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Best Practices in the Organization, Management and Conduct of an Effective Investigation of Events at Nuclear Power Plants

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FOREWORD

IAEA Safety Standards Series No. SF-1 entitled Fundamental Safety Principles: Safety Fundamentals states the need for operating organizations to establish a programme for the feedback 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, lessons learned are disseminated to the staff of the organization and to the relevant national and international organizations, and corrective actions are effectively implemented.

This publication has been developed to provide advice and assistance to nuclear installations, and related institutions including contractors and support organizations to strengthen and enhance their own feedback process through the implementation of best practices in organization, management and conduct of an effective investigation of events.

Conducting an effective investigation of events is essential in supporting a proactive safety management approach of preventing events from occurring. Event investigation is the heart of the operating experience feedback programme and in an operating organization it is essential to develop and maintain necessary expertise in this area. Experience has shown that it is not sufficient to identify only the direct causes of an event and the event is bound to recur unless all the root causes and casual factors for an event are identified and necessary corrective actions are developed and implemented.

The present publication is the outcome of a coordinated effort involving the participation of experts of nuclear organizations in several Member States. It was developed to further elaborate on how to implement the event investigation requirements in the area of feedback of operating experience, as specified in the IAEA Safety Requirements publication NS-R-2 on Safety of Nuclear Power Plants: Operation. This document will also complement the publication IAEA Services Series No. 10 – PROSPER Guidelines – Guidelines for Peer Review and for Plant Self-Assessment of Operational Experience Feedback Process and it is intended to form part of a suite of publications developing the principles set forth in these guidelines. Other publications of this suite are: IAEA-TECDOC-1477, Trending of Low Level Events and Near Misses to Enhance Safety Performance in Nuclear Power Plants; IAEA-TECDOC-1458, Effective Corrective Actions to Enhance Operational Safety of Nuclear Installations; IAEA-TECDOC-1581, Best practices in Identifying, Reporting and Screening Operating Experience at Nuclear Power Plants; and IAEA-TECDOC-1580, Best Practices in the Utilization and Dissemination of Operating Experience at Nuclear Power Plants.

The IAEA wishes to thank all participants and their Member States for their valuable contribution. The person responsible for the preparation of this publication was S. Fotedar of the Division of Nuclear Installation Safety.

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1. INTRODUCTION

1.1. Background

Operating experience is a valuable source of information for learning and in the process improving the safety and reliability of nuclear power plants. One of main elements of this process is the investigation of the events so as to identify various root causes which were responsible for the event. Unless root causes are properly identified and corrective actions implemented events are bound to recur and in the process affect the safety and reliability of the nuclear power plant.

The Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1 [1] states the need for establishing the processes for the feedback and analysis of operating experience, including initiating events, accident precursors, near misses, accidents and unauthorized acts, so that lessons may be learned, shared and acted upon.

The IAEA Safety Requirements publication NS-R-2 on Safety of Nuclear Power Plants: Operation [2] establishes in paragraph 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 their direct and root causes. The investigation shall, where appropriate, result in clear recommendations to the plant management, which shall take appropriate corrective actions without undue delay. Information resulting from such evaluations and investigations shall be fed back to the plant personnel."

The IAEA Safety Guide NS-G-2.11 A System for the Feedback of Experience from Events in Nuclear Installations [3] states in paragraph 2.8 that "an effective system for the feedback of operational experience relating to safety should cover ... investigation of events; [and] in-depth analysis, including causal analysis, of safety significant events".

Reference [3] in paragraph 4.2 also specifies that "the operating organization or licensee, as appropriate should have procedures in place specifying the type of investigation that is appropriate for an event of any particular type. Such procedures typically outline the conduct of an investigation in terms of means of initiation, duration composition of investigation team, terms of reference for the investigation team and format of final report."

Effective use of operating experience (OE), both internal and external, requires an effective investigation process for the analysis of events to identify fundamental weaknesses in the plant organization, equipment (i.e. structures, systems and components), procedures and human performance. The outcome of an effective investigation yields the identification of appropriate plant or facility specific corrective actions that will minimize the likelihood of similar events occurring.

1.2. Objective

This publication has been developed to provide advice and assistance to regulatory organizations, nuclear utilities, individual nuclear plants and other relative institutions to strengthen and enhance their own OE feedback process. This is achieved through the implementation of best practices for the organization, management and conduct of effective event investigations. It is recognized that alternative means exist and that an organization can effectively achieve this overall performance objective without meeting the specific criteria, attributes or practices described in the present publication.

1.3. Scope

This publication describes best practices regarding the investigation of events to ensure that it is effectively organized and conducted to determine the direct causes, root causes, contributing factors, lessons learned to improve safety and prevent recurrence of the problem. The publication also provides guidance on the organization for the collection of data and information after an event has occurred, to support the application of a root cause analysis.

In this sense, the publication concentrates on how to organize and perform an investigation for the effective collection of information to determine why the event happened and determine what are the lessons learned to preclude recurrence.

This publication provides recommendations on how to perform an effective event investigation and provides advice on selecting and using root cause analysis techniques for different events. The publication does not include the detailed description of the root cause analysis methodologies or creation of corrective actions. The reader is referred to IAEA-TECDOC-1278, Review of Methodologies for Analysis of Safety Incidents at Nuclear Power Plants [4] and IAEA-TECDOC-1458, Effective Corrective Actions to Enhance Operational Safety of Nuclear Installations [5] for more information on these topics.

Every nuclear utility/NPP has its own OE process. Figure 1 shows a flow chart of a typical OE process. In order that the OE process of the NPP is effective, a set of key activities has to be carried out (Fig.1). Each of these activities is regarded as essential and the OE process will not be effective if any of them is omitted or inadequately performed. The present publication focuses on the investigation of an event. It is not intended to cover other relevant stages of an effective operating experience programme.

