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Trending of low level events and near misses to enhance safety performance in nuclear power plants

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International Atomic Energy Agency

November 2005

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FOREWORD

The IAEA Safety Fundamentals publication, Safety of Nuclear Installations, Safety Series No. 110, states the need for operating organizations to establish a programme for the collection and analysis of operating experience in nuclear power plants. Such a programme ensures that operating experience is analysed, events important to safety are reviewed in depth, and lessons learned are disseminated to the staff of the organization and to relevant national and international organizations.

As a result of the effort to enhance safety in operating organizations, incidents are progressively decreasing in number and significance. This means that in accordance with international reporting requirements the amount of collected data becomes less sufficient to draw meaningful statistical conclusions. This is where the collection and trend analysis of low level events and near misses can prove to be very useful. These trends can show which of the safety barriers are weak or failing more frequently. Evaluation and trending of low level events and near misses will help to prevent major incidents because latent weaknesses have been identified and corrective actions taken to prevent recurrence. This leads to improved safety and production.

Low level events and near misses, which may reach several thousand per reactor operating year, need to be treated by the organizations as learning opportunities. A system for capturing these low level events and near misses truly needs to be an organization-wide system in which all levels of the organization, including contractors, participate.

It is desirable that the overall operational experience feedback (OEF) process should integrate the lessons learned and the associated data from significant events with those of lower level events and near misses. To be able to effectively implement a process dealing with low level events and near misses, it is necessary that the organization have a well established OEF process for significant events.

The IAEA wishes to thank all participants and their Member States for their valuable contributions. The IAEA officer responsible for the preparation of this publication was H. Werdine of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. Overview

It is well recognized that organizational factors have a major impact on the behaviour of individuals and therefore on their performance in safety issues. Human errors are therefore an indicator of the performance of an organization. Since most of the near misses and many of the low level events are caused by human errors, they are a very valuable source for the evaluation of organizational performance. A trend of the number of low level events may be used as an indicator for the early detection of a change in organizational performance.

This publication is intended to complement the IAEA Safety Fundamentals on the safety of nuclear installations [1] and other IAEA publications which address the improvement of the safety performance of nuclear power plants [2–17]. It illustrates the advantages of using the operating experience with low level events and near misses for the identification and prevention at an early stage of degraded plant performance.

1.2. Objective

The objective of this publication is to provide guidance for the enhancement of operational safety performance through the use of the low level events and near misses as an important input to the operational experience feedback (OEF) process. In addition to improving operational safety performance, the same methods can be applied to advance the overall performance of the plant and organization.

This guidance is provided to assist organizations in how to deal with these types of events — not only to investigate individual items separately, but to perform a total assessment. This assessment should include trend analysis to assist organizations in the prevention of declining safety performance.

1.3. Scope

This publication is intended to aid organizations in collecting, evaluating and trending low level events and near misses. This information can be used for establishing and/or enhancing their current system of operating experience evaluation regarding these events. In addition, this publication can be used as a reference for regulators.

1.4. Structure

This publication contains eight sections and six appendices. The operating organization, and the policies and knowledge necessary for an efficient use of information derived from low level events and near misses are discussed in Section 2. Additional information on detecting and reporting criteria on low level events and near misses is given in Section 3. Section 4 presents the process of using operating experience feedback for systematically addressing low level events and near misses. Section 5 addresses indicators, followed by internal and external lessons learned in Section 6. The need to verify programme effectiveness is addressed in Section 7, which also highlights the need and possibilities for conducting self-assessments and independent reviews of the OEF process. Conclusions for this publication are provided in Section 8.

2. ORGANIZATION AND POLICIES

2.1. Organization

The OEF process, which should include the low level events and near misses, should have a structure and organization in which functions and responsibilities are clearly defined. Human and financial resources should be adequate. Tools and equipment should be user friendly and should allow the organization to process and analyse a possible high number of reports and present results in a proper manner.

2.2. Policies and guidance

The OEF process that includes low level events and near misses should take into account the national legislation, regulatory requirements and good national and international practices. The regulatory requirements should be regarded as minimum criteria.

A clear policy should commit staff and management to an ongoing effective prevention of events. Written guidance should exist to document the process, e.g., how internal event information, including low level events and near misses, is processed and staff is informed of trends and associated corrective actions. The formal integration of the OEF process into the organization should be clear, and formal communication links should exist with internal and external organizations.

2.3. Knowledge and skills

The OEF process staff should be sufficient in number, experienced, well qualified and capable of effectively performing associated activities. Qualification should include excellent knowledge of the plant (components and systems). These qualifications should also include training in the OEF process, analysis of data from low level events and near misses, principles of safety culture, human and organizational factors and root cause analysis.

The use of a permanent or temporary multidisciplinary group of personnel should be considered in composing the OEF group. In this case, professionals from different areas are qualified to investigate and derive results from reported low level events and near misses.

The staff of the organization, mainly operators and maintenance and technical support (e.g. engineering, chemistry and radiation protection) personnel, should possess the knowledge and skills required to identify and report low level events and near misses but also to understand the benefit provided to the organization when the results of trends are acted upon.

3. DETECTION OF LOW LEVEL EVENTS AND NEAR MISSES

3.1. Reporting threshold

Today, the nuclear industry is striving to collect more information on occurrences that could improve operational safety performance. To achieve this, the reporting threshold should be lowered from incidents to anomalies with minor or no impact on safety. This will provide an insight on precursors, which are near misses or low level events that provide information for determining advance warnings or an increased probability of a significant event.

Experience has shown that a relationship exists between those events affecting nuclear safety, performance, reliability, and individual events that have no significant impact on performance. This relationship is demonstrated in Fig. 1 and is often confirmed following the evaluation of individual events at a plant.

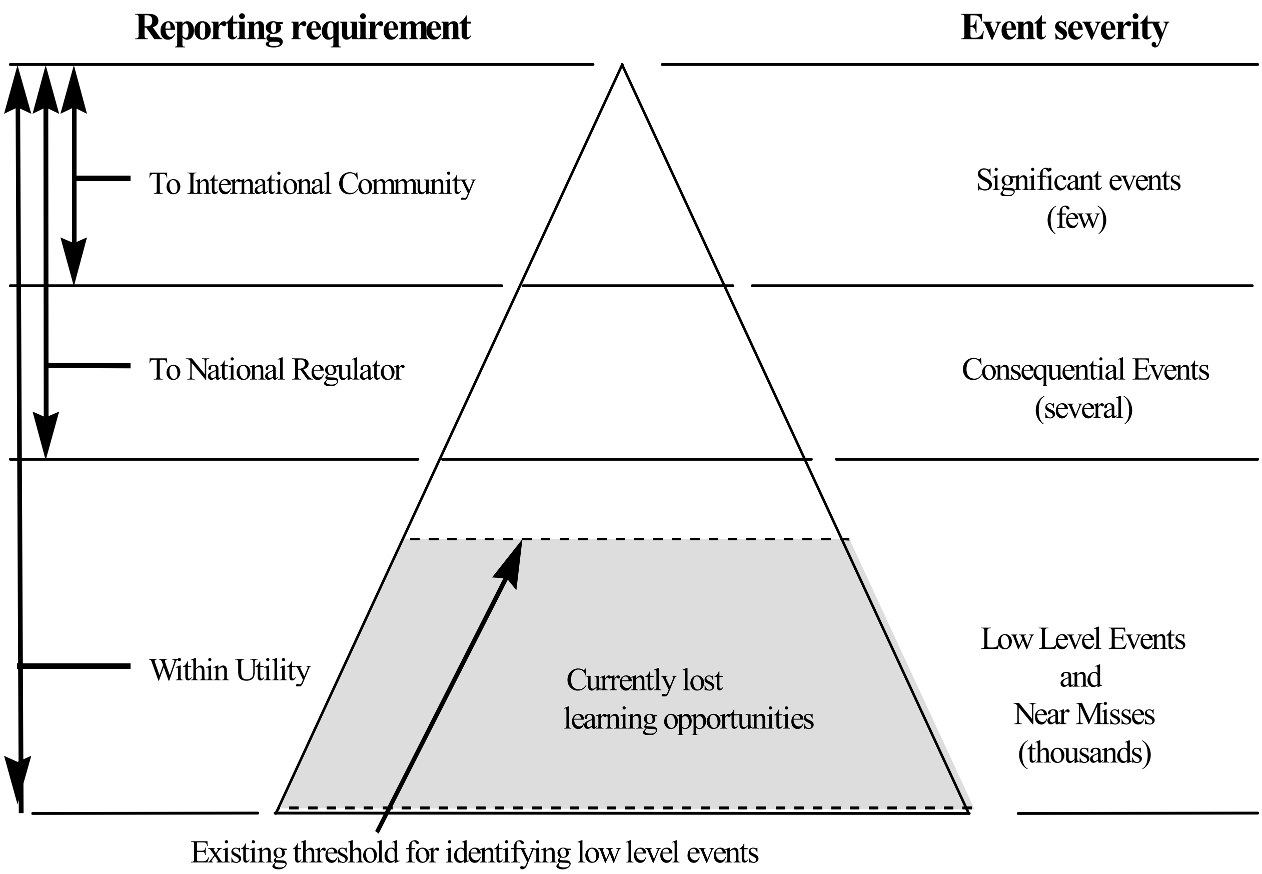

FIG. 1. Relationship between events that affect nuclear safety and other, less significant events.

In addition to showing event severity, Fig. 1 illustrates reporting requirements. The figure also shows an existing threshold for identifying low level events and near misses. The events below this threshold can be viewed as currently lost learning opportunities.

To better identify the threshold between significant events and low level events and near misses, Fig. 2 illustrates the relation between an identified deficiency and its consequence.

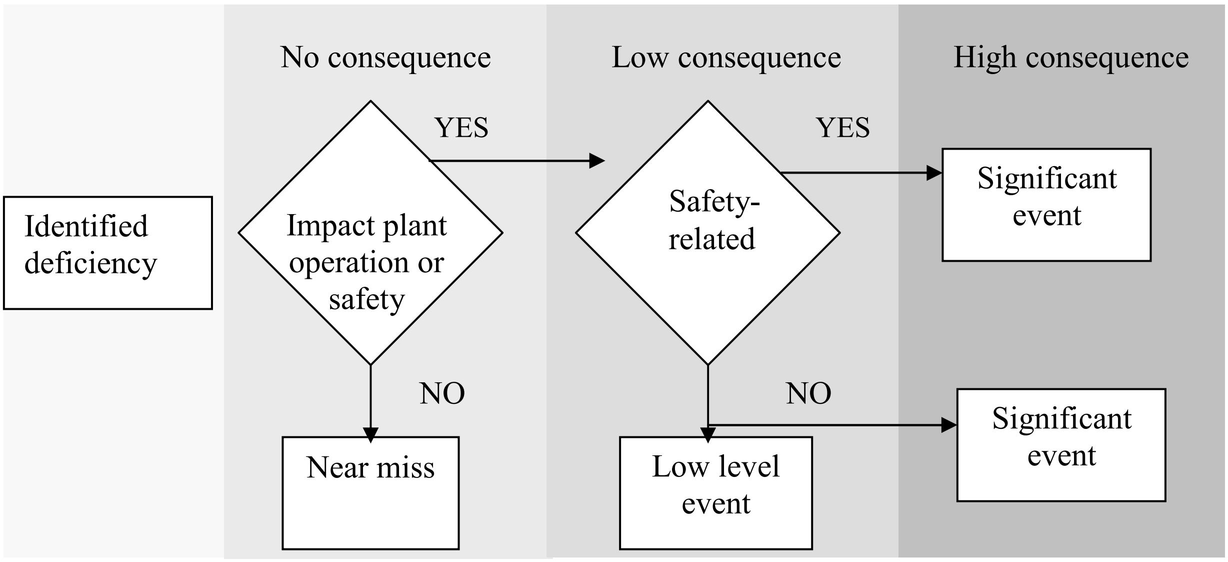

FIG. 2. Relationship between near misses, low level and significant events.

3.2. Strong reporting culture

It is generally agreed that an essential element of the safe operation of nuclear power plants is having a strong and continuously improving safety culture. The IAEA's INSAG series publications on Safety Culture [10], Defence in Depth in Nuclear Safety [11], Basic Safety Principles for Nuclear Power Plants [12], Management of Operational Safety in Nuclear Power Plants [13] and Key Practical Issues in Strengthening Safety Culture [14] provide discussions of the universal features and tangible evidence of a strong safety culture.

Those organizations that recognize the need for a strong safety culture and continually strive to improve will generally find and correct their problems before they develop into serious performance issues. However, it remains a difficult task to recognize, evaluate and correct low level events or deficiencies before they deteriorate safety performance.

The management of a nuclear power plant should establish a policy and reinforce a culture of open communication between management and plant staff. This policy should encourage staff to continuously look for ways to minimize human error and improve the quality of work and plant performance. Open communication means that problems are brought to light and are not minimized. In order to make this possible, an atmosphere of mutual trust and confidence shall be established, maintained and supported by a blame- and sanction-free culture.

In order to become proactive and maintain control of emerging problems, management must be aware of what problems are developing. Management involvement should be visible, and cannot stop at the identification of problems, even if minor. Only then will emergent problems be anticipated and thus prevented by systematically examining trends and symptoms.

Management should be self-critical, should encourage individuals to deal with problems immediately and should create an environment which is supportive for individuals to voluntarily report omissions or mistakes.

Management should routinely carry out monitoring, control and performance assessment through a number of activities, including walking around the plant and observing the work done, being visible, available, listening, and acting on employee suggestions and complaints.

3.3. Motivating people to report

In the environment of a continuously improving safety culture, low level events, small degradations and near misses are discovered and reported by all organization personnel. Plant staff should understand and believe that the self-reporting of errors will not have negative consequences for the reporting person, that the information gained will never be misused for, e.g. the assessment of individuals, and that no punitive action will be taken where there was no violation or malevolent interest.

Often, human errors are immediately corrected by the person who has committed the error. Therefore these errors may no longer be accessible for analysis if they are not reported, and a wealth of information is lost.

There are two major advantages in using this information:

- Since nothing serious has happened in a near miss or a low level event, a free discussion about the origin of the error is possible.

- The person who has committed the error may have knowledge about the causal factors.

4. SYSTEMATIC APPROACH TO USING VALUABLE DATA FROM LOW LEVEL EVENTS AND NEAR MISSES

A systematic approach to the use of information on low level events and near misses is required to ensure consistent improvement in operational safety and overall performance. Application of this approach involves the processing of an increased number of reported events, which includes coding and trending of data generated by the analysis of low level events and near misses (e.g., situational context, causes, consequences, means of detection). This analysis allows for the validation of potential trends with common characteristics and/or underlying organizational weaknesses (see Fig. 3).

