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Abstract – *The U.S. Nuclear Regulatory Commission Industry Trends Program (ITP) collects and analyzes industry-wide data, assesses the safety significance of results, and communicates results to Congress and other stakeholders. This paper outlines potential enhancements in the ITP to comprehensively cover the Initiating Events Cornerstone of Safety. Future work will address other cornerstones of safety. The proposed Tier 1 activity involves collecting data on ten categories of risk-significant initiating events, trending the results, and comparing yearly performance with prediction limits (allowable numbers of events, above which NRC action may occur). Tier 1 results would be used to monitor industry performance at the level of individual categories of initiating events. The proposed Tier 2 activity involves integrating the information for individual initiating event categories into a single risk-based indicator, termed the Baseline Risk Index for Initiating Events or BRIIE. The BRIIE would be evaluated yearly and compared against a threshold. BRIIE results would be reported to Congress on a yearly basis.*

I. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) provides oversight of plant safety performance on a plant-specific basis using both inspection findings and plant-level performance indicators as part of its Reactor Oversight Process (ROP). Public health and safety assurance is divided into three strategic performance areas: reactor safety, radiation safety, and safeguards. These areas are subdivided into seven Cornerstones of Safety: initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection. Individual issues that are identified as having generic safety significance are addressed using other NRC processes, including the generic communications process and the generic safety issue process.

As discussed in SECY-01-0111 [1], the NRC's Office of Nuclear Reactor Regulation (NRR) initiated the ITP in 2001 to complement these processes by monitoring and assessing industry-level trends in safety performance. The purposes of the ITP are to provide a means to confirm that the nuclear industry is maintaining the safety performance of operating reactors and, by clearly demonstrating that performance, to enhance stakeholder confidence in the efficacy of the NRC's processes. The objectives of the ITP are the following:

- Collect and monitor industry-wide data that can be used to assess whether the nuclear industry is maintaining the safety performance of operating plants and provide feedback on the ROP
- Assess the safety significance and causes of any statistically significant adverse industry trends, determine if the trends represent an actual degradation in overall industry safety performance, and respond appropriately to any safety issues that may be identified
- Communicate industry-level information to Congress and other stakeholders in an effective and timely manner.

The existing ITP is summarized in SECY-05-0069 [2] and on the NRC public website at http://www.nrc.gov/reactors/operating/ oversight/industry-trends.html. Presently, the ITP is monitoring various industry indicators developed by the former NRC Office of Analysis and Evaluation of Operational Data (AEOD), industry-level data from the ROP performance indicators, and Accident Sequence Precursor (ASP) data. The AEOD indicators were reported annually in the NUREG-1187 series [3] up through 1999. Industry-level data from the ROP indicators are updated quarterly and presented on the NRC website. Finally, the ASP results were reported annually in the NUREG/CR-4674 series up through 1998. The most current status of the ASP program is summarized in SECY-04-0210 [4]. This most current set of diverse performance indicators was chosen for initial inclusion in the ITP based mainly on historical precedent and availability of data.

II. REASONS FOR ENHANCING CURRENT ITP PERFORMANCE INDICATORS

Current ITP performance indicators have both strengths and weaknesses. Strengths include availability of historical results, continuity and consistency in yearly evaluations, and broad coverage of the Cornerstones of Safety. However, weaknesses in the Initiating Events and Mitigating Systems Cornerstones of Safety include (1) overlapping coverage by performance indicators from different sources, (2) limited risk coverage, and (3) difficulties in interpreting the risk significance of significant adverse trends.

In terms of risk coverage, work documented in NUREG-1753 [5] indicates that the ROP indicators "Unplanned scrams" and "Scrams with loss of normal heat removal" probably cover less than 20 percent of the total internal event core damage risk for the Initiating Events Cornerstone of Safety. (The other 80 percent of risk involves less frequent initiating events that cannot be monitored on a plant-specific basis over the limited, three-year time period covered by the ROP indicators.) This limited coverage of risk by the ROP performance indicators is supplemented by inspections.

