTO/C.
Prairie Island 1	SWS/CCW	DDP FTS	2Q2002	1.66E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 2 DDP FTS.
		DDP FTS	2Q2002	1.66E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 2 DDP FTS.
		DDP FTS	3Q2002	3.52E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 3 DDP FTS.
Prairie Island 2	EAC	EDG FTLR	1Q2000	-8.66E-09	Green	9.1	340.05	1.50%	Green	None		MSPI using 1 EDG FTLR.
		EDG FTS	4Q2000	1.26E-07	Green	15.17	0	1.50%	Green	None		MSPI using 1 EDG FTLR and 1 EDG FTS.
		EDG FTLR	2Q2001	2.26E-07	Green	199.42	0	1.80%	Green	2001013	Green	MSPI using 2 EDG FTLR and 1 EDG FTS. SDP result from Phase 2 analysis.
		EDG FTS	4Q2001	3.62E-07	Green	79.87	8.78	2.30%	Green	None		MSPI using 2 EDG FTLR and 2 EDG FTS.
	HRS	AOV FTO/C	3Q2001	-1.90E-08	Green	13.97	390.88	1.90%	Green	None		
Salem 1	EAC	EDG FTLR	3Q2002	2.84E-06	White (Green)	103.3	87.8	1.50%	Green	2002010	Green	MSPI using 3 EDG FTLR and 1 FTR.
		EDG FTLR	3Q2002	2.84E-06	White (Green)	103.3	87.8	1.50%	Green	None		MSPI using 3 EDG FTLR and 1 FTR.
		EDG FTLR	3Q2002	2.84E-06	White (Green)	103.3	87.8	1.50%	Green	None		MSPI using 3 EDG FTLR and 1 FTR.
		EDG FTR	3Q2002	2.84E-06	White (Green)	103.3	87.8	1.50%	Green	2002010	White	MSPI using 3 EDG FTLR and 1 FTR. SDP result in May 2003 letter from NRC to utility, referencing the results of a March 26 SERP workshop. EDG 1C unavailable 283 hours.
	HPI	MDP FTR	1Q2000	-8.34E-09	Green	41.1	0	0.60%	Green	None		
	SWS/CCW	MDP FTR	2Q2000	-1.14E-07	Green	N/A	N/A	N/A	N/A	None		
Salem 2	HPI	MDP FTS	1Q2000	4.20E-08	Green	11	0	0.50%	Green	None		
	SWS/CCW	MOV FTO/C	1Q2001	1.44E-07	Green	N/A	N/A	N/A	N/A	2000011		Inspection report 2000011 discusses failure of similar valve (21SW127) in Unit 1 on 1/24/01. For that event, the other HX was already unavailable, so both CCW HXs were unavailable. For this simultaneous outage, the SDP result of green was from a Phase 3 analysis. (Phase 2 workbooks for Salem not available at the time.) The same inspection report describes the Unit 2 failure of 22SW127 on 1/4/01, but does not mention any SDP evaluation.

Note 1 - For system failures occurring within a single quarter, the MSPI evaluation includes all of the failures within the quarter (plus any previous failures).

Note 2 - If the proposed front stop is applied and the resulting color is different, then the color using the front stop is presented in parentheses.

Note 3 - If blank, there was no identified performance deficiency requiring an SDP.

Acronyms: AOV (air-operated valve), CDF (core damage frequency), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), FTLR (fail to load and run for 1 hour), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), MSPI (mitigating systems performance index), RHR (residual heat removal system), ROP (reactor oversight process), SDP (significance determination process), SSU (safety system unavailability), SWS/CCW (service water system/component cooling water system), UA (unavailability)

Table I.1 MSPI/SSU/SDP Comparison for MSPI Failures (continued)