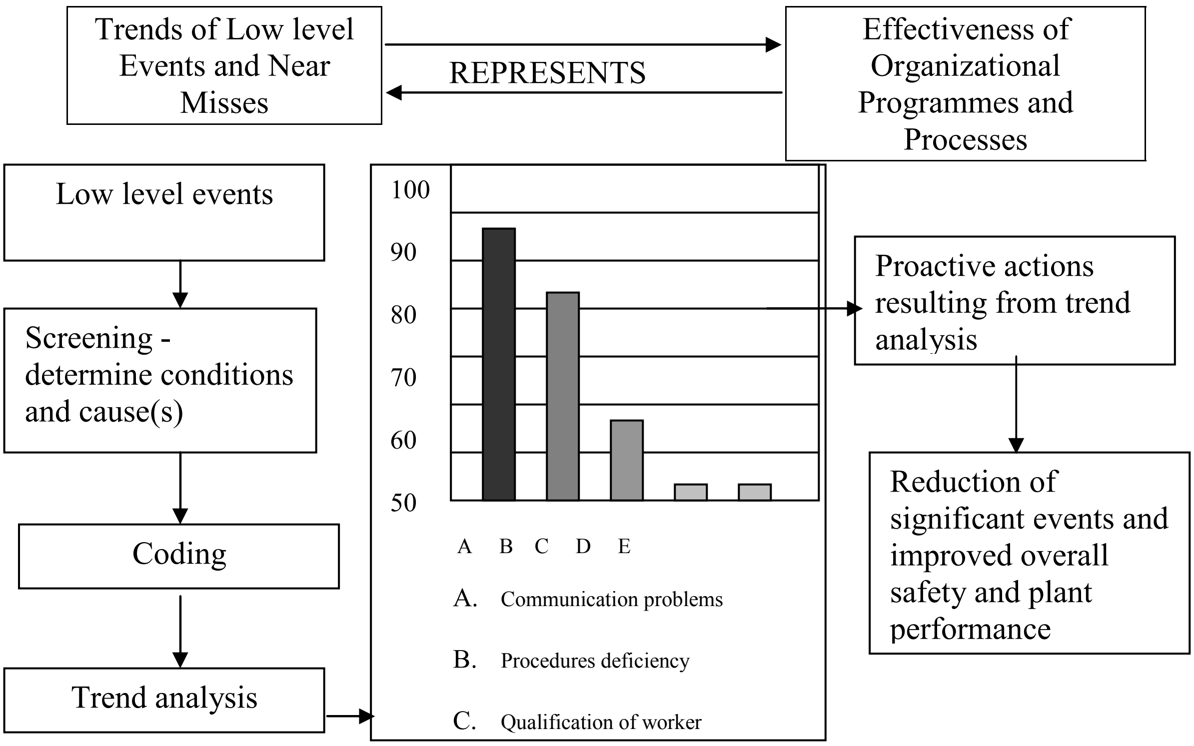

FIG. 3. Demonstration of the use of low level event and near miss data to improve the organization through reduction of significant events and improved plant performance.

4.1. Preliminary analysis and screening

Screening of event information is undertaken to ensure that all significant safety relevant matters are considered and that all applicable lessons learned are taken into account. Not all events require a full root cause analysis. For low level events and near misses, categorization (coding) of the events should be completed by a designated experienced person, without a need for in-depth analysis. The screening process should select events for further detailed investigation and analysis. This should include prioritization according to safety significance, and recognition of adverse trends. Only in the case of more significant or complicated events is additional analysis and detailed investigation necessary.

Due to the fact that many of the basic causes of events contain an element of human factor issues, event information should be collected and acted upon in a timely manner. The quality of screening depends on the use of highly experienced and knowledgeable personnel, including those with a specific knowledge of human performance and individual and organizational behaviours. Individuals without the appropriate knowledge and skills might render the data unusable or cause corrective actions to be developed for problems that may not exist.

4.2. Event processing and coding

All events, independent of their consequences, should be coded and collected in the event database. In order to deal efficiently with a large number of events, the event information should be properly assessed and coded to include important facts from the event (status of the plant, date, time, involved equipment and persons) and information about the causes of the event. One possible, widely used coding system based on event causes is described in Appendix III.

The coding of events, i.e. giving the correct attributes (codes) to each event record, is an essential part of the information flow, since this step reduces the event information to the few essential characteristics that are used for further analysis. Proper coding is the basis for a valuable set of data. This structured information is fed into the event database, which simplifies further analysis.

The main point of using codes for trending is to allow for the identification of specific aspects on which the organization could act. Evaluating low level events and near misses for organizational factors and then applying organizational factor codes allows for the detection of organizational weaknesses through adverse trends.

Special attention should be given to ensure that events are coded consistently by different individuals; this is known as rater reliability. Good rater reliability will minimize variation within the data and help to provide valid analyses and appropriately focused corrective actions.

4.3. Data collection system

The operational experience database should include information based on accessible sources.

The following guidance is given to develop a structure of information sources for low level events and near misses: Data collection should include all deficiencies and/or events, including the related organizational and human factor issues. Equipment failures and other such deficiencies may also be reported in other systems, such as a work management system for maintenance. If they are reported in another system, these systems should be linked together. For example, the OEF database could have related fields that reference other data collection systems. All data collection systems within the plant should use a consistent set of codes. Additional qualities of a good data collection system are described in Appendix IV.

4.3.1. Possible sources of information for the data collection system

Typical examples of sources of information from internal operating experiences are:

- safety indicators, when providing information on trends;
- reports and data from operation, maintenance, testing, quality assurance, etc.;
- material conditions resulting in component failure rates;

- human performance issues leading to personnel errors, management and organizational errors;

- results from plant specific safety assessments (like PSAs);

- trend analysis of selected items based on plant specific experience.

Typical examples of sources of information from external operating experiences are:

- event reports provided by other plants in the same country, from countries with plants that have the same vendor, and at international levels from organizations such as the World Association of Nuclear Operators (WANO);

- experiences of other utilities with their safety programmes (e.g. quality assurance, ageing, surveillance);

- research results that are directly applicable to resolve safety issues.

4.4. Trend analysis process

It is important to identify trends (improving, declining or stagnant) in plant performance and other areas that may not be apparent to the day-to-day observer. Therefore, data should be analysed periodically to identify adverse trends. Trending facilitates correction of minor problems in aggregate through the identification of issues or problem areas.

Trending is a process used to identify degrading conditions on the basis of the analysis of past plant events and near misses (precursors). The goal of any trending programme should be to identify an abnormal trend early enough so that the organization can take the appropriate action to prevent additional related events. The initial evaluation should determine whether a special cause or a common cause for the adverse trend exists.

A special cause might be a change to an existing programme or process that results in increased awareness or attention. For example, if an organization has added ‘change management’ as a cause code to the trending programme and made everyone aware of the new code, this may cause many of the departments to now code the low level events as being caused by change management.

This new level of organization awareness may be a special cause for an increase in change management issues and may not reflect the real cause of the events. If the trend is evaluated to determine if a common cause exists, and a common cause is identified, then an investigation is conducted to determine the root or direct causes and establish corrective actions to prevent related events.

Corrective actions that address identified weaknesses should be specified and implemented through the corrective action programme. Industry experience indicates that trending of event information in this manner makes full use of investigation information and can provide useful indications of the inherent safety culture for line managers. One example is that an organization will trend the event causal factors derived from apparent and/or root cause analysis for the last three months to determine any common causes for the events. If common causes are identified, an in-depth analysis will be conducted to determine the root cause.

A single low level event or near miss is not safety significant. An accumulation of low level events in the same area or with a similar pattern, however, may indicate a lack of or a failure in a programme. While the event itself is insignificant, the deficiency in the programme in question may be a more serious issue, which has to be analysed and corrected. Such a failure would not be detected by single low level events; only the accumulation and/or a trend may indicate a need for appropriate action. An effective process must have management involvement and be proactive instead of reactive in nature.

4.4.1. Trend analysis techniques

The organization can accomplish additional analysis by correlating data and identifying a clustering of certain causes, consequences and detection mechanisms (see Fig. 3) in the different areas. Declining trends indicate that there might be a generic problem that has not been detected. One effective tool to support trend analysis is the barrier analysis technique. Appendix V contains several techniques for analysing data, such as Pareto analysis, Pareto charting, confidence factors and control charts. These techniques are not only available methods, but represent proven techniques for analysing data. The mathematical formulas presented might be too stringent and limiting, depending on the circumstances of the trend analyses. Trend analysts are encouraged to discuss and verify any questionable or doubtful trend results and conclusions with the appropriate knowledgeable parties. This discussion may identify any special causes or contributors. The results of such an analysis are:

- on a physical barrier level: the identification of failed or missing barriers that were not recognized as important in the analysis of individual events;

- on an organization or management level: the identification of a lack of a generic programme or the absence of a programme that systematically maintains the installed barriers in a good and effective condition.

Basically a trend analysis shows the strength of the concept of defence in depth, and the care that is taken to keep the concept of defence in depth effective. The following information is useful for trending:

- the means and the persons through which latent failures were detected (this allows the identification of groups of persons who are specifically sensitive to certain types of failures, and the identification of effective detection means) [18];

- steps in the work process (this may give an indication of steps in the work process that need a better surveillance or pre-job briefing) [19]; and

- information related to organizational factors that may be specific to the plant and that may not be listed in the coding list in Appendix III.

Appendix I contains case studies of the evaluation of operating experience illustrating the necessity and usefulness of total impact assessment. One important step is the application of an appropriate trending programme. One example of such a trending programme including a categorization system is given in Appendix III, illustrated with examples of low level events and near misses.

Corrective actions resulting from event analysis[1] and trending should be defined and implemented, and should address not only the specific causes of particular events but also common problems identified by trend analysis. The final stage of any OEF process should be assessment of the corrective actions' effectiveness, which is done in accordance with established criteria. Recurrence of events is an important indicator in the evaluation of the OEF process effectiveness.

Figure 4 provides detailed guidance for the screening, investigation and trend review necessary for a comprehensive process dealing with the information captured through the operating experience feedback programme.

4.5. Cause analysis

The screening process determines events that need a deeper analysis. The IAEA Safety Requirements for the operation of nuclear power plants [2] state in para. 2.21 that "Operating experience at the plant shall be evaluated in a systematic way. Abnormal events with significant safety implications shall be investigated to establish the direct and root causes. The investigation shall, where appropriate, result in clear recommendations to the plant management, which shall take appropriate corrective action without undue delay. Information resulting from such evaluations and investigations shall be fed back to the plant personnel." Effective event analysis results in the determination of causes and failed barriers. There are many well known methods for the analysis of determining the causes of an event. The following paragraphs provide short descriptions of some of these methods.

The analysis of any event should be performed by an appropriate method. It is common practice that organizations regularly involved in the evaluation process use standard methods to achieve a consistent approach for the assessment of all events. These standard methods normally make use of different techniques. Each technique may have its particular advantages for cause analysis, depending on the type of failure or error. Therefore, it is not possible to recommend any single technique. The use of one or a combination of techniques in event analysis should ensure identification of the relevant causes and contributing factors[2] which aid in the development of effective corrective actions.

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[1] Event analysis is the process that is used to identify the root causes and contributing factors. It is an analysis of an event or condition to determine what events and conditions led to the outcome, as well as a determination of how to prevent an undesired outcome and obtain the desired result.

[2] A contributing factor is an event or condition that is not directly responsible for the problem but whose existence has complicated the problem or made the consequences more severe than if only the root cause had existed.

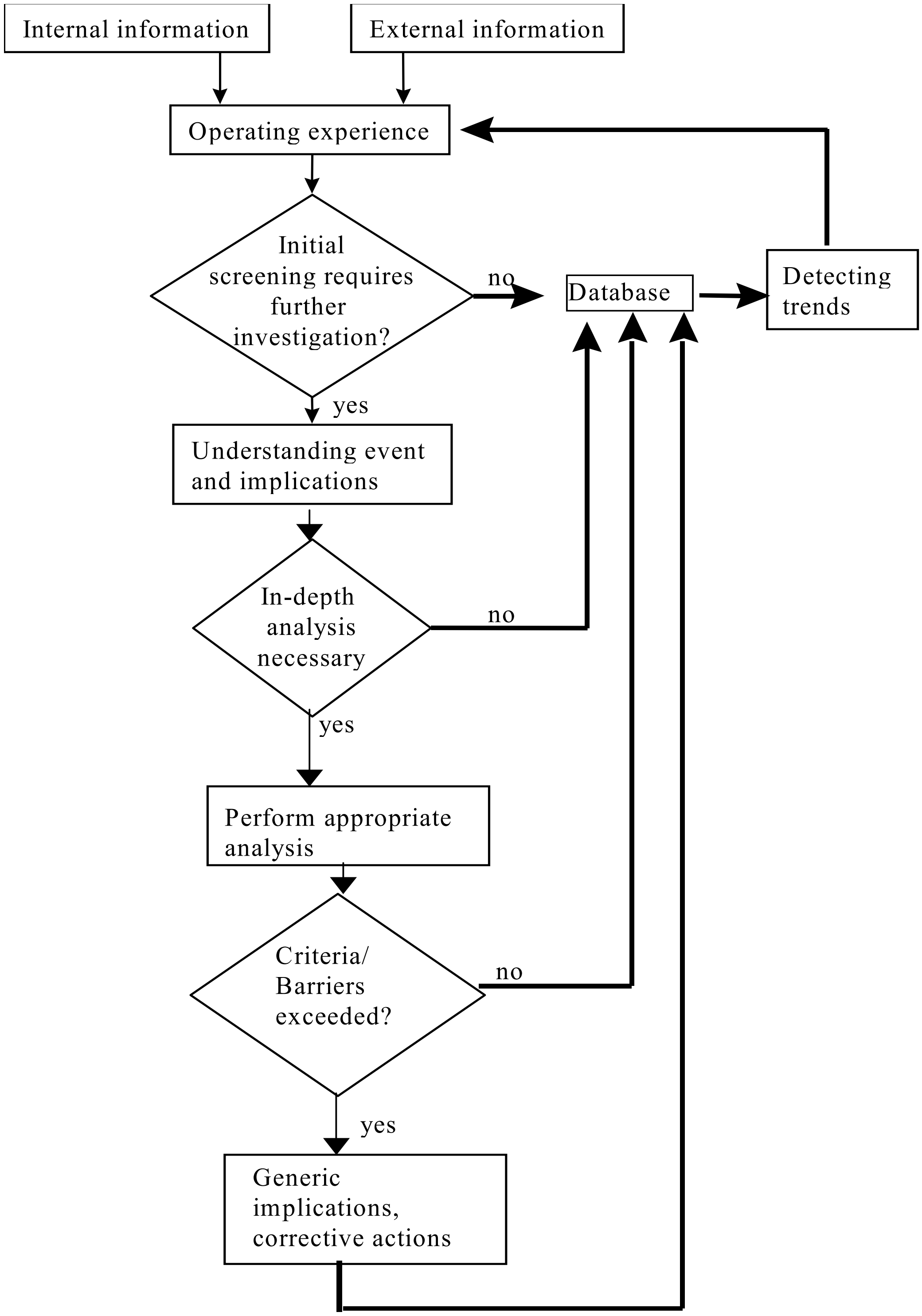

FIG. 4. Assessment of information on operating experience.

4.5.1. Cause and effect analysis

This method of event analysis is performed by describing the problem, asking the question "why?" and asking the question again of each successive answer until the question can no longer be answered meaningfully (endpoints are reached). Using cause and effect analysis, broken barriers are identified and analysed. If displayed in a flow chart, the results proceed from right to left in reverse chronological order.

4.5.2. Change analysis

This method of event analysis compares a successfully performed activity to one that was unsuccessful. The method consists of developing a matrix to address who, what, when, where, and the associated conditions that existed when the problem occurred. Then these elements, as they existed before the problem occurred, are compared to those after its occurrence. Known differences can be identified and evaluated to identify causes of the problem. This method also is used to provide input for a cause and effect or event and causal factors analysis.

4.5.3. Events and causal factors charting

Events and causal factors charting was developed as a way to investigate accidents. The primary purpose of this method is to provide the entire background behind a problem. Answers to who, what, when, where, why and how are developed in pictorial form using a variety of symbols. The method consists of developing a sequence diagram using event, causal factor and condition symbols that describe chronologically how the problem developed and occurred.

4.5.4. Human performance enhancement system (HPES) survey

The HPES process addresses the many ways in which human performance factors affect personnel when their actions cause, or contribute to, a problem. Selection of the correct causal factors for a human performance problem is dependent upon determining the internal and external factors that affected the behaviour of the performer. The method is implemented by completing a number of survey forms, which inquire and categorize human performance problem conditions, causal factors and contributing factors. The survey forms by themselves are not a stand-alone method. The survey generally is used to identify conditions that can be input into cause and effect analysis or an event and causal factors chart. This investigative method was developed by the Institute of Nuclear Power Operations (INPO).

