Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 155 (2008) 243–252
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

# Effectiveness evaluation methodology for safety processes to enhance organisational culture in hazardous installations

A. Mengolini *, L. Debarberis

*European Commission, Joint Research Centre, Institute of Energy, Petten, The Netherlands*

Received 13 November 2006; received in revised form 5 October 2007; accepted 19 November 2007
Available online 28 November 2007

**Abstract**

Safety performance indicators are widely collected and used in hazardous installations. The IAEA, OECD and other international organisations have developed approaches that strongly promote deployment of safety performance indicators. These indicators focus mainly on operational performance, but some of them also address organisational and safety culture aspects. However, operators of hazardous installations, in particular those with limited resources and time constraints, often find it difficult to collect the large number of different safety performance indicators. Moreover, they also have difficulties with giving a meaning to the numbers and trends recorded, especially to those that should reflect a positive safety culture.

In this light, the aim of this article is to address the need to monitor and assess progress on implementation of a programme to enhance safety and organisational culture. It proposes a specific process-view approach to effectiveness evaluation of organisational and safety culture indicators by means of a multi-level system in which safety processes and staff involvement in defining improvement activities are central. In this way safety becomes fully embedded in staff activities. Key members of personnel become directly involved in identifying and supplying leading indicators relating to their own daily activity and become responsible and accountable for keeping the measurement system alive. Besides use of lagging indicators, particular emphasis is placed on the importance of identifying and selecting leading indicators which can be used to drive safety performance for organisational and safety culture aspects as well.


*Keywords:* Safety; Organisational factors; Performance indicators; Improvement activities

## 1. Introduction

Safety performance indicators (SPI) are widely collected and used in hazardous installations, in both the process and nuclear industries. Collection of SPIs is a very positive step towards learning with a view to improvement. Indicators are not static and can be adapted to the conditions and performance of the plant concerned. A high level of safety is the result of a complex interaction between good design, operational safety and human performance. Experience has shown that focusing on any single aspect of performance can be ineffective and misleading. Therefore, SPIs should consider aspects of the different layers that contribute to the safety of a hazardous installation (see Fig. 1). There is general agreement that looking for effectiveness in human and organisational performance and safety management is indispensable. This is clearly linked with self-assessment and continuous improvement of utilities and regulatory organisations. A change in the “safety paradigm” has taken place in the last 30 years. From purely technical aspects (Seveso, 1976) attention shifted first to human error (TMI, 1979) and then to safety management and safety culture issues (Bhopal, 1984; Chernobyl, 1986; Challenger, 1986). After events such as Tokaimura (1999), Davis Besse (2002) and Columbia (2003) the focus has further shifted to the organisation at large. Some authors [1] acknowledge the increasing role played by organisational factors in safety as the third age of safety, after hazard control technologies were identified as the first age and human factors as the second (see Fig. 2). For example, introduction of the ALARP/ALARA (As Low As Reasonably Practicable/As Low As Reasonably Achievable) concept marks a cultural change and shift of safety paradigm that focuses more on the organisation as a whole and not only as a physical structure. Organisational and safety culture aspects can certainly provide significant indications of the safety awareness

* Corresponding author. Tel.: +31 224 56 5253; fax: +31 224 56 56 41.
*E-mail address:* anna.Mengolini@jrc.nl (A. Mengolini).

0304-3894/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2007.11.078

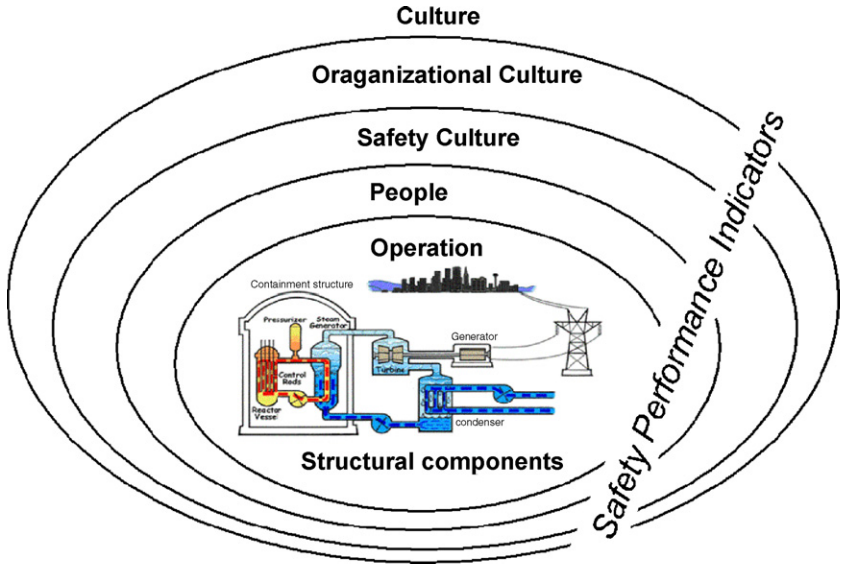


Fig. 1. Contributors to the safety of hazardous installations.

of the organisation. Development of suitable indicators therefore becomes extremely important. Organisational and safety culture indicators can provide early warnings that critical processes are not working as they should. Analyses of recent events in both the nuclear and non-nuclear fields show how identification of these "early warnings" is crucial in accident prevention [2]. Some authors [3], reporting on the WANO performance indicators, recognise the need for a "very special and sensitive safety culture for nuclear installations". However, identification of suitable indicators for safety culture and safety awareness is a difficult process, as acknowledged by recent studies and research on the topic [4–8].