As a first step in enhancing the ITP to remedy the weaknesses discussed above, the Initiating Events Cornerstone of Safety was chosen as the area of focus. Work focused on development of performance indicators that did not overlap in coverage, significantly increased the risk coverage, and provided a mechanism for determining the risk significance of changes in performance, at both the individual initiating event level and at the integrated, Cornerstone of Safety level. The process and results are documented in the following sections.

III. ENHANCEMENT PROCESS FOR INITIATING EVENTS CORNERSTONE OF SAFETY

To enhance the ITP coverage of the Initiating Events Cornerstone of Safety, a three-step process was used. The first step was to identify appropriate initiating event classes. Then methods for trending and establishing performance-based prediction limits for these individual initiating event classes were developed (Tier 1, performance-based monitoring of individual initiating event classes). Finally, an integrated, risk-informed indicator was developed by combining the individual initiating event category information (Tier 2, risk-informed monitoring at the Cornerstone of Safety level). Each of these steps is discussed in this section.

III.A Identification of Risk-Significant Initiating Event Categories

The initiating event study [6]. provides data for a large number of initiating event categories for the period calendar year (CY) 1987 through CY 1995. (NRC is continually updating these data, but NUREGs are no longer being published. Instead, the results are posted on an internal NRC website, with plans to post them on the NRC public website.) A subset of these categories has been identified as being risk significant in NUREG-1753. The list of risk-significant initiating event categories considered in the enhanced ITP is presented in Table I. This list includes ten initiating event categories applicable to pressurized water reactors (PWRs) and nine applicable to boiling water reactors (BWRs). Initiating event categories broken down into separate PWR and BWR categories were shown to have statistically significant differences in frequencies in the initiating events study. For the other initiating event categories, PWR and BWR frequencies were not significantly different, and both types of reactors were combined to obtain frequencies. In general, these risk-significant initiating event categories cover approximately 90% of the internal event core damage risk (excluding internal flooding) from the 103 operating commercial nuclear power plants in the U.S. Also, there is no overlap between these initiating events categories.

TABLE I. Risk-Significant Initiating Event Classes Covered by the BRIIE

Pressurized Water Reactors (PWRs)	Boiling Water Reactors (BWRs)
1. Loss of offsite power	1. Loss of offsite power
2. Loss of vital AC bus	2. Loss of vital AC bus
3. Loss of vital DC bus	3. Loss of vital DC bus
4. Loss of feedwater	4. Loss of feedwater
5. Small loss of coolant accident	5. Small loss of coolant accident
6. PWR general transient	6. BWR general transient
7. PWR loss of heat sink	7. BWR loss of heat sink
8. PWR stuck open safety/relief valve	8. BWR stuck open safety/relief valve
9. PWR loss of instrument air	9. BWR loss of instrument air
10. Steam generator tube rupture	

The three enhanced ITP risk-significant initiating event categories that correspond roughly with ROP performance indicators (Items 4, 6, and 7 in Table I) occur frequently enough such that they can be monitored on a plant-specific basis over a period of one or three years. However, their coverage of internal events core damage risk is approximately 20%. The ITP enhancement also includes the other risk-significant initiating event categories listed in Table I because of two reasons: including these other categories increases the risk coverage to approximately 90%, and events within these categories are frequent enough to monitor on an industry-wide basis. In the enhanced ITP, these risk-significant initiating event categories would replace the ROP "Unplanned scrams" and "Scrams with loss of normal heat removal" and ex-AEOD "Automatic reactor scrams while critical" performance indicators. At present, it is not clear whether the ROP "Unplanned power changes" performance indicator would remain in the enhanced ITP. This performance indicator has no direct relation to CDF, and a decision would have to be made whether its inclusion is appropriate in the enhanced ITP coverage of the Initiating Events Cornerstone of Safety.