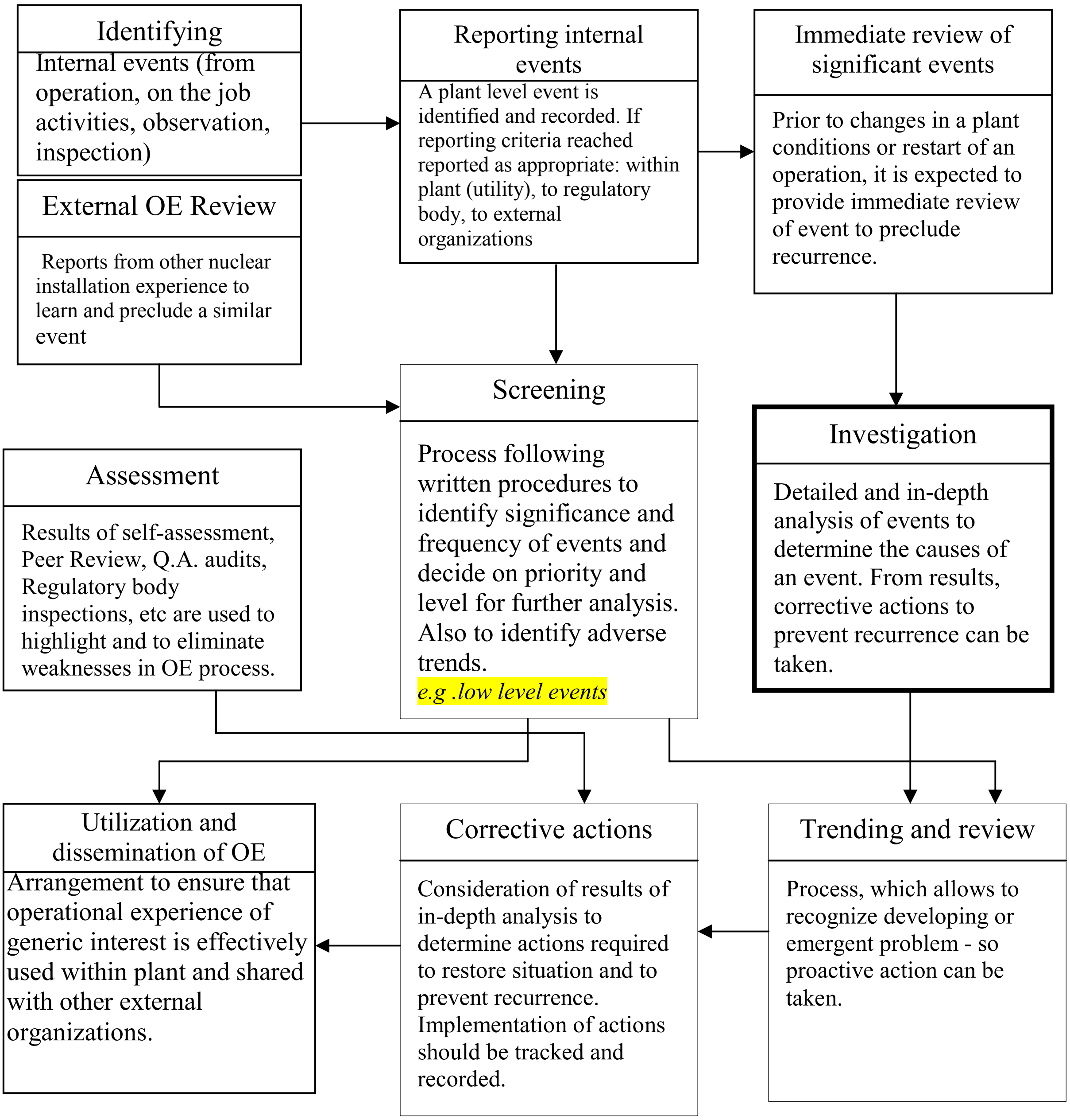

FIG 1. Flow chart of a typical OE process.

1.4. Essential management characteristics

A primary responsibility of management is to develop a culture and establish organizations and programmes to perform effective investigation of events at their respective nuclear sites. The management culture necessary for a successful programme is not only focused on what happened, why it happened and what facility will do to correct the issue but to also ensure that corrective actions to prevent recurrence are implemented and assessed to ensure they are effective.

1.4.1. Overall characteristics

The investigation of events is effective when the following overall characteristics are adequately addressed:

- Commitment from management to provide required resources, set the initial scope and to grant the authority to the investigation team in order to improve safety;
- Policies, guidelines and objectives established by management to align the organization to effectively implement the process and to establish expectations and priorities;
- Investigations are performed in a timely manner and results are reported to the relevant level of management for taking appropriate actions.

Additional requirements for an effective investigation of significant events (those requiring a root cause analysis) are:

- Independence of the team from the line organization (while not essential, it is desirable);
- Knowledgeable personnel in the team, including technical experts and facilitators who are experts in investigation techniques and organizational and human aspects.

1.4.2. Role and responsibilities of management

Management is responsible for the following:

- Establishing and implementing an event investigation process within the management system;
- Providing appropriate resources;
- Selecting the lead investigator with authority to communicate with the manager having the ultimate responsibility;
- Ensuring trained personnel and providing ongoing retraining and complementing with external experts if required;
- Providing access to information to conduct the investigation;
- Protecting the investigation team from any external or internal pressures, such as undue time pressures, pressures from involved line organization or peer pressure, etc.;
- Promoting an open communication in support of the investigation team;
- Support a non punitive culture;
- Verifying the accuracy of the draft report without influencing the course of the investigation.

2. EVENT INVESTIGATION

In order to provide an adequate framework to conduct an investigation, the investigating organization must select the methodology that will be fully supported. This is required to ensure that a common understanding and acceptance of the methodology is in place. Further, this will facilitate adequate level of training to the team leaders and others appropriate to their role on the team.

2.1. Training and competence

Training and competence are prerequisites for members and potential members of the investigation team. Investigation training includes (as a minimum):

- Root cause analysis methodologies;
- Investigation techniques;
- Human and organization factors.

Also personnel involved in the investigation of events keep the knowledge and competence up to date by participating frequently in event investigation.

2.2. Levels of investigation

According to IAEA-TECDOC-1581 on Best Practices in Identifying, Reporting and Screening Operating Experience at Nuclear Power Plants [6], events are classified in three categories: significant events, near misses and low level events:

- In the case of a significant event, a team is brought together to perform a root cause analysis;
- In the case of near misses and low level events, a simple investigation may be conducted to determine the apparent cause of the event;
- All events (including near misses and low level events) are used for trending. Trending of events over a period of time may identify common cause events that warrant a root cause analysis.

The criteria to determine the level of an event are to be taken from organization's technical specifications and supporting procedures. All incidents are screened against some pre-defined categorization system to determine the level of investigation necessary. While on some events management may be able to use their discretion not to perform a root cause, these exceptions need to be carefully trended to ensure that systemic programme weaknesses are not developed. Examples of event investigation hierarchy levels are provided in Appendix I.

2.3. Timing of the invesigation

2.3.1. Preparation of the investigation

As soon as the event investigation team has been constituted, the scope of the investigation and roles of the team members are documented. A presentation of the available information is given to the team and initial discussion on the approach to the investigation is carried out.

2.3.2. Initiation of the investigation

Investigations are conducted on a timescale consistent with the safety significance of the event. It is essential that for any event the investigation start as soon as possible. The best results will be obtained if the event investigation begins prior to end of the shift in which the event occurred. An event notification form is used to document the initial event, including key parameters such as plant status and other observations (see Appendix II for an example).

2.3.3. Key points of an investigation

By starting the root cause analysis as quickly as possible, recommendations can be addressed to line management to reduce the probability of similar events until the corrective actions to prevent recurrence can be implemented.

The main points of an event investigation and subsequent report can be summarized as:

- Definition of the event (captured through the event notification form);
- Collection and documentation of supporting information (using various techniques such as plant parameters, log books, interviews, etc.);
- Analysis of data, including both technical and human performance factors;
- Cause determination (apparent, contributing and root causes);
- Determination of safety significance and extent of condition;
- Communication of findings to management;
- Self-assessment of the investigation.

Details on the content of the event report are given in Section 6.3.

2.3.4. Completion of the investigation

It is important that an event Investigation be completed accurately and timely. International industry reference uses 20 weeks time period for completion of all the investigation work. Best practices, however, have completion dates well within this time frame. Failure to complete an event investigation in a timely manner may result in such issues as recurring events, loss of management attention, and loss of focus of the investigation team. The completion of the investigation takes place with the approval of the final report with the results of the investigation.

Results from the event investigation are recommendations for corrective actions to avoid recurrence and occurrence of similar events, which is the ultimate goal of root cause analysis. The organization is responsible for implementation of the corrective actions [5].

3. PREPARING FOR THE INVESTIGATION

In the following chapter the main attributes of a project management approach to starting an investigation will be described. Some of these attributes may not be necessary for investigation of less significant events.

3.1. Assigning an investigation team leader

Once it has been decided that a root cause analysis is to be performed, one of the first steps in conducting the investigation is to select an investigation team leader. The leader possesses a wide range of skills including: investigation techniques, leadership, report writing, root cause analysis, and wide ranging human, organizational and technical knowledge. It is a best practice that a team leader is selected from an OE programme.

3.2. Defining the scope of the investigation

The first activity of an investigation is to define the scope of the investigation. This can be achieved under a formal agreement between the team leader and the senior management. The scope should include overall goal of the team and specific objectives for each member of the team. As new information becomes available to the team this objective may be modified. At this point, it is also a good practice to identify any specific issues that are left outside of the investigation scope, and sustain this decision.

3.3. Composition of the team

The team leader in conjunction with management selects the team. The team includes specialists with technical skills in appropriate fields to cover all aspects of the investigation including human and organizational factors.

It is not recommended that one individual, alone, be given the duty of conducting a root cause analysis, except for investigation of less significant events. Team dynamics and interaction will improve the quality and timeliness of root cause analysis. Therefore, the size of the event investigation team needs to be appropriate for the level of the investigation (see appendix I).

In order to ensure objectivity for all the investigations, the team is supported by highest level of management to avoid any external pressure.

Organizational independence of the team becomes more important with the increasing significance, scope and time schedule of the event investigation. The size of the team may also increase accordingly because of the need of specific technical specialists in areas such as metallurgy and non destructive inspection, etc.

3.4. Management of the investigation

An investigation is a part of the OE process, but project management techniques may be used to improve the efficiency and quality of the investigation process. This is more important for complicated or large investigations.

