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Risk-based Safety Performance Indicators for Nuclear Power Plants

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ABSTRACT

In a Concerted Action (CA), sponsored by the European Commission within its 5th Framework Program, a consortium of eleven partners from eight countries has reviewed and evaluated the application of Safety Performance Indicators (SPIs), which – in combination with other tools – can be used to monitor and improve the safety of nuclear power plants. The project was aimed at identification of methods that can be used in a risk-informed regulatory system and environment, and to exploit PSA techniques for the development and use of meaningful additional/alternative SPIs. The CA included the review of existing indicator systems, and the collection of information on the experience from indicator systems by means of a specific questionnaire.

One of the most important and challenging issues for nuclear plant owners and/or regulators is to recognize early signs of deterioration in safety performance, caused by influences from management, organization and safety culture (MOSC), before actual events and/or mishaps take place. Most of the existing SPIs as proposed by various organizations are considered as “lagging” indicators, that is, they are expected to show an impact only when a downward trend has already started. Furthermore, most of the available indicators are at a relatively high level, such that they will not provide useful information on fundamental weaknesses causing the problem in the first place.

Regulators’ and utilities’ views on the use of a Safety Performance Indicator System have also been a part of the development of the CA.

KEY WORDS: Safety Performance Indicators, SPI, Probabilistic Safety Analysis, PSA, safety culture, risk-informed, risk-based

INTRODUCTION

A nuclear power plant Safety Performance Indicator (SPI) is a basic parameter (described qualitatively or quantitatively) that is perceived as having potential meaning (or relationship) to plant safety.

If properly selected, SPIs are useful in evaluating and comparing performance (over time for a given plant or group of plants, over a cross section of plants at a given time, etc.), and in serving as a basis for making decisions that affect plant safety performance.

Currently, the potential use of safety performance indicators includes:

1) Monitoring performance;
2) Identifying and rectifying potential degradations in performance; and
3) Developing effective strategies for improving performance and enhancing operational safety.

In general, the worthiness of a risk-based performance monitoring system can be described in terms of the following desirable attributes [1]:

1) Adequately represents plant safety performance, and directly relates such performance to risk and/or constituents of risk (reliability, availability, probability and frequency).
2) Identifies significant manifestations of organizational and other factors that could signal "deterioration" in safety performance before actual adverse safety impacts are realized.
3) Has small potential for spurious correlations.
4) Is implemented (defined and calculated) unambiguously and consistently across all plants.

5) Complements (and not replaces) other available means for assessing licensee performance (e.g., inspection activities).

In consideration of these desirable attributes, the focal point of developing any SPIs should be an effective use of probabilistic safety assessment (PSA), as PSA provides a formal and most logical means for quantifying the safety significance of operational events, corrective actions, design modifications, and changes in plant configuration (plant condition). In other words, PSA appears to be a consistent framework for defining the most meaningful set of SPIs, and for linking these with the most effective top-level safety indicators. Furthermore, it is important that a relatively small number of the best predictive SPIs (e.g., those event forerunners that are related to, or affected by, safety culture and organizational performance) be used to augment the more obvious/explicit PSA-based SPIs. However, since the basis for the assessment of the risk influence of management and organizational aspects are not embedded within the current PSA framework, it is not easy to assess the appropriateness of the current performance indicators that are proposed for assessment of management and organizational factors. In addition, there is no general agreement on the approach to the assessment of the impact of organizational and safety culture on the safety performance of nuclear power plants, and the ways these influences, if any, could be tracked. A Concerted Action (CA) project, entitled "Evaluation of Alternative Approaches for Assessment of Safety Performance Indicators (SPI) for Nuclear Power Plants", has been conducted under the sponsorship of the European Commission. The SPI project, coordinated by GRS, comprised eleven partner organizations from eight countries representing regulatory organizations, utilities, and technical support organizations. The objectives of the SPI project were:

1) To review the state-of-the art and existing approaches to collection and reporting of Safety Performance Indicators.
2) To identify strengths and deficiencies of the existing practices in various countries.
3) To identify best practices relative to the needs of the regulators and the utility organizations.
4) To formulate the relationship between safety inspection and performance monitoring, as manifested by the information obtained from PIs.
5) To identify future research needs as related to incorporation of the risk impact of organizational aspects.
6) To develop a list of candidate methods and recommendations for future development and implementation guidelines.