Plant	System	Failure	Date	MSPI		SSU				SDP		Comments
				Delta CDF (1/y) (4Q2002 Data) (note 1)	Color (note 2)	Unplanned Outage Time (h)	Fault Exposure Time (h)	Result	Color	Failure Mentioned in Inspection Report?	SDP Color Indicated in Inspection Report (note 3)	
San Onofre 2	HPI	MDP FTS	3Q2000	-2.05E-08	Green	6.3	0	0.80%	Green	None		
	SWS/CCW	MDP FTR	1Q2001	-2.02E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 1 SWS MDP FTR.
		MDP FTR	4Q2001	-1.64E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 3 SWS MDP FTR.
		MDP FTR	4Q2001	-1.64E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 3 SWS MDP FTR.
		MDP FTR	1Q2002	-1.46E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 4 SWS MDP FTR.
		MDP FTR	4Q2002	-9.53E-08	Green	N/A	N/A	N/A	N/A	None		MSPI using 6 SWS MDP FTR.
		MDP FTR	4Q2002	-9.53E-08	Green	N/A	N/A	N/A	N/A	None		MSPI using 6 SWS MDP FTR.
San Onofre 3	SWS/CCW	MDP FTR	3Q2001	-4.81E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 2 SWS MDP FTR.
		MDP FTR	3Q2001	-4.81E-07	Green	N/A	N/A	N/A	N/A	None		MSPI using 2 SWS MDP FTR.
Surry 1	EAC	EDG FTLR	3Q2000	2.00E-07	Green	83.68	0	1.50%	Green	None		MSPI using 1 EDG FTLR and 1 EDG FTR.
		EDG FTR	3Q2000	2.00E-07	Green	83.68	0	1.50%	Green	None		MSPI using 1 EDG FTLR and 1 EDG FTR.
		EDG FTS	4Q2001	2.96E-07	Green	0.5	237.77	2.70%	White	2001007	Green	MSPI using 1 EDG FTLR, 1 EDG FTR, and 1 EDG FTS. SDP result from Phase 1 (?) analysis.
		EDG FTS	4Q2002	3.91E-07	Green	85.35	0	3.20%	White	None		MSPI using 1 EDG FTLR, 1 EDG FTR, and 2 EDG FTS. ROP/SSU for Unit 2 (EDG shared by both units) is 2.9% and white.
Surry 2	EAC	EDG FTS	3Q2000	4.58E-08	Green	18.94	0	1.80%	Green	None		MSPI using 1 EDG FTS and 1 EDG FTLR.
		EDG FTLR	3Q2000	4.58E-08	Green	18.94	0	1.80%	Green	None		MSPI using 1 EDG FTS and 1 EDG FTLR.
		EDG FTLR	3Q2001	1.31E-07	Green	22.32	336.03	3.10%	White	2002008	Green	MSPI using 1 EDG FTS and 2 EDG FTLR. SDP result from Phase 1 (?) analysis.
		EDG FTLR	4Q2001	4.00E-07	Green	133.15	0	3.20%	White	None		MSPI using 1 EDG FTS and 4 EDG FTLR.
		EDG FTLR	4Q2001	4.00E-07	Green	133.15	0	3.20%	White	None		MSPI using 1 EDG FTS and 4 EDG FTLR.
Surry 1/2	SWS/CCW	DDP FTR	2Q2000	<1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR.
		DDP FTS	3Q2000	<1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR and 1 DDP FTS.
		MOV FTO/C	2Q2001	<1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR, 1 DDP FTS, and 1 MOV FTO/C.
		DDP FTS	2Q2002	<1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR, 2 DDP FTS, and 1 MOV FTO/C.
		MOV FTO/C	4Q2002	1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR, 2 DDP FTS, and 3 MOV FTO/C.
		MOV FTO/C	4Q2002	1.97E-07	Green	N/A	N/A	N/A	N/A	None		Surry 1 MSPI using 1 DDP FTR, 2 DDP FTS, and 3 MOV FTO/C.

Note 1 - For system failures occurring within a single quarter, the MSPI evaluation includes all of the failures within the quarter (plus any previous failures).

Note 2 - If the proposed front stop is applied and the resulting color is different, then the color using the front stop is presented in parentheses.

Note 3 - If blank, there was no identified performance deficiency requiring an SDP.

Acronyms: AOV (air-operated valve), CDF (core damage frequency), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), FTLR (fail to load and run for 1 hour), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), MSPI (mitigating systems performance index), RHR (residual heat removal system), ROP (reactor oversight process), SDP (significance determination process), SSU (safety system unavailability), SWS/CCW (service water system/component cooling water system), UA (unavailability)

Table I.2 Additional SSU and SDP Whites not Listed in Table I.1

Plant	System	Failure	Date	MSPI		SSU				SDP		Comments
				Delta CDF (1/y) (4Q2002 Data) (note 1)	Color (note 2)	Unplanned Outage Time (h)	Fault Exposure Time (h)	Result	Color	Failure Mentioned in Inspection Report?	SDP Color Indicated in Inspection Report (note 3)	
Millstone 2	HPI	MDP FTR	3Q2000	N/A	N/A	0	654.2	3.10%	White	2000011	Green	This condition event was discovered during periodic testing. Pump operation beyond 4 hours was determined to be questionable. Not an MSPI failure. SDP modeled recovery by placing a spare pump into service.
Prairie Island 1	SWS/CCW	MDP FTR	4Q2000	N/A	N/A	N/A	N/A	N/A	N/A	2000013	White	No safety-related electrical power to backwash system. Not an MSPI failure.
Prairie Island 2	SWS/CCW	MDP FTR	4Q2000	N/A	N/A	N/A	N/A	N/A	N/A	2000013	White	No safety-related electrical power to backwash system. Not an MSPI failure.
Surry 1	EAC	EDG FTR	2Q2001	N/A	N/A	131.35	192.03	2.10%	Green	2001006	White (Yellow)	Degraded condition identified during disassembly of EDG. Not an MSPI failure. SDP initially yellow but later changed to white. Recent SDP Phase 3 analysis indicates yellow with a longer fault exposure time.
Surry 2	EAC	EDG FTR	2Q2001/ 3Q2001	N/A	N/A	131.35 + 22.32	192.03 + 336.03	3.10%	White	2001006	White (Yellow)	Degraded condition identified during disassembly of EDG. Not an MSPI failure. SDP initially yellow but later changed to white. Recent SDP Phase 3 analysis indicates yellow with a longer fault exposure time.

