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Operational safety performance indicators for nuclear power plants

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FOREWORD

Since the late 1980s, the IAEA has been actively sponsoring work in the area of indicators to monitor nuclear power plant (NPP) operational safety performance. The early activities were mainly focused on exchanging ideas and good practices in the development and use of these indicators at nuclear power plants.

Since 1995 efforts have been directed towards the elaboration of a framework for the establishment of an operational safety performance indicator programme. The result of this work, compiled in this publication, is intended to assist NPPs in developing and implementing a monitoring programme, without overlooking the critical aspects related to operational safety performance.

The framework proposed in this report was presented at two IAEA workshops on operational safety performance indicators held in Ljubljana, Slovenia, in September 1998 and at the Daya Bay NPP, Szenzhen, China, in December 1998. During these two workshops, the participants discussed and brainstormed on the indicator framework presented. These working sessions provided very useful insights and ideas which where used for the enhancement of the framework proposed. The IAEA wishes to acknowledge the support and contribution of all the participants in these two activities.

The programme development was enhanced by pilot plant studies. Four plants from different countries with different designs participated in this study with the objective of testing the applicability, usefulness and viability of this approach. The IAEA gratefully acknowledges the work developed and the effort made by the four participating plants.

The work performed by all the participating experts, and the comments and ideas contributed by worldwide experts on operational safety are greatly appreciated. The IAEA officers responsible for this report were A. Gómez Cobo and J. Hashmi of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

The safe operation of all nuclear power plants is a common goal for all involved in the nuclear industry. However, as a concept, safety is not easy to define. Even more difficult is the establishment of a clear definition of an adequate level of safety. Nonetheless, there is a general understanding of what attributes a nuclear plant should have in order to operate safely. The challenge lies in measuring the attributes.

A high level of safety is the result of the complex interaction of good design, operational safety and human performance. Experience has shown that focusing on any single aspect of performance is ineffective, and can be misleading. What is more valid is the total picture presented by a complete set of indicators designed to monitor all aspects of operational safety performance. This report attempts to provide a framework for identification of performance indicators which have a relationship to the desired safety attributes, and therefore to safe plant operation.

The actual values of the indicators are not intended to be direct measures of safety, although safety performance can be inferred from the results achieved (Fig. 1). The numerical value of any individual indicator may be of no significance if treated in an isolated manner, but may be enhanced when considered in the context of other indicator performances. On the other hand, specific indicator trends over a period of time can provide an early warning to plant management to investigate the causes behind the observed changes. In addition to monitoring the changes and trends, it may also be necessary to compare the indicators against identified targets and goals to evaluate performance strengths and weaknesses. Each plant needs to determine which indicators best serve its needs. Selected indicators should not be static, but should be adapted to the conditions and performance of the plant, with consideration given to the cost/benefit of maintaining any individual indicator.

In the past the nuclear industry has often looked upon safety and production as conflicting objectives. However, the operating experience developed over the past thirty years has led the industry to understand that this is not so. In fact, plants with excellent safety records also tend to be good performers. Therefore, a complete set of parameters to monitor NPP performance should include both safety and economic performance indicators. Nonetheless, the objective of this report is to identify a set of indicators to monitor performance in areas that directly affect the operational safety of the plant. Thus, purely economic indicators have not been included.

It should be recognized that while indicators provide valuable information in the effective management of plant performance, they are but one of a larger set of tools — including PSA, regulatory inspection, quality assurance and self-assessment — that can be used by nuclear plant operators to assess operational safety performance. The integration of information compiled through the application of all such evaluation tools will yield the best results.

Two areas of increasingly common application are “risk based” indicators, and “safety culture” indicators. A brief introduction to safety culture indicators is presented in Annex I. Annex II deals with risk based indicators.

The work developed during the IAEA project on ‘‘operational safety performance indicators’’ and presented in the following Sections was enhanced by pilot plant studies. Four plants from different countries with different designs participated in this study with the objective of testing the applicability, usefulness and viability of this approach. Information on these pilot exercises is compiled in Annex III.

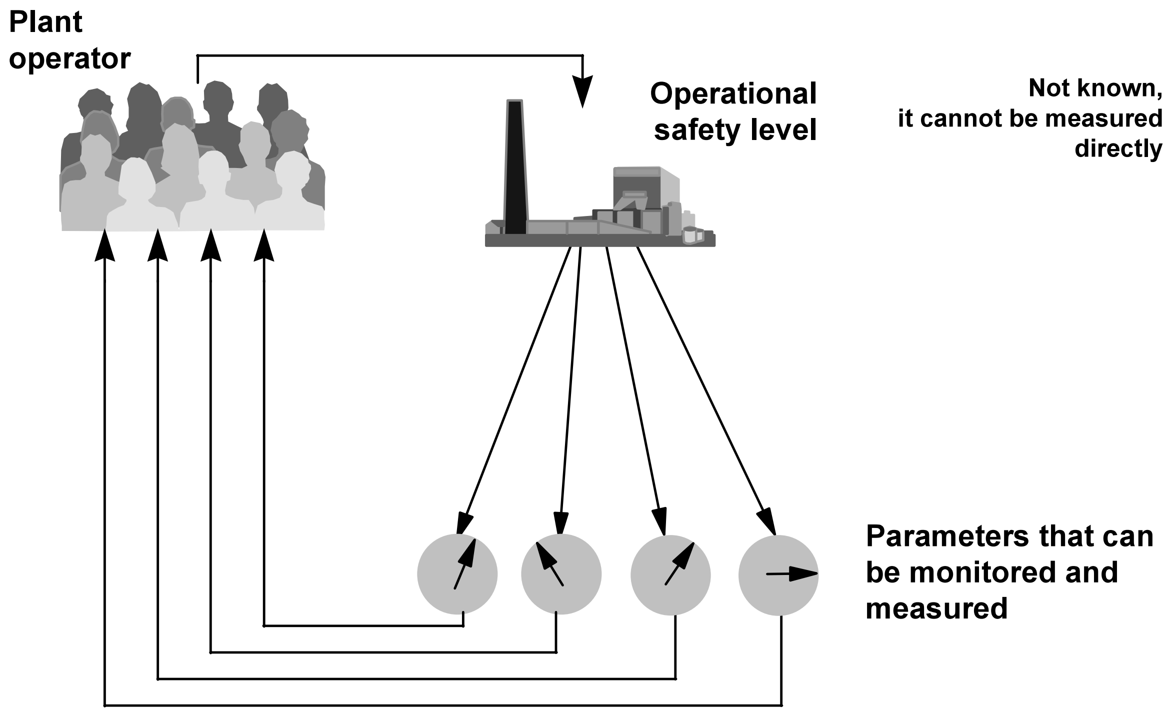

FIG. 1. Inferring safety performance from the information provided by the indicators.

2. PLANT SAFETY: SAFETY ATTRIBUTES

The development of the IAEA framework began with the consideration of the concept of nuclear power plant safety performance. To ensure a reasonably complete set of operational safety indicators, a decision was made to work down a "structure" in which the top level would be operational safety performance and the next level would be *operational safety attributes*, from which a set of *operational safety performance indicators* could be developed (see Fig. 2).

In defining the key attributes, it was necessary to determine the key elements associated with plants that operate safely. Three important aspects were addressed — *nuclear power plant normal operation*, *nuclear power plant emergency operation*, and the *attitude of nuclear power plant personnel towards safety*. On this basis three key attributes were chosen that are associated with plants that operate safely:

- Plants ***operate smoothly***.
- Plants ***operate with low risk***.
- Plants ***operate with a positive safety attitude***.

Because these attributes cannot be directly measured, the indicator structure was expanded further until a level of easily quantifiable or directly measurable indicators was identified (see Fig. 3).

3. OPERATIONAL SAFETY PERFORMANCE INDICATORS: A HIERARCHICAL STRUCTURE

Using the attributes as a starting point for indicator development, a set of *operational safety performance indicators* were identified. Below each attribute, *overall indicators* were established. Associated with each overall indicator was a level of *strategic indicators*. Finally, each strategic indicator was supported by a set of *specific indicators*, most of which are already in use in the industry[1]. Indicators were developed one level at a time to ensure that all relevant safety aspects of each attribute were covered.

The *overall or key indicators* were envisioned to provide overall evaluation of relevant aspects of safety performance. *Strategic indicators* were intended to provide a bridge from overall to specific indicators. *Specific* or *plant specific indicators* represented quantifiable measures of performance. Specific indicators were chosen for their ability to identify declining performance trends or problem areas quickly so that after proper investigation, management could take corrective actions to prevent further performance degradation.

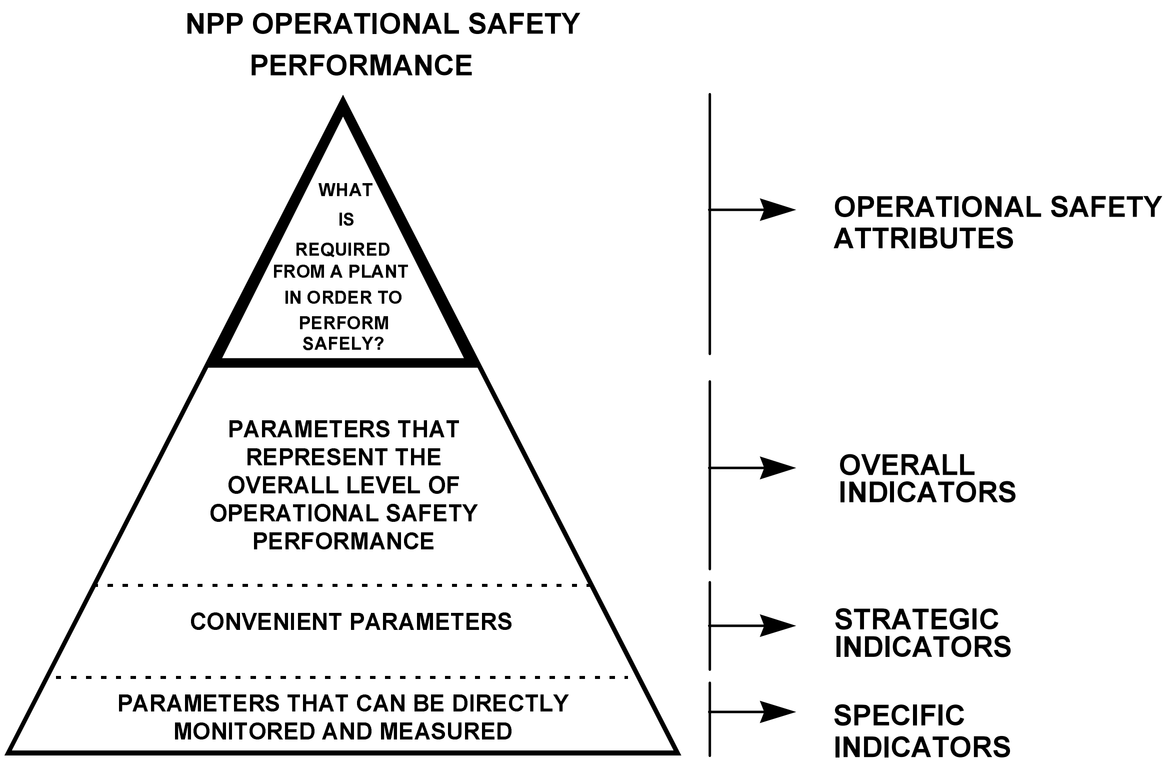

FIG. 2. An approach to monitoring NPP operational safety performance.

[1] The early IAEA activities on operational safety performance indicators showed the need for defining low level indicators which would be closely related to individual plant programmes. Bearing this in mind, two consultants' meetings were organized in 1991. The objective of these two meetings was to provide guidance for the development and use of plant specific indicators in the area of operational safety. During these two meetings, a preliminary concept for the indicator framework (overall indicators — strategic indicators — specific indicators) was developed and a set of examples was provided.

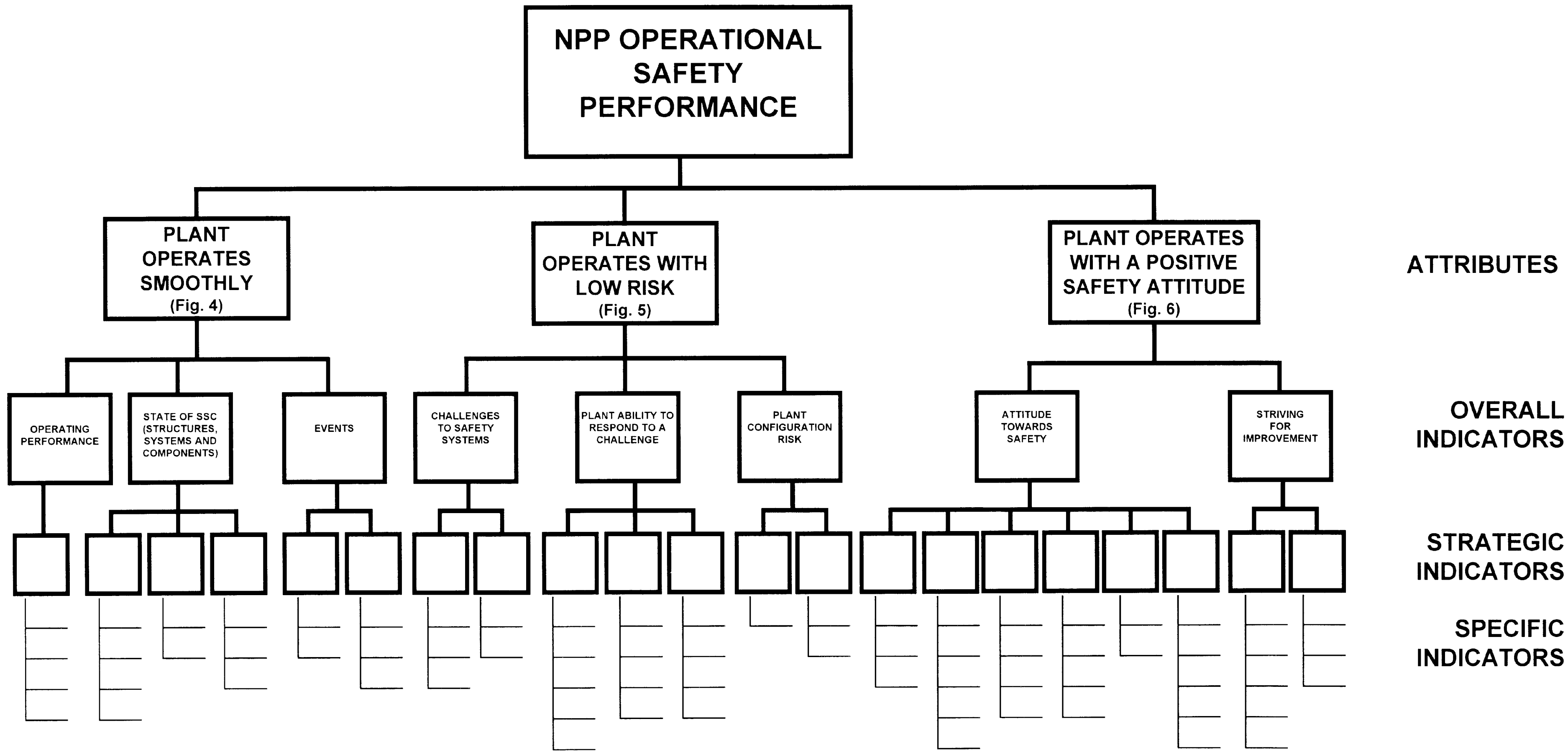

FIG. 3. Operational safety performance indicator framework.

In the original conception of this design, there was no intention to propose an aggregation of data from lower levels (*specific indicators*) to obtain a quantifiable value for the higher levels indicators (*strategic and overall indicators*). The intention was to use quantitative information provided by the specific indicators to analyse performance trends relative to established goals. Evidence of declining performance would then be utilized to develop a qualitative indication of performance at higher levels. However, some of the plants participating in the pilot studies (see Annex III) chose to assign quantitative values to each specific indicator, based on performance relative to the goal. These values were then aggregated by some means to derive a quantitative value for the higher level indicators and attributes. Annex III provides examples of the various means by which some of the pilot plants aggregated data for the purpose of performance assessment. Plants contemplating implementation of this programme are encouraged to adopt the specific method of data evaluation that best supports plant specific needs and resources.

The World Association of Nuclear Operators (WANO) has developed a set of ten performance indicators in use by all nuclear power plants. Where possible, these indicators have been proposed as specific indicators, as they are already in use and require no additional effort on the part of nuclear plant personnel. Where reference to WANO indicators has been made, the intent is to use the WANO definitions.

The following sections describe, for each safety attribute, the related overall and strategic indicators, and provide several examples of specific indicators. The indicators chosen are considered the most adequate parameters to assist in monitoring the safety attributes. However, it is important that each plant develop a programme that reflects its own specific needs. The suggested performance indicator framework is depicted in Figs 3–6 and AII-1. Examples and definitions of the specific indicators chosen are provided below.

3.1. PLANT OPERATES SMOOTHLY

Figure 4 shows the overall indicators chosen to represent the degree of smoothness with which the plant operates. These indicators are *'operating performance', 'state of SSC (structures, systems and components)',* and *'events'*.

3.1.1. Overall indicator: Operating performance

The first means of preventing accidents is to strive for high quality plant operations with infrequent deviations from the normal operational state. Normal operating systems take care of the power production in the nuclear power plant. The states of normal operation pose no challenge to the safety of the plant.

The plant disturbances are predominately caused by equipment failures in process or automation systems and by errors in testing, maintenance and operations. The challenges arising from anticipated abnormal occurrences would be countered in a straightforward manner by an appropriate response of normal plant systems.

One strategic indicator is defined here as appropriate to monitor this area.

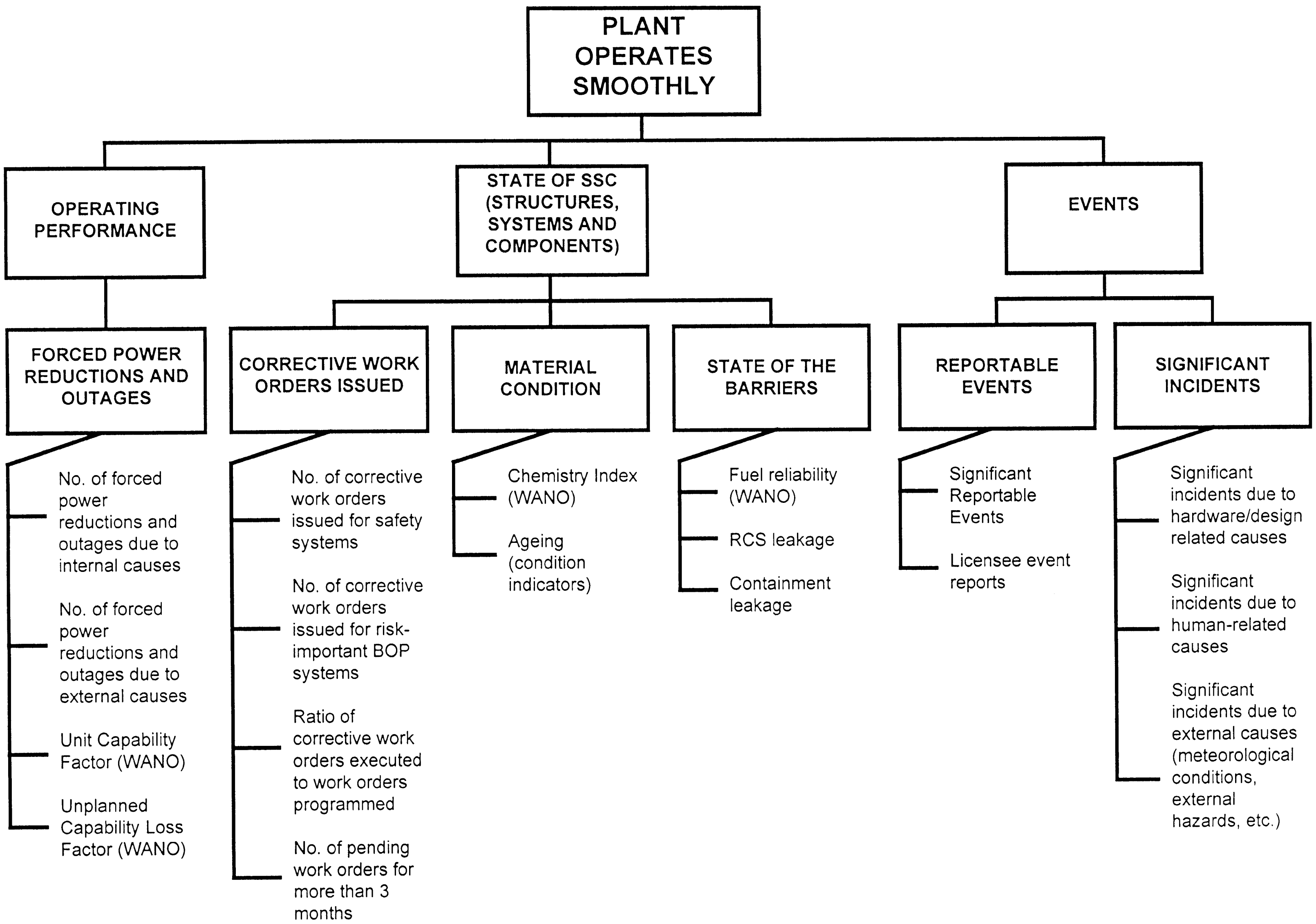

FIG. 4. Operational safety performance attribute "Plant operates smoothly".

3.1.1.1. Strategic indicator: Forced power reductions and outages

This measure addresses forced power reductions of some predefined percentage or more and forced outages.

Any operation at a power level less than the planned power level is considered a power reduction. The minimum power reduction that is reasonable to measure should be considered specifically by each plant.

Some forced power reductions and outages can be caused by conditions which are not under the control of plant management. An ideal indicator would take this into account.

Four examples of specific indicators are proposed:

Specific indicator: number of forced power reductions and outages due to internal causes.

Specific indicator: number of forced power reductions and outages due to external causes.

The number of forced power reductions and outages due to internal causes reflects the overall quality of plant operations and maintenance, and is directly tied to the ability of the licensee to maintain the reliability of systems, components and to operate the plant within its design limitations. The grid instability or failure is an example of external cause for a forced power reduction or outage. A more detailed and plant specific categorization of the forced power reductions and outages according to causes, for instance, gives more information about possible actions to be taken.

Specific indicator: unit capability factor (WANO performance indicator).

Specific indicator: unplanned capability loss factor (WANO performance indicator).

3.1.2. Overall indicator: State of structures, systems and components (SSC)

The detection and correction of deficiencies is a part of normal day to day activities at a nuclear power plant. The objective of a plant maintenance programme is to preserve the inherent reliability, availability, and safety of plant structures, systems and components, and to restore the reliability and availability of plant structures, systems and components when they become degraded. Maintenance includes preventive, predictive, and corrective maintenance as well as surveillance activities and all activities associated with placing systems out of service and returning them to service in order to perform maintenance. Operations and maintenance personnel are responsible for assuring the operability of plant components, systems and structures.

Measures of the status of the SSC reflect the contribution of the maintenance programmes to the plant safety performance through the reliability of plant components, systems and structures.

In addition to a good and efficient maintenance programme, as described above, a good control of the chemistry in the plant will help to ensure that the life of safety related equipment will be as long as expected by the equipment design.

Three strategic indicators related to the overall indicator 'state of equipment structures, systems and components' are defined, i.e. *'corrective work orders issued', 'material condition'* and *'state of the barriers'*.

3.1.2.1. Strategic indicator: Corrective work orders issued

A maintenance work order is a work package used to direct and document maintenance activities. Usually a corrective work order is issued for all troubleshooting, corrective maintenance and minor modifications. A large amount of corrective maintenance may reflect potential reliability problems, but, also, maintenance deficiencies.

Four examples of specific indicators are proposed:

Specific indicator: number of corrective work orders issued for safety systems.

A high number of corrective work orders issued for safety or safety related systems mean a clear deterioration of the systems reliability.

Specific indicator: number of corrective work orders issued for risk important BOP systems.

Some BOP systems are safety related or risk significant in the sense that deficiencies in their performance can not only lead to reactor scrams and plant transients but also jeopardize the plant ability to respond to disturbances. Therefore this indicator provides a measure of the deterioration of the BOP systems that are risk significant. Each plant will have to decide which systems should be included in the framework of this indicator.

Specific indicator: ratio of corrective work orders executed to work orders programmed.

A high number in this indicator indicates an effective maintenance programme and thus gives confidence that the equipment is adequately being looked after.

Specific indicator: Number of pending work orders for more than 3 months.

A high number in this indicator indicates an inefficient maintenance programme and thus gives an alarm that equipment is not being adequately looked after.

3.1.2.2. Strategic indicator: Material condition

A good control of the plant chemistry and the ageing will help to ensure equipment life according to the design.