Typical attributes to consider are:

MANAGEMENT
- Planning;
- Resource allocation;
- Assigning roles and responsibilities;
- Logistic;
- Schedule and milestones.

INVESTIGATION
- Reporting;
- Coordination of activities;
- Intermediate approvals.

DELIVERABLES
- Assessment of the technical, managerial, organizational and human issues involved;
- Recommendations or suggestions to address the causes found;
- Proposed corrective actions.

As early as possible after the investigation team has been selected, the team needs to ensure everyone has a consistent understanding of the event description, preliminary information available and the project plan.

4. COLLECTING THE INFORMATION

One of the first steps to be taken for a root cause investigation is the collection of information. Information in this case is a broad category which includes the facts, data, evidences, testimonies, etc. relating to the event that is collected and evaluated to help determine the root cause(s) of the event.

4.1. Types of information to be collected

From the collected information, we gather the facts, and search for the evidence to sustain them. There are three main types of information to be considered:

(a) Physical evidence

Physical evidence includes: equipment, components, tools, liquid samples, computer disks, personnel protective equipment worn during the event, debris, etc. Physical evidence could even include for example laboratories testing for determination of fitness for duty issues. Sometimes the investigation team may require analysis from specialized laboratories.

The inspection of physical evidence must not result in altering the evidence. When it is necessary to remove physical evidence, it should be done in a controlled, careful and methodical manner.

(b) Documentary evidence

Documentary evidence includes all documentation related to the event, such as operating procedures, logbooks, internal and external operating experience, etc.

It is really important that the documents used during the work (preferably originals if not certified copies) are collected as quickly as possible since these documents may be altered or lost.

(c) Personnel evidence

Information collected from personnel is usually very important in order to understand what happened, but needs to be confirmed before it is used as evidence. Witness recollection declines rapidly after an event, therefore, it is important to start the investigation as soon as possible.

Personnel information includes, information obtained from interview and related directly to the event (testimony) and information on personal history such as training, working environment, individual experience etc.

4.2. Preserving the evidence

One of the critical issues to be resolved during evidence collection is the balance between evidence preservation and plant recovery efforts. It’s extremely important to preserve evidence in its failure condition to be able to conduct a successful analysis. In order to preserve some physical evidence it is necessary to collect this evidence as soon as possible after the event, thus reducing the opportunity for unauthorized or unintended removal, corrosion or alteration. This may require securing or placing in quarantine, the event scene and/or certain pieces of documentary or physical evidence; i.e.:

Obtaining any perishable data such as;

- Temperatures, pressures, radiation levels, water levels;
- Chemical samples from equipment;
- Pictures and videos of the scene.

5. SELECTING THE EVENT ROOT CAUSE ANALYSIS METHODOLOGIES AND TOOLS

Several root cause analysis methodologies have been developed by different organizations and in different countries to support the investigation of events. Some of these methodologies use check lists with pre-determined categories of root causes which help to simplify and streamline the analysis but at the same time limit in some way the domain of associated outcomes or may provide excessive focus in a pre-determined area. Most of these methodologies use similar tools, although their taxonomies will differ. Expertise on several methodologies within an organization is beneficial. Professionally applied, they should all produce reliable findings and conclusions.

Certain methodologies are widely available and unrestricted (like HPES), whereas others are integrated systems and require a licence (MORT).

Most integrated methodologies use a combination of tools (e.g. barrier analysis, change analysis and event and causal factors charting). These tools are described more fully in section 5.2. The following sections briefly describe several methodologies and tools commonly used in the industry; however, others may also be available

5.1. Methodologies

A methodology is an integrated system of conducting a root cause analysis. It usually has its own taxonomy, and is one way of organizing the facts and findings in order to arrive at a logical set of findings and conclusions. The tools described in section 5.2 complement these methodologies.

Following is a list of some commonly used methodologies:

(a) HPES (human performance enhancement system);
(b) MORT (management oversight and risk tree);
(c) SOL (Sicherheit durch organisationales Lernen);
(d) ASSET (assessment of safety significant event team);
(e) MTO (MAN, TECHNOLOGY, ORGANIZATION).

(a) Human Performance Enhancement System (HPES)

HPES is a methodology developed by Institute of Nuclear Power Operations (INPO). It is widely distributed within the nuclear industry. It is user friendly and makes extensive use of graphic representation. For these reasons other methodologies similar to HPES have been developed based on this technique and adapted as necessary by different organizations for their specific needs.

This methodology utilizes event and causal factor charting in which the tools of the barrier analysis, change analysis and cause and effect analysis have been graphically incorporated into the same chart. The integrated graphic shows the direct causes, the root causes, the contributing causes, the failed barriers with their interconnections and dependencies. Although valid for all types of issues (technical, procedural, etc), the methodology is oriented to enhance the determination of the human performance issues. A Human performance specialist is recommended to be part of the team. Nevertheless, due to its systematic approach, the methodology can be very well used after a short practical training by non specialists. The team members are kept current with the technique by frequently practising the methodology and participating in investigation teams. This methodology is mostly used for significant events. The HPES system is useful to help question potential contributing causes that may be initially outside the mindset of the investigator. A full analysis typically requires 200-300 man-hours on average. Lower level events can be investigated in a simplified format with less resource.

(b) Management Oversight and Risk Tree (MORT)

The MORT methodology is utilised for significant events for which organization and management issues are apparent. The implementation of this technique presents a certain complexity which requires expert users with a relatively higher expenditure of man-hours and resources for the investigation. It is based on developing the analysis through several interconnected fault trees each one representing a domain of investigation. A predetermined check list of around 100 generic problems and 200 basic causes is utilized. Some versions of this technique were registered as a commercial product and are supported by software to expedite the diagnosis.

(c) Sicherheit durch organisationales Lernen (SOL)

SOL was initially developed by the University of Berlin in collaboration with the TÜV. It requires a multidisciplinary team in order to ensure a wide approach. It covers the identification of human factors as well as technical, organizational and management factors. During the first phase of the analysis the event objective data is collected, without questioning its significance. In the second phase the data is organized in elements of the event as individual actions performed by the personnel, organization unit or by the systems. This is then classified chronologically by each person and represented in a graphic actor-action-time. The methodology uses a predetermined set of direct causes and contributing factors. On the basis of the selected direct causes the method proposes questions to be addressed to help identifying the contributing causes. These elements are successively added to the graphic actor-action-time facilitating in this way the progress of the investigation and the further collection of information.

(d) Assessment of Safety Significant Event Team (ASSET)

ASSET is an IAEA methodology developed for investigating events of high significance with related managerial and organizational issues. Issues and corrective actions identified by ASSET methodology are often at high level, more applicable to management policy and philosophy, and of a generalized nature. However, this methodology is no more used by IAEA.

(e) Man-Technology-Organization (MTO) Investigation

MTO is a systemic theory with a focus on the interactions between man, technology and organizations. This methodology leads to the identification of root causes related to human and organizational factors. MTO-investigations are similar to HPES. The methodology consists of event, cause, derivation, barrier and consequence analysis. To structure the process events and causal factors flow-charts are used.

MTO investigations are mostly used for significant events related to human and organizational factors. Proper training in the application of MTO is required to conduct an MTO investigation.

The common objective of all these methodologies is to determine:

- What was expected;
- What has happened (real consequences);
- What could have happened (potential consequences);
- Cause-effect relations;
- Faulty/failed technical elements (structures, systems or components);
- Failed or missing barriers;
- Inadequate procedures;
- Inappropriate actions (Human, management, organizational).

And subsequently to identify:

- Direct causes;
- Contributing factors;
- Root causes;
- Common causes;
- Lost opportunities;
- Recurrent causes from previous events.

The results of the analysis are essential to establish and implement the effective corrective actions to preclude the recurrence of the event.

5.2. Tools

Once the team leader has defined the level of investigation to carry out and has assembled an investigation team, an adequate combination of methodologies or tools are selected based on the nature of the event. An investigation tool is a technique which has been developed through experience to uncover a specific type of cause or causal factor. Best practices indicate that using a combination of tools improves the quality of investigations. Many of methodologies described in 5.1. have been developed by combining the use of certain number of basic tools, such as the following:

(a) Event and causal factor charting;
(b) Cause and effect analysis;
(c) Interviewing;

(d) Task analysis;
(e) Change analysis;
(f) Barrier analysis;
(g) Fault tree analysis;
(h) Event tree analysis;
(i) Review of plant operating experience.