Note 1 - For system failures occurring within a single quarter, the MSPI evaluation includes all of the failures within the quarter (plus any previous failures).

Note 2 - If the proposed front stop is applied and the resulting color is different, then the color using the front stop is presented in parentheses.

Note 3 - If blank, there was no identified performance deficiency requiring an SDP.

Acronyms: AOV (air-operated valve), CDF (core damage frequency), DDP (diesel-driven pump), EAC (emergency ac power), EDG (emergency diesel generator), FTLR (fail to load and run for 1 hour), FTO/C (fail to open or close), FTR (fail to run), FTS (fail to start), HPI (high pressure injection system), HRS (heat removal system), MDP (motor-driven pump), MOV (motor-operated valve), MSPI (mitigating systems performance index), RHR (residual heat removal system), ROP (reactor oversight process), SDP (significance determination process), SSU (safety system unavailability), SWS/CCW (service water system/component cooling water system), UA (unavailability)

APPENDIX J. TECHNICAL BASIS FOR USING THE CONSTRAINED NON-INFORMATIVE PRIOR

Appendix J
Technical Basis for Using the Constrained Non-Informative Prior

J.1 Introduction

Assessment of current performance is very different from assessment of long-term average performance. But most PRA-related data analysis is concerned primarily with long-term average performance; it typically reflects an assumption that the parameters being estimated are essentially static. Much of it regards data from different sources as being representative of a homogeneous population, or at least considers the mean values of performance parameters extracted from these sources to be the quantities of interest, and the right quantities to use in PRA. Even "population variability" methods, while recognizing that performance varies from one member of the population to another, are typically aimed at extracting long-time averages of performance parameters. Such quantities are long-time averages over different *performance states.*

The problem of determining whether *current* performance deviates from historical norms, based on sparse current data, is more difficult than estimating a long-term average. In many problems of interest, although a significant body of historical evidence is available, current performance information is too sparse to be the sole basis for an assessment of how well the system is currently performing. Therefore, it is desirable to apply current data within a Bayesian framework, making use of a broader body of evidence related to performance. The "constrained non-informative prior" (CNIP) does this satisfactorily in the MSPI. This appendix summarizes why the CNIP works as well as it does and the basis for its selection, indicates where there is room for improvement, and suggests possible future directions.

J.2 Prior Distributions Evaluated

All approaches discussed within this section are Bayesian, in that they formulate a prior distribution on performance parameters,[1] update these distributions with current data to derive posterior distributions of current values of performance parameters, and then use information from the posteriors in a decision rule. NUREG-1753 (Ref. J.1) studied several ways of using prior information to estimate current performance:

• Update the "Industry" Prior	The industry prior reflects variability across the industry of the long-term average value.
• Update the Constrained Non-Informative Prior (CNIP)	Mean of the prior distribution is the industry mean. Other characteristics of the prior are determined by the requirement to be "non-informative." This prior is updated with current failure and demand information
• Maximum-Likelihood Estimate (MLE)	Makes no use of historical information; derives an estimate entirely from current failure and demand information. This is non-informative in an intuitive sense, but true "non-informative" priors actually need to have more complex mathematical properties.

[1] Even the MLE can be thought of in this way. For the demand failure probability case, the MLE is like having previously observed zero failures in zero demands, which we "update" with current data by adding current failures to the (zero) numerator and current demands to the (zero) denominator. For this reason, NUREG-1753 actually refers to the MLE as being based on a "zero" prior.

The assessment process used in NUREG-1753 was the following.

1. Begin with a "baseline" value of unreliability, corresponding to industry average behavior. Build this value into a prior distribution on unreliability.
2. Update this prior with current performance information: for example, the number of demands n and number of failures x observed in a particular component group within a particular assessment period (time window).
3. Take the mean of the posterior distribution as the estimate of current unreliability. Subtract from this the baseline value, in order to obtain an estimate of the change in unreliability.
4. Multiply the change in unreliability by the associated Birnbaum importance to obtain an estimate of the change in the applicable risk metric ("core damage frequency," in the case of NUREG-1753).
5. Compare the change in the risk metric with decision thresholds to determine the appropriate programmatic response.