This paper is presenting the results of the Concerted Action.

CURRENT STATUS OF THE APPLICATION OF SPI

The state-of-the art of the application of SPIs can be summarized as follows:

- In all countries operating nuclear power plants performance indicators are either being tracked or are being proposed that can be applied to monitor the safety performance of the plants.
- There is no unified approach concerning terminology and definition of "performance indicators", "safety indicators", and "safety performance indicators".
- Most widely applied is the WANO set of performance indicators (10 quantitative indicators reported annually by nearly all NPPs worldwide, in order to monitor the safety and economic performance of NPPs).
- In many countries the WANO set, complemented by other indicators, is used by utilities and regulators to monitor the safety performance of NPPs.
- There is practically no calibration of safety performance indicators in order to give a quantitative measure of plant safety (resp. risk).
- Evaluation of safety performance indicators applies relative thresholds which are based on past experience.
- Safety performance indicators are generally applied in combination with other methods to monitor plant safety (e.g. inspections, PSA, precursor studies).
- Approaches have been developed to monitor status and trends of safety management and safety culture by means of specific indicators. Calibration in terms of influence on plant safety (resp. risk) is not available.
- Similarly it is intended to find indicators to detect early signs of deterioration of safety. Proposals have been developed, but there is no accepted approach. Furthermore, the relationship of "safety culture and organizational aspects" to fundamental PSA input parameters and models needs to be better established using actuarial plant data.
- Plant specific PSAs, taking into account actual operational experience, produce safety performance indicators (CDF, release category frequencies) based on an integrated view. However, the current PSA methodology does not take into account (potential) influences from safety management or safety culture, which have not yet been manifested in the operational experience.

IDENTIFICATION OF BEST PRACTICES

As the concept of SPIs is relatively new, and the existing information on the application of, and experiences with, SPIs is sparse, specific information from different institutions has been collected by means of a comprehensive questionnaire. In this way, information was collected from both regulators and utilities on their experience, needs and uses of safety performance indicators for safety decision-making. Specifically, the objectives of the questionnaire were:

- To determine the status of SPIs, their form and their applications to safety and safety decision-making. This includes a description of the SPIs that are in use and the way in which they are being applied and interpreted in actual practice by regulators and utilities,
- To collect expert opinion regarding typical applications and interpretations of the SPIs, and the potential for their misuse and misinterpretation,
- To collect information on the specific needs and the future directions for the development of risk-based SPIs, and
- To assess future research and development needs, in particular in terms of data collection and reporting requirements.

The Safety Performance Indicator Questionnaire (SPIQ) was distributed to a selected group of European (including Eastern and Central European), North American and Far Eastern nuclear regulatory authorities and nuclear utilities. The returned questionnaires were then synthesized and summarized.

In all 23 questionnaires were completed and returned, 13 from utilities and 10 from regulatory bodies. This number was judged to be sufficiently representative of the nuclear power community as to allow substantive views to be deduced as to the practices and needs of both the regulatory and utility organizations.

RISK-BASED PERFORMANCE INDICATORS

Starting in the mid-1980s, the use of performance indicators (PI) - as a way to monitor and track the performance - became acceptable by nuclear regulators and utility organizations. These indicators were established based on the insights from a limited number of Probabilistic Risk Assessments (PSAs) and on operational and inspection experience. They have consisted of numerical information on parameters that had been perceived to have a relationship to safety and operational performance.

