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# APPLICATION AND SELECTION OF NUCLEAR EVENT INVESTIGATION METHODS, TOOLS AND TECHNIQUES

Final Technical Report

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# List of acronyms and definitions

| | |
|---|---|
| AEB | Accident Evolution and Barrier function |
| ASSET | Assessment of Safety Significant Event Team |
| ATHEANA | A Technique for Human Event Analysis |
| CAS-HEAR | Computer-Aided System for Human Error Analysis and Reduction |
| CCDF | Conditional Core Damage Frequency |
| CCDP | Conditional Core Damage Probability |
| CCF | Common Cause Failure |
| CRT | Current Reality Tree |
| ECFC | Event and Causal Factors Charting |
| ESReDA | European Safety Reliability and Data Association |
| FRAM | Functional Resonance Analysis Method |
| HF | Human Factors |
| HFIT | Human Factors Investigation Tool |
| HOF | Human or Organisational Factors |
| HPEP | Human Performance Evaluation Process |
| HPES | Human Performance Enhancement System |
| HPIP | Human Performance Investigation Process |
| HRA | Human Reliability Analysis |
| IAEA | International Atomic Energy Agency |
| IE | Initiating Event |
| IET | Institute for Energy and Transport |
| INES | International Nuclear Event Scale |
| IRS | Incident Reporting System |
| LL | Lessons Learned |
| MORT | Management Oversight and Risk Tree |
| MTO | Man, Technology, Organisation |
| NPP | Nuclear Power Plant |
| NRC | (United States) Nuclear Regulatory Commission |
| NUSAC | Nuclear Safety Clearinghouse (action of Safety of Present Nuclear Reactors Unit at IET) |
| OEF | Operating Experience Feedback |
| PRCAP | Paks Root Cause Analysis Procedure |
| PROSPER | Peer Review of the effectiveness of the Operational Safety Performance Experience Review |
| PSA | Probabilistic Safety Assessment |
| PWR | Pressurised Water Reactor |
| RCA | Root Cause Analysis |
| SAR | Safety Analysis Report |
| SOL | Safety through Organisational Learning |
| SPNR | Safety of Present Nuclear Reactors Unit at IET |
| STEP | Sequential Timed Events Plotting |
| TSO | Technical Support Organisation |
| WGOE | Working Group on Operating Experience |
| 3CA | Control Change Cause Analysis |

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# EXECUTIVE SUMMARY

This document is a final report prepared by the European Clearinghouse on Operational Experience Feedback at the Joint Research Centre — Institute for Energy and Transport. It presents the results obtained in the last phase of a project launched as part of the technical task ‘Comparative study of event assessment methodologies with recommendations for an optimised approach in the EU’ in 2010-2011. The main goal of this final report is to evaluate existing practices and arrive at some conclusions and recommendations that will help in selecting and applying instruments to improve the quality of nuclear event investigations.

Analysis of the responses received to a questionnaire on existing event investigation practices yielded the following main findings:

1. Event investigation teams are typically composed of technical specialists from the departments concerned in the plant, professional event investigators and representatives of management. The serious shortcoming of current practice in recruiting event investigation teams is that psychologists, human factor specialists and external experts/consultants are rarely included in the team.
2. The event investigation process itself has a positive influence on safety for personnel interviewed or otherwise involved. Besides the final report and recommendations, involvement in the event investigation process seems to be useful in enhancing insight into and attitudes towards safety, increasing awareness and improving competencies, and discovering unknown dependencies between different functions or departments.
3. During the last ten years event investigation practices have not changed very much as regards the use of particular methods and tools. The most frequently used RCA methods at European nuclear plants remain HPES, MORT, ASSET and MTO. The choice of RCA tools is heavily restricted by their purpose and the needs of the method used; however, the most ‘popular’ ones are basic RCA tools (ECFC, barrier analysis, change analysis, task analysis and interviewing), which are used in practically all investigations.
4. In most organisations the same event investigation instruments have been implemented and used for a long time (more than 10 years). Usually RCA methods and tools are obtained for free and there are no obvious trends towards replacing them with new ones.
5. To further improve existing practices in event investigation it would be desirable to:
   - develop comprehensive software for further computerising the event investigation process, including RCA methods such as HPES and MORT;
   - resume IAEA technical support for the ASSET method;
   - improve the education of event investigators by organising appropriate training, drafting simpler manuals and guidelines, and providing more practical examples;
   - organise more intensive exchange of experience among event investigators.
6. The need for an independent investigation, free from any interference by vested interests (such as line management, supervisory authorities, certification bodies or commercial partners), has increasingly been recognised on account of its contribution to the overall quality of the investigation. However, the principle of the independence of event investigations is not in practice considered as an important and necessary feature.
7. Existing practices demonstrate that event investigations frequently continue to remain focused on analysing the direct and immediate causes of events instead of attempting to dig deeper to identify latent root causes, such as human, organisational and management-related factors. Although the importance of correctly identifying these HOF-related causes is commonly understood, there is still a tendency for the analysis to focus solely on the technical issues of the event.

During this study, some methodological inconsistencies, barriers, bottlenecks and emerging traps in the event investigation process were identified and analysed more thoroughly; some methodological and practical recommendations were put forward as to how these obstacles could be overcome.

In order to avoid the ambiguities and misunderstandings currently surrounding the terms and definitions used in event investigation in general, and root cause analysis in particular, several improved definitions were suggested. With the aim of better distinguishing between event investigation instruments of different levels and applicability, an original system of classification of basic RCA methods and tools was suggested. This system should help in comparing characteristics and selecting the most appropriate instruments for investigating a particular event. Detailed recommendations for selecting root cause analysis methods and tools are also presented.

With a view to explaining possible scenarios leading to event recurrence, the study examined potential negative impacts and emerging traps in the event investigation process. Some specific suggestions as to how RCA could be conducted more effectively were put forward.

1. The level of investigation necessary (troubleshooting, apparent cause investigation or root cause analysis) should be determined correctly during the event review/screening. Decisions should be properly substantiated and based on a set of objective criteria evaluated against clearly defined thresholds. Attempts, based on personal opinions, to simplify and speed up the investigation of safety-relevant events by avoiding a detailed root cause analysis process should be resisted.
2. Root cause analyses undertaken on ‘near hits, near misses and close calls’ can be just as productive as or even more effective than those done on major incidents. Typically, root causes for ‘near hits, near misses and close calls’ are the same as those for major incidents. Only the consequences or outcomes differ, and they are the result of luck.
3. Preparing properly for root cause investigation is an important prerequisite for success. Preparatory steps such as establishing and implementing an effective event investigation process within the management system, providing appropriate resources, selecting the relevant lead investigator, staffing the investigation team with experienced and adequately trained personnel, drafting in external experts if required, creating favourable conditions for the investigation and protecting it from undue time pressures are necessary to achieve good results.
4. Identifying and describing root causes for most events requires additional competencies from the human and social sciences. These types of competencies are traditionally very rare in a world of technicians and engineers and even amongst managers. Including human performance engineering specialists, psychologists and/or sociologists in the event investigation team should be considered.
5. A typical mistake in conducting RCA should be avoided — namely concentrating on the direct causes or symptoms of a problem instead of the actual root cause, basically because often the investigation team stops asking ‘WHY?’ too early. The investigation should not be limited to the technical flaw and/or individual failure such as ‘operator error’. It should go far and deep enough and cover all organisational levels, including senior management.
6. The benefits offered by RCA methods and tools using cause categorisation trees, ready-for-use universal checklists, computer software based on them and so-called ‘expert systems’ suggesting solutions for a given root cause should not be overestimated. Categorisation schemes restrict thinking by causing the investigator to stop at the categorical cause. Checklists give people the false sense that the correct answer must be among the listed items. Cause categorisation trees and computer software based on them create the illusion of finding the best solutions. These shortcomings and the disadvantages revealed by operational experience practices should also be taken into account during event investigation and offset by thorough evidence-based analysis of all causes and their inter-relationships.
7. All root causes of an event investigated should be identified the first time wherever possible; it is cheaper, less painful, and more efficient than discovering only one root cause per problem.

8. The degree of independence of the investigation should be increased as much as possible, at least by including independent experts in the investigation team. The final outcome of an investigation depends on the stakeholders' confidence in it, which to a certain extent is linked to the objectivity, integrity and competence of the investigative body. The appointment of members of the investigation team has to find the right trade-off between expertise (i.e. experts who know the field and its culture, technical advances and latest modifications, but are liable to lack impartiality) and independence (impartial members who have no link with the field, but are liable to lack expertise). Investigators (lead and team) require the assurance that taking part in an investigation will not harm their careers in any way.
9. Corrective actions and improvements should be based on reliable root cause analysis results, not on guesses and assumptions derived from ineffective shallow investigations like apparent cause analysis or troubleshooting. This could help avoid wasting time and resources on short-cut investigations and best-guess corrective actions, and improvement programmes will become more cost-effective.
10. Management's approach to and support for event investigation is essential. Management should encourage identification of the real root causes of an event and not limit the investigation to lower-ranking personnel or influence the investigation in a particular direction (especially when underlying causes of incidents are ultimately supervisory and/or managerial and their identification could be uncomfortable).

The effectiveness of the event investigation and operational experience feedback process mostly depends on the safety culture of an organisation's personnel, and of its senior management especially. Management should not just pay lip service to safety but demonstrate and confirm their commitment in the practical decisions they take during the preparation and conduct of an investigation, in evaluating its results and in generating, approving and implementing the corrective actions.

# 1. Introduction

Learning from experience is acknowledged as one of the pillars of the modern approaches to risk management in different industries generating or employing highly concentrated energy flows and thus creating high risks for personnel, the public and the environment. Examples of such areas are the nuclear, gas, oil, chemical and aviation industries. Investigations and analyses of events in these industries are seen as valuable sources of information on safety, and thus constitute important insights towards safety improvement. During recent years there has been a surge in the development of knowledge and systematic approaches, methodologies and tools to aid the event investigation practices adopted within the nuclear industry. However, despite obvious achievements in developing instruments for event investigations and the plentiful resources used to implement numerous corrective actions, accidents are still occurring and recurring, sometimes on an upward trend. They illustrate multiple technical and organisational failures as well as weaknesses in quality management and safety culture, including deficiencies in the operational experience feedback process and cases where lessons are not fully learned. It is therefore necessary to analyse, evaluate and attempt to improve the quality of event investigations with the aim of identifying corrective actions and learning lessons that are better substantiated and more able to be practically implemented.

With a view to collecting available information on practical experience with the individual event investigation methods and tools currently used in the nuclear industry, a questionnaire [1] was prepared and a survey was conducted in 2010-2011.

In parallel with the survey, an interim report on the topic ‘Comparative analysis of nuclear event investigation methods, tools and techniques’ was prepared in 2010 [2]. Based on available technical, scientific, normative and regulatory documentation, the interim report includes a review and brief comparative analysis of information on event investigation methods, tools and techniques either suggested or already used in the nuclear industry. The report identified the advantages and drawbacks of the different instruments.

The aim of the interim report [2] was to serve as a ‘reference guide’ bringing together in one place analyses and critiques of the RCA methods and tools that are most commonly used for risk-related applications in nuclear power plants. In particular, the scope, underlying models and data, strengths and weaknesses, and other characteristics of the methods and tools were investigated so that thoughtful use would be made of any method or tool. It was not the intention of this document to offer specific judgments about whether various approaches should be used. Such judgments are highly dependent on the application and the corresponding needs. Rather, the intent was to provide information relevant to making a judgment, given a specific application or if a method/tool is selected for use, as to whether compensatory steps might be appropriate to ensure that a limitation of a method/tool does not overly impact the results of an analysis.

# 2. Objective and scope of the final report

As part of the technical task ‘Comparative study of event assessment methodologies with recommendations for an optimised approach in the EU’ under the NUSAC work programme for 2010–2011, this scientific research project was launched by the JRC/IE SPNR in 2010. The general objective of the project is to conduct background research in support of specific scientific and technical fields that are relevant to nuclear safety. Specifically, it aims to improve practice in selecting and using nuclear event investigation methods and tools in order to intensify the operational experience feedback process.

The first phase of the project involved compiling, reviewing, comparing and evaluating the most recent data on developments in and systematic approaches to nuclear event investigations by organisations (mainly utilities) in the EU Member States.

During the second phase of the project a survey was conducted in 2010–2011 in order to collect information on current event investigation practices in the nuclear industry.
The present document — the final report on the project — has been prepared on the basis of data obtained from the survey [1], the interim report [2] and other available information gained from nuclear power plant operational experience. This final report aims to analyse countries' responses to the survey questionnaire, evaluate existing practices and put forward some conclusions and recommendations to help in selecting and applying instruments to improve the quality of nuclear event investigations. It is intended to provide useful guidance and information for organisations wishing to develop or strengthen their capabilities in this area.

# 3. Methodology of inquiry

To perform the survey of practical experience with the event investigation methods and tools currently used in the nuclear industry, a questionnaire [1] was developed. Questions were formulated with the aim of covering the most important features of the methods and tools used, in order to evaluate their effectiveness and usability, and also taking into account experience gained when performing other surveys relating to event investigations [2, 3-14]. The questionnaire can be found in Annex A1 to this report. It comprised 47 questions divided into three parts.