Following is brief description of commonly used tools:

(a) Event and causal factor charting

This tool is the first to use for all investigations. It provides a graphic display of the event on a time line highlighting occurrences and contributors. It is performed by asking successively what? how? and why? This tool helps to identify what is known and what needs to be known chronologically, thus helping to set the direction of further investigation. As more information is discovered, the chart is updated thus providing a continuous graphical indication of the progress of the investigation.

The attributes of the Event and causal factor charting tool are:

— The graphic display concisely captures the entire event. Better than long narrative descriptions;
— Breaks down the entire case into a sequence of occurrences;
— Shows exact sequence of events from start to finish in a chronological order;
— Allows addition of barriers, conditions, secondary events, presumptions;
— Facilitates the integration of information gathered from different sources;
— Useful for both simple and complex problem solutions;
— Many causal factors become evident as the chart is developed;
— Presents the information in a structured manner.

Application: This method is always used for any event investigation in which a timeline or sequence of events might apply regardless of the initiating event being equipment failure or human performance.

(b) Cause and effect analysis

The purpose of this tool is to identify root causes by examining the relationship between cause and effect. It is performed by asking successively what effects have occurred and why, and proceeding from the last failure/deficiency backwards to find the cause.

The attributes of the cause and effect analysis are:

— Successively ask and answer the why question;
— Where to stop: Stop to the farthest cause that can be corrected within the operating organization;
— Arrives to the underlying cause of an event in a very direct manner;
— Similar to a fault tree analysis but showing only the actual failed branches.

Application: A cause and effects analysis is often used in addressing events initiated by both human performance and equipment failures.

However, most root causes initiated by equipment failure usually require a more detailed variant of a cause and effects analysis known as fault tree analysis. Fault tree analysis creates an analytic diagram based on Boolean algebra. This fault tree is designed to list all possible failure mechanisms and using scientific research to verify or refute the possible causes until the true initiating mechanism can be determined. A fault tree analysis is recommended for equipment initiated events.

For most events initiated by human performance issues, it is usually easier to use this tool later in the event investigation. Because of its logic and relationship aspects, a cause and effect analysis does not lend itself to use as one of the primary investigation tools for human performance issues. Human performance issues often have multiple influences on the event and often cannot be clearly specified until late in the investigation.

(c) Interviewing

Interviewing is a face-to-face communication and questioning to obtain enhanced insight on facts. It is one of the key ways to find out what happened and provide context to the facts. In order to obtain accurate and factual information from the interviewees it is necessary to consider the respondents sensibilities. For this reason interviewer requires special training. The initial questions are prepared in advance. Many questions are derived from other tools (such as task analysis, change analysis, etc).

The attributes of the interviewing tool are:
— Is an important tool for data gathering;
— Focused on fact-finding not fault finding;
— Need a non blame environment;
— Requires a degree of skill on the part of interviewer;
— Is done as soon as possible: facts become less clear, memory is lost and opinions established as time passes;
— Some direct witness not always available: may have been injured, you will have to select others.

Refer to Appendix III for a more detailed description of interviewing techniques.

Application: Interviewing is the most essential tool and is used for all investigations.

(d) Task analysis

Task analysis is performed in two steps:

— PAPER & PENCIL to study how the task SHOULD be done by reviewing the procedures and other documents, developing questions and identifying potential problems;

— WALK-THROUGH the area of event to learn how the task is done by simulating the task on the plant, observing workers and re-enacting the task to determine how the task was actually performed, and identifying potential problems

The purpose of these steps is to:
— Become familiar with the task;
— Learn the potential difficulties.

The attributes of the task analysis paper and pencil tool are:
- Provide investigators with a good insight of the task;
- Identify questions to use later for interviewing;
- Useful for analyst not familiar with the task;
- May not identify how the task was actually done.

The attributes of the task analysis walk-through tool are:
- Re-enact the task with the persons involved with the event;
- If not available perform the task with another person who is normally performing the task;
- Limitations may exist to access the area after the event;
- Note differences between actual re-enactment and procedure steps;
- Very helpful to identify contributing factors that relate to physical environment and man-machine interface.

The first part of task analysis, how the task should have been performed can be a complex and time consuming process if this technique is used thoroughly. Normally subject matter expertise on the team and documents such as written procedures make it unnecessary to do a fully detailed task analysis. Often the work order process, pre-job brief, procedure and closing activities are used to create a very brief analysis of how the task should have been preformed.

The second part of task analysis, how the task was actually performed is almost always used as an investigation tool of human performance issues involved in events. It is absolutely critical to view the event from the standpoint of the individuals involved in the event. To accomplish this goal you must be able to stand in the shoes of the individuals involved. It is almost impossible to recognize many of the human factors and environmental issues without walking through the event and these issues typically play a significant role in events in nuclear power plants.

Application: Task analysis compares how the task should have been performed with how the task was actually performed, the output which frequently becomes an input into a change analysis.

(e) Change analysis

The tool is designed to determine what changed compared to previously successful occasions, if the change introduced was responsible for the consequences and what was the effect of the change in the event.

The attributes of the change analysis tool are:
- Useful if you suspect some change has contributed to the event;
- Do not lead directly to the root cause;
- It is a tool frequently used for quality audits;
- Need follow-up with other methodologies.

Change analysis will provide significant clues to help pinpoint inappropriate actions that may ultimately lead to the underlying root cause. However, not all changes found during an event investigation may necessarily play a role in the event.

Application: This method of analysis is used for almost all event investigations. In most cases, either the tasks or elements of the task will have been completed successfully before. Therefore, for most events for failure to occur something must have changed. Change analysis is a technique used early in the investigation that will provide input into the more thorough investigation tools.

(f) Barrier analysis

The purpose of this tool is to identify the defence-in-depth failures, barriers that failed or the missing barriers. In particular it helps to determine what barriers should have been in place to prevent the undesirable outcome, which barriers were missing, failed or circumvented, and what threat has been or has not been prevented by a barrier (target-threat).

The attributes of the barrier analysis tool are:

- Useful to evaluate defence-in-depth;
- Need technically experienced people in the area being analyzed;
- Best used in conjunction with other methodologies.

Application: Barrier analysis is almost always used in event investigations. In most nuclear power plants, significant barriers have been installed to protect the plant and their employees. Barrier analysis is a tool to help determine whether barriers failed, barriers were circumvented or barriers were needed to have been put in place but were not present.

(g) Fault tree analysis

Fault tree analysis presents a top-down graphical representation of the possible explanations of a failure. It is implemented by reasoning from the general to the specific. There is no need to follow a chronological pattern. It helps to determine possible failure modes for the event to occur, which of these factors may have failed and what can be added/modified to reduce the probability of occurrence. It also provides a graphic display of the event rationale by using logic symbols (such as and/or) to chain the actions.

The attributes of the fault tree analysis tool are:

- Top event is the major event;
- The graphic tree shape representation provides a structured vision of the event;
- Similar in approach to E&CF charting and to cause and effect analysis but with all branches;
- Generally used to provide a graphic representation to a complex problem with many possible scenarios;
- Good to conduct risk studies and improve/modify systems.

Application: To identify critical paths and relative importance of paths for achievement of top event. This is typically done to help in assessing safety significance of the event.

(h) Event tree analysis

The purpose of this tool is to identify potential outcomes from an initial event. It helps to determine what happens when a line of defence is successful and what happens when it fails.

The attributes of the Event tree analysis tool are:

- Starts by an initiating event (not the final event);
- Depicts what happens if the line of defence is successful (S) or fails (F);
- Branching stops when a significant consequence or concern is identified;
- Useful in quantitatively determining the probability of the different consequences when the probability of each line of defence is known;
- Allows dependence and domino effects that are difficult to model in fault trees;
- Allows for determining the effectiveness of possible corrective actions to prevent recurrence by quantitative analysis of possible future failures if proposed corrective actions were to be implemented.