4.5.5. Task analysis

Task analysis is a tool that can be used to clearly identify all facets of a particular problem related activity. Conducting a task analysis typically includes re-enacting an unsuccessful activity step by step to determine why the activity failed. Individual tasks that were performed are analysed either on paper or by observing a re-enactment of the task, preferably by those who were involved in the original problem. Task analysis normally is performed to provide input for cause and effect or event & causal factors analysis.

4.5.6. Barrier analysis

A method closely connected to the concept of defence in depth and specially designed to analyse and evaluate failed barriers is 'barrier analysis', which is described below.

4.5.6.1. Defence in depth and barriers

Barriers are designed and established to prevent the propagation of an unexpected, undesired situation into a more severe situation. The concept of defence in depth is the placement of multiple barriers to protect personnel, equipment and the environment, and to enhance the safety and performance of human–machine systems. Barriers can be either physical or administrative, such as system interlocks, locked doors and valves, and automatic protective systems. Physical barriers prevent inappropriate actions by design. They will always work unless they are misused, bypassed or allowed to degrade. Administrative barriers can be grouped into 'hard' administrative barriers which enforce a desired behaviour, such as procedures, checklists and administrative controls, and 'soft' administrative barriers which promote the desired behaviour, such as training, communication and supervision. Administrative barriers generally work by requiring or promoting desired actions or by discouraging undesired actions. They can also be used to detect or compensate for inappropriate actions or conditions. The failure of one barrier has usually, because of the concept of defence in depth, no consequences. For an event to occur, it is necessary that several barriers fail in a series path (Fig. 5). If one barrier remains intact, it will prevent or mitigate the consequences of the event.

4.5.6.2. Barrier analysis as a tool

Simple logic tells us that every causal factor that affected, or allowed another contributory causal factor to affect, a safety target, is an indication of a barrier that did not exist or failed. Barrier analysis can therefore be of assistance in conducting causal factor analysis. When conducting root cause analysis, we are likely to focus on the last barrier and not on all barriers that failed. Subsequently our corrective actions focus on prevention of the specific event and not on the prevention of similar events. To establish effective corrective actions, we must track and trend all the causal factors, i.e. all barriers that failed.

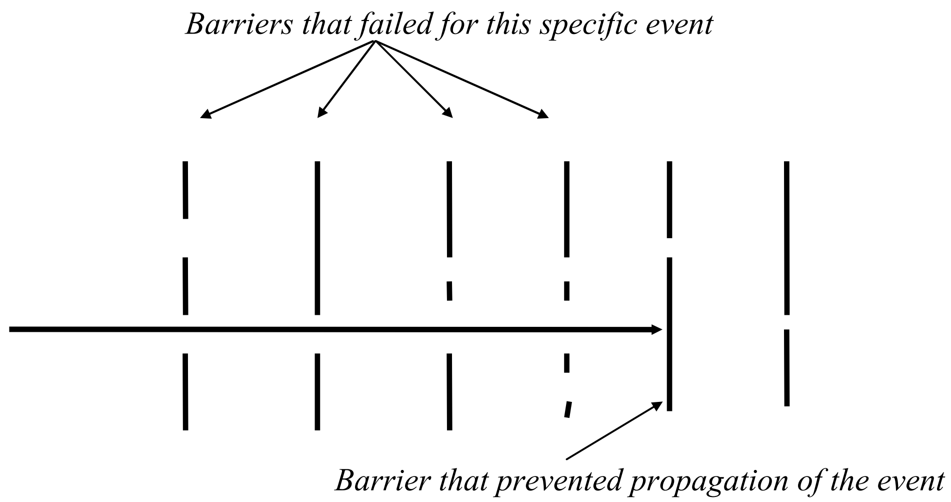

FIG. 5. System of safety barriers.

4.5.6.3. Conducting a barrier analysis

There are three steps to perform a barrier analysis:

- Step 1. List all applicable barriers, physical or administrative, that should have prevented the event, cause or consequence.

- Step 2. Assess the barriers to determine why a barrier failed. (Was the barrier missing, weak or ineffective?)

- Step 3. List one at a time each event code, cause code and consequence of an event.

Corrective actions should focus on addressing the causes, and should be incorporated into the organization's corrective action process or programme. Subsequent follow-up should be conducted to verify that the adverse trend has been corrected, or to modify the original corrective actions.

4.6. Corrective actions

Actions taken in response to events constitute the main objective of the OEF process to enhance NPP safety. They are aimed generally at correcting a situation, preventing recurrence or enhancing safety. The safety significance of an event determines the depth of the cause analysis needed and, subsequently, determines the type, the number and the time limit for implementation of corrective actions. It should be noted that the designation of safety significance can be changed during the analysis of the event. The regulatory body should be kept informed of any such changes so that it can fulfill its duties and responsibilities, e.g. making information available on incidents.

4.6.1. Development and implementation of corrective actions

The development of recommended corrective actions following an event investigation or a common cause assessment should be based on removing the root causes and the contributory causes, and on strengthening the weak or broken barriers that failed to prevent the event. The organizations are responsible for implementing corrective actions promptly and effectively. Ownership should be promoted through involvement of the members of the organization's event investigation team in formulating the corrective actions to be recommended.

Recommendations on corrective actions should be made on the basis of either internal or external feedback information and should be identified prior to, or as a result of, a thorough analysis of an event. The affected plant should develop corrective actions. However, in some cases, such as generic safety issues, the development of corrective actions should involve other relevant organizations and, depending on the national structure, may involve the regulatory body. Recommended actions should aim at improving human performance, equipment, or managed processes; for example: changes to the work environment; modifications to equipment, installation of additional devices and means to prevent recurrence of the same or similar events; improvement of procedures and administrative means, additional checks and control; training of personnel to perform jobs properly; changes to the planning and scheduling of work and/or of the individuals assigned to particular duties. In addition to their suitability for the affected nuclear power plant, corrective actions may also be applicable to other operating plants, plants under construction, or future plant designs, operating limits and conditions, improvement of procedures and training of personnel. The corrective actions may also have implications for other operating organizations and regulatory bodies. One element of the screening process carried out centrally or at plant level should be to consider the applicability of corrective actions taken by other plants in response to an event investigation. Where such a corrective action is screened and found to be relevant, it should be included in the plant's own corrective action plan. A number of important factors should be taken into account when determining corrective actions. These should include the need to restore or maintain the desired level of nuclear safety, to address human and organizational factors, and to consider the overall impact of the action on existing documentation and operational aspects and the changes to the planning and scheduling of work and/or of the individuals assigned to particular duties.

Corrective actions should be compared against actions that are in progress or are part of other action plans. Generating too many actions may overwhelm the intended beneficiary and leave some important ones outstanding for too long. Corrective actions can be either immediate, interim or long term necessitating detailed evaluation. Examples of immediate actions are measures to recover from a plant transient or to isolate contaminated areas.

4.6.2. Effectiveness review of corrective actions

A tracking process should be implemented to ensure that all approved corrective actions are completed in a timely manner, and that those actions with a long lead time to completion remain valid at the time of their implementation in the light of later experience or more recent discoveries. A periodic evaluation should be carried out to check the effectiveness of actions implemented. Primarily, implementation and tracking of corrective actions should be performed by the NPP management. The regulatory body may monitor the progress of certain recommended actions. This may be done by requiring plants or operating organizations to provide periodic progress reports.

In addition to the documentation and tracking of actions associated with each single event, a systematic compilation of actions should be made which may, taken over a number of years, provide an information base of lessons learned. When these actions are compiled and sorted on the basis of the systems affected or safety issues raised, they can serve as solutions for similar problems which may arise in the future, or at other plants.

5. INDICATORS

The plant should have indicators of operational performance and the effectiveness of corrective actions taken in response to identified deficiencies. Most nuclear power plants collect and publish a standard set of performance indicators such as radiation exposure, number of unplanned reactor trips, forced outage rates, plant availability, human performance, ratio between number of low level events and total number of events, number of corrective actions delayed and so forth.

Numerical indicators to monitor operational performance are used by operators and regulatory bodies worldwide, and these existing indicators should also be used for trending low level events and near misses where possible. However, since these performance indicators are measured at such a high level, by the time a negative trend in performance is recognized the plant may be on its way to declining performance. A key contributor to this declining performance is the fact that these high level performance indicators may fail to identify organizational weaknesses causing the decline in performance.

Therefore, it is important that nuclear power plants have the capability to trend, analyse and recognize early warning signs of deteriorating performance. It is necessary that plants be sensitive to these warning signs, which may not be immediately evident.

Experience has shown that a relationship exists between those events affecting nuclear safety, plant performance, plant reliability and individual events that have no significant impact on plant performance (see Fig. 1).

Many of the human performance challenges that affect the strength of barriers, which in turn affect the margin to safety, are classified as low level events. However, continuously challenging the barriers that keep these events at this low level will eventually result in failure. Some examples of organizational issues are given in Appendix I. The knowledge that minor events are precursors of more significant events indicating missing barriers or failures in barriers, and the fact that human errors continue to occur, should encourage the management of nuclear power plants to systematically collect data on human errors in low level events[3] and near misses.

Some examples of indicators for monitoring low level events and near misses are given below:

- Reported human error rate,
- Low level industrial safety events (not resulting in lost work time),
- Number of low level events and near misses related to human error,
- Trends from field observations,
- Coaching contact time,
- Number of human performance related assessments,

[3] A low level event is an undesirable occurrence or series of occurrences with minimal consequences which do not reach the threshold of a significant event.

- Number of management observations,
- Percentage of self-reported human errors in all errors,
- Procedure use and adherence events,
- Equipment mispositioning events (loss of configuration control),
- Engineering calculation errors,
- Equipment rework errors,
- Overtime rate (outage and non-outage),
- Recurring events and trends.

6. INTERNAL AND EXTERNAL LESSONS LEARNED

6.1. Internal lessons learned

Lessons learned from the analysis of the OEF process are an important component of a plant safety management programme. Even though organizations are performing at high levels of safety and reliability, there still remains a need for learning from a dynamic operational experience process to continue to improve nuclear safety, plant performance and quality.

A good organization is a learning organization, willing and able to learn from its own experience. Operational events are learning opportunities but the events affecting safety are infrequent, as national and international records show. This positive fact may also result in complacency, which could lead to a loss of attention, which in turn may result in a loss of safety awareness and staff competence. Vigilance may decrease if staff is seldom 'triggered' by the occurrence of events[4].

Therefore, organizations ignoring low level events and near misses do not fully benefit from the OEF process. By taking lessons from low level events and near misses, the plant staff can prevent the development of significant events at early stages.

It is important to integrate the analysis of low level events and near misses into the overall event analysis and use these results to identify existing precursors to the infrequent significant events. For example, during the root cause analysis of a significant event, the data associated with low level events and near misses should be assessed for any common cause(s).

6.2. External lessons learned

The use of external operational experience allows each organization to learn from the experience of other organizations and implement corrective actions to preclude similar events from occurring at their nuclear facilities. The following aspects should be considered:

- A systematic review of significant external information, along with trends from low level events and near misses, should be made;
- Personnel qualified to determine applicability to the NPP should perform the review;
- Appropriate corrective actions should be initiated to preclude occurrence of a similar event at the NPP;
- Information in the form of lessons learned should be disseminated to appropriate personnel;
- A periodic assessment of the use of the external OEF process should be conducted to monitor effectiveness.

The process of learning from external operational experience should include national and international experience. National (e.g. INPO, VNIIAES-Rosenergoatom) and international organizations (IAEA, NEA and WANO) provide a system of information exchange and recommendations for significant events.

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[4] In this publication: any variance, such as an operational deviation, abnormality, equipment failure or human error, or procedure non-conformities.

7. PROGRAMME EFFECTIVENESS

A periodic review of all stages of the OEF process should be undertaken to ensure that all of its elements are performed effectively. Continuous improvement of the OEF process should be the objective of the review. An effective OEF process can significantly contribute to minimizing the recurrence of events. In general, there are three approaches to undertaking such a review: a self-assessment by the operating organization, independent assessments, and audits. These reviews may assist in identifying the early signs of declining performance. Examples of early signs of declining performance can be found in Appendix VIII.

7.1. Self-assessment

The operating organization should periodically review the effectiveness of the OEF process. The purpose of this review is to evaluate the overall process effectiveness and to recommend remedial measures to resolve any weaknesses identified. Indicators of process effectiveness should be developed. These may include the number, severity and recurrence rate of events, causes of different events, etc. This self-assessment review should also:

(a) verify that corrective actions arising from the OEF process are implemented in a timely manner;

(b) evaluate the effectiveness of solving the original problems and preventing recurrence; and

(c) review recurring events to identify whether improvements in the OEF process can be made.

The operating organization should issue a periodic report, at least annually, which summarizes the activities performed which consider the framework of the OEF process. Such a report should list the internal and external experience that has been analysed, the corrective actions approved and the status of their implementation. A target completion date should be assigned for those corrective actions still under way.

In order to provide an effective OEF process, and improving safety culture and plant performance, it is desirable that the organization have in place a systematic self-assessment of operational experience. The findings of the self-assessment process may range from significant to low level events and near misses. The self-assessment process should also include a feedback mechanism to correct any self-assessment deficiencies.

The self-assessment process should permeate through all levels of the organization by being an integral part of the work pattern. In scope, it should cover all areas important to safe operation.

Experience has shown that the establishment and implementation of the self-assessment process are not sufficient steps in themselves to ensure its success. Success depends on continued application of well established principles and on maintaining the self-assessment process. Improving operational performance is a relatively slow process with no shortcuts.

The detailed information on self-assessment scope, methods and international practices is available in Ref. [8] and in the IAEA Safety Guide: A System for Feedback of Experience from Events in Nuclear Installations [9]. The IAEA guidelines for PROSPER [10] also provide instructions and mechanisms for a sound plant self-assessment programme.

7.2. Independent assessment including international organizations

Although a systematic self-assessment process is very useful for monitoring current trends in operational performance, it does not guarantee that all operational areas are properly covered and the self-assessment complies with the best international practices. That is why independent assessments should be made on a periodic basis.

There are several possible options to conduct independent assessments of operational experience and the effectiveness of the plant's self-assessment process, such as peer review and technical review missions. Examples of independent assessments are the IAEA PROSPER and OSART missions/peer reviews and WANO peer reviews.

The main purposes of a peer review are to determine whether the OEF process meets internationally accepted standards and whether the plant's self-assessment is effective and comprehensive, and to identify areas for improvement. For example, the peer review should compare the OEF process of an operating organization/licensee with guidance and equivalent good practices elsewhere.

7.3. Audits

An experienced group not directly involved in the OEF process itself should audit the OEF process at regular intervals. This audit team is usually made up of quality assurance staff belonging to the same operating organization. A good practice would involve at least one member from a different organization.

The OEF process may also be periodically reviewed by external audit or inspection, e.g. by the regulatory authority or external organizations. The regulatory body may consider the OEF process, including low level events and near misses, as an item for regulatory inspection.

8. CONCLUSIONS

Industry experience has shown that the precursors of a significant event[5] are present long before the significant event occurs. The precursors are advance messengers of the event and must be embraced by the utility to prevent the more significant events. Many of the precursors present as degrading safety culture and degrading plant material condition. These degraded conditions are often the result of ineffective change management, i.e. implementation of staffing cuts without fully evaluating the risk and impact associated with this action. As the workload increases, the ability of personnel to focus on the task at hand decreases. This lack of focus will start to surface as minor problems or events that have no real impact on the plant. Left unattended, these minor problems or events will accumulate and contribute to more significant events or failures.

Effective trending and analysis will provide early identification of the accumulating less significant, low impact events (low level events and near misses) and provide the opportunity to take effective corrective actions prior to the occurrence of more significant events.