Examples included information on:

- The frequency of plant transients (scrams, safety system actuations, significant events, forced outage rate, and equipment forced outage rate),
- Equipment performance (safety system failures, significant events, equipment forced outage rate),
- Weaknesses in programmatic areas (administration, licensed operators, other personnel, maintenance, design, miscellaneous, etc.), and
- Collective radiation exposure.

These PI reporting programs included periodic data for each plant, as well as trends of plant performance over time (short-term self-trend) and comparisons with other plants (long-term deviations from peers). These reporting systems have been enhanced over the last decade and include changes that have been made to calculate trends and deviations separately for operating periods and for shutdown/refueling periods. The distinction of plant operating status have been made, in some countries, because experience had shown that the PI data and their associated trends and deviations had been greatly affected by plant activities, which vary with the plant's operational mode (shutdown, refueling outage, maintenance, etc.).

This approach to collection and reporting of PIs is primarily “count-based” and is only implicitly related to safety and risk.

More recently, a number of approaches, that attempt to relate indicators more directly to safety and risk, have been developed. Examples include the studies conducted and published in Reference [1], the on-going potential enhancements to the Reactor Oversight Process (ROP) of the U.S. Nuclear Regulatory Commission [2], and the program being pursued by the International Atomic Energy Agency [3].

Over the last 30 years, PSAs have been developed and used to systematically evaluate measures of plant risk, in order to better understand plant behavior (including dominant accident sequences and individual risk contributors), and to establish a basis for comparing safety among plants and comparing safety of given plants with safety goals. Clearly, there are a variety of uses of PSA. Since PSA results in meaningful measures of plant safety, one of such potential uses is in the safety performance monitoring, provided the PSA is of adequate quality and scope.

Generally speaking, a well-constructed PSA model provides a relationship of the impact of initiators and plant conditions (including external hazards) on the risk of core damage (Level-1 PSA); and on the risk of radiological releases (Level-2 PSA); on the risk of environmental and health consequences, including fatalities (Level-3 PSA). Indeed, to the extent that the PSA is comprehensive with respect to attempts to account for all initiators and plant conditions (or all categories of initiators and conditions) that may impact safety, it could serve as a reliable basis for reporting plant safety. Thus, PSA is a natural choice for establishing a framework for safety performance monitoring. Other frameworks for the identification and use of safety performance indicators are clearly less rigorous, and are typically only qualitative in terms of their correlation with safety [1].

One of the deficiencies of the existing PSAs is the absence of a generally accepted approach for inclusion of the effects of management, organization and safety culture (MOSC) influences into the analysis. Studies of major accidents in various industries indicate that accidents rarely arise from random failures of hardware, but instead arise from a combination of active and latent human and organizational errors [4,5]. A discussion of safety culture issues is also provided in References [6] and [7].

In this environment the results of the SPIQ as discussed earlier have resulted in six “high priority” areas for future work as summarized in the following table 1 and discussed below.

Table 1. High priority needs based on the SPI Questionnaire

Identified Needs	State-of-the Art	Data Adequacy
1. Establish SPIs that are more directly linked to risk	Mature	Generally Adequate
2. Evaluation of operational and event data to identify potential “event forerunners” and MOSC influences	Mature	Questionable
3. Identify the most important PSA parameters that could be sensitive to MOSC influences	Mature*	Questionable
4. Identify and monitor “lead indicators” that could signal potential deterioration in safety performance and inclusion of MOSC influences within PSAs	Not mature	Questionable
5. Monitoring and tracking MOSC indicators	Not mature	Questionable
6. Establishing data collection and reporting requirements to enhance uniformity and consistency in evaluating and reporting SPIs	Not mature	

* It is recognized that a generally acceptable approach for inclusion of MOSC influences into the PSA framework is not yet available; however, adequate knowledge exists to identify those aspects of risk that could be sensitive to MOSC influences.

Establishment of risk-based SPIs

The development of SPIs that follow the PSA hierarchy and/or that are more directly linked to PSAs, is being undertaken by various regulatory organizations and the International Atomic Energy Agency (IAEA); however, differences exist in regards to the selection approach, reporting, and the display of SPIs, which require to be streamlined. In addition, the scope of the SPIs needs to be better defined and more consistently established.

