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Indicators of safety culture – selection and utilization of leading safety performance indicators

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SSM Perspective

According to the Swedish RadiationSafety Authority's Regulations concerning Safety in Nuclear Facilities (SSMFS 2008:1) "the licensee shall ensure that safety in the nuclear activity is routinely monitored and followed up, deviations are identified and handled so that safety us maintained and continuously develops according to the objectives and directives that apply" (2 Chap., 9 §, 8 point). The deviations may concern deviations from safety goals and directives as well as deviations from procedures and instructions that are applied in the nuclear activity. Safety indicators can be a suitable aid in the monitoring and follow up of the nuclear activity. However, safety indicators or safety performance indicators can also be an aid in the proactive safety management of a nuclear activity.

SSM expects, as a part of the safety management, that safety culture to be regularly assessed by the licensees and indicators of safety culture can be a useful tool both for licensees and the regulators.

Background

SSM has identified a need for an overview, analysis and evaluation of safety performance indicators and particularly safety culture indicators in the domain of nuclear safety. Current safety performance indicators are usually lagging i.e., measuring something that has happened. In order to be able to monitor the effects of proactive safety work as well as anticipate vulnerabilities the organizations should define leading indicators. Those should be able to grasp organizational practices and processes that precede changes in the safety performance of the organization.

Objectives of the project

The overall objective of the project was to provide an overview of the selection and effects of leading safety performance indicators in the domain of nuclear safety. The project should provide guidance on the selection and interpretation of leading indicators as well as information on the theoretical justification of the intended measures. Indicators should be categorized on the bases of the underlying phenomena they seek to measure as well as based on the nature of data they produce. The project should also propose a tentative model of the influence of the leading indicators on nuclear safety in terms of their effects.

The project was built on VTT´s work on the evaluation of safety critical organisations and safety culture as well as IAEA´s ongoing work concerning leading indicators of nuclear safety.

Results

The project has resulted in a broad overview of the definition of safety performance indicators, the existing types of indicators and the utilization of safety performance indicators in the nuclear industry. The project has given deeper knowledge in the different kind of safety performance indicators (leading and lagging) including safety culture indicators and how they are related to safety management in the nuclear domain. A framework for selection and use of safety performance indicators has been developed supported with examples.

Effect on SSM supervisory and regulatory task

This framework for selection and examples of safety performance indicators, including safety culture indicators, will give a good support for the development of the regulatory indicators in the area. Also, the project has given further knowledge in how to evaluate safety critical organisations with the emphasis on the nuclear industry (see Evaluation safety-critical organisations – emphasis on the nuclear industry, SSM Report Research 2009:12).

Project information

Project managers at SSM: Lars Axelsson and Per-Olof Sandén
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Project number: 1604

Summary

Safety indicators play a role in providing information on organizational performance, motivating people to work on safety and increasing organizational potential for safety. The aim of this report is to provide an overview on leading safety indicators in the domain of nuclear safety. The report explains the distinction between lead and lag indicators and proposes a framework of three types of safety performance indicators – feedback, monitor and drive indicators. Finally the report provides guidance for nuclear energy organizations for selecting and interpreting safety indicators. It proposes the use of safety culture as a leading safety performance indicator and offers an example list of potential indicators in all three categories. The report concludes that monitor and drive indicators are so called lead indicators. Drive indicators are chosen priority areas of organizational safety activity.

They are based on the underlying safety model and potential safety activities and safety policy derived from it. Drive indicators influence control measures that manage the sociotechnical system; change, maintain, reinforce, or reduce something. Monitor indicators provide a view on the dynamics of the system in question; the activities taking place, abilities, skills and motivation of the personnel, routines and practices – the organizational potential for safety. They also monitor the efficacy of the control measures that are used to manage the sociotechnical system. Typically the safety performance indicators that are used are lagging (feedback) indicators that measure the outcomes of the sociotechnical system. Besides feedback indicators, organizations should also acknowledge the important role of monitor and drive indicators in managing safety.

The selection and use of safety performance indicators is always based on an understanding (a model) of the sociotechnical system and safety. The safety model defines what risks are perceived. It is important that the safety performance indicators can help in reflecting on this model. Key questions to ask when selecting and utilizing safety performance indicators are 1) what is required from the nuclear power plant to perform safely and 2) what is required from the organization in order to be aware of its safety level and enhance its safety performance.

The indicators should provide information on whether these requirements are met or not, where the organization should put more effort to meet the requirements and finally, does the organization have an accurate view on the requirements.

Content

1 Introduction

Contemporary view on safety emphasises that safety critical organizations should be able to proactively evaluate and manage safety of their activities. This proactivity should be endorsed in the organizational safety management. Safety, however, is a phenomenon that is hard to describe, measure, confirm, and manage. Technical reliability is affected by the performance of the employees. Furthermore, the effect of the management actions, working conditions and the culture of the organization can not be ignored when evaluating the overall safety of the activities.

Scientists in the field of safety critical organizations state that safety emerges when an organization is willing and capable of working according to the demands of their task, and when they understand the changing vulnerabilities of their work (Dekker, 2005; Woods & Hollnagel, 2006; Reiman & Oedewald, 2007). Adopting this point of view we state that managing the organization and its sociotechnical phenomena is the essence of management of safety (Reiman & Oedewald, 2009). Thus, management of safety relies on a systematic anticipation, monitoring and development of organizational performance. Various safety indicators play a key role in providing information on current organizational safety performance. An increasing emphasis has been placed also on the role of indicators in providing information to be used in anticipation and development of organizational performance. These indicators are called *leading indicators*.

The safety performance indicators that have commonly been used have often been lagging – measuring outcomes of activities or things and events that have already happened. In order to be able to monitor the effects of proactive safety work as well as anticipate vulnerabilities the organizations should define leading indicators. Those should be able to grasp organizational practices and processes that antecede (lead) changes in safety performance of the organization. Hollnagel (2008) calls this kind of control feed-forward control. This kind of control relies on anticipated effects instead of past outcomes contrary to the traditional feedback-based safety management.

Understanding and managing organizational processes and practices has become the primary concern of safety management and science (Reason, 1997; Reiman & Oedewald, 2007). Safety management has been conceptualised as culminating in the problem of system control in complex sociotechnical environments (Rasmussen, 1997; Reiman & Oedewald, 2009). Hollnagel and Woods (2006, p. 348) summarize that "in order to be in control it is necessary to know what has happened (the past), what happens (the present) and what may happen (the future), as well as knowing what to do and having the required resources to do it.” The system should be controlled in a manner that it remains within the boundaries of its safe performance. If safety is understood as something more than the absence of risk and the negative, the indicators should also be able to focus on the positive side of safety - on presence of something (Hollnagel, 2008, p. 75; Rollenhagen, 2010). This requires a model of the system as well as an outline of how the system produces safety (Hollnagel, 2008; Reiman & Oedewald, 2009).

The aim of this report is to provide an overview on leading safety indicators in the domain of nuclear safety. The report first aims at clarifying the purposes and types of safety performance indicators. The report explains the distinction between lead and lag indicators and proposes a framework of three types of safety performance indicators – feedback, monitor and drive indicators. Finally the report provides guidance for nuclear energy organizations for selecting and interpreting leading safety indicators. It proposes the use of safety culture as a leading safety performance indicator and offers an example list of potential safety performance indicators in all three indicator categories.

2 Safety, performance and safety performance indicators

2.1 What is a safety performance indicator?

The literature on safety performance indicators shows that the concept of safety indicator is all but clear (see Safety Science, 47 (2009) for the latest scientific discussion on the issue) and there are different purposes for using safety indicators. For example, indicators can be seen as national or international tools for defining political goals and for following whether the goals are met (cf. Valtiovarainministeriö, 2005). Indicators can also be seen as tools for the authorities for defining their regulative activities and the goals they expect safety critical organizations to fulfil and for following whether theses goals are met. Indicators can also be seen as a way to communicate safety issues for the public (cf. Karjalainen, 2009, p. 88). Finally, safety performance indicators can be used by the organization to gain information on its current safety level and on the efficacy of its safety improvement efforts.

The definition of safety is all but clear. In practice the different definitions of the measured object (safety) that are used explicitly or implicitly affect the selection of the indicators and the interpretation of the collected data. Many indicators embed an idea of safety as an absence something or the missing inadequacy of something, e.g., the fewer the number of unplanned scrams or INES rated events, the higher the safety level. Another bad example would the using the number of human errors to postulate the safety level, i.e. the fewer human errors the higher the safety level. Often the concept of safety remains undefined in the indicator system. This leads to the above mentioned examples where interpretations about safety level are made based on scarce and often deficient data.

Chakraborty et al. (2003) argue that a "nuclear power plant Safety Performance Indicator (SPI) is a basic parameter (described qualitatively or quantitatively) that is perceived as having potential meaning (or relationship) to plant safety". Wreathall (2009, p. 494) defines a safety indicator as follows: "Indicators are proxy measures for items identified as important in the underlying model(s) of safety". Similarly to Wreathall's view, we see that defining safety performance indicators and their purpose should start by defining what is this "safety" that we are talking about. What is it that we are trying to find indications of?

The selection and use of safety performance indicators is always based on an understanding of the sociotechnical system and system safety. This understanding is often at least partly implicit or tacit understanding, meaning more or less justifiable opinions on what is important for nuclear safety and what things should be taken care of when assuring nuclear safety. These opinions then affect both the selection and the interpretation of the safety performance indicators. In this report we use a term *safety model* to indicate this underlying model of how safety is created in the sociotechnical system. We argue that in order to be able to select and utilize safety performance indicators in a manner that they would approximate the correct level of nuclear safety the safety model should be *systemic* incorporating people, technology and the organization.

We approach safety of the nuclear power plants from the point of view of nuclear safety as distinct from for example occupational safety. We define safety as an emergent property of the entire sociotechnical system. Thus, safety is a dynamic property or a state that includes people and technology. It is important to realise that safety is not a system; the organization is (Reiman & Oedewald 2008). Safety management requires the management of the organization. Safety performance indicators should provide information on this organizational ability to fulfil the core task. This means that they should provide information on the safety culture of the organization.

According to our definition, the essence of safety culture is the ability and willingness of the organization to understand safety, hazards and means of preventing them, as well as ability and willingness to act safely, prevent hazards from actualising and promote safety. Safety culture refers to a dynamic and adaptive state. It can be viewed as a multilevel phenomenon of organizational dimensions, social processes and psychological states of the personnel.

To conclude, in this report safety performance indicators are approached from organizational point of view. The indicators are seen as organizational tools for the evaluation and improvement of safety used as part of the safety management process of the organizations.

2.2 Functions of organizational safety performance indicators

When looked from an organizational point of view the purposes of safety indicators can roughly be categorized into three groups; a) monitoring the level of safety in the organization, b) changing and developing the means of managing safety in the organization, and c) motivating the management and the personnel to take the necessary action (cf. Hale, 2009, p. 479).

Monitoring the level of safety in the organization

In their documents and guidelines both IAEA and WANO seem to emphasize the monitoring function of safety indicators. They see safety performance indicators primarily as a way to monitor the level of safety performance of the plant (cf. IAEA, 2000, p. 1; WANO, 2009). Often the monitoring is accomplished by looking at trends of the indicator data over some period of time. For example, a guideline by IAEA (2000, p. 1) states that "specific indicator trends over a period of time can provide an early warning to plant management to investigate the causes behind observed changes."