Unless the number of observed failures x is fairly large, the scatter in x is significant compared to x itself. For many cases of practical interest in this program, x is not large, even when performance is degraded. Therefore, using a maximum-likelihood estimate of current unreliability (x/n, dividing observed failures by observed demands) gives rise to a noisy signal. One implication of this is a high probability of a false indication of declining performance, which wastes resources in regulatory and licensee response, and creates issues of false perceptions. On the other hand, using a prior that is narrowly focused on the baseline estimate strongly biases the posterior towards that baseline; if performance changes significantly, much data will be required to shift the distribution to the right area.

NUREG-1753 compared the behavior of the CNIP with the MLE and with the "industry prior," with respect to their respective efficacies in the above decision rule. The behavior of each alternative was investigated in specific postulated scenarios. Given baseline unreliability performance, the conditional probability of falsely assessing degraded performance was determined, and similarly for the probability of falsely assessing "good" performance given that performance was actually degraded. In NUREG-1753, the CNIP was found to be the best of the alternatives considered at that time. The MLE has a false-positive problem: it uses the number of failures directly, and as indicated above, this is a noisy signal. The "industry prior" has the opposite problem: it gives less prior density to large excursions, creating a false negative potential. The CNIP falls between these extremes and provides the best combination of minimizing both *false positive* and *false negative*.

Although the CNIP is an improvement over the other alternatives, using the CNIP in the above process still yields a significant false-indication probability in many cases of practical interest. Therefore, in some cases, a small number of failures can trigger a regulatory response, even if the failures occurred within the observation window by coincidence, rather than because of declining performance. In other cases, a low value of the CNIP density for high failure probability requires the accumulation of a significant number of failures before the posterior density becomes significant in that region. Because of the form of the CNIP, if the baseline failure probability is a very small number, the CNIP accords a very low prior probability to significantly degraded performance, and it takes a certain amount of data to overcome this. Notwithstanding these shortcomings of the CNIP, the results of the pilot program indicate that the CNIP generally provides reasonable overall results.

J.3 Research on Advanced Prior Distributions

Research into the ideal approach to address the issues discussed above is ongoing. A purist Bayesian approach would integrate all available information into a prior that reflected a considered assessment of how likely performance is to be degraded, how bad performance is when it is degraded, and how good performance is when it is good. Preliminary work has been done to explore the behavior of decision rules based on such a prior. One such formulation, a "mixture prior," has shown real promise in reducing the potential for false indications. For small numbers of failures, the posterior distribution from updating the mixture prior is not much different from the prior, so the false positive failure probability is reduced. For larger numbers of failures, the posterior distribution switches over to reflect a significant probability of degraded performance. These characteristics are highly desirable for this performance assessment application.

However, these benefits of the mixture prior come at a certain price in complexity and in data required to support development of the prior. The CNIP has only one parameter: its mean value. Given the mean, other parameters of the CNIP are determined from the requirement that the function be non-informative in a certain mathematical sense. In the MSPI process, for each component type, the mean of the associated CNIP is currently taken to be the long-term industry-average behavior of that component type. For many component types, estimates of this value can be developed. More flexible priors, such as the mixture prior, involve more parameters. Thus, although the mixture prior itself is not difficult to work with analytically, assessment of these additional parameters for applicable component types would need some work. Consensus would need to be developed regarding the characteristics of "good" and "degraded" performance, including prior probabilities of these conditions. Most available data have not been collected or analyzed with this kind of application in mind. These sorts of reasons are generically why non-informative priors are discussed in the first place.

J.4 Conclusions Regarding the Use of the CNIP

The technical basis for using a Bayesian framework for performance parameters is well-founded. NUREG-1753 identified that of the practical options that were considered, the CNIP displayed the best characteristics from the perspective of minimizing both *false positive* and *false negative* indication. The CNIP can be practically implemented because of the simple algebraic formulation resulting from the update process. It is recognized that the CNIP is not perfect, but the results of the pilot program as documented in this report indicate that the overall results are reasonable. Moreover, to address possible concerns with residual issues of *false positive* and *false negative* that could arise from the mathematical formulation of the MSPI including the CNIP, the concepts of "frontstop" and "backstop" have been proposed. These effectively constrain the minimum and maximum number of failures of components within a system that result in WHITE performance to ensure reasonableness of results. At present, the CNIP is programmatically the best available alternative, while research into improved methods continues.

J.5 References

J.1 H. G. Hamzehee, et al., U.S. Nuclear Regulatory Commission (NRC). NUREG-1753, "Risk-Based Performance Indicators: Results of Phase 1 Development." NRC: Washington, D.C. April 2002.