It is strongly suggested that nuclear power plants increase the use of feedback from low level events in their day-to-day activities, as this is an important contributor in improving safety performance. There are strong indications that timely corrective actions on trends of declining performance help to avoid further degradation (i.e. occurrences of safety significant events).

[5] Significant events are defined as events that are consequential and in most cases have an impact on safety. The level of event considered significant varies between nuclear power plants and regulatory bodies.

APPENDIX I. EXAMPLES OF FACTS ARISING FROM LOW LEVEL EVENTS AND NEAR MISSES

TABLE I.1. LOW LEVEL EVENTS

TYPE	BRIEF DESCRIPTION	FAILED BARRIERS AND FAILED GOOD WORK PRACTICES	CONSEQUENCES	CORRECTIVE ACTIONS AND LESSONS LEARNED
MANAGEMENT	Workers observed no monitoring when going from a higher radioactive zone to a lower one and when exiting radioactive protection areas. Workers also observed eating, drinking and smoking in radiological areas.	Management expectations not clearly defined, no supervision.	Spreading of low levels of contamination and a small increase in internal radiation uptake by individuals.	Management expectations must be clearly defined in operating procedures.
OPERATIONS	Operator failed to follow the procedure for a routine test.	Procedural adherence.	Test was required to be repeated, resulting in startup delay.	Acceptance of workarounds should not be tolerated.
MAINTENANCE	Maintenance worker worked on wrong equipment safety train.	Self-checking, pre-job briefing, supervision.	Equipment unavailable.	Importance of self-checking and constant vigilance of workers and supervisors.
PROGRAMMES AND PROCEDURES	A transmitter was constantly drifting out of spec; on investigation, several similar incidents were found.	Maintenance programme for trending equipment failure history.	Unnecessary maintenance; equipment out of service.	Equipment failure trending to maintain plant reliability.
TRAINING	In refurbishing a liquid relief valve, the spring tension was incorrectly set.	Inadequate training, lack of supervision, lack of verification.	Post-maintenance testing confirmed that valve spring testing was incorrect; maintenance rework required delaying unit startup.	Supervisors should ensure that workers are properly qualified through pre-job briefings.
EQUIPMENT FAILURE	During an emergency load sequencing operation test, one emergency feedwater pump (one of three pumps) failed to start according to programme.	None, as fault found on test.	Deficiency report suggested defect in switch-off mechanism.	Develop a schedule for replacement of circuit breakers with a more reliable design.

TABLE I.2. NEAR MISS EVENTS

TYPE	BRIEF DESCRIPTION	FAILED GOOD WORK PRACTICES	POTENTIAL CONSEQUENCES	CORRECTIVE ACTIONS AND LESSONS LEARNED
MANAGEMENT	A worker was decontaminating a piece of equipment; unknown to him a highly radioactive component was lodged inside. During cleaning the lodged component came loose and fell into a waste container, later to be discovered by workers.	There was a failure to identify this as high hazard work and therefore no special training was provided, such as mock-up training. This went unnoticed by management at their daily review meetings and by the senior health physicist.	The worker was fortunate not to receive a large unplanned radiation exposure.	A questioning attitude by management should have uncovered the potentially dangerous work situation.
OPERATIONS	An operator reached for the wrong panel switch but stopped himself before activating it.	Self-check and constant vigilance.	Impairment to reactor cooling system resulting in a reactor trip.	Reinforcement of the self-check programme.
MAINTENANCE	Operator electrically isolated auxiliary feed pump p1under approved work order. Maintenance worker commenced working on p2 in error. Supervisor caught error and stopped work.	Pre-job briefing, self-checking and supervision.	It was fortunate that the pump was not called on to operate, as the maintenance worker could have been seriously injured. Also, neither of the 2 auxiliary pumps would have been available.	Constant vigilance is required. A bar code reader system was installed to verify that the correct equipment is being worked on.
PROGRAMMES AND PROCEDURES	A system engineer specified work on a safety support system but was unaware of an undocumented physical change to the system. Shift supervisor caught the error before work commenced.	Configuration management problems. Many undocumented physical changes and long-existing temporary changes.	It was fortunate that the shift supervisor caught the error in the requested work; otherwise the safety support system would have been significantly impaired.	Maintaining good configuration management of the plant is essential to safe operation. The plant on paper must represent the physical plant and must be supported by safety analyses.
TRAINING	A control maintainer recalibrated the reactor regional overpower (rop) detectors for the shutdown system for all three channels. The procedures require different maintainers for each of the three channels.	This was the first time the maintainer worked on the (rop) detectors. Inadequate training was provided along with stressing that this was a special safety system important to reactor safety.	This was not caught until after reactor startup. By working on all three channels, the maintainer could have created a common mode problem for all three channels, significantly impairing the shutdown system.	There is a need to convey to workers the importance to safety of the system/equipment they are working on, as well as to provide adequate training. This is an example of non-conservative operation.
OUTAGES	While working from a scaffold, a maintenance worker dropped a wrench from a height of 15 feet.	Worker safety.	It was fortunate that nobody was in the line of fall of the wrench, as that person could have received serious injury.	Work safe practices must be reinforced. A tool restraint programme was implemented.

I.2. Examples of significant events that could have been avoided with corrective actions developed from the analysis of previously identified low level events and near misses

This section attempts to illustrate, through real life examples from operating experience, that declining safety performance can be detected and corrected at an early stage through the use of low level events and near misses as amplifiers of weak signals of emerging problems. The five examples provided show significant events from different plants that, retrospectively, could have been avoided with earlier corrective actions ensuing from previous low level events. Nevertheless, they still were acted upon efficiently when put in perspective with the information available from those low level events, enabling an amplification of the root causes underlying them.

I.2.1. Example 1

Breach of containment following maintenance activities on the equipment and emergency airlocks

- Event description

Following a pressure test for the emergency airlock, it was required that a blank flange be put on a pipe going through the airlock. The purpose of the blank flange was to maintain the airlock containment function. This pipe was used to pressurize the airlock with air from a flexible joint linked to the plant air system. Since the procedure did not specify the location of the flange, the mechanic reasoned it was to be attached to the air supply line (a logical thing to do, since he normally put blanks downstream of air valves). So he re-opened the valve, confirmed that the air was coming from the flexible joint, and installed the blank on the air supply line. With the air supply now disconnected from the airlock and the blank flange in the wrong location, the containment was breached. The situation existed for about 15 hours, and each opening of the airlock door on the reactor building side was creating a breach of containment. This was detected when the mechanics discussed the job on a shift turnover. Another mechanic had performed the job before, so was aware of the correct installation and the consequence of not reinstalling the blank correctly. The information was immediately communicated to the shift supervisor and the situation was corrected. The total unavailability of the containment function of the reactor building was about 30 minutes (18 openings of about 100 seconds each).

Two days later, another pipe modification was required in preparation for the reactor building pressure test that was planned for two weeks later in the coming outage. The job was to install a tee downstream (auxiliary building side) of an air supply valve connected to the equipment airlock. Because the work documents did not specify clearly what the tee looked like or where it should be installed, there was some confusion as to the expected installation. The tee the planners intended to be installed was in fact a long pipe with two outlets that were connected to the ventilation system. The workers understood from the evaluation of the existing configuration that the tee was to be installed where an existing spool piece was installed upstream (containment side) of the valve connected to the airlock. They contacted the system engineer to say that the tee was missing and that they needed a drawing. No drawing was found, and because there was no particular requirement (other than holding air at 125 kPag), the system engineer suggested they fabricate a new tee and install it. The workers did manufacture a tee, as they understood it, to replace the spool piece, and installed it. Again, in this situation, an opening of the airlock door on the reactor building side was causing a breach of containment. The situation was detected after 2 hours by an operator who heard about the other event on the emergency airlock and was puzzled by the installation he saw on the front of the airlock. He followed the piping and found the anomaly. The situation was corrected right away.

- Consequences

The immediate consequence was to create two breaches of containment for a total duration of about 40 minutes. Even if the reliability target is set at 10^{-3} y/y (8.8 h/y), this was considered as a serious breach in safety provisions. Another potential consequence if the mistakes had passed undetected is that, during the high pressure test of the reactor building (done at 125 kPag), it would have been impossible to enter the reactor building in an emergency, invalidating some scenarios credited in outage safety analysis.

- Causes

The main cause identified for both events is that the procedures used for the job were not precise enough to fulfil the needs of a new user. These procedures were used adequately for years because normally the job was done with qualified personnel who had done the job before. In this event, however, the two mechanics, even thorough experienced, were not familiar with the task. They demonstrated a good questioning attitude, but the communications were ineffective. They started the job without any pre-job briefing, as the task was not identified as critical. In the second case, the work authorization described a modification on the air system (not the containment system), so no need for a particular qualification was identified by the shift supervisor.

- Low level precursors and other significant events

In numerous events that occurred in the past two years, it appeared that procedures that had been used for years suddenly seemed to be less than adequate, because new personnel or personnel not familiar with the task had difficulty to perform optimally with those documents. The lack of personnel with proper training/qualification/knowledge of the task was creating a breach in the first line of defence; this weakness highlighted a second weak barrier not identified previously (written procedures). The tendency was significant enough that, in a trending exercise, it was underlined as a precursor to a more serious event. In the past two years, 35 event analyses (on ~300 events) identified procedures as the direct cause or contributing factor. Had this been earlier recognized, pre-job review of the procedures with knowledgeable personnel could have precluded the breaches of containment.

- Corrective actions

Generic corrective actions that are suggested by these low level events, which could have prevented this significant event and that were finally taken after the event, are: systematic pre-job briefing before executing a safety system procedure for the first time (to mitigate the procedure problem); training/qualification on a special safety system; revision of some procedures; and supervision.

I.2.2. Example 2

Electric cable fire while drying a filter in the reactor building

- Event description

Following concerns about tritium release in the low level waste storage area, it was decided that all the filters coming from heavy water systems (coolant and moderator) should be dried before being sent to the low level waste storage area. A cask and a dryer were designated for this activity. The filter was successfully dried, but it took more than 10 days. To accelerate the drying process for subsequent filters, the heater power was to be increased. Workers were requested to install equipment with increased drying power. However, no precise guidance was provided.

The new arrangement consisted of a larger cask and heaters with a total power level of 2 kW. The previous heaters had provided only 200 W. The new cask completely covered the heaters. The workers did place spacers between the heaters and the cask but did not provide for significant airflow. A flexible air duct was provided to ventilate the top of the cask, which was connected directly to the reactor building ventilation system. The installation was then left to be used for filters, without any surveillance requirements established.

After a few hours, tritium levels were rising at the gaseous effluents monitor. The shift supervisor directed that the drying activity be stopped and the flexible air duct disconnected. He did not know that there were heaters under the cask. Because of the continued heat input, the filter dried out and spread dry particulate contamination. A radiological emergency (not an emergency action level) was declared and the heaters were unplugged. After gaining an understanding of the installation and of what had occurred, the shift supervisor asked for a redesign of the installation to make sure that heavy water vapour would go through the recovery system instead of directly to the ventilation (reducing any release of tritium outside, which was in fact the initial concern). After some modification, the drying was restarted. As radiological protection workers were cleaning, one of them noticed that there was a smell of something overheating. It was explained to him that it was normal because it was the filter that was drying.

After a couple of hours, some flames were seen coming from underneath the installation and a fire emergency was declared. Once inside, a radiological protection technician evaluated the radiation field and it was judged acceptable to go near and try to extinguish the fire. After two unsuccessful attempts, they decided to remove the cask from the heater. After this was done, they succeeded in extinguishing the fire. It seemed that the fire was of electrical origin. The cable powering the heaters was overheated by the heaters and caused the electrical insulation to burn.

- Consequences

There were no serious consequences because there was no combustion loading in the room. Nevertheless, the spread of contamination could have been significant if the filter had caught fire.

- Causes

Numerous causes were identified in this sequence, but the main high level contributors were lack of supervision, no pre-job briefing and no co-ordination. The absence of a procedure covering all steps of the job was considered a failed barrier, particularly since this was not a routine task. Responsibilities for each of the steps of the job were not known or defined.

- Low level precursors and other significant events

Multiple low level events seemed to point to a significant decrease of supervisory activity since the last re-organization, leading to lack of organizational clarity in new or infrequently performed activities or in activities involving more than one unit. In addition to that, clear expectations were frequently missing and pre-job briefings were not conducted. Before this event, trending on low level events and licensee event reports identified supervision of activities as one major area where improvement was needed. Some facts encountered were: thermal treatment done without the presence of a fire watch; workers from an outside company who did not know the fire protection requirements; a work area left without fire detection while the automatic fire detection system was disabled; a work supervisor who had to leave the job site and did not transfer responsibility; and no validation that equipment released for maintenance was adequately isolated or protected. It was clear that the design modification process was poor.

In the past two years, 40 event analyses identified supervision/co-ordination as a cause or contributing factor. When looking specifically at organizational clarity, 31 event analyses found a weakness in either *roles and responsibilities* (the decision on who does what), *formalization* (formal documentation) or organizational knowledge (communication and internalization of those responsibilities).

- Corrective actions

Generic corrective actions that are suggested by these low level events, which could have prevented this significant event and that were taken after the event, are: increased supervision in the field (first line managers); requirement for a supervisor for any new or non-routine activity; designation of a co-coordinator for activities involving more than one group or unit, and revision of the existing design modification process.

I.2.3. Example 3

Two valves in the reactor pressure vessel head cooling system were inoperable due to wrong connection of instrument air hoses during modification work

- Event description

The original installation of two valves in the reactor pressure vessel head cooling system was recognized as deficient regarding environmental conditions (heat) and maintainability (heat, radiation). The valves are located in the containment of a boiling water reactor (BWR) plant. The valves were to be moved to a less harsh environment. The modification work was performed during the annual refuelling outage. As part of the work, the instrument air hoses for both valves had to be removed and the copper lines were to be lengthened. After the valves were relocated outside the containment, the instrument air hoses were connected to the wrong valves. In this configuration, the controller for the valve that delivered cooling water to the head now operated a bypass valve and the controller for the bypass valve now operated the cooling supply valve. The connection failure was not detected until after the valves were placed in service.

- Consequences

Inoperability of components due to false connection.

- Causes identified

The instrument air hoses were connected to the wrong valves. The mechanic did not assure himself that the hoses were connected to the right valves. The removed hoses were not labelled. Post-modification testing was inadequate.

- Low level precursors and other significant events

In numerous events that occurred in the past years, it appeared that false installation and omitted testing after maintenance work led to inoperability of components. Around 40 examples of low level events with the same identified causes were found.

- Corrective actions

Generic corrective actions that are suggested by these low level events, which could have prevented this significant event and that were finally taken after the event, were: complete and comprehensive planning and installation of modification work; improving the self-checking methods; labelling of components; improving the maintenance instructions; and complete testing after maintenance and/or modification work.

I.2.4. Example 4

Two out of four channels of a reactor protection system were inoperable due to failure to properly restore the system subsequent to testing during a refuelling outage

- Event description

Two transmitters measuring the conductivity of the feedwater were detected to be inoperable. These measurements are part of the reactor protection system. The function of the measurements is to isolate the feedwater system in the case of seawater leakage in the turbine condenser. The four measurement channels were calibrated during the refuelling outage and the terminal strips of two channels were left disconnected after the calibration. Disconnection of the channels was not documented. After the work, the terminal cubicle was independently inspected and the disconnected terminals were detected, but the supervisor did not question the cubicle inspection report. The lack of vigilance of the instrument technician was the main contributor to this event. The procedures were not comprehensive enough and the coming weekend influenced the supervisor’s and the technician’s review of the cubicle inspection report.

- Consequences

There were no serious consequences because the protection system works with two out of four channels. The two operable channels would have triggered the isolation of the feedwater system if needed.