Safety management process should utilize the indicators for example as triggers for investigating in-depth whether there is substance for concern in the organization (Wreathall, 2009, p. 494). These investigations can be made e.g. by a small focused audit, by a field investigation or by a survey of the workforce. These in turn provide a more focused and indepth indicator of the status of the area of concern.

The challenge in using safety performance indicators for monitoring the current safety level is the unclear causal link between past events and the current safety performance. Monitoring should not rely solely on lagging indicators but also on indicators of current activities and the potential of the organization to succeed in the future. We will return to this topic in various sections of this report.

Changing and developing the means of managing safety in the organization

A partly distinct purpose for using safety indicators besides monitoring the safety level is to use them for change or improvement. First of all, safety indicators can be used as a tool for setting specific development goals and measuring the effectiveness of improvements (cf. IAEA, 2000; WANO, 2009). Second, safety performance indicators can be used to facilitate change and development in the desired direction. This can be done by selecting indicators that promote the wanted behaviour and new practices or inhibit unwanted activity. For example, if the organization is implementing a practice of having bre-job briefings before safety significant tasks are started the amount of such briefings can be selected as a safety performance indicator to be followed annually or even more often.

Motivating the management and the personnel to take the necessary action

Besides helping in goal setting and progress evaluation, the process of utilizing leading indicators and the selected safety performance indicators as such can also have an effect on the actual safety performance. Leading indicator process itself offers intrinsic value in helping to address the role of organizational factors in human performance (EPRI, 2001b). This is an important point that has not always been given sufficient attention when discussing the selection and use of safety indicators.

Safety indicators are cues for the personnel about the priotirities and interests of the management and they can shape the personnel's ideas on what safety or safe behaviour is or should be like. Thus, the indicators steer the behaviour in the organization. Sometimes the behaviour steering power of the indicators is intensified by embedding the indicators into the incentive system of the organization. Unfortunately, this steering effect remains often unintentional and might lead to problems when the explicit goal of the safety indicators is to monitor the safety level and not change or develop some specific issue being measured.

Safety performance indicators can also be used to explicitly motivate certain kind of behaviour from the employees or the management. Hudson (2009, p. 484) reminds that "to shape managers' behaviour most organizations will require indicators that can show significant variation on a quarterly or annual basis". Safety performance indicators should aim at countering the focus on short term production effects such as cost cutting that manifests in safety only after the manager already has probably moved on. However, Hudson (Ibid.) points out that in order to influence motivation the effect of the measure on the performance of the plant should be understood. Thus, the indicators should be experienced as meaningfull by the personnel.

To summarize, safety indicators can have different types of effects on the behaviour in the organization:

- Direct effects on the measured metric: selection of some specific indicator increases that kind of behaviour (e.g. counting the number of management walk arounds per month increases the amount of management walk arounds)
- Direct effects on the indicated phenomenon: the selection of some specific indicator increases the underlying (psychological) phenomena (e.g. counting the number of management walk arounds per month increases the

management's commitment to safety and personnel's interest in safety)

- Unintended effect: the personnel become more interested in managing the indicator itself rather than the phenomenon of which it is supposed to provide an indication. For example, the management optimizes the number of walk arounds and neglects other (important) issues that are not being measured.

We will return in Section 6 to the difference between metric and indicator. Here it is sufficient to say that a metric denotes the operationalization of the indicator (how it is measured), whereas an indicator denotes something that one wishes to measure with the use of one or more metrics.

2.3 Types of safety performance indicators

Safety performance indicators can measure various aspects of nuclear safety. Sometimes safety performance indicators are focused only on human performance or human factors and sometimes the object is nuclear safety in general. We have emphasized that the object of safety performance indicators should be the functioning of the sociotechnical system and thus nuclear safety in general.

Different categorizations of safety performance indicators exist in the literature. We can differentiate at least six typologies of indicators:

- outcome versus activity based indicators
- leading versus lagging indicators
- input versus output indicators
- process versus personnel indicators
- positive versus negative indicators
- technical versus human factors indicators

It is important to note that these categorizations are partly overlapping, especially concerning the first three categories. For example, the division between outcome and activity indicators are often considered similar to that of the division between lagging (outcome) and leading (activity) indicators. OECD (2003) defines activities indicators as means for measuring actions or conditions that should maintain or lead to improvements in safety. Outcome indicators in turn measure the results, effects or consequences of these activities.

Outcome indicators are usually similar to lagging indicators, and they show the safety performance in terms of measures of past performance e.g. injury rates, radiation doses, and incidents. Input indicators are usually called leading indicators, and they monitor the processes that are effecting and maintaining safety performance. These include leadership, training activities and work processes. OECD's guidance document on safety performance indicators (2008, p. 5) argues that "outcome indicators tell you *whether* you have achieved a desired result (or when a desired safety result has failed). But, unlike activities indicators, they do not tell you *why* the result was achieved or why it was not."

In this report we categorize indicators into three types of indicators, feedback, monitor and drive indicators. The feedback and drive indicators correspond closely with outcome and activity indicators, respectively. The monitor indicators are a set of indicators often neglected in previous discussions on safety performance indicators. They indicate the current level of safety in the organization. We will return to these indicator types in Section 4, after looking at the past utilization of indicators at the nuclear industry.

3 Utilization of safety performance indicators in the nuclear industry

Different types of safety indicators have been utilized in the nuclear industry for a long time. For example, unit capability factors and INES-events have been used to indicate the (safety) performance of the plant. High capability factors have been used as indicators for a positive indicator of safety performance, whereas INES-events are a negative indicator. Also WANO offers a set of performance indicators including capability factors and unplanned reactor scrams (see below) with trend data for several years and different power plants.

3.1 Indicating nuclear safety

In an NKS-project conducted together with Carl Rollenhagen and Ulf Kahlbom (see Reiman et al. in press) we asked 30 experts from the Finnish and Swedish nuclear organizations (power companies, regulators, and consultants) what issues they would consider if they would have a task of evaluating the nuclear safety of a given power plant. Figure 1 illustrates a combination of all the answers that we received (see Reiman et al. in press).

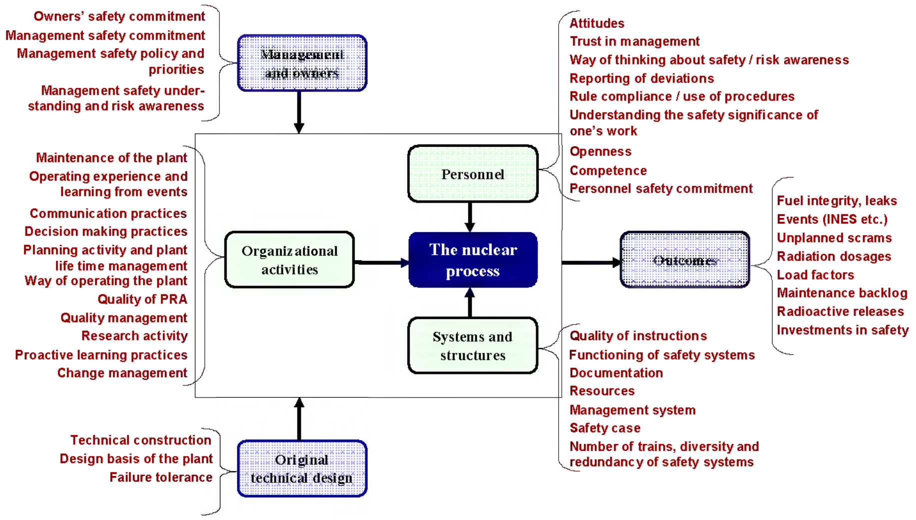

Figure 1. Indicators that the interviewees explicitly raised as signals of the safety level of the plant (from Reiman et al. in press). The indicators have been arranged according to general themes that emerged from the definitions – management and owners, technical design of the plant, organizational activities, personnel, systems and structures, and finally, the outcomes.

Many people emphasized technical data and performance measures that can be compared to other power plants – outcomes of the organization. Another emphasis was on the organizational activities that produce safety. Personnel-related issues were also considered important indicators of the level of nuclear safety. What the respondents seemed to lack was an overview of the relation of different indications of the safety level. A few divided nuclear safety explicitly into a) the technical condition of the plant and b) its operation and management. (Reiman et al. in press)

In terms of this study it is noteworthy that the responses can be categorized according to whether they indicate outcomes, organizational activities or current states or structures in the organization (system and structures as well as personnel). Clearly the experts in the Nordic nuclear industry considered that nuclear safety cannot reliably be evaluated by relying on only one type of indicator. Rather several sources of information are needed.

3.2 Indicator systems

In Finland the regulator, STUK, has developed an indicator system for supervising the nuclear safety of the Finnish nuclear power plants. The indicator system divides nuclear safety into three sectors: 1) safety and quality culture, 2) operational events, and 3) structural integrity. These three sectors are divided into a total of 14 indicators (figure 2).

Nuclear safety		
A.I Safety and quality culture	**A.II Operational events**	**A.III Stuructural integrity**
1. Failures and their repairs	1. Number of events	1. Fuel integrity
2. Exemptions and deviations from the Technical Specifications	2. Direct causes of events	
3. Unavailability of safety systems	3. Risk-significance of events	2. Primary and secondary circuits integrity
4. Occupational radiation doses	4. Accident risk of nuclear facilities	
5. Radioactive releases		3. Containment integrity
6. Investments in facilities	5. Number of fire alarms	

Figure 2. STUK's indicator system, from Kainulainen (2009, p. 88)

An interesting indicator in terms of this study is the accident risk of nuclear facilities. This indicator is based on the result of probabilistic risk analyses (PRA) (figure 3). STUK reminds that "when assessing the indicator, it must be remembered that it is affected by both the development of the power plant and the development of the calculation model. Plant modifications and changes in methods, carried out to remove risk factors, will decrease the indicator value. An increase of the indicator value may be due to the model being extended to new event groups, or the identification of new risk factors. In addition, developing more detailed models or obtaining more detailed basic data may change risk estimates in either direction" (Kainulainen 2009, p. 121).

The above example also illustrates the point that was made in Section 2.1 that the utilization of the indicators is based on an understanding of the sociotechnical system. When this understanding deepens it can actually be seen as a decrease in safety level as measured by the safety performance indicators. What actually happens then is of course not a real decrease in safety but a calibration of the model to better correspond with reality. In other words, the safety level has in reality already been closer to the new decreased level than the old indicated level, but the previous models of safety have been unable to indicate it.

Chakraborty et al. (2003) point out that "PSA [the old acronym for PRA] provides a formal and most logical means for quantifying the safety significance of operational events, corrective actions, design modifications, and changes in plant configuration (plant condition). In other words, PSA appears to be a consistent framework for defining the most meaningful set of SPIs, and for linking these with the most effective top-level safety indicators." PRA is focused on the propability of the nuclear power plant to be safe in the future, and thus it is a leading indicator of nuclear safety.