The first part of the questionnaire was aimed at collecting personal and background information, namely basic information on the specialists participating in nuclear event investigations and how this activity is managed in various countries. The questions in the first part were as follows:

1. Name, address and country of the organisation responding to the questionnaire.
2. Name, position and e-mail address of the person completing the questionnaire.
3. Number of years employed as an incident investigator.
4. How long (number of years) did you work in the nuclear/nuclear safety area before you became an event investigator?
5. Percentage of your total working time devoted to incident investigations and associated activities.
6. Number of incident investigations in which you have been involved.
7. Have you received formal training in event investigation/root cause analysis methods? If so, please specify the type and duration of the course.
8. Number of investigators typically participating in an event investigation in your organisation.
9. What is the most common composition of an investigation team (please specify roles, functions, positions).
10. Are external specialists (outside experts/consultants from other organisations, corporate investigators from the utility's central department) involved in establishing/performing event investigations in your organisation?
11. Average duration of an event investigation in your organisation (days) (limited apparent cause/specialist/supervisor's investigations of near-misses and low-level events should not be taken into account).
12. Time spent on different activities during the investigation, such as planning, data collection, analysis, drafting recommendations/corrective actions, writing the report (as a percentage of the overall duration of the investigation).
13. Who initiates the investigation in your organisation (investigators themselves, plant management, regulatory organisation, others — e.g. plant committee, commission, group), or is it started automatically as required by the relevant procedure if preconditions are fulfilled?

14. Please evaluate the following (using the scale 'insufficient' 1-2-3-4-5 'adequate'):
    - Human resources (personnel available to conduct an investigation);
    - Time available to perform a good quality investigation;
    - Managers' support for investigations;
    - Availability of investigation guidelines/manuals/method (tool) descriptions/software to support the investigation.
15. Do you feel that the investigation can be conducted objectively and free of pressures aiming to influence the investigation in a particular direction? If not, please explain why.
16. In your opinion, what influence on safety does the event investigation process itself have for personnel interviewed or otherwise involved (over and above the final report and recommendations)? (Enhanced insight into and attitudes towards safety, increased awareness and improved competencies, discovery of unknown dependencies between different functions or departments, etc. should be considered.)
17. In what area(s) has the event investigation been most beneficial for your plant/organisation: (a) reducing maintenance costs; (b) improving equipment availability; (c) improving equipment reliability; (d) reducing operating costs; (e) increasing nuclear safety; (f) improving environmental protection, (g) other (please specify).
18. Are there national regulatory requirements of any sort regulating event investigation in your organisation? If so, please provide the references of the latest edition of the relevant document (please attach a copy of document or indicate the internet address, if possible).
19. What international/foreign requirements/guides do you use for event investigation in your organisation? (please give references or the internet address if possible).
20. Which methodologies are used for event investigation in your organisation? Please tick one or more as appropriate: (a) root cause analysis — RCA; (b) probabilistic safety assessment — PSA; (c) deterministic safety analysis; (d) safety culture assessment; (e) other.

The second part of the questionnaire was aimed at collecting information about current practices, in order to identify the strengths and weaknesses of root cause analysis approaches, methods and tools used by nuclear industry organisations for nuclear event investigation. The questions in this part were as follows:

1. Which root cause analysis (RCA) method(s) have you used for event investigation in your organisation?
2. Which RCA tools and techniques have been used for event investigation in your organisation?
3. How were the RCA methods and tools currently used for event investigation in your organisation acquired (obtained for free; purchased from a vendor; developed internally; obtained and then adopted)?
4. If you have developed any new or existing RCA methods/tools in your organisation, please specify the method/tool and briefly describe the development(s).
5. For how long have the RCA methods and tools been used in your organisation (years)?
6. What factors determined your choice of RCA methods and tools? (a) recommendations of the IAEA, WANO; (b) suggestions of the national regulatory body; (c) suggestions of management of your organisation; (d) suggestions of experienced colleagues; (e) recommendations in

literature (please indicate source); (f) your previous experience; (g) there was no need for choice — you used methods and tools which were in place in your organisation.

7. What is the degree of methodological definition of RCA methods used for event investigation in your organisation: (a) well defined; (b) loosely defined; (c) not defined (no methodology — collection of concepts).

8. Is your organisation currently considering changing the RCA method/tool used? (a) yes; (b) no; (c) don't know. If yes, please indicate the reason for your new choice.

9. Please evaluate the extent to which RCA methods and tools used for event investigation in your organisation meet the following criteria:

   9.1. Clear definition of the problem and its significance for safety.

   9.2. Clear delineation of the known causal relationships that combined to cause the problem.

   9.3. Ability to identify and to establish clearly the causal relationships and interdependencies between the causal factors, the root causes and the problem defined.

   9.4. Clear presentation of the evidence used to support the existence of identified causes.

   9.5. Clear substantiation of the solutions (proposed corrective measures) and explanation of how they will prevent the problem recurring.

   9.6. Ability to document clearly criteria B9.1 to B9.5 listed above in a final RCA report so others can easily follow the logic of the analysis.

   9.7. Availability of a mechanism for testing logic in establishing and analysing causal relationships and interdependencies.

   9.8. Time needed for constructing an event evolution model (chart, tree, and diagram).

   9.9. Accuracy required for constructing an event evolution model (chart, tree, and diagram).

   9.10. Extent of influence of subjectivity and emotions on output.

   9.11. Suitability to address complex system-wide issues (without need to involve other RCA methods and tools).

   9.12. Extent of training and professional expertise needed for the RCA method to be mastered.

   9.13. Level of automation, i.e. availability of specific software for creating charts/diagrams, categorisation, analysing causes, performing integrity checks, generating reports (universal software, such as MS Office, is not taken into account).

   9.14. The potential level of scope of the investigation — suitability to analyse events, influenced by: 1 — the work and technological system; 2 — the staff level; 3 — the management level; 4 — the company level; 5 — the regulator and association level; 6 — the government level.

   9.15. How would you rate the effectiveness of the RCA methods/tools used?

The third and last part of the questionnaire contained four questions requesting some additional information:

1. What other strengths and weaknesses of RCA methods and tools used could you indicate?

2. What further needs and suggestions for the development or improvement of RCA methods and tools could you indicate?

3. Any other comments concerning existing event investigation practices.

4. Please give your overall opinion and any suggestions concerning this questionnaire.

The questionnaire was sent to 79 addressees representing nuclear power plants, regulatory bodies, technical support organisations, and research or consulting institutions mainly in the EU Member States. The list of addressees was drawn up based on their participation in several workshops recently held by the Institute for Energy and Transport and/or the IAEA in the field of event investigation, root cause analysis and human and organisational factors. Some individual experts directly participating in nuclear event investigation or involved in developing relevant investigation methods and tools were also included.

# 4. Analysis of the survey results

The response rate was relatively low. Only 22 responses with adequately filled-in questionnaires from 13 countries were received. These were Bulgaria: 2, Serbia: 1, Hungary: 1, Slovenia: 2, Spain: 3, Czech Republic: 1, Sweden: 2, Switzerland: 1, United Kingdom: 1, Lithuania: 1, Slovakia: 3, US: 1, Finland: 3. Some questions were found by some respondents to be too difficult or unclear to answer: several respondents (6 out of 22) failed to complete the entire questionnaire, leaving some important questions unanswered (especially regarding the qualitative evaluation of RCA methods and tools used against selected criteria).

The relatively low number of responses received and the low quality of feedback information provided could be explained by the following main reasons:

1. In some countries individual event investigators at the utilities are not authorised to respond to such surveys without harmonising the data to be provided with management and/or national nuclear safety regulatory authorities. In such cases only one response to the questionnaire from the country concerned could be prepared containing data based on the official approach to event investigations.
2. Preparation of reasonable answers to all questions contained in the questionnaire took too much time and required adequate qualifications and experience in event investigations.
3. Survey participants lacked motivation to fill in the questionnaire.
4. Unsuccessful selection of survey participants: some of the responses seem to have been prepared by people responsible for operational experience feedback but not really involved in event investigations. If persons trying to fill in the questionnaire have not taken an active part in routine event investigations (typical for personnel of regulatory bodies in most countries), the information provided sometimes seems to be of low value.

According to the answers given, the responses to the questionnaire were prepared by event investigators having on average 8.2 years experience in event investigations. The minimum time spent as an event investigator is 2 years, and the maximum 25 years. Before becoming event investigators, these people worked in the nuclear or nuclear safety area for an average of 10.5 years; however, 4 cases exist where persons were appointed to the event investigation group without any previous experience in the nuclear safety area. The percentage of total working time of respondents devoted to incident investigations and associated activities varies between 10 and 100 per cent (53.3% on average).

The total number of event investigations performed with the involvement of each respondent during his/her career ranges from 8 to 600 (100.3 on average). Each investigator took part in 15.4 event investigations per year (the minimum number of events investigated per year is 0.5, and the maximum 80). This difference is puzzling and raises additional questions about the correctness of answers provided. Statements about hundreds of root cause investigations performed in some specific nuclear power plant and dozens (30-80) of events per year analysed with the personal participation of a particular investigator do not look very convincing. A possible reason for such inconsistency could lie in the different understanding and treatment of the term ‘root cause analysis’. Some people and organisations report a lot of events investigated using RCA; however, most of these events (especially low-level events and ‘near misses’) are actually analysed using apparent cause analysis or troubleshooting but not RCA. Operational experience shows that a specific nuclear power plant is able to perform not more than 3-5 comprehensive root cause analysis investigations (up to 10 at most) per year due to the relatively limited resources available for this activity [16].

### *4.1. Analysis of basic information on the organisation of event investigations*

An average of 6.3 investigators usually participates in event investigations, although this number ranges from 1 (minimum) to 20 (maximum). Most of the investigators responding to the questionnaire state that they have received formal training in event investigation/root cause analysis methods (16 out of 18). However, the prevailing form of training for most respondents is participation in workshops (duration 3-5 days and sometimes even 2 days) organised by the IAEA or other specialised organisations providing training of this type. Questions about the extent and content of training, the appropriateness of the existing training system and future training needs in the area of event investigation/root cause analysis methods, tools and techniques remain topical and should be considered in future.

Data on the typical composition of event investigation teams are presented in Table 4.1. These show that an event investigation group most frequently consists of technical specialists from the plant's departments concerned (experts, engineers, technicians, operators, supervisors), event investigators and representatives of management. Only four respondents state that the plant's nuclear and/or radiation safety officers or inspectors from the regulatory body take part in the event investigations. Prevailing practice, in that psychologists, human factor specialists and also external experts/consultants are rarely included in the event investigation team, could be regarded as a serious shortcoming. Two assumptions can be derived from these data:

- The principle of the independence of event investigations [17, 18] is not considered as an important and necessary attribute.
- Technical issues are considered to be a much more important area for finding root causes of events than potential human factor problems.

**Table 4.1. Typical composition of an event investigation team**

| | **Position or functions of members of the event investigation team** | **Number of responses** | **% of total** |
|---|---|---|---|
| 1. | Representatives of management (reactor or production managers, chief engineers, heads of division/department) | 8 | 38 |
| 2. | Investigators/event analysis experts (including members of operational experience office/group and corrective actions review committee) | 17 | 81 |
| 3. | Nuclear and/or radiation safety officers | 4 | 19 |
| 4. | Specialists representing the plant's departments concerned (experts, engineers, technicians, operators, supervisors) | 19 | 90.5 |
| 5. | Inspectors from the regulatory body (including resident inspectors, INES/IRS national coordinators and officers) | 4 | 19 |
| 6. | Psychologists, human factor experts | 4 | 19 |
| 7. | External experts/consultants | 1 | 5 |

Depending on the type of incident, external experts/consultants from other organisations are sometimes invited to participate in the investigation (11 cases out of 19). Six responses state that external experts/consultants from other organisations are 'never' involved in the investigation, and only two reply 'always'. It is even rarer to include corporate investigators from the utility's central department in the event investigation team: 12 respondents say 'never' and only 6 say 'sometimes', depending on the type of incident.

If limited apparent cause/specialist/supervisor's investigations of near-misses and low-level events are not taken into account, the average duration of an event investigation in different organisations is up to 32.8 days depending on the type of event. However, considerable disparities exist: the minimum duration of the investigation could be only 3 days and the maximum duration up to 100 days. This result also illustrates the fact that some event investigators do not differentiate their activities properly between RCA, apparent cause analysis and troubleshooting.

Most respondents agree on the typical breakdown of time spent on different activities during the investigation (Table 4.2). Analysis of the data gathered takes up the most time: from 20% to 65% (36.1% on average). The second biggest time-consuming activity is data collection, which takes 5-50% of the time (25.8% on average). Other stages of the investigation also take considerable time: planning: 8.3%; drafting recommendations/corrective actions: 16.2%; writing the report: 12.9% on average.

### Table 4.2. Breakdown of time spent on different activities during the investigation

| | **Stages of event investigation** | **Time spent, % of total** |
|---|---|---|
| 1. | Planning | 8.3 |
| 2. | Data collection | 25.8 |
| 3. | Analysis | 36.1 |
| 4. | Drafting recommendations/corrective actions | 16.2 |
| 5. | Writing report | 12.9 |

Event investigation in most organisations is started automatically as required by a particular validated plant procedure if preconditions are fulfilled (according to the responses of 12 recipients). Sometimes it is also initiated by the plant management (8 responses), the regulatory body (6 responses), the plant committee, commission or group (6 responses) and even by investigators themselves (4 responses).