The hierarchical development and implementation of risk-based SPIs should follow the PSA hierarchy that includes the relevant indicators representing, for instance:

- Initiating events
- Reliability of functions, systems, trains and components
- Mitigation potential of engineering systems
- Mitigation potential of emergency actions.

The degree to which SPIs can be related to risk, including the extend of coverage of the expected risk magnitude, is driven by the scope of the available PSAs, the availability of data, and the prominence of the various risk contributors at specific plants. Nonetheless, a greater coverage of the risk by the SPIs should tend to enhance the applicability of the resulting SPI system in the safety monitoring and oversight process.

In addition, the risk impact of issues such as organizational and management influences are not currently assessed; therefore, issues that can be perceived to have a measurable impact of plant safety (either deterministically or probabilistically), that can signal deterioration in safety performance should also be included in such a hierarchical framework, as further discussed below.

Evaluation of operational and event data to identify potential “event forerunners” and MOSC influences

It is recommended to identify potential forerunners that are influenced by MOSC, by undertaking a review of the existing reports (in particular, the reports on the underlying root causes of major events and “near-misses”) to examine the management, organization and safety culture influences, if any, and how they could potentially be considered as more generic MOSC driven influences on performance leading to the occurrence of events and/or ”near misses”. These potential forerunners can then be used for the development of a generic list of SPIs. Furthermore, guidelines need to be developed regarding the data collection and reporting requirements. It is recognized that such guidelines may need to be general in nature to allow for their smooth implementation into any existing reporting and/or feedback experience systems.

The evaluation of MOSC forerunners will most likely be subjective in nature, even though one may be able to devise an appropriate objective scale into which they can be mapped.

Over time, MOSC problems are expected to eventually find their way into all facets of plant operation, inspection, maintenance, training, etc. Thereby, one of the aspects of the review should be to determine if any trends and/or changes in the reliability of plant systems, structures and components (SSCs), or in human performance can be deciphered from the operational and maintenance data. For data to be useful for analysis, there needs to be sufficiently detailed root-cause analyses that accompanies the data. Of course, it is possible that the quality of the data and the associated root-cause reports may not lend themselves to such a trending analysis; nevertheless, it is essential that an attempt be made to identify any potential trend. It is possible, that this review may result in specific recommendations for data collection and reporting requirements, including data quality assurance. In which case, trends of this nature can only be identified at a later date.

Identify and monitor "lead indicators" and inclusion of MOSC influences into PSA framework

In order to more completely develop a risk-based SPI system, it is desirable to review the existing literature with regards to the consideration of MOSC within the PSA framework. Based on this literature survey, a concise summary of the currently available methods for consideration of MOSC influences within probabilistic risk assessment framework should be outlined; this should include a critique of the available methods, and the identification of areas that would benefit from additional research. Finally, the available survey should identify the most important PSA parameters (hardware and/or human reliability, etc.) that could be sensitive to MOSC influences.

One of the key shortcomings of the present approach to performance monitoring is the absence of "lead indicators" that can be viewed as "forerunners" to events and accidents.

It would be essential to identify strong candidates for "lead indicators" that can correlate directly or indirectly with safety performance, and possibly with risk, to be used for tracking by various pilot plants to determine their viability for use within a risk-based SPI system. These lead indicators should be able to identify significant manifestations of organizational and other factors that could signal deterioration in safety performance before actual adverse safety impacts are realized.

Identification of potential MOSC indicators and inclusion of MOSC influences within PSAs

Selected groups of SPIs, including the "lead indicators" may have some direct/indirect correlations to PSA basic parameters, while others may be well outside of the current PSA parametric regime; however, if organizational influences are included within a PSA framework on a consistent and technically acceptable manner, then one should be able to determine correlations and/or relationships between these "lead indicators," MOSC indicators (that may or may not be one of the same) and the more global PSA parameter-base.