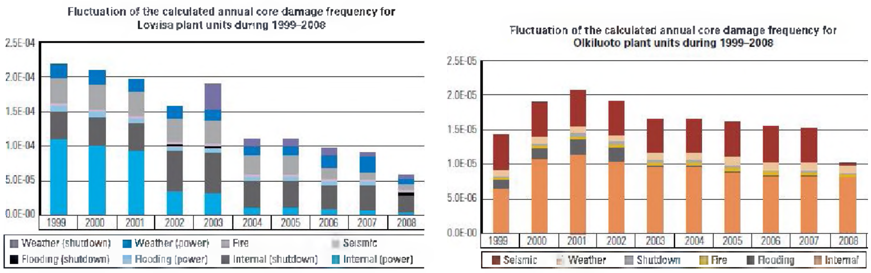

Figure 3. PRA calculations for the Finnish plants 1999-2008, from Kainulainen (2009, p. 121)

However, Chakraborty et al. (2003) note that within the PSA framework does not address the risk influence of management and organizational aspects and thus it is not easy to assess the appropriateness of the safety performance indicators that are proposed for assessment of management and organizational factors.

Besides the actual safety performance indicators that were depicted in figure 2, STUK publicizes each year the following information from Olkiluoto 1&2 and Loviisa 1&2 nuclear power plants (Kainulainen 2009):

- Unit cabability factors / load factors (ten year trend)

- Daily average gross power for the reporting year
- Operation and operational events
- Annual maintenance outage – activities and performance
- Events during the year subject to special report
- INES-classified events (ten year trend)
- Non-compliancies during the year with Technical Specifications
- Reliability of the plant's safety functions (failures during the year in the plant's safety functions and the systems, equipment and structures implementing them)
- Failures or signs of wear in the integrity of equipment and structures critical to plant safety
- Fuel leaks
- Events in the treatment, storage or final disposal of low- and intermediate-level waste
- Development of the plant and its safety – activities and performance
- Management and safety culture – activities and performance
- Functionality of the management system – activities and performance
- Personnel resources and competence – activities and performance
- Operational experience feedback – activities and performance
- Occupational radiation safety – activities and performance
- Collective occupational radiation doses since the start of the operation
- Annual radiation doses to the critical groups since the start of operation
- Radioactive nuclides originating from the plant
- Emergency preparedness

This information is not explicitly considered as safety performance indicator information. However, many of the issues that STUK attends to do indicate the safety level of the power plants, and as such they can also be considered safety performance indicators – just qualitative in type.

3.3 State-of-the-art on safety performance indicators

In their study on safety performance indicators in eight countries and eleven partner organizations representing regulatory organizations, utilities, and technical support organizations at the nuclear field Chakraborty et al. (2003, p. 2) summarize the state-of-the art of the application of safety performance indicators as follows:

• In all countries operating nuclear power plants performance indicators are either being tracked or are being proposed that can be applied to monitor the safety performance of the plants.

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

Chakraborty et al. (2003) propose that the development of risk-based safety performance indicators "should follow the PSA hierarchy that includes the relevant indicators representing, for instance:
• Initiating events
• Reliability of functions, systems, trains and components
• Mitigation potential of engineering systems
• Mitigation potential of emergency actions" (Ibid., p. 4).
They (Ibid.) further note that organizational and management influences should be included in the indicator framework but offer limited guidance on how to accomplish this.

IAEA (2000, 1) leaves the choice of specific safety performance indicators up to the organizations by stating that "*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.*" However, IAEA presents a hierarchical structure or framework for supporting indicator selection and utilization and provides examples of suitable indicators. It encourages the use of those safety performance indicators WANO has developed (see below), that form the basis for the safety performance indicators currently used in nuclear power plants.

The WANO Performance Indicator Programme supports the exchange of operating experience information by collecting, trending and disseminating nuclear plant performance. Specific key indicator areas are intended to give a quantitative indication of nuclear plant safety and reliability, plant efficiency and personnel safety areas. In 2008 these key indicator areas were:

- unit capability
- unplanned capability loss
- forced loss rate
- collective radiation exposure
- unplanned automatic scrams per 7 000 hours critical
- industrial safety accidents rate
- safety system performance
- fuel reliability
- chemistry performance
- grid-related loss factors
- contractor industrial safety accident rate (WANO, 2009).

WANO members report on most of these indicators on a quarterly basis. The data is collected through WANO members' Web site, trended and posted on the WANO members' Web site. WANO published and distributed its first performance indicator report in 1991. The level of reporting has grown so that in 2008 82 percent of the operating nuclear power plants reported all eleven indicators (WANO, 2009).

In practice, WANO safety indicators are often complemented with other indicators in the nuclear plants. For example, when Flodin & Lönnblad (2004) reviewed safety performance indicators in use by the Swedish utilities, they found that the selection of indicators was based both on the WANO indicators and on indicators defined by the users themselves. The Swedish utilities used well over 20 indicators for follow-up of safety at the plants, including the 8 WANO indicators that were available at that time.

IAEA (2000, 23) states that safety indicators chosen should include a combination of indicators that reflect actual performance that is sometimes called lagging indicators and those that provide an early warning of declining performance that is sometimes called leading indicators. The American Electric Power Research Institute (EPRI) also emphasizes that there are more indicator types than just one. EPRI strongly encourages the use of leading indicators for their member utilities and provides tools and guidelines for this (EPRI, 2000, 2001a). These tools and guidelines are constructed so that they are also in line with the principles of INPO (Institute of Nuclear Power Operations).

Next we will look more closely at the differences between leading and lagging safety performance indicators.

4 Leading and lagging indicators of safety

4.1 Distinguishing lead from lag

The distinction between leading and lagging safety performance indicators is not clear cut. Some safety scientists and practitioners have described them more as a continuum than two separate entities and have even suggested that the distinction between leading and lagging is not that important at all (Hale 2009).

The categorization of safety performance indicators into lead and lag is dependent on the underlying model of safety. If one has a mechanistic and technical-oriented view on nuclear safety, near-misses can be considered leading indicators. More systemic and dynamic view of an organization and system safety would not view near-misses as leading indicators, rather more as indicators of past safety performance. Another typical safety model emphasizes the latent failures (pathogens) of the sociotechnical system as creating conditions for accident (Reason, 1997).

A working group for the UK Oil and Gas Industry (Step-Change in Safety, 2001, 3) has defined leading safety indicators as “something that provides information that helps the user respond to changing circumstances and take actions to achieve desired outcomes or avoid unwanted outcomes” while lagging indicators were seen as “the outcomes resulting from our actions”. The working group used the analogy of sailing yacht as an example of leading and lagging indicators. In a yacht, the compass, wind indicator and radar provide information that can be used to control the boat to maximise speed in the direction that we want to go, whilst avoiding danger. They can thus be seen as leading indicators, which provide information about the current situation that can affect future performance. The log on the other hand provides a measure of how far we have travelled. This parallels lagging indicators, which are the outcomes of our actions.

OECD’s guidance document on safety performance indicators at the chemical industry (2008, p. 5) defined leading indicators (or in their usage Activities Indicators) as follows: “Activities indicators are designed to help identify whether enterprises/organizations are taking actions believed necessary to lower risks.” Examples of activities indicators given in the document include “Are there systematic procedures for hazard identification and assessment?”, “Are safety issues adequately addressed in regular meetings of employees?”, “Is there an adequate recruitment procedure?" and "Is management actively committed to, and involved in, safety activities".

HSE (2006) defines leading indicators as follows: "The leading indicator identifies failings or 'holes' in vital aspects of the risk control system discovered during routine checks on the operation of a critical activity within the risk control system". The definition seems to view accidents from an epidemiological model (Hollnagel, 2004) and emphasize the indicators' role in identifying latent failures and system deficiencies before they manifest. Hale (2009, p. 479) emphasizes that the indicator is leading or lagging in respect to whether "it leads or lags the occurrence of harm, or at least the loss of control in the scenario leading to harm".

The health metaphor can be used to illustrate the challenges of measuring safety. It has for long been pointed out that health of an individual human being is something more than the absence of illnesses or injuries. Health is an active state requiring and enabling certain activities; acquisition of nutrition, exercise, vitality. Often people do not explicitly consider their health or they take it for granted until the negative signs of health surface. These negative signs such as high blood pressure or rise in temperature are lagging indicators. Safety has close parallels to health. Safety is also a state of activity, not only absence of accidents or incidents. Monitoring safety requires more than monitoring the signs of "illnesses", that is, incidents, deficiencies, errors. One must also be able to monitor the activities, processes and mental states of the personnel that contribute to the level of safety that the organization is producing. It is not enough just to note that there have been no incidents during the year or the trend of the incidents is declining. One must also know why the situation is so, and how the current safety management processes are contributing to the safety level.

4.2 Leading indicators as precursors to harm or signs of changing vulnerabilities

Several reasons for using leading indicators have been proposed in the literature:

- they provide information on where to focus improvement efforts,
- they direct attention to proactive measures of safety management rather than reactive follow up of negative occurrences or trending of events,

- they provide early warning signs on potential weak areas or vulnerabilities in the organizational risk control system or technology,

- they focus on precursors to undesired events rather than the undesired events themselves,

- they provide information on the effectiveness of the safety efforts underway and

- they tell about the organizational health, not only sickness or absence of it.

Typically lead and lag indicators are considered on a time scale where lead indicators precede harm and lag indicators follow harm. According to that, lagging indicators can be used in providing feedback on the functioning of the system to be used as further inputs into the system. Lagging indicators would thus indicate the current safety level of the system. We disagree with this definition.

Kjellén (2009, p. 486) defines a leading safety performance indicator as an indicator that changes before the actual risk level has changed. This definition deviates from many current usages and definitions of the concept. The distinction between indicators that change before and after the actual risk level changes is an important one. It also has important implications for the requirements of leading indicators. For the indicator to be sensitive to changes in the organizational risk control system that predate the rise of the risk level, it cannot focus on "failings", "holes" or even "near-misses" or "deviations". The indicator has to provide information on the activities and the organizational means of controlling risk.

EPRI's definition of leading indicators resembles Kjellén's definition in some important aspects. According to EPRI (2000, A-3), "leading indicators provide information about developing or changing conditions and factors that tend to influence future human performance". Thus "effective leading indicators provide a basis for predicting or forecasting situations in which the potential exists for a change in human performance, either for better or worse."

Both Kjellén (2009, p. 486) and EPRI (2000) seem to view leading indicators not as measures of precursor to harm but as measures of signs of changing vulnerabilities. This means that leading indicators should measure things that might one day become precursos to harm or cause a precursor to harm. We agree with this perspective. All in all we define leading indicators as follows (cf. Dyreborg 2009):

> *Lead safety indicators indicate either the current state and/or potential development of key organizational functions or processes as well as the technical infrastructure of the system. The current state includes a view on the changing vulnerabilities of the organization as well as its internal model of how it is creating safety. The lead monitor indicators indicate the* ***potential*** *of the organization to achieve safety. They do not directly predict the safety related outcomes of the sociotechnical system since these are also affected by numerous other factors such as external circumstances, situational variables and chance.*

In the next chapter we present an organizational theoretical view on safety indicators and system safety that parallels leading indicators with safety culture.