Evaluations of the resources available to conduct investigations (using the scale 'insufficient' 1-2-3-4-5 'adequate') show that investigation teams are on average satisfactorily or well endowed with human resources (average evaluation 3.5) and enough time is allowed to perform the investigation (average evaluation 3.6). Management's support for the investigation is also rated as 'sufficient' or 'good' (average evaluation 3.7) as is the availability of investigation guidelines/manuals/descriptions/software to support the investigation (average evaluation 3.8). However, evaluations vary considerably from country to country.

Most respondents (20 out of 22) expressed the opinion that in their organisations events can be investigated objectively and free of pressures aiming to influence the investigation in a particular direction. Only two respondents disagreed. Explaining the reasons for their negative answer, one of the respondents accurately pinpointed one of the fundamental problems of event investigations: '*More serious or "unfavourable" findings or identified causes not comfortable to the plant management may be refused as "unacceptable"*'. Another respondent didn't explain the reason for his negative answer, stating that '*This kind of question should be anonymous*'. It seems from these answers that some of the data provided in responses to the questionnaire cannot be considered reliable if respondents do not feel independent from management and/or the regulatory body.

It is common ground among all participants in the survey that the event investigation process itself has a positive influence on safety for personnel interviewed or otherwise involved. Besides the final report and recommendations, being involved in the event investigation process can be useful in enhancing insight into and attitudes towards safety, increasing awareness and improving competencies, and discovering unknown dependencies between different functions or departments, etc.

Data provided in the answers to the questionnaire demonstrate that for a particular plant/organisation the event investigation has been most beneficial in improving equipment reliability (11 responses) and increasing nuclear safety (18 responses). Some of the respondents do not distinguish between specific areas, asserting that all the areas mentioned (including reducing maintenance costs, improving equipment availability, reducing operating costs, improving environmental protection) are almost always influenced positively. Such important areas as staff and management safety culture, personnel performance and human factors also benefit (see Table 4.3).

### Table 4.3. Distribution of responses with regard to the areas benefiting from event investigation

| | **Areas benefiting from event investigation** | **Number of responses** |
|---|---|---|
| 1. | Reducing maintenance costs | 4 |
| 2. | Improving equipment availability | 10 |
| 3. | Improving equipment reliability | 11 |
| 4. | Reducing operating costs | 3 |
| 5. | Increasing nuclear safety | 18 |
| 6. | Improving environmental protection | 5 |
| 7. | Other: staff & management safety culture, personnel performance and human factors | 5 |

Event investigations in most organisations are performed in accordance with national regulatory requirements (17 responses out of 21). Relevant international/foreign requirements/guides are also widely used (17 responses out of 19). IAEA, US NRC, WENRA, WANO and INPO documents are most frequently used.

Based on an accepted classification system of event investigation methodologies, methods and tools [2], data on the most frequently used methodologies are presented in Table 4.4. Based on the absolute majority of responses, root cause analysis remains the leading methodology for nuclear event investigations. Since probabilistic safety assessment, deterministic safety analysis and safety culture assessment are also mentioned in some responses, they are mostly employed in pursuit of objectives other than routine event investigation or as complementary instruments to RCA.

### Table 4.4. Methodologies used for nuclear event investigation

| | **Event investigation methodologies** | **Number of responses** |
|---|---|---|
| 1. | Root cause analysis | 21 |
| 2. | Probabilistic safety assessment | 9 |
| 3. | Deterministic safety analysis | 6 |
| 4. | Safety culture assessment | 7 |

## *4.2. Analysis of information on specific features of RCA methods and tools*

The importance of differentiating between event investigation methodologies, methods, tools and techniques is demonstrated in [2]. The lack of an agreed system of definitions to differentiate them makes it impossible to objectively compare their characteristics and select the most effective instruments on a logical basis. With a view to comparing the particular features of event investigation instruments of the same level, the suggested classification system distinguishing RCA methodology and methods from tools (see Fig. 2.1.1 and Fig. 3.1 in [2]) was followed.

Asking which root cause analysis method(s) had been used for event investigation in specific organisations, respondents were offered 18 methods to choose from. They are: HPES — Human Performance Enhancement System; HPIP — Human Performance Investigation Process; HPEP — Human Performance Evaluation Process; MORT — Management Oversight and Risk Tree; ASSET — Assessment of Safety Significant Event Team; PROSPER — Peer Review of the effectiveness of the Operational Safety Performance Experience Review process; SOL — Safety through Organisational Learning; MTO — Man-Technology-Organisation Investigation; AEB — Accident Evolution and Barrier function; STEP — Sequential Timed Events Plotting; PRCAP — Paks Root Cause Analysis Procedure; CERCA — a computer-based event investigation method; 3CA — Control Change Cause Analysis; HF-RCA — root cause analysis method of the GRS (Germany); GO — method for analysis of dynamic systems; DYLAM — Dynamic event Logic Analytical Method; DETAM — Dynamic Event Tree Analysis Method; other.

However, only 9 methods out of the 18 suggested were noted as used in practice in the responses received. Figure 4.1, showing the frequency of use of different root cause analysis methods, illustrates the fact that during the last ten years the existing event investigation practices have not changed very much when compared with data presented by the IAEA and WANO in 2002–2008 [17, 19, 20]. According to 12 respondents, the most frequently used method at European nuclear plants is event investigation based on INPO's Human Performance Enhancement System (HPES). Other methods which are fairly often used are: MORT — Management Oversight and Risk Tree analysis (5 responses), the IAEA's ASSET (4 responses) and MTO (3 responses). The remaining 5 methods (HPIP, SOL, AEB, STEP, PRCAP) are used locally in a specific country.

In order to identify the most frequently used event investigation tools, respondents were invited to choose from a list of 22 items. The tools included in the list are: Event and Causal Factors Charting (ECFC); Cause and effect analysis; Interviewing; Task analysis; Why-why chart; Pareto analysis; Storytelling; Change analysis; Barrier analysis; Fault tree analysis; Event tree analysis; Causal factor tree analysis; Kepner-Tregoe problem solving; Human factors investigation tool; Interrelationship diagram; Current reality tree; REASON®; PROACT®; REALITYCHARTING®; TAPROOT®; CAS-HEAR; other.

The results of the survey demonstrate (Figure 4.2) that out of the 22 suggested only 14 tools are really used. Some basic event investigation tools are used in practically all investigations. These are: ECFC, Barrier analysis, Change analysis, Task analysis and Interviewing. Some other tools seem to be quite common: Cause and effect analysis is mentioned in 9 responses, Event tree analysis and Human factors investigation tool are mentioned in 8 responses. The remaining few tools (such as Why-why, Pareto diagrams, Storytelling, Fault tree analysis and TapRooT®) are used to a limited extent (locally in some specific countries/organisations).

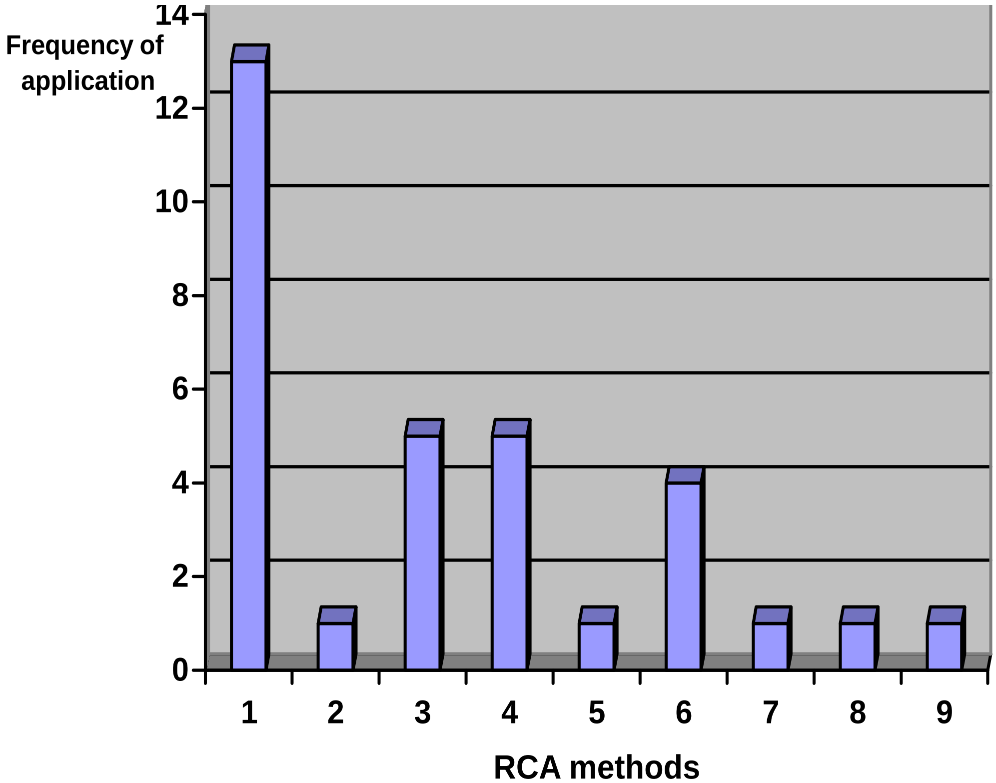

Figure 4.1. Frequency of application of different root cause analysis methods
1 — HPES, 2 — HPIP, 3 — MORT, 4 — ASSET, 5 — SOL, 6 — MTO, 7 — AEB, 8 — STEP, 9 — PRCAP

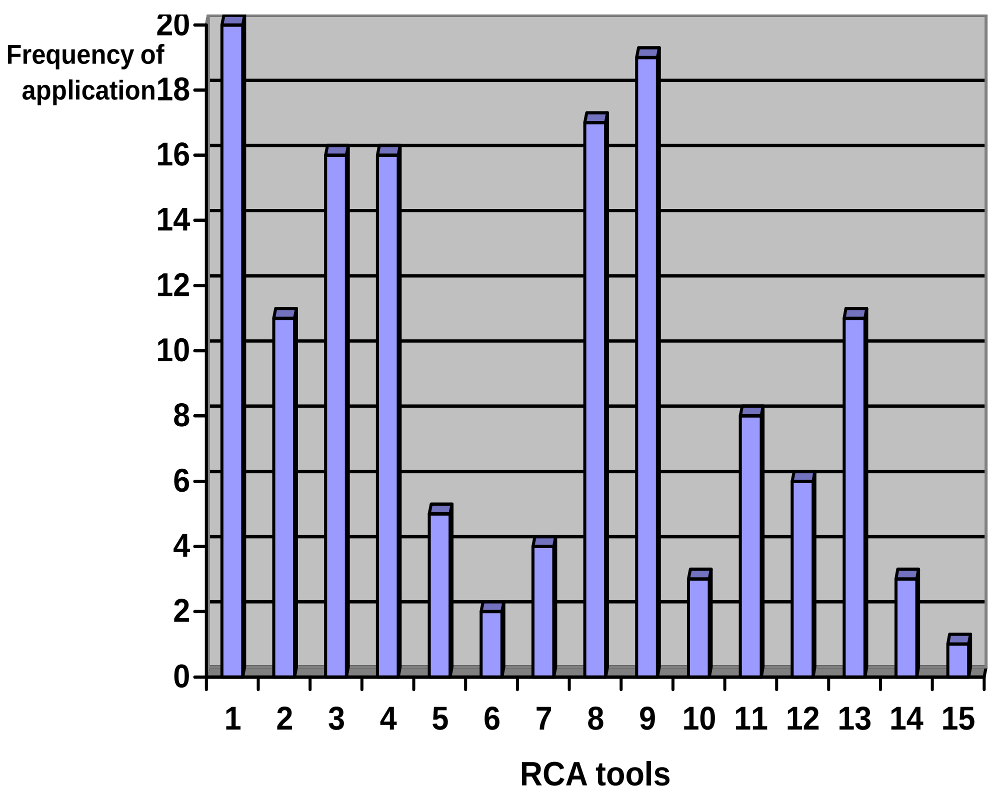

Figure 4.2. Frequency of application of different root cause analysis tools
1 — ECFC, 2 — Cause and effect analysis, 3 — Interviewing, 4 — Task analysis, 5 — Why-why, 6 — Pareto diagrams, 7 — Storytelling, 8 — Change analysis, 9 — Barrier analysis, 10 — Fault tree analysis, 11 — Event tree analysis, 12 — Causal factor tree analysis, 13 — Human factors investigation tool, 14 — TapRooT®, 15 — Interrelationship diagram

Analysis of the information collected gives rise to some observations:

1. The classification system for event investigation methods and tools is not perfect. Basic (elementary) event investigation tools which are used independently from other ones should be distinguished from more complex derivative tools which are based on the combined use of several basic (elementary) tools. Examples of basic (elementary) tools could be: Barrier analysis, Change analysis, Task analysis, Interviewing, Why-why, Storytelling. The remaining tools listed in the questionnaire (e.g. ECFC, TapRooT® and others) seem to belong to the group of complex derivative tools.
2. The differences between these two groups of event investigation tools should be taken into account when comparing their prevalence and positive and negative features and giving recommendations for their selection and/or usage.
3. The selection of a particular event investigation method strongly determines the selection of appropriate investigation tools and techniques.

Most respondents state that RCA tools currently used for event investigation in their organisation are obtained for free (14 responses), obtained for free and then adopted (8 responses) or developed internally (9 responses). Only two respondents indicate that their organisation uses RCA tools purchased from a vendor. In most organisations the same RCA methods and tools have been used for a long time: the average is 14 years. Most investigators assume that the degree of methodological definition of RCA methods used for event investigation in their organisation is substantial (16 responses out of 18); however, two respondents state that there is no defined methodology — only a collection of concepts is used for investigating events.