III.B Performance Monitoring of Risk-Significant Initiating Event Categories (Tier 1)

The proposed Tier 1 activity involves trending risk-significant initiating event categories and monitoring yearly industry performance against prediction limits. To accomplish this, up-to-date baseline frequencies were established for each of the risk-significant initiating event categories (Table II). Then, given these baseline frequencies and estimated yearly industry total critical reactor years of operation, the ITP enhancement determinedperformance-based prediction limits on the industry-wide numbers of events. Ten risk-significant initiating event categories are covered for PWRs, while nine are covered for BWRs. Data for these initiating event categories – numbers of events and corresponding reactor critical years – are already being collected and analyzed by the NRC on a continual basis, so no additional data collection is needed to support the Tier 1 activities.

The prediction limits in Table II are statistically determined and performance based, and include both aleatory uncertainty (the randomness of the event count in the future year) and epistemic uncertainty (lack of perfect knowledge of the value of the baseline frequency). Both 95% and 99% limits are presented for illustrative purposes. An expert elicitation approach is proposed to decide which set of limits (or some other set) is most appropriate for the Tier 1 activity. For informational purposes, the actual industry performances for fiscal years (FYs) 2002 and 2003 are also shown in Table II. In FY 2003, the PWR General Transients exceeded the 95% and the Loss of Offsite Power exceeded both limits (due to the widespread grid blackout on August 14, 2003).

As an example of the Tier 1 trending analysis, the historical performance of the PWR general transient category is shown in Figure 1. Over the period FY 1988 through approximately FY 1997, industry performance improved considerably (the initiating event category frequency dropped). However, over the period FY 1998 through FY 2001 (the period used for determining an up-to-date baseline frequency), the industry performance was essentially constant.

TABLE II. Tier 1 Performance-Based Prediction Limits

Risk-significant Initiating Event	Baseline Mean Frequency (per Plant per Critical Year)	Reactor Critical Years Assumed for One Year of Industry Operation	Expected Number of Events Over One Year	95% Prediction Limit (Industry Event Counts Over One Year)	99% Prediction Limit (Industry Event Counts Over One Year)	Actual Industry Event Counts for FY 2002	Actual Industry Event Counts for FY 2003
PWR General Transients	7.64E-1	61.72	47	61	67	30	62
BWR General Transients	8.95E-1	31.77	28	39	44	22	22
PWR Loss of Heat Sink	9.74E-2	61.72	6	12	14	3	5
BWR Loss of Heat Sink	1.90E-1	31.77	6	12	14	6	9
Loss of Feedwater	1.02E-1	93.49	10	16	19	2	9
Loss of Offsite Power	1.71E-2	93.49	2	5	7	1	11
Loss of Vital AC Bus	2.75E-2	93.49	3	7	8	4	3
Loss of Vital DC Bus	2.96E-3	93.49	0.3	2	3	0	0
PWR Stuck Open SRV	3.12E-3	61.72	0.2	2	3	0	0
BWR Stuck Open SRV	2.13E-2	31.77	0.7	3	4	1	0
PWR Loss of Instrument Air	1.22E-2	61.72	0.8	3	5	1	1
BWR Loss of Instrument Air	1.08E-2	31.77	0.3	3	3	0	0
Small/Very Small LOCA	4.65E-3	93.49	0.4	3	4	0	0
PWR Steam Generator Tube Rupture	4.37E-3	61.72	0.3	2	3	0	0