5 Safety culture as a leading safety performance indicator

5.1 Criteria for good safety culture

According to our approach (see Reiman et al., 2008; Reiman & Oedewald, 2009), the essence of safety culture is the ability and willingness of the organization to understand safety, hazards and means of preventing them, as well as ability and willingness to act safely, prevent hazards from actualising and promote safety. Safety culture refers to a dynamic and adaptive state. It can be viewed as a multilevel phenomenon of organizational dimensions, social processes and psychological states of the personnel. Reiman and Oedewald (2009, 43) have stated that a nuclear industry organization has a high-level safety culture when the following criteria are met:

- Safety is genuinely valued and the members of the organization are motivated to put effort on achieving high levels of safety
- It is understood that safety is a complex phenomenon. Safety is understood as a property of an entire system and not just absence of incidents
- People feel personally responsible for the safety of the entire system, they feel that they can have an effect on safety
- The organization aims at understanding the hazards and anticipating the risks in their activities
- The organization is alert to the possibility of an unanticipated event
- There are good prerequisites for carrying out the daily work
- The interaction between people promotes a formation of shared understanding of safety as well as situational awareness of ongoing activities

The above-mentioned dimensions can be seen as criteria in an organizational evaluation. If an organization shows all the above-mentioned characteristics, it has a high-level safety culture and thus a high potential for managing its activities safely. In practice, however, organizations show varying degrees of safety value and motivation. Furthermore, the risk and safety conceptions of the personnel are usually partially accurate and partially flawed. Thus the indicators have to reach the social and structural aspects of the organizations and provide information on how well the organization is able and willing to carry out its core task. Especially important in this regard is to identify those aspects of the organizational ability that have vulnerabilities or can create vulnerabilities elsewhere in the organization.

Reiman and Oedewald (2009) propose that when evaluating an organization and its safety culture, four main elements of an organization should be taken into account. Those are the organizational functions, social processes and psychological properties of the personnel (see also Reiman et al., 2008). The basis for the criteria used in the evaluation is the fourth element of the organization; the organizational core task and production technology. This is the source of the inherent hazards of the sociotechnical system. Organizational evaluation is one type of means of providing safety performance indicator data. Thus, the criteria used in organizational evaluation can also be used when considering the question of what should the safety performance indicators aim at indicating?

5.2 Monitoring safety culture in the sociotechnical system

Adopting the view on the organizational safety culture described in Section 5.1 has implications for safety performance indicators. The framework is based on presence of certain organizational attributes instead of absence of indications of harm. Thus, also the selected safety indicators should be able to show a presence of certain dimensions and measure their level. We argue that the preoccupation with the concepts of harm and accident in the discussion on indicators has led to a neglect of the critical issue worth indicating: the functioning of the sociotechnical system including the way it is currently producing safety (not necessarily – or hopefully – harm and accidents).

We argue that lagging indicators do not tell about the safety level of the system or dynamics of the system's functioning. Instead lag indicators only tell about the outputs of the system. These outputs are produced by the internal dynamics of the various organizational dimensions influenced by external variability and chance. Likewise, leading indicators are not only indicators of something that precede harm as they have been conceptualized in frameworks based on epidemiological accident models (cf. Hale, 2009). Leading indicators either influence safety management priorities and the chosen actions for safety improvement, or they tell about the dynamics of the sociotechnical system (not about the inputs to the system or merely about the functioning of safety barriers). These leading indicators are labelled drive indicators and monitor indicators in this report, respectively.

The distinction between lead and lag indicators can be illustrated with the help of Hollnagel's (2008, p. 70) feedforward model of safety management. Hollnagel (2008) argues that more emphasis needs to be put into controlling the system by anticipated or expected disturbances and deviations (feedforward) instead of actual outcomes (feedback). In figure 4 we have created a model loosely based on Hollnagel's ideas (2008) to illustrate the three types of indications; feedforward, or leading drive indicators, leading monitor indicators and lagging, or feedback indicators.

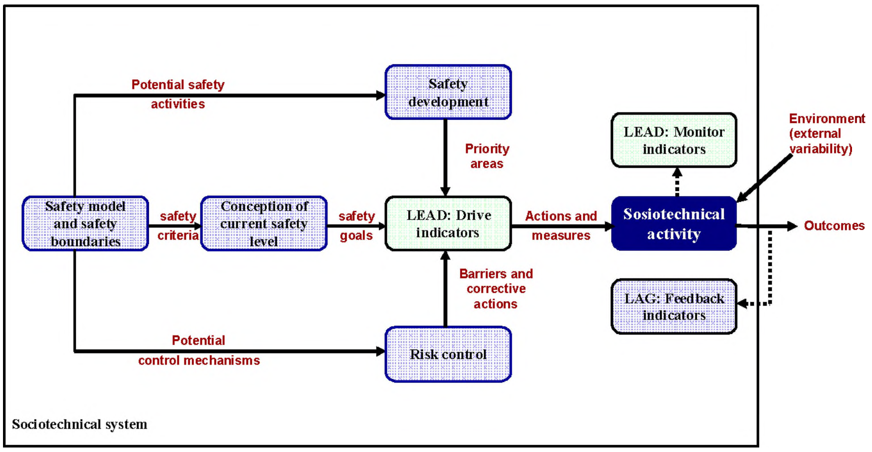

Figure 4. The sociotechnical system model indicates the influence of various organizational elements on selection and utilization of safety performance indicators. The model differentiates three types of safety indicators. The "outcomes" in the model indicate situation specific outputs of the system and not emergent properties of the system such as nuclear safety.

Figure 4 illustrates that the safety model prevalent in the organization creates the criteria that the organization uses in making interpretations about the current level of nuclear safety. This conception of current safety level influences the goals that the top management sets for the organization to achieve. These goals again influence what criteria are selected for the drive indicators. The selection of drive indicators is influenced by two parallel organizational functions; that of risk control and that of safety development. Drive indicators are turned into actions that influence the sociotechnical activity. Monitor indicators provide a view on the dynamics of the system in question; on the activities taking place, abilities, skills and motivation of the personnel, routines and practices – the organizational potential for safety. After this potential has actualized in specific situations into outcomes, the feedback indicators can provide a view on the outputs of the sociotechnical system. Figure 4 differentiates the following nine elements:

Safety model and safety boundaries: This means the underlying, often implicit model of what safety is and how it is achieved in an organizational context. Safety boundaries refer to the perceived hazards of the organization and the space that these hazards leave for carrying out activities safely. Even though each employee has their own more or less uniform model of safety, the element in figure 4 refers to the model of people involved in the selection and utilization of safety performance indicators. The safety model defines the risks that are perceived and it is thus "the Achilles heel of feedforward control" (Hollnagel, 2008, p. 68). Disturbances that are not acknowledged or foreseen in the model will no be transformed into drive indicators and corresponding safety interventions either. For more information on safety models, see e.g. Hollnagel (2004, 2008), Reiman and Oedewald (2009) and EPRI (2000, appendix C).

Conception of current safety level: The conception of current safety level refers to views on the level of safety at the power plant held by the top management and other people involved in selecting and interpreting safety indicators. As with the safety model, the conception is seldom homogenous within the group in charge on safety indicators, but for clarity's sake the figure presumes these conceptions can be grouped together. The conception of safety level influences the goals that are set for the drive indicators as well as safety interventions (how much gap is perceived between the present state and an ideal state).

Risk control: This means the organizational approach aimed at controlling the variance in human behaviour and technological performance by means of various safety barriers. Safety barriers can be physical, functional, symbolic or incorporeal (Hollnagel, 2004). Physical barriers include the containment building in the nuclear power plant as well as walls, doors, valves, fences, safety belts, filters and so on. A functional barrier system works by impeding the action to be carried out by setting preconditions that have to be met before an action can be carried out (e.g. a lock). Symbolic barriers require an act of interpretation in order to achieve their purpose (e.g. signs, signals). Finally, incorporeal barriers lack material form or substance and depend on the knowledge of the user. Typical incorporeal barriers are rules, guidelines, safety principles, restrictions and laws. (Hollnagel, 2004.)

Safety development: Safety development refers to the organizational approach aimed at improving the organizational conditions for achieving safety. Safety development can focus on improving the processes of the organization as well as enhanching the personnel's awareness and understanding concerning the work that they and other members of the organization do. Instead of constraining behaviour, safety development aims for building up the know-how and other prerequisites for the personnel to do their work well and safely in changing situations. Both risk control and safety development are needed to manage safety.

Drive indicators: Drive indicators are measures of the fulfilment of the selected safety management activities. Thus, they are chosen priority areas of the organizational safety activity. They are based on potential safety activities from the safety model and the priority areas defined by the safety policy. The drive indicators are turned into control measures that are used to manage the sociotechnical system; change, maintain, reinforce, or reduce something. The main function of the drive indicators is to direct the sociotechnical activity by motivating certain safety management activities.

Monitor indicators: These indicators reflect the potential and capacity of the organization to perform safely. The indicators monitor the functioning of the system including but not limited to the efficacy of the control measures. These indicators monitor the internal dynamics of the sosiotechnical system.

Feedback indicators: Feedback indicators measure the outcomes of the sociotechnical system. An outcome means a temporary end result of a continuous process or an organizational activity. An important qualifier of an outcome is that outcome always follows something; it is a result or consequence of some other factor or combination of factors and circumstances.

Sosiotechnical activity: Sosiotechnical activity refers to all the activities, work, tasks and processes (physical and social) taking place in the sociotechnical system.

Sosiotechnical system: The common term for an organization composed of people and technology. The name reminds of the fact that technology is always designed, used and maintained by people, as well as of the fact that people do not act in a social and technical vacuum but rather in a sosiotechnical context with its shared norms and tools. The safety performance indicators should provide information on the sociotechnical system and its capability for safety. The challenge comes from the fact that safety performance indicators are always selected and utilized within the same system that they are supposed to measure.

In addition to the nine elements the figure includes "outcomes" as outputs from the sociotechnical system and "environmental influences" as inputs into the system. Outcomes are situational end results or situational actualization of the safety potential of the organization. Thus, safety is not an outcome. Safety is a dynamic non-event where non-events are not possible to characterize. Thus, we have to look at the term ”dynamic” and search for the way the non-event is created and acknowledge that we cannot ever reach the non-event itself.

Environmental influences refer to deviations and disturbances beyond control of the organization. These deviations still have an effect on the situational performance and outcomes of the sociotechnical system, for better or worse.

Figure 4 illustrates that the underlying safety model provides the potential control mechanisms as well as a view on potential safety improvement activities. These areas are then tackled with drive indicators in terms of priority areas of safety development, corrective measures of deficiencies in existing safety barrieres or implementation of new safety barriers. What has been omitted from the figure 4 is the feedback of information from the indicators into the safety model and the two safety management strategies. Figure 5 illustrates the information and feedback that each indicator type provides.

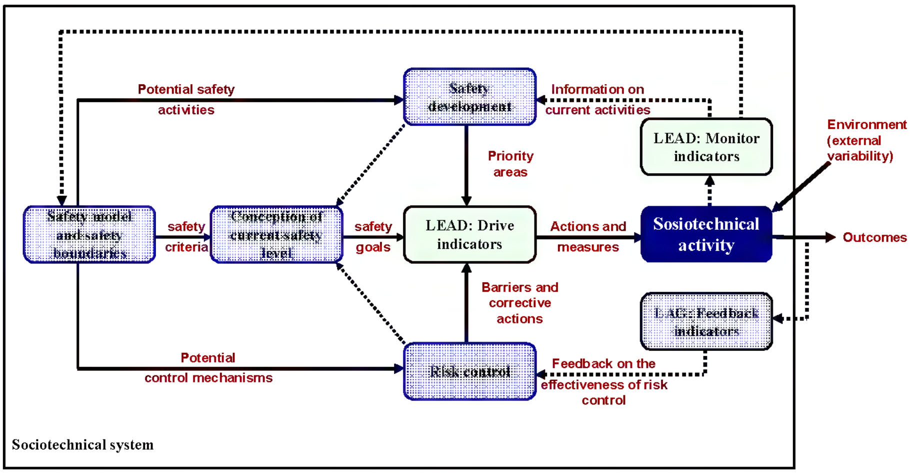

Figure 5. Sociotechnical system model of lead and lag indicators with the information transfer lines added

In figure 5, it is worthwile to note that there are no lines from the feedback indicators to the conception of safety level or to the safety development. In practice feedback indicators are often used to define safety priorities or make conclusions about the level of safety. That is not a correct use of the feedback indicators. These function only within the predefined risk control framework, finetuning and adjusting the selected safety barriers and making corrective actions to safety systems. The influence to safety model and to the understanding of current (and future) safety level should always go through the monitor indicators (see also Figure 7).