- Causes identified

Numerous causes were identified in this sequence, but the main contributors were lack of vigilance of the technician and inadequate procedures. The procedure did not require documentation of disconnection or connection of the terminals. Schedule pressure had an influence on the attentiveness of the supervisor.

- Low level precursors and other significant events

In numerous events that occurred in the past years, it appeared that careless restoration of the systems after work led to inoperability of safety systems. Some examples of low level events with the same identified causes are:

(a) Omitted restoration of a shut-off valve in the residual heat removal (RHR) system after maintenance work;
(b) Automatic opening of a recirculation valve of the main cooling system was prevented due to disconnected terminals after testing;
(c) An emergency diesel generator stopped due to improper manoeuvreing of the reset screw of overspeed protection;
(d) A feedwater pump control actuator inoperable after maintenance;
(e) Pressure indication of a safety relief valve inoperable after outage work;
(f) Several connectors left unlocked after maintenance work;
(g) The earth cable of an electric motor left disconnected after outage work;
(h) A connection was not removed during modification work.

- Corrective actions

Generic corrective actions that are suggested by these low level events, which could have prevented this significant event and that were finally taken after the event, were: improving the self-checking methods; increased supervision in the field; improving the maintenance instructions; and complete testing after maintenance and/or modification work.

I.2.5. Example 5

Unplanned withdrawal of a control rod during performance of control rod surveillance testing

- Event description

On a day shift, the day shift superintendent was exiting the control room to perform plant duties. Prior to leaving he held an informal briefing with the senior reactor operator (SRO) and reactor operator (RO), providing overall guidance for the conduct of the control rod testing. The SRO regarded this briefing as an informal notification and preliminary discussion of the test to be performed. The RO thought that it was the pre-job briefing for the test. There were 133 control rods to be tested; 128 were in fully withdrawn position, 24 were fully inserted, and one was in an intermediate position. The normal practice was to test all the fully withdrawn control rods, then the intermediate control rods and finish with the fully inserted rods. During this test, a second RO was assigned to perform peer checking of the activity. Contrary to the normal practice, the decision was made to test intermediate and inserted control rods prior to completion of testing of the withdrawn control rods. This was due to the availability of an additional operator, necessary to support the testing of the intermediate and inserted control rods. After completing the testing on 105 of the fully withdrawn rods, the RO selected and tested the intermediate position rod, then selected a fully inserted rod and moved it in the outward direction. Following that mispositioning event, appropriate levels of control room supervision were notified and action was taken to replace the control rod in the correct position and verify core thermal limits.

- Consequences

This event had no real impact on safety, but could potentially have led to violation of core thermal limits.

- Causes identified

The causes and error precursors[6] identified were related to monotony of the task, board repetitive actions from an established pattern, and failure to adequately self-check, allowing the intended component to be manipulated incorrectly.

- Low level precursors and other significant events

Some similar events occurred at the plant in the past five years, in addition to different events with similar causes. Those events were pointing to improvement opportunities in work practices and procedure adherence in operation activities. Examples are:

(a) Inappropriate control rod movement during power reduction; the direct cause was related to work practices (inadequate self-checking and attention to details).
(b) Control rod mispositioning event while performing rod operability testing.
(c) Inadequate self-checking was identified as the first weakness.
(d) Pressure drop of condensate header and automatic startup of condensate pumps following inadequate positioning of the pumps' hand switches.
The manoeuvre was done during shift turnover and without a procedure.
(e) Control rod withdrawal in violation of a procedure.
One rod was forgotten in a previous withdrawal and was pulled a longer distance than initially authorized.
(f) Starting the wrong diesel generator during a surveillance test.
The activity necessitated peer checking, but the supervisor allowed the surveillance to continue while the second operator was absent.
(g) Valve mispositioning on the cooling water system.

Also, the industry did report many similar events through INPO Report INPO/SOER 84-02 on Control Rod Mispositioning [20].

- Corrective actions

The corrective actions suggested by those events, which could have prevented this significant event and that were taken after this event, were: communication and training on proper self-

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[6] Unfavourable factors embedded in the work site that increase the chances of error during performance of a specific task by a particular individual.

checking methods and expectations; review of supervisor workload; training on procedure use and adherence; and training on efficient pre-job briefing.

After those corrective actions were put in place, it was observed that events identifying self-checking deficiencies as a cause decreased by half, and supervisory activities in the field increased by 20%.

I.3. Examples of organizational issues

- Uncertainties on management objectives and expectations.
- What are future cost cutting measures (staff reductions, lay-offs).
- Ineffective management and leadership development.
- People are not prepared to assume positions of greater responsibility.
- Poor implementation of changes in the organization.
- Total impact of changes not evaluated or co-ordinated.
- New operational procedures are prepared, with some mistakes, and result in some equipment damage. (In the old procedures, oil must circulate 5 min before pumping starts; in a new procedure, which is more comprehensive and detailed, there is no requirement on how long the pump must be lubricated before starting.)
- Communication.
- Performance indicators do not accurately reflect actual plant conditions.
- Managers not receptive to outside input or using industry operating experience.
- Lack of teamwork between managers.
- Competition between different sections (departments) may lead to breakdown of communication in the organization.
- Unwillingness to face and correct small problems.
- People don’t accept criticism well. Criticizing performers may lead to lack of openness in the future. Some experts may have difficulties admitting things they don’t understand, while others do have a mindset on how to perform the work.
- Complacency — willingness to accept the status quo (together with unwillingness = the worst example of unacceptable behaviour).
- Insufficient resources provided to accomplish the work at hand.
- Cutbacks have resulted in the need to do more work with less people.
- Because of language problems, managers are not able to read reports about external information and external practices; there are not enough financial resources to translate all information and receive them.
- Schedule pressure — ineffective planning resulting in more work needing to be completed immediately.
- Reliance on lagging performance indicators looking at past performance (plant capacity factor, cost of generation, etc.).

APPENDIX II. PROGRESSION OF A NEAR MISS TO A LOW LEVEL EVENT AND TO A SEVERE ACCIDENT

Relationship between significant events and low level events or near misses

Significant events, low level events and near misses all share something in common: latent weaknesses that result in failed barriers and root causes. All these types of events differ only in their resulting consequences.

As far as defence in depth is concerned, the analysis of any level of event can be used to provide information for an effective corrective action programme. The challenge here is to identify which latent weaknesses contributed most to the common causes and then to implement effective corrective action(s). This is where the use of coding and trending is helpful.

As far as single human performance events are concerned, reporting and discussing the events may be quite sufficient, as in isolation they don't provide an indication that a widespread improvement is needed. On the other hand, seeing re-occurrences of a high number of such events which share some common pattern or causal factors should result in a more generic corrective action.

Significant events normally develop through deficiencies in barriers that were not detected during normal operation. We may operate believing that a strong defence in depth is in place, with multiple barriers preventing events, when in fact there may be significant weaknesses that go undetected. The benefit of low level event analysis is that we can find deficiencies in barriers that normally go unchallenged and may be ineffective in stopping a significant event. In addition, large numbers of low level events and near misses may increase the probability of occurrence of a significant event, which in itself is a sufficient reason for addressing these types of events.

Past accidents, either in the nuclear industry or in other types of facilities, have occurred when a series of small latent weaknesses combined with an additional failure which resulted in a serious event. Defence in depth normally ensures that a single failure does not degenerate into an event with serious consequences for either the public, the personnel or the nuclear power plant itself.

The previous proposal illustrates that it would be poor management to leave low level events and near misses unreported. In all probability, they contain factors that may be present in significant events or even in incidents or accidents and should therefore be seen as precursors. Reporting and analysing those low level events and near misses allows detection of latent weaknesses that may indicate the need for improvement and definition of corrective actions to prevent more significant failures.

Latent weaknesses in the programmes

Ineffective programme implementation (work planning and scheduling, preventive maintenance, self-assessment):

- Ineffective corrective actions (recurring problems);
- Cumbersome processes (that force people to work around the process, e.g. work management, engineering design).

There are cases where procedures are never applied. For example, the procedure for calculation of a leak balance sheet in power operation was never used, since it was long and complex. Instead of this, the operators used another, implicit, unwritten one.

Latent weaknesses in operations

- Lack of a questioning attitude:
  mechanical application of procedures by operators, even when they know the procedures are wrong; weakness of initiatives.
- Operator errors due to inattention to detail:
  many examples of operator errors were published, like switching on or switching off the wrong pump for various reasons.
- Valve misalignment errors.
- Training inadequacy.
- Failure to perform equipment checks and surveillance:
  During the startup period of a unit, many equipment (valves) must be put into the right position. Field operators use the checklist and then, at a certain time (periodically), they check the position. A few days after connecting a generator to the grid, it was discovered that valves on the emergency feedwater system were in a wrong position (closed). This event leads to violation of TS. Learned lesson: a failure was discovered in the equipment check and surveillance programme during the startup period, but the control room personnel didn’t follow instructions.
- Unclear operating procedures.
- Mechanical application of procedures by operators, even when they know that procedures are wrong; weakness of initiatives.
- Decision making dominated by concern for production.
- Large number of employee grievances.
- Willingness to live with long-standing equipment problems.
- Lack of openness.
- Total impact of plant material condition deficiencies not evaluated — cumulative effect of equipment out of service not evaluated.

Latent weaknesses in maintenance

- Large backlog of maintenance items,
- Large backlog of overdue maintenance and preventive maintenance items,
- Inoperable automatic equipment,
- Reactor trips due to maintenance errors,
- Poor housekeeping and material conditions,
- Non-aggressive approach to resolving material condition issues,
- Failure to follow procedures,
- Lack of global overview of the process.

Latent weaknesses in engineering

- Problems in maintaining configuration management,
- Poor preparation of plant modifications,
- Inadequate support of operations/maintenance,
- Repair plants not ordered — procedures not changed,

- Incomplete procedures, procedures with implicit steps of conditions,
- Unauthorized plant modifications,
- Lack of urgency to resolve long-standing material condition problems.

Latent weaknesses in radiological practices

- Poor planning and implementation of radiological work practices,
- Worker over-exposure,
- Inadequate radiological training,
- Upward trend in radiation exposure and personnel contamination.

Progression of a near miss to a low level event to a severe accident

The term ‘near miss’ comes from aviation, describing two aircrafts approaching each other during flight at a distance less than that usually considered to be safe, but where nothing actually happens. This may be a result of an action preventing a serious event from happening.

Figure II.1 illustrates how an inappropriate action develops either into a near miss (fortunate situation) or into an event. Figure II.2 shows the progression of a low level event to a more significant event to a severe accident, depending on how many lines of defence are breached. Lines of defence include physical barriers, administrative barriers (procedures, checklists) and good work practices (as a result of training, safety culture, etc.). The examples given below describe typical near misses in nuclear power plants. Further examples of near misses are contained in Appendix III.

Examples for near misses that occurred:

- An operator places his hand on the wrong switch; however, immediately prior to actuating the switch he recognizes his mistake.

- A craftsman in the turbine building sees a fellow craftsman not utilizing proper safety equipment and practices. He points out this problem to his peer and a potential industrial safety accident is avoided.

- A craftsman wearing anti-contamination clothing is working on a ledge by the reactor cavity. The craftsman slips and would have fallen into the cavity if he had not been wearing a safety harness.

- An operator is walking through the plant when he looks up and sees a craftsmen kick a tool off a scaffold. Quick action on the part of the operator prevents injury.

These examples show near misses as something that happened without consequences. Had the timing of the individual actions been different, the outcome of the event may have significantly changed.

At some utilities the reporting of near misses is called ‘good catches’, to point out the fact that a significant event was prevented by timely detection and appropriate action by the individuals involved.

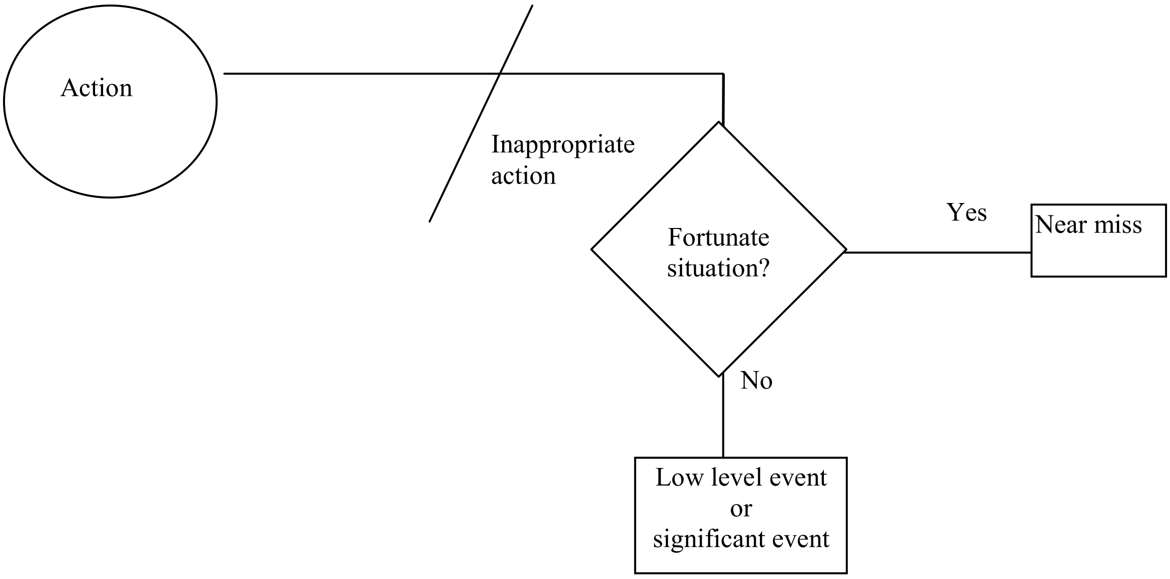


FIG. II.1. Progression of an action by violating good work practice.

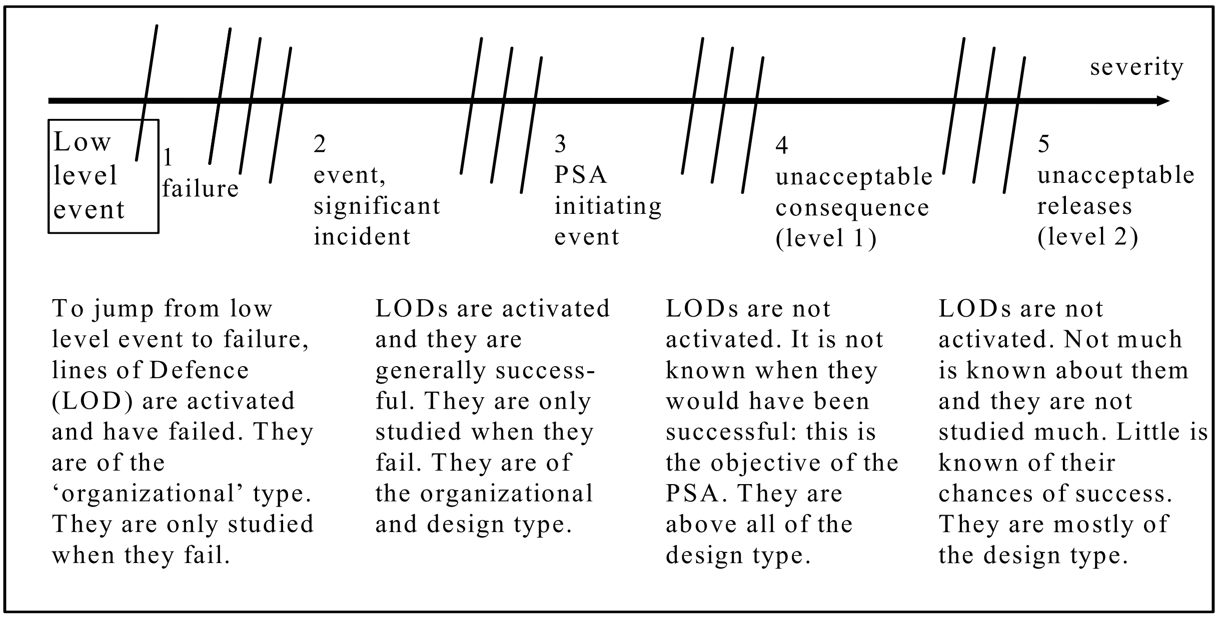


FIG. II. 2. Development from a low level event to a severe accident.