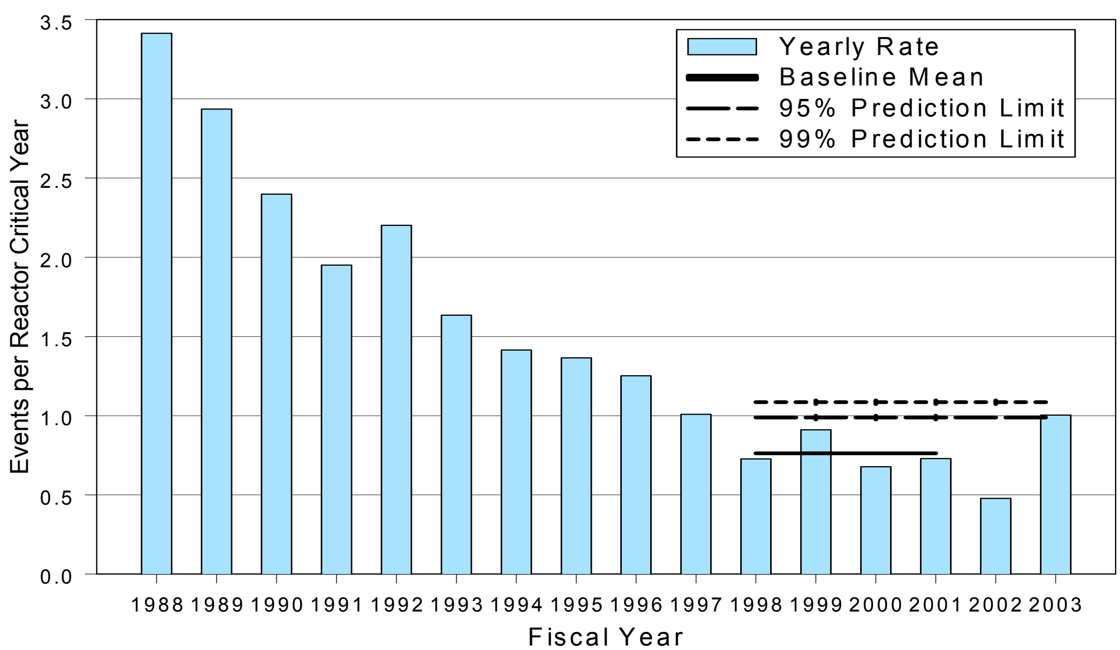

Figure 1. PWR General Transient Initiating Event Trend

These ITP Tier 1 activities will help the NRC identify degrading industry performance as an adjunct to the plant-specific performance assessment performed as part of the ROP. Tier 1 activities and results are not reported to the U.S. Congress in the annual accountability report. However, the Tier 1 results will be placed on the NRC public website for access by interested stakeholders.

III.C Risk-Informed Monitoring of Initiating Events Cornerstone of Safety (Tier 2)

An integrated performance indicator is proposed for the enhanced ITP Tier 2 coverage of the Initiating Events Cornerstone of Safety. It involves evaluating the risk significance of changes in industry initiating event category performance (the results of the Tier 1 activity). Risk significance is evaluated in terms of an index related to change in core damage frequency (CDF) or ΔCDF. The indicator combines operating experience for risk-significant initiating event categories with associated internal event CDF-based importance information.

The indicator is able to appropriately combine frequent and infrequent initiating event categories with different risk measures (Birnbaum importances). This indicator is termed the Baseline Risk Index for Initiating Events, or BRIIE. The main use of the BRIIE is to combine individual initiating event category performance changes into an integrated, risk-informed indicator at the Initiating Events Cornerstone of Safety level. The BRIIE would solve two deficiencies in the present ITP: no systematic and defined method for determining whether individual initiating event category performance changes or adverse trends are risk significant, and no systematic and defined method for integrating individual initiating event category performance changes into an overall risk result at the Cornerstone of Safety level. Results of the BRIIE would be reported to the U.S. Congress in the annual accountability report.

The BRIIE formulation, related to changes in CDF (ΔCDF per plant), is given by the following equation:

$$BRIIE = \Delta CDF_{estimate} = \sum_{i=1}^{m} B_i(\lambda_i^* - \lambda_{i,baseline}) \qquad (1)$$

where

$BRIIE$ = estimate of plant-average change in core damage frequency resulting from changes in industry-average initiating event performance (*m* different initiating event classes)

B_i = plant-average Birnbaum importance for the initiating event class *i*

λ_i = industry-average current frequency for the initiating event class *i*

$\lambda_{i,baseline}$ = industry-average baseline frequency for the initiating event class *i*.

BWRs and PWRs have different core damage frequencies, which depend to some extent on different initiating events. The risk weights for various initiating event categories are also different for the two types of reactors. Therefore, BRIIE results are proposed for each reactor type. However, the two BRIIE results could be combined into a single index, if desired.