SPIs proposed by recent approaches (IAEA [9,10], OECD [11]) and other recent studies [4] include, besides indicators linked to operation and design, indicators linked to positive safety attitude, to safety awareness and to safety culture. However, although the number of SPIs proposed is high, they partly reflect or give an effective measure of safety culture. This fact may become critical in setting targets and effectively directing

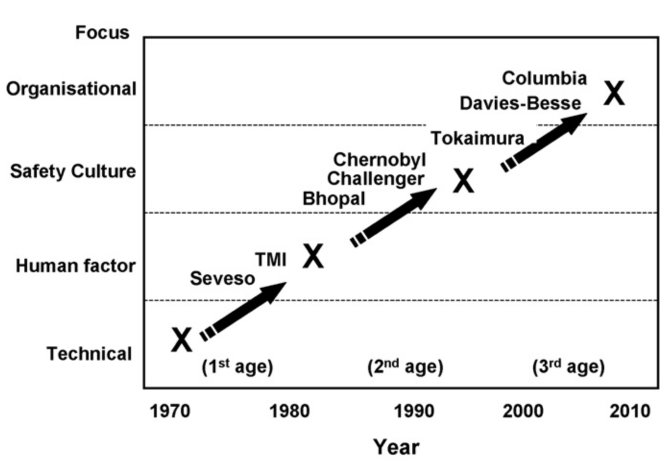


Fig. 2. Chronological development of safety concepts.

improvement programmes for small organisations with limited resources and time constraints.

In this context, the aim of the approach presented in this article is to respond to the need to monitor and assess progress against set targets with a view to implementation of a programme to enhance safety and organisational culture [12]. It proposes a specific process-view approach for effectiveness evaluation of safety culture and safety awareness indicators by means of a multi-level system that has been deployed at a nuclear research reactor.

The authors believe that the approach developed can be of benefit to hazardous installations other than nuclear plants. In particular, it can help organisations with limited resources and time constraints (i.e. small and medium-sized enterprises) in their attempts to monitor and assess improvements in organisational and safety culture aspects.

## 2. Approaches to development of safety performance indicators

Organisations face the question of choosing, among the large numbers of indicators collected, those that are meaningful and usable for improvement purposes and, in particular, those which indicate a positive safety culture. This is especially true of nuclear installations that have limited resources and skills to spare for indicator collection.

The issue with safety is that, in spite of the effort put in, the success is not directly visible, in particular because there are no visible returns in the shape of profits. Resources channelled into improving productivity bring relatively certain outcomes, whereas those allocated to enhancing safety do not in the short term [13]. The tendency is therefore to use reactive indicators that reflect past performance, known as lagging or output indicators. They provide a measurement of the output of the process monitored and are used mainly for corrective programmes, often after undesired events. This is undoubtedly important, in

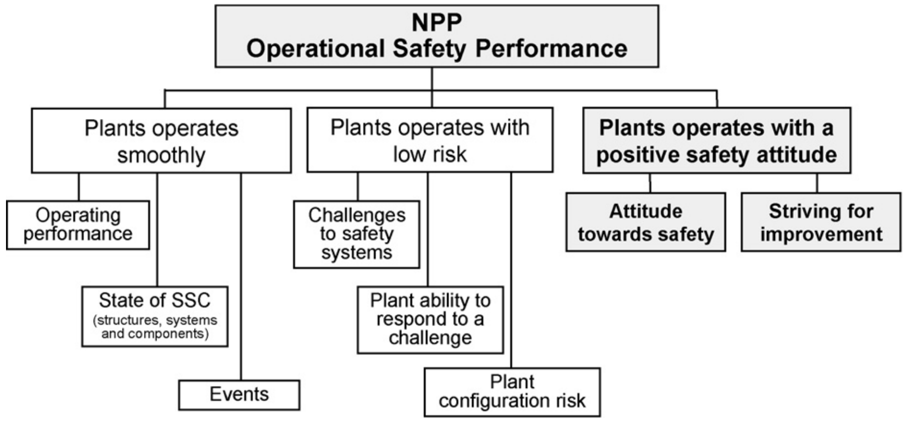


Fig. 3. NPP Operational safety performance indicator framework (IAEA TECDOC 1141 [9]).

particular for studying trends, analysing causes and foreseeing problems, notably in case of slow deterioration of the process. However, past performance is a poor predictor of future results. Moreover, an unbalanced focus on production or measurable events, like product volumes or incident occurrence, may lead to the idea that safety and prevention are not important [6]. Therefore, there is a need for unbiased objective information about the real conditions within the organisation [7]. Although this is a difficult task, it can be achieved by developing, alongside lagging indicators, leading indicators. Taking training as an example, it can be relatively easy to increase the training effort on safety by increasing the number of training days allocated to staff. However, the quality, appropriateness, diversity and complementary nature of the training is probably much more relevant to its effectiveness. For this reason, leading indicators have to be conceived, taking into account not only quantitative but also qualitative elements in order to measure performance effectively. Leading indicators are those on which the organisation can act to leverage achievement of the organisational goals monitored by the lagging indicators.