Application: This is typically done to help in assessing safety significance of the event.

Appendix V summaries a comparison of different tools described above.

6. COMPLETING THE EVENT INVESTIGATION

At the end of the Event investigation, the team has a good idea of "what happened" and "why." As the information is collected the team will then begin to analyze this information in a structured approach, in order to integrate evidence, draw conclusions, report results and propose corrective actions.

The ultimate goal of event investigation is to prevent recurrence of the event or similar events.

6.1. Integrate information

Collected and derived information is properly integrated to confirm that pertinent factual findings and analytical results have been considered, that no significant information gaps exist, and that all factual and analytical discrepancies and conflicts have been resolved as far as possible. To achieve this, investigator team needs to:

- Cross-check of information sources;
- Confirm adequacy of scope and depth of information collected;
- Validate factual consistency;
- Correlate and confirm analytical results;
- Resolve factual and analytical differences.

Cross-checking of information sources includes comparison and validation within and between two evidence areas: those specific to actual event occurrence (from onsite witnesses, physical evidences, records, etc.), and those related more generally to the system and disciplines involved (expert testimony, physical-engineering information, historical information about the system, operational evaluation, configuration control, etc.). Cross-checking from these sources helps to reveal existing inconsistencies and discrepancies of information and confirm that necessary and sufficient evidence either has or has not been collected to arrive at complete and valid conclusions. If there is not sufficient evidence, more in-depth analysis of information is needed and more detailed evidence is sought.

If any contradiction between sources exists (such as those between the testimonies of witnesses, between an expert and a witness, between witness testimonies and physical evidences, between physical evidence and paper evidence, between engineering analysis and physical, paper or people evidence), investigators use all practical means to resolve the discrepancies. If this effort proves unfruitful, investigators indicate the existence of contradictory evidence and cautiously conclude. Another valuable aid in analyzing and evaluating contradictory information is an expanded and more detailed look at a portion of the causal factor diagram. Sometimes the contradictions or discrepancies are not important enough or relevant enough to really justify concern.

When there is insufficient factual evidence or analytical results for valid conclusions, investigators search for additional facts and perform more in-depth analysis of the collected evidence, identify possible conclusions which can be definitely rejected or excluded, and indicate information deficiencies which can not be resolved practically and for which conclusions are impossible.

Selection and use of appropriate analytical methods and tools are fundamental for validating and correlating factual findings. Cause and effect evaluation is essential to validate the information gathered, possible assumptions and conclusions of the investigation team.

6.2. Draw conclusions

Event investigation conclusions identify the what and why of incident causation. Conclusions also identify the areas within the operating system and work processes where deficiencies existed. Conclusions are made of findings (significant facts discovered and the analytical results obtained through evaluation of those facts, including the strengths and the weaknesses in the operating system and the work situation in which the event occurred) identifying how the event happened; probable causes identifying what contributed to the event, and areas for improvement specifying what should be done in response to the event investigations findings and probable or root causes. If a contributing factors relating to safety culture is observed Appendix VI can be referred for guidance.

Probable causes are the underlying errors and deficiencies, which led either directly or indirectly to event occurrence. The direct cause relate to what happened and how it happened, and are concerned with specific work site factors. Indirect causes identify why the event was allowed to happen and are found in management system factors. Direct causes are often also identified as the immediate or proximate basis for the primary happening. Indirect or contributing factors are those, which contributed to hazard build-up, hazard release or exposure, failure of mitigating measures, inadequate plans or preparations, inadequate hazard detection or correction, management system breakdowns, etc. root causes are the fundamental cause(s) of an event that if corrected, will prevent recurrence of the event or adverse condition. Good practices and strengths are documented. On the other hand, negative findings are questioned about their contribution to this event. If the findings contributed to the event, they are classified as a contributing factor or direct cause, depending on the direct contribution to the event. Non contributing findings are documented and addressed through appropriate actions.

It is a good practice that each conclusion is supported by a set of crossed evidence, which has been assessed in a careful manner, so to remain strong, to avoid misinterpretations and useless discussions.

It is important for the licensee and the regulator to understand how significant an event was with respect to safety. Typically events have no direct consequence due to the built in redundancy and defence of the systems. However, all events are due to failed barriers, hence a failure of one or more barriers that caused the event may have no actual consequence (other than economic) but may reduce the defence in depth. A reduction in defence in depth will potentially expose the plant to much higher risk levels than are acceptable. This can be defined using PSA techniques and/or by calculating core damage frequencies. For more information on this reference can be made to IAEA-TECDOC-1417, Precursor Analysis – The Use of Deterministic and PSA Based Methods in the Event Investigation Process at Nuclear Power Plants [7]. Such analysis can be undertaken to help determine the need for certain corrective measures and their relative importance.

Areas for improvement represent the investigative team's conclusions regarding areas where managerial controls and safety measures should be applied to prevent recurrence of this or similar events. They derive from findings and probable causes and form the basis for structuring specific recommendations for corrective actions. Note that areas for improvement identify system and organizational needs as perceived by the investigation team, and recommendations specify what to do, not how to do it. It is not only essential that continuity exists among findings, probable causes, and areas for improvement, but also that all conclusions rest firmly upon a strong factual base. They track logically, clearly and directly back through analytical bridges to their foundations facts. They track forward through additional analysis to practical, realistic, specific corrective action recommendations.

6.3. Report results

The investigation report conveys in a clear and concise language the results of the investigation (the facts surrounding the occurrence, the analysis of these facts, and the conclusions). The investigation report constitutes a record of the occurrence by which the investigation is measured as to thoroughness, accuracy, and objectivity.

The investigation report consists of the following information:

- Summary;
- Facts;
- Analysis;
- Conclusions.

Other information may include:

- Extent of conditions and causes;
- Lessons learned;
- Assessment of immediate and interim action previously taken;
- Discussions/observations.

Facts relate to the what, where, why, and when of the occurrence. The analysis section of the report is based on the factual information developed and consists of the reasoning of the investigators, which supports the conclusions. This section also includes significance and consequence of event and review of operating experience. The conclusion section consists of the findings, the probable causes and contributing factors to the occurrence, the areas for improvement, and the recommendations.

The investigation report fully covers and explains the elements of the causal sequences of the occurrence and also describes the management systems which should have, or could have, prevented the occurrence.

Appendices VII and VIII provide examples illustrating details of investigation of both less significant and complex events.

6.4. Propose corrective actions

Corrective actions could be proposed by the investigation team to address the causes of the event and other areas for improvement. These may be documented in the event investigation report or in a separate document. Guidance on developing corrective actions is provided in Ref. [5].

7. QUALITY ASSESSENT OF EVENT INVESTIGATION

Since the event investigation process is an important tool to prevent future or similar events, it is imperative that completed investigation be assessed for effectiveness. The final root cause analysis product is assessed to rate the overall quality of a root cause analysis. Appendix IV is one example of a root cause scorecard to measure the quality of a root cause investigation.

Key points to be covered in a self-assessment include:

- Early start and timely completion of investigations;
- Charter/terms of reference;
- Proper team composition, including a lead investigator who is trained and experienced in root cause assessment techniques, human and organization factors and subject matter experts;
- Appropriate selection of analysis techniques;
- Appropriate use of previous events (OE), adherence to established RCA process, management involvement in investigation;
- Feedback form for the quality assessment of the event investigation.

APPENDIX I
EXAMPLES OF EVENT INVESTIGATION HIEIRARCHY LEVELS

Panel of Inquiry (POI)

An inquiry initiated at Board level (Company Board or Corporate Nuclear Safety Committee) to investigate significant events that are deemed to warrant an in depth, formal investigation **independent** of the **Business Units** (NPPs) involved.

A panel of inquiry will be chaired by an **independent senior company** (for example, an independent member of the corporate nuclear safety committee) officer and will include appropriate **specialists**, **trained root cause analyst**, (from other NPPs), panel secretary and where appropriate a company inspector.

The arrangements for the establishment, conduct, and follow-up of panel of inquiries are detailed in a procedure.