However, feedback indicators can provide clues about the functioning of the organization - if they are analyzed from that perspective. When used in this manner, indicators indicating a small event in terms of outcomes (e.g. an unplanned reactor scram) might tell more about the current functioning of the system than indicators that show a large event (for example, partial loss of cooling accident). This is due to the fact that large events already change the sociotechnical system; they have immediate consequences for the technical systems, they are interpreted and made sense of by the personnel, investigations and other initiatives to prevent the event from recurring are made. Smaller events go easily unnoticed in the sociotechnical system, and thus by inspecting more closely (with the use of monitor indicators and other data) what led to these events organizations can learn a lot about the dynamics of their organization.

Figure 6 shows examples of lagging indicators as well as the two types of leading indicators – monitor and drive indicators.

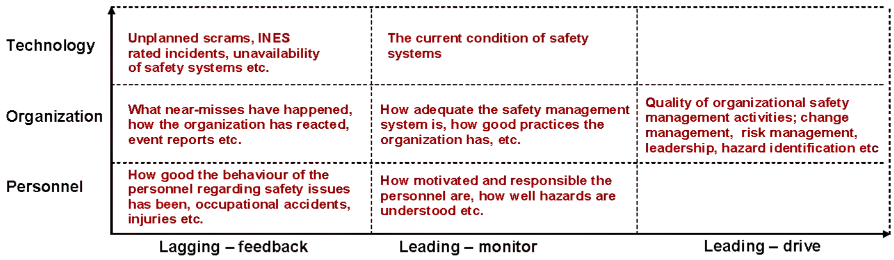

Figure 6. Examples of lag and lead indicators (for more examples see appendixes A, B and C).

As proposed by IAEA (2000), the selection of safety performance indicators should always start by considering *what is required from an organization or a NPP to perform safely*. When focusing on *leading* safety indicators specifically, the basic question goes: what is required from an organization in order to be aware of its safety level and enhance its safety performance. Interestingly this is what safety culture studies have been trying to find out for years. In fact, several writers have connected the concept of leading safety performance indicators to safety culture concept and proposed the use of safety culture or climate as a leading safety indicator (cf. Mearns, 2009; Grabowsky et al., 2007, see also Zwetsloot, 2009, 495). It is both practical and economical to consider safety indicators and safety culture indicators together, not as separate measurement and improvement tools that in the worst case are collected and handled by different actors in the organization.

6 Framework for the selection and use of safety performance indicators

6.1 The role of indicators in safety management

The selection strategies of the indicators for the three types differ. The monitor indicators should be chosen based on an analysis of the functioning of the sociotechnical system (an operational nuclear power plant for example) in question, and the identified key success factors. Feedback indicators should be chosen based on the identification of critical signals of increased risk as well as otherwise negative unwanted events. Even if occupational accidents do not necessarily bear a relation to nuclear safety they are unwanted negative events and as such they are worth measuring. Only for the drive indicators does the typical advice given in safety indicator guidance documents apply: They should be selected to reflect the key issues of concern and priority areas of the organization. In that way, several potential drive indicators can be prioritized according to the current needs of the organization. Each year drive indicators can be adjusted depending on the issues to address as well as findings from the monitor indicators.

The indicator types can also be connected: The organization can select some key area of concern as a drive indicator, e.g. competence management, and then identify monitor and feedback indicators that would allow a follow-up on the progress of competence management activities (for examples of lead drive indicators of competence management, see Appendix A of this report). Monitor indicators could be the amount and quality of training that the organization gives as well as the general knowledge level of the personnel (operationalized as e.g. number and types of degrees among the personnel, test scores, etc). Feedback indicators could be, e.g., the types of root causes found from incidents (whether competence related or not), annual performance evaluations done by superiors and increase in the quality of work.

Characteristics of effective safety performance indicators in managing safety are (Dupont; Hale 2009, p. 480):

- The indicator is valid; aka it measures what it intends to measure
- The indicator is reliable;
- The indicator is sensitive to changes in what it is measuring
- The indicator is not susceptible to bias or manipulation
- The indicator is cost effective
- The indicator is interpreted by different groups in the same way
- The indicator is broadly applicable across company operations
- The indicator is easily and accurately communicated

Selection of safety indicators should always start from the consideration of what are the key issues to monitor, manage and change. Only after these issues have been identified should one start to define safety management actions that seek to address the key issues as well as indicators to help the process. The safety indicators are utilized as part of the safety management process, not as an independent goal or function as such. **The role of the safety performance indicators is to provide information on safety, motivate people to work on safety and contribute to change towards increased safety**.

6.2 The selection of key safety performance indicators

When selecting the indicators it is important first to consider what needs to be monitored and not how these are monitored (OECD 2008, p. 17, see also EPRI, 2000). Otherwise the selection of indicators can be biased by relying on what is considered as possible or convenient to measure, and not on what information needs to be obtained about the safety level of the organization. The operationalization of the indicator is herein called "metric" (sometimes called 'measure) and the difference between metrics and indicators is illustrated in figure 7.

Grote warns about relying only on indicators where data is easily available: "focus on frequency may lead people to focus on indicators purely because they are frequent, but which happen to be completely irrelevant for increasing [production] safety" (Grote 2009, p. 478). An example would be counting and trending the amount of trash found on the plant area; it might give an indication about the housekeeping practices of the organization, but does not necessarily bear any relation to process safety. Another rarer phenomenon is the presence of foreign particles ("trash") at the process. Although fortunately most power plants should find it difficult to make a reliable trend out of these findings, the few instances nevertheless provide an important lagging indicator about the state of the safety culture at the organization.

Woods (2009, p. 499) reminds us about the lesson from the Columbia accident investigation: "Organizations need mechanisms to assess the risk that the organization is operating nearer to safety boundaries than it realizes – a means to monitor for risks in how the organization monitors its risks relative to a changing environment". This monitoring of how well the organization is monitoring its risks (second-order or metamonitoring) is an important yet difficult endeavour. Some monitor indicators provide information on the ability of the organization to monitor its risks adequately – for example mindfulness and vigilance (and especially the potential discrepancy between external and internal audit findings, see Appendix B) provides information on organizational blind spots. Also, the "understanding of hazards" and "understanding of the organizational core task" -indicators provide information on the ability of the organization to correctly spot the hazards and evaluate their risks in relation to the tasks that they carry out.

The monitoring of the organizational capability for monitoring its risks can also be done by comparing the effect of drive indicators on the feedback and monitor indicators. If there is no effect or the effect is not in line with the goals of the drive indicators, the indicators and the safety management methods might be based on an inadequate model of safety. This is illustrated in figure 7 where a process model of selection and utilization of safety performance indicators is presented.

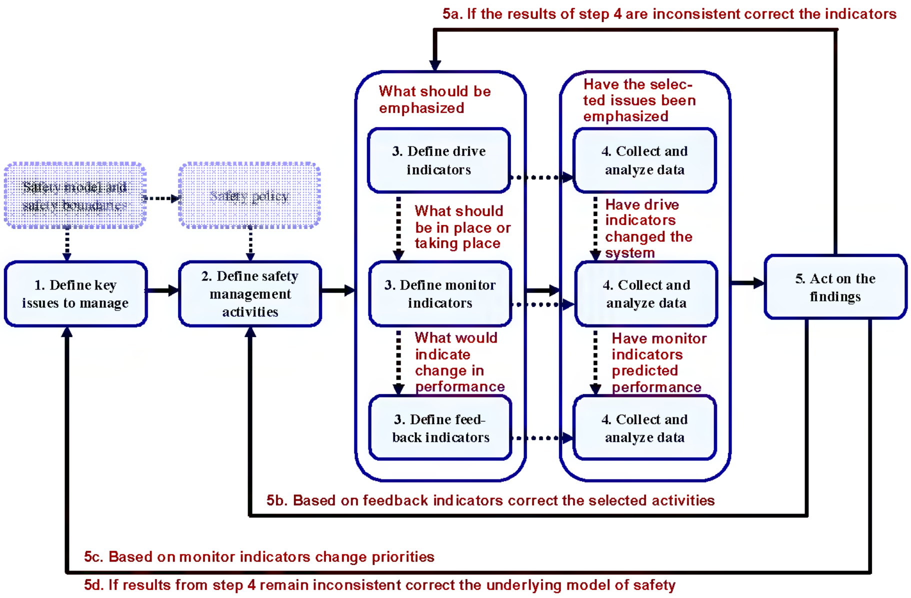

Figure 7. Process model for selection and utilization of safety performance indicators

As illustrated in figure 7 the process for selection and utilization of safety performance indicators starts by defining the key issues to manage. This definition is influenced by the underlying safety model. Second step consists of defining safety management activities based on the key content issues to be managed. These activities are concrete initiatives, methods or practices that the organization carries out in order to assure its safety.

Step three is the actual selection of indicators. Key questions to ask at this step are 1) what issues or content areas should be emphasized in the organization (define drive indicators for them) 2) what systems and structures should be in place and what processes should be happening (define monitor indicators for them) and 3) what would indicate a change in performance (define feedback indicators for them).

Step four is the ever-ongoing step of collecting and analysing the indicator data. This step is challenging and wrong conclusions from the indicators can contribute to a decline in the safety level by e.g. misaligned safety activities or false belief in the efficacy of the preventative measures already taken. Sections 6.3 and 6.4 provide some guidance on interpreting indicator data. In terms of monitor indicators the crucial thing is to gather information on the current functioning of the sociotechnical system. This requires data on the technical condition of the plant, group processes at the organization, organizational factors and human resources (called “psychological properties” below).

Step five follows the analysis of the indicator data. At this step corrective or preventive actions are taken based on the findings. If the results of the indicators are inconsistent the indicators have to be corrected (step 5a). This can mean for example that monitor indicators show a steady decline in safety level despite drive indicators showing successful emphasis on the chosen safety management areas or the feedback indicators showing increasing number of events while the monitor indicators have not changed. In such a situation all the indicators have to be analysed and their rationale and underlying model questioned. If the inconsistencies are big enough the process should return to the step one. The feedback indicators provide information that can be used in correcting safety management activities (step 5b). This means for example conducting a root cause analysis for an event and defining corrective measures and corresponding drive indicators for facilitating the implementation of the measures. Monitor indicators provide a view on the current safety level of the organization and point to the necessary changes in priorities if safety level shows signs of degradation (5c). Finally, if the three types of indicators consistently show inconsistent results, the underlying model of safety might be flawed (5d). For example, if the plant has numerous events and near-misses even when the monitor indicators claim a high level of safety, the monitor indicators might be based on too narrow a conception of safe performance. To conclude, the selection and utilization of safety performance indicators is a continuous process where all three types of indicators are analysed and finetuned to better correspond with reality (cf. EPRI, 2000).