Two examples of specific indicators are proposed:

Specific indicator: Chemistry Index (WANO performance indicator).

Specific indicator: ageing related indicators (condition indicators).

Finding adequate ageing related plant specific indicators does not, at the moment, appear to be a very easy task. Each plant that decides to implement ageing related indicators will have to define them, probably based on the approaches they use to diagnose the condition of the SSC.

3.1.2.3. Strategic indicator: State of the barriers

Defence in depth is one of the basic principles of nuclear power plant safety. In order to avoid contamination of the environment and radioactive doses to the public, the source of the risk needs to be isolated by concentrically located barriers: cladding, primary coolant boundary and containment. Therefore, it is very important to establish indicators that help to monitor the state of these barriers.

Three examples of specific indicators are proposed:

Specific indicator: fuel reliability (WANO).

Specific indicator: RCS leakage.

Specific indicator: containment leakage.

3.1.3. Overall indicator: Events

Every event is an indicator of some plant deficiency. There are different types of events with causes of various nature and different level of safety impact. Those events which expose equipment deficiencies would also be noted by the overall indicator described in Section 3.1.2. Some events could challenge multiple plant systems and cause disturbances that may not be easily mitigated. The safety significance of an event can be minimal (e.g. the failure of a single fuse, leading to no consequence) or significant, as e.g. the failure of an entire safety system.

Fire events are not explicitly included as indicators in this part of the framework. It is recognized that fire events can have high safety significance but, on the other hand, the number of fires in nuclear power plants is, in general, small and, for many plants, probably, not significant enough to be tracked as an indicator. However, there are other lower level fire-related events that, if monitored, could provide an early indication of future problems in relation to "fire safety". Therefore, the plant has to decide whether to include fire related indicators in their operational safety indicator system.[2]

Two strategic indicators are defined, i.e. '*reportable events*' and '*significant incidents*'.

3.1.3.1. Strategic indicator: Reportable events

The intent of this strategic indicator is to monitor those events that are considered to have higher safety significance, namely those of interest to other organizations, such as the specific regulatory body or other nuclear operators through WANO, events in IAEA-INES scale of level 1 or higher, etc.

Two examples of specific indicators are proposed:

Specific indicator: significant reportable events.

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[2] A discussion of fire related indicators is provided in Appendix I of IAEA-TECDOC-1134, Use of Operational Experience in Fire Assessment of Nuclear Power Plants, IAEA, Vienna (2000).

The criteria for selecting the events to account for in this indicator could be, for example, events in the IAEA-INES scale of level 1 or higher.

Specific indicator: licensee event reports.

This indicator will be defined according to country specific regulations.

3.1.3.2. Strategic indicator: Significant incidents

The intent of this strategic indicator is to account for those events that, even though they are not necessarily reportable (externally), are still significant according to plant specific selected criteria.

Three examples of specific indicators are proposed:

Specific indicator: significant incidents due to hardware/design related causes

Specific indicator: significant incidents due to human related causes.

Specific indicator: significant incidents due to external causes (i.e. meteorological conditions, external hazards, etc.).

These indicators should be defined according to plant specific criteria.

3.2. PLANT OPERATES WITH LOW RISK

This safety attribute considers the overall risk of the plant and can be monitored using the traditional deterministic approach and the probabilistic approach (see Fig. 5). Therefore, the proposed framework needs to present both approaches for monitoring this safety attribute. It should be noted that the probabilistic and deterministic approaches, as discussed in this document, are not mutually exclusive, but rather, complementary.

3.2.1. Deterministic approach

The safety attribute 'plant operates with low risk' considers the overall risk of the plant and can be monitored by three overall indicators, the number of *'challenges to safety system',* the *'plant ability to respond to such challenges'* and the *'risk associated to the plant configuration'.*

3.2.1.1. Overall indicator: Challenges to safety systems

This overall indicator is directly related to plant safety. A low number of challenges translates into a lower possibility of having nuclear transients and/or accidents due to a reduced number of accident initiators.

In order to produce *plant specific indicators* that are meaningful, each plant should decide how to group the *challenged systems* according to a clear definition of safety system boundary. However, it seems appropriate to separate the *specific indicator* related to the RPS/ECCS/emergency electric power supply systems from the specific indicators related to other safety related systems.

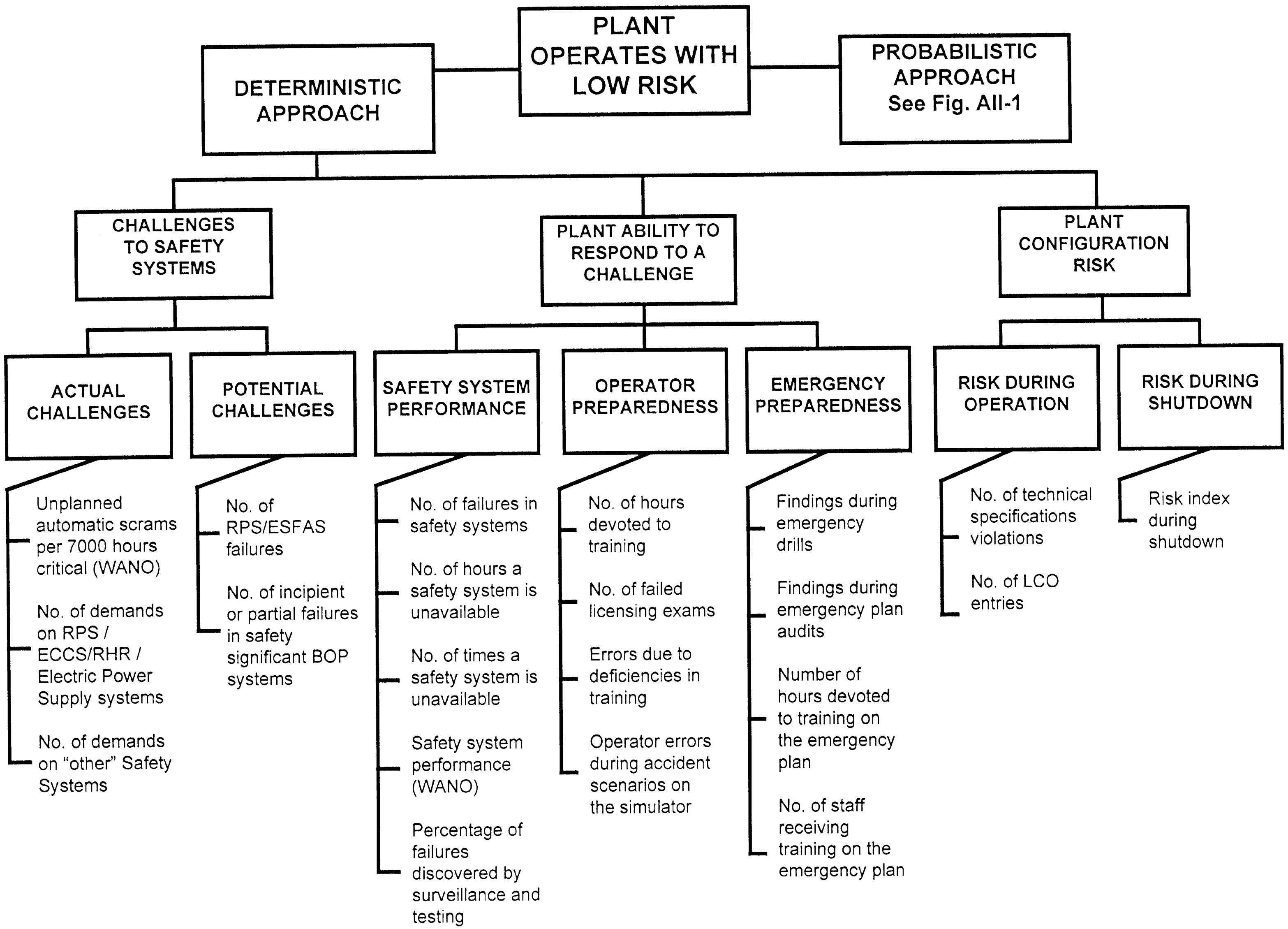

FIG. 5. Operational safety performance attribute "plant operates with low risk".

Two strategic indicators are proposed, i.e. *'actual challenges'* and *'potential challenges'*.

3.2.1.1.1. Strategic indicator: Actual challenges

Within this strategic indicator, the following examples of specific indicators are proposed:

Specific indicator: unplanned automatic scrams per 7000 hours critical (WANO performance indicator).

Specific indicator: number of demands on RPS/ECCS/RHR/emergency power supply systems.

It gives a direct indication of the number of challenges to the systems that support the reactivity control safety function, challenges to the systems which support the control of inventory and core cooling safety functions and challenges to safety related power supply systems.

Specific indicator: number of demands on "other" safety systems.

It gives a direct indication of the number of challenges to other safety related systems. All automatic and spurious actuations are counted. Each plant has to determine which systems to include, based on a risk related rationale.

3.2.1.1.2. Strategic indicator: Potential challenges

Looking at the actual challenges to safety systems may not provide a very useful measure, since, in general, the number of challenges to safety systems is very small. More and more plants look at low level events in order to get an early warning of future challenges.

The proposed indicators aim at monitoring *low level events* that might, in principle, not appear important since they do not seem to pose significant challenges to the plant. However, since they give an early warning of future plant challenges, it seems clear that their contribution to the risk may not be negligible. It should be noted that that the *number of near misses* could also be included as an example of specific indicator in the area of plant challenges; however, the difficulty for providing an unambiguous definition and the difficulty of monitoring this indicator need to be acknowledged.

Specific indicator: number of RPS/ESFAS failures.

This indicator is an indirect way of monitoring the number of spurious scrams or spurious safety system actuations. Due to the fact that the number of scrams is usually very low, counting the number of RPS/ESFAS failures found, for example, during tests or during normal operation, can be a useful indicator for an early detection of deficiencies that could cause a scram later in time.

Specific indicator: number of incipient or partial failures in safety significant BOP systems.

This indicator is another indirect way of monitoring the number of scrams. Due to the fact that the number of scrams is usually very low, accounting for the number of this type of precursors (BOP failures detected during normal operation or during tests) can be a useful indicator for an early detection of deficiencies that could cause reactor scrams later in time. Each plant has to determine which systems to include, based on a risk related rationale and on the knowledge of which systems failures would lead to a reactor trip.

3.2.1.2. Overall indicator: Plant ability to respond to a challenge

When a challenge to the plant occurs, the plant should respond in such a way as to prevent any damage to the reactor core, and in the event that some damage occurs, the plant should mitigate the consequences to prevent radioactive releases to the environment. Furthermore, in the event that some radioactive releases to the environment occurs, it is necessary to protect public health and safety.

Three strategic indicators are proposed, i.e. *'safety system performance', 'operator preparedness'* and *'emergency preparedness*'.

3.2.1.2.1. Strategic indicator: Safety system performance

Safety system performance is of obvious importance to plant safety. The unavailability can arise from different sources such as the following:

- unavailability during the performance of surveillance tests;
- unavailability during the performance of maintenance;
- unavailability due to human errors during the performance of tests or maintenance activities (for example components left in wrong positions after maintenance activities);
- unavailability due to equipment failures.

In order to produce plant specific indicators that are meaningful, each plant should decide how to group the safety significant systems for the purpose of accounting for *system failures or system unavailabilities* (i.e. considering the ECCS as a whole vs. treating high pressure safety injection and low pressure safety injection systems independently or even going further to define train level indicators. In other words, indicators may be produced at the safety function level, system level or train level, division level, etc.).

Five examples of specific indicators are proposed:

Specific indicator: number of failures in safety systems.

It gives an indication of the safety system reliability.

Specific indicator: number of hours a safety system is unavailable.

It gives an overall indication of the readiness of stand-by safety systems to respond to challenges to the plant. It is desirable that each safety system be monitored with its own indicator. In order to increase the number of occurrences to measure (and therefore have a more sensitive indicator) the hours of unavailability at the train level can be monitored. Additionally, each plant may consider further subdivision of this indicator based upon the root causes of system unavailabilities. By unavailability it is understood that the train is out of service and unable to comply with its safety function.

Specific indicator: number of times a safety system is unavailable.

This indicator is related to the previous one, but it accounts for the number of times a safety system is unavailable. The reason to monitor it separately is because for plants with the same number of hours of safety system unavailability, the plant that performs more maintenance activities has a higher probability of leaving equipment in the wrong position (misalignment errors).

Specific indicator: safety system performance (WANO performance indicator).

Specific indicator: percentage of failures discovered by surveillance and testing.

This indicator is a measure of the effectiveness of the plant programmes in identifying equipment problems before this equipment is required in real situations.

3.2.1.2.2. Strategic indicator: Operator preparedness

The operator actions during the course of an abnormal event can be such that they can exacerbate the progression of an accident. Therefore, indicators that monitor this domain can potentially detect areas of deficiency before they become a problem. It is difficult to define indicators in this area because of their intangible nature.

The following four examples of specific indicators are proposed:

Specific indicator: number of hours devoted to training.

This indicator refers to the training for control room personnel and other staff who, in a plant disturbance, have to be able to respond to such challenge. This indicator could be either an absolute value (i.e. hours per year) or a ratio between training hours and working hours. Each plant shall determine what plant staff and which training should be counted for this indicator.

Specific indicator: number of failed licensing exams.

This indicator is a measure of the quality of operator training and the selection process of the operator.

Specific indicator: errors due to deficiencies in training.

This indicator reflects the quality of training received by operators so that they are able to adequately address plant challenges.

Specific indicator: operator errors during accident scenarios in the simulator.

This indicator would require collection of data from simulator training. It is a measure of preparedness of the operators to cope with a variety of abnormal and/or accident situations.

3.2.1.2.3. Strategic indicator: Emergency preparedness

Emergency management is that last barrier to protect the public if an external radioactive release cannot be avoided. Therefore, the level of preparedness of the plant in order to cope with an emergency also provides a measure of the plant ability to respond to the challenges.

The following examples of specific indicators are proposed:

Specific indicator: findings during emergency drills.

Specific indicator: findings during emergency plan audits.

Specific indicator: number of hours devoted to training on the emergency plan.

Specific indicator: number of staff receiving training on the emergency plan.

3.2.1.3. Overall indicator: Plant configuration risk

Different plant configurations happen due to planned and unplanned maintenance activities, operational requirements and occurrence of operational events. It is well known that the risk associated to some plant configurations can be very high. Therefore, it is important to establish the means to monitor this parameter.

3.2.1.3.1. Strategic indicator: Risk during operation

The most adequate way to monitoring the risk during operation at power is the implementation and use of a PSA based risk monitoring system, as discussed in Annex II, however, such a tool is still not available in many nuclear power plants.

Even if a PSA or a risk monitor are not available and because of the safety significance of this parameter, it is necessary to find deterministic or engineering based indicators to monitor the risk of the plant during operation at power.

The following examples of specific indicators are proposed:

Specific indicator: number of technical specification violations.

This indicator has also been proposed as an example of indicators to monitor the level of compliance with procedures, rules and licensing requirements (see Section 3.3.1 below).

Specific indicator: number of LCO (limiting conditions for operation) entries.

3.2.1.3.2. Strategic indicator: Risk during shutdown

During shutdown the large amount of maintenance tasks performed and the combinations of system unavailabilities may lead to high risk configurations. An indicator of the level of risk during this operational state will promote risk awareness during shutdown and will help to minimize the hours spent in risk significant configurations during shutdown conditions.

Specific indicator: Risk index during shutdown.

Based on a deterministic defence in depth based approach (i.e. safety function fulfilment, technical specification requirements, single failure criteria, etc.) a measure of the risk associated with certain configurations can be defined.

3.2.2. Probabilistic approach

This attribute is quantifiable at a plant level by the estimated core damage frequency from a probabilistic safety assessment (PSA). Also, given the well defined structure of a PSA, probabilistic measures can be obtained at many different levels. All this probabilistic measures are potential candidates for the so called risk based indicators.

The indicators proposed, both for long term and short term evaluations, are described in Annex II.

3.3. PLANT OPERATES WITH A POSITIVE SAFETY ATTITUDE

Figure 6 shows the overall indicators chosen to monitor the attitude of the plant staff towards safety. These indicators are *'attitude towards safety'* and '*striving for improvement*'.

3.3.1. Overall indicator: Attitude towards safety

This overall indicator covers implementation and attitudes toward managerial programmes necessary to operate the plant in a safe manner, respecting administrative limits, with low impact on the health and safety of the plant workers. It consists of managerial and supervisory control, quality assurance programme implementation, adherence to licensing and/or technical specification requirements, and respect for internal procedures of the plant. Improper safety attitude would result in breakdown or lack of adequate management or supervisory control, breaches of operating, surveillance, or testing procedures, violation of technical specifications, QA/QC problems, etc.

Six strategic indicators are proposed, i.e. '*compliance with procedures, rules and licensing requirements', 'attitude towards procedures, policies and rules', 'radiation protection programme effectiveness', 'human performance', 'backlog of safety related issues'* and '*safety awareness*'.

3.3.1.1. Strategic indicator: Compliance with procedures, rules and licensing requirements

The purpose of the indicator is to assess how well personnel maintain the plant within licensing requirements and comply with other procedures and rules. Licensing requirements include technical specifications, FSAR licensing basis, QA programme, fire protection programme, emergency plan, and others, depending on the licensing policy of the country. As a vital part of safety culture, it is essential that plant personnel understand the reasons for the safe limits of operation and the consequences of license violations.

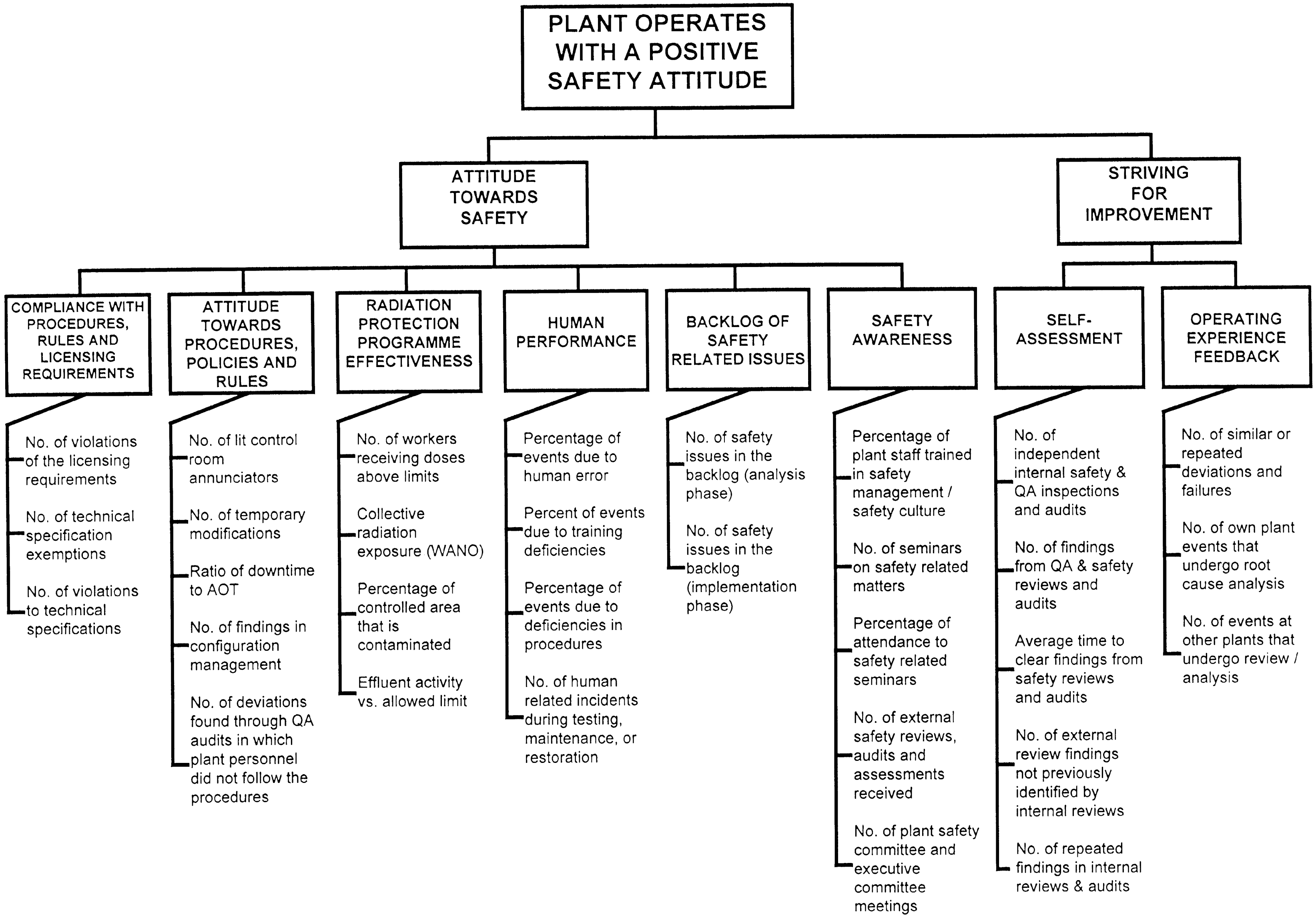

FIG. 6. Operational safety performance attribute "Plant operates with a positive safety attitude".

Three examples of specific indicators are proposed:

Specific indicator: number of violations of the licensing requirements.

The indicator measures the attitude of the personnel toward the importance of the licensing requirements. It also reflects the effectiveness and appropriateness of administrative controls.

Specific indicator: technical specification exemptions.

The purpose of this indicator is to ensure that the risk from potentially unsafe situations is minimized. A low number indicates that a pro-active approach is taken to problem solving.

Specific indicator: number of violations to technical specifications.

The indicator measures the attitude of the personnel toward the importance of the licensing requirements, specifically of the technical specifications. It also reflects the effectiveness and appropriateness of administrative controls.

3.3.1.2. Strategic indicator: Attitude towards procedures, policies and rules

This is an indication of the attitude of the personnel as a consequence of administrative control policies, level of safety culture, and/or adequacy of training.

Five examples of specific indicators are proposed:

Specific indicator: number of lit control room annunciators.

The purpose of this indicator is to measure the awareness of the operators of the importance of annunciators and the plant's response to operational deficiencies.

Specific indicator: number of temporary modifications.

This indicator gives a measure of the number of problems that have been temporarily solved and indirectly assesses the effectiveness in providing a permanent or definitive solution.

Specific indicator: ratio of downtime to allowed outage time (AOT).

The purpose of this indicator is to measure the effectiveness of managerial processes and controls and attitude of operators and maintenance personnel. This indicator can also be interpreted to mean the actual time in a technical specification LCO divided by the allowed LCO time.

Specific indicator: number of findings in configuration management.

This indicator is very important because it provides a direct measure of the consistency between the actual plant features and their documentation, and, therefore, it also provides an indirect measure of how well plant staff are informed of the current plant status.

Specific indicator: number of deviations found through QA audits in which plant personnel did not follow the procedures.

This indicator provides a measure of the compliance with procedures and an indirect measure of how much the procedures are followed by plant personnel.

3.3.1.3. Strategic indicator: Radiation protection programme effectiveness

This is an indication of the effectiveness of the radiation protection programme, of the appropriateness of administrative control and of the level of safety culture in the plant. These measures are directed towards control of the sources of radiation, to the provision and continued effectiveness of protective barriers and personal protective equipment, and to the provision of administrative means for controlling exposures of the personnel and contamination of materials and areas in the plant.

Four examples of specific indicators are proposed:

Specific indicator: number of workers receiving doses above limits.

This indicator is a measure of controls and verification activities and of adherence to the requirements of the radiation protection programme. Some plants may have internal limits that are lower than the limits imposed by law. In this case, the indicator should refer to the internal limits of the plant.

Specific indicator: Collective radiation exposure (WANO performance indicator).

Specific indicator: Percentage of controlled area that is contaminated.

This indicator reflects the effectiveness of the radiation protection programme in minimizing the spread of contamination by plant workers.

Specific indicator: Effluent activity vs. allowed limit.

This indicator provides a measure of public risk awareness.

3.3.1.4. Strategic indicator: Human performance

The purpose of this indicator is to monitor the influence of human factors on different safety related activities in the plant. It indicates the degree of importance of human errors in these activities.

Four examples of specific indicators are proposed:

Specific indicator: percentage of events due to human error.

This is a measure of the contribution of human errors to plant events. It indicates the degree of preparedness of operating personnel to handle routine tasks.

Specific indicator: percentage of events due to training deficiencies.

This is a measure of the contribution of the deficiencies in the training programmes to plant events. It has to be borne in mind that the preparation of training programmes is also a human activity and therefore deficiencies in training can be treated as part of the human performance area.

Specific indicator: percentage of events due to deficiencies in procedures.