The BRIIE formulation uses industry-average (or PWR- or BWR-average) Birnbaums and combines the industry-wide data to generate the "common industry current frequency" for each initiating event category. Alternative formulations are possible using plant-specific Birnbaums and/or plant-specific initiating event category data and then summing the individual plant results to obtain an industry result. Results using all of the various calculation methods indicated that the proposed formulation in Equation (1) provides the most BRIIE sensitivity.

As formulated in Equation (1), the BRIIE is similar to the proposed Mitigating Systems Performance Index (MSPI) being piloted in the ROP [7, 8]. Both the BRIIE and the MSPI use Birnbaum importance measures as weighting factors. (The MSPI approach combines CDF, Fussell-Vesely importance, and basic event probability information, but the result is equivalent to the Birnbaum importance measure.) Also, both determine current performance and compare that with baseline performance to evaluate changes in performance. However, the MSPI is being applied to the Mitigating Systems Cornerstone of Safety on a plant-specific basis, while the BRIIE applies to the Initiating Events Cornerstone of Safety on an industry-wide basis. Also, the BRIIE integrates all of the initiating event categories into a single indicator at the Cornerstone of Safety level, while the MSPI does not integrate the results for the five individual mitigating systems into a single indicator.

BRIIE results, although representing industry-wide results, are presented as average results per plant. This is done because the NRC and stakeholders are more familiar with results per plant, rather than integrated industry-wide impacts. If the PWR BRIIE result for a future year is calculated to be 1.0E-6/year (per PWR), then the PWRwide impact is actually (1.0E-6/year/PWR)(69 PWRs) = 6.9E-5/year. Similarly, if the BWR BRIIE is 1.0E-6/year (per BWR), then the BWR-wide impact is actually (1.0E-6/year/BWR)(34 BWRs) = 3.4E-5/year. These industry-wide impacts should be kept in mind when establishing reporting thresholds for the BRIIE.

Simulations of expected future performance of the PWR and BWR BRIIEs were performed to obtain 95% and 99% prediction limits. Results are presented in Table III.

TABLE III. BRIIE 95% and 99% prediction limits.

Reactor Type	95% Prediction Limit (ΔCDF)	99% Prediction Limit (ΔCDF)
PWR	2.2E-5/year/PWR	3.5E-5/year/PWR
BWR	7.2E-6/year/BWR	1.1E-5/year/BWR

Reporting thresholds for the two BRIIEs should be established considering the following information:

- Uncertainty in the BRIIEs and the 95% and 99% prediction limits from simulations
- Distributions of the Birnbaum importance measures and understanding of the groups of plants that have large values for specific initiating event classes
- Major contributors (i.e., dominant initiating event categories) to the BRIIEs
- Sensitivity of BRIIEs to initiating event classes, especially those with lower frequencies
- Other factors, such as the NRC Safety Goal Policy and Regulatory Guide 1.174 [9].

An expert panel would be established to propose threshold values that satisfy policy and operational needs and objectives.

Table IV shows the relationship among the ROP, the ITP, and the report to Congress. It shows the potential actions that the ITP might take if a prediction limit is exceeded.

IV. BRIIE HISTORICAL PERFORMANCE AND SENSITIVITY

Historical performance of the BRIIE (ΔCDF basis) is shown in Figure 2 for FY 1997 through FY 2003. For all years except FY 2003, the PWR BRIIE dominates the BWR BRIIE in terms of variance from a baseline ΔCDF of 0.0. This illustrates the reason why separate BRIIEs are proposed for PWRs and BWRs. For FY 1999, the PWR BRIIE peak of approximately 1.1E-5/year (per plant) is driven by the occurrence of two loss of DC bus initiating events. This illustrates the sensitivity of the BRIIE to relatively infrequent but risk-important initiating events.

V. IMPLEMENTATION STEPS

To implement the proposed ITP enhancements for the Initiating Events Cornerstone of Safety, several steps must be taken:

1. Conduct a pilot exercise to set thresholds for both the Tier 1 individual initiating event categories and the Tier 2 BRIIE, based on the current example calculations. From this we can learn what is the best way to present information to a panel and what additional information would be helpful when setting the thresholds.