Survey respondents indicated that the factors which had determined their choice of RCA methods and tools include:

- recommendations of the IAEA, WANO — 7 responses;
- suggestions of the national regulatory body — 3 responses;
- suggestions of the organisation's management — 7 responses;
- suggestions of experienced colleagues — 6 responses;
- previous personal experience — 7 responses.

For 4 respondents there was no need for choice — the methods and tools used were already in place; however, nobody made their choice based on recommendations in the literature. Practically all respondents (17 out of 18) declared that their organisations were not currently considering changing the RCA method/tool used (or respondents were not aware of any such plans).

Such a conservative approach with regard to the acquisition of new modern event investigation tools could be due to several reasons:

- Investigators are fully satisfied with the effectiveness of event investigation tools already in place and they have no demands for new ones.
- Investigators have insufficient information about the potential advantages of new modern event investigation tools and recommendations for their selection and/or usage.
- Investigators and/or management are not motivated enough to explore the opportunities for increasing the quality of event investigations and the effectiveness of the operational experience feedback process.
- Acquisition and implementation of new modern event investigation tools is not considered a robust investment of financial and human resources due to the high costs of modern computerised commercial tools and the considerable length of time needed for training.

A summary of respondents' opinions regarding the advantages and disadvantages of event investigation methods and tools used in their organisations is presented in Table 4.5. Survey participants were asked to evaluate to what extent particular RCA methods and tools met the 15 selected criteria. They were invited to use the scale 'bad, low' = 1 2 3 4 5 = 'excellent, high'. The exception is answers to question 14, where number 1 represents suitability for analysing events at the level of the work and technological system (lowest level), and number 6 represents suitability for analysing events at the highest level — the government.

The results presented in Table 4.5 comprise only those event investigation methods and tools which were evaluated in responses to the questionnaire. Some of the RCA methods and tools proposed for evaluation did not elicit responses, so that no information about their effectiveness was received. Most respondents were able to evaluate only one or two methods or tools that had been used in their organisation. Consequently, the bulk of the RCA methods and tools included in Table 4.5 were evaluated by a limited number of respondents (sometimes only 1 or 2), and the amount of data collected is not sufficient for statistical analysis. Only the most frequently used method, HPES, was evaluated by 11 respondents. For this reason, the objectivity of evaluations should not be assumed to be very high.

Comparing RCA methods (see Table 4.5), the most 'excellent, high' evaluations were scored by SOL and PRCAP (6 highest evaluations each), MORT (4 highest evaluations) and MTO (2 highest evaluations). The lowest evaluations were most frequently scored by MTO (4 'bad, low' evaluations), AEB (3 'bad, low' evaluations), STEP (2 'bad, low' evaluations), and MORT (1 'bad, low' evaluation). However, the highest overall effectiveness was scored by ASSET (4.25 points), MORT, SOL, MTO and PRCAP (4.0 points). The most widely used RCA method, HPES, was on average evaluated moderately: only two criteria were rated 4.0 or more (clear presentation of the evidence and ability to document clearly the definition of the problem, facts, causal relationships and logic of analysis in a final RCA report), while its overall effectiveness was rated 3.64. Some evaluations look a little confusing and seem to be subjective and not adequately substantiated. For example, methods which are well supported with specific software (such as SOL, PRCAP, MORT) are not rated or rated poorly for the level of automation, while methods not supported with any software, such as ASSET, are rated quite well. Some doubts about the validity of evaluations are also raised by the practically smooth or obviously too-high ratings given to some methods against all criteria (e.g. SOL, PRCAP, ASSET).

Comparing features of RCA tools (see Table 4.5) seems to be even more complicated. Only a few respondents provided more or less acceptable evaluations of some RCA tools. The most widely used RCA tools such as ECFC, task analysis, interviewing, change analysis, and barrier analysis are thus evaluated by a few respondents only. The probable reason for this seems to be that these tools are used in combination as ECFC, and also their use is compulsory in HPES. It could be assumed that the evaluation of HPES provided by most respondents contains an integral rating of the basic RCA tools used for carrying out HPES. Another difficulty hindering attempts to compare evaluations received lies in the fact that most of the RCA tools rated are used for different purposes and/or employed in specific combinations with other tools and methods. Thus, data collected about specific features of particular RCA tools are insufficient to make a statistical analysis and draw well substantiated conclusions.
However, an analysis of the evaluations received can yield some interesting observations.

1. Most respondents evaluate only one or two particular event investigation methods or tools which they use in practice in their organisations. Event investigators are not informed, trained and experienced enough to evaluate and compare other RCA methods and tools employed in other countries/organisations, including newly developed modern computerised tools. This could be regarded as a serious obstacle hindering the dissemination of good practices and operational experience feedback.
2. Some respondents are unduly satisfied with the advantages of a specific method or tool which has been in use for a long time in their organisation. For example, in some responses particular

methods or tools are evaluated as ‘good’ or ‘ excellent’ against practically all 15 selected criteria (see Table 4.5), including those criteria against which an evaluation could not be given (e.g. questions 9.7, 9.8, 9.13).

Besides evaluating them against 15 criteria listed in Table 4.5, some respondents indicated other strengths and weaknesses of RCA methods and tools used. The most important of these are presented in Tables 4.6 and 4.7. Most of the comments made confirm characteristics of event investigation methods and tools already determined by another investigators and practitioners [2].

**Table 4.5. Results of quantitative evaluation of effectiveness of event investigation methods and tools**

| | RCA methods / tools used → | HPES | MORT | ASSET | SOL | MTO | AEB | STEP | PRCAP | ECFC | C-E analysis | Interviewing | Task analysis | Pareto | Change analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Criteria** | **Evaluations (average values)** | | | | | | | | | | | | | |
| 1. | Clear definition of the problem and its significance for safety | 3.45 | 4.0 | 4.25 | 5.0 | 3.0 | 3.0 | 3.0 | 5.0 | 4.0 | 3.0 | 3.5 | 2 | 2 | 4.0 |
| 2. | Clear delineation of the known causal relationships that combined to cause the problem | 3.64 | 5.0 | 4.0 | 5.0 | 4.0 | 3.0 | 3.0 | 5.0 | 5.0 | 3.0 | 2.0 | 2 | 1 | 3.5 |
| 3. | Ability to identify and to establish clearly the causal relationships and inter-dependencies between the causal factors, the root causes and the problem defined | 3.64 | 5.0 | 4.25 | 5.0 | 4.0 | 4.0 | 4.0 | 5.0 | 5.0 | 3.0 | 3.5 | 3 | 2 | 3.5 |
| 4. | Clear presentation of the evidence used to support the existence of identified causes | 4.0 | 4.0 | 4.25 | 5.0 | 5.0 | 3.0 | 3.0 | 5.0 | 4.0 | 3.0 | 3.0 | 4 | 1 | 3.0 |
| 5. | Clear substantiation of the solutions (proposed corrective measures) and explanation of how they will prevent the problem recurring | 3.45 | 4.0 | 4.75 | 4.0 | 4.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3.5 | 4 | 3 | 4.0 |
| 6. | Ability to document clearly criteria 1 to 5 listed above in a final RCA report so others can easily follow the logic of the analysis | 4.09 | 4.0 | 4.25 | 4.0 | 5.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.0 | 3 | 3 | 3.5 |
| 7. | Availability of a mechanism for testing logic in establishing and analysing causal relationships and interdependencies | 3.54 | 4.0 | 4.0 | 3.0 | 2.0 | 4.0 | 3.0 | 3.0 | 3.0 | 2.0 | 2.5 | 4 | 4 | 3.5 |
| 8. | Time needed for constructing an event evolution model (chart, tree, diagram) | 3.64 | 3.5 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | 3.0 | 4.0 | 2.0 | 3 | 5 | 3.5 |
| 9. | Accuracy required for constructing an event evolution model (chart, tree, diagram) | 3.64 | 4.0 | 4.5 | 5.0 | 3.0 | 3.0 | 3.0 | 5.0 | 5.0 | 3.0 | 2.5 | 4 | 4 | 3.5 |
| 10. | Extent of influence of subjectivity and emotions on output | 3.18 | 3.0 | 3.25 | 3.0 | 2.0 | 3.0 | 3.0 | 3.0 | 4.0 | 3.0 | 3.0 | 5 | 5 | 4.0 |
| 11. | Suitability to address complex system-wide issues (without need to involve other RCA methods and tools) | 3.54 | 5.0 | 4.25 | 5.0 | 1.0 | 2.0 | 2.0 | 5.0 | 4.0 | 2.0 | 2.5 | 3 | 2 | 2.5 |
| 12. | Extent of training and professional expertise needed for the RCA method to be mastered | 3.36 | 4.0 | 4.3 | 3.0 | 3.0 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 4.5 | 5 | 3 | 4.0 |
| 13. | Level of automation, i.e. availability of specific software for creating charts/diagrams, categorisation, analysing causes, performing integrity checks, generating reports | 2.7 | 2.0 | 4.0 | | 2.0 | 2.0 | 3.0 | | 4.0 | 3.0 | 2.5 | 2 | 2 | 3.0 |
| 14. | Potential level of scope of the investigation — suitability to analyse events, influenced by the work/technological systems, the staff, the management, the company, the regulator and the association, or the government | 3.77 | 5.0 | 4.3 | 4.0 | 4.0 | 1.0 | 2.0 | 4.0 | 6.0 | 3.0 | 3.0 | 2 | 4 | 2.0 |
| 15. | Overall effectiveness of RCA methods/tools used | 3.64 | 4.0 | 4.25 | 4.0 | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 | 3.5 | 5 | 4 | 4.5 |

Respondents submitted a number of suggestions for improving existing practices in event investigation. The most important and frequently repeated suggestions are the following:

- Develop comprehensive software for further computerising the event investigation process (for creating charts/diagrams, categorisation, analysing causes, performing integrity checks, generating reports). Software to assist the analysis is needed for HPES and MORT.
- Resume IAEA technical support for the ASSET method.
- Improve the education of event investigators by organising appropriate training, drafting simpler manuals and guidelines, and providing more practical examples.
- Exchange experience among investigators.
- Include external specialists, independent investigators and human and organisational factor experts in the event investigation teams.
- The investigation should wherever possible be ordered by persons holding the highest offices in the management hierarchy.
- More efforts during analysis of an event should be put into identifying/defining root causes (RCs). A well-defined comprehensive taxonomy of causal factors should be used; however, it should be borne in mind that taxonomy cannot always offer the exact cause/causes of an event. 100 % accuracy in identifying RCs using a specific procedure is not possible. Further 'manual digging' is therefore necessary.
- A more standardised and formalised procedure should be developed for event analysis, providing specific instructions and steps for the investigation to reduce the influence of the investigator's perception/impression/subjectivity.
- It is effective to use two or more complementary RCA methods or tools.
- Management support for investigators is imperative; continuous assessment of those involved in the process and in setting corrective/preventive actions is needed. The effectiveness of the investigation output directly depends on how correctly the RCA process was applied.
- Presentation of the event, the results of the investigation and the recommendations developed to management is very important.

**Table 4.6. Strengths and weaknesses of RCA methods used**

| RCA methods used | Strengths | Weaknesses |
|---|---|---|
| ASSET | - Well structured method appropriate for retrospective analysis of similar events that tend to recur<br>- Appropriate for analysis of a single safety-related occurrence | - No longer supported by IAEA<br>- Organisational factors and policies are too generalised |
| | Free, applied quickly, IAEA manual | Needs experience and practice, manual not easy to follow |
| | - Well structured<br>- Appropriate for analysis of single occurrences and for retrospective analysis of similar/recurring events | - Can be widely used for any type of event<br>- No longer supported by IAEA |
| | Very clear to understand, well structured, wide application, easy staff training | Restricted application for human factor events |
| HPES | - Clear and logical representation of the event information<br>- Appropriate for human and organisational factor-related events | - Time consuming<br>- Depends on investigator skills and expertise |
| | - Useful especially when combined for visual representation of information<br>- Flexible and logical and helps investigator to consider all the aspects easily | Requires some 'special talents': power of observation, deductive thinking, etc. |

| | | |
|---|---|---|
| | Systematic, simple and quick (partly because it uses standardised causal factors) | Does not cover every aspect (for instance organisational factors); focuses on human errors |
| | Good ability to determine what happened, how and why | Little automation. Too 'liberal'; dependent on investigator (subjective influence) |
| | Takes human factors into account | Does not take organisational factors into account deeply enough |
| | Flexible | Great dependence on interviews |
| | Allows the investigator flexibility | Risk of forgetting to consider some aspects |
| | Flexibility | Misses some facts on events |
| HPIP | Widely used, covers individuals' contribution to the event development | More examples needed |
| MORT | Comprehensive, systematic. Possibility of analysing several causal factors simultaneously | Requires a lot of time and expertise |
| AEB | Free, focused on failures and errors | Graph not always clear because potentially overlooks data and factors |
| MTO | Requires relatively low level of training | Problem with parallel events |

**Table 4.7. Strengths and weaknesses of RCA tools used**

| RCA tools used | Strengths | Weaknesses |
|---|---|---|
| ECFC combined with PSA | Very good for complicated events | Method is complicated and is not used for simple events |
| E&CFC | Ability to connect different problems/causes and to be reduced to a simple level for use in short presentations | No full software available, so still performed manually (with aid of MS Office programs) |
| | Good visual aid when presenting, helps to drill down into underlying issues | Not always used at the start of the investigation and used as a timeline rather than an analysis tool |
| Change analysis | Good starting point, simple to use | Must be combined with other tools |
| | Accurate tool | Only for special cases |
| Task analysis | Accurate tool if procedure is used | Only for special cases |
| Interviewing | Best for human and organisational issues | Dependent on interviewer skills |
| | Direct, first-hand information is obtained | Must be carried out shortly after the event |
| Cause and effect analysis | Organises data and develops analysis | Time consuming, needs practice |
| Causal Factor Diagram | Makes the event description and its causes easier to understand | Not a very powerful investigation tool |
| Human Performance Investigation Tool | Helps to gain context relating to the situation. Helps to define corrective actions to combat certain behaviours | Can sometimes focus on the last individual in the chain rather than on the organisational issues |
| TapRooT | Provides detailed procedures | Risk of tunnel vision |
| Pareto | Good management tool | Limited use (indicators, trending, etc.) |

## 5. General observations regarding existing practices in event investigations

There is broad consensus about the objectives, goals and main principles of event investigations for different industries [21]. Members of an accident investigation team and all stakeholders involved in an investigation should feel responsibility toward it and follow specific rules on the conduct expected of them and the ethical principles that should govern their behaviour. A general framework for accident investigation based on broad consensus may include:

- Strict adherence to the objective of carrying out the investigation in order to prevent accidents and incidents and enhance safety — not to apportion blame or liability.
- The necessity and duty to investigate all major accidents and important near-accidents in order to learn lessons and take corrective actions.
- Allocation of resources for the investigation in proportion to the scale and complexity of the incident and the scope for learning lessons.
- Formulation and follow-up of recommendations with the aim of reducing the relevant risk factors involved.