This is a measure of the contribution of the deficiencies in the procedures to plant events. It has to be borne in mind that the preparation of procedures is also a human activity and therefore deficiencies in procedures can be treated as part of the human performance area.

Specific indicator: number of human related incidents during testing, maintenance, or restoration.

The number of human related incidents during test or maintenance activities gives an indication of the degree of proficiency of the plant personnel. The final objective is to count the events that result into train unavailability due to components left in the wrong position (breakers left open, mis-aligned valves, etc.). However, in order to increase the number of occurrences to be considered (and therefore have a more sensitive indicator), all types of maintenance related human incidents can be accounted for. An increase in this indicator draws attention to human behaviour problems.

3.3.1.5. Strategic indicator: Backlog of safety related issues

This indicator provides a measure of the problem solving capacity of the organization.

Two examples of specific indicators are proposed:

Specific indicator: number of safety issues in the backlog (analysis phase).

The indicator measures the total number of safety issues that are potentially applicable to the plant and have not been analysed in terms of their applicability and for which an action plan has not been drawn up. A consistent definition of what constitutes a safety issue needs to be followed by the organization.

To obtain more meaningful indicators, this indicator can be divided in three more specific indicators: *issues in backlog for more that three months, issues in backlog for more than six months, issues in backlog for more than a year.*

Specific indicator: number of safety issues in the backlog (implementation phase).

This indicator gives a measure of the total number of safety issues that have already been analysed and found applicable to the plant, but for which no action has been taken for their resolution.

To obtain a more meaningful set of indicators, this indicator can be divided in three more specific indicators: *issues in backlog for more that three months, issues in backlog for more than six months, issues in backlog for more than a year.*

3.3.1.6. Strategic indicator: Safety awareness

The purpose of this strategic indicator is to assess the level of interest in improving the knowledge of the staff in safety related matters, the openness towards external new ideas and in particular the interest in improving staff attitude towards nuclear safety.

Specific indicator: percentage of plant staff trained in safety management/safety culture.

This indicator gives a measure of the management's interest in spreading safety culture among the staff.

Specific indicator: number of seminars on safety related matters.

This indicator gives a measure of the plant management's interest in introducing new concepts and trends in safety culture among the plant staff and of the interest in "learning from others".

Specific indicator: percentage of attendance at safety related seminars.

This indicator gives a measure of the plant staff's interest in improving their knowledge in safety related matters.

Specific indicator: number of external safety reviews, audits and assessments received.

This indicator gives a measure of the plant management's interest in finding their deficiencies based on the experience provided by other experts external to the plant. It measures the level of "openness" and of the interest in learning and improving the self-assessment practices.

Specific indicator: number of plant safety committee and executive committee meetings.

This indicator gives a measure of the plant management's and plant owner's interest in following and taking decision making actions on safety related activities, issues and events.

3.3.2. Overall indicator: Striving for improvement

Striving for improvement means the plant has established a strong positive safety culture where continuous improvement is the expected behaviour and a commitment of all employees. Deficiencies in this area are manifested in poor safety reviews and audit programmes, inadequate implementation of operating experience feedback, a lack of or incomplete root cause analyses, low effectiveness in clearing safety review and audit findings and poor communications between levels in the organization.

Figure 6 shows the two strategic indicators proposed, i.e. *'self-assessment'* and *'operating experience feedback'*.

3.3.2.1. *Strategic indicator: Self-assessment*

Safety reviews and audits are very important part in the framework of the plant self-assessment activities. Internal safety reviews and audits are performed to assess effectiveness of the plant programmes and procedures, to verify by examination and evaluation of objective evidence whether elements of the programmes and procedures conform to specified requirements, to assess the effectiveness of controls and verification activities, to report findings and deficiencies to all levels of management who need to be informed and who take corrective action, and to verify that corrective actions have been planned, initiated, or completed.

Five examples of specific indicators are proposed:

Specific indicator: number of independent internal safety and QA inspections and audits.

Internal safety and QA inspections and audits are important tools for improving plant safety and correcting deficiencies. The number of such reviews and audits will be based upon management policy, the evaluation of results of previous reviews and audits, as well as regulatory requirements. The purpose of the indicator is to assess the fulfilment of the scheduled safety review and audit programme.

Specific indicator: number of findings from QA and safety reviews and audits.

This indicator gives a measure of the deficiencies found in safety related matters. It also provides an indirect measure of the efficiency of the inspection and audit processes.

Specific indicator: average time to clear findings from safety reviews and audits.

The purpose of the indicator is to assess the effectiveness in clearing safety review and audit findings.

Specific indicator: number of external review findings not previously identified by internal reviews.

This is a measure of the effectiveness of the self-assessment activities.

Specific indicator: number of repeated findings in internal reviews and audits.

This indicator provides a measure of the effectiveness of the self-assessment activities and of the troubleshooting actions, i.e. to reach the root cause of the problems and implement the adequate remedies. It also provides information on the quality and completeness of the internal review and audit programmes.

3.3.2.2. *Strategic indicator: Operating experience feedback*

Operating experience feedback (OEF) results from reviews of actual events which have happened either at the plant or at other installations. The purpose of OEF is to identify potential vulnerabilities and to improve the operational safety level of the plant. OEF is used also to improve training, to identify the need for plant modifications, and to improve operating instructions. Failure to apply lessons learned from the OEF system or its inadequate implementation would be manifested by occurrence of events similar to those which have happened previously.

Three specific indicators are proposed:

Specific indicator: number of similar or repeated deviations and failures.

This is an indication of the quality of operating experience and particularly of root cause analysis feedback. Deviations and failures considered are those which happened during operation, were noted during shutdown or discovered during inspection that challenged nuclear safety

Specific indicator: number of own plant events that undergo root cause analysis.

Specific indicator: number of events at other plants that undergo review/analysis.

Root cause analyses and reviews are aimed at addressing the latent weaknesses and the management programmes that failed to detect the latent weaknesses. The indicator is a measure of effectiveness and appropriateness of the feedback of operating experience.

4. OPERATIONAL SAFETY PERFORMANCE INDICATORS: CHARACTERISTICS

In the implementation of a programme to monitor operational safety performance, consideration should be given to the quality of the information that each indicator provides. Earlier activities performed under the auspices of the IAEA on "development of operational safety indicators to be used as a prevention tool" identified a set of ideal characteristics of operational safety indicators. Based upon this guidance, the following characteristics are suggested:

- there is a direct relationship between the indicator and safety,
- the necessary data are available or capable of being generated,
- indicators can be expressed in quantitative terms,
- indicators are unambiguous,
- their significance is understood,
- they are not susceptible to manipulation,
- they are a manageable set,
- they are meaningful,
- they can be integrated into normal operational activities,
- they can be validated,
- they can be linked to the cause of a malfunction,
- the accuracy of the data at each level can be subjected to quality control and verification, and
- local actions can be taken on the basis of indicators.

In addition to these characteristics, indicators chosen to support an operational safety monitoring programme should include a combination of indicators that reflect actual performance (*sometimes called lagging indicators*), and those that provide an early warning of declining performance (*sometimes called leading indicators*). Specific indicators should capture lower level problems to allow for timely identification and intervention that can prevent more significant events.

When properly used, indicators are a valuable tool for operating nuclear power plants safely. When used improperly, undue pressure may be applied to plant personnel resulting in management or manipulation of the indicators, rather than performance assessment. In fact, improper use of operational safety performance indicators can result in actions that are not in the best interests of reactor safety. The effectiveness of plant management in promoting the use of indicators as a tool for performance improvement is vital to the success of any operational safety performance monitoring programme.

5. CONCLUSIONS

This report represents the culmination of a four year effort to develop a comprehensive framework for the development of a programme to monitor nuclear plant operational safety performance. The framework was derived from the concept that, while safety is difficult to define, it is easy to recognize. By pinpointing the attributes associated with plants that operate safely, it is possible to define objective measures of operational safety performance.

The programme development has been enhanced by pilot plant studies, conducted over a 15 month period from January 1998 to March 1999. One of the final conclusions reached by the participating plants is that the proposed framework provides a good approach. It is interesting to note that while each plant utilized the proposed indicator framework as a starting point, individual plant programmes were adapted to meet plant specific needs. Despite changes in the selection of indicators, all of the plants involved chose to maintain the basic indicator organization, thus providing validation for the concept.

Additional indicators to address organizational attitude may enhance the proposed framework. Indicators related to industrial safety attitude and performance, staff welfare, and environmental compliance, while not contributing directly to issues of operational safety, may be valuable in some environments as measures of overall organizational attitude. Plants may choose to consider such additions to the IAEA proposed framework as needs dictate.

Annex I

A BRIEF INTRODUCTION TO SAFETY CULTURE INDICATORS

Industrial experience and research findings have shown that major concerns regarding the safety of nuclear power plants and other complex industrial systems are not so much about the breakdown of hardware components or isolated operator errors as about the insidious and accumulated failures occurring within the organization and management domains. Performance of the organizations operating nuclear power plants has become a major preoccupation of those concerned with safety. Accordingly it is seen needful to find and develop operational performance indicators which would be of more anticipatory nature. They could provide more information about antecedent causes of events and thus possibly measure also the performance of the functional units within the plant organization.

The International Nuclear Safety Advisory Group (INSAG-4)[1] formed by the IAEA has maintained in their report that the establishment of a safety culture within an organization is one of the fundamental management principles necessary for the safe operation of a nuclear power plant. Safety culture is both structural and attitudinal in nature and relates to the organization and its style, as well as to attitudes, approaches and the commitment of individuals at all levels in the organization.

The information obtained from the events and failures occurred at the plant are generally utilized with the intent of learning by experience to reach and maintain a high performance level. Learning from experience is an important aspect of safety culture. The concept of safety culture has been used extensively to explain the underlying causes of performance based events, both positive and negative, across the nuclear industry. Yet attempts to operationally define the concept of safety culture and assess it have been less apparent.

The assessment of individual and organizational performance is not as straightforward as the assessment of technical performance for some system, because ratings will usually be subjective. The indicators can be formulated as statements or questions like those proposed by INSAG-4. Various rating methods have been developed within behavioural sciences which rely on the construction of measuring scales. The data can be collected in various ways, such as discussions, structured interviews and questionnaires. The data can be collected and scored by people inside or outside the organization to be assessed.

The development discussions provide one possibility for data collection where superiors and subordinates meet regularly with discussions on performance. The use of typed behaviour classes can support such discussions with some kind of scoring mechanism. The use of structured interviews performed by outside people might provide the most reliable data. The problem is, however, that both data collection and assessment can be very resource consuming. A questionnaire is easier to administrate and to treat, but results may be more difficult to interpret.

INSAG-4 represents probably the most complete description so far of the safety culture concept along with its definition, features and tangible manifestations. A comprehensive set of safety culture indicators is presented as an Appendix to this publication.

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Culture — A Report by the International Nuclear Safety Advisory Group, Safety Series no. 75-INSAG-4, IAEA, Vienna (1991).

Shortly after the publication of INSAG-4, interest was expressed as to whether it was possible to make an assessment of safety culture in a particular organization. Difficulties of performing such a review are not to be underestimated, since so much of the required characteristics lie below the surface. To be sure, comprehensive checks on equipment, documentation and procedures would not necessarily reveal the strength of safety culture in an organization.

In order to properly assess safety culture, it is necessary to consider the contribution of all organizations which have an impact on it. Therefore, while assessing the safety culture in an operating organization it is necessary to address at least its interfaces with the local regulatory agency, utility corporate headquarters and supporting organizations.

In the framework of the IAEA ASCOT (Assessment of Safety Culture in Organizations Team) activities, significant work has been done with respect to indicators to determine the effectiveness of safety culture. IAEA-TECDOC-860, ASCOT Guidelines, issued in 1996, which is based on the Appendix of INSAG-4, proposes key indicators for the different areas that need to be considered when assessing safety culture at NPPs.

Annex II

RISK BASED INDICATORS

II–1. INTRODUCTION

Probabilistic safety assessment (PSA) is a comprehensive, structured approach for identifying failure scenarios. It includes a mathematical method for deriving numerical estimates of risk. It is widely recognized that PSA is a very powerful tool for assessing the risk associated with the operation of nuclear power plants. Plant specific PSAs have been performed for most operating power plants.

In recent years, improvements in related software and hardware have reduced the time necessary to re-quantify a PSA from days to minutes. This much increased capability has opened new opportunities for the on-line use of PSA models to rapidly re-calculate the risk associated with varying plant configurations, thus providing a quantitative assessment of the impact of planned activities (i.e. maintenance, tests, changes) and unplanned events. Risk monitors have been developed and are in use, which are capable of generating forward-looking risk profiles for planning purposes, and backward-looking risk profiles for performance assessments.

Given the value of the available PSA models and the significant information that can be extracted from them to evaluate, monitor and communicate plant safety related information, it is important to identify the type of indicators that can be extracted from the PSA which are most appropriate for the different uses and needs of plant management and staff.

This annex is a summary of a report prepared during a consultants meeting held in Vienna from 15 to 19 July 1996. The PSA based indicators proposed in this report are consistent with the operational safety performance indicator framework presented in the main body of this publication.

II–2. PROBLEM FORMULATION

Indicators to monitor the safety performance of NPPs can be developed for a number of reasons, i.e. to present the plant safety status, or to display changes in the operational conditions and the plant response.

Presentation of plant safety status is valuable for management and for regulatory use. Displaying the changes due to operational conditions supports decision making for a goal directed safety management.

PSA contains a large amount of safety related information and is capable of quantitatively address the above mentioned issues.

PSA models are based on a large quantity of parameters and basic information. It would not be possible, neither practical, to use all these parameter as indicators. Besides, there are different levels of importance of the parameters and not every piece of information included in the PSA is significant to safe plant operation. Therefore, PSA based indicators need to be selected at different levels of the PSA analysis, based on their importance and on the insights they provide to both NPP management and operator.

II–3. WHAT INDICATORS

Figure II–1 presents the proposed PSA based indicator framework. This structure is consistent with the operational safety performance indicator framework proposed in the main body of this report. The main difference lies in that the PSA is a tool that allows the quantification of the indicators proposed for all the levels. This means that numerical figures can be obtained for all the risk based indicators proposed.

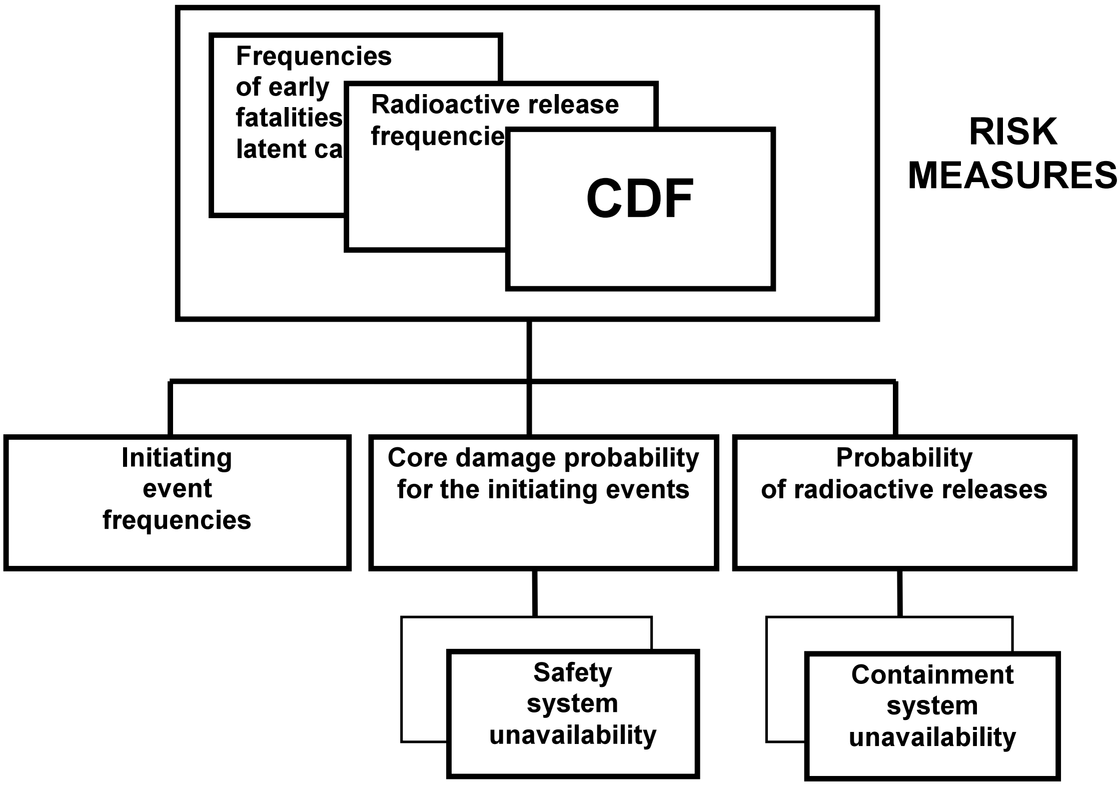

FIG. II–1. Plant operates with low risk (probabilistic approach).

II–3.1. Global indicator: Plant risk

This indicator considers the overall risk resulting from plant operation. Risk can be readily measured at the plant level by performing a plant specific PSA. Depending on the scope of the PSA, this attribute can be measured in terms of individual risk, population risk, frequency of release categories or core damage frequency (CDF). If the objective of the PSA is to assess and periodically monitor plant safety, the attribute most commonly used to perform this function is CDF. Given the logical structure of a PSA study, specific contributors to CDF which are explicitly important indicators can be identified and used for monitoring purposes. These lower tier indicators (i.e. initiating event frequencies, unavailability of safety systems, etc.) are discussed below.

II–3.2. Second level indicators

Main contributors to CDF, therefore individually important and deserving to be individually monitored, are frequency of initiating events (IEs) and indicators of the plant ability to respond to events.

II–3.2.1. Frequency of initiating events

For each accident sequence contributing to core damage, the CDF results from the combination of the frequency of the accident initiator and of the probability of core damage, given that the initiator has occurred. Therefore, initiating event frequency is a key component of plant risk.

IE frequencies are defined by unique plant features and design characteristics often implemented with the intent of minimizing such frequencies[1]. These design features are part of the preventive characteristics of the plant. Maintaining these characteristics consistent with their original design contributes to keeping the potential number of challenges to the plant at acceptable levels.

Opportunities exist for plant personnel to inadvertently and significantly affect initiator frequencies, because these are often influenced by the availability and/or performance of non safety grade systems. Initiator frequencies can be increased by many means, for example by not promptly restoring all non safety grade equipment to service; by maintenance activities on systems and components; by testing; by plant modifications; by operator errors.

The *CDF indicator* does not provide information regarding the balance between IE frequency and plant ability to respond to events. By monitoring CDF alone, the increase in initiator frequency may be masked by an assumed high ability of the plant and the operators to respond to the event and prevent core damage. Therefore, it is necessary to monitor IE frequencies as part of the indicator programme.

An indirect and coarse indicator of initiating events frequency is the “number of reactor protection system and safety system actuations”. Although these are important parameters to be monitored, they do not provide an appropriate monitoring of initiating event frequencies.

A more appropriate approach is to monitor initiating event frequencies either individually or by groups (i.e. loss of coolant accidents, loss of power, transients, steam generator tube rupture). For each initiating event or group of events, an analysis can be performed to determine which routine plant activities or events may affect their frequency. In some cases, this analysis is supported by FMEAs or fault tree analysis. In some cases, operating experience is used as the source. In this case, the analysis focuses on identifying likely dominant contributors affected by plant activities. The resulting correlation between plant activities/events and initiating event frequencies may be limited at the beginning, but will improve with time as experience is folded into the process.

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[1] This applies mainly to internal initiating events and internal hazards. *Internal initiating events are hardware failures in the plant or faulty operations of plant hardware through human error or computer software deficiencies. Internal hazards include internal flooding, fire and missile impact (IAEA Safety Series No. 50-P-4).*

Monitoring and reporting increases in initiating event frequencies, together with daily global changes in core damage frequency, provide a more complete understanding of plant risk.

II–3.2.2. Indicators of the plant ability to respond to occurrences

The *normal operating states* of the nuclear power plant are the states designed to assure everyday production and related plant activities. Minor disturbances during normal operations are dealt with by normal operating equipment.

If an *initiating event* occurs and the plant status goes beyond the designed normal operating state, the normal operating equipment will not be sufficient to cope with the situation: the actuation of safety systems will be required.

While the safety systems can cope with the initiating event and prevent core damage, the occurrence is an incident. When for some reason the plant equipment cannot deal with the initiating event, a core damage occurs, and the situation is then an accident.

If an accident were to occur and in order to keep the consequences inside the plant such that radioactive pollution of the environment and radioactive doses to the population around the plant can be avoided, the proper function of the mitigating features (containment and containment systems) would be required. If the containment is not successful in performing its function, the accident could result in large radioactive releases.

The main task of the NPP safety management is to avoid large radioactive releases by avoiding initiating events and maintaining a high reliability of the prevention and mitigation systems.

This ability of the plant to respond to an initiating event consists of:

1. responding to the incident or *accident prevention*
2. responding to the accident or *accident mitigation.*

The plant PSA is able to give quantitative information on both of these areas by characterizing the plant's ability to respond by two major indicators: *probability of core damage* for each initiating event and *probability of radioactive release*.

Plant response to the incident

The highest level indicator of the plant response to the incident is the *probability of core damage (CDP)* for each initiating event. This indicator can be calculated by the PSA model, and shows how successful the prevention of core damage would be in case of the given initiating event.

The *CDP indicator* is more sensitive than the CDF to some modifications in the plant safety level that may be masked, at the CDF level, by the low frequency of some initiating events.

The *safety function unavailabilities* can be used as intermediate level indicators. As mentioned, PSA can provide indicators for different levels. According to the behaviour and the sensitivity of the indicators used, the proposed framework can be modified and other intermediate indicators selected. For the purpose of this report, which is an overview of the PSA based indicators, it has been considered that *CDP* and *system unavailability indicators* can provide sufficient information to determine if aspects related to plant ability to respond to events require attention or improvement.

The *system unavailability indicators* are the lower level indicators. These indicators can explain the behaviour of the *CDP indicators*.

Depending on the information needed to explain the higher level behaviour, lower level indicators such as *train* or even *component unavailability indicators* can be selected. However, in order to build up a good and efficient risk based indicator system, the developer of the indicator programme has to be aware of the usefulness and benefits of the different indicator levels.

An important idea behind using probabilistic *system unavailability indicators* is that the effect those unavailabilities have on the overall risk can also be reflected. Additionally, the probabilistic indicators give information on what performance is to be expected from the systems.

The use of importance calculations for each level of indicators, allows to obtain very useful information explaining the contribution of different factors. Such calculations are extremely useful for high level indicators, where the indicator behaviour is not so obvious.

Plant response to the accident

The plant ability to respond to accidents is influenced by the availability of the active containment systems and the design features of the passive containment. The indicator of the plant response to the accident would be *the probability of unsuccessful containment function*, or *the probability of radioactive releases*. A level 2 PSA would be necessary to obtain this indicator.

The lower level indicators would be *the containment system unavailability indicators.*

II–4. HOW TO OBTAIN RISK BASED INDICATORS

Risk based indicators can be used for different purposes — depending on the purpose sought, short term or long term evaluations have to be performed.

‘Living PSA’ is the tool necessary for the calculation of the long term indicator. For the calculation of instantaneous risk, or risk associated with a specific plant configuration the necessary tool is the risk monitor tool, which provides a fast answer for the issue to be evaluated.

Regarding the level and scope of the PSA models used to produce risk based indicators, state of the art tendencies suggest that the PSA should include all the internal and external initiating events relevant to the plant.

For the calculation of the *probability of radioactive release indicator*, it would be necessary to have a level 2 PSA.

II–4.1. Plant risk indicator: CDF

II–4.1.1. The short term risk indicator (instantaneous risk: CDF_I)

For the evaluation of the risk associated to a specific situation, the *CDF indicator* has to be calculated considering the given plant configuration and data associated (e.g. the expected IE frequencies in such a situation). This can be done for the past, present and future as many times as needed and for as short a period as needed. Of course, limitations as to the time and calculation tool available can affect results, and a daily basis calculation seems to be a good compromise.

For later usage it is worthwhile to record the results of the calculations performed.

II–4.1.2. The long term risk indicator (average risk: CDF_A)

There are two ways of calculating long term risk. The first is by calculating the average risk by integration of the instantaneous risk values obtained from the risk monitor with respect to the considered time frame. The second is by calculating the risk using the 'Living PSA' model and the average basic event probabilities for the given period of time. Note, however, that the two calculations may give different results depending on the models and methods used and how unavailabilities have been accounted for.

II–4.2. Initiating event frequency indicator

The initiating event frequency in the PSA is a value based on different assumptions, generic and plant specific information. Sometimes, special analyses are performed to determine the IE frequencies.