As explained in Fig. II.2 it can be said that a serious accident may develop from a low level event in the following manner: a failure or a set of failures is revealed through a declared incident (incident report) because the lines of defence set up (maintenance, monitoring, operation, design quality, etc.) have been broken. The incident can then degenerate into an increasingly serious accident as other lines of defence are successively broken. This process of aggravation of the situation is stopped when a line of defence has been activated and has correctly played its role. It is noteworthy that these last, successful lines of defence are not generally studied.

In this situation, the process of jumping from near misses to a low level event and then to an effective failure of the installation is the same one, and generally, the defence lines activated by a successful good catch are not documented and studied. Nevertheless, it could be very interesting because the mechanism of failure of the different types of defence lines do not depend on the force of these lines. To have a severe accident, it is necessary to break a lot of defence lines. Thus, the origin of the accident is a simultaneous failure of several lines of defence which may be of very different types.

In order to illustrate the general approach shown in Fig. II.2, an example is given below (see Fig. II.3).

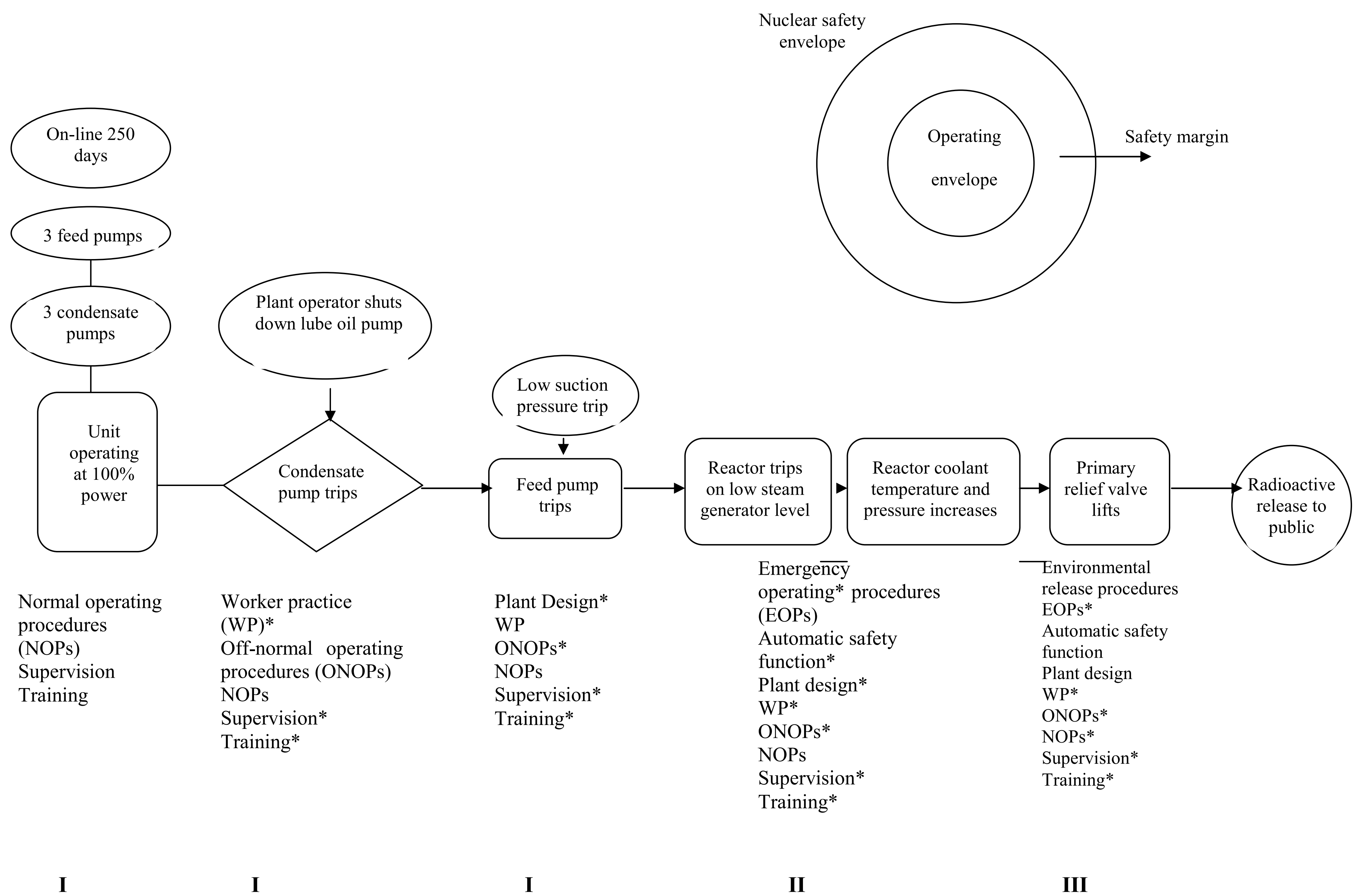
The initial conditions of the nuclear power plant are as follows:

- The plant has been operating at 100% power for 250 days;
- 3 main condensate pumps are running;
- 3 main feed pumps are running.

The following scenario is assumed:

The plant is operating at 100% reactor power when a plant operator inadvertently trips a running condensate pump. One minute later, one feed pump trips on low suction pressure (+1 minute). Approximately one minute after the feed pump trips (+2 minutes), the reactor automatically trips on a low steam generator level. Following the reactor trip, primary system temperature increases rapidly, due to loss of heat sink, and a primary system relief valve lifts resulting in an environmental release to the public (+10 minutes).

Reviewing the lines of defence associated with this event: in the beginning, had the worker's practice and supervision been appropriate, the condensate pump would not have tripped. Had the off-normal operating procedures (ONOPs) been properly used (worker practice, supervisor training, use of off-normal operating procedures), the trip of the feed pump and resulting reactor trip due to low steam generator level could have been avoided. Had the emergency operating procedures (EOPs) (worker practice, supervision, training, use of off-normal and emergency operating procedures) been properly utilized, the release of radioactive material to the public would have been avoided.



* Broken lines of defence

FIG. II.3. Example of lines of defence.

APPENDIX III. TRENDING CODES

Best international practices demonstrate that the most frequently identified performance problems fall into several categories. As a good example on how to implement a trending code, we selected seventeen categories. If we identify each one by a letter and a number, we have an identification system, very useful for a trending analysis:

A. *Communication* — the presentation and exchange of information
   1. type of communication
      a. verbal,
      b. written;
   2. information not provided to end user;
   3. too much information provided to end user;
   4. no feedback provided to message initiator.

B. *Procedures and documents* — the written presentation or exchange of information
   1. type of procedure/document
      a. permanent,
      b. temporary;
   2. format confusing to end user;
   3. errors in technical content of the document;
   4. not properly co-ordinated with change implementation.

C. *Displays and labels* — the design of equipment used to communicate information from the plant to the person
   1. equipment layout and usability;
   2. equipment labels unreadable or incorrect.

D. *Environmental conditions* — physical condition of the work area
   1. poor working conditions
      a. lighting/temperature/noise,
      b. cramped/overcrowded conditions;.
   2. protective equipment required
      a. industrial safety equipment,
      b. radiological protection equipment.

E. *Workers' schedule* — factors that contribute to the ability of the workers to perform their assigned task
   1. worker fatigued;
   2. interruptions of work in progress;
   3. poor co-ordination of related activities.

F. *Work practices* — the methods workers use to complete work assignments
   1. document that states work practice
      a. administrative procedure,
      b. job procedure;
   2. error detection method used
      a. self-checking,
      b. check by second person;
   3. error detection practices not used;
   4. procedures not used;

5. improper tool usage;
6. worker not prepared for task.

G. *Work planning and scheduling* — how planning, scoping, assignment and scheduling of the task to be performed is accomplished

1. insufficient time allotted for worker to prepare for task;
2. insufficient time and/or personnel assigned to task;
3. task planning/scoping did not identify all conditions;
4. personnel assigned to task not qualified.

H. *Supervision* — methods used to direct workers in the performance of tasks

1. supervision not interfacing with workers;
2. task progress not adequately tracked;
3. direct supervisor/achievement resulted in loss of overview rule;
4. emphasis on schedule exceeds emphasis on doing work correctly.

I. *Training/qualification* — how people are trained and qualified to perform tasks

1. how was training conducted
    a. classroom/laboratory,
    b. skill learned at previous job;
2. contents of training programme did not support task performance;
3. training inadequate to perform task.

J. *Change management* — process by which changes are implemented

1. change not implemented in a timely manner;
2. risk and/or consequence of change not considered;
3. change implementation not co-ordinated with all affected departments.

K. *Personnel and materials management* — how personnel and materials are assigned to a task

1. insufficient supervising resources provided;
2. insufficient personnel assigned to task;
3. inadequate materials provided to complete task.

L. *Management* — techniques used to control or direct plant activities

1. goals and objectives do not address all known problem areas;
2. lack of timely response to known problems;
3. risks/consequences of tasks not properly assessed;
4. policies, practices, procedures not properly defined.

M. *Design configuration* — the layout of systems and subsystems to support operations and maintenance

1. design changes not implemented in a timely fashion;
2. misapplication/-interpretation of design requirements;
3. unauthorized design changes implemented;
4. design change not properly co-ordinated with design change implementation.

N. *Equipment selection and installation*

1. wrong equipment specified for application;
2. equipment not properly installed;
3. inappropriate service requirements.

O. *Maintenance/Testing* — the process of maintaining equipment in optimum condition

1. type of maintenance
    a. corrective,
    b. preventive,
    c. surveillance test;
2. maintenance not performed in a timely fashion;
3. maintenance not performed properly; and
4. required testing not performed.

P. *System operation* — actual performance of the equipment or component

1. failure as noted during system startup, operation or shutdown;
2. failure as the result of improper operation;
3. failure as the result of lack of preventive maintenance.

Q. *External influences* —- outside the immediate control of the organization

1. non-human (Act of God);
2. human (regulatory, sabotage, distractions).

APPENDIX IV. QUALITIES OF A GOOD COLLECTION SYSTEM

- Deficiencies and/or events, including the related organizational and human factor issues, should be reported, evaluated, and appropriate information entered.
- Who can report: anybody, including contractors.
- How to report: defined organizational structure; clear procedure, communication to those individuals involved.
- Criteria for dealing with event: low level event is below or outside of the INES scale, so this scale is not appropriate for use.
- Categorization with respect to safety significance.
- Simple; easy to understand.
- Feedback to: person reporting the event; communicate immediate corrective action plan to other affected units and to all involved plant personnel.
- Encouragement to report; readily accessible, simple, non-punitive.
- Meeting regulatory requirements.
- A good reporting system may include a few serious reports and maybe thousands of low level events.
- A database with appropriate coding, maintained by knowledgeable, experienced individuals.
- Information periodically provided to senior management.
- One system for all low level events, near misses and deficiencies.
- Identified (central) group to manage process, co-ordinate decisions and recommend actions to senior management.
- Example criteria:
- Clear criteria for further investigation per unit:
  - Full investigation/root cause investigations: <6/year.
    - Partial investigation: not more than 60 events.
    - Corrective actions to eliminate the consequence of ~600 events.
    - Trending on ~6000 low level events.

It should be noted that because of plant specific circumstances it is difficult to derive a general set of criteria, and therefore it may be difficult to make comprehensive comparisons between plants.

APPENDIX V. TREND ANALYSIS TECHNIQUES

The techniques described below are not the only methods available, but represent proven techniques for analysing data. The mathematical formulas presented might be too stringent and limiting, depending on the circumstances of the trend analyses.

V.1. Pareto charts and analysis

V.1.1. Pareto principle

The Pareto principle is a mathematical model used to describe unequal distributions. It was discovered by Italian economist V. Pareto, who observed that 80% of the wealth in Italy was held by 20% of the people. The Pareto principle, or 80/20 rule, is a naturally occurring pattern that can be applied to any field. The Pareto principle helps us find the ‘big hitters’. Using the Pareto principle allows us to concentrate our limited resources on resolving/improving the big hitters which are creating the most problems. In this way, we can maximize the effectiveness of our improvement efforts.

There are six steps to conducting a Pareto analysis:

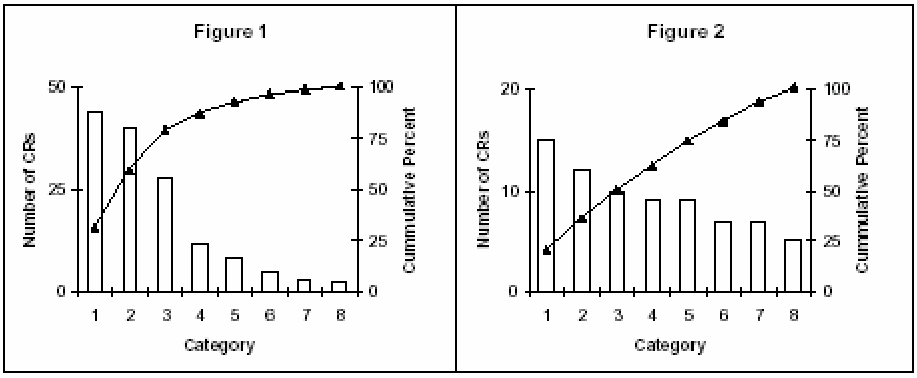
(1) Collect data (from initiated condition reports (CRs))
(2) Categorize data/problems (based on trend codes for ‘binning’ purposes)
(3) Specify a time period (e.g., a month)
(4) Calculate the cumulative percentage of each category, % = part/total
(5) Arrange each category in descending order
A Pareto chart depicts the problem or issue categories as bars. Problem categories are plotted in descending order (see the chart). The chart does not show how the data are changing over time. Therefore, once the big hitter categories are identified, each category should be plotted for the past 6–12 months as appropriate.
(6) Identify which problem categories comprise 80% (or approximately 80%) of the total. To apply the Pareto principle, there must be a concentration of problem categories. If the issues are distributed equally, then the 80/20 rule does not apply.

V.1.2.Pareto chart

A Pareto chart depicts the problem or issue categories as bars, and is a snapshot in time (e.g., a month). Problem categories are plotted in descending order (see the chart). The chart does not show how the data are changing over time. Therefore, once the big hitter categories are identified, each category should be plotted for the past 6–12 months as appropriate.

In Figure V.1, the first three categories constitute 80% of total issues. Therefore, the Pareto principle (or 80/20 rule) can be applied. The first three categories are the big hitters, and should be reviewed further. In addition, time series data should be plotted for these categories to see how each category trends over time (for example, see sample chart C in Attachment 5).

If the issues are not concentrated and are evenly distributed (as shown in Fig. V.2), the Pareto principle may not apply.