Some examples of the ethical principles that a code should include are [21]:

- Integrity. At all times the activities carried out should be in accordance with the high standards of integrity required of the role played, profession pursued or position held by the individual.
- Objectivity. When collecting, analysing, describing or communicating facts, the main emphasis should be on objectivity.
- Logic. Facts should be applied in a logical manner.
- Prevention. Facts and analysis should be used to develop findings and recommendations that will improve safety.
- Independence. The investigative body, its investigators and staff should be independent of the national judicial system, other authorities and all other actors and parties involved.

The investigative process consists of several interconnected phases and steps in the iterative processing of facts, findings and analysis [21]:

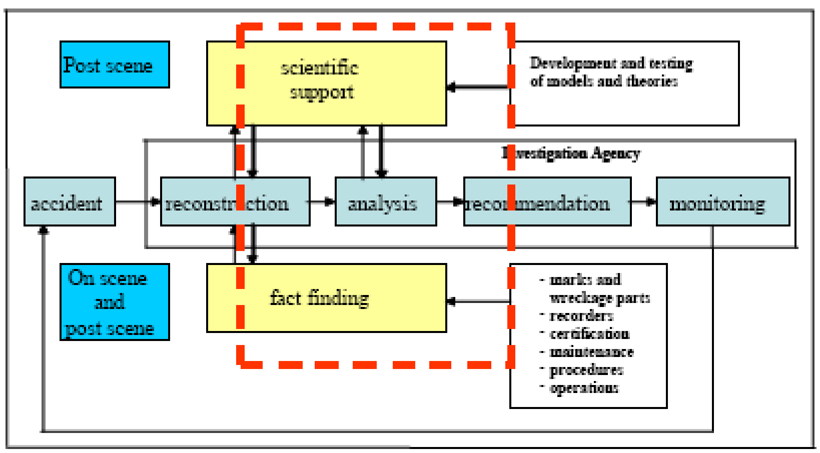


Figure 5.1. General structure of the event investigation process

The *rationale* in accident investigations consists of diagnosing unknown situations through an iterative reasoning cycle in which a temporary and conditional adaptation of the hypothesis under investigation takes place. One way of looking at the investigation is that it is about reducing uncertainty about what happened, why it happened and what should be done about it by applying the knowledge available to the investigator(s) based on the evidence obtained during the investigation. In that sense, management of the investigative process can best be described as:

- Structuring known facts and findings;
- Structuring unknown information that will require further collection or analysis.

Finally, throughout the investigation, a cyclic decision-making process takes place, covering perception, analysis, decision-making and action. In particular, where information deficiencies occur due to lack of evidence or data, additional ways of collecting data must be explored.

It is commonly recognised that the most important methodology for incident investigation and qualitative evaluation is root cause analysis. The RCA methodology is built on a basic principle — recognition that controlling causes translates into controlling the problem. The general logic of RCA follows the classical process: define the undesired outcome, define the analysis requirements, gather data, analyse data, form conclusions, check conclusions, and recommend corrective action [2, 22, 23]. The theory behind root cause analysis is deceptively simple: event-based problems are solved by eliminating or mitigating at least one root cause.

Despite its limitations and shortcomings [2], RCA serves well for identifying, analysing, eliminating or mitigating root causes and causal factors of an undesired outcome. It helps organisations to identify risk or weak points in processes, underlying or systemic causes and corrective actions. RCA enables people to understand, recognise and discuss the underlying beliefs and practices that result in poor quality/safety in an organisation (see Figure 5.2 [13]). Information from RCA shared between and among organisations can help to prevent future events. However, the effectiveness of an event investigation rests less on the root cause analysis methods, tools or techniques used than on the thoroughness of the investigation conducted. Investigation methods and tools are only as good as their users: tools are servants not masters. Used properly by adequately qualified and experienced investigators, any of them can be effective and produce good results.

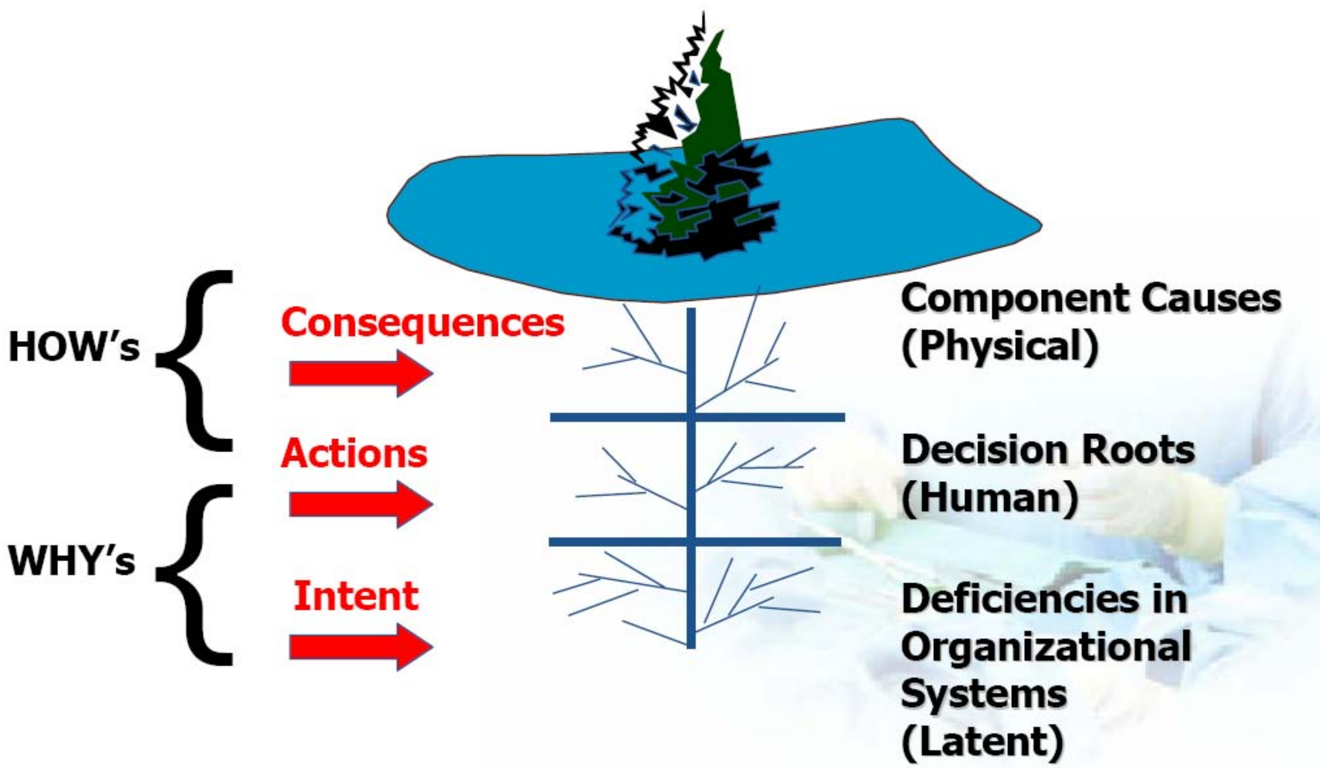


Figure 5.2. The 'root' system of an event

Analysis of existing practices in event investigations in the nuclear industry (including the survey findings) shows that there are several groups of obstacles hindering efforts to make the process of feedback of OE gained from event investigations more effective:

1. Thresholds for initiating event investigation at specific level (troubleshooting, apparent cause investigation or root cause analysis) are not clearly defined. It is recommended [2, 10, 17, 24] that every organisation should establish their own threshold criteria or sentinel events for defining the level of analysis depending on the type of industry, the organisation and the potential risk involved in its activities. Following the idea of continuous improvement, the threshold criteria should be periodically reviewed and revised: if no problems are meeting the threshold criteria, they should be tightened; if time and resources spent on investigation exceed the acceptable limits, they should be relaxed. Such flexibility allows organisations to set

threshold criteria that are based on management decisions or engineering judgment about event consequences and are easily managed following business, corporate or even personal interests.

2. There is no adequate system of commonly agreed terms, definitions and classification even for the most important concepts of event investigations and no standards for event investigation methods and tools. Definition of the basic concepts is of utmost importance, because 'you will always find what you are looking for'. A typical example of the ambiguous treatment of such basic terms is the continuing controversy around the main object of the entire methodology — the meaning of the notion 'root cause'. In the absence of an accepted system of terminology any investigator can call any cause of a problem a 'root cause,' and he/she will be correct. For the same reason, root cause analysis is anything that anybody wants it to be: any event-based problem-solving methodology could be called a root cause analysis, and that assertion would be correct. The view exists that the root cause is a myth [25], because seeking the 'root cause' is an endless exercise: no matter how deep you go there is always at least one more cause you can look for. Some specialists recommend even avoiding the word 'cause' in accident investigations and rather talk about what might have prevented the accident. Definitions of such frequently found root causes of events as 'human factors', 'organisational factors', 'safety culture', etc. also have different meanings for different people.

3. The quality of many event investigations is relatively low. This seems to apply not only to the nuclear industry, but also to other high-risk industries and areas, including such specific areas as health and safety [23] and environmental protection [26]. A classic mistake in the use of RCA is to concentrate on the direct causes or symptoms of a problem instead of the actual root cause, basically because the investigators stop asking 'Why?' too early [2, 10, 22]. Many accident investigations do not go far and deep enough. They identify the technical cause of the accident, and then connect it to a variant of 'operator error' — the line worker who forgot to insert the bolt, the engineer who miscalculated the stress, or the junior line manager or supervisor who made the wrong decision. But this is rarely the whole issue. When determination of the causal chain is limited to the technical flaw and/or individual failure, typically the actions taken to prevent a similar event in the future are also limited: fix the technical problem, change the procedure, and replace or retrain the individual responsible. Putting these corrections in place leads to another mistake: the belief that the problem is solved. So, many accident investigations stay at the surface — thus leaving room for the same type of events to recur. Furthermore, weaknesses in investigation could block the ability to find both generic characteristics from the analysis of the event and other characteristics of interconnected events [2, 8, 21].

4. The importance of the principle of independence of the investigation is commonly acknowledged [17, 21] but this principle is rarely implemented in the bulk of organisations. Protecting the investigation team from any external or internal pressures, such as undue time pressures, pressures from the line organisation involved or peer pressure, etc., is one of the responsibilities of management [17], but this requirement seems to be theoretical — far removed from real practice. The findings of the survey [1] confirm this notion: independent external experts/consultants are rarely included in the event investigation teams.

5. The existing system of information about OE from events is not comprehensive and user-friendly. Much of the valuable information gained from event investigations is stored in the form of raw data: it is not adequately systematised, catalogued, classified and coded, so it is not converted into knowledge that is ready for use and learning. And a lot of event-related information is stored in databases with restricted access and cannot be used by researchers or even by regulators (the WANO database is a typical example).

6. The drawbacks in applying root cause analysis are the time necessary to conduct a proper investigation and the expense it entails, in part because all parties involved are taken away from the processes linked to the plant's operation. In addition, performing root cause analysis can require training and retraining the personnel participating in the investigation at each incident, especially when the incidence rate is low and skills are lost due to infrequent opportunities to practice investigations. Consequently, root cause analysis systems are not usually well received by supervisory personnel, who are typically 'too busy' for the paperwork or unwilling to thoroughly study and execute a complicated RCA process [38].

The lack of commonly agreed definitions and concepts within the field of accident investigation (especially regarding the notion of cause) leads to confused thinking, unclear goals and inadequate results and makes it difficult to compare different methods, tools and techniques [2, 13, 15]. Knowledge gained from theoretical and practical results and experience accrued by event investigators, scientists and practitioners concerning the classification, comparison and selection of event investigation methods and tools has none of the features of a library for scientists or a tidily ordered toolkit for practitioners. Why?