There are a number of factors which, even though they do not cause initiating events directly, can affect the expected initiating event frequencies. These factors might not be monitored by the traditional safety performance indicators: as they present no special interest, no information is collected on them.

There are methods and approaches to support estimations of changes in the expected initiating event frequencies, such as FMEA, fault tree analysis, probabilistic fracture mechanics analysis, or engineering judgement.

The *initiating event frequency indicator* can be calculated for each group of initiating events as defined in the PSA, or a further grouping can be done in order to obtain a higher level indicator (for example, transients, LOCAs, etc.). The integration of the frequencies into a higher level indicator can show the vulnerability of the plant to the nature of the initiating event, and it is useful to initiate long term design modifications, or to strengthen the preparedness of the personnel.

II–4.3. Core damage probability indicator

The *core damage probability indicator* measures how adequately the plant is prepared to cope with a given initiating event.

The PSA contains all the models to calculate the probability of the core damage for each initiating event. The ease with which this indicator can be calculated depends on the construction approach of the PSA. However, it can always be calculated as the sum of core damage sequence frequencies belonging to the given initiating event divided by the initiating event frequency.

II–4.4. System unavailability indicator

The *system unavailability indicators* give explanation on the behaviour of the *probability of the core damage indicator*. Some *system unavailability indicators* can help to understand the changes in some *IE frequency indicators*.

Two different types of *system unavailability indicators* can be obtained. It should be noted that both indicators give different type of information.

(1) System unavailability due to unavailabilities and failures of system components and support systems.

    This indicator should be accompanied by support system unavailability indicators to explain the sources or reasons for the obtained indicator figures. These indicators can be obtained directly from the PSA models for the selected systems.

(2) System unavailability due to unavailabilities and failures of the system components only.

    This indicator does not reflect the true unavailability of the system to perform its function. However, it can be useful to track deterioration in system performance. The calculation of these *system unavailability indicators* may require additional modelling effort, or manipulation of the existing PSA system models (i.e. in order to separate the support system contributions).

II–5. USE OF RISK BASED INDICATORS

II–5.1. Short term and long term applications

The risk based indicator system is a safety information tool. Generally, this tool can be used to monitor safety performance and to alert the user if parameters exceed certain levels or follow undesired trends.

Different kinds of information can be derived from the PSA as indicators for *long term* or *short term* applications.

The *long term* risk based indicators focus on monitoring plant behaviour in order to obtain insights on the past history of NPP safety and to update the calculated average CDF. *Long term* use includes analysis of past plant behaviour by integrating the occurred events, failures and unavailabilities. This information (including CDF trends, comparison between expected and calculated CDF, etc.) is of interest to regulators and high level plant management.

Long term risk based indicators can also help to recognize ageing effects on components and systems. This information is important for the plant staff and can initiate design changes or modifications to testing and maintenance strategies, etc.

Moreover, the *long term risk indicators* can be produced for planning purposes. For long term planning, the assumptions regarding planned design changes, expected component behaviour, etc. can be introduced in the PSA models and data and analysed to obtain the expected average CDF for the next period.

Risk based indicators for *short term* use require instantaneous evaluation of risk. This type of application provides information on changes in CDF due to plant events (backward looking) and risk associated with planned activities (forward looking).

II–5.2. Backward looking and forward looking applications

Two additional perspectives in the use of risk based indicators have to be considered: the *backward looking* and the *forward looking* applications.

Backward looking applications involve the reporting and analysis of events occurred such as initiating events, precursors including their development from an initial event, component failures, common cause failures, human errors, occurred unavailabilities, etc. and their integration in the PSA to obtain the indicators of past risk. These indicators will help to identify plant vulnerabilities, deficiencies in human performance, needs for design modifications or backfittings, needs for modification of maintenance strategies, needs for modification of technical specification requirements. etc.

Forward looking applications involve the integration in the PSA models of planned measures, configuration changes, planned maintenance activities, etc. and the PSA calculations to obtain the *indicators of the expected risk*. These indicators will help to prevent high risk configurations, to assess possible changes to operating procedures, proposed design changes, to plan maintenance strategies and outages, etc.

Annex III

PILOT STUDIES

III–1. INTRODUCTION

The main body of this report on “Operational Safety Performance Indicators” was prepared as a result of several consultant meetings held since December 1995. In December 1997, a pilot study was initiated in order to validate the applicability, usefulness and viability of the approach for implementation at nuclear power plants. A secondary purpose was to obtain feedback regarding the difficulties encountered in implementing the programme and to identify recommendations for adjustments to the framework based upon pilot plant experiences and perceptions.

Four NPPs from different continents and with different reactor designs agreed to act as partners with the IAEA in the pilot studies project. This Annex describes the scope of the pilot studies and summarizes the experiences, findings, insights, lessons learned and recommendations of the plants which agreed to implement this approach to operational safety performance monitoring.

III–2. OBJECTIVES

The main objective of the pilot studies was to validate the applicability and usefulness of the framework. It was expected that the pilot studies would provide feedback on whether the document could be used to develop indicators that would meet the needs of operating nuclear plants.

The participation of four plants from different countries and with various reactor designs was considered a valid pilot study sample for the purpose of determining the usefulness of the approach, identifying the problems experienced in implementing this framework, and developing recommendations for programme improvement. The pilot studies were neither a safety review of the plants nor an evaluation of the plant safety level.

III–2.1. General programme objectives

The general objectives of the programme were to gather feedback from the plant about:

- the feasibility of the proposed framework, and its usefulness,
- the usefulness of each individual indicator proposed; the validity of each indicator, i.e. whether the indicator provided meaningful information and the need for developing new indicators for monitoring the different specific areas,
- the definition of the selected indicators,
- processes used to collect the data for the indicators,
- additional efforts required for data collection,
- resources required to collect the data (human and other costs), and
- management feedback on the indicators and the framework.

III–2.2. Plant specific objectives

The participating plants developed the programme bearing in mind the following specific objectives:

- to establish a basis from which to implement such an indicator programme,
- to obtain feedback on how well the plant was performing in relation to operational safety,
- to obtain feedback on weak points, i.e. an indication of areas needing further attention (possible resource optimization),
- to obtain feedback on the effectiveness of, or need for further self-assessment,
- to achieve an improved understanding of the value of these indicators, and
- to benefit from the opportunities to exchange experiences with other nuclear professionals, i.e. to exchange ideas on how other nuclear power plants might use similar programmes.

III–3. DEVELOPMENT OF THE PILOT STUDIES

A fifteen month schedule for the pilot study was prepared starting from January 1998. The following activities were completed during this period:

- selection of indicators,
- review of definitions of indicators,
- establishment of the necessary organizational support,
- data collection and analysis,
- development of support software, and
- preparation of reports.

Each participating plant developed an application software for handling the data and calculations required to produce the indicators.

A meeting was convened in November 1998 to discuss the progress made to date in the implementation of the programmes. Each participating plant provided a description of their current programme and detailed their progress to date, including any insights developed during the initial period of programme development and implementation. The meeting also focused on a review of the proposed framework for operational safety performance monitoring, and the development of recommendations for revisions to that framework, based upon pilot plant experiences and perceptions. The result of this work has been included in the framework described in the main body of this report.

A final meeting was held in June 1999 to discuss the results and conclusions of the pilot studies and to prepare the final document of the IAEA project on “indicators to monitor NPP operational safety performance”.

II–4. IMPLEMENTATION OF THE PILOT STUDIES: THE EXPERIENCES OF PARTICIPATING PLANTS

III–4.1. Selection of indicators

Plant A

The plant does not yet have an established performance indicator programme. This pilot study, however, marked the beginning of the establishment of such a programme. The team put together by the management had, as its first task, "the selection of indicators to be studied". The first basis of selection was data availability for evaluation of the indicators. To this end, each proposed indicator was looked at to evaluate the data requirements. Once the data requirements were identified, it was quickly realized that certain indicators could not be produced as either the database was not sufficiently large or the available data was not in a form that could be used for evaluation of the concerned indicators. As an example of a database that was not large enough, some indicators could not be evaluated as they required a well established Root Cause Analysis (RCA) programme. The plant's RCA programme is quite recent, and as such it does not provide a five year database, which the plant considers to be a minimum for a meaningful evaluation. Some indicators could not be produced due to a lack of facilities. For example, the plant currently lacks equipment to measure iodine for the indicator "fuel reliability". Indicators that were immediately obvious as not being meaningful for this plant, such as "attendance at seminars," were also screened out.

After the initial screening, about 60% of the total proposed indicators were selected. It was decided that at the end of the pilot study the team would suggest changes in the database management, including the establishment of new databases. This would then enable the plant to start monitoring at some later stage the indicators that were screened out due to data problems. This screening process consumed up to 10 man-days (almost 0.5 man-months).

Table III–1 presents the list of indicators that the plant decided to evaluate during the pilot study.

It was intended that, if some of the indicators were dropped on completion of the evaluation because they did not seem to be meaningful for the plant, then in the next phase of the project new indicators would be proposed to gauge the concerned overall indicator.

The framework adopted at the conclusion of the pilot study is shown in Figs III–1 to III–3.

Plant B

According to the activities schedule agreed with the IAEA for implementation of the programme the plant launched its programme in January 1998 with the selection of indicators.

After a complete and thoughtful revision of the IAEA's framework document, and following the hierarchical structure proposed, the selection of indicators was carried out for the plant. This set of specific indicators was included in the four monthly and annual reports.

Text cont. on page 42.

TABLE III–1. INDICATORS SELECTED FOR EVALUATION IN THE PILOT STUDY (PLANT A)

S.No.	Indicator Name
1	Number of forced power reductions and outages due to external causes
2	Number of forced power reductions and outages due to internal causes
3	Unit capability factor (WANO)
4	Unplanned capability loss factor (WANO)
5	No. of corrective work orders for safety systems
6	No. of corrective work orders for BOP systems
7	Ratio of corrective work orders executed to work orders programmed
8	RCS leakage
9	Containment leakage
10	Unplanned automatic scram per 7000 hours critical (WANO)
11	No. of demands on RPS/ECCS/RHR/Electric Power Systems
12	No. of RPS/ESFAS failures
13	No. of failures in a safety system
14	No. of hours a safety system is unavailable
15	No. of times a safety system is unavailable
16	Safety system performance (WANO)
17	Percent of failures discovered during surveillance and testing
18	No. of hours devoted to training
19	No. of failed licensing exams
20	No. of deviations found through QA audits in which plant personnel did not follow procedures
21	No. of workers receiving doses above limits
22	Collective radiation exposure (WANO)
23	Effluent activity versus allowed limits
24	No. of safety issues in backlog (analysis phase)
25	No. of safety issues in the backlog (implementation phase)
26	Percentage of plant staff trained in safety management/safety culture
27	No. of seminars on safety related matters
28	No. of external safety reviews, audits and assessment received.
29	No. of independent internal safety and QA inspections and audits
30	No. of findings from QA inspections and safety reviews and audits
31	No. of external review findings not previously identified by internal reviews
32	No. of repeated findings in internal reviews and audits

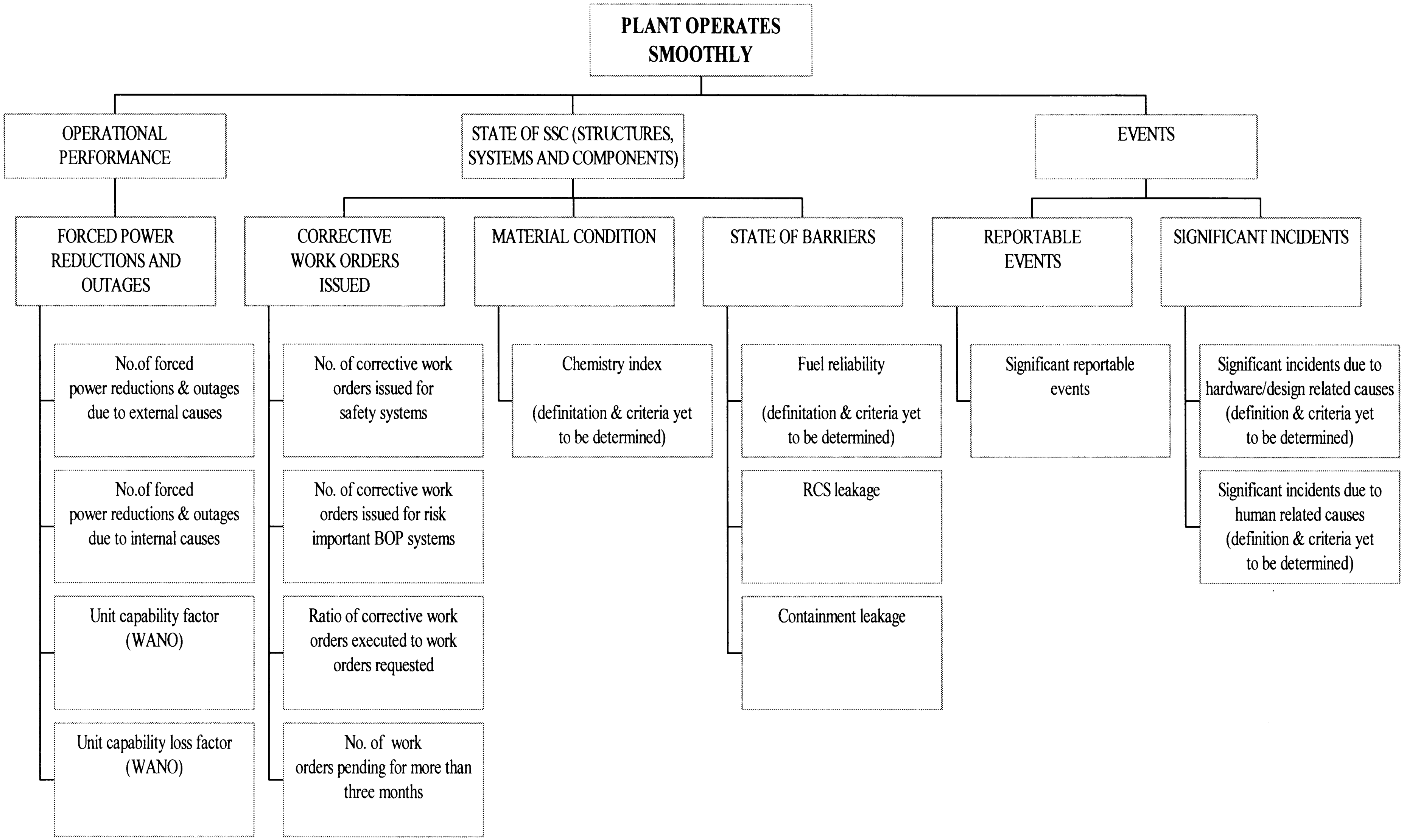


FIG. III–1. Plant operates smoothly — indicators selected by plant A.

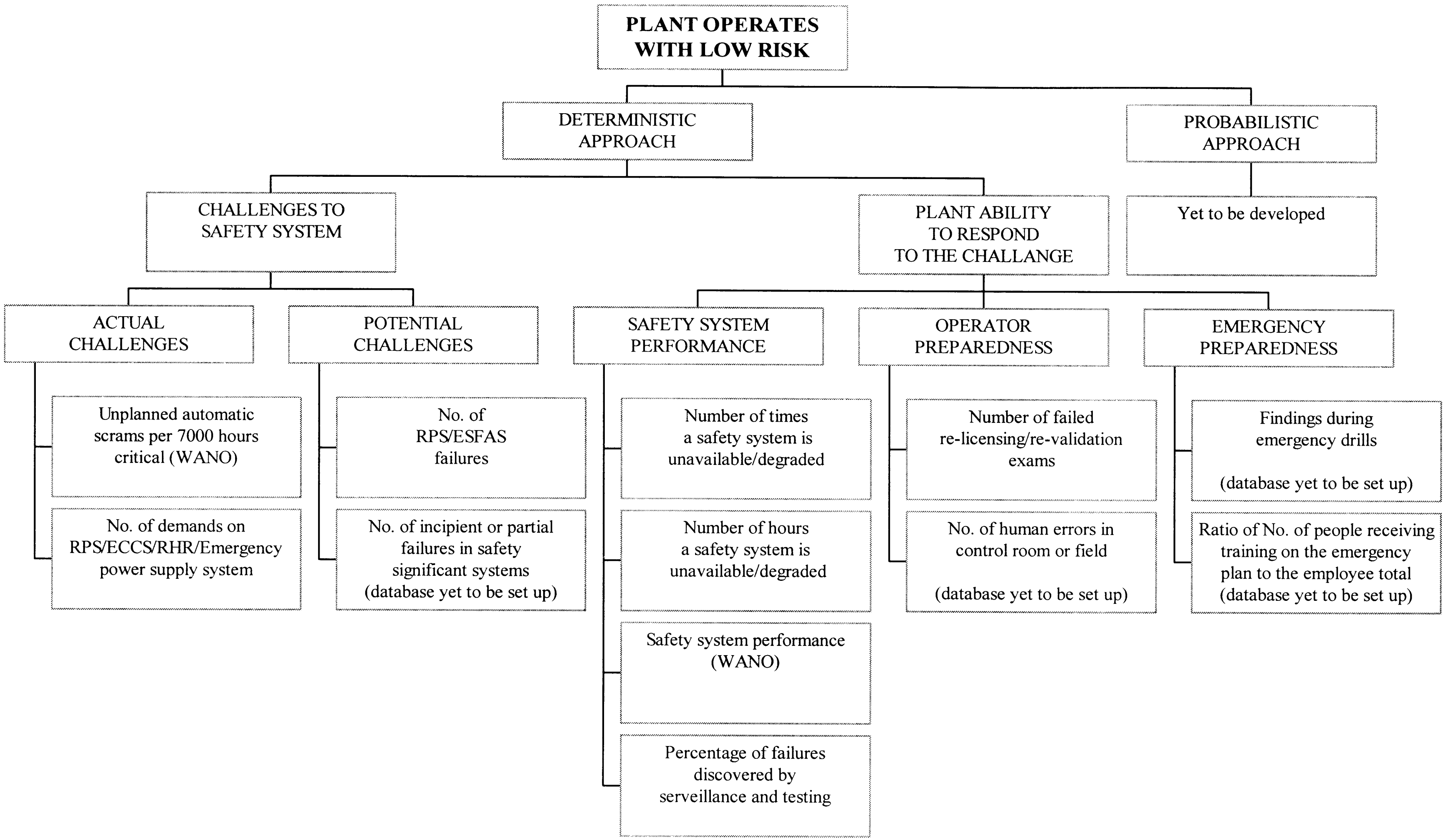


FIG. III–2. Plant operates with low risk — indicators selected by plant A.

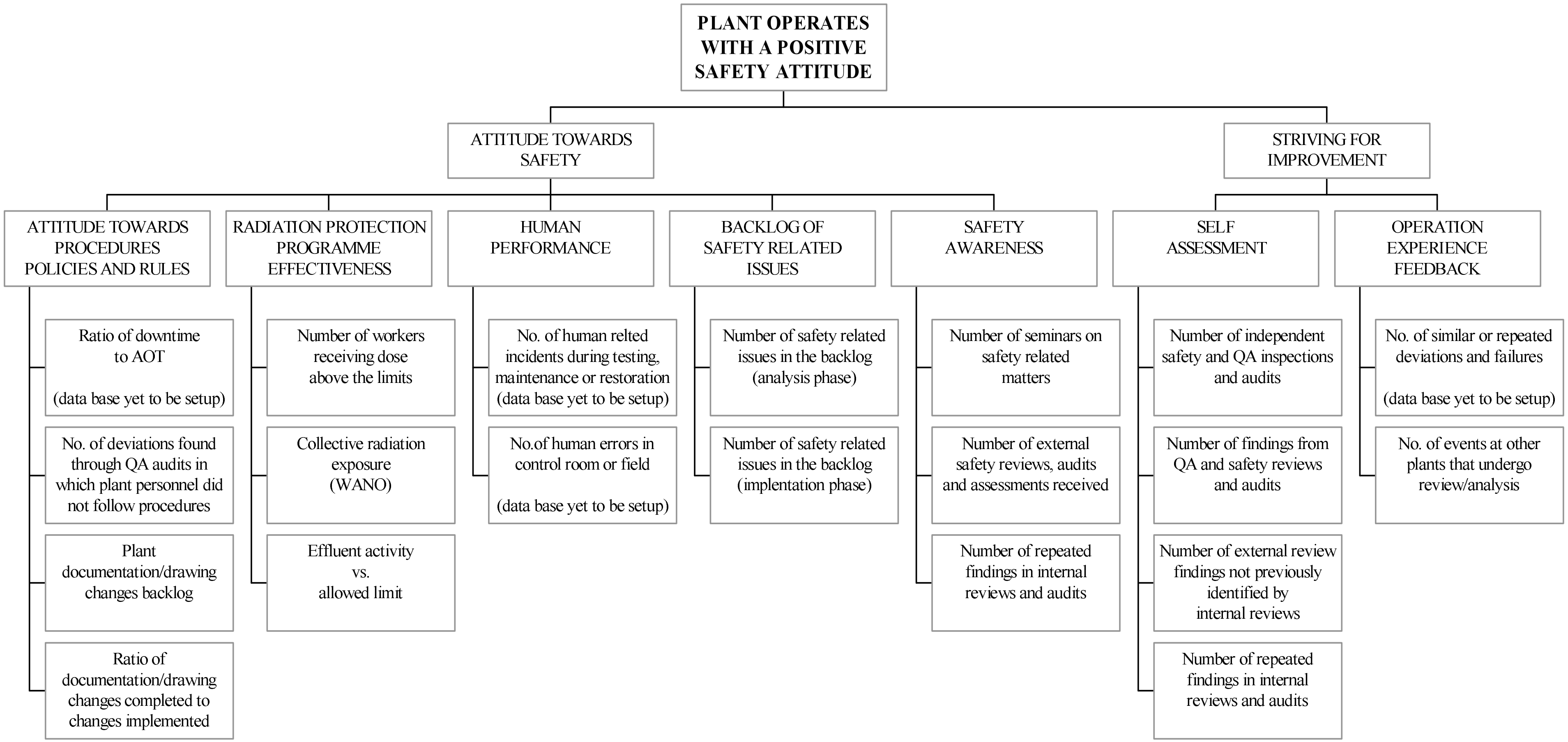


FIG. III–3. Plant operates with a positive safety attitude — indicators selected by plant A.

Basically, the selection focused on the following criteria:

- Indicators already in use in the plant.
- The usefulness of the indicators.
- The organizational and technical features of the plant.

All section heads and/or supervisors involved in the areas covered by the indicators participated actively in the selection.

The framework adopted by Plant B is shown in Fig. III–4.

Plant C

The programme, as currently implemented, is based upon the model developed by the IAEA in 1996. While the basic IAEA framework has been preserved, the design of the model has been adapted to suit site specific needs and programmes. The three key attributes were maintained, as well as many of the strategic groupings proposed by the IAEA. However, additional groupings were incorporated to enhance the usefulness of the tool for site performance monitoring.

Additionally, site specific indicators were selected. Most of the indicators chosen were aspects for which the plant already collects data to support some other aspect of performance monitoring. This was done intentionally to eliminate the burden of creating many new indicators. Some of the proposed examples of specific indicators were eliminated from the plant specific model because they were not considered a critical parameter for performance monitoring. For example, because accredited operator training programmes require a certain number of hours of attendance at training sessions, this indicator was rejected by the plant as not providing sufficiently useful information.

A paper describing the concept developed at the IAEA and a draft version of the indicator model were prepared by a small team of experts including one person who had participated in the development of the original IAEA design. The draft model was then reviewed by the site management team, who assigned a small group of personnel at the director level to review the individual indicators chosen.

The framework adopted by plant C is shown in Fig. III–5.

Plant D

This plant started commercial operation in 1994 and developed its first business plan at that time. A set of performance indicators was selected, with reference to the practices of other utilities that operate the same type of plants, and incorporated in the business plan to provide a statistical measure of how plant performance changed over time. The safety indicators were mainly lagging in nature. Amongst them, some of the ten WANO indicators were used, but only those with clear definitions and standard formulas for calculation. The plant utilized the same set of performance indicators with very few changes until 1997.

After the first OSART mission in the fall of 1996, the station management put additional emphasis on improving management. In a world of diminishing resources, improvement of the management programme and services was considered critical.