2. The Birnbaum importance measures used to quantify the PWR and BWR BRIIEs were obtained from SPAR Rev. 3i and 3 models in the summer of 2002 for this demonstration exercise. Final Birnbaum importance measures should be obtained from the improved SPAR Rev. 3 models being completed by the NRC. The initiating event frequencies and the basic event failure probabilities in the SPAR models should be updated before the final Birnbaum importance measures are estimated.

3. Perform studies using the SPAR models to provide information about the robustness of the BRIIEs. That is, determine if the BRIIE is insensitive to uncertainties in the parameter estimates. Compare with industry PRA models where possible.

4. Develop procedures, processes, and quality assurance guides for the Tier 1 and Tier 2 activities.

TABLE IV. Relationship among the ROP, ITP, and Report to Congress

	Reactor Oversight Process						Industry Trends Program	Report to Congress
	Likely Responses to Individual Occurrences of Initiating Events						Annual Occurrences of Initiating Events	Integrated Indicator
Initiating Event Class	Early Notification (10CFR 50.72)	Incident Investigation (MD 8.3)	Routine or Special Inspections	Significance Determination Process	Licensee Event Report (10CFR 50.73)	Accident Sequence Precursor Analysis	Action To Be Taken If Industry Prediction Limit Is Exceeded for Indicated Initiating Event Class:	Action To Be Taken If BRIIE Threshold Is Exceeded:
General Transient	X				X		Investigate to determine reasons for exceeding the prediction limit. Take actions as necessary following established processes (generic communications, generic safety inspections, etc.)	Document reasons for the exceedance and what has been done to address them.
Loss of Heat Sink	X				X			
Loss of Feedwater	X				X			
Loss of Offsite Power	X	X	X	X	X	X		
Loss of Vital AC Bus	X	X	X	X	X	X		
Loss of Vital DC Bus	X	X	X	X	X	X		
Stuck Open Safety Relief Valve	X	X	X	X	X	X		
Loss of Instrument Air	X	X	X	X	X	X		
Small/Very Small LOCA	X	X	X	X	X	X		
Steam Generator Tube Rupture	X	X	X	X	X	X		

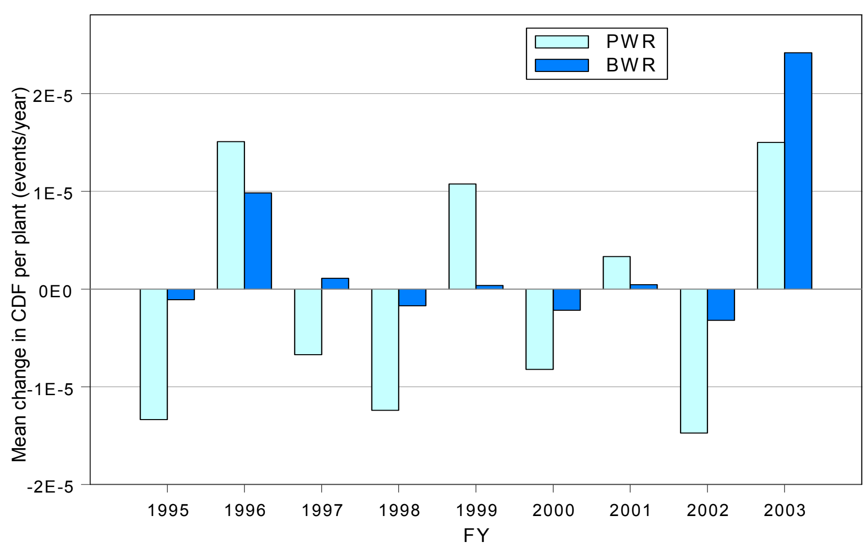

Figure 2. Historical Performance of the BRIIE

5. The proposed Tier 1 and 2 activities should be formally incorporated into the ITP over a several-year period. This allows for refinements as experience with these activities is accumulated.

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