Dyreborg (2009, p. 475) also points out the important distinction between the necessary countermeasures for lead and lag indicators: "Decreasing lead indicator performance levels calls for improvement of existing risk control parameters, whereas decreasing lag indicator performance levels without such a lead indicator decrease, calls for a revision of the risk control, i.e., reconsidering the causal relation between lead and lag indicators." In our model this means that if feedback indicators show a decrease without explanation from the monitor indicators, the underlying safety model might need revising. Correspondingly, a decrease in monitor indicators requires improvement of safety management activities directed by the drive indicators.

A concise summary lists of potential safety performance indicators are presented in Appendixes A, B and C. The lists should be considered a pragmatic tool to guide attention to the relevant aspects, not as a formal auditing check list or an indicator set.

Drive indicators are categorized as follows (see Appendix A):

- *Technology management*
    - Process for hazard identification and risk management
    - Process for design and engineering
    - Process for plant life management
- *Leadership*
    - Management safety leadership
    - Superiors' safety activity
    - Safety communication
- *Work management*
    - Communication and cooperation practices
    - Process for work and procedure management
    - Resource management
    - Practices of organizational learning
- *Human resource management*
    - Competence management and training
    - Integration of competence
    - Subcontractor management
- *Strategic management*
    - Setting of safety policy and safety goals
    - Operation and maintenance of the plant
    - Change management
    - Contingency planning and emergency preparedness

Monitor indicators are categorized in the following manner (see Appendix B):

- Organization and management
- Psychological states and conceptions
- Social processes
- Technical condition of the plant

Feedback indicators are grouped into four categories (see Appendix C):

- Systems, structures and components
- Human factors
- Process safety performance
- Organizational safety performance

There needs to be fewer monitor indicators than there are drive indicators in any given organization. This is due to the fact that all the monitor indicators should be followed regularly whereas drive indicators are selected depending on prioritization and the specific needs of the organization. Thus, too many indicators provide an information overload. Nevertheless, the number of indicators should be sufficient to provide a reliable view on the status of safety culture and system safety at the organization. Thus, the indicators presented in Appendix A-C are not all meant to be taken into use, but rather they represent the scope of potential indicators. Also, the indicator lists should not be considered inclusive in terms of covering all potential or even necessary indicators in terms of guaranteeing nuclear safety.

6.3 Relation of monitor indicators to performance

Safety performance indicators are just what the name implies, *indicators of safety performance*. As such, the indicators themselves are not that important. More important is what they tell about the safety performance, aka what they are indicating. Problems occur when management is driven by a goal of optimizing the indicators and not the phenomena underlying them. Hopkins (2009, p. 464) calls this "managing the measure rather than managing safety". In such case the indicators are no longer indicating what they were supposed to indicate. They become loosely coupled to the phenomenon of interest. This means that they still have a connection to safety performance, but the connection is neither direct nor just one of indication – the act of optimizing certain indicator also has an effect on the underlying phenomena. This effect might show in other indicators, or it might remain hidden as a latent factor in the organization. The effect of managing the measure instead of safety differs depending on the type of the measure; leading, lagging, activity or outcome. Hopkins (2009) argues that activity indicators (as opposed to outcome indicators) are most susceptible to management, since it is possible to reduce their quality without sacrificing their quantity, e.g. by taking more people into training at the same time. However, this critique presupposes that indicators are always quantitative.

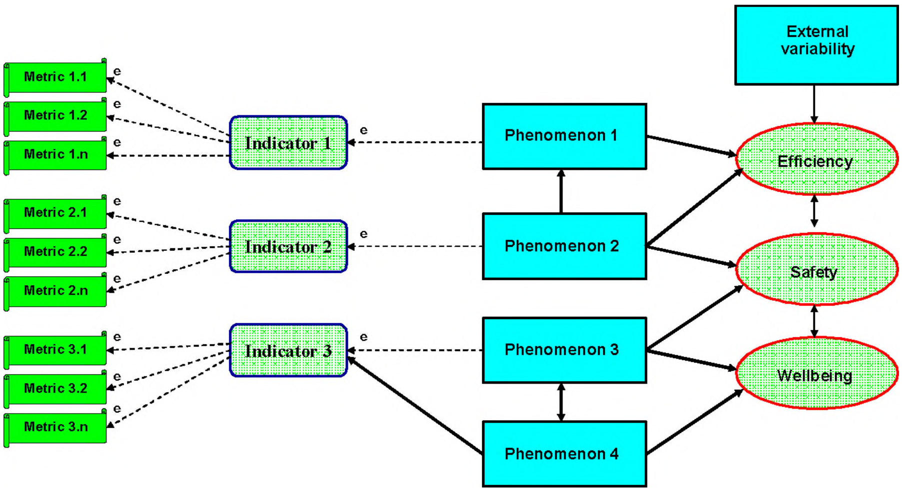

Figure 8. The relation between metrics (*how* something is measured), indicators (*what* is being measured), phenomena (what is the indicator an indication of) and safety. Dotted arrows indicate that something is inferred from something else (with the associated measurement error). Straight arrows indicate that one thing influences the other thing.

The relation of safety performance indicator and safety can be clouded by various factors depicted in Figure 8:

- The indicator can be a valid indicator of the underlying phenomenon, but the phenomenon does not bear a relationship to nuclear safety

- The indicator can be a valid indicator of the underlying phenomenon, but the effect of the phenomenon on system safety is clouded by the effect of other relevant phenomena (this is the problem with most indicators)

- The indicator as such can be a valid indicator of the underlying phenomenon, but the operationalization (metric) of the indicator is such that the measure has a high degree of error (calibration error, hesitancy in reporting, optimizing the score instead of the attending the phenomenon etc).

- The phenomenon in question cannot be accurate measured by one indicator, rather multiple indicators are needed.
- Multiple causal links and directions; e.g. careless attitude toward personal risks causes occupational accidents (lag indicator) that decrease overall employee wellbeing (lead indicator) and trust in the safety management systems (lead indicator) with a combined effect of decreased system safety and increase in unsafe behaviours (lag indicator).

For example, occupational accidents can tell about the state of process safety as measured by e.g. the number of reactor scrams and development initiatives, or the use of human performance tools. This is due to the fact that these are all affected partly by the same underlying phenomena. In this case the underlying phenomena could be workplace norms concerning thoroughness and proficiency. Still, one cannot decipher solely from an increase in occupational accidents that there is a problem with norms. Norms are only one possible explanation and there is need for corroborative evidence from other indicators before making any judgments.

6.4 Making inferences about the level of safety

In modern, complex safety-critical organizatios accidents often result from a combination of various circumstances, deficiencies and variabilities in performance which by themselves would have been harmless (Hollnagel 2004). This represents a challenge for safety performance indicators since they are always piecemeal and abstracted from the everyday work. If an organization where all the indicators suggest a good level of safety can suffer a major accident, what use are safety performance indicators in the first place? This fact emphasizes the importance of having leading indicators that focus on development; safety can never be guaranteed by relying on lagging indicators, rather it needs a continuous focus on lagging indicators of past deficiencies, leading indicators of current technical, organizational and human conditions and leading indicators of technical, organizational and human processes that drive safety forward.

The above example also gives emphasis on using multiple indicators to evaluate system safety amd recognising the limitations of the used indicators. The value of any one individual indicator may be of no significance if treated in an isolated manner, but may be important when considered in the context of other indicators (IAEA, 2000). As Mearns (2009) points out, indicators do not necessarily represent reality, but are an attempt to reflect the truth in the form of multiple and different forms of data. Ale (2009, 470) compares industrial safety indicators to physical examination in health care. Body temperature is a good indicator for a person's health just as are pulse rate and blood pressure. Medical examination often starts with checking these vital statistics. However, sometimes a good state of these indicators does not suffice to be certain that there is not something wrong. For example a broken bone may not change these vital statistics. These statistics also show large variability over individuals. An indicator is thus always "just" an indicator. Its actual meaning needs to be thought through carefully. As IAEA (2000, 1) points out in its tecdoc, the actual values of the indicators are not intended to be direct measures of safety. Instead safety performance can be *inferred* from the results. EPRI (2000) also sees interpreting the meaning of indicator data as the most essential step in the process of using leading indicators. Yet, according to EPRI's case studies, interpretation is also the point were the process of using leading indicators is most likely to falter. Often the data collection process assumes primary importance at the expence of interpretation. EPRI recommends that leading indicator data should be addressed in quarterly meetings of the management steering group and other interested personnel in order to understand the big picture. EPRI highlights the fact that data do not think, people do. The indicator data as such is not interesting. The group work in interpreting the data produces the only meaningful outcomes in the process of utilizing leading indicators.

When making inferences one of the biggest questions is the standard against which the indicator is evaluated. *Comparison with others* is one of the ways of interpreting the meaning of indicator results; if one is in the worst quartile the indicator shows a low level of safety in comparison to the plants at the highest quartile. This necessitates that the phenomenon that is being measured has a normal distribution within the population of all organizations. Otherwise even a bad result can look good if the other organizations score even worse. Thus, relying on *absolute scores* is often a better option.

Timescale is another variable to be considered when making inferences: often both external comparison and internal assessment are based on trends. This means that if the performance shows a steady regression along a certain timeline (that is not happening at peer organizations) there is a cause for concern. Again, trending is also relative not absolute, and judgment is based on extrapolating past performance into the future. Another way of trending is to project current organizational activities into future and make changes to counteract, maintain or strengthen those projected trends. This requires a good model of the organization and can be considered an instance of the feed-forward strategy advocated by Hollnagel (2008). Whatever the strategy for making inferences it has to be remembered that few if any of the indicators are totally independent of one another. They are all measures of safety culture and probably have some correlation with each other.

7 Conclusions

The purpose of safety performance indicators is to provide information on safety, motivate people to work on safety and contribute to change towards increased safety in the organization. Differentiation of safety performance indicators and safety culture indicators is unnecessary, since they should measure the same phenomena.

Safety indicators are tools for effective safety management process. Safety management needs a continuous focus on lagging indicators of past deficiencies, leading indicators of current technical, organizational and human conditions and leading indicators of technical, organizational and human processes that drive safety forward. Drive indicators are chosen priority areas of organizational safety activity. They are based on the underlying safety model and potential safety activities and safety policy derived from it. Drive indicators influence control measures that manage the sociotechnical system; change, maintain, reinforce, or reduce something. Monitor indicators provide a view on the dynamics of the system in question; the activities taking place, abilities, skills and motivation of the personnel, routines and practices – the organizational potential for safety. They also monitor the efficacy of the control measures that are used to manage the sociotechnical system. Typically the safety performance indicators that are used are lagging (feedback) indicators. Besides feedback indicators, organizations should also acknowledge the important role of monitor and drive indicators in managing safety.