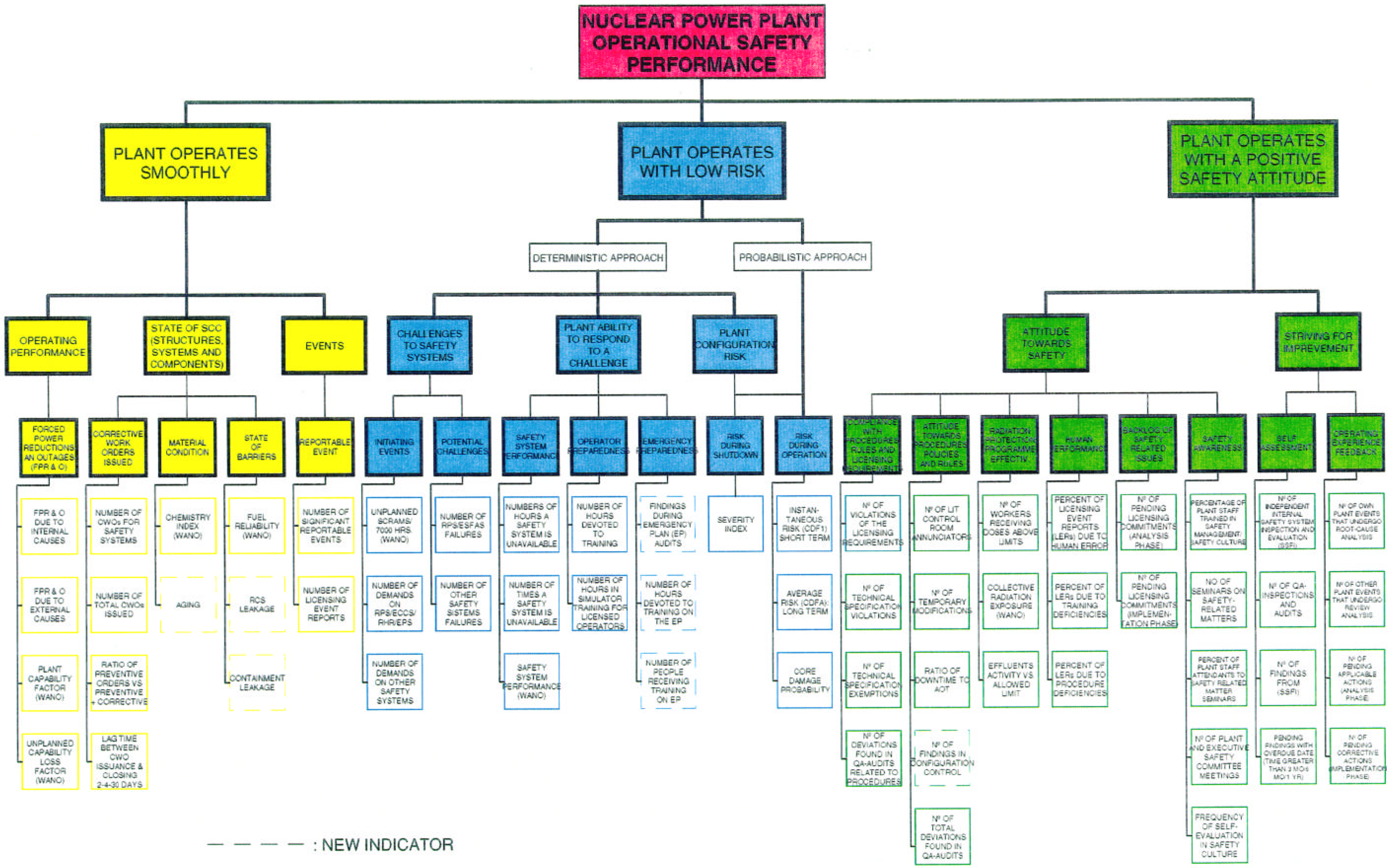


FIG. III–4. Indicator framework adopted by plant B.

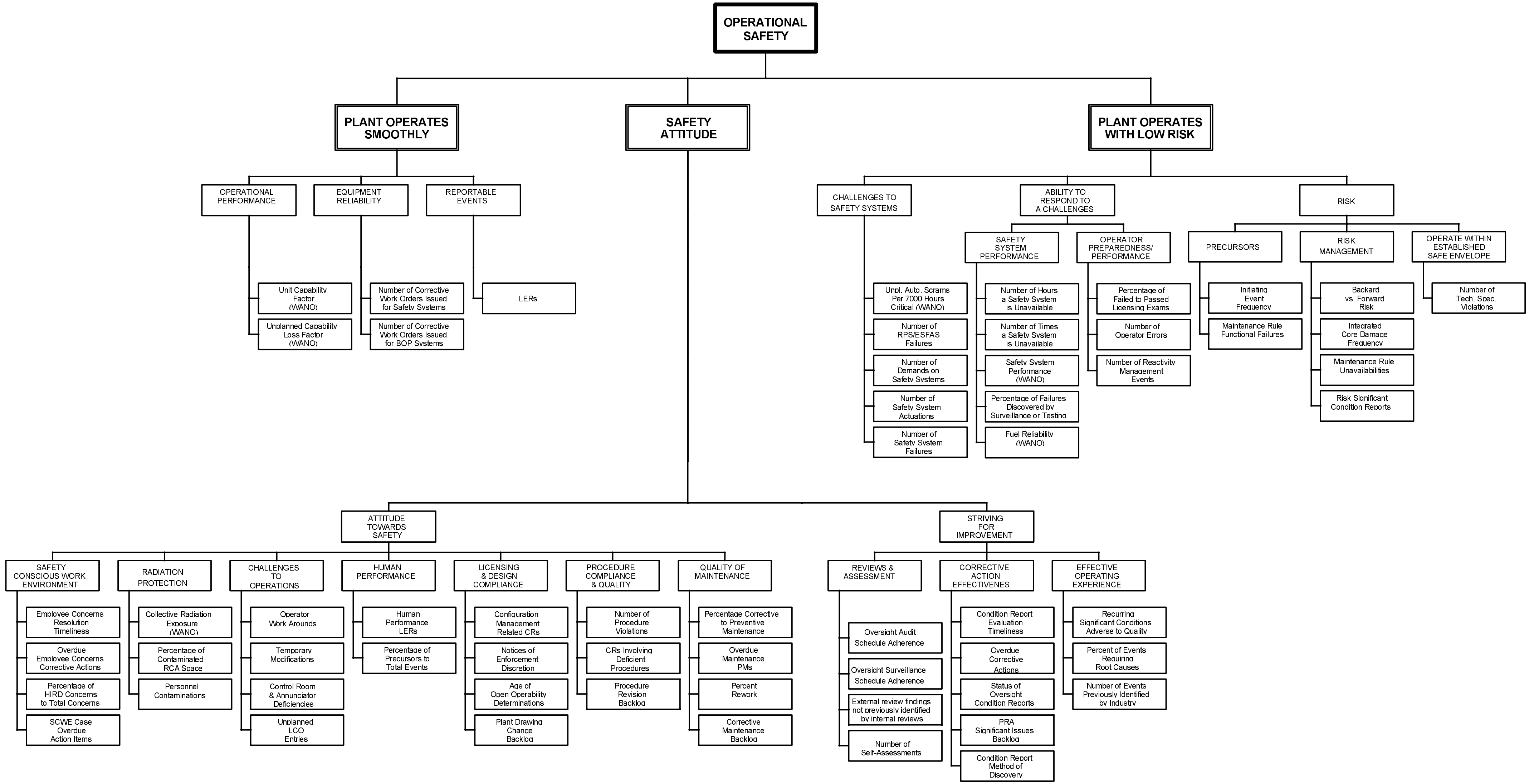


FIG. III–5. Indicator framework adopted by Plant C.

In late 1997, the first five-year corporate business plan was drawn up; it was put into effect in 1998. In order to align it with the corporate business plan, the station management plan for 1998 was revised to include a new set of performance indicators. Indicator selection was accomplished using the IAEA-J4-CT-2883 draft working document for selecting safety performance indicators. All ten WANO indicators were included. In November 1998, a workshop on “operational safety performance indicators” organized by the IAEA was held in the station. The station management adopted the indicator framework developed at the IAEA, including the three attributes and the strategic groupings. The 1999 management plan was subsequently expanded to include a total of 95 *specific indicators* (or first level), most of which represented plant specific measures.

The implementation of the programme required the modification of computer programs and plant procedures, training and communication to the staff. During the process of selecting the performance indicators, some concerns were raised that there were “already too many indicators” and that “some indicators identify problems that need fixing and activities that have positive impacts”. The latter could create unnecessary personal conflicts amongst concerned departments, especially with regard to aggregated measures for reporting to senior management. For this reason, the communication and discussion process to reach final agreement on the indicator definitions took much longer than expected.

The station is still evaluating the application of risk based indicators. Currently, resource priority has been given to finalizing the level 2 PSA study. The plant management is confident that this group of indicators will be included in the management plan for the year 2000.

The report for the first quarter of 1999 on the performance indicator programme reveals that much improvement work remains to be done to meet the long term goals.

The framework adopted by plant D is shown in Figs III–6 to III–8.

III–4.2. Establishing indicator definitions

Plant A

The team did not propose any changes to indicator definitions for indicators already being reported to WANO.

The team reviewed each indicator and prepared a plant specific definition. The monitoring durations were also established. After the team reviewed the indicators in a given attribute, the draft was discussed by the team members and the project co-ordinator. The definitions were modified where required, and a final draft was prepared. It was foreseen that these definitions could undergo a change during the indicator evaluation phase. This task was one of the most challenging, as it had to be ensured that the indicators would be meaningful for the plant. The entire process of defining the selected indicators for the three attributes took almost one man-month of work.

On completion of the evaluation process for the selected indicators some changes in the definitions were made. Two examples are provided below.

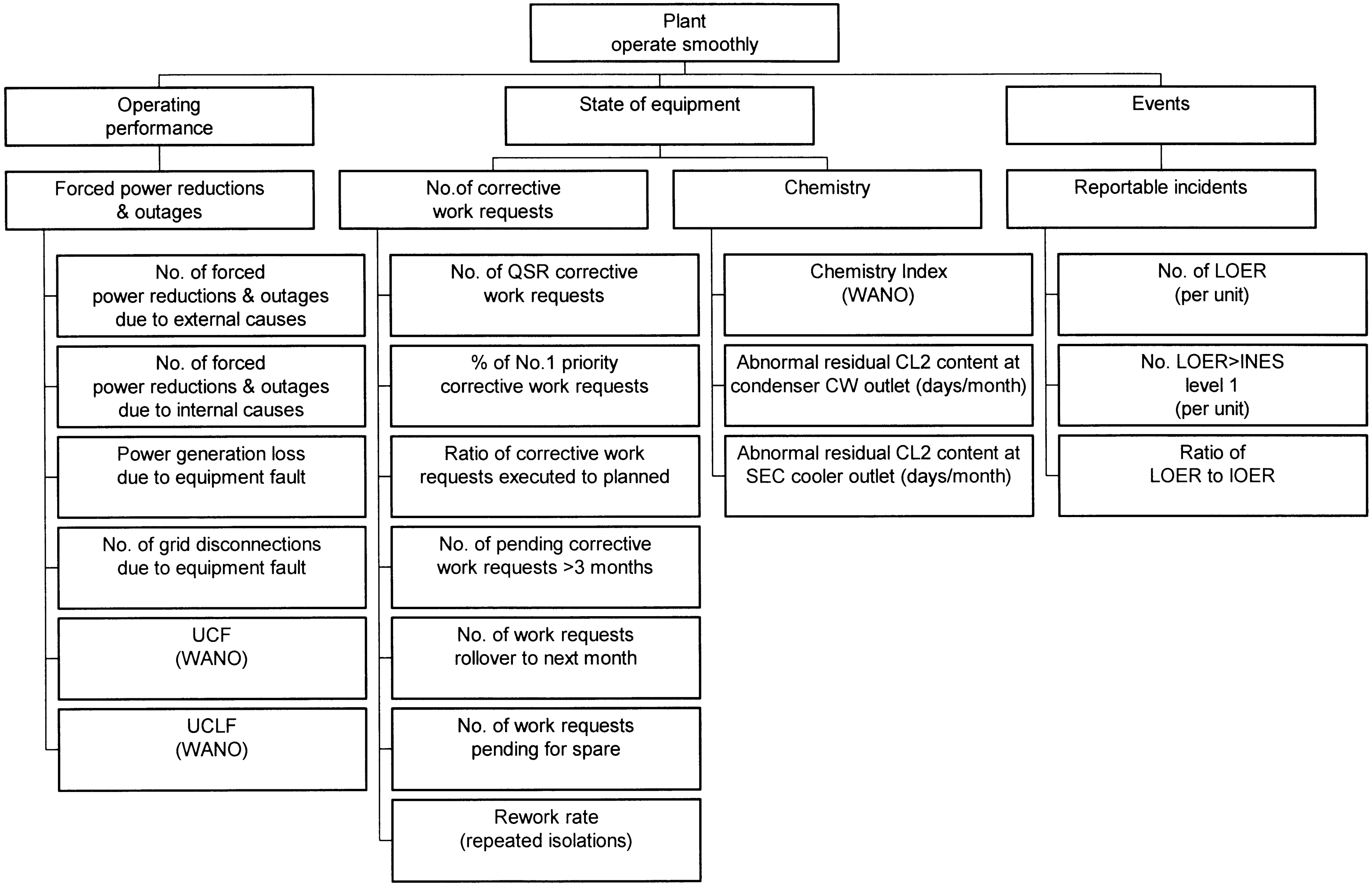


FIG. III–6. Plant operates smoothly — indicators selected by plant D.

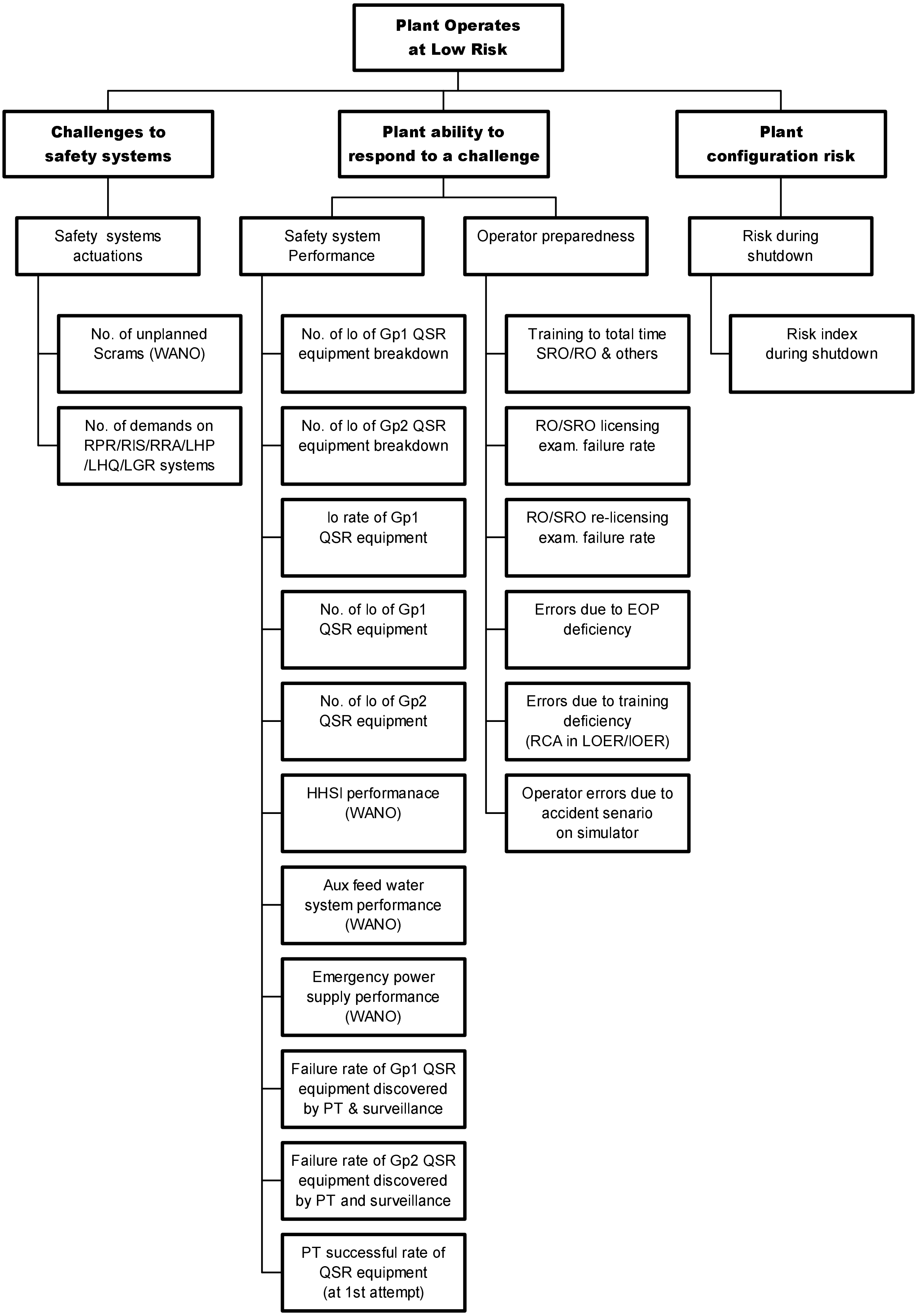


FIG. III–7. Plant operates with low risk — indicators selected by Plant D.

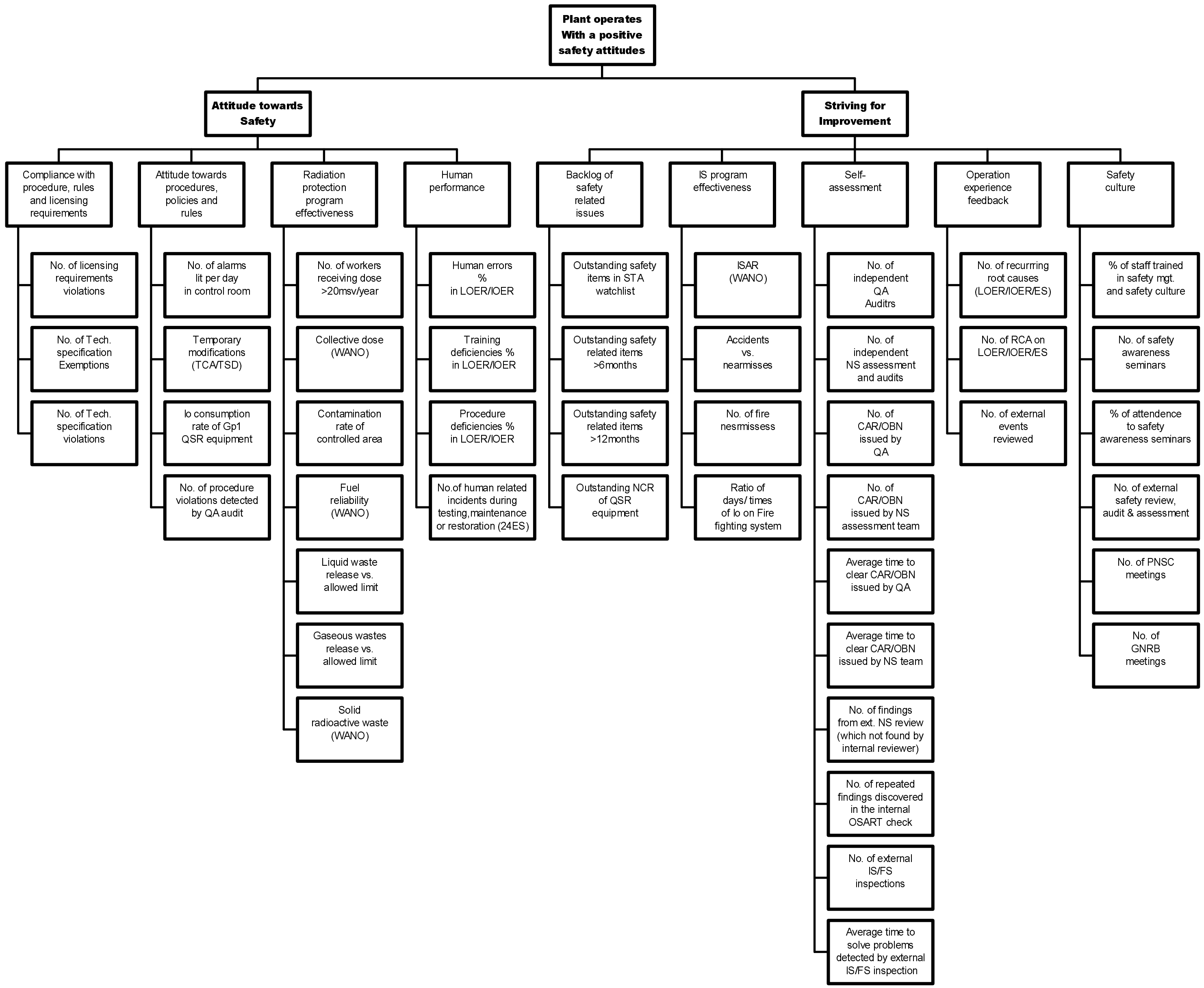


FIG. III–8. Plant operates with a positive safety attitude — indicators selected by plant D.

1. “Number of failures in a safety system” and “Number of times a safety system is unavailable”.

   By the very nature of these indicators the resulting counts would be very small as safety systems rarely fail. In order to increase the counts and make the indication more sensitive, these indicators were combined into one and redefined as “Number of times a safety system is unavailable or degraded”. Adding the words “degraded” allows counting at the component level, thus increasing the counts significantly.

   For this redefined indicator all the unsafe faults are counted, whereas safe faults/preventive maintenance occurrences are counted only if they cause unavailability or degradation when the system is required to be available for its intended function.

   During the evaluation process it was found that this indicator gives a good overall picture of the ability of the system to respond to a challenge. However, to obtain a better understanding of pre-emptive actions that may be required before the indicator goes “bad” it was seen appropriate to also trend the safe and unsafe failures separately. A decreasing trend for unsafe failures and an increasing trend for the safe failures may combine to give a satisfactory overall trend. However, an increasing trend for safe failures is clearly undesirable.

2. “Errors due to deficiencies in training”

   This is seen to be too restrictive as a measure of “operator preparedness”. It is more a measure of the quality of training. This indicator has been redefined as “Number of errors in the control room or field”. The counts would be irrespective of the root cause or plant status.

Plant B

The establishment of a clear and simple definition for each indicator was considered a key part of the programme implementation. As a matter of fact, the section heads and/or supervisors who were going to be the responsible/owners for data collection, tracking and trend analysis for each indicator participated directly in the development of its definition. It was seen as very significant for the future of the programme that the ‘owner’ of each indicator agree with the established definitions.

Plant C

The establishment of indicator definitions was a key step in development of the programme. The goal of the director team was to review the indicators for appropriateness and ease of data collection and to establish the definitions to be used for each of the chosen indicators. This effort required not only discussions within the director team on the reason for indicator selection, but also extensive interface with programme co-ordinators responsible for providing the data to achieve agreement on data parameters, data collection, and trending and reporting mechanisms.

Plant D

The station believes that the key to success in the implementation of the operational safety performance indicator programme is to adopt a "disciplined approach". All too often performance measurement programmes were established with good intentions, but some failed because they were short-sighted, ill conceived, and unfocused. Most of these shortcomings can be traced to one source**:** the lack of a viable approach to performance measurement from the start.

The development of a precise description for each indicator definition is an important step for data collection and calculation. All the indicators selected were studied by a cross-functional group of experienced staff who had attended the IAEA's operational safety performance indicator workshop. The programme facilitator reviewed all the proposed plant specific definitions before they were included in the standardized computer input card. The computer input card was formatted to provide the necessary information, such as the names of the responsible branches for data collection and verification, calculation formulas, etc. A responsible manager was assigned to ensure the quality of data collection, data processing and to co-ordinate data trending and follow-up of relevant corrective actions derived from the performance variances. The criteria for evaluating the performance variances were formulated on each input card and a colour coding system was used to identify the variances.

III–4.3. Identification of goals

Plant A

While goals were identified for some indicators because of previous work (e.g. for safety system performance) it was decided to look at trends, verify definitions and methodology for all the indicators first. Keeping these evaluations in mind, goals could be more meaningfully identified at the end of the pilot programme.

The following steps are suggested for the next phase of the project for indicators for which goals have not been set or cannot easily be derived using PSA or risk based arguments:

1. obtain a statistical distribution based on at least a five year database,
2. the mean of the distribution can then be used as the target,
3. if a low value is considered good, then the 20^{th} percentile can be used as the level below which the indicator would be judged excellent
4. if a low value is considered good, then the goal would be to maintain the performance indicators below a band of ±10% around the target, without, however, showing a bad trend.

As the programme progresses, these levels may be readjusted to better reflect actual operational experience.

Plant B

After the selection and definition of the set of indicators to be monitored by the plant, the next natural step was the establishment of their corresponding goals.

The goals represent the standards or levels the plant wants or needs to follow, maintain, or achieve. In this way, the programme can provide an early warning to plant management for decision making.

Similarly to the definition and selection of indicators, the responsible 'owners' were involved in the establishment of the goals. For the purpose of goal setting, it was considered a good practice to take into account the data results compiled during at least three to five years of operating experience.