Monitoring and tracking of risk-based SPIs

The monitoring and tracking of an appropriate set of SPIs should follow an initial "pilot" period where data can be assessed and the value of the selected SPIs can be evaluated in terms of their effectiveness in showing trends, correlation to actual plant safety, ease of interpretation, communication, and identification of "spurious" correlations. Finally, the appropriateness of the SPIs to inspection and audit programs need to be carefully assessed. In addition, threshold values for regulatory action need to be defined relative to the selected set of indicators. It is noted that the pilot application should also help determine the need for the delineation of indicators along the variations in design (PWR, BWR, VVER, etc.) and plant configuration (full power, shutdown, refueling, etc.).

Establishment of data collection and reporting requirements to enhance uniformity and consistency in evaluating and reporting of risk-based SPIs

The final step in the implementation of a uniform and consistent risk-based SPI system involves the establishment of data collection and reporting requirements that enable both utilities and regulators to utilize the information that is conveyed by the indicators for their specific applications, while avoiding unnecessary burdens on either side. This requires a review of the data collection and reporting systems at the national level with an effective utilization of the international experience, to define a simple, and effective data collection and reporting system. Analysis of trends, interface with living PSA programs, and PSA-based event analyses are natural elements of an effective data collection and reporting system, with due attention to PSA scope and quality. Furthermore, an effective system can only benefit from periodic evaluation and refocusing activities. Note that in areas where the current state-of-the-art does not allow the selection of a definitive process, an adequate interface to on-going research programs is also essential.

IMPACT OF MANAGEMENT, ORGANIZATION AND SAFETY CULTURE (MOSC) ON SAFETY PERFORMANCE

To recognize early signs of deterioration in safety performance before actual events and/or mishaps take place is one of the most important and challenging issues for nuclear plant owners and/or regulators. If SPIs are to be useful for focusing attention on potential problem areas, it is important that they are selected in a fashion that they also identify manifestations of organizational and safety culture factors that could signal "deterioration" in safety before actual adverse safety impacts are realized.

It is clear that the issue of identifying and including potential event "forerunners" into SPIs is not a straightforward process. In general, the MOSC influences on safety performance can be viewed to consist of two categories, namely:

- Category I - Indirect impact on hardware

- Category II - Indirect impact on operator performance.

Category I impacts include indirect influences of deteriorations in operations, inspection, maintenance, engineering design and safety analysis, radiological controls, outage activities, event analysis, and regulatory relations, on the plant hardware performance and reliability. This includes the potential impact on maintenance errors that could result in an increased frequency of initiating events (i.e., accidents).

On the other hand, Category II impacts include the indirect impact of deteriorations in management and personnel relationship, on the performance of operators. This also includes potential impacts on some of the maintenance errors.

In order to enable the inclusion of key event forerunners into SPI systems the two-step approach identified above, consisting of the review of event reports to identify MOSC forerunners and the review of reliability data to identify MOSC influences, appears to be workable.

Note that there is a possibility that the tracking of the event "forerunners" may also show "early signs" for potential deterioration in performance in a well-run and well managed plant. However, if these plants are truly not expected to be prone to potential problems in MOSC issues, their organization should have management plans in place to identify and correct such problems. Therefore, development and implementation of a process for identification of early signs of degradations in safety performance (i.e., MOSC forerunners), which is one of the main deficiencies in the current approach to SPIs, should to a great extend be based on the available "best practices", to be followed by additional methods development.

REGULATORY USE OF SPI

Safety Performance Indicators are quantitative measures providing monitoring of several aspects of plant safety over time, and when taken as a whole can be used to help regulatory oversight activities.

The inherent difficulty in measuring safety performance with a quantitative measure, especially leading indications of safety deterioration, makes it important to use several different sources of information to help establish and prioritize regulatory activities. It is important in today's economic conditions that efficiency measures desired by utilities should not prevent effective regulatory decisions to guard public safety. Regulatory activities can impact the plant economics and this often requires extra work to ensure such impacts are justified. The rational use of indicator systems can help to reduce this burden.