Technical Panel of Investigation (TPI)

An investigation initiated by a **business unit director** to investigate events which do not warrant a panel of inquiry but which nevertheless require an in depth formal investigation. (internal team but chairman usually independent from main department involved in the event)

The investigation team will typically comprise a **departmental manager** (chairman), appropriate **technical specialists**, a **trained root cause analyst** and where appropriate the location company inspector

Root Cause Analysis (RCA) Investigation

An investigation employing **full root cause analysis** techniques to determine the fundamental cause(s) and contributing factors that, if corrected, would prevent recurrence of an event or condition.

A root cause investigation can be conducted by **an experienced individual** trained in appropriate root cause analysis techniques or for more complex issues a **multi-discipline team** containing a **trained** root cause analyst.

Apparent Cause/Specialist Investigation

A **limited** investigation to quickly and simply determine the most **immediate**, or **apparent cause** of a less significant event or sub-standard condition **without** recourse to **full root cause analysis** by considering the readily-available facts with little or no detailed investigation. **One person** may conduct this type of investigation, however needs to have an understanding of root cause techniques.

Supervisor's Investigation

An **initial investigation** conducted by a line supervisor to **preserve evidence** for any subsequent investigation and determine the **most immediate** or **apparent cause** of an event involving a member of their team.

APPENDIX II
EXAMPLE OF AN INITIAL WITNESS SHEET FOR ROOT CAUSE INVESTIGATIONS

Name: ____________________________ Group: _________________________________
Date: ____________________________ Position: _________________________________

1. When did the event occur (date and time)?

2. Describe the accident sequence from start to finish (i.e. Please provide your perspective on WHAT HAPPENNED.)

3. Describe the work activity including identifying guiding documents such as W/R or W/O Number, Procedure Number, etc. other related activities, and environmental conditions leading up to the event.

4. Describe your role or job function and actions you took before and during the event.

5. Describe anything unusual you observed during the event (sights, sounds, odours, alarms, individual actions or behaviours, etc.)

6. Describe any conditions that may have influenced the event (i.e. equipment malfunction, equipment position, weather, time of day, inexperience, etc.)

7. What do you think caused the event (i.e. WHY did it happen?)

8. How could this event have been prevented?

9. Other information or additional comments that might be important to the investigation team.

10. List other possible witnesses.

Signature: ________________________________ Date:___________________________________

APPENDIX III
INTERVIEWING TECHNIQUES

NOTE: Due to the importance and nature of event investigations, interviews must be conducted in a professional manner. Interviewers must be capable of extracting factual information from interviewees who may feel threatened, be hostile, be emotional, or have trouble recalling the information in an unbiased way or have trouble expressing themselves clearly. For all of these reasons, interviewers must acquire through comprehensive training, a level of expertise in the various techniques of interviewing.

Following is an abbreviated list of subject areas that would be included in such a training programme:

Preparation

— Schedule the appointments;
— Choose an appropriate location;
— Make sure you are interviewing the right people;
— Having question areas or themes prepared in advance;
— Have required reference documents at hand;
— Be mentally prepared and focussed.

Introduction

— Introduce yourself;
— Explain the purpose of the interview;
— Do not be confrontational;
— Control your body language.

Asking questions

— Seek to understand why not just what;
— Control the interview;
— Keep questions simple and focused;
— Use a funnel approach: broad leading to specific questions;
— Anticipate unsatisfactory replies: have a means to deal with them;
— Avoid jargon;
— Avoid devious or trick questions;
— Focus on facts;
— Anticipate interviewee questions;
— Be aware that interviewing is not interrogating.

Listening Techniques

— Listen to answer before asking next question;
— Be relaxed, friendly;
— Maintain eye contact;
— Use a neutral body language;
— Do not let note taking interfere with listening.

Recording the Information

- Take brief notes while listening;
- Add more detail as soon as possible from memory;
- If you do not understand, ask for clarification
  - do not wait until next day
  - discuss with counterparts
- Request copies of documents for later study;
- Use of electronic recording devices should be carefully considered.

Cultural Differences

- Try to recognize positive and negative aspects and take them into account during the review;
- Be alert for sensitive issues: treat them with care;
- Treat plant staff with respect at all times;
- Reinforce understanding through confirmatory discussions;
- Don’t assume, ask questions.

APPENDIX IV
EXAMPLE OF ROOT CAUSE QUALITY MEASURE FORM

Measure **PIP Number** ____________________ **Date** __________________

(Pt Value)

Measure (Pt Value)	
	ROOT CAUSE EVALUATION
_____ (5)	**Breadth:** Did the root cause process thoroughly consider all possible contributors (i.e., human, programme, and organizational weaknesses)? Did the approach use a 'wide funnel' when considering possible causes?
______(5)	**Depth:** Did the determination of the failure scenario ask the "Why" question enough times to get to the underlying cause? The "Why Staircase" can be used to show the "Why" questions and answers. Was benchmarking of organizational and programmatic issues performed?
______ (5)	**Validity:** Were interviews and other data collection methods accomplished in a timely fashion to take advantage of fresh memories and hot trails?
______ (5)	**Methodology:** Does the RC report clearly document the methodology used to determine the Root Cause and Contributing Cause conclusions?
______ (10)	**Definition Test**. Would the event have been prevented if the root cause(s), by itself, had been corrected?
______ (5)	**Clarity:** Is (are) the root cause(s) clearly stated?
______ (5)	**Cause Code:** Does the selected cause code(s) agree with the root cause(s)?
______ (5)	**Timeliness:** Was the root cause completed within the timeliness guideline?
______ (5)	**Report Content/Format:** Is the report clearly written and easily understandable by a person unfamiliar with it? Does the benchmarking section state the conclusion and list the recurring event determination? Does the report clearly link the corrective actions to the root/contributing causes? Were any additional operability issues addressed?
	CAPR Criteria (CAPR = Corrective Actions to Prevent Recurrence)
______ (5)	**Alignment:** Does the set of CAPRs directly address the set of root causes?
______ (5)	**Extent of Condition:** Do the corrective actions address the extent of condition and the scope of "similar" events that are expected to be prevented?
______ (5)	**Practicality and Cost Effectiveness:** Can the CAPRs be implemented? Are they cost effective? Are new failure modes of the new CAPRs considered?
______ (5)	**Ownership and Accountability:** Have the responsible implementing groups agreed to the CAPRs?
______ (5)	**Clarity and Precision:** Is each CAPR clearly worded such that the implementing group can implement it correctly?
______ (5)	**No Promises:** Is each CAPR worded for required completion (i.e. "generate", "implement", or "perform")? Unacceptable wording includes such statements as "initiate actions to", "design modification", "evaluate", and "perform study".
______ (5)	**Staying Power:** Will the CAPRs be effective for the remaining life of the plant? "Providing training," "sending notes", and "having discussions" are generally not acceptable as CAPRs.
______ (5)	**Benchmarking/Proven Solutions:** Does the benchmarking section clearly indicate how other plants/industries have resolved and prevent the same issue? Does it review the effectiveness of the actions?
______ (5)	**Stop the Bleeding:** Are immediate and interim corrective actions sufficient to prevent recurrence of the event until CAPRs can be implemented?
______ (5)	**Timeliness:** Are the schedule dates for completion of CAPRs reasonable?

______ (100) **TOTAL POINTS**

APPENDIX V
SUMMARY OF ROOT CAUSE TOOLS

Tools	When to use	Advantages	Disadvantages	Remarks
Event and Casual Factor Cause and Effect Task Analysis	Use for multi-faceted problems such as reactor trips or plant transients. Also good for evaluating equipment failures.	Provides visual display of analysis process. Identified probable contributors to the condition.	Time-consuming and requires familiarity with process to be effective.	Requires a broad perspective of the event to identify unrelated problems. Helps to identify where deviations occurred from acceptable methods.
Fault Tree Analysis	Use when there is a shortage of experts to ask the right questions and whenever the problem is a recurring one, helpful in solving programmatic problems.	Can be used with limited prior training.	May only identify area of cause, not specific causes.	If this process fails to identify problem areas, seek additional help or use cause-and-effect analysis.
Change Analysis	Use on singular problems. Especially useful in evaluating equipment failures.	Simple 6-step process.	Limited value because of the danger of accepting wrong, "obvious" answer.	A singular problem technique that can be used in support of a larger investigation. All root causes may not be identified.
Barrier Analysis	Use for procedural or administrative problems. Also good for human performance problems.	Provides systematic approach.	Requires some familiarity with process to be effective.	May also be used for equipment failures.