Plant C

Once the indicators were selected and their definitions were agreed to, goals were established for each indicator. Again, this process required discussion and negotiation with the responsible programme 'owners' to identify what constituted a reasonable expectation for performance. Goal development was driven by a number of considerations, including:

- Availability of industry benchmark data
- Evaluation of previous plant operational performance, to establish a baseline for goal setting
- Evaluation of performance relative to established performance improvement programme goals
- Management expectations for continuous improvement.

The processes of defining indicators and goals have proved to be the most challenging and time consuming aspect of establishing a plant performance monitoring programme utilizing the model developed at the IAEA. It continues to be one of the most challenging aspects of the programme, as the organization evaluates the effectiveness of the indicators in measuring the specific safety attributes. However, this step is considered essential for programme development in (1) focusing the organization on the elements or parameters which are fundamental for operational safety performance monitoring, and (2) developing organizational 'ownership' of the performance monitoring programme.

Plant D

The station management believes and widely communicates the slogan *"what gets measured gets done*". For example, once an indicator was developed to track an item (e.g. "lit annunciators"), the operating staff became much more aggressive in reducing this number. However, it should be noted that the development of certain indicators could produce unexpected results. An indicator to reduce the number of outstanding alarms in the control room may lead to an unintended outcome of increasing the number of jumpers. Additional measures would then be needed to ensure jumper control.

In setting goals, the station management observed the following five points:

1. The cause and effect of outcomes are not easily detected.
2. Poor results do not necessarily reflect poor execution.
3. Numerical quotas do not fix defective processes.

4. Measurements only approximate the actual system.
5. Performance measures do not ensure compliance with laws and regulations.

The station management plan requires the plant to achieve the WANO top quartile performance by the year 2002. As a result, goal setting for the ten WANO indicators was clear. For the remaining indicators, goals were established with the consideration of:

- industry benchmarks
- corporate business plan expectations
- previous plant performance
- achievability of the goal, with some measure of flexibility.

Setting goals required extensive discussions and negotiations with responsible managers and staff concerned to convince them to use the model developed at the IAEA and the indicators proposed. Even today, disagreements remain in some areas.

III–4.4. Data display and interpretation

Plant A

Data covering a five-year period were analysed for the purpose of evaluating the indicators. The main goal of the evaluation for this pilot study was not to use the results to judge current plant performance or compile recommendations for the plant, but *to judge the indicators*. On the basis of this evaluation, when indicators were not considered meaningful, they would be ruled out for our plant. For example, the “number or percentage of hours spent on training” might not be meaningful for a plant with a mandated training programme and attendance.

It should be noted that some indicators provide valuable information when viewed separately, but when viewed together they provide additional information. As an example the “number of times a system is unavailable/degraded” may show a decreasing trend and the “unavailable hours” may show a zero slope. Both trends are thus satisfactory. However, when these are viewed together they show that the down time per occurrence is increasing, which is not satisfactory. It may therefore be useful to add another indicator designated “Number of hours per occurrence of system unavailability or degradation”.

It is felt that the “number of repeated findings in internal reviews and audits” is also useful in evaluating “Safety Awareness”.

The following scheme is proposed for the next phase of the project.

A target would be defined. A band of ±10% around the target would be the caution band. The 20th percentile (80th percentile if high is good) would define the level of excellence. A colour and indexing scheme would be used. The red area would be outside the ±10% band in the “bad” direction. An indicator value in the “red area” would be colour coded red. A value within the ±10% band around the target would be colour coded yellow (caution). A value between the 20th percentile and the ±10% band would be white (satisfactory). A value below the 20th percentile would be green (excellent). The corresponding values would be:

Colour	Assigned value	Meaning
Red	3	Unsatisfactory
Yellow	2	Caution
White	1	Satisfactory
Green	0	Excellent

Additionally, the trend would also be colour coded. A bad trend would be yellow with a value of 1. A good or stationary trend would be white with a value of zero. For a specific indicator the status would be displayed by an aggregate colour. The aggregate colour would be dictated by the aggregate value which would be the sum of the absolute value and the trend value.

If, for example, the indicator value is between the 20th percentile and the ±10% band the absolute colour would be white (value 1). If the trend at the same time was bad then, the trend colour would be yellow (value 1). The aggregate value would then be the sum, that is, two. Thus the specific indicator would display a yellow colour.

If the absolute colour is red (3) and the trend colour is yellow (1) then the aggregate colour would still be red but its value would be 4.

It is understood that, once the programme is established as a result of this pilot study, the indicators will be tracked for trends (absolute or against goals depending on the indicators). These indicators will not serve any regulatory or public relations purpose and will not be used for interplant comparisons. These indicators will be solely intended as tools for plant management to better manage plant safety.

Plant B

According to the agreed schedule for the implementation of the programme, three four-monthly reports and one annual report on the pilot study were issued during the exercise.

These reports, containing the results obtained for the plant of the selected indicators for the period covered, were thoroughly analysed by the corresponding plant committees.

An evaluation was made to emphasize the highlights and results against objectives, trends and targets and in order to investigate the reasons behind any observed deviation and/or change.

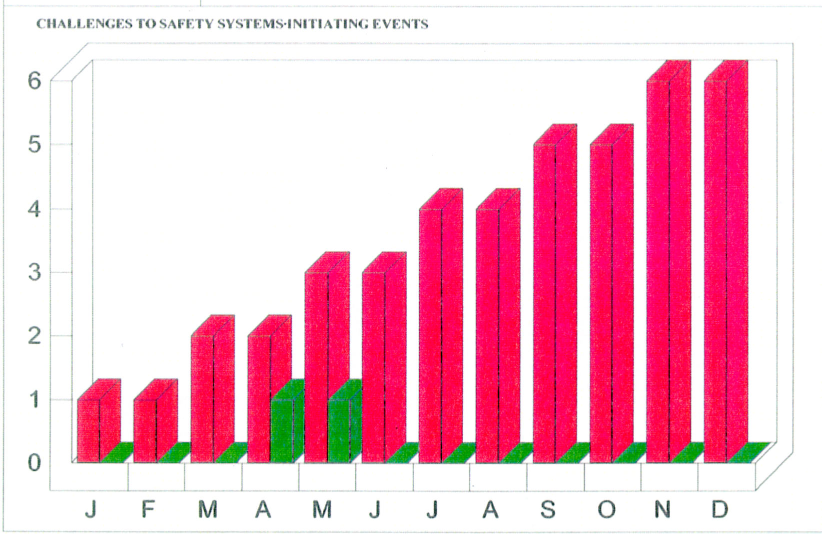
Graphic displays of the indicators including definition, goal, graphic values, reference, comments and action, responsible co-ordinator/'owners', monthly numerical anticipated and actual values, etc. were used to show their results for each period. These displays are available on the local area network of the plant to keep the plant staff fully informed. Figure III–9 provides an example of the plant's indicator display.

Plant C

The plant specific programme developed to monitor operational safety performance provides a framework for organizing safety significant data. But in evaluating the data, it became clear that what might not be considered significant when viewed separately, could take on different meaning when viewed relative to other critical information. As a result, the plant sought methods to enhance the value of the model by aggregating the data in such a way that a "big picture" could emerge regarding the organization's overall safety performance.

PLANT OPERATES WITH LOW RISK

0017 **NUMBER OF DEMANDS RPS/ECCS/RHR AND EPS**



1999	Anticip.	Actual
JANUARY	1	0
FEBRUARY	1	0
MARCH	2	0
APRIL	2	1
MAY	3	1
JUNE	3	
JULY	4	
AUGUST	4	
SEPTEMBER	5	
OCTOBER	5	
NOVEMBER	6	
DECEMBER	6	

INDICATOR

Number of demands per year on the reactor protection system, emergency core cooling systems, residual heat removal and emergency power systems. (All manual, automatic and spurious actuation are counted)

GOAL

The number of demands during the year will be 6 or less.

REFERENCE

CONCEPT

Number

COMMENTS AND ACTIONS

RESPONSIBLE

COORDINATOR

O.T.O

FIG. III–9. Example of an individual indicator display — plant B.

Building upon performance monitoring conventions already in use at the plant, a performance rating system was developed. Each specific indicator was evaluated against an established goal. Performance relative to the goal was assigned one of four colour/number ratings as follows:

Colour	**Assigned value**	**Meaning**
Green	2	Indicates excellence or a significant strength
White	1	Indicates satisfactory performance; meeting established performance goals
Yellow	-1	Denotes needed improvement
Red	-2	Indicates unsatisfactory performance; not meeting management expectations

These data are displayed in three different ways:

- **Graphic displays of individual indicators**

  Graphic displays of each of the specific indicators have been created depicting the indicator definition, raw data goal, analysis/action, comments and general progress statement. Figure III–10 provides an example of an individual indicator display.

- **Colour window display**

  Coloured windows, organized in accordance with the established framework, provide a means by which to evaluate the overall "wellness" of the organization during a given month. The colours provide a quick visual indication allowing management to identify at a glance which areas contribute most to positive (GREEN/WHITE) or negative (YELLOW/RED) performance. The display serves as a type of diagnostic tool for management to understand the sources of performance strengths and weaknesses, and to answer the question: "Where are the problems?" Figure III–11 provides an example of a monthly plant specific colour window display.

- **Trend display**

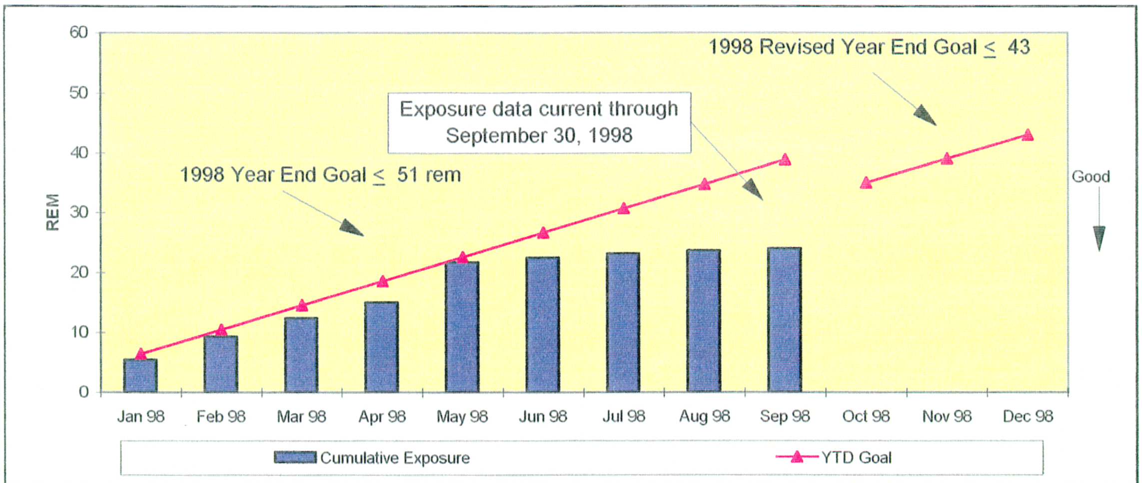
  While the colour windows provide a "snapshot in time" by which to evaluate monthly performance, they cannot address the real issue: "Is operational safety performance remaining stable, improving or declining?" To evaluate this aspect of performance, the plant has adapted the model to index and graph safety performance in order to identify discernible trends over time.

  Each of the specific indicators is assigned a number rating from (-2) to (+2), corresponding to the appropriate colour. Within each category, number ratings are averaged to obtain a rating at the strategic indicator level. The process is completed at successively higher levels until a composite numerical score for operational safety performance is obtained. This score is then plotted on a scale which corresponds to a range of performance from (-2) to (+2). Plotting the data in both a negative and positive direction from the zero point allows for visualization of improvement and early identification of declining performance.

Currently, only simple averaging is utilized to obtain the overall composite score. When aggregated in this way, the number value of the composite rating is not considered to be significant; however, the process does provide a means by which to monitor overall organizational safety performance trends over time. Although this process appears to yield valuable information regarding performance trends, this aspect is being closely evaluated to determine its overall viability. Figure III–12 provides a graphic display of the plant trend in "operational safety attitude".

Collective Radiation Exposure (INPO Indicator)

Progress: *Satisfactory performance continues.*



Raw Data

	Jan 98	Feb 98	Mar 98	Apr 98	May 98	Jun 98	Jul 98	Aug 98	Sep 98	Oct 98	Nov 98	Dec 98
Cumulative Exposure	5.507	9.370	12.374	15.070	21.770	22.541	23.236	23.740	24.016			
YTD Goal	6.400	10.455	14.509	18.564	22.618	26.673	30.727	34.782	38.837	35.033	39.012	43.000
Annual Goal	51	51	51	51	51	51	51	51	51	43	43	43

Definition

This indicator depicts the cumulative radiation exposure for the year (rem year to date) vs. the year-to-date and annual radiation exposure goals.

These goals represent the level of exposure which we strive to stay below consistent with the as low as reasonably achievable (ALARA) philosophy.

Analysis/Action

The unit is currently experiencing a lower than anticipated source term as a result of the extended shutdown.
This reduced source term has translated directly into lower radiation exposure associated with working most primary plant systems. As a result, the annual exposure goal has been revised from 51 to 43 rem.

Goal

The Goal for 1998 has been revised from less than or equal to 51 rem to less than or equal to 43 rem.

Comments

Exposure data is through September 30, 1998.

Data Source: ***Analysis by:*** ***Owner:***

FIG. III–10. Example of an individual indicator display — plant C.

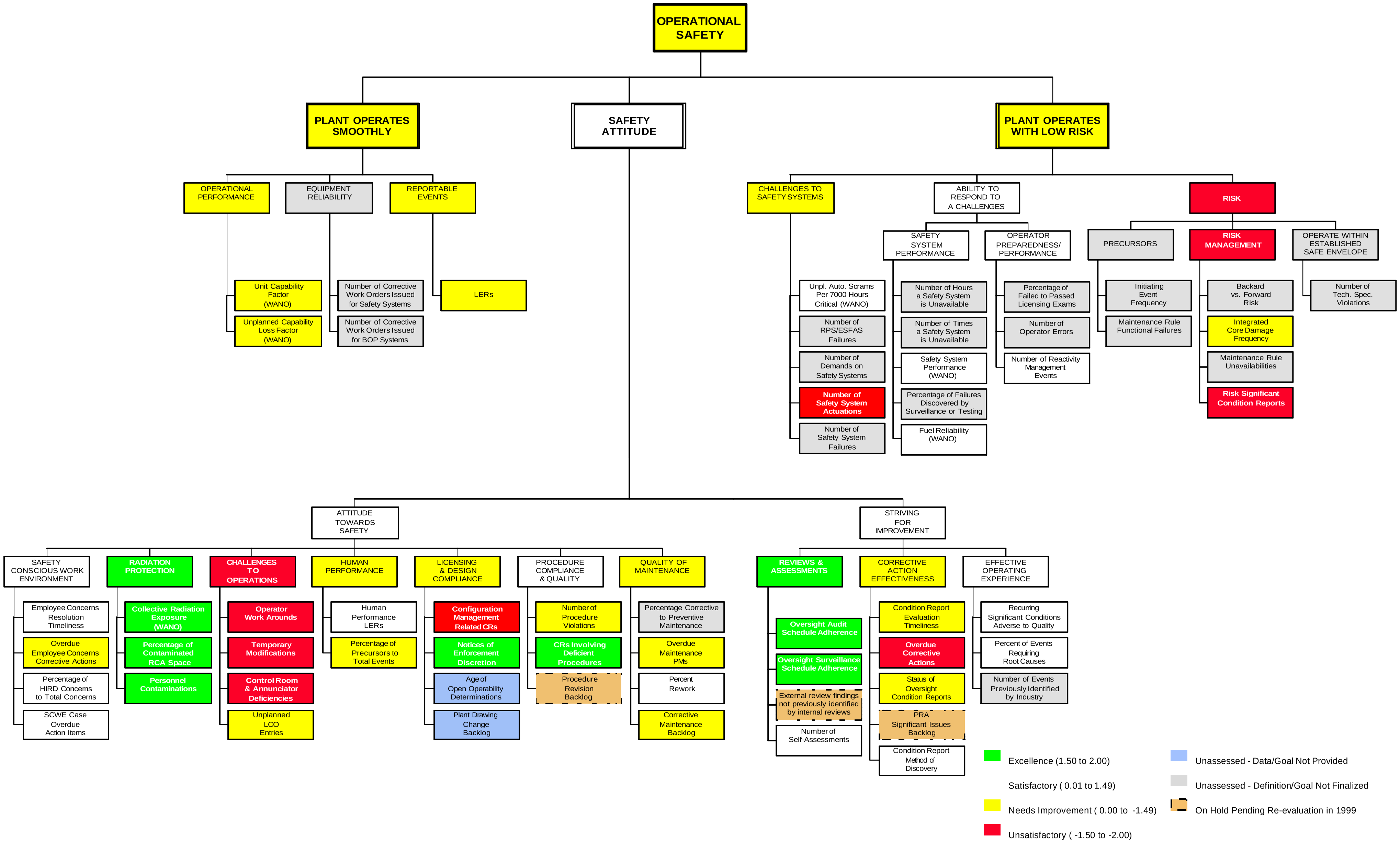
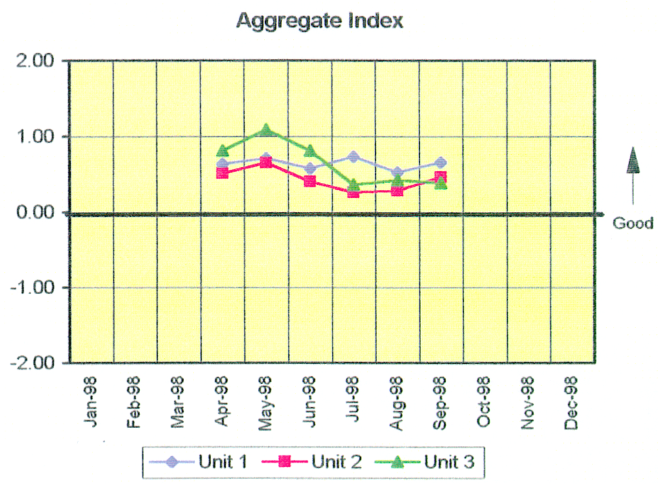


FIG. III–11. Colour display designed by plant C.

Operational Safety Attitude

Unit Performance

Progress: ***Performance remains in the satisfactory range for all three Units, normalized data shows a relatively stable trend for Units 1 and 2, and a declining trend for Unit 3.***



Raw Data

	Jan-98	Feb-98	Mar-98	Apr-98	May-98	Jun-98	Jul-98	Aug-98	Sep-98	Oct-98	Nov-98	Dec-98
Unit 1				0.63	0.71	0.58	0.73	0.52	0.65			
Unit 2				0.51	0.65	0.40	0.26	0.28	0.46			
Unit 3				0.81	1.09	0.81	0.36	0.42	0.38			

Definition

The Safety Attitude Indicator focuses on some of the "softer issues" associated with development of a healthy safety attitude. This indicator is designed to measure the attitude with which the plant is operated and maintained. Capturing this aspect of safety requires that we look across a number of lower level indicators (not traditionally aggregated) to effectively evaluate what the organization is willing to "tolerate" with respect to deficient conditions. Indicators in the following key categories have been chosen:

Safety Conscious Work Environment **(SCWE)**, Workplace Risk **(WR)**, Challenges to Operations **(CO)**, Human Performance **(HP)**, Licensing & Design Compliance **(L&DC)**, Procedure Compliance & Quality **(PC)**, Quality of Maintenance **(QM)**, Reviews & Assessments **(R&A)**, Corrective Action Effectiveness **(CA)** and Effective Operating Experience **(OE)**.

The Index scale is based on a point value assigned to each category with respect to unit performance versus unit goals. A positive 2 is considered a significant strength, a positive 1 considered satisfactory, a negative 1 indicates improvement needed, and a negative 2 is considered a significant weakness.

Analysis/Action

For the purpose of trend analysis, the data is normalized to improve the usefulness of this indicator. The normalized trend through September is relatively stable for Units 1 and 2, and shows a decline for Unit 3.

Unit 1 Culture Index shows improvement this month, primarily due to improvement in Oversight audit and surveillance schedule adherence. This area had a positive impact on all three units.

Unit 2 performance also shows improvement this month, primarily in the areas of procedure compliance, quality of maintenance and corrective action effectiveness.

Unit 3 performance shows a slight decline this month. Although progress was noted in corrective action effectiveness, performance declined in the areas of challenges to operations, human performance, procedure compliance and quality of maintenance.

Goal

For each unit, the goal is to show a stable or improving trend over time with respect to Operational Safety Attitude.

Comments

Data Source: Unit Indicators | ***Analysis by:*** | ***Owner:***

FIG. III–12. Graphic display of the plant trend in "operational safety attitude" — plant C.

Plant D

The introduction of the computerized Station Information System (SIS) in 1998 has helped improved communication of performance measurement internally amongst employees, as well as externally between the organization and its customers. The emphasis on measuring and improving performance (result-oriented management) has created a new climate, affecting all departments within the company. Station staff believe that a result-oriented organization requires timely and accurate information on programme and supporting services. Collecting and processing accurate information depends on the effective communication of mission-critical activities. Additionally, the performance monitoring programme is helpful in justifying plant improvement programmes and their costs.

Prior to starting the operational safety performance indicator programme, an implementation procedure was written and incorporated in the station procedure manual. Training was provided to all concerned staff prior to the use of new or modified procedures.

Standard data collection forms and computer data input formats were also designed for use by authorized persons in each individual area. While the computer format governs the method of data processing, each performance indicator co-ordinator is responsible for data verification. Any missing information can easily be seen and picked up by the responsible manager. The most important step is the verification by the performance indicator co-ordinator of the effectiveness and validity of the data. The performance indicator co-ordinator also carries out calculation and trend analysis. Performance variances are reported to the responsible manager for strategic actions.

Information obtained by the performance indicator programme is available at all 800 computer terminals. In addition to providing a graphic display of information and trends, the station utilizes a colour rating system to assess indicator performance relative to established goals. Colour ratings for each indicator are aggregated to produce ratings for higher level indicators or "windows". If any specific indicator in a given area is rated "red" or "unsatisfactory," the higher level window is also assigned a "red" rating to flag the area for management attention and action. These colour "windows" provide an effective management tool for review of performance in critical areas. To allow multiple sets of indicators to be compiled into an overall measure, the station is in the process of developing a performance index system. This system is expected to enhance management review of station performance for the purpose of decision making.

Key indicator results are also displayed graphically on 2 large LED display boards at the plant and office entrances. The responsible manager for each performance indicator must review performance results with his branch heads on a monthly basis and establish improvement strategies for those indicators rated other than "green" or "significant strength". Indicators reported as "unsatisfactory" or those persistently rated as "needs improvement" are reviewed in the Plant Nuclear Safety Committee. A performance indicator programme report is distributed to all branches and departments monthly and discussed in the senior management meeting.

The station maintains an intranet Web page for dissemination of station information in-house. The performance indicators programme resides in this Web page. The Web page is menu-driven and user-friendly (see Figs III–13 to III–23). A click on the "station performance indicators programme" menu button on the Station Information System guides the user, on any computer terminal within the station, to input source data or to obtain indicator information from the system. Evaluation, verification of data and trend analysis can also be performed at authorized computer terminals. The inclusion of performance indicators on the LAN computers has made a great contribution toward the success of the performance indicator information dissemination, and has also contributed to spread a clear message that *"what gets measured gets done*".

III–4.5. Logistics and resources required to support programme development

Plant A

Resources did not pose a severe problem once the management at the plant committed itself. However, in spite of the commitment to safety the earlier title of the project namely "Indicators to Monitor NPP Safety Performance" caused apprehensions that these may be used for regulatory purposes. Once the title was changed to "Indicators to monitor NPP Operational Safety Performance" the Headquarters had no qualms about approving the pilot study. Once Headquarters approved the project, the plant management faced a problem of freeing the appropriate manpower for the pilot study. The commitment of the management and the interest of certain officers overcame this hurdle and a team was finally put together. By appointing an officer already co-ordinating the PSA and PSA applications projects as the co-ordinator of this pilot study, a number of inter-group problems were solved. As a result, the team was easily able to draw on the resources of both the PSA and performance analysis groups.

At the end of the pilot project it was felt that, in order to implement a well established programme, a dedicated team with one supervising engineer would be needed. Software development could be catered to by another Division specializing in computer software and hardware. The team could also draw on the PSA database.

Plant B

The implementation of the programme implied an additional effort by the plant. This effort basically consisted of a number of man-hours and technical means devoted to its development.

Depending on the starting point of each plant, this effort may be more or less significant. For example, this plant had a well established performance indicator programme, and did not require extensive resources to initiate the new project. In any case, there was a need for a general co-ordinator for external and internal relations regarding the programme and the supplementary participation of the indicator 'owners'.

Plant C

Given the extended shutdown of the plant, initial efforts concentrated on the development of the "safety attitude" attribute. Over the course of the last year, the plant has been slowly expanding the use of indicators to address the other attributes.