The latest approaches to safety performance indicators are those proposed by the IAEA [9] and OECD [11]. They both rely on a top–down approach grouping arbitrary system elements. The result is that a large number of indicators are usually targeted, listed and collected more or less systematically, e.g. number of significant events, number of forced power reductions, dose to personnel, number of unplanned shutdowns, leakage from cooling system, load factor (%), number of reported events, number of audits and technical reviews.

IAEA TECDOC 1141 “Operational safety performance indicators for nuclear power plants” [9] classifies SPIs as follows: plant operates smoothly, plant operates with low risk and plant

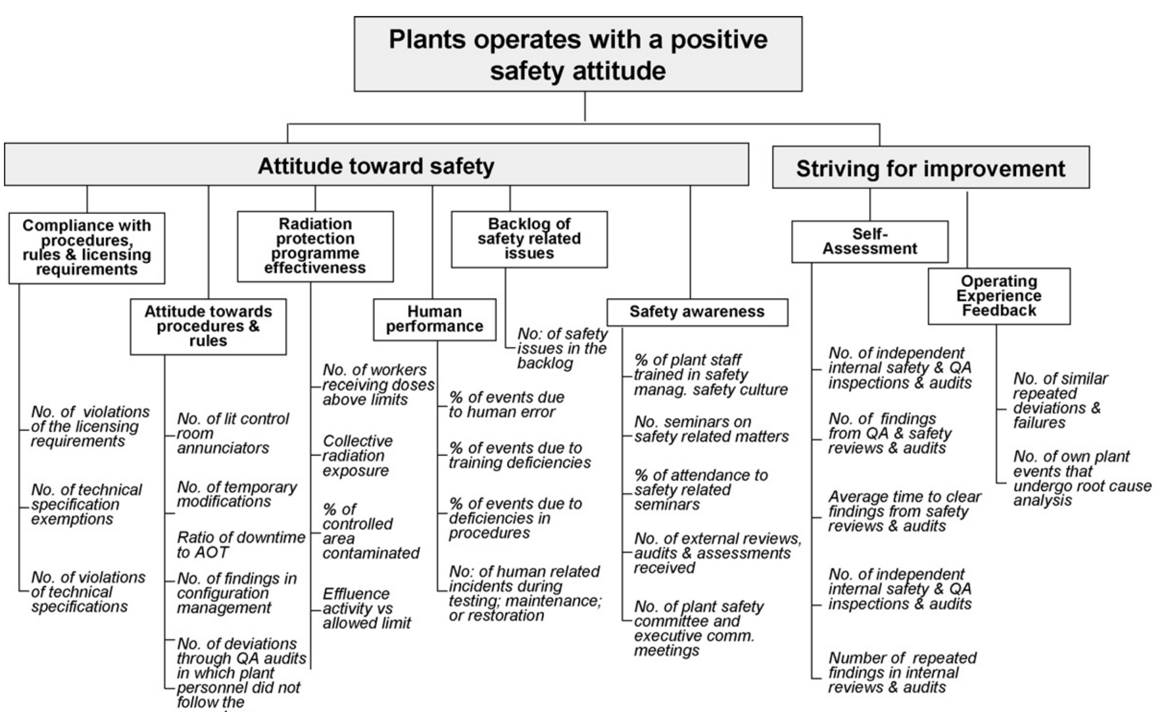


Fig. 4. Operational safety performance attribute “Plant operates with a positive safety attitude (IAEA TECDOC 1141 [9]).


Fig. 5. Safety culture dimensions (IAEA).

operates with a positive safety attitude. For each attribute overall indicators of relevant aspects of safety performance are identified and further deployed in specific indicators with the aid of strategic indicators (see Figs. 3 and 4 for detailed safety attitude attributes).

The number of indicators is high, however, and each utility has to choose which of them best serve its needs. Most of the indicators presented are lagging indicators and there is a lack of focus on indicators linked to organisational and safety culture aspects. The IAEA's perspective of safety culture has expanded with time as its understanding of the complexities of the concept have developed. The term "safety culture" is now understood as a specific type of organisational culture in high-reliability organisations. For this reason, the IAEA is actively identifying and developing suitable safety culture indicators. The IAEA points out that there is no simple set of indicators to monitor safety culture at a plant and that identification of performance indicators to monitor safety culture is a continuous challenge [8]. The aim is to select effective leading indicators that can provide early signs of any deterioration in safety culture.

The IAEA approach to development of safety culture indicators is based on identifying attributes for each dimension of safety culture: accountability for safety is clear, safety is a clear recognised value, safety is integrated into all activities, safety leadership is clear and safety is learning-driven (see Fig. 5). Attributes, indicators and measures are defined for each dimension [8]. However, the approach used is highly structured and top–down and does not allow identification of direct staff involvement in the safety management process. Nor does it allow direct process ownership and empowerment.