One clear conclusion of an experts' workshop held in the course of the Concerted Action is that Safety Performance Indicators are not to be used in isolation. They are seen as a complement to other regulatory activities. This conclusion is based on the belief that no single method of analysis is capable of adequately representing and measuring safety. Rather, the broader the set of available tools at the disposal of the regulatory body, the easier it will be to support the regulatory activity.

Based on the available information, especially that generated within this Concerted Action, several research areas have been identified to help define a useful set of indicators for regulatory use.

- Considerable effort has to be put on the definition of a hierarchical structure that, on the one hand allows different degrees of involvement of the management levels, and act as a means to communicate with the public. Lower level indicators need to be sufficiently detailed to support technical work and to enhance the communication between the regulator and the plant personnel. Detailed, lower level indicators need to provide a sound and auditable basis for regulatory decisions, while aggregated higher level indicators provide management with a clear-cut picture of the plant safety status.
- A necessarily high research effort needs also to be put on the definition of the thresholds that regulatory bodies can use to guide their responses. To this end, the use of probabilistic methodologies are potentially most useful. They could provide a common framework to establish the levels for regulatory concern that can be defined in a uniform manner across plants. The quality and completeness requirements of PSA models is a concern here that needs also specific research, especially for comparison between plants. In particular, if comprehensive PSA models do not exist for a given plant, the possibility of defining thresholds for regulatory response based on PSA insights gained from the existing models and experience from other similar plants should be researched
- A simple and clear way of communicating the safety level, in a consistent manner, of the plants under the scrutiny of a particular regulatory body is also of interest. Raw indicators may be difficult to understand and potentially counterproductive. An adequate way of presenting information to the public is needed whether by means of a color code or otherwise.
- The means of properly incorporating MOSC issues into the regulatory indicators framework needs also to receive a specific research effort, and this should make full use of existing organization and human factors programmes and research.

UTILITY USE OF SPI

Currently, the selection of Performance indicators which are observed and reported by utilities is very individual and generally based on each plant's special needs and goals for development and comparisons. With the exception of the ten WANO indicators, which are well defined and the survey of which is coordinated by WANO, the definitions of all other indicators are mostly plant specific or in some cases country specific. In several countries efforts have been made and are still ongoing to coordinate the selection and specification of safety performance indicators on a country wide basis.

The basic application of performance indicators by the utility companies has three different main objectives as follows:

- The supervision and guidance of the plants and units within the utility companies with the following purposes:
  - Performance supervision within departments and sections of the plant
  - The application as a management tool within the integrated management systems
- The direct comparison of plant performance with other plants on an international basis
- The documentation of plant performance for the regulatory organization

The utilities are supporting an approach on two tracks as follows, of which the first one should be prioritized to allow an early start with the deterministic indicators.

Development of a standard set with a limited number of indicators for world wide application

Many utilities see a potential for a broadened use of performance indicators including SPIs. The number of indicators should be limited, in order to avoid too much extra burden on the organizations (approximately 15 to 20 SPIs are envisioned as a realistically manageable number). Such a set of SPIs could preferably be based on SPIs already in use or proposed in work previously performed, such as the WANO set of PIs or the IAEA approach [3].

Based on those SPIs an optimal new set could be selected based on an integrated view of safety relevant attributes. Defining which those attributes should be needs additional research. Guidelines would need to be developed considering utility as well as regulatory requirements, including definition of the user groups (that could include utilities; utilities and regulators; utilities, regulators and the public).

A SPI system for utility use may not require common thresholds being defined. A use of color codes would of course be based on quantitative measures, but for utility use it is not necessary to couple the levels to specific actions to be taken. Several utilities mention in the questionnaire that one of the major purposes of their SPI system is to focus attention and trigger discussions during management meetings. By regular use and presentation of SPIs to the staff as well as to management it can be shown that there is a focus on safety (as well as on other areas, compare the use of Balanced Scorecards).