Text cont. on page 64.

FIG. III–13. Station information system — plant D (1 of 11).

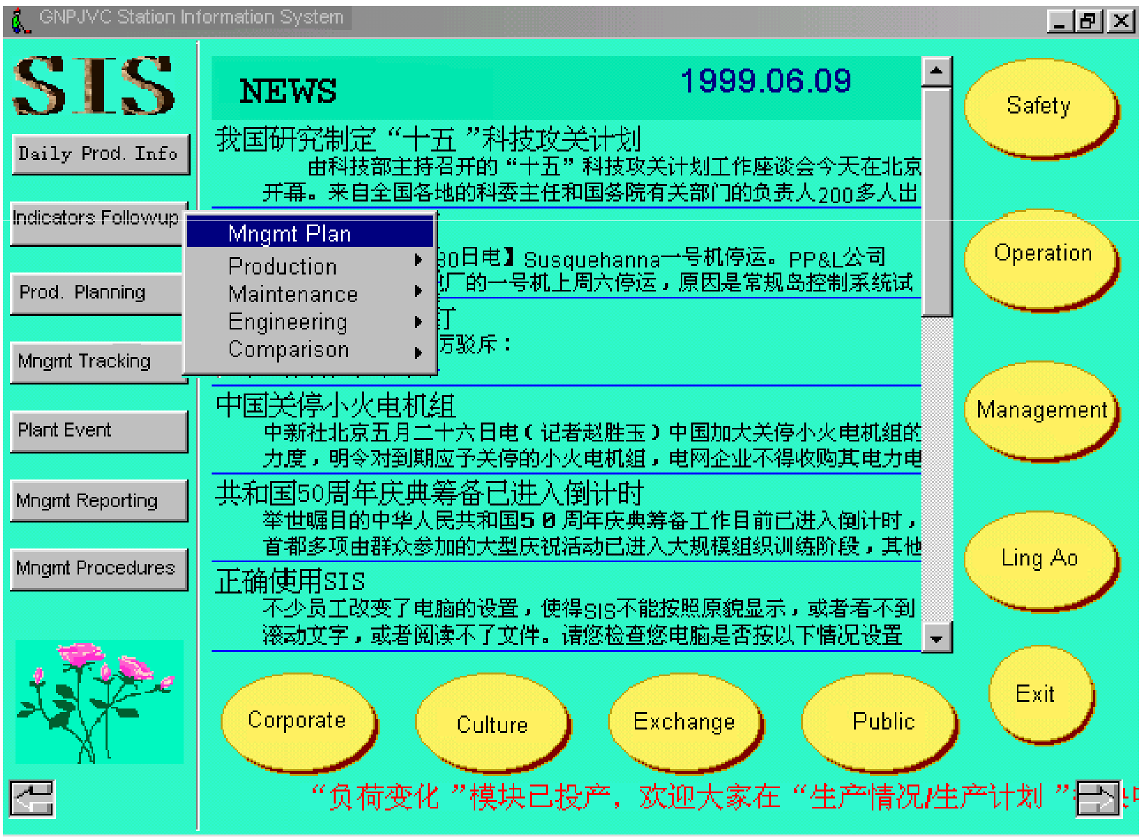


FIG. III–14. Station information system — plant D (2 of 11).

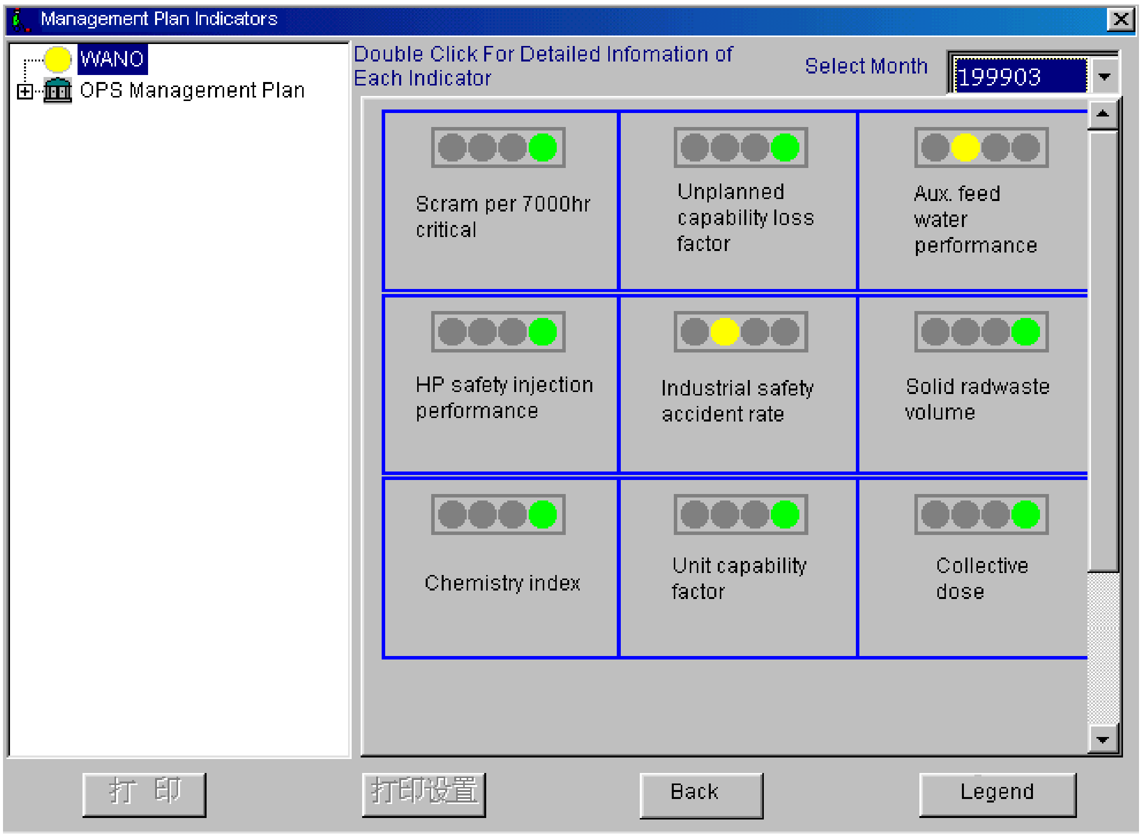


FIG. III–15. Station information system — plant D (3 of 11).

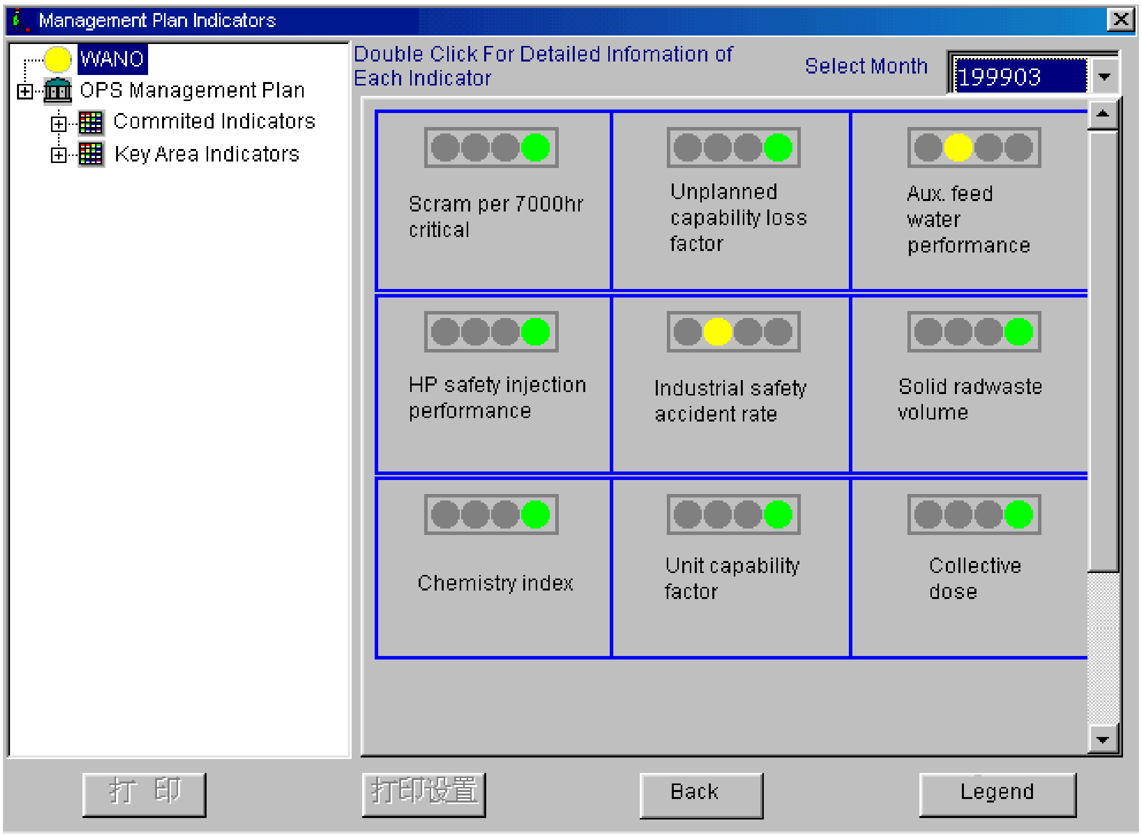


FIG. III–16. Station information system — plant D (4 of 11).

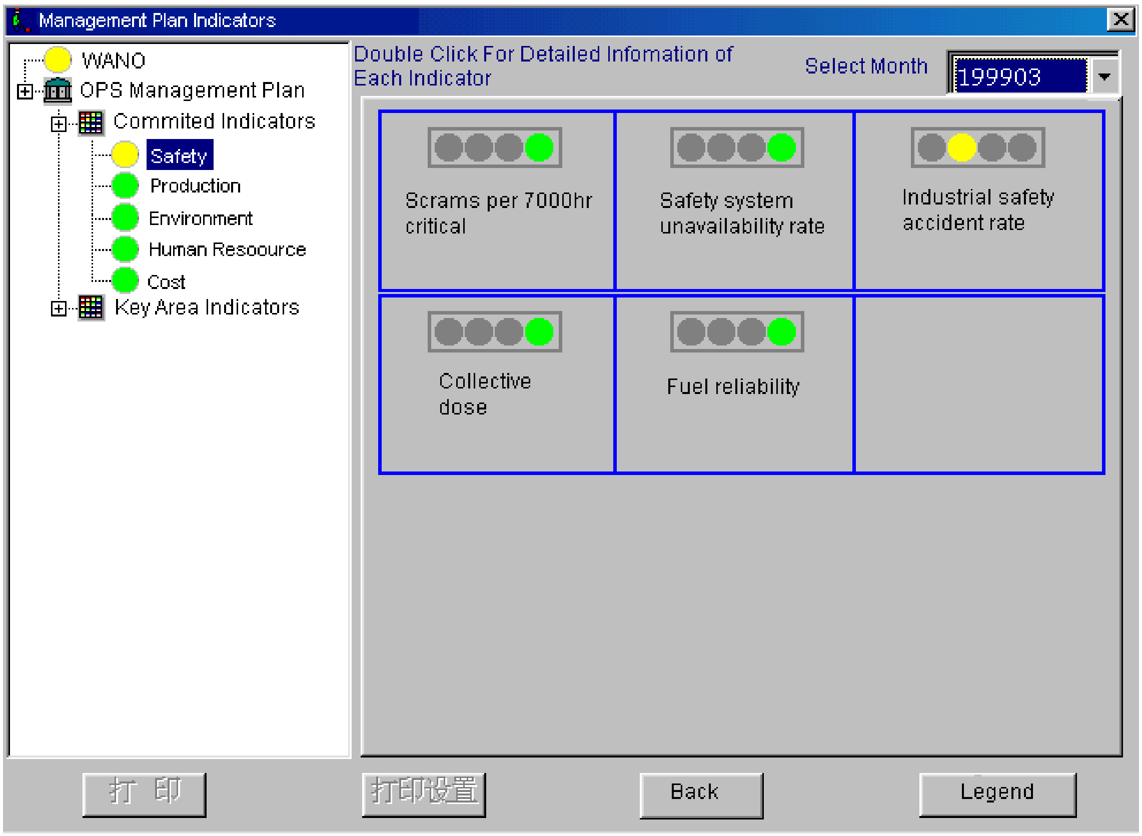


FIG. III–17. Station information system — plant D (5 of 11).

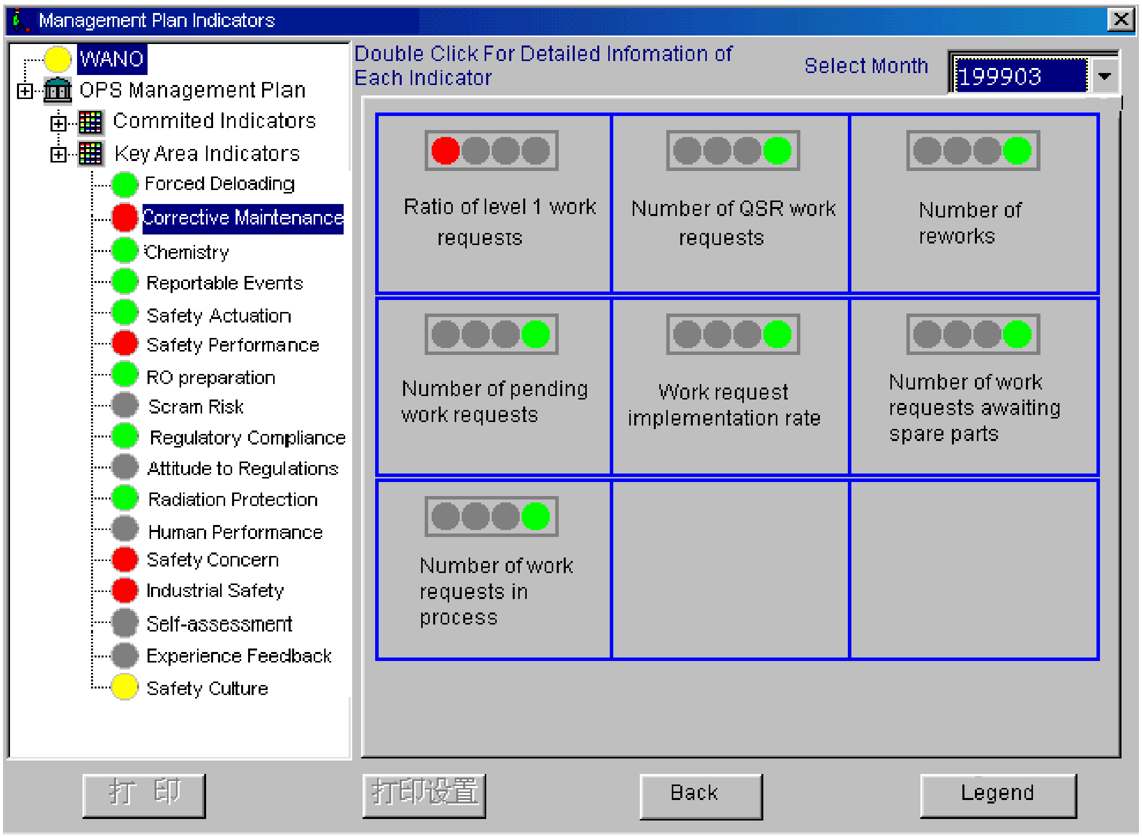


FIG. III–18. Station information system — plant D (6 of 11).

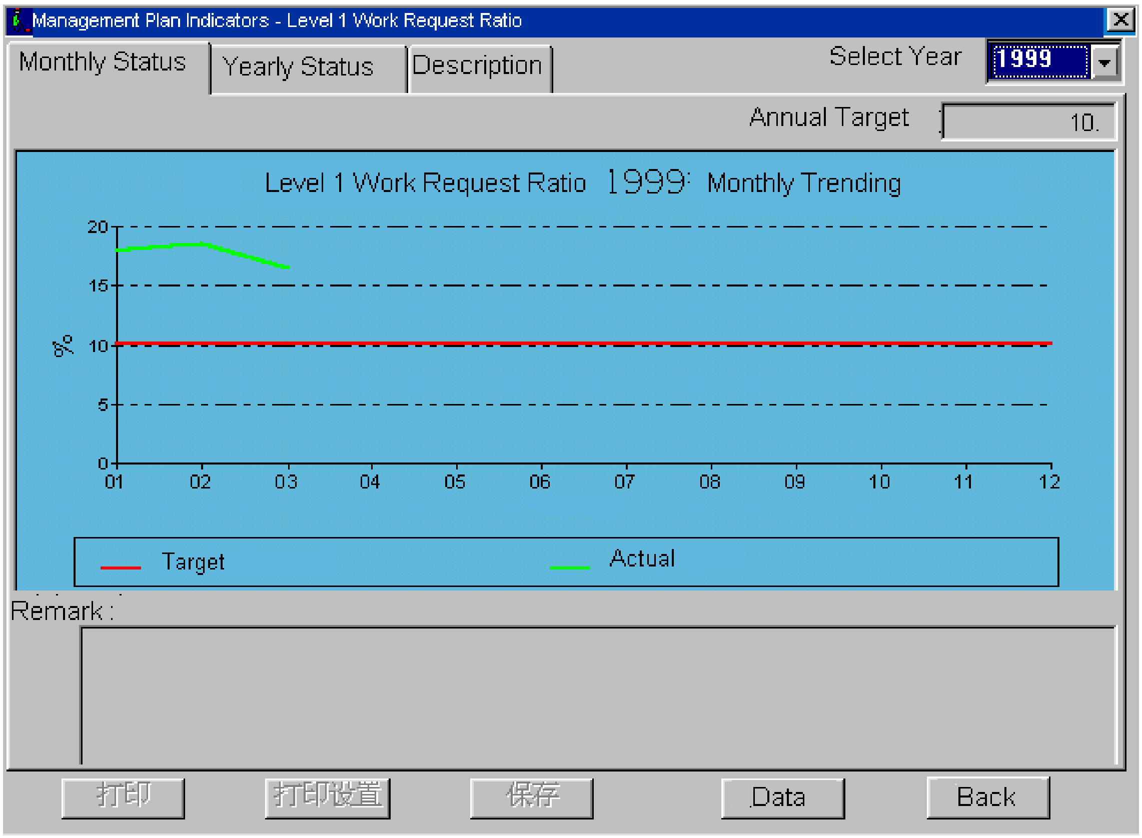


FIG. III–19. Station information system — plant D (7 of 11).

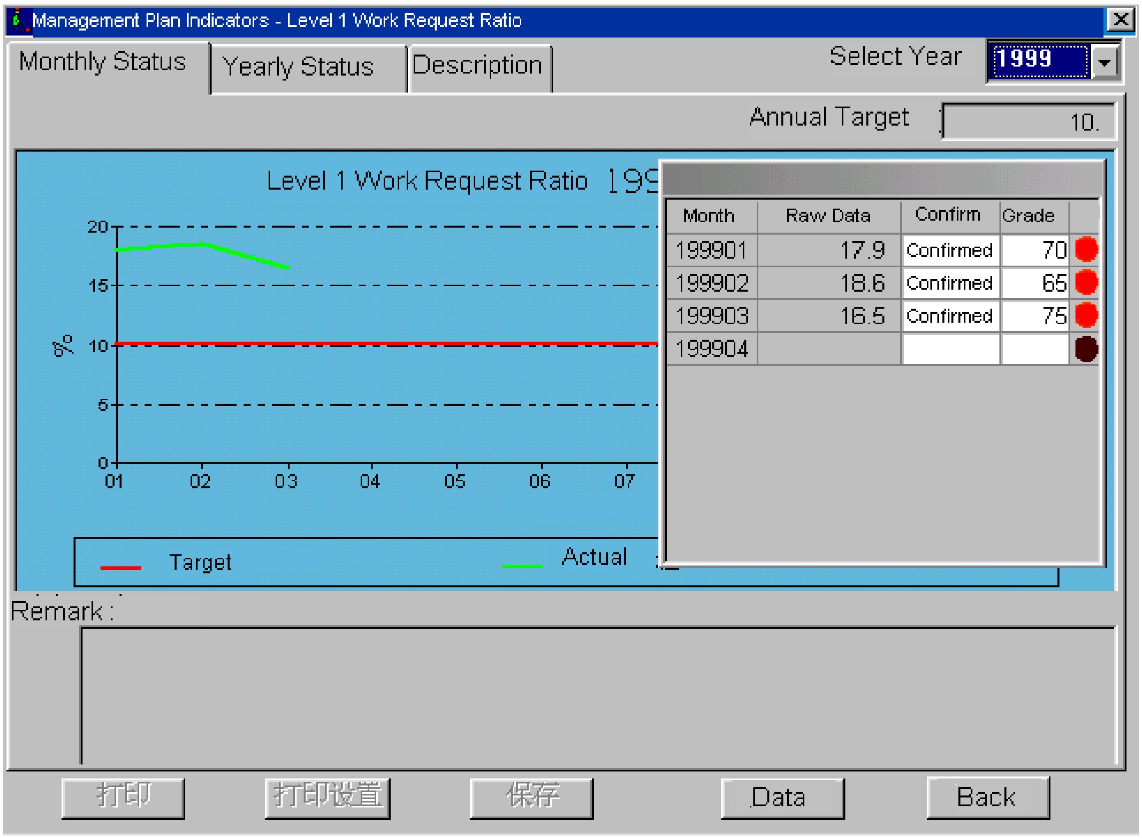


FIG. III–20. Station information system — plant D (8 of 11).

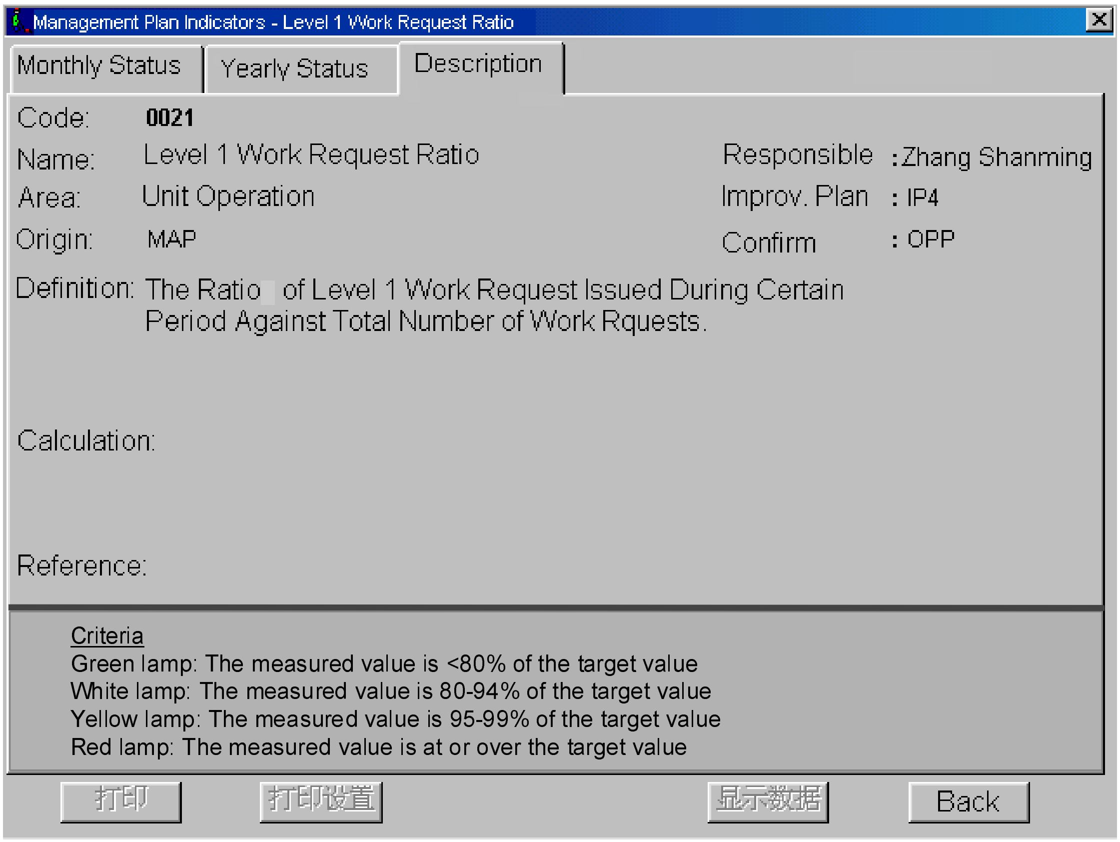


FIG. III–21. Station information system — plant D (9 of 11).