V.2. Control chart

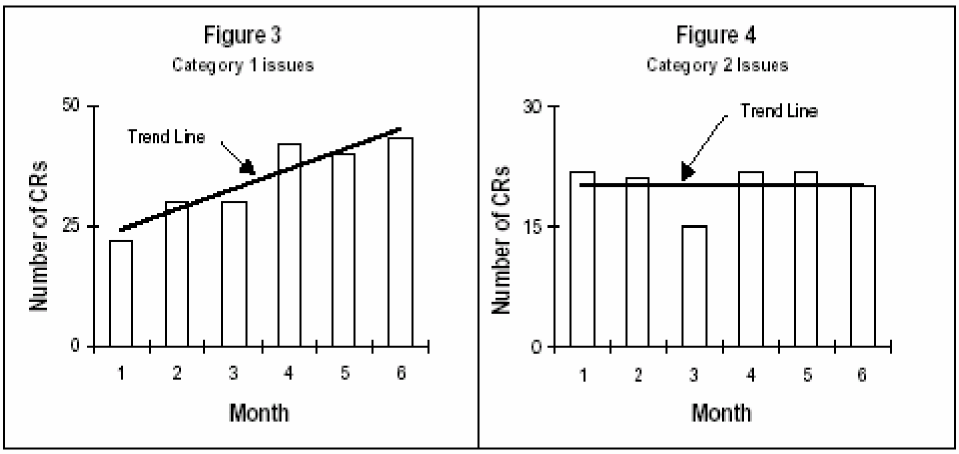
The control chart is a management control tool that shows results of measurements over a period of time, with statistically determined upper and lower limits. This tool can be used for both human performance and equipment performance issues.

(1) For each parameter (e.g., configuration control in the operations or design process, in engineering or material conditions) to be evaluated, determine the mean (average) number of CRs over a period of time (e.g., 6 months).

(2). Determine the standard deviation of the CR data set. The standard deviation is a measure of how widely values are dispersed from the average (mean) value. A statistical function is available in Excel for calculating the standard deviation of a population (STDVEP).

(3) When the number of CRs for a parameter is greater (or less) than 2 standard deviations above (or below) the mean, this area should be further reviewed/analysed to determine potential causal factors for the deviation.

(4). If there are insufficient data to determine a reasonable mean and a standard deviation, professional judgment should be used to make a determination of a trend.



V.3. Trend charting

The trend analyst may utilize appropriate charting and/or calculation methods to trend data to determine if a potential trend exists. The trend analyst analyses the available data for these areas, to identify which areas require more detailed investigation. If a system, programme or organizational trend is identified, the analyst should review the available data to focus attention on specific areas.

If the trend analyst normalizes trend data in order to provide for a more realistic analysis, the normalization method utilized should be clearly identified. For example, the analyst may choose to normalize a human performance error rate taking into account the total number of person-hours worked when analysing a department's event history.

APPENDIX VI. PROGRAMME FOR PROCESSING INFORMATION TO IDENTIFY TRENDS

The purpose of this appendix is to illustrate by a small selection of actual operating cases the importance of reporting, evaluating and trending low level events and near misses in order to prevent the occurrence of events which can be safety significant and may lead to unwanted radiological doses or have a negative impact on the economic performance of the plant.

The sections of this appendix comprise:

VI.1. Examples of the use of trend codes
VI.2. Example of a decision instrument for screening information
VI.3. Case studies
VI.4. Example of a method to analyse potential consequences of low level events and near misses.

Section VI.3. of this appendix contains case studies. In case study 1, an evaluation of twelve reported events of not following work procedures could have prevented the seven day delay in operation startup. Case 2 describes the lucky situation that the same operator who detected the failure of a light-bulb was in the daily morning meeting. Thus, he could give advice that further analysis of the event was needed. After performing the analysis, a serious modification error was revealed. In case study 3, trending of twelve delayed maintenance activities could have prevented the (almost) violations of technical specifications. Additional examples of illustrative cases are given.

VI.1. Examples of the use of trend codes

This section describes the necessity to determine a limited number of categories to classify low level events and near misses, and provides good practice for trend codes. To illustrate the application of trend codes, a set of examples is provided. We are using Appendix III as a reference

Example 1:

A craftsman is assigned to repack a valve on the auxiliary steam system. He assembles the required tool and materials and goes to perform the work. During disassembly of the valve, after the packing gland has been removed, the packing is blown out of the valve and the craftsman receives a steam burn on his hands. Investigation of this event showed the following:

- The valve to be worked on was not properly isolated for performance of the maintenance activity: Trend codes F.4, O.3.
- The supervisor did not discuss the task assignment with the craftsman: Trend codes A.1.a, A.2, H.1.
- The craftsman did not use the appropriate safety equipment to prevent burns: Trend code F.3.
- No written instructions that defined the task, safety precautions or work techniques were provided to the craftsman: Trend codes A.1.b, a.2, F.4.

Example 2:

A long standing material condition problem resulted in replacement of a safety related pump. The new pump was installed but failed within the first 30 days of operation. Investigation of this event showed the following:

- During plant operation, the replacement pump was not operating within its normal operating parameters: Ttrend codes M.2, N.1.
- The pump was installed in a vertical position, as against a horizontal position as required by the manufacturer: Trend code N.2.
- Repair parts to support the new pump had not been ordered to support the new installation:. Trend codes J.3, K.3.
- Training on maintenance of the new equipment was not provided: Trend codes I.2, G.4.

Example 3:

The operator and his supervisor conducted a pre-job briefing. After the brief, the operator reviewed the procedure and walked through the evolution. At that time, the telephone rang and the operator answered, then returned to the evolution in progress. He immediately put his hand on the wrong switch, operating the wrong valve.

Investigation of this event showed the following:

The operator became distracted when he answered the telephone. The operator failed to self-check his performance of the operation in progress when the telephone rang. Subsequently, he did not verify that his hand was on the proper switch prior to actuating the component. Trend codes D.1.a, E.2, F.2.a, F.3 and A.1.a, A.2, P.1.

Example 4: Malfunction of pressure limiting valves (low level event)

Through an in-service-inspection during an outage it was found that a pressure limiting valve did not open completely. A root cause analysis revealed that the lubrication grease has been hardening due to high temperature. Further inspections showed the same situation at other comparable valves.

Generally these valves are additional redundancies to safety and relief valves. In the case of an initiating event, only 3 out of 6 valves would have operated well, whereas a result of the plant specific PSA shows that 4 valves are necessary when all 8 safety and relief valves do not open (one of these valves is already sufficient). However, use of a specified type of grease, appropriate for the environmental conditions, would have avoided this situation. Trend code O.1.

Example 5: Loss of control of steam generator level and recovery (near miss)

The reactor was in shutdown condition. The auxiliary feedwater was in service. The operator adjusted the levels on the three steam generators and left to have a coffee. There was another engineer who saw that the levels had slowly drifted, and he called the operator. When the operator jumped to adjust the levels, they were very close to the boundary of automatic scram. Trend code E.2.

Example 6: Scram avoided by questioning attitude (near miss)

A control technician had to do tests on the four protective trains of the core. He began his test at train 1, which is located near the door. As he was called, he went out for a moment, and when he came back, he was about to open train 4 instead of train 1.

Explanation: He usually works on the other reactor of the same unit, and in this other reactor train 4 is located near the door. He remembered this just before opening the drawer of train 4 and stopped his action. Otherwise, the plant would have run into a reactor trip initiated by two drawers being opened simultaneously. Trend codes E.2, F.3.

Example 7: Near loss of site power (near miss)

After a loss of off-site power on reactor 3, application of the procedure requires the operator to go out of the control room, to the area where the contactors are situated. There he has to switch on the contactor manually, using a switcher.

He did not find the switcher in the area of reactor 3; therefore, he went into the area of reactor 4, found a switcher and connected it to the contactor of reactor 4. He was just pressing the button, but not closing the switch, when another operator said: What are you doing in the area of reactor 4? Trend codes E.2, F.3, I.1.

Example 8: Loss of main feedwater (near miss)

The reactor operated at 30% power. The field operator was testing one turbine driven main feedwater pump. The second turbine driven main feed pump was in operation. The last part of the test was to switch off manually the pump being tested. When the field operator turned the pump off, the pump did not stop because the operator in the control room had overridden the test. The field operator went to the control room to investigate the problem. After the field operator and the control room operator had resolved their problems, the field operator returned to the pumping station. When the field operator arrived at the pumping station, he did not initially verify the pump he was about to stop. As he prepared to push the stop button, he realized he was about to stop the only operating turbine driven main feed pump. Trend code F.3.

VI.1. Example of a decision instrument for screening information

One example of a decision instrument for initial screening of reported information is shown in the following. In this example, all incoming information, called condition report (CR), is checked against a decision tree. A matrix, given as Table VI.1, supports the decision making and can be used when reviewing and resolving conditions. Some typical condition level guidelines and examples to illustrate Fig. VI.1. are given in Figs VI.2((a)–(d)).

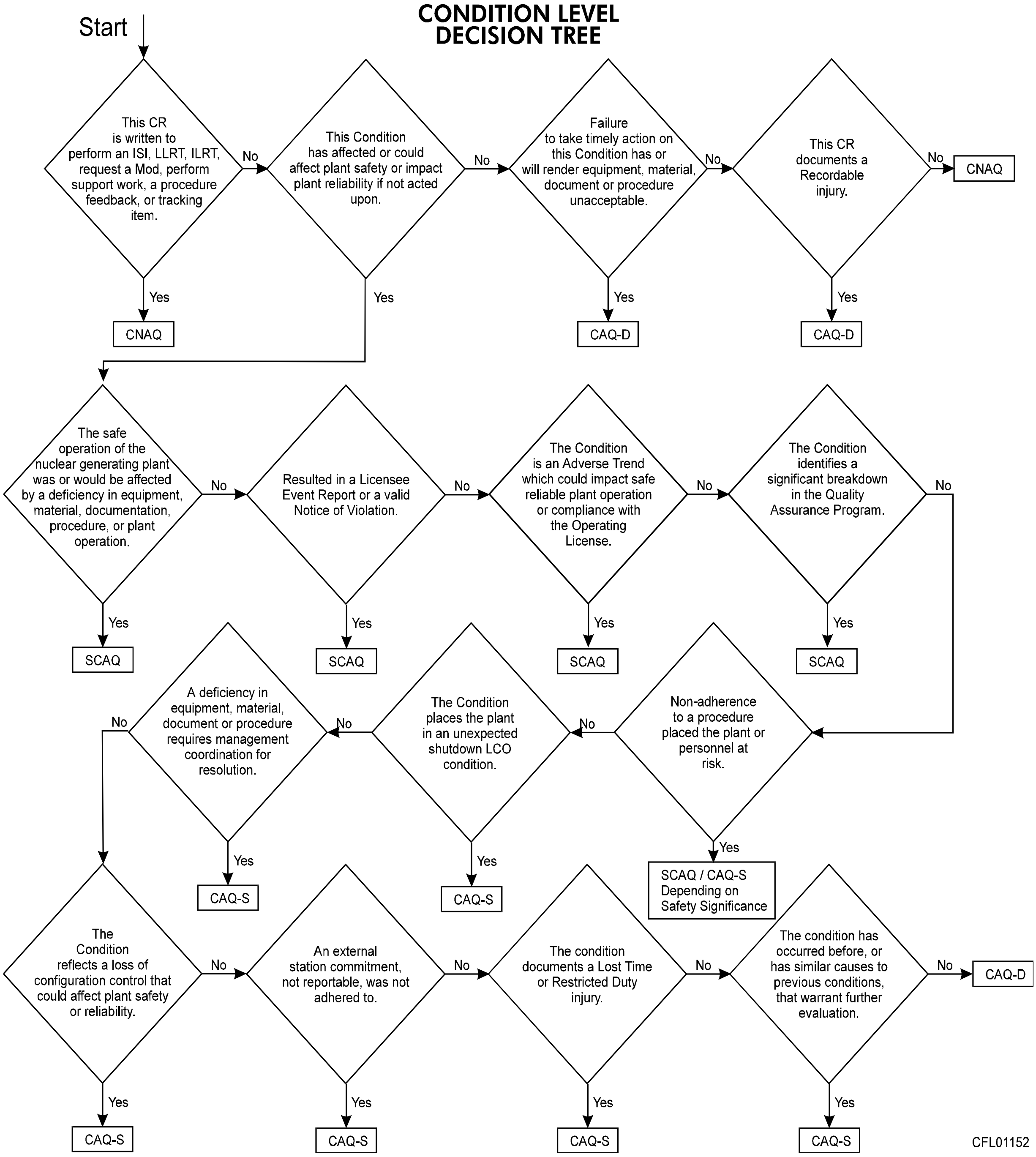


FIG. VI.1. Example of a decision tree for screening information for further detailed investigations.

CNAQ:	Condition not adverse to quality
CAQ-D:	Condition adverse to quality, department level
CAQ-S:	Condition adverse to quality, station level
SCAQ:	Significant condition adverse to quality.

TABLE VI.1. EXPECTATIONS CORRELATED TO DIFFERENT TYPES OF CONDITIONS

EXPECTATION	CNAQ[a]	CAQ-D[b]	CAQ-S[c]	SCAQ[d]
Review potential as precursor for more significant events, evaluate for higher level condition and upgrade as applicable	X	X	X	X
Evaluate the effect of the recurrences on the plant, and whether the recurrences are indicative of a problem that warrants additional action or escalation of the CR level		X	X	X
Consider condition applicability across departmental lines where appropriate; consider generic implications			X	X
Compensatory actions are taken until final corrective action can be taken		X	X	X
Recurrences of the same issue should be evaluated for consistent ownership			X	X
Obtain management (nominally division level or next level of supervision) review			X	X
Search plant history for trends to determine if the condition is recurring, including exceedance of thresholds				X
Include input from the right technical sources and appropriate stakeholders		X	X	X
Elevate conditions that cross departmental lines or have repeat occurrences to a higher level CR as appropriate		X	X	
Provide a reasonable level of assurance that the condition will not recur			X	X
Documentation should provide a logical progression of facts that result in a cause determination			X	X
Obtain department management review of the adequacy of cause determination and actions			X	X
Review industry operating experience for similar issues				X
Ensure that corrective actions are selected specific to the cause and will effectively prevent recurrence of the condition			X	X
Ensure the correct person is assigned, considering the scope of the condition			X	X
Assess implementation of corrective actions by performing a review that is discussed with management			X	X
Provide a high degree of confidence that the corrective actions are specific to the cause and ensure that the condition will not recur				X
Document clear methodical reasoning as to why the corrective actions will prevent recurrence				X
Verify and document the effectiveness of corrective actions by performance of an effectiveness review				X

[a]CNAQ: Condition not adverse to quality; [b]CAQ-D: Condition adverse to quality, department level
[c]CAQ-S: Condition adverse to quality, station level; [d]SCAQ: Significant condition adverse to quality

Condition not adverse to quality (CNAQ)

Guidelines

- Condition does not affect plant safety, reliability or public safety.
- Trending this condition adds no value to improving plant performance.
- Tracking of items.
- Requests for modifications, support, plant improvements, evaluations and suggestions.
- Non-consequential human performance issues.
- Injury requiring First Aid.

Examples

- Boxes returned to warehouse without packing material.
- Trash drum without a cover.
- Procedure feedbacks that are enhancements.
- Contamination monitor out of service due to high background.
- A need to correct non-consequential typographical or grammatical errors, or updating organizational assignments, in procedures.
- A need to make minor drawing changes which do not impact the technical content of the drawing.
- Errors in a proposed design or design change (on drawings, in the calculations, in specifications, etc.) which are discovered during the procedural design process by independent or supervisory review.
- ‘Actuated–closed’ power operated (motor, air, etc.) valves that have been backseated but which have a current engineering justification demonstrating that backseating is acceptable.
- Lost dosimeter.
- Database entry errors that have/had no impact but need to be tracked for recurrence.
- Components found out of position during in-process reviews (e.g. independent verifying activities for equipment clearance orders, operating procedures or surveillance procedures) which have/had no adverse effect on the facility.

FIG. VI.2. Condition not adverse to quality (CNAQ): guidelines and examples.

Condition adverse to quality, department level (CAQ-D)

Guidelines

- Procedure non-adherence that does not affect safe, reliable operation of the plant.
- Procedure non-adherence that does not affect personnel safety.
- A deficiency in equipment, material, documentation or procedure that does not affect the safe, reliable operation of the plant.
- A deficiency in equipment, material, documentation or procedure that does not affect personnel safety.
- A recordable injury.
- Repeat issues.