When selecting the indicators it is important first to consider what needs to be monitored, what are the critical goals of the organization, i.e. the core task that needs to be taken care of? PRA should also be utilised in identifying the most safety significant issues to monitor. The selection and use of safety performance indicators is always based on an understanding (a model) of the sociotechnical system and safety. The safety model defines what risks are perceived. It is important that the safety performance indicators can help in reflecting on this model. Key questions to ask when selecting and utilizing safety performance indicators are 1) what is required from the nuclear power plant to perform safely and 2) what is required from the organization in order to be aware of its safety level and enhance its safety performance. The indicators should provide information on whether these requirements are met or not, where the organization should put more effort to meet the requirements and finally, does the organization have an accurate view on the requirements.

The selection and utilization of safety performance indicators is a continuous process where all three types of indicators are analysed and finetuned to better correspond with reality. The safety performance of the plant is always inferred from the data from all the indicators analysed together. There is no direct correspondence between one indicator and nuclear safety. Rather the safety performance indicators can provide a holistic view on the potential of the nuclear power plant to guarantee nuclear safety and point out key areas of concern where attention is required. This requires skill in analysing the indicator data and interpreting the results in organizational theoretical framework.

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Appendix A: Examples of drive indicators

A concise summary list of potential leading drive indicators is presented. The list should be considered a pragmatic tool to guide attention to the relevant aspects, not a formal auditing check list or an indicator set. The main categories are based on Reiman and Oedewald (2009; see also Reiman et al 2008), and the specific contents of the categories include input from OECD (2008), and IAEA (1999, 2000, 2002, 2003, 2008).

Organizational functions

- **Process for hazard identification and risk management (INDICATOR)**
    - Proactive measures are in place to identify new hazards and improve existing safety measures (METRIC)
    - PRA is utilized in decision making (METRIC)
    - Hazard identification and risk assessments are used to develop policies, procedures and practices (METRIC)
    - Responsibilities for hazard identification are clear in the organization (METRIC)
    - Hazard identification deals with technical, human and organizational issues in adequate depth (METRIC)
    - Adequate barriers are set against the identified hazards (METRIC)
    - Independent safety reviews are carried out regularly and proactively (METRIC)
    - Human performance tools are used in assessing the risks of individual tasks (METRIC)
- **Process for design and engineering (INDICATOR)**
    - There is an access to the appropriate tools and data for design and engineering (METRIC)
    - There is a procedure to ensure that key safety issues are addressed in the design and engineering phase of the plant and its components (METRIC)
    - There is a procedure to maintain and update the plant design basis documentation (METRIC)
- **Process for plant life management (INDICATOR)**
    - Systematic ageing management programme exists (METRIC)

- There is a procedure for the identification of possible degradation mechanisms (METRIC)
- Operating experience and research are utilized in identifying plant life management issues (METRIC)
- There is a long term plan for monitoring the condition of safety critical components and assuring that safety functions remain available in future (METRIC)
- There is a long term plan for maintaining the integrity of the pressure vessel (METRIC)
- There is a procedure for repairing or replacing parts to prevent or remedy unacceptable degradation (METRIC)

- **Setting of safety goals and safety policy (INDICATOR)**
  - Safety policy is defined (METRIC)
  - Safety policy is reviewed and updated regularly (METRIC)
  - Clear safety goals are set (METRIC)
  - Safety goals are relevant for the organization (METRIC)
  - Safety goals are defined both for short and long term (METRIC)
  - Personnel participate in setting safety goals (METRIC)
  - There is an action program for reaching the safety goals (METRIC)
  - The action program includes responsibilities and accountabilities (METRIC)
  - Follow-up on safety goals is done on a regular basis (METRIC)
- **Management safety leadership (INDICATOR)**
  - Owners of the power plant show a commitment to safety activities (METRIC)
  - Management is actively committed to, and visibly involved in, safety activities (METRIC)
  - Safety is a clearly recognized value at the organization (METRIC)
  - Safety is a criteria in management decisions (METRIC)
  - Conservative decision making is practiced in ambiguous situations (METRIC)
  - Positive feedback is given on safety conscious behaviour of the personnel (METRIC)

- Reporting of deviations, worries and own mistakes is encouraged by the management (METRIC)
- Management invests financially in safety (METRIC)

- **Immediate superiors' safety activity (INDICATOR)**
  - Immediate superior supports the organizing of work and management of daily routines (METRIC)
  - Superior provides positive feedback on safety conscious behaviour of the personnel (METRIC)
  - Superior provides fair treatment of subordinates, understanding that errors are natural, but not all violations can be tolerated (METRIC)
  - Superior monitors the personnel's coping skills, stress and fatigue levels as well as technical skills (METRIC)
  - Reporting of deviations, worries and own mistakes is encouraged by the management (METRIC)

- **Safety communication (INDICATOR)**
  - Feedback is provided to personnel on near-misses and incidents (METRIC)
  - There is adequate information dissemination on safety issues received from other organizations (METRIC)
  - The personnel are reminded about safety issues in meetings and internal communiqués (METRIC)
  - The personnel are informed about the overall safety level and current challenges on a regular basis (METRIC)
  - Open communication on both positive and negative issues exists in the organization (METRIC)
  - There are both formal and informal communication channels for raising safety concerns in the organization – up to the highest level if necessary (METRIC)
  - The safety significance of various rules and procedures is clearly communicated to the personnel (METRIC)

- **Communication and cooperation practices (INDICATOR)**
  - There are sufficient exchange opportunities for safety relevant information within and between units (METRIC)
  - Work climate supports team work and knowledge sharing (METRIC)

    - Information that is relevant for work is easily accessible (METRIC)
    - The bottlenecks of information flow have been identified and controlled (METRIC)
    - Information flow in change of shifts situations is assured (METRIC)
- **Integration of the know-how of various professional groups (INDICATOR)**
    - Professional groups appreciate each others' competence and role (METRIC)
    - Variety of views and opinions are encouraged and decisions are based on expertise not formal position (METRIC)
    - Human and organizational factors are integrated into technical investigations and projects (METRIC)
    - The hands-on experience of technicians is utilised by foremen, managers and engineers (METRIC)
    - Different safety fields (occupational safety, process safety, radiation safety, environmental safety, security) are coordinated and their interfaces are considered (METRIC)
- **Resource management (INDICATOR)**
    - The availability of sufficient workforce is ensured (METRIC)
    - All the plant functions (maintenance, operations, engineering, safety, administration, human resources) have sufficient resources (METRIC)
    - Tasks are allocated in a manner that promotes both work motivation including skill development as well as the safe and efficient carrying out of the given task (METRIC)
    - Tools and instruments are appropriate and up-to-date (METRIC)
    - Work conditions support safe work (METRIC)
    - There is a system for ensuring that time pressure does not compromise quality in safety-critical tasks (METRIC)
    - Product and tool purchasing is based on knowledge of their conditions of use as well as their potential hazards (METRIC)
    - Human performance issues such as fatigue and communication are taken into account in work schedule planning (METRIC)
- **Process for work management and procedure management (INDICATOR)**

- All areas of operation are covered by adequate and documented procedures (METRIC)
- Procedures and instructions are up-to-date and revised accordingly (METRIC)
- Revisions in procedures and instructions are communicated to the users (METRIC)
- The safety relevance of the procedures and instructions is clearly stated in them (METRIC)
- Procedures and instructions are clear and easily understood by those who have to apply them (METRIC)
- The know-how of the “shop-floor” personnel is utilised in creating and revising of rules and instructions (METRIC)
- Safety procedures are coordinated with or integrated in operating procedures (METRIC)
- The discrepancy between formal rules and actual work is monitored (METRIC)
- Work Permit System is implemented and continuously developed (METRIC)
- The interfaces and interaction of various work processes is identified (METRIC)

- **Competence management and training (INDICATOR)**
    - An adequate system for identification of current competence profiles exists (METRIC)
    - There are clear objectives established for training programs (METRIC)
    - There is adequate training in (a) technical areas, (b) safety issues including human factors and the nature of safety and accidents, and (c) the uncertainties and potential hazards of nuclear power (METRIC)
    - There is a sufficient number of refresher courses on basic safety and technical issues (METRIC)
    - There is an adequate system for familiarization and induction of new personnel (METRIC)
    - There is a mechanism in place to ensure that the scope, content and quality of the training programs are adequate (METRIC)
    - Feedback is gathered from the trainees and it is utilized in developing the training program (METRIC)

    - Competence is maintained for both new and old technology (METRIC)
    - Simulators and simulated operations are utilized in training (METRIC)
    - Operating events (own plant as well as outside) are utilized as training material (METRIC)
    - An adequate recruitment procedure exists for identifying competence needs and selecting suitable candidates (METRIC)

- **Operation and maintenance of the plant (INDICATOR)**
    - The plant is operated in a safe manner according to its technical specifications (METRIC)
    - There is a program of preventive maintenance in place and it is revised according to maintenance history (METRIC)
    - There is a system for documenting history data on equipment and their maintenance actions (METRIC)
    - History data is used in analysis of reliability and maintenance needs of the equipment (METRIC)
    - Condition monitoring for equipment is utilised to target preventive maintenance (METRIC)
    - Conservative decision making principle is applied in making decisions about the operational safety of the plant (METRIC)

- **External cooperation (INDICATOR)**
    - There are well-established channels for communication with the national authorities (METRIC)
    - There is a policy or procedure for cooperation and communication with community organizations and the media (METRIC)
    - There are well-established channels for communication and system for supporting and funding external research on nuclear safety related issues (METRIC)
    - There is a well-developed system for communication and co-operation with current and potential suppliers and customers to the enterprise (METRIC)
    - There is a well-developed system for sharing and discussing safety related information with other safety-critical organizations (METRIC)
    - The organization actively participates in the international cooperation on nuclear safety related issues (METRIC)

- **Contractor and purchase management (INDICATOR)**
    - There is a process for purchase of outside work (METRIC)
    - Contractors are trained on safety culture issues and work practices of the plant (METRIC)
    - The know-how of the contractors' personnel is ensured (METRIC)
    - A record of contractor safety performance is utilised in decision making concerning contracts (METRIC)
    - Contractors have possibilities for expressing safety worries and providing safety proposals on issues they notice (METRIC)
    - The knowledge needed in-house is analysed and measures to maintain it are taken (METRIC)
    - There is a procedure for control of products including their specifications and requirements as well as activities for inspection, testing, verification and validation of the products (METRIC)
- **Practices of organizational learning (INDICATOR)**
    - There is a comprehensive system for reporting incidents and other learning experiences such as near misses (METRIC)
    - There is a systematic corrective action program in place to deal with deviations (METRIC)
    - Operating experience is collected and analysed from other nuclear power plants (METRIC)
    - There exists practices for the identification of new vulnerabilities (METRIC)
    - There is a system for gathering development initiatives from the personnel (METRIC)
    - There is a system for investigation and analysis of internal incidents that takes into account technical, human and organizational factors in equal degree (METRIC)
    - Development initiatives are carried out and followed upon (METRIC)
    - Daily work practices create an increasing awareness of the hazards of the work (METRIC)
    - Adequate reactive and proactive indicators of process safety and safety culture have been defined and are followed up (METRIC)
    - There is a system for analysing the common safety related findings (trends, root causes, changes, variety of corrective actions, generalizability to other components / equipment) from

events, near misses and maintenance history at the organization (METRIC)

    - Internal and external safety assessments and audits are utilised to improve safety performance (METRIC)

- **Change management (INDICATOR)**

    - There is a clear definition of what constitutes a technical change or an organizational change (METRIC)

    - The amount and pace of changes that the organization can handle is considered when planning changes (METRIC)

    - There is a procedure for planning, implementing and follow-up on technical and organizational changes (METRIC)

    - Technological changes are anticipated, and their risks are evaluated (METRIC)

    - A risk assessment is done for organizational changes prior to committing to one (METRIC)

    - Usability and maintainability issues of new technology, tools and modifications are considered in already design and implementation stages (METRIC)

    - Human and organizational factors are adequately considered in change management (METRIC)

    - It is assured that the organizational memory is not lost with the changes by e.g. documentation and knowledge transfer (METRIC)

- **Contingency planning and emergency preparedness (INDICATOR)**

    - The organization has an adequate on-site emergency preparedness plan (METRIC)

    - There is regular training on emergencies on-site (METRIC)

    - There is an adequate system for alarming within the enterprise as well as for external alarming of authorities and the public (METRIC)

    - The organization has provided adequate information on the potential hazards and accident scenarios to the public authorities such as first response personnel, police, military, medical facilities, and the environmental authorities (METRIC)

Appendix B: Examples of monitor indicators

A concise summary list of potential leading monitor indicators is presented. The list should be considered a pragmatic tool to guide attention to the relevant aspects, not a formal auditing check list or an indicator set. The main categories are based on Reiman and Oedewald (2009), and the specific contents of the categories include input from OECD (2008), IAEA (1999, 2000, 2002, 2003, 2006, 2008) and Weick and Sutcliffe (2007). The technical condition of the plant is not dealt with in this report due to its plant-specific nature and the fact that the focus of this report is mainly on human and organizational factors.