Regulators probably need to be stricter when it comes to actions to be taken at certain threshold levels, if using SPIs for their inspections or communications with the plants.

Development of risk-based indicators

For nearly all nuclear power plants - in most cases plant specific - PSAs (of varying completeness) have been performed. In an increasing number of countries PSAs have to be submitted by the utilities in the regulatory framework [8]. Many utilities make use of PSA results for optimizing system design and plant operation under safety aspects. PSA methods are routinely used also in "accident precursor studies" in order to evaluate the safety significance of abnormal events. Insights from the available PSAs can be used in developing and applying risk-based SPIs. PSA methodology is also required to set action levels (or thresholds) for individual SPIs within internal utility self-assessments or for regulatory use.

The use of risk-based SPIs enhances any "risk-informed" safety evaluation and decision making process, which also makes use of other information and criteria. This use of other information helps compensate for the known limitations of PSA (such as incompleteness of scope) whilst maintaining the broad consensus that fundamental safety requirements – like defense-in-depth and sufficient safety margins - have to be maintained independent from quantitative risk considerations ([9]). "Risk-informed" decision-making processes require integrated safety assessments, using probabilistic as well as deterministic methods.

German utilities – on request of the regulator - are currently developing a "safety management system" (SMS) to be supported by quantitative (safety) performance indicators [10]. The "safety management system" will constitute an essential part of an integrated quality management system. In this context it is argued, that SPIs – to be really useful - have to be integrated into the management process, which - being a closed loop - needs a feedback element in order to identify deviations from the intended goals and to trigger the necessary improvements. It is obvious that such kind of indicators have to be calibrated by establishing their quantitative correlation with safety (resp. risk).

CONCLUSIONS

A Concerted Action (CA), sponsored by the European Commission within its 5th Framework Program, has successfully promoted co-operation between eleven partners, including regulators, utilities and support organizations from eight countries. The CA has reviewed and evaluated the existing approaches to defining and using Safety Performance Indicator (SPI) systems, and resulted in a number of recommendations on research needs in order to establish a comprehensive SPI system, taking into account risk information and influences from management, organization and safety culture on plant safety.

By means of a questionnaire information was collected from both regulators and utilities on their experience, needs and uses of SPIs for decision making. Almost common agreement has been found that it should be possible to establish a relationship between SPIs and risk.

Overall findings have been listed on the candidate methods/approaches for the structure, selection and reporting of risk-based SPIs, including the delineation of specific recommendations for the development and implementation of guidelines and strategies for risk-based SPIs, relative to the needs of the European regulators and utility organizations. In addition, recommendations have been developed to include the key attributes of a "risk-based" safety performance monitoring system, including interface requirements between the operators/licensees and regulators.

Several experts were summoned in a workshop, organized within this CA, to discuss how MOSC influences could be make part of a SPI system. As a result of this workshop and of the further research undertaken, several recommendations were obtained, including a plan to enable inclusion of key event forerunners into SPI systems, where a two-step approach is recommended, consisting of a review of existing event reports to identify MOSC forerunners and a review of existing reliability data to identify MOSC influences. Additionally it is recommended to develop methods for inclusion of MOSC influences into PSAs, as PSA provides a complete and integrated means available for the quantitative assessment of nuclear power plant safety performance.

SPIs can help to enhance the efficiency and effectiveness of nuclear regulators by helping focus their activities on safety-significant issues in such fields as periodic safety evaluations, reporting and inspections. Several research areas have been identified to help to define a useful approach for the application of SPIs by regulators, including the very definition of the structure of the SPI system, and the thresholds that would trigger regulatory actions..

Nuclear utilities apply SPI for the following purposes: the supervision and guidance of the plants and units within the utility companies, the direct comparison of plant performance with other plants on an international level, and the documentation of plant performance for the regulatory organizations. Needs and possibilities for further developments of these applications have been identified.

In a final workshop hosted by the European Commission, the conclusions of this CA have been presented to the international community.

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