This table has been taken directly from “Root Cause Analysis INPO 90-004 Good Practice. Revision 1

APPENDIX VI
INVESTIGATION OF ATTRIBUTES RELATED TO SAFETY CULTURE

During the event investigation safety culture characteristics and particular behaviours and attitudes are identified. If required the reporting of the result of the event investigation presents the safety culture characteristics practiced at the nuclear installation.

The event investigation is also directed in assessing how the management systems are used to promote and support a sustainable strong safety culture by reviewing how:

— A common understanding of the key aspects of safety culture is ensured within the organization;
— The means are provided to support individuals and teams to carry out their tasks safely and successfully, taking into account the interaction between individuals, technology and the organization;
— A learning and questioning attitude is reinforced at all levels of the organization;
— The means are provided for the organization to continually seek the development and improvement of its safety culture as part of the continuous improvement process.

The event investigation recognizes that safety culture is both structural and attitudinal in nature and relates to the organization and its style.

After the occurrence of a significant event, sometimes there is a tendency on the part of the investigators to assume that absence of the safety culture in the organization and its individuals is the cause of the event. This, however, is a misconception because with safety as a primary goal in a nuclear organization there always be a safety culture that has developed. The issue is whether the existing culture in the organization and individuals is appropriate and functional, and directed towards achieving the safety goals. The event investigation addresses these areas during the review evaluation.

For the purpose of the evaluation, investigation and enhancement of safety culture, the following IAEA publications are used as guidance:

- INSAG-4 Safety Culture, Safety Report Series No. 75;
- INSAG-13 Management of Operational Safety in Nuclear Power Plants, Safety Report Series define Safety Management System;
- INSAG-15 Key Practical Issues in Strengthening Safety Culture, Safety Report Series;
- Safety Reports Series No. 11 - Developing Safety Culture in Nuclear Activities, Practical Suggestions to Assist Progress;
- TECDOC-1321 Self-assessment of Safety Culture in Nuclear Installations, Highlights and Good Practices;
- TECDOC-1329 Safety Culture in Nuclear Installations. Guidance for use in the Enhancement of Safety Culture;
- Safety Requirements GS-R-3 The Management System for facilities and Activities;
- Safety Guide GS-G-3.1 Application of Management System for Facilities and Activities.

APPENDIX VII
EXAMPLES OF INVESTIGATION OF LESS SIGNIFICANT EVENTS

For the purpose of this appendix the selected examples have been summarized to highlight in the discussion paragraph the following information:

- How long it took to assemble the team;
- What was the position/expertise of the members of the team;
- Was some person of the operating experience group leading the team?;
- Investigation techniques used;
- Number of people interviewed;
- Total man-hours involved;
- Small comment on the most important challenge/difficulty to overcome during the investigation.

EXAMPLE A:

Subject: Extra High Radiation Area (EHRA) boundary entered without proper Radiation Personnel (RP) support.

Discussion:

This root cause analysis was initiated when it was realized by radiation protection that 2 operators had violated the regulations requiring RP personnel at the job site when entering a high radiation area. Very early in the initial discussions with these operators it became apparent that a second event had also occurred. (i.e., these individuals continued to work with a dose rate alarm sounding in violation of plant RP practice). The scope of the investigation was determined to include both events. Most of the immediate corrective actions and interim corrective actions were implemented within 24 hours of the event.

A team of 4 individuals were assembled to conduct the event investigation. The investigation continued for a period of 8 weeks. Most of the data collection and interviews of approximately 20 individuals occurred in the first 2 weeks of the root cause analysis. The total labor involved in this management discretion root cause (i.e., management chose to perform a root cause even though the categorization criteria did not require it) was 400 labor hours.

EXAMPLE B:

Subject: Fuel transfer system conveyor drive shaft failure.

Discussion:

On March 25, 2005, the plant had a failure of the fuel transfer system conveyor cart to move. After an engineering inspection it was quickly determined that the key connecting the shaft extension to the chain coupling was no longer engaged in the chain coupling keyway. Immediate corrective actions included suspending core reload until the equipment failure mechanism was determined, fixed, and tested.

This root cause was initiated several days after the event when it was decided by management discretion that this would be a good event to learn what happened and take actions to avoid similar events in the future. The root cause analysis was performed using the fault tree analysis tool.

A team of 3 individuals were put together with human performance, system, and civil engineering expertise. The investigation continued for approximately 7 weeks. The total labor involved in this management discretion root cause was approximately 400 labor hours.

EXAMPLE C:

Subject: Relief valve failed open

Discussion:

On August 8, 2004, during normal operation at 100% power, 1HR-1 relief valve spuriously failed open. A unit power reduction was required for appropriate isolation to replace the relief valve. This root cause was initiated as required by the screening criteria for events which result in unexpected power reduction. Immediate corrective actions included replacement of the 1HR-1 with a spare valve.

One individual with engineering, system, and human performance was assigned to investigate the event. It was quickly determined that the initial equipment failure was due to a fractured spring when the valve was disassembled. Later metallurgical examination determined the primary failure mechanism was due to extremely hard spring material (HRC>50). The event investigation took approximately 8 weeks and 150 hours of labour by the event investigator.

The root cause analysis was performed using the fault tree analysis tool. One of the major concerns of this investigation was the analysis for similar type valves. The extent of condition issue was appropriate analyzed and addressed with appropriate corrective actions.

APPENDIX VIII
EXAMPLES OF INVESTIGATION OF COMPLEX EVENTS

EXAMPLE A:

Subject: Fuel cleaning accident at NPP

At the invitation of the Member State, the IAEA conducted an independent expert review mission to review the results of the investigation performed by the regulatory authority of the fuel cleaning incident at a NPP. The duration of the mission was 8 days. The team's activities included:

— Interviews;
— Observations in the field;
— Analysis of documentation.

The team was composed of 10 people, including:
— Team Leader;
— Deputy Team Leader;
— 8 External experts.

This investigation was an independent review mission of an investigation performed by the regulatory authority which was completed previously.

SUMMARY OF INVESTIGATION

Some data:
— More than 600 hours were spent reviewing documents, interviewing personnel and preparing the report;
— The team spent approximately three days conducting interviews and reviewing programmes and processes at regulatory authority offices before travelling to NPP where they continued the review for 5 days.

METHODOLOGY

The areas of emphasis for the review were the following:
— Evaluation of the root cause of the incident including the analysis performed by NPP and the regulatory body;
— Review of the classification criteria used for the licensing and operation to estimate the safety significance of the fuel cleaning activity as compared to IAEA safety standards. Consideration of novelty, complexity and previous history;
— Evaluation of the assessment and approval process for modifications made to the fuel cleaning equipment and subsequent operations both at NPP and regulatory authorities level;
— Evaluation of operational safety performance during the fuel cleaning operation and subsequent identification of the problems leading to the incident;
— Adequacy of the procedures being used to conduct the fuel cleaning activity, including prerequisites and precautions;

— Adequacy of clearly defined roles and responsibilities for the conduct and supervision of the fuel cleaning activity;
— Assessment of the reliance on the contractor and the time pressure related to a prescribed fuel outage schedule;
— Effectiveness for licensing the fuel cleaning activity falling outside of the licensing basis of the plant;
— Adequacy of the training provided to NPP operation, maintenance and radiation protection personnel on the fuel cleaning operation;
— Evaluation of emergency response capability and criteria for this incident;
— Evaluation of the radiological release and worker radiation dose;
— Assessment of the adequacy and timeliness of the corrective actions proposed to prevent recurrence of a similar event.

The IAEA Safety Standards were used as the basis documents by the team for their review, supplemented by appropriate Agency guidelines that have been modified to support each review area (e.g.: IRRT, OSART, and PROSPER guidelines).

FINDINGS

A total of 23 issues were identified from which 13 recommendations and 10 suggestions were formulated. In the area of design of the cleaning system 8 contributing causes were identified.