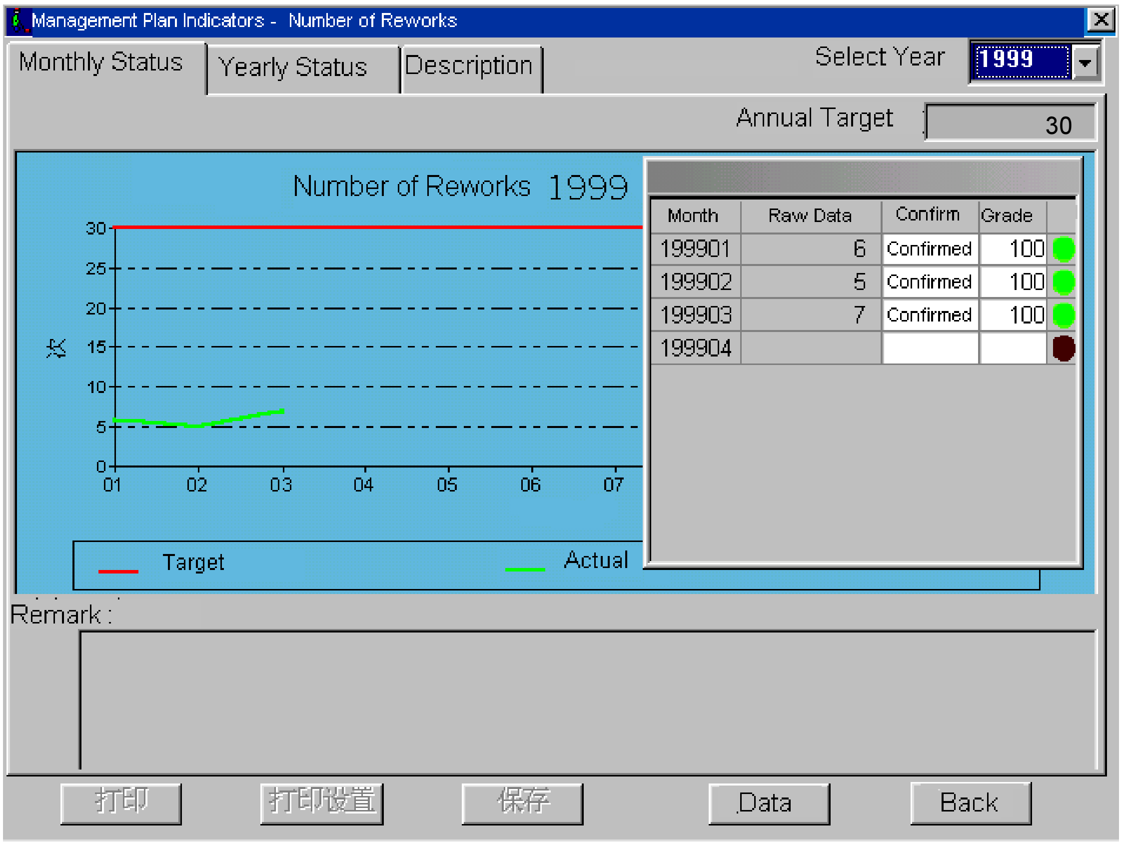


FIG. III–22. Station information system — plant D (10 of 11).

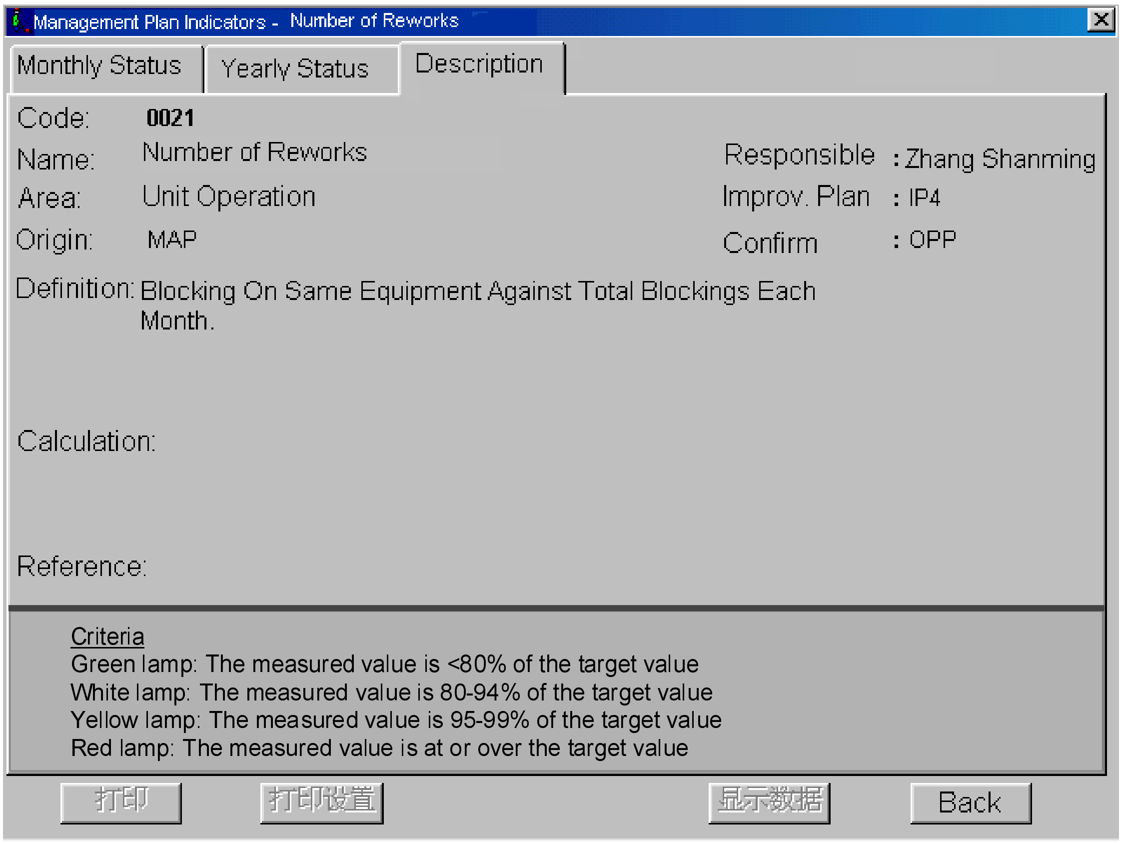


FIG. III–23. Station information system — plant D (11 of 11).

Because the plant had relatively well developed data collection and performance monitoring systems, few additional physical resources were required. However, there has been a significant man-month effort to select and define the indicators and goals, as described above. This process, from inception to utilization, extended over a period of one and a half years. And although the programme is considered operational, work is under way to expand the indicators monitored, to refine indicator definitions and goals, and to enhance the evaluation and interpretation of the data.

Plant D

The current data collection and performance measurement systems were developed in 1997. Additional resources were allocated for the last six months to improve the information technology support programmes to prevent redundancy of databases. Because the use of the intranet has become a valuable tool to help collect data and share information from different sources, a project team is dedicated to work on the continuous development of this system with the aim of increasing the capability to transfer data in support of the performance based management systems of the plant.

III–4.6. Management involvement

Plant A

Each quarterly report was made available to the plant management. However, the plant management decided not to interfere with the work during the development of the pilot study, placing reliance on the project co-ordinator. Once all the indicators have been evaluated, a seminar will be arranged for plant management and senior plant personnel. The team will present its work at the seminar. This will be done with the intention of obtaining feedback. Discussion sessions will follow and a final version of the proposed programme (selected indicators, definitions, methodology for evaluation, etc.) will be prepared to serve as the basic document governing the implementation of the programme.

Periodic meetings involving the management and the team supervisor would be needed to discuss the status of indicators and draw out a plan of action. In addition, the indicator status would be made available on the local LAN network. Hard copies would also be sent out to the management.

Plant B

The main purpose of the IAEA project on "operational safety performance indicators" was to establish a very complete set of useful indicators so as to get a very valuable tool, at all tiers of plant management, for decision making based upon indicator trends and target accomplishment.

Therefore, plant management involvement in the development process of the programme appeared to be fundamental. The clearly stated support of the programme by the plant director, and the awareness of the complete process by the Plant Nuclear Safety Committee and other concerned committees of the company, were critical for the success of the programme and its final implementation.

Plant C

This concept represents a significant departure from previous performance monitoring programmes. Management support for programme development and management involvement in performance evaluation is essential to the success of this type of programme.

Currently, operational safety performance indicators are reviewed on a monthly basis by plant management and by the plant Nuclear Safety Assessment Board.

Plant D

Plant management reviews the performance indicators on a monthly basis in the management direction team meeting. Responsible managers analyse all performance variances and set strategic actions for improvement. The Plant Nuclear Safety Committee reviews all variances concerning nuclear safety. Plant performance results are reviewed and discussed with corporate management monthly. Plant and corporate management are strongly supporting the development of risk based indicators, with the aim of generating forward looking risk profiles for performance assessment.

The station has received excellent support and encouragement from the corporate management for upgrading all LAN computers and for developing the intranet for effectively enhancing plant performance measurement, analysis, and results dissemination. Drive from the corporate management to look into the different approaches that can be taken to develop a performance index system is another example of keen support from senior management.

III–4.7. Insights and lessons learned

Plant A

- Looking at indicators in isolation does not always provide the optimum benefit.

- Already existing databases need to be scrutinized to see if they will serve the purpose. Data collection and analysis systems may need changes. Some new databases may be required.

- Not all indicators proposed in the main body of this report were judged to be meaningful. New plant specific indicators were substituted by the plant in order to asses the same overall/strategic areas.

- Not all indicator definitions in the main body of this report were adequate for the plant. Several definitions had to be adapted so that the most meaningful results could be obtained.

- In general, goals need to be established to give meaning to trends. However, it is sometimes difficult to define goals for some indicators such as number/percentage of hours spent on training. Without a goal, trending of this indicator is not useful. On the other hand, there may be some trends that have meaning irrespective of goals. Some guidelines in defining such difficult goals could, therefore, be helpful.

Plant B

- Improvement has been noted in existing plant indicators as a consequence of the IAEA indicators study and its implementation.

- Some areas of the plant were not evaluated before implementation of the IAEA indicators programme.

- Difficulties were encountered in adapting the proposed IAEA indicators to the plant's characteristics.

- Some of the indicators proposed in the main body of this report were not judged to be useful to the plant.

- Difficulties were encountered in convincing plant staff that these indicators were not "more of the same" or just additional work. There is a general impression that the plant has too many indicators.

- Difficulties were found in defining goals for some indicators.

- Some of the indicators are defined in such a way that they are difficult to monitor.

Plant C

- The process of selecting and defining indicators and goals has been very useful in creating a dialogue within the organization on operational safety performance monitoring. This dialogue has served to increase organizational awareness and has promoted critical thinking on those issues fundamental to monitoring operational safety performance.

- The design of the model enhances data significance and evaluation. The plant's adaptation of the model developed at the IAEA and colour window display allows for visualization of performance across a number of parameters. This increases the chances that performance strengths and weakness will be evaluated in the correct context.

- The colour display provides a valuable management tool for evaluating overall plant "wellness" at a glance. The tool allows management to visualize the performance of many indicators, but does not require review of every indicator. Those indicators showing performance excellence can be selectively reviewed by management, if desired. Those showing performance weakness can be reviewed in greater detail to assess the reasons for poor or declining performance and to develop corrective actions for improvement. However, the colour display tends to be cumbersome and requires colour printing capability.

- There has been some reluctance to accept what is seen as "yet another performance monitoring programme" and a general concern that there are already "too many indicators".

- The process of obtaining agreement on indicator definition and goals tends to be time consuming.

- The programme requires a long term commitment not only for development, but to continuously evaluate the effectiveness and validity of the data.

Plant D

- The station's operational safety performance indicator programme is on the charted path of achieving its goals. However, it is difficult to obtain agreement from all departments on the unified indicator system, given the complexity of the four levels and with the expectation that the lower level indicators should serve its next upper level as leading indicators.
- The assumption of achieving the set goals at the lowest level indicators should warrant the zero performance variances at the first level indicators.
- Senior management's enthusiasm for arranging a performance indicator seminar requiring all department managers and facilitators to attend during the third quarter of 1999 is a very promising support to the indicator programme based on the one developed at the IAEA.
- To support the indicator programme, it is necessary for all managers to understand *Dr. Deming's* statement:
  - Management's job is prediction and there is no prediction without theory;
  - There are no data on the future, data from the past must be used to form a base for prediction;
  - 94% of the changes required for improvement will require action by management.

III–5. EXAMPLES OF SPECIFIC INDICATORS

Although all plants participating in the pilot study utilized the proposed framework as a starting point, each plant adapted the indicator organization to meet plant specific needs. The selection of indicators was also based on the availability of data, site-specific data collection systems, and/or previously existing indicators. Figure III–24 depicts the indicators chosen by each of the four plants to monitor "operating experience feedback". It should be noted that while the attribute "plant operates with a positive safety attitude" and overall indicator "operating experience feedback" were maintained by each plant, some of the specific indicators selected varied among them.

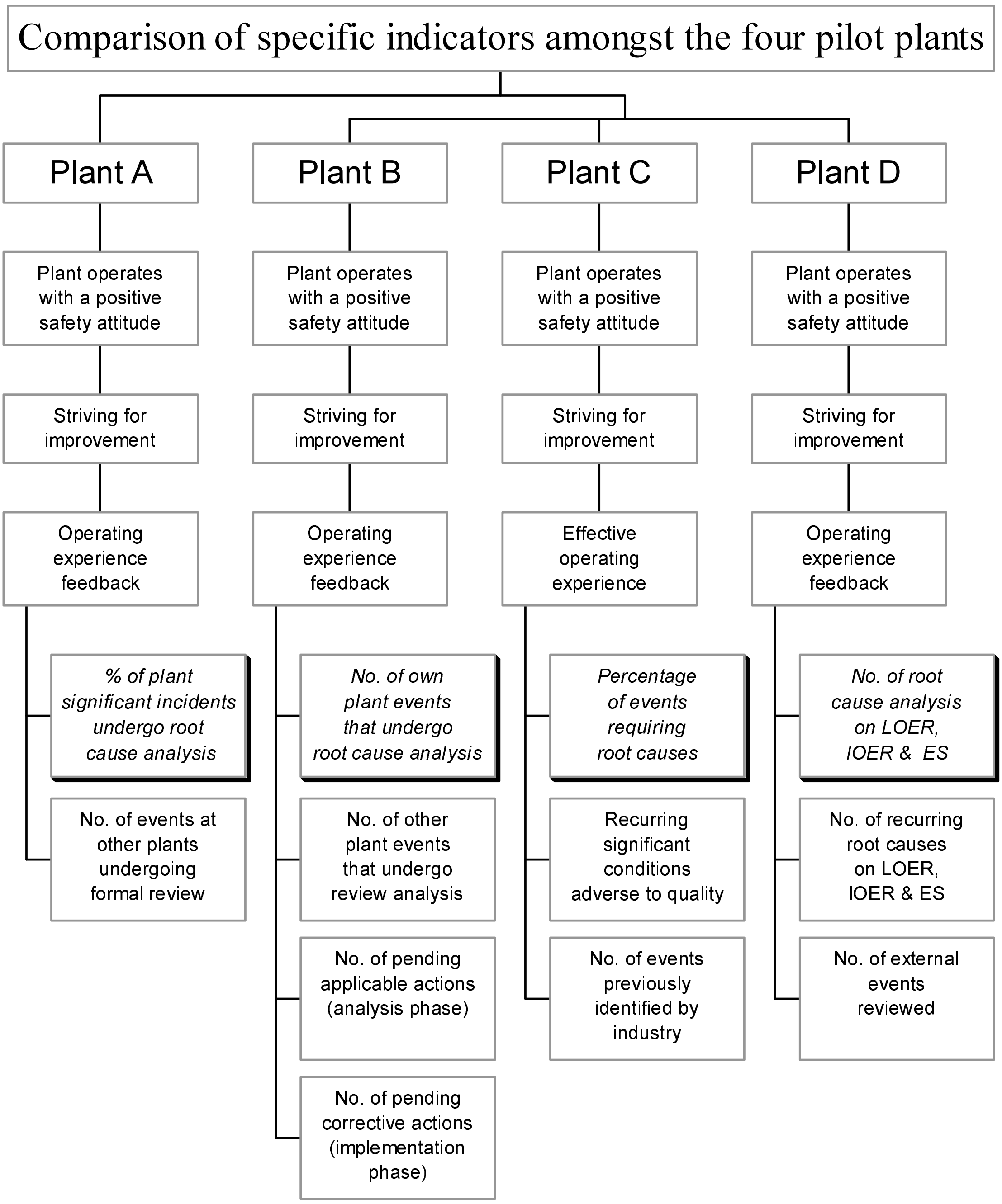


FIG. III–24. Indicators selected to monitor "operating experience feedback" by the pilot plants.

Even when the specific indicators chosen appeared to be the same, differences were identified in the definition of indicators, indicator goals, formula calculations, etc. These differences are illustrated in Table III–2.

TABLE III–2. COMPARISON OF SPECIFIC INDICATOR DEFINITIONS AMONG THE PILOT PLANTS

IAEA model	Plant A	Plant B	Plant C	Plant D
No. of own plant events that undergo root cause analysis	Percentage of plant significant incidents undergoing root cause analysis	No. of own plant events that undergo root cause analysis	Percentage of events requiring root cause analysis	No. of root cause analysis on licensing operation events, internal operation events and event sheets
Definition of indicator	The ratio of significant issues that undergo root cause analysis to the total number of significant incidents reported for the strategic indicator "significant incidents".	No. of events, as defined in Regulatory Body Safety Guide 1.6, that undergo a root cause analysis	The ratio of Level 1 Condition Reports (CRs) to the total number of CRs generated, expressed as a percentage. All Level 1 CRs represent high significance issues and require performance of a root cause investigation to determine the source of the problem	All the reportable licensing operation events and the near miss (internal operation events) events require root cause investigation by the cross-functional RCA team. 30% of the total reportable abnormal events require root cause investigation by the concerned department
Goal	To be determined	>90% of the events undergo root cause analysis	The goal is for the percentage Level 1 CRs to be <5% of the total CRs generated, with a declining trend overall	100% RCA on both LOERs and IOERs. 30% RCA for the reported event sheets

Each of the plants participating in the study agreed that the selection of indicators, definitions and goals was an important step in creating a plant specific tool. The process of developing indicator goals and definitions helps to focus the organization on the critical elements of nuclear safety performance that should be measured.

However, as Table III–2 illustrates, this process introduces significant variation in how the indicators are defined and measured. Comparison of data and benchmarking among plants utilizing plant specific definitions should be approached with extreme caution. Invalid comparisons can lead to the establishment of inadequate goals and forfeit the benefit that this tool can provide.

III–6. CONCLUDING REMARKS

The four plants participating in these pilot studies were obviously in different stages of programme development. Nonetheless, there were a number of common conclusions that could be drawn from their collective experience:

- **The IAEA framework for the establishment of a programme to monitor operational safety performance is considered an excellent approach.**

  Each plant participating in the study has recognized the inherent value of the IAEA concept and framework, and has maintained the overall hierarchical organization of indicators.

- **Plant specific adaptation of the proposed IAEA framework is required to produce an effective management tool.**

  Although the overall framework is considered effective, each participating plant has felt the need to introduce plant specific adaptations to suit individual data collection systems, plant characteristics, etc.

  Plants that embark on this programme should understand that the model provides a starting point for development, but cannot be implemented without significant review and evaluation. In fact, it is the process of indicator selection, definition and goal setting that helps to focus the organization on those elements that are critical for operational safety monitoring. Plants should be prepared to invest the time necessary for programme development and adjustment and recognize that this process may extend over an extended period of time and require additional resources. Management ownership and use of the performance indicators selected is a key element for the effective use of this tool.

- **Goal setting enhances the effectiveness of performance monitoring.**

  Even though the process of establishing goals is a difficult task, goal development is considered to be an important step in programme development. Trends can be derived from collection of numerical data alone. However, the significance of the data and the benefit derived is enhanced by establishing meaningful goals and targets against which performance can be evaluated.

- **Staff reluctance to embrace a new programme may be encountered.**

  While staff acceptance of this programme was not an issue for Plant A, for whom this effort represented a first attempt at the comprehensive use of indicators for performance monitoring, those plants with well established programmes encountered greater resistance. Many individual programme ‘owners’ or overseers saw the effort as additional work and “more of the same”. Programme co-ordinators at some plants faced concerns that there were “already too many indicators”. In these plants, there was a need to work with staff at the programme level and to solicit the support of management at lower levels within the organization in order to effectively implement the programme.

- **The programme does not facilitate comparisons among nuclear plants.**

  The lower level indicators which form the basis for the plant programmes are often highly dependent upon site specific definitions and data collection systems, preventing viable comparisons on a plant-to-plant basis. Unit differences at multi-unit sites may also create difficulties in adapting this model for common use.

- **An evaluation of overall plant performance may be enhanced by assessing the individual indicators relative to each other.**

  The experience of certain plants in aggregating performance monitoring data by use of colour window and trend displays may assist management in focusing on areas of deficiency and provide a means to evaluate the overall "wellness" of the organization. Plants using this approach have found it helpful to identify acceptance criteria associated with each colour to preclude the introduction of subjectivity associated with colour ratings. Additional experiential data will be helpful in evaluating the benefit of this approach.

- **Quality assurance and plant documentation systems should be established to ensure that the operational safety monitoring programme remains viable.**

  As with other plant activities, it is important to develop documentation systems to ensure that the criteria, goals and calculations associated with a given indicator are traceable. In addition, a quality assurance process, consistent with the plant Quality Assurance Programme, should be established to ensure that the performance monitoring programme remains valid.

ABBREVIATIONS

AOT	allowed outage time
BOP	balance of plant
CAR	corrective action report
CCF	common cause failure
CDF	core damage frequency
CDP	probability of core damage
CL2	chlorine
CW	cooling water
ECCS	emergency core cooling system
EOP	emergency operating procedures
ES	event sheet (24ES: reported within 24 hours)
ESFAS	engineering safety features actuation system
FMEA	failure mode and effect analysis
GNRB	regional nuclear review board
Gp	group
IE	initiating event
INES	international nuclear event scale
Io	in-operability
IOER	internal operation event report
IS	industrial safety
IS/FS	industrial safety/fire safety
ISAR	industrial safety accident rate
LCO	limiting conditions for operation
LGR	220 kV back-up supply and 6.6 kV supply system
LHP	diesel generator set “a”
LHQ	diesel generator set “b”
LOER	licensing operation event report
NCR	non-conformance report
NPP	nuclear power plant
NS	nuclear safety
OBN	observation report
OSART	Operational Safety Review Team (IAEA)
PNSC	plant nuclear safety committee
PT	periodic test
QA	quality assurance
QC	quality control
QSR	quality and safety related
RCA	root cause analysis
RCS	reactor coolant system
RHR	residual heat removal
RIS	safety injection system
RO	reactor operator
RPR, RPS	reactor protection system
RRA	residual heat removal system
SEC	essential cooling water system
SIS	station information system
SRO	senior reactor operator
SSC	structures, systems and components

STA	shift technical advisor
TCA	temporary connection/modification (electrical/control)
TSA	temporary connection/modification (mechanical)
UCF	unit capability factor
UCLF	unplanned capability loss factor
WANO	World Association of Nuclear Operators

CONTRIBUTORS TO DRAFTING AND REVIEW

Ballesio, J.	SAIC, United States of America
Bonaca, M.	Northeast Utilities, United States of America
Calduch, F.	Central Nuclear de Cofrentes, Spain
Campbell, R.	International Atomic Energy Agency
Diaz Francisco, J.M.	International Atomic Energy Agency
Domenech Rojo, M.A.	International Atomic Energy Agency
Fuhrmann, C.	TÜV Nord, Germany
Gómez Cobo, A.I.	International Atomic Energy Agency
Hamlin, K.	WANO, United Kingdom
Harrington-Burns, D.	Millstone Station, United States of America
Hashmi, J.	International Atomic Energy Agency
Iqleem, J.	Karachi Nuclear Power Complex, Pakistan
Lau, S.	Daya Bay NPP, People's Republic of China
Lehtinen, E.	VTT AUTOMATION, Finland
Levstek, M.	Slovenian Nuclear Safety Administration, Slovenia
Meslin, T.	Centre nucléaire de production d'électricité de Saint-Laurent-des-Eaux, France
Niehaus, F.	International Atomic Energy Agency
Palomo, J.	Iberdrola, Spain
Pettersson, L.	Vattenfall Energisystem AB, Sweden
Saqib, N.	Karachi Nuclear Power Complex, Pakistan
Schmocker, U.	Federal Nuclear Safety Inspectorate, Federal Office of Energy, Switzerland
Szikszai, T.	Paks NPP Ltd, Hungary
Zhong, W.	International Atomic Energy Agency

Consultants Meetings

Vienna, Austria: 11–15 December 1995, 15–19 July 1996, 25–29 November 1996,
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