- Providers of commercial event investigation tools are not interested in their standardisation, through fear of losing their uniqueness in the market, with a potential negative impact on their business.
- Scientists and researchers/developers of the methodologies, methods and tools are interested in establishing their self-importance/significance or self-image (a natural human trait) by inventing 'new' instruments for analysis, more sophisticated specific definitions and barely understandable theories that differ only minimally from already existing ones, and in getting their work into print.

The ongoing discussion around the term 'root cause' seems to be of the utmost importance and deserves more thorough attention, because it reflects at least two different philosophies governing event investigation practices, defining possible outcomes and influencing the effectiveness of the entire learning from operational experience process. The existing variety of definitions of root cause could be divided into two groups depending on the role of management which is assigned to the entire event investigation process from the outset [2].

1. First group: definitions stating that root causes are only those causes which could be reasonably identified and fixed by management:
   (a) Root causes are specific underlying causes which can reasonably be identified, controlled to fix by management and those for which effective recommendations for preventing recurrences can be generated [Rooney, 27].
   (b) A root cause is the most basic cause (or causes) that can reasonably be identified and that management has control to fix and, when fixed, will prevent (or significantly reduce the likelihood of) the problem recurring [Paradies, 28].
   (c) A root cause is the most basic cause that can be reasonably identified and that management has control to fix [Paradies, 29].
   (d) A root cause is the most basic cause that can reasonably be identified and that management has control to fix and, when fixed, will prevent or significantly reduce the likelihood of the problem's occurrence or existence [30].
2. Second group: definitions stating that root causes do not depend on management's ability to fix them:
   (e) Root causes are the most fundamental reasons for an incident or condition, which if removed will minimise the risk of recurrence of the incident or condition [Conger, 31].
   (f) A root cause is the fundamental cause of an initiating event, correction of which will prevent recurrence of the initiating event (i.e. the root cause is the failure to detect and correct the relevant latent weakness(es) and the reasons for that failure) [IAEA, 32].

(g) Root cause: any cause in the cause continuum that is acted upon by a solution such that the problem does not recur [Gano, 10].
(h) A root cause is the absence of a best practice or a failure to apply knowledge that would have prevented the problem [Paradies, 33].
(i) Root cause (of an incident): an initiating event or failing from which all other causes or failings spring. Root causes are generally management, planning or organisational failings. [34]

The main difference between the definitions of root causes assigned to these two groups is a distinct approach to the role of management. Definitions (a) to (d) are based on the assumption that only those causes which can be controlled and fixed by management can be recognised as root causes. Definition (a) describes 'root cause' even more narrowly: it states that only those causes for which effective recommendations for preventing recurrences can be generated can be recognised as root causes. Accordingly, definitions (a) to (d) promote a philosophy according to which a root cause is not a direct result of objective reality but a consequence of management's ability (or inability) to control existing reality and fix emerging problems. Such an approach is very popular and widespread in the nuclear industry, especially among event investigators subordinate to management. It is strongly promoted by some providers of commercial root cause analysis tools and software. By way of an illustration, Herrmann [35] says that one of the pitfalls to be avoided in event investigation are weak reviewers — people overly concerned about looking bad in front of management, the regulator, etc. Such definitions of the root cause are methodologically incorrect for the purpose of event investigation, because they introduce essential limitations of the scope and potential outcome of an investigation: it looks as if root causes could be found only at the levels lying below management. However, it will be shown later that according to statistics and the opinions of numerous investigators root causes frequently lie precisely inside the management, and only better management could help to prevent (or significantly reduce the likelihood of) the problem recurring.

Root cause definition examples (e) to (i) declare that there is no dependency between the root cause and management's ability (or inability) to control it. Despite the abundance of definitions, no one of them is perfect. For example, definition (f) lacks clarity and concreteness, because other undefined terms are used for the purpose of explanation, and the requirement 'to prevent recurrence of the initiating event' seems completely unrealistic: some event probability will always exist. Definition (e) seems to be quite logical; however, it stresses that several root causes should be found, not one. But if so, all of these root causes should be removed to minimise the risk of recurrence of the incident or condition. However, observations have revealed that such a recommendation is not very realistic and practical because the availability of resources for numerous corrective actions to fix a lot of root causes is always limited in all organisations. Recognition of several root causes in definitions (a), (b), (e) and (g) means that the distinction between 'root cause' and simply 'cause' is lost. The need 'to prevent recurrence of the event or problem' appears to be a common shortcoming of definitions (g) and (h). The absence of best practice or the failure to apply existing knowledge — the basis for definition (h) — seems to be more likely a direct cause than a root cause, because a lot of information concerning event investigations is accumulated. The weakness of definition (i) is in its one-sidedness: a root cause could be not only the initiating event but also some action or condition.

Taking the above considerations into account, it seems reasonable to use the following definition of root cause:

***The root cause is the most fundamental reason for an incident or adverse condition, which if removed will effectively prevent or minimise recurrence of the incident or condition.***

## 6. Bottlenecks in existing event investigation practices

Considerable resources have been devoted to operational feedback systems and especially event investigation and analysis. A lot of operational experience is accrued in all the so-called high-risk industries, such as aviation, energy, chemicals, gas, oil, mining or transport. Considering the nuclear industry only, 440 nuclear reactors producing electricity around the world have been in operation for approximately 14 000 cumulated reactor-years. In each operating unit from several hundreds to several thousands of events occur each year (taking into account all types of events, including accidents, serious events important for safety, incidents, near misses and low-level events). Thousands of records and reports about these occurrences are stored in IAEA/NEA, WANO, US NRC and a number of other regional and national databases. The volume of information on events and accidents, their causes, circumstances, consequences, corrective actions and lessons learned could be measured in terabytes and is steadily growing. However, despite these substantial efforts even major events still recur, and there are some indications that their frequency is increasing.

Leaving aside peculiarities and specific conditions, with rare exceptions we can state that most events which are occurring today or will occur tomorrow are not new — similar events have happened somewhere before, and information about these events that could be helpful to prevent them recurring does exist somewhere. The same view is shared by many managers and experts [21]: the same types of events reoccur with the same type of causes. The general problem is that the system of feedback of information based on operational experience is not effective enough to prevent or even reduce the frequency of events recurring.

So why do events nevertheless recur? Why can they not be prevented despite the unimaginable progress made by information technology in processing operational experience data and the billions spent on implementing corrective actions? Since these questions are clearly too general and too complex, their importance compels us to try to find some at least partial answers.

If attempts to prevent an event recurring have proved unsuccessful, it could be analysed using classical root cause analysis methodology. Such an event was able to happen because some direct causes exist:

- Information about previous events does not exist or is incorrect (events were not investigated or the investigation was too superficial; the real root causes of the event were not found, and no lessons to be learned were identified).
- Correct information about previous events and lessons learned exists but is not accessible or could not be found easily by the relevant people.
- No attempts were made to find existing information about previous events and lessons learned.
- Measures based on the existing information about how to prevent recurrence of the event were inadequate or were not implemented adequately.

Digging deeper and looking for causal factors and latent root causes of the event’s recurrence, at least three groups of closely related reasons could be identified that lie behind the direct causes listed above:

1. Methodological factors (thresholds for specific levels of investigation not set; lack of standards for event investigation methods and tools; lack of a system of agreed terms and definitions; principle of independence of the investigation not fulfilled);
2. So-called human or organisational factors (HOF) linked to the quality/safety culture and ethics of personnel at all levels, including management (conflict between business/carrier interests and safety goals; imperfect system of values; objective features of human nature; lack of motivation and/or insufficient resources provided, etc.). Events with a clear indication of HOF causes are still described as almost entirely caused by technical factors. Culture-related organisational factors are rarely considered in event and incident investigation. Here the role of the senior management is essential [36]: organisations and persons may be unwilling to be self-critical because of potential repercussions (internal/external). Even if recognised, HOF issues are typically understood as human performance errors at the individual worker level.

3. Knowledge management-related factors: typical when only raw OE information exists; data are not processed/structured/coded and not converted into knowledge, or information is not accessible due to restrictions.

An event and causal factors chart aiming to explain possible scenarios leading to event recurrence, potential negative impacts and emerging traps in the event investigation process is presented in Figure 5.3. The chart was created by summarising the results of the survey [1] and considering the existing experience of event investigations [2] as well as direct communication with experienced investigators working for the nuclear industry. The normal (theoretical) flow of the event investigation process is shown in green, and an alternative route leading to event recurrence is shown in pink.

The first barrier in the way of event investigation (see Figure 5.3) is the event review/screening. This activity is usually performed by an authorised plant committee, board, commission or group with the active participation of management. The event investigation may be started automatically as required by some validated plant procedure if the preconditions are fulfilled; sometimes it is also initiated by the plant management or regulatory body. The level of investigation necessary is determined during the review/screening depending on the level of the event, subject to a set of criteria taken from the organisation's technical specifications and supporting procedures [17]. Since thresholds for initiating an event investigation at a specific level (troubleshooting, apparent cause investigation or root cause analysis) are not standardised and seldom even clearly defined, a degree of freedom exists to choose a low level of investigation even for events that are important for safety or involve valuable OE information. Such decisions (e.g. not to perform a root cause analysis) could be based on opinions of screening board members, engineering judgment or management discretion [16, 17]. In practice, a nuclear plant may actually perform three to five or maybe even ten good root cause analyses per year (a trend can be observed towards performing fewer and fewer RCAs per year — 2-3 RCAs per unit per year on average) [36]. But NPPs carry out hundreds or even thousands of short-cut (apparent cause) analyses instead, claiming at the same time that the rate of root cause analysis is growing and that key performance indicators are therefore improving. The thousands of corrective actions based on guesses and assumptions derived from inefficient shallow investigations are driving the improvements in those indicators. So time and resources are wasted on short-cut investigations and best-guess corrective actions, and many nuclear managers complain that improvement programmes are not cost-effective.

The second potential barrier in the way of successful event investigation (see Figure 5.3) lies in its preparation. Making the relevant preparations for an investigation is the direct responsibility of management [17]: they should establish and implement an event investigation process within the management system, provide appropriate resources, select the lead investigator, ensure that the investigation team is staffed with adequately trained personnel, draft in external experts if required and protect it from undue time pressures. Failure to fulfil these requirements leads to the appointment of a weak investigation team and/or the creation of unfavourable conditions for investigations. For example, the investigation team should not be pressured to produce results prematurely either by internal deadlines or external influences (regulator). This could result in superficial analysis in order to come up with easy-to-accomplish corrective actions. The more serious the issues identified, the longer it takes to fix them (especially if organisational changes are needed).

The third potential barrier hampering achievement of the highest quality and the best outcome from event investigations is in execution of the investigation itself. Here there are numerous traps of a methodological or organisational nature or to do with human factors and the safety/quality culture which were analysed above in chapter 5 and in [2]. Sometimes they are aggravated by insufficient support from management, and specifically limited access to information to conduct the investigation, lack of protection of the investigation team from external or internal pressures such as pressures from the line organisation involved or peer pressure, inadequate communication in support of the investigation team, and a punitive culture. Practice demonstrates the existence of these circumstances, although their elimination is the direct responsibility of management. Potential also exists to influence the investigation in a particular direction or to restrict it to identifying individual failures of shop-floor workers or junior engineering personnel. This is especially evident when underlying causes for the incidents are ultimately supervisory and/or managerial. Most situations which arise within an organisational context can be resolved through a variety of approaches. These different approaches generally require different levels of resource expenditure to implement. And, due to the immediacy which exists in most organisational situations, there is a tendency to opt for the solution which is the most expedient in terms of dealing with the situation. In doing this the tendency is generally to treat the symptom rather than the underlying fundamental problem that is actually responsible for the situation occurring. Yet, in taking the most expeditious approach and dealing with the symptom, rather than the cause, what is generally ensured is that the situation will, in time, return and need to be dealt with again.

The next obstacle sometimes hindering proper identification of the event's root cause is the prevailing practice of harmonising the investigation results with management. This activity should theoretically be limited to verifying the accuracy of the draft report without influencing the course of the investigation [17]. However, in practice it frequently leads to adjustment of the outcome of the investigation: more serious or 'unfavourable' findings or identified causes that are uncomfortable for the plant management may be refused as 'unacceptable'. This practice is supported by the complexity of the systems involved, the specificity of the causal nature resulting in the fact that validation of root causes relies on expert judgments and cannot be tested or confirmed in the same manner as the direct causes (i.e. via simulation, tests, etc.). In addition, senior managers are not typically provided with training in RCA techniques or HOF and may therefore be reluctant to accept report conclusions if HOF issues are identified.

The last serious barrier in the way of successful event investigation (see Figure 5.3) lies in the stage of generating, approving and implementing corrective actions. It is imperative that corrective actions should be proposed by the investigation team to address the causes of the event and other areas for improvement. This activity is also strongly influenced when suggested corrective actions are harmonised with management. Completion of a magnificent RCA and proper identification of root causes does not mean that the problem at hand goes away. The investigation team might make recommendations that do not work or might make good recommendations that are not approved by management. Good recommendations might be approved but might not be implemented [37].

Knowledge management-related causal factors and latent root causes of event recurrence play a considerable role too. Since the volume of information relating to events and accidents is vast and is permanently growing, only a small part can be used in practice. The primary reason for this situation is that existing raw information is not converted into knowledge due to lack of resources or motivation: it is not properly prepared, screened, classified, catalogued, and formatted in a user-friendly form. So the relevant data are difficult to find, retrieve and use. Another important factor impeding the use of event-related information is the restricted access to numerous databases.