The OECD has developed guidance and reports on SPIs for both the process and nuclear industries. The *"OECD Guidance on Safety Performance Indicators"* report [11], produced in the framework of the Inter-Organisation Programme for the Sound Management of Chemicals, was designed to help industrial enterprises, public authorities and communities near hazardous installations to develop and implement means to assess the performance of their chemical safety activities. The report does not provide a precise methodology, but guidance on how to develop and use safety performance indicators that can help to determine whether there are improvements over time. Each organisation should adapt the chosen indicators so that they are consistent with its specific context. In particular, the guidance identifies activities indicators, designed to help show whether the organisation is taking action to lower the risk (usually in the form of a checklist), and outcome indicators, designed to help measure whether such action is in fact leading to real, measurable improvements (e.g. "to what extent have injuries from chemical accidents been reduced as a result of the off-site emergency preparedness plan?"). A presentation of the OECD proposal, with examples of outcome and activities indicators, is given in Table 1. As can be seen, no specific indicators are directly given; instead a framework for developing them is proposed.

As far as nuclear safety is concerned, the OECD NEA report on "*Regulatory Uses of Safety Performance*" [14] provides insights into safety performance indicators for nuclear power plants. The report summarises the approaches of nuclear regulators to SPIs and identifies commonly used indicators. Most countries have established a hierarchy of SPIs that helps to make the process of constructing a system of SPIs more rigorous. The indicators are structured in line with a set of cornerstones of safety performance (see Table 2). It should be noted that the indicators commonly used by regulators seem to be those that are well-established and easy to collect and cover cornerstones such as events, mitigating systems, barriers integrity, workers dose, releases, human performance, compliance with regulations and emergency preparedness. On the other side, there is a set of cornerstones that are not well represented by commonly used indicators. These include material condition and ageing, fire and occupational safety, global plant performance, operational preparedness, licensee self-assessment, operating experience feedback and plant security.

Other performance indicators widely used in the nuclear industry are the set of nine performance indicators proposed by the WANO [15], six of which are specific quantitative indicators, the others being more plant-specific. However, the WANO indicators mainly reflect operational performance and are less directly linked to safety performance.

## 3. A process-view approach to development of safety performance indicators

The methodology proposed has been tailored to the specific needs of a nuclear research organisation. In particular, it stems from the actual difficulties encountered in defining and implementing an effective set of safety culture indicators as part of a programme to enhance safety culture recommended by an IAEA Integrated Safety Assessment of Research Reactor (INSARR) mission. Because the process of developing effective performance indicators is time-consuming, it is not possible to consider the whole system at once. Therefore, the focus will be on specific processes to which the methodology will be applied. In this way it is possible to test the validity and usability of the methodology and, if appropriate, extend it.

The methodology is based on a systematic process-view approach to safety goals. In this context, clear goals are set by committed management and deployed at different levels in the organisation in order to match individual staff responsibilities and behaviour. The challenge posed by the approach is to convert the goals into enabling activities – *enablers* – that should be reflected in individuals' contributions, responsibilities and

Table 1
OECD guidance on safety performance indicators

| Area | Example of sub areas | Example of outcome indicators | Example of activities indicators |
|---|---|---|---|
| Policy and general management of safety | Overall policies | Extent management is involved in safety activities | Is the safety policy conveyed to all relevant stakeholders? |
| | Safety leadership | Extent employees follow established procedures related to safety | Is the management actively committed to and involved in safety activities? |
| | Safety performance review and evaluation | Number of audits and technical reviews completed in relation to the number scheduled | Is there a procedure to communicate the results of audits, inspections and similar activities to the employees? |
| Administrative procedure | Hazard identification and risk assessment | Extent of incidents related to unknown risks (non identified in risk assessment) | Is an incident case history record kept? |
| | Management of changes | Percentage of change requests that are processed as “emergency changes” | Is there a clear definition of change (modification)? |
| Technical issues | Design and engineering | Extent of modifications necessary after performance of risk assessment | Is there a procedure for incorporating general ergonomic and specific man-machine related aspects in design and engineering? |
| | Inherently safer processes | Extent of inherently safer processes (measured by appropriate technical methods) | Are there decision criteria based on a life-cycle concept? |
| External cooperation | Cooperation with public authorities | Reduction in numbers of inquiries form the authorities | Are there well-established and trustful channels for communication with the public authorities, both formal or informal? |
| Emergency preparedness and response | Internal preparedness planning | Number of on-site emergency response exercise per year | Is the on-site plan based on a thorough identification of possible accident scenarios? |
| Accident/near-miss reporting and investigation | Reporting of accidents, near misses and other learning experience | Number of reported incidents | Is there a clear procedure for reporting, with well-defined roles and responsibilities? |
| | Investigations | Extent of incidents that are investigated in accordance with established procedures | Is there a procedure for investigation and analysis of incidents? |
| | Follow up | Number of appearances of the same root cause | Is there a system for follow-up of incident investigations and related recommendations? |