There needs to be fewer monitor indicators than there are drive indicators. This is due to the fact that all the monitor indicators should be analysed and monitored regularly whereas drive indicators are selected depending on prioritization. Thus, too many indicators provide an information overload. Nevertheless, the number of indicators should be sufficient to provide a reliable view on the status of safety culture and system safety at the organization.

Organization and management

- **Management system (INDICATOR)**
  - The extent to which the management system aligns with and contributes to the achievement of organizational goals (METRIC)
  - The quality and clarity of the safety policy and safety goals (METRIC)
  - The quality and clarity of standards and expectations for safety behaviour (METRIC)
  - The clarity of the organizational structure including the extent to which roles and responsibilities have been clearly and unambiguously described (METRIC)
  - The clarity of the description of how work is to be prepared, reviewed, carried out, recorded, assessed and improved (METRIC)
  - The identification of the interaction and interfaces of the various work processes (METRIC)
  - The quality of procedures for hazard identification, assessment and control (METRIC)
  - The quality of the operating experience and corrective actions program (METRIC)

  - The clarity of integration of the consideration of process safety, HSE (health, occupational safety, environment) and security issues (METRIC)

  - The extent to which the system provides the means to support individuals and teams in carrying out their tasks safely and effectively (METRIC)

- **Human resources (INDICATOR)**

  - Extent to which the personnel has been trained in accordance with the planned training programme (METRIC)

  - Extent to which the personnel have a knowledge of the work processes (METRIC)

  - Extent to which the personnel have suitable skills, knowledge and experience to carry out their tasks safely and effectively (METRIC)

- **Work conditions (INDICATOR)**

  - The quality of documentation and procedures (METRIC)

  - Documentation relating to the original design basis is available and up to date to reflect all the modifications made to the plant and procedures since its commissioning (METRIC)

  - Time pressure and work load in safety-critical tasks (METRIC)

  - The amount of slack resources to cope with unexpected or demanding situations (METRIC)

  - Staffing in critical posts (METRIC)

- **Work practices (INDICATOR)**

  - The extent to which human performance tools are utilized in daily practice (METRIC)

  - The extent of personnel compliance with safety rules (METRIC)

  - The extent to which work is carried out in accordance to the processes described in the management system (METRIC)

  - The extent of visible management commitment to safety and the management system (METRIC)

  - The extent to which the decision making in the organization utilizes all the necessary competence and is transparent in its content and progress (METRIC)

  - The extent to which information is effectively communicated throughout the organization and to the external stakeholders (METRIC)

- **Strategy and external relations (INDICATOR)**
    - The adequacy of the maintenance program (METRIC)
    - The budget for safety improvements (METRIC)
    - Relations to corporate headquarters are open and based on mutual trust, and organizational goals are in line with those of the headquarters' (METRIC)
    - Relations to the regulator are open and honest (METRIC)

Psychological states and conceptions

- **Work and safety motivation (INDICATOR)**
    - The extent to which the personnel feel that their work is meaningful and important (METRIC)
    - The extent to which the personnel have a motivation to spend effort on safety related issues (METRIC)
    - The extent to which the personnel are interested in safety matters, and try to learn more on hazards and safety (METRIC)
    - The extent to which the personnel prioritize safety over production in conflict situations or under time pressure (METRIC)
- **Sense of control (INDICATOR)**
    - The extent to which the personnel have a realistic sense of control, which enables them to perceive their capabilities and limitations, and to learn from their job (METRIC)
    - The extent to which the work load of workers is not too high nor too low (METRIC)
    - The extent to which the personnel the demands of the tasks are in line with the skills of the workers (METRIC)
    - The extent to which the personnel the time pressure that workers feels is not too high (METRIC)
    - The extent to which the personnel feel that they can influence safety related issues (METRIC)
- **Understanding of the organizational core task (INDICATOR)**
    - The extent to which the personnel understand the task and goals of the organization (METRIC)
    - The extent to which the personnel understand how their task relates to the overall goals of the organization (METRIC)

    - The extent to which the personnel know the safety policies and the operating principles of the organization (METRIC)

- **Understanding of hazards (INDICATOR)**

    - The extent to which the personnel understands the hazards that are connected to their work (METRIC)

    - The extent to which the personnel understand the safety significance of their work along with its connections to the work of the others (METRIC)

    - The extent to which the personnel understand the hazards stemming from human and organizational factors related issues in addition to the inherent technological hazards (METRIC)

    - The extent to which the personnel are aware of the limitations of human performance capacity (METRIC)

    - The extent to which the personnel understand the safety significance of their own tasks (METRIC)

    - The extent to which the personnel understands the relevant ageing phenomena of the systems, structures and components (METRIC)

    - The extent of awareness of technical / physical condition of systems, structures and components (METRIC)

- **Understanding of safety (INDICATOR)**

    - The extent to which the complex and emergent nature of safety (a dynamic non-event) is understood along with the fact that safety must be created every day (METRIC)

    - The extent to which the organization's contribution to safety by the means of norms, practices and shared values and meanings is understood (METRIC)

    - The extent to which errors are understood as being a natural part of work at all levels of the organization (METRIC)

    - The extent to which Human Factors are considered a neutral phenomena and not something to be avoided (i.e., a negative phenomenon). (METRIC)

    - The extent to which the personnel have basic knowledge of human performance issues. (METRIC)

    - The extent to which the defence-in-depth principle is understood among the personnel. (METRIC)

- **Sense of personal responsibility (INDICATOR)**

    - The extent to which the personnel have a willingness to spend personal effort on safety issues and take responsibility for their actions. (METRIC)

    - The extent to which the personnel are able to perceive that they have an effect on the outcome of their work, and that their way of working (inc. attitudes) influences that of the others. (METRIC)

    - The extent to which the personnel have a sense of personal ownership for an equipment, an area of plant or the entire operations of the plant. (METRIC)

    - The extent to which the personnel exhibit a wider responsibility for the overall safety of the organization (METRIC)

- **Mindfulness and vigilance (INDICATOR)**

    - The extent to which the personnel reflect the social dynamics of the organization. (METRIC)

    - The extent to which the personnel continuously seek to identify new risks and enhance their view on the hazards of their work. (METRIC)

    - The extent to which the personnel at all levels exhibit a questioning attitude. (METRIC)

    - The extent to which the personnel remain humble toward their knowledge of the hazards and their competence (METRIC)

    - The extent to which the personnel are aware of the limitations of standard operating procedures and more detailed instructions (METRIC)

    - The extent to which external audits provide results that are in accordance with the finding of internal audits or prevalent conceptions of the personnel (METRIC)

    - The extent to which the personnel continuously search for improvements in organizational systems and procedures (METRIC)

Social processes

- **Sensemaking and joint attribution of meaning to past, present and future events (INDICATOR)**

    - The extent to which the organization remains open to multiple interpretations of possible future scenarios, and does not force a single truth on its employees. (METRIC)

  - The extent to which past successes are not considered as guarantees of future success. (METRIC)
  - The extent to which history of the organization is considered as socially constructed and subject to change. (METRIC)
  - The extent to which argumentation is based on facts and accuracy as much as possible instead of formal position of the arguer and the attractiveness of the argument for the organizational self-image. (METRIC)
  - The extent to which the meanings given to past events do not constrain the necessary actions related to nuclear safety by, e.g., labelling safety issues in negative terms or event investigations as blame seeking. (METRIC)

- **Norms and values related to safety (INDICATOR)**
  - The extent to which nuclear safety is a shared value in the organization. (METRIC)
  - The extent to which safety conscious behaviour and uncertainty expression is socially accepted and supported. (METRIC)
  - The extent to which the relationships between the management and the personnel are based on trust. (METRIC)
  - The extent to which the relations between various personnel groups are based on trust and shared safety norms. (METRIC)
  - The extent to which there is an open atmosphere concerning reporting of errors and deviations. (METRIC)
  - The extent to which there exists a strong social identity that allows the personnel to feel as belonging to the organization. (METRIC)
  - The extent to which the norms and stereotypes created by the subgroups in the organization are not counterproductive to cooperation with other groups. (METRIC)

- **Habit and routine formation (INDICATOR)**
  - The amount of routine work and routine tasks at the organization (METRIC)
  - The extent to which habits and routines are reflected from time to time (METRIC)
  - The extent to which tasks and situations where routines may develop and where they might have consequences for safety are identified (METRIC)
  - The extent to which routines are based on a good understanding of their safety significance (METRIC)

- **Optimizing and local adaptation (INDICATOR)**
  - The extent to which tasks are adapted to the circumstances on the field, aka how much adaptation is there (METRIC)
  - The extent to which the local adaptations are based on understanding of their effects on safety (METRIC)
  - The extent to which there exists a management awareness of the adaptations and trade-offs taking place at the field. (METRIC)
  - The extent to which there exists an awareness of the adaptations and trade-offs taking place at the organization. (METRIC)
  - The extent to which the gap between work as prescribed and work as actually done is known and monitored at the organization (METRIC)

Appendix C: Examples of feedback indicators

Systems, structures and components

- Ratio of preventive and corrective maintenance
- Number of unplanned automatic reactor scrams
- Capability factors for the units
- Percentage of safety critical equipment that fail inspection / test
- Fuel leaks
- Equipment forced outage rate

Past process safety performance

- Availability of safety systems
- Number of INES events
- Number of safety critical equipment that fail to operate as designed
- Number of unplanned automatic scrams

Human factors

- Lost-time incidents (Industrial safety accident rate)
- Sick leave
- Radiation doses / exposure
- Turnover
- Job satisfaction and work motivation scores from yearly surveys
- Amount of procedure violations
- Root causes of events dealing with human behaviour issues

Past organizational safety performance

- Structural / equipment anomalies discovered by inspections vs. chance
- Non-compliances with Tech Specs
- Recurrence of incidents with similar root causes
- Backlog of corrective actions

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