Consequently, the general objective of an event investigation — to prevent or at least minimise the risk of recurrence of the event — could be achieved if all the abovementioned barriers are overcome successfully. If the investigation process fails because of at least one of these barriers, the root causes of the event will not be properly identified, and corrective actions will be ineffective — they will not prevent the recurrence.

Here it is worth stressing the essential role of management, which not only has direct responsibility, but also directly controls and influences all stages of an event investigation process (see Figure 5.3). However, the impact of management does not always lead to improvement of the quality of root cause analysis. Often, when a fault-oriented, punitive management style predominates, 'fault' and 'cause' are confused, and incident investigations typically seek to assign fault — and protect supervisors or higher organisational level personnel — by generating reports that document alleged responsibility.

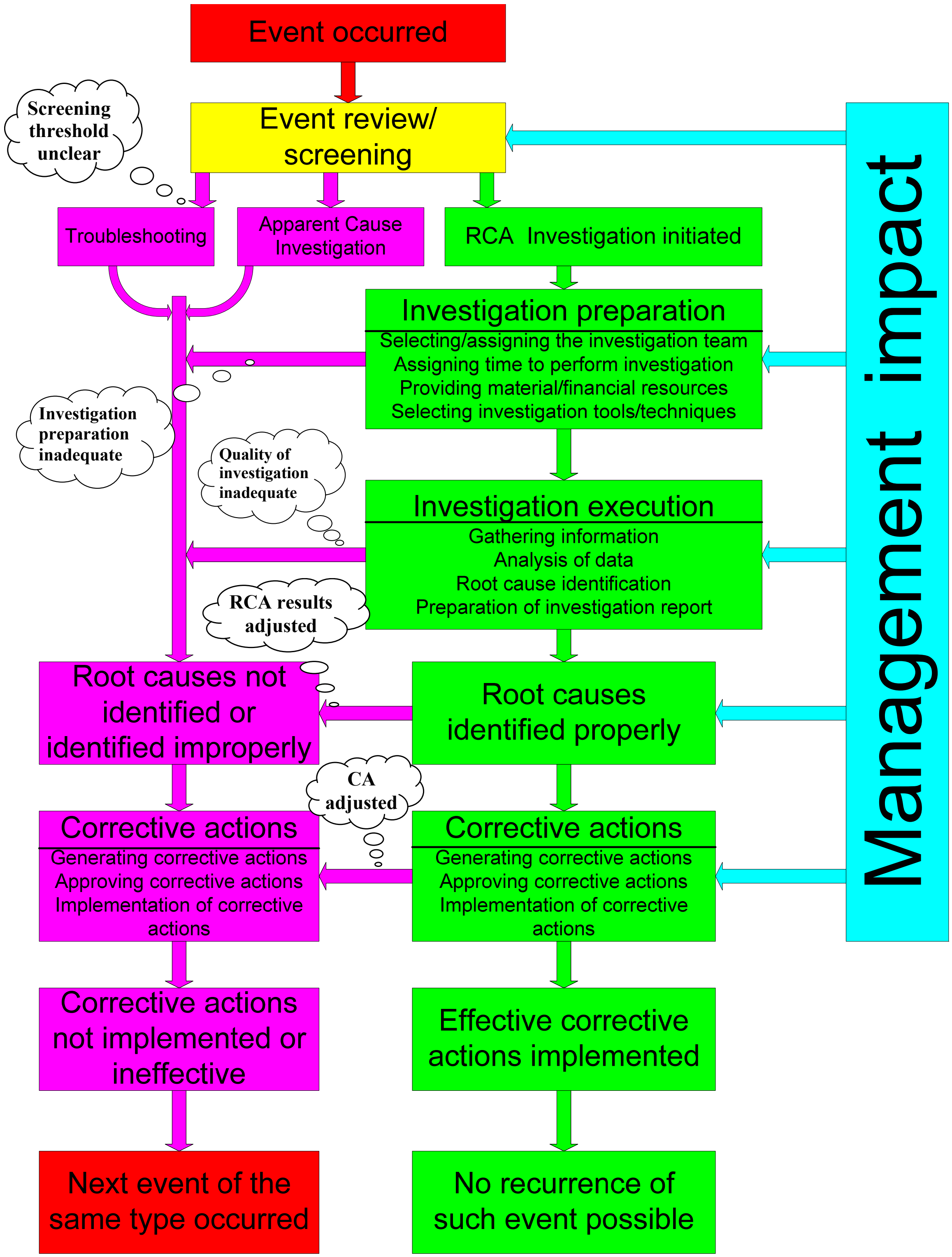


Figure 5.3. Possible routes of the event investigation process with potential negative impacts

The next question which logically should be asked is: why does management sometimes try to divert the event investigation process from identifying the real root causes of an event or avoid implementing the essential corrective actions to prevent recurrence? Why are such cases becoming more frequent despite management's universally declared commitment to safety as the overriding priority?

The answer to this question could be found by analysing the factors influencing the safety culture of an organisation, which in fact is developed, controlled and driven by the safety culture of the top management. According to W. Edwards Deming, most problems are management controllable — embedded in the manner in which management decides to operate the organisation [18, 39, 40, 41]. Corporate top managers influence safety not only through their decision-making on budgets and policies, but also through their daily actions and attitudes (see [2], Fig. 2.4.6). These channels of influence are important in forming the safety culture of the company, and the primary role of leaders in developing the organisational safety culture is essential. In nuclear and other high-risk industries safety culture is closely related to the handling of risk. However, the top management's commitment to safety is often affected by the conflict between safety and production such that safety improvements based on event investigation results and OE lose priority in favour of business interests.

An unfavourable environment for event investigation and the OE process could result from the following drawbacks in top management beliefs and behaviour [41, 42]:

1. Putting short-term production cost-cutting objectives ahead of long-term safety goals. Key decisions are made by management based on accounting principles that do not recognise the concept of the cost of (poor) quality/safety. This is the most widely observed trend caused by growing economic pressure to reduce operating costs. In many countries nuclear facilities are constantly challenged to reduce operating costs due to the competition induced by deregulation of private facilities or decreased funding for government-owned facilities. This changing operating environment can lead to some services such as root cause analysis being considered as 'unnecessary' expenses (especially by those who typically review the budget without understanding what RCA is), following which resources are cut or staff not directly engaged in operations are reduced. The remaining staff have to do more and are likely to have less opportunity to undergo the training needed to keep the appropriate qualifications up to date.

2. Placing schedule considerations ahead of safety — a practice closely linked to the previous issue and also widespread in different industries including the nuclear sector. Hurrying to meet deadlines at any price leads to insufficient time being allowed to investigate an event, hasty conclusions and ineffective corrective actions.

3. Maintaining an environment that is unfavourable to a questioning attitude. In some organisations fear is not driven out: it is not possible to discuss openly problems that may exist — mentioning a problem can be a career-limiting move. People who have the courage to talk about problems are then labelled as whistle-blowers and are often punished in both overt and subtle ways. Sometimes this is because acknowledging the problem will reveal that past efforts to fix it have been unsuccessful.

4. Arrogance and overconfidence. Any organisational culture that creates an environment in which the captain, chief surgeon, scientist, pilot, top manager or president cannot be viewed as capable of making a mistake and cannot be questioned has embraced an arrogance that will ultimately lead to negative results or even disasters. Some organisations use such arguments to justify their decisions and actions: '*Our organisation is made up of the best minds in our field. We've graduated from the top universities. We are highly experienced nuclear engineers. We are the*

*largest company in this field. We've been successful in this business for over 100 years. We have top level safety/security certificates. We invented this technology. We hold more patents than any other company. We have the top scholars in the field. We ride in private jets. We have private boxes at big sporting events*' [2-104]. Such an approach frequently leads to significant quality, environmental, health and safety problems.

5. Underestimating the importance of fundamental knowledge, research and/or education. In some cases, people embark on new projects without fully understanding what the outcomes will be, which is fine if the lack of understanding is taken into account.

6. Pervasively believing in entitlement. The entitlement belief system is one in which employees believe they are entitled to their jobs and their benefits due to years of service, past sacrifices and past performance. They believe they should be immune to the vagaries of market forces, the impact of new technologies and changes in customer requirements. When the belief in entitlement is pervasive, employees believe no one else would want to have their job and put up with all they have to put up with. They expect rises every year, regardless of the organisation's performance. Entitlement is created by management's failure to continually share business and performance information with the workforce.

7. Autocratic leadership, resulting in 'endullment' of personnel. Endullment is the opposite of empowerment: when employees have no sense of control over or involvement in what they must do, they turn off, passively resist, become apathetic, fail to complete assignments. The same process occurs when management adopts an autocratic approach to decision making and does not share information with the workforce, does not provide a balanced scorecard or performance indicators and does not engage the members of the workforce in a collaborative effort to continuously improve their performance in order to secure their mutual economic well-being.

Leaders who succumb to any of these seven fundamental temptations will not want to acknowledge their problems. They will ignore these concepts as unrealistic fiction and revert to their focus on costs, schedule, political manipulation, arrogance, ignorance, entitlement or endullment, resulting in weaknesses in safety culture, ineffective corrective actions and recurrence of events.

# 7. Recommendations

## *7.1. Methodological recommendations*

In order to avoid the ambiguities and misunderstandings currently surrounding the terms and definitions used in event investigation in general, and root cause analysis in particular, the following improved definitions are proposed.

**The root cause is the most fundamental reason for an event, which if removed will minimise the risk of the event's recurrence**.
Root causes do not need to be under the organisation's or management's control (initiators and factors may exist outside the organisation), but the responsibility for effective barriers lies with the organisation. Root causes rarely appear alone, especially for complex systems.

**Root cause analysis (RCA)** is an event investigation methodology consisting of a set of working methods, establishing an inquiry strategy and describing an integrated system of event investigation activities. RCA is designed to gain an understanding of the real or potential occurrence, its precursors, circumstances, conditions, direct and root causes, organising the facts and data obtained in order to arrive at a logical set of findings and conclusions, and making it possible to derive effective corrective actions and/or countermeasures to prevent or reduce the probability of future recurrences.

Root cause analysis should be distinguished from simplified event investigation techniques such as apparent cause analysis and troubleshooting.

**Apparent cause analysis** is based on a limited investigation that tries 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.

**Troubleshooting** is a logical, systematic, experience-based process to identify failures, malfunction(s) or their symptoms within a technical system, to determine and eliminate their direct causes.

**The root cause analysis (RCA) method** is a set of general procedures and rules establishing the tactics of an inquiry and providing discipline and guidance for the user to follow RCA methodology in a particular way. Each RCA method may involve many steps and processes and has wide usage; it is implemented using one or more (sometimes a combination of several) RCA tools and techniques and usually has its own taxonomy.

**A root cause analysis tool** is a relatively simple event investigation instrument, developed through experience to assist investigators in identifying the root causes, providing detailed step-by-step working procedures for event analysis that can be recorded, repeated and verified. It is merely one of the vehicles for implementing and expressing the particular RCA method; it should be distinguished by its limited use, relatively narrow scope and concretely defined inputs, procedures and outputs.

**A root cause analysis technique** is a specific practical manner of application of a root cause analysis tool requiring some skill, experience and knowledge.

With a view to better distinguishing between event investigation instruments of different levels and applicability, the following system of classification of basic RCA methods and tools is suggested (see Figs 7.1 and 7.2). This system should make it easier to compare their characteristics and select the most appropriate instruments for event investigation. The suggested classification is not comprehensive: many more different methods and tools are used in different industries for event investigation, and new ones are being constantly developed. However, the suggested system could be treated as a template which could be adopted and expanded if required. Some of the universal tools presented in Figure 7.2 could be used not only for root cause analysis, but also for other event investigation methodologies, e.g. probabilistic safety analysis.