Table 2
OECD SPIs according to safety areas

| Safety cornerstones | Indicators areas | Common indicators |
|---|---|---|
| Reactor safety | Events | Unplanned scrams, safety systems actuations, safety significant reportable events, unplanned power changes |
| | Mitigating systems | Safety system availability, safety system failures |
| | Barriers integrity | Fuel reliability, pressure boundary leak rate, hermetic zone tightness |
| | Materials | – |
| Radiation safety | Occupational radiation safety | Radiation exposure to workers – collective dose |
| | Public radiations safety | Public dose, liquid release, gaseous/air-borne release |
| Industrial safety | Fire safety | – |
| | Occupational safety | – |
| Global plant performance | Not developed | – |
| Safety management/safety related processes | Human performance | Events due to human or organisational failure |
| | Compliance attitude | Number of technical specification deviations, number of technical specification exemptions |
| | Operational preparedness | |
| | Emergency preparedness | Drill participation/training on emergency response |
| | Management of plant modifications | – |
| | Maintenance | – |
| | Self-assessment | – |
| | Operating experience feedback | – |
| | Backlog of safety issues | – |
| Physical protection/security | – | – |
| Investments | – | – |

empowerment. The aim is therefore to develop input/leading indicators to monitor the activities to improve specific safety processes. In this context, the number of indicators should be limited in order to avoid overload, as management could quickly lose interest if too many indicators were used. It is wiser to have a few effective indicators that focus on the main process safety risks or on the areas where the greatest assurance of business risk is needed. The approach in this paper is tailored to applications in hazardous installations other than nuclear power plants, by means of value-focused discussion groups involving staff at different levels within the organisation.

This tailored approach was developed after analysis and comparison of current research activities and proposals on the development of safety culture indicators where the need for a common approach and for validation thereof is acknowledged.

As stated earlier, the difficulty of defining safety culture measurements is generally recognised and has been acknowledged in recent publications concerning studies performed in different fields, such as the chemical industry and maritime transport [4,5]. It is generally recognised that imposition of a fixed set of indicators is unlikely to work because of national, cultural and technical differences. However, it is essential to have a frame that can guide management in developing suitable indicators.

Development of sound safety performance indicators is also important for research reactors, which are key components of the nuclear industry as they provide irradiation services, experiments, training and operating experience vital to developing and sustaining the industry. Research reactors are also vital to international science, research and technological development, in particular in areas such as radioisotopes production or medical and industrial applications. It is therefore very important to keep them safe from both accidents and sabotage, not only as an obligation to prevent adverse consequences for humans and the environment, but also to prevent any concomitant damage to science and industry. In particular, the need to develop indicators relating to organisational and safety culture aspects emerged during discussions with management on the importance of a learning organisation oriented proactively towards improvements [12]. This was coupled with the need felt within the organisation to avoid indicators that could allow easy or convenient conclusions on the safety of the organisation.

To this end, this approach is proposed in order to develop leading indicators to be used as tools for monitoring improvement activities designed to achieve safety goals set at top management level.

### *3.1. Methodology*

A system for reporting safety performance indicators should not rely solely on collection of statistics. It is recognised, especially from experience in other hazardous industries such as oil extraction and chemicals, that statistics are not enough to give an unbiased and true picture of the situation [7]. Statistics on, for example, near misses, relevant incidents, unplanned shutdowns, etc. should be combined with an assessment of safety culture aspects such as accountability for safety, communication, integration of safety into all activities, open-door policy, trust, management commitment and learning attitudes. In this context, social sciences methods can help, such as questionnaires, interviews, accident investigations and focus groups.

Designing a system of safety performance indicators for hazardous installations is very complex and may become unfeasible if there is no systematic process view geared to safety goals and in the case of organisations with limited resources. In general, indicators, targets and objectives make sense if defined in a context of process management, such as safety management.

Clear goals need to be set by committed management and the goals need to be deployed by means of enabling activities which can be reflected as much as possible in individual contributions, responsibilities and recognition.

In this context, a few explicit key goals must be found. The set of activities which lead to achievement of the goals, called *enablers,* have to be defined in a clear cause-effect relationship. Each *enabler* needs to be broken down into basic activities. It is practical and commonly accepted to limit the "deployment of goals" to the third level. Third-level deployment implies a strong link between objectives and individual behaviour which has to be defined as part of the job description of the individual. Only in this case can effective indicators be defined. The concept is presented in Fig. 6.

*Enablers* are concerned with *what* is done and *how*. Results are concerned with *what* is achieved. In total quality management (TQM), leading indicators connected to enabling activities are used systematically in order to achieve desired results. Indicators related to the first level are output/lagging indicators for the process that is being monitored, while indicators at the second and third levels are input/leading indicators designed to improve the process. Frequency of collection and analysis of individual indicators at different levels need to be diversified and tailored to the process.

At the first level, contrary to standard NPP practice where indicators are collected quarterly or monthly [10], in small hazardous installations such as research reactors indicators are normally collected once a year to monitor trends in performance over the past. They are used by organisations for reporting purposes and for analysing trends from previous years.

At the second and third levels collection and analysis are progressively more frequent. Activity indicators at the third level normally require monthly collection and analysis. This is feasible since the activities at the third level reflect the input of one or just a few individuals. The activities related to the leading indicators need to be built into the various job descriptions. Most of the information may even be available as a running chart, which is precisely what is required for process control.

The strategic goal of hazardous installations is to minimise accidents and risks. This can be broken down into different fundamental goals, such as prevention of accidents. This in turn is reflected by various leading indicators, for example the number of near misses, number of inspections, etc.

### *3.2. Aggregation of performance monitoring*

Aggregation is a means of combining lower-level indicators, thus allowing the management to evaluate and compare higher-level indicators [16].