Examples

- Condensate system valve tags do not agree with P&ID labels.
- Badge for terminated employee is still active.
- Component returned to service without checklist signed by shift supervisor.
- Lube oil temperature setpoint calculated incorrectly.
- P&ID incorrectly identifies feedwater heater isolation valves.
- A potential environmental release path for transformer oil has been identified.
- Minor leakages in secondary steam systems which require routine maintenance to correct.
- Design basis for non-safety related equipment does not match field configuration.
- A typographical error in a procedure which could cause unintended actions to be taken.
- A worker slips on an oil spill and sprains his ankle, resulting in a recordable injury.
- The event was indicative of a quality deficit in the equipment clearance order (ECO) programme.
- The event was a non-administrative procedure violation of the ECO programme.
- Failure to obtain a fire breach permit when required.

FIG.VI.3. Condition adverse to quality, department level (CAQ-D) guidelines and examples.

Condition adverse to quality, station level (CAQ-S)

Guidelines

- A deficiency in equipment, material, documentation or procedure that requires management level co-ordination to resolve.
- The condition places the plant in an unexpected shutdown LCO condition.
- Procedure non-adherence places the plant or personnel at risk.
- Loss of configuration control that could affect plant safety or reliability.
- An external station commitment, not reportable, was not adhered to.
- A lost time accident or restricted duty injury.
- Repeat issues with generic implications.
- Recurrence of conditions adverse to quality that warrant apparent cause determinations and corrective actions.

Examples

- Increased rate of failure and corrective maintenance activities indicate reduced reliability of a piece of equipment.
- The setpoint for stator high temperature alarm is set incorrectly and the current configuration may not be adequately controlled.
- An individual entered the high radiation area on a wrong radiation work permit.
- Locked high radiation area door found open.
- Constant process flow for the unit vent noble gas monitor was undetected for 3 days; a repeat event.
- Failed surveillance test.
- Failure of communication equipment used for safe shutdown.
- Loss of configuration control, i.e. potential/actual valve/switch mispositioning event.
- Unplanned changes in reactor power or generator output.
- Design basis for safety related equipment does not match field configuration.
- A worker slips on an oil spill, breaks his leg, and is hospitalized for three days.
- An error in the equipment clearance order process posed a risk of personnel injury.
- An error in the equipment clearance order process posed a risk of equipment damage.
- The event describes a generic weakness in the equipment clearance order programme.

FIG. VI.4. Condition adverse to quality, station level (CAQ-S:) guidelines and examples.

Significant condition adverse to quality (SCAQ)

Guidelines

- Condition that results in a licensee event report or cited notice of violation.
- If left uncorrected, would affect plant safety, reliability, or public safety.
- Procedural barriers intended for plant safety were violated.
- Significant breakdown in the quality assurance programme.
- Life threatening industrial safety event.
- An adverse trend which could affect safe and/or reliable plant operation or compliance with the operating licence.

Examples

- While moving the fuel assembly, a thimble plug was knocked over.
- Adverse trend involving inadequate operational procedure accuracy.
- Unexpected objects found on lower core support plate.
- Individual radiation exposure greater than administrative or regulatory limits.
- During power ascension, main steam to de-aerator valve drifted open unexpectedly resulting in an uncontrolled power increase of 2%.
- Seven workers were severely burned when a steam line they were working on burst.
- The equipment clearance order event resulted in personnel injury.
- The equipment clearance order event resulted in equipment damage.

FIG. VI.5. Significant condition adverse to quality (SCAQ): guidelines and examples.

VI.2. Case studies

The purpose of this appendix is to illustrate by a small selection of actual operating cases the importance to report, evaluate and trend low level events and near misses in order to prevent events from occuring which can be safety significant, lead to unwanted radiological doses or have a negative impact on economical plant performance.

In case study 1, an evaluation of 12 reported events of not following work procedures could have prevented the seven day delay in operation startup.

Case 2 describes the lucky situation that the same operator who detected the failure of a light-bulb was in the daily morning meeting. Thus, he could give advice that further analysis of the event was needed. After performing the analysis, a serious modification error was revealed.

In case study 3, trending of 12 delayed maintenance activities could have prevented the (almost) violations of the technical specifications.

CASE STUDY 1

Initial plant conditions

- Plant is in a refuelling outage.

- Reactor core reload is complete.
- Reactor vessel reassembly is complete.
- Reactor coolant system is at reduced inventory to facilitate the removal of steam generator nozzle dams.
- Safety injection surveillance testing on train B is in progress.

Event

At 5:30 p.m. a safety injection initiation signal is received. The plant emergency diesel generators start and the associated electrical busses are de-energized, then re-energized as the diesels load electrically.

The initial investigation showed that a train A safety injection initiation signal had been received from the reactor protection system.

Analysis of the event

Analysis of this event showed that the reactor operators performing the safety injection system surveillance test on train B were actually working in the train A safety injection system cabinet.

When the operators recognized their mistake, they attempted to back out of the test following the procedure steps in reverse order. While repositioning the train A safety injection test switches with safety injection train B in test, the safety injection logic was satisfied and initiation took place.

Further analysis of this event identified:

- During the previous six weeks operators had performed surveillance tests on the wrong system or component four times.

- The need to perform self-checking prior to starting any test or evolution was not stressed at the pre-evolution briefing. This failure to self-check had resulted in seven valve and four breaker mispositionings during the previous month.

- Procedure non-adherence had been a recurring problem throughout the refuelling outage. Twelve events had been reported during the previous six weeks.

Because no significant consequence was associated with the previously mentioned events, these events were considered as isolated cases or near misses, and therefore no corrective action was taken.

When the utility looked at the above mentioned information, it realized that in the previous six weeks 27 opportunities (previous low level/near miss events) to prevent this event had been overlooked.

Had these events been tracked and trended using a programme similar to that identified in Appendix III of this publication, the need to initiate corrective actions would have been identified and action taken.

This action would have strengthened/re-enforced self-checking techniques and expectations, which may have prevented additional wrong train and valve mispositioning events. Had procedure adherence been discussed during the pre-evolution briefing, the operators would have informed the control room that they were working on the wrong train, and appropriate compensatory action would have been discussed.

The restart of the reactor was delayed approximately seven days while additional corrective actions were taken to resolve the noted problems. The lesson learned by the utility is that tracking and trending of the lower tier events will identify adverse trends in human performance, which, if corrected, will help to prevent more significant events.

CASE STUDY 2

Many plants in eastern Europe were built according to Soviet design. The norms (technical requirements) are(were) different from national norms. There are, in these nuclear power plants, some exceptions to the rules.

In one of them (a PWR), there were modifications to the essential electricity supply system. Old equipment was changed by new one. All changes were prepared with 'high responsibility' in time. Everything was successful and everybody was happy. But, nevertheless, an event occurred. It is described below.

Initial plant conditions

- The unit is in full power mode.
- Train B has new electrical equipment (trains A and C have still the old one).
- Periodical testing of train B (1/3 safety systems) is in progress.

Event

During the routine periodical test, one I&C worker tried to check the condition of the electrical bulbs (fortunately or not, the train was in test condition) and the whole train was switched off. Nothing happened.

In the morning meeting it was announced that the whole train was switched off without any consequences during the routine test.

As a result, a work order to the maintenance department to check the condition was written.

Analysis of the event

After a detailed analysis was made, it was discovered that everything was done according to the norm, but according to the national norm, and at the connecting point there were different connections to the ones before between the new and the old part of the equipment. The old part was still supplied according to the original standard scheme. When the train was in normal operation status, the event did not occur. It was discovered a few months after finishing the work.

- Discussion with I&C people: a similar situation had happened a month ago (a short description was found in the I&C log; no special event report was written).
- Next day the result of the maintenance activity was known:
  - a special meeting of I&C, electricity, operation and maintenance people was organized,
  - people from the technical department were invited,
  - results of corrective actions for the process of modification were suggested.

Necessary corrective actions were taken immediately. During investigation of the event it was found that there were many low level discrepancies in the modification process. These had been found two times before, but countermeasures were not taken.

A reporting system without low level barriers and criteria did not catch a single non-safety-significant event (the burning fuse) which had hidden weaknesses in the process of modification.

CASE STUDY 3

Initial plant conditions

The plant is operating at 100% power and has taken train A of essential cooling water out of service for maintenance. This places the plant in a 72 hour shutdown action statement.

This maintenance activity has been on the plant maintenance schedule for 12 weeks. The final schedule was locked down three weeks prior to the scheduled start date.

Following plant policy, during the three week period prior to the scheduled activity the maintenance supervisor walked down the work, verifying that all the necessary repair parts and work documents were correct and available.

Event

Work on the train A essential cooling water pump was in progress. The pump packing had been removed and the mechanic was preparing to install the new packing. When the mechanic removed the packing from the material staging area, he noted that he had removed 12 rings of packing from the pump and only 8 rings of packing were available to be re-installed.

He immediately informed his supervisor, and additional packing was obtained and the pump returned to service prior to expiration of the limiting condition for the operation action statement. The pump was scheduled to be out of service for 48 hours; the actual return to service of the pump was delayed for approximately 8 hours. (Total out of service time for the pump was 56 hours.)

Analysis of the event

Investigation of this event showed that the supervisor had not done a physical verification of the necessary repair parts, that he had relied on the material requisition form to verify that the necessary repair parts were available.

Follow-up investigation in the condition reporting database, using trending codes, as explained in Appendix III, identified 12 instances in the preceding three months where the return to service of technical specification related equipment had been delayed because the necessary repair parts were not available. Additionally, 32 non-technical-specification-related equipment schedule performance problems, related to repair parts, were identified.

Therefore, further investigation was necessary to understand the event and the generic implications. The subsequent investigation showed the following:

- In 8 of the 13 events identified in this report, the supervisors had relied on the material requisition form to ensure that the necessary repair parts were available. (The remaining five delays were the result of increased work scope.)
- Six supervisors were involved in the eight limited condition for operation related events being reviewed.
- 80% of the remaining shop supervisors were involved in the 32 non-technical-specification-related equipment events identified.

Results of more in-depth investigation

The results of this more in-depth investigation showed that the major contributor to this event was the fact that the plant was going through a downsizing effort. As a result of this effort, additional administrative burdens such as time keeping, maintenance of personnel logs and development of training schedules had been assigned to the maintenance supervisors.

The use of trending showed that this was not an isolated case; subsequently, discipline was not imposed, but corrective action was taken to reduce the administrative workload on the maintenance supervisor, allowing the supervisors to focus on their primary assignment of ensuring that scheduled maintenance activities are ready to work as scheduled.

Cause of the event

The root cause of this event was ineffective change management; the full impact of the reduction in the administrative workforce and the shifting of the administrative workload to the maintenance supervisors was not fully evaluated prior to implementation.

APPENDIX VII. EXAMPLE OF ENHANCING SAFETY CULTURE BY ENCOURAGING ALL PERSONNEL TO REPORT LOW LEVEL EVENTS

As indicated in Section 3, the general approach to safety culture can be enhanced if low level events, small degradation and near misses are discovered and reported by all plant personnel. As an example, all maintenance workers should internally report any low level events. However, these workers are usually not trained to identify precursors to safety problems. They have generally a good training to identify the precursors of work accidents, but work accident precursors and safety accident precursors are different.

There are two items which must be taken into account: work safety and nuclear safety during operation.

Work safety type analysis	Nuclear safety type analysis
The problem is essentially LOCAL (limited to the work area).	The problem occurs at the GLOBAL level of the plant (extended to the interactions of all the systems of the plant).
There is a lot of operating experience feedback, and the analysis is based on it.	There is no operating experience feedback (serious nuclear accidents).
Little or no method, in any case no model; analysis based on 'self-experience'.	Methodology of analysis based on deterministic, probabilistic safety methods.
All the employees are interested.	Only the safety specialists are interested.
Knowledge is based more on classical functional analysis.	Knowledge is based more on PSAs and human reliability analysis.

Some of the current methods of preliminary work analysis contain elements that can be used for nuclear safety analysis. However, they do not seem to be adapted as a whole case to the problem at hand. It would be a mistake to simply transpose what is usually done for work safety to the nuclear safety. Work safety methods are generally designed for resolving the problem of risk from the point of view of work safety (agents, the job site, or the system directly concerned by the job at hand). Nuclear safety analysis poses a completely different problem and can even lead to contradictory conclusions. For nuclear and work safety together, the problem is more difficult and compromises are often impossible.

As far as nuclear safety analysis is concerned, it seems that the problem is essentially caused by a fault in the global view of the system. However, this global view of the system is very difficult to perceive. In particular, it has been noticed in incident analyses that even nuclear safety specialists missed this point, but PSA models give them the solution.

Therefore, there are two methods and two different objectives, which are explained in the following example.

A maintenance craftsman identified a material deficiency on a charging pump suction flange. Based on his experience he knew that fixing this deficiency would take about 5 minutes. Therefore, he gathered his tools and started to work. The control room was not aware that maintenance was in progress on the charging pump. So the control room operator performed an automatic test of the pump suction valve. When the suction valve opened, water from a refuelling water storage tank flooded the building.

The investigation of this event showed:

The craftsman wanted to do a good job, but he did not see how his actions could be the origin of a safety event. This event identifies the need for risk awareness and a good safety culture that must be supported by a global vision of the plant.

APPENDIX VIII. MONITORING EARLY SIGNS OF DECLINING PERFORMANCE

Prompt assessment of OEF process effectiveness is also possible by monitoring the early signs of declining performance. Industry experience has shown that areas to consider when looking for the early signs of declining performance are:

- Corporate coverage, supervision and support.
  - Do board of directors receive reports that accurately reflect plant performance?
  - Are problems detected or issues raised prior to prompting by outside organizations?

- Nuclear management capability
  - Is the senior plant management team experienced in nuclear power operations?
  - Does the plant develop future plant managers?
  - Do recurring problems persist after corrective action is taken?
  -

- Operating philosophy and strategy
  - Can the staff incorporate the value, vision and standards of the organization into their own work, do they apply them to their daily activities?
  - Do operators go to extraordinary measures to keep the unit operating?
  - Over the past several years, how many reactivity events have occurred? What is the trend in these events?
  - Is the total impact of inoperable automatic functions, equipment and operator workarounds assessed, and appropriate compensatory action taken?

- Learning organization (self-evaluation/corrective action effectiveness)
  - Can station management and staff compare the plant's performance to the rest of the industry?
  - How often do outside organizations identify issues the plant is not aware of?
  - Does the plant wait for outside organizations to identify problems before making a change?
  - Does the plant use its own and industry operating experience to improve?

- Staff capability
  - Do the members of the nuclear staff support the operating philosophy, strategy and established policies?
  - How do the managers ensure that work is done thoughtfully and carefully?
  - Has the turnover of personnel increased, especially of many good employees? If so, why are they leaving?

- Implementation of results
  - Over the past few years, what is the trend in, e.g., reactivity events, and how do they compare to other plants? Has the plant taken strong action to reduce their number and significance?
  - What is the trend in equipment problems? Does the trend of unplanned capability loss factors reflect reliability problems when compared with an overall set of performance indicators?
  - Are small negative performance trends being monitored?
  - Do corrective actions address people? processes? the organization?

When the outcome of such an assessment suggest the onset of degraded safety performance, the regulator may provide guidance for those who are supervising the nuclear power plant.

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DEFINITIONS

event. In the context of the reporting and analysis of events, an event is any unintended occurrence, including operating error, equipment failure or other mishap, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

near miss. A potentially significant event that could have occurred as the consequence of a sequence of actual occurrences but did not occur owing to the plant conditions prevailing at the time.

root cause. The fundamental cause of an initiating event which, if corrected, will prevent its recurrence, i.e. failure to detect and correct the relevant latent weakness(es) and the reasons for that failure.

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