REPORT

The final report was organized in the following chapters:

Introduction
Executive summary
1. Management systems;
2. Regulatory oversight/interface, and legislative aspect of the incident;
3. Root cause analysis/risk analysis;
4. Fuel performance characteristics, chemistry, thermo hydraulics and operations;
5. Radiation protection and radiological dose assessment;
6. Emergency planning and preparedness.

EXAMPLE B:

Subject: Assessment of inoperability of control rods

At the invitation of the Member State, the IAEA conducted an independent expert review mission to assess the results of the investigation performed of an event related to inoperability of the control rods at a NPP. The duration of the mission was 6 days. The team's activities included:

— Interviews;
— Observations in the field;
— Analysis of documentation.

The team was composed of 2 people, including:

- 1 IAEA participant;
- 1 external expert.

These two members were included in the member state regulatory authority investigation team. A committee of nine persons was also created to review the information produced by the NPP. Members of this committee were experts from organizations such as: Regulatory body, university department of material sciences and engineering, institutes for metal sciences, main supplier, plant utility.

For the root cause analysis performed by the NPP the team was composed by 11 persons.

The investigation was an independent review mission to assist the member state regulatory authority in the assessment of a root cause analysis of the event and to evaluate the adequacy of the measures proposed by the NPP. Also to produce a report, with appropriate recommendations for the regulatory authority.

SUMMARY OF INVESTIGATION

Some data:

- The team spent approximately five days conducting interviews and reviewing programmes and processes at regulatory authority offices before travelling to NPP where they continued the review for 1 day to observe the actual situation on site and interview NPP staff;
- More than 100 hours were spent reviewing documents, interviewing personnel and preparing the report;
- 22 documents were reviewed, including inspection reports, technical details of the material, technical specifications, corrective measures programme and direct and root cause analysis based on ASSET methodology.

The team reviewed the plant actions immediately after the event to verify if they were appropriate and the plant’s corrective action plan. The team reviewed also the basis for the decision to restart the plant after the event.

METHODOLOGY

The following technique was used:

- ASSET methodology used by the NPP for its root cause analysis and reviewed by the independent team.

The overall methodology was based on performing interviews and discussions, analysis of documentation and observations of the plant status.

FINDINGS

The root cause analysis performed by the NPP identified 9 corrective measures.

A total of 4 additional recommendations were formulated by the team, directed to support the corrective measures identified by the NPP.

REPORT

The ASSET report for the root cause analysis performed by the NPP was organized in the following chapters:

- Status of the unit and involved systems before the event;
- Chronological sequence of the event;
- Status of the unit and involved systems after the event;
- Assessment of results;
- INES scale assessment;
- Analysis;
  - Title of the event
  - Description of what happen
  - Characteristics of the failure
  - Table of the types of causes (direct, contributing causes, oversight/monitoring weakness, root causes)
  - Discrepancy identified for each cause and proposed associated corrective active
  - List of corrective measures
  - Conclusions and suggestions
  - List of attachments
  - List and signature of the NPP root cause analysis team members

The final report of the team was organized in the following chapters:

(1) Introduction/background;

(2) Objectives of the mission;

(3) Team composition and scope of the mission;

(4) Conduct of the mission;

(5) Areas of emphasis for the review;

(6) Documents available for review;

(7) Operational safety aspects review (event sequence and plant status);

(8) Metal science/material behaviour;

(9) Observations on the field;

(10) Conclusions and recommendations.

EXAMPLE C:

Subject: Independent analysis of a safety system failure.

At the invitation of the plant an investigation was conducted that lasted 50 days from starting to issuing the report (about half of it effective days on site) to perform an independent analyses of the event, including related issues which preceded and issues which followed the safety system failure event.

The team's activities included:
- Gathering information;
- Determining the sequence of events (using the events and causal factors chart);
- Analyzing the information using several investigation techniques process;
- Determining causes of identified issues;
- Preparing an extent of condition and extent of cause review;
- Preparing recommendations.

The team was composed of five people, including:
- Team leader, external expert on MORT analysis;
- 2 external team members;
- 2 internal team members.

This investigation was a follow up of an assessment performed by an IAEA mission which was completed previously. This IAEA mission was, in its turn, a root cause analysis conducted to complement the self-investigation performed by the plant.

SUMMARY OF INVESTIGATION

Following some data:
— More than 700 hours were spent reviewing documents, interviewing personnel, developing root cause analyses and preparing the report;
— 120 documents were reviewed;
— 25 plant, contractor, and headquarters personnel from various levels were interviewed;
— 10 members of the regulatory body were interviewed.

METHODOLOGY

The following techniques were used:
— Events and Causal Factors (E&CF);
— Management Oversight and Risk Tree (MORT);
— IAEA review team assessment.

(E&CF) charting process was used to draw a picture of the complete sequence of events. The E&CF chart was used to establish the relationships among the influences and contributing conditions to the sequence of events. During the investigation, the E&CF chart was used to assist the team in identifying gaps in information needed to complete the investigation of the incident and the organizational behaviour after the incident.

The **Management Oversight and Risk Tree (MORT)** analysis process was used to assure the completeness of the interview questions. The MORT analysis also was used as the primary method to identify areas of management system, organizational, and programmatic weaknesses that contributed to the incident. The specific branches from the technical side of the MORT analysis that were used included: maintenance, inspection, supervision, task performance errors and procedures. The specific branches from the management system factors side of the MORT analysis that were used included: management policy, management implementation and risk assessment (including technical information, hazard analysis process, human factors, procedures, and general design).

The **IAEA review team**: The assessment performed by an IAEA review team was used by the MORT team as input, saving the need for re-analyzing that part of information.

The team conducted an **Extent of Condition and Extent of Issue (cause) Evaluation** to take into account the organizational and historical context that existed beyond the issue under inquiry. The extent of condition and extent of cause review was included under special request from regulatory authorities to take into account the apparent breakdowns in the internal oversight functions. As defined in the USNRC inspection manual procedure 95-001, extent of condition is defined as the extent to which the actual condition exists with other plant processes, equipment or human performance. Extent of issue (cause) is defined as the extent to which the root causes of an identified problem have impacted other plant processes, equipment or human performance.

FINDINGS

A total of 9 issues were identified from which 16 recommendations were formulated. Taken together, they were aimed to address the conclusions and the extent of condition and extent of issue.

REPORT

The final report was organized in the following chapters:

I. Table of Contents
II. Introduction
III. Acknowledgements
IV. Summary of Investigations
V. Methodology
VI. Investigation findings
VII. Recommendations
VIII. Final Comments

A. Attachments
   - A.1 Charter specification for the investigation
   - A.2 List of interviewees
   - A.3 List of documents reviewed
   - A.4 Causes and recommendations from previous investigations

EXAMPLE:

Subject: Independent analysis of a safety system failure.

At the invitation of the NPP the IAEA conducted a review mission to perform an independent root cause analysis of the event. The duration of the mission was 8 days.

The team's activities included:

- Interviews;
- Observations in the field;
- Analysis of documentation.

The team was composed of six people, including:

- Team leader (IAEA);
- 1 external expert on MORT analysis ;
- 2 external team members;
- 2 internal team members.

SUMMARY OF INVESTIGATION

Following some data:

- More than 350 hours were spent reviewing documents, interviewing personnel, developing root cause analyses and preparing the report;
- 60 documents were reviewed;
- 39 plant, contractor, and headquarters personnel from various levels were interviewed;
- Several observations were performed in the field in 4 different locations of the safety system to assess the failure.

The team also reviewed the plant actions immediately after the event to verify if they were appropriate and the plant's corrective action plan.

METHODOLOGY

The following technique was used:

- Events and Causal Factors (E&CF);
- Management Oversight and Risk Tree (MORT).

The E&CF was used to establish the relationships among the influences and contributing conditions to the sequence of events, to identify the primary effects and determine the root causes.

Both branches of MORT, the technical side and the management system factors side were used.

FINDINGS

The root causes identified from the E&CF were basically the same as those identified by MORT i.e. a common list of root causes was created using inputs from both analysis. This gave additional assurance that the main points have been captured and adequately addressed.

A total of 7 issues were identified from which 14 recommendations were formulated.

REPORT

The final report was organized in the following chapters:

I. Table of contents
II. Introduction
III. Description of the methodology
IV. Sequence of events
V. Causes and contributors
VI. Recommendations

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