In the specific methodology presented, performance is monitored at different levels and aggregation can be performed at *activity level,* at *enablers level* or at *goal level.* However defined, the performance indicators of the various activities ($\mathrm{PIA}_i$) contributing to a particular enabler ($E_j$) are aggregated by weighted summation, in order to obtain a numerical value $\mathrm{PIE}_j$:

$$\mathrm{PIE}_j = \sum_i \mathrm{PIA}_i \times \mathrm{WA}_i,$$

where $\mathrm{WA}_i$ are weighting factors defined by an elicitation process that may involve different representatives within the organisation. Participation could also be extended to the regulatory body to guarantee unbiased judgment and foster open communication. For some performance indicators a minimum

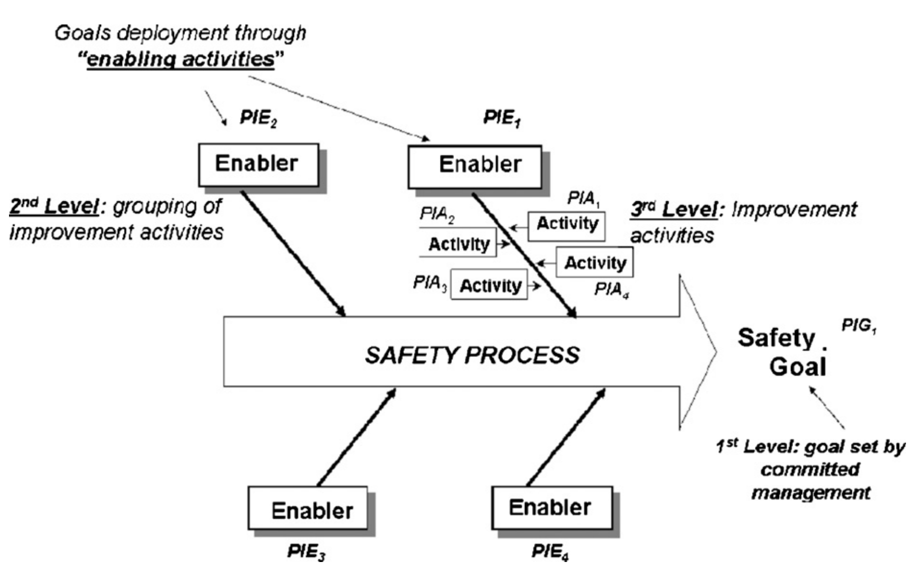


Fig. 6. Safety goals deployment into enablers and activities.

level of acceptability may be established. Non-numerical values are converted into numerical values, also by an elicitation process [12].

The same aggregation process is envisaged for obtaining the performance indicator connected to the goal ($PIG_j$):

$$PIG_j = \sum_i PIG_i \times WG_i$$

where $WG_i$ are once again weighting factors pre-defined by an elicitation process (see Fig. 6).

## 4. Deployment of the methodology

It is acknowledged that the top management sets the strategic goals. On the other hand, direct participation by staff involved is recognised as a good way systematically to find out enablers, activities and indicators. In particular, structured brainstorming, via focus groups with staff members, is recognised as a viable way to identify effective indicators. The concept of staff involvement in defining the processes to achieve goals is referred to as strategy deployment.

The first process addressed by focus groups was learning and safety awareness. The brainstorming sessions brought together cross-functional groups of employees with the purpose of collecting ideas on how and what they would do to contribute to this goal. During the sessions, creativity needs to be stimulated: this can be achieved by using safety dilemmas to help people think and participate actively.

### *4.1. Brainstorming: defocusing phase*

At this stage staff are free to suggest and propose whatever they think. Inputs are then recorded. Most of the ideas proposed are relevant and represent what staff believe they or others can do to achieve the goal. In general, people tend to be very practical about what to measure, reflecting their daily tasks. An overview of the contributions collected during the focus group on learning and safety awareness is presented in Table 3.

Table 3
Brainstorming results: learning and safety awareness

| | |
|---|---|
| Potential activities | Manage discussion groups on safety issues |
| | Launch discussion on root cause analysis findings |
| | Promote job rotation |
| | Encourage near miss reporting |
| | Lead improvement teams |
| | Foster knowledge preservation |
| | Encourage respect |
| | Walk around |

The brainstorming phase provides a host of ideas and information directly related to what the personnel believe. They tend to be practical about the measure they propose and to link it to their daily activities.

### *4.2. Focusing phase*

Next comes the focusing phase in which management involvement is required and commitment from top management is essential. Fig. 7 gives an example of the possible form which Table 3 could take within a process view.

The difficulty with identification of effective safety culture measurements is that more than one indicator is needed to define the effectiveness, in general qualitative indicators, and the efficiency, in general a quantitative indicator, of an activity at the second and third levels in the proposed approach. As an example, the activity "perform root cause analysis (RCA)" cannot be represented by the number of RCA initiated. Another measure should be added, for example the number of discussions organised with employees on RCA findings. This also serves as a reminder of the importance of adapting and tailoring a specific

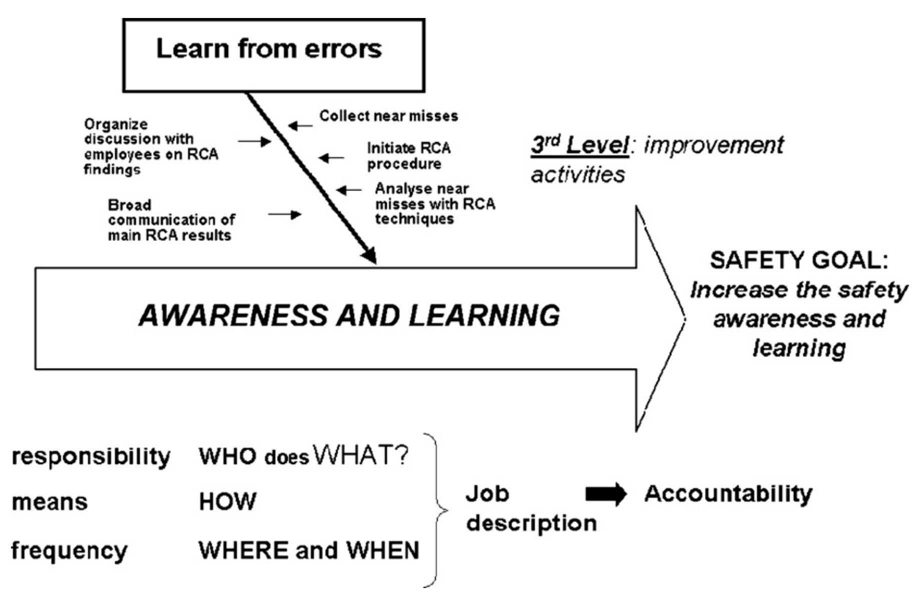


Fig. 7. Safety goals deployment into enablers and activities: example for "*Learning and Awareness*".

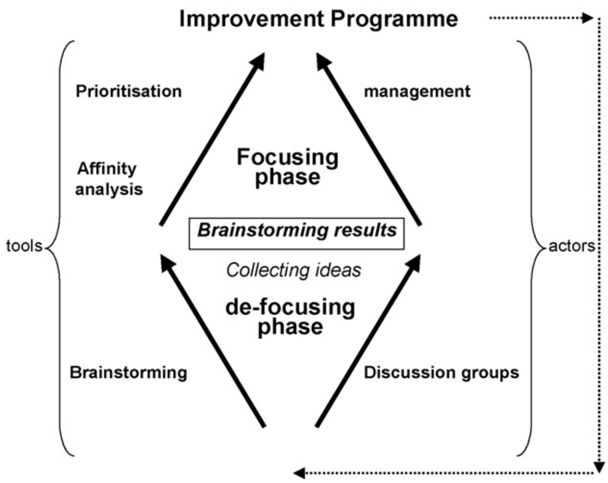


Fig. 8. Schematic view of the process.

approach to each organisation, as each has its own national and organisational culture.

If the process is well designed, the activities selected are the ones that, if targeted, lead to the stated goal. It is evident from the example in Fig. 7 that leading indicators have to be found in order to quantify and qualify the efficiency and effectiveness of the various input activities. A new series of improvement activities are then defined, e.g. collection of near misses, initiation of RCA, organisation of discussions with employees on RCA, broad communication of main RCA results. According to the defined activities, suitable performance indicators can be identified.

It is important clearly to identify the persons responsible for the various activities (*who* does *what*) or to define such responsibilities in the job definition of staff/management. Consequently, the person responsible for the activities becomes the key source of data for the measurement matrix and has to think of his/her own way to carry out the activity together with and complementary to various other tasks related to the job. At this stage the person responsible can indicate and define the easiest way to supply meaningful data, that is to say *how* to measure and *where/when* the indicator can most conveniently be found and supplied. It is important to rely on a simple but robust data collection and storage system; the integrity of the database must also be assured. An overview of the process is given in Fig. 8.

The system allows target-setting on certain critical leading indicators and, if required, leverage can be obtained at any time by raising some relevant targets.

### 4.3. Improvement programme

The methodology presented aims at defining a three-level approach to evaluate the effectiveness of safety processes. This approach allows improvement programmes at different levels. One critical feature is identification of leverage activities on which to focus for improvements in processes.

The methodology is based on a bottom-up approach; it starts with definition of clear safety goals by top management, but also involves personnel in defining the activities related to processes. This approach complements the top–down approaches fostered by the IAEA and OECD, which are very useful for structuring the problem. However, it is beyond their scope to give clear guidelines and suggestions on how to involve staff directly. In this respect, the approach proposed enhances staff awareness of individual tasks and establishes clear channels and processes of communication. The approach proposed has two important features: a participatory problem-solving process implemented by means of focus group discussions and a more explicit culture change process that stems directly from the problem-solving process and is structured around dissemination of information on the problems identified and the remedies chosen to address them. The culture change process seeks to produce changes at leadership level. Therefore, the proposed approach reflects an integrative approach to safety management proposed by some authors [1] where behavioural and organisational approaches are combined into an integrative approach to safety. The approach is in line and consistent with the safety culture dimensions proposed by the IAEA: accountability for safety is clearly defined by means of individual ownership of the activities involved in the safety process; safety is integrated into the activities of the staff; communication is enhanced by focus group discussions and clear job definitions; and the learning process is guaranteed since processes are discussed and feedback used.

The methodology presented is not abstract, but involves personnel directly in the form of discussions, participation in achieving safety goals and direct responsibility and accountability for monitoring and measuring improvements.

## 5. Conclusions

This article has presented an overview of approaches to developing safety performance indicators. SPIs are plant-specific; therefore each plant has to determine which indicators best serve its needs. Moreover, experience has shown that focusing on any single aspect of performance can be ineffective and misleading. A complete set of indicators is needed to monitor every aspect of operational safety since any individual indicator may be of no significance if treated in isolation. The most widely used lagging indicators are radiation doses, lost work rates, number and severity of events and number of automatic trips. These are in line with those proposed by the IAEA and OECD. However, development of leading indicators linked to human and organisational factors has been recognised as indispensable for improving safety, acknowledging a shift of the safety paradigm from a technical focus to a focus on the organisation as a whole.

In this context, the aim of this article was to address the need to monitor and assess progress on implementation of a programme to enhance safety and organisational culture. It proposed a specific process-view approach for effectiveness evaluation of organisational and safety culture indicators by means of a multi-level system deployed at a research reactor. This approach can be of help to other hazardous installations that, like research reactors, have limited resources and time constraints.

The proposed method of evaluation focuses on involving staff in defining activities which are important to deployment of safety processes. First of all personnel need to be involved in focus group discussions to identify activities which could be important for achieving specific safety goals. Then members of staff are made responsible for specific activities, thus guaranteeing their motivation and commitment plus inclusion of safety in their "daily" tasks. This approach enhances staff awareness of their tasks and creates clear channels and processes of communication. The approach proposed is in line with the commonly identified safety culture dimensions proposed by the IAEA: accountability for safety is clearly defined by means of individual ownership of the activities involved in the safety process; safety is integrated into the activities of the staff; communication is enhanced by focus group discussions and clear job definitions; and the learning process is guaranteed since processes are discussed and feedback used. Moreover, the approach proposed offers a series of advantages such as enhancement of communication via focus groups, clear accountability for safety by means of direct involvement of each individual in specific safety processes, and empowerment and motivation since each individual feels part of the process by virtue of the feeling of belonging to the organisation. All key personnel are involved in identifying and supplying leading indicators relating to their own daily activity and are responsible and accountable for keeping the measurement matrix alive.

The approach proposed is non-abstract in that it involves personnel directly, by means of discussion, in achieving goals and ensures responsibility and accountability for the activities and for measuring them.

## Acknowledgments

We wish to thank all the personnel of the installation taking part in the improvement process who have contributed with motivation and enthusiasm to the implementation of the safety culture enhancement programme.

## References

[1] D.M. DeJoy, Behaviour change versus culture change: divergent approaches to managing workplace safety, Saf. Sci. 43 (2005) 105–129.
[2] A. Mengolini, Y. Dien, S. Pierlot, Safety culture and organisational factors in accident analysis, in: Proceedings of the Seminar, Petten, NL, 14 October 2005, EUR 22148 EN (2006).
[3] L. Mampaey, Meeting the energy challenge for the environment: the role of safety, Nucl. Eng. Des. 236 (2006).
[4] M. Maroño, J.A. Pena, J. Santamaria, The "PROCESO" index: a new methodology for the evaluation of operational safety in the chemical industry, Reliab. Eng. Syst. Saf. 91 (2006) 349–361.
[5] J.R.W. Merrick, M. Grabowski, P. Ayyalasomayajula, J.R. Harrald, Understanding organisational safety using value-focused thinking, Risk Anal. 25 (4) (2005).
[6] C. Olive, T.M. O'Connor, M.S. Mannan, Relationship of safety culture and process safety, J. Hazard. Mater. 130 (2006) 133–140.
[7] J.E. Vinnem, T. Aven, T. Husebø, J. Seljelid, O.J. Tveit, Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector, Reliab. Eng. Syst. Saf. 91 (2006) 778–791.
[8] O. Svenson, I. Salo, P. Oedewald, T. Reiman, A.B. Skjerve (Eds.), Nordic perspectives on safety management in high reliability organizations: Theory and applications. Stockholm, Akademitryck, Valdemarsvik, (2005).
[9] International Atomic Energy Agency. Operational safety performance indicators of nuclear power plants. IAEA-TECDOC-1141 (2000).
[10] N. Saqib, M.T. Siddiqi, Thresholds and goals for safety performance indicators for nuclear power plants, Reliab. Eng. Syst. Saf. 87 (2005) 275–286.
[11] Organization for Economic Cooperation and Development. OECD guidance on safety performance indicators. Series on chemical accidents No. 11, 2003.
[12] A. Mengolini, L. Debarberis, Safety culture enhancement through the implementation of IAEA guidelines, Reliab. Eng. Syst. Saf. 92 (2007) 520–529.
[13] J. Reason, Human Error, Cambridge University Press, 1990.
[14] Organization for Economic Cooperation and Development, Regulatory uses of safety performance indicators. NEA/CNRA/R (2006) 1.
[15] World Association of Nuclear Operators, Performance indicators (2005).
[16] N. Saqib, M.T. Siddiqi, Aggregation of safety performance indicators to higher-level indicators, Reliab. Eng. Syst. Saf. 93 (2008) 307–315.