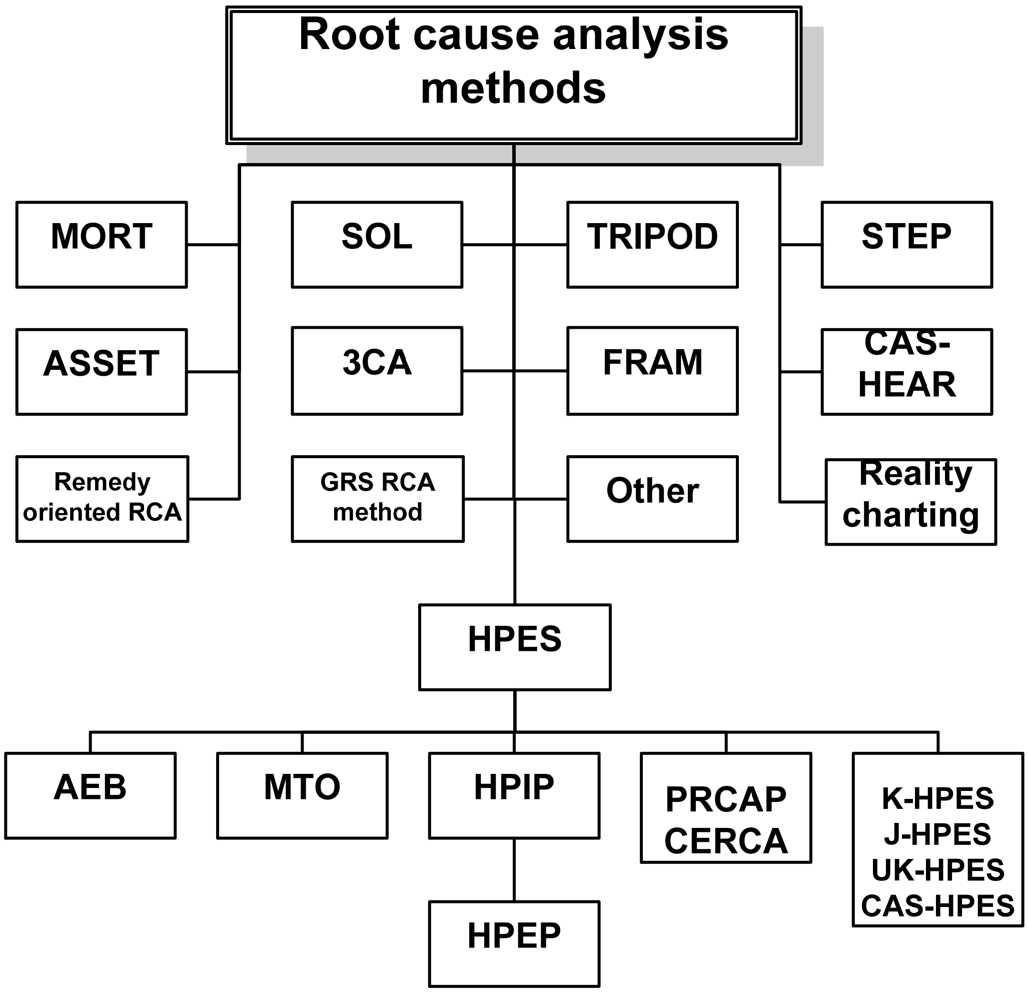


Figure 7.1. Some of the most popular and commonly used root cause analysis methods

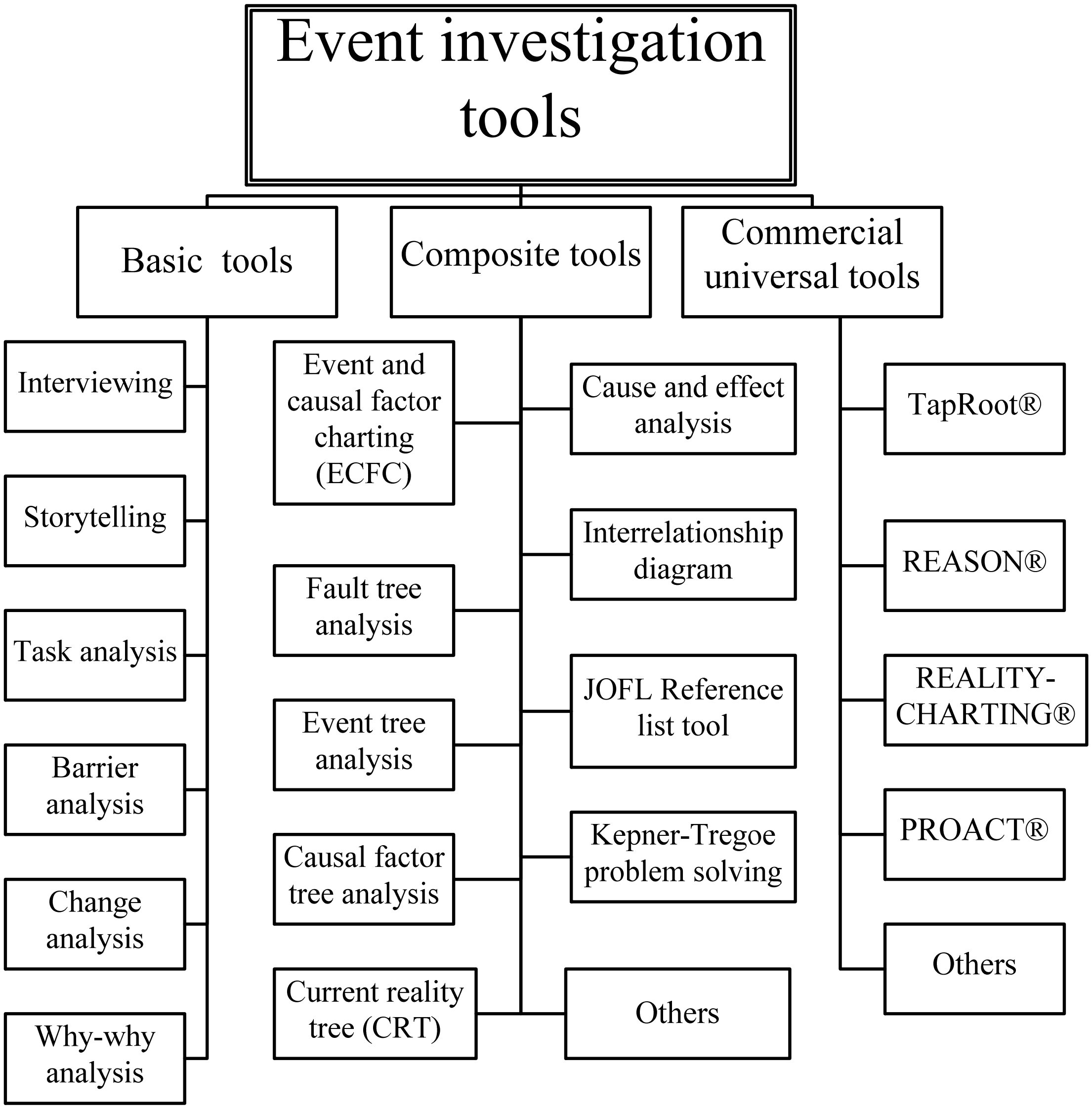


Figure 7.2. Some of the most popular and commonly used event investigation tools

## 7.2. Recommendations for selecting RCA methods and tools

The results of the survey (see chapter 4) show that the problem of selecting the most effective and appropriate method and tool for event investigation is not very topical for experienced practitioners in the nuclear industry and/or regulatory institutions. The problem emerges in new organisations entering the nuclear industry or expanding their nuclear programmes, which are establishing and developing new operational experience feedback systems based on event investigation results.

Following the principle of separating event investigation instruments of different levels and the suggested classification system for RCA methods and tools (see Figs 7.1 and 7.2), the first step is to select the RCA method. Here it should be kept in mind that most of the internationally recognised root cause analysis methods, when used properly, will enable the investigation team to identify the root cause(s) of an event or adverse condition, if the investigation is adequately prepared, the investigation is independent, and both personnel and management have an appropriate safety culture. The following factors should be given preliminary consideration when selecting an RCA method:

1. Results of benchmarking within and outside the nuclear industry with regard to value, comprehensiveness, operational reliability and efficiency;

2. Recommendations by international organisations and experienced colleagues;
3. Amount of training needed to successfully use the method;
4. Availability of software to support the method;
5. Costs.

Priority should be given to the first two characteristics: it should be ensured that factors such as cost, availability of software, training needs, time and ease will not take precedence over the important characteristics of value, comprehensiveness of analysis, operational reliability and efficiency.

The more comprehensive process of selecting the appropriate RCA method for the needs of an organisation should consist of several sub-steps and meet the following criteria [16]:

*1. Determine your internal RCA needs.*

- Are you looking to set up an entire RCA-based event investigation system or to investigate a single incident only?
- Will your RCA effort focus on 'incidents' only, chronic failures only, or both?
- Will management support be solicited?
- Will management systems be implemented?
- Will teams be dedicated to carrying out RCAs?
- Will hourly personnel and external experts participate in investigation teams?
- Will additional technical resources be required?
- Will additional technical equipment be required?

*2. Determine the appropriate RCA method to use for your environment*

- Evaluate simplicity of method.
- Evaluate analysis flexibility.
- Evaluate quality of materials and job aids.
- Evaluate training flexibility.
- Evaluate method comprehensiveness.
- Evaluate system to track for results.
- Evaluate overall value of method (cost-benefit analysis).

*3. Determine how to implement it: in-house or outsource*

- Does the facility possess the instructional technology skills and resources to develop in-house courses on the evaluated and proven RCA method?
- Is it more economical and timely to develop courses in-house (cost-benefit)?
- Would utilising past vendor training be appropriate for in-house instructors?
- Is there any copyright infringement concern in utilising past vendor training in-house?
- Are qualified RCA instructors with field experience available in-house?
- Would in-house instructors be dedicated to supporting and mentoring their students?
- Would management be willing to fund the RCA method development in-house?
- Would management be willing to wait for completion of the skill development and then implementation?

*4. Choose the appropriate RCA vendor*

- Does the vendor provide the RCA method chosen by the facility?
- Does the vendor have training in RCA for field personnel, engineers and management?
- Does the vendor possess various methods that complement each other and provide specifically designed training to the appropriate level of audience?
- Does the vendor's instructor(s) have field experience in implementing RCA? How much?
- Does the vendor's instructor(s) have experience in instructional technology and applied learning to increase presentation retention rates?
- Can the vendor provide references of successful client field applications, including nuclear industry applications?

- Does the vendor have products/services to support the RCA method (management system support models, software, on-site facilitation services, follow-up capabilities, etc.)?
- Is the vendor willing to customise instruction and materials to accommodate your needs?
- Is the vendor willing to work on specific, ongoing in-house failures during training?
- Does the vendor possess the staff-related skills to deal with managerial culture transformations?
- Is the vendor willing to partner? Share risk?
- Does the vendor possess the staff capacity to handle your requirements? Domestically? Internationally?

Obviously, this list of criteria is not as comprehensive as it possibly could be; however, it is a good starting point. The key to starting is clearly defining what is wanted and obtaining internal support for the vision. Then the task will be to solicit the qualified vendors to help realise the vision.

After the appropriate RCA method is chosen, the next step is to select root cause investigation tools and techniques. The need and freedom to select the appropriate RCA tools are limited (sometimes very strictly) by the following conditions:

- Suitable RCA tools could be already defined during the selection of a particular RCA method.
- Chosen RCA tools should be applicable to the type of event that has occurred and is to be investigated.
- Some RCA tools serve specific purposes only (for example, collecting information and evidence, presenting the event sequence graphically, etc.) and cannot be replaced by other tools (see Fig. 7.2).
- Some RCA tools (especially basic and universal ones — see Fig. 7.2) are employed in practically all event investigations.

In any event, during selection of the appropriate RCA tools it is recommended that reference be made to Table 7.1, which compares the features of some of the most frequently used RCA tools.

## Table 7.1. Comparison of features of some root cause analysis tools and techniques

| RC tool | Type of event | Amount of information needed | Single E/ repeated E/ trend | Safety significance | Time needed to implement | Resources and training needs | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|
| **Interviewing** | All | Low | Single E<br><br>Repeated E | Any | Quick | Trained and experienced interviewer | Information gathering technique for investigations | Information gathering technique for investigations |
| **Task analysis** | All | Low/task-specific | Parts of any event | Can be used for any | Time needed to complete process is moderate; however, individual causal factors can be identified quickly | Minimal training required<br><br>Someone familiar with the type of task being evaluated | Easily identifies differences between the proper performance of a task and the performance of the task at the time it was carried out when it was related to the event being investigated<br><br>Very helpful to identify causal factors that relate to physical environment and man-machine interface | Usually requires the availability of an individual technically knowledgeable about the task being evaluated<br><br>May not be effective when task cannot be re-enacted<br><br>Used specifically for single tasks, cannot be used for complex evolutions by itself<br><br>Technique cannot be used on its own to identify root causes |
| **Change analysis** | All | Low to medium | Single E | Recommended for low/ medium | Medium | Minimal training required | Best technique for identifying causes of issues when something changes between a successful development and one that has contributed to an event or issue<br><br>Can be used for any type of change from a standard approach | Must be used together with task analysis when change being evaluated is composed of more than one task<br><br>If used in isolation, can result in only the obvious changes being identified<br><br>Cannot be used for first-time developments<br><br>Can overlook gradual changes or evaluator can accept the wrong (obvious) answer.<br><br>Technique cannot be used alone to identify root causes |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Barrier analysis** | All | Medium | Single E<br><br>Repeat E | Any | Short | Minimal training required<br><br>Someone technically familiar with the process or development being investigated | Can identify probable causal factors with a systematic approach<br><br>Used in conjunction with E&CF, can identify process weaknesses and the effectiveness of proposed CAs | If the evaluator is not familiar with the technical aspects of the event being investigated, they may not recognise all barriers<br><br>Technique cannot be used alone to identify root causes |
| **Event and causal factor chart** | All | High/entire event | Single E<br><br>Repeated E | All significance levels | Time needed to complete process is long; however, individual causal factors can be identified quickly | Trained/experienced E&CF evaluator | Provides an illustration of the whole problem from initiating event through to recovery actions. | Time-consuming<br><br>Evaluator needs experience for proficiency<br><br>Technique is not useful for evaluating trends unless they are the result of a sequence of issues over a period of time |
| **Cause and effect analysis** | Non-complex events | Low, but causal factors must be identified before this technique is used | Single E | Recommended for low to medium | Quick | Minimal training required<br><br>Someone familiar with the process | Provides an easy approach for identifying root causes, for non-complex events | Begins after causal factors are identified, therefore when viewed by itself it will not provide all background information to understand a complex problem<br><br>Requires experience to ask the right questions |
| **Fault tree analysis** | Equipment | High | Single E<br><br>Repeated E | High | Long | Minimal training required; however, technical knowledge of the issue being investigated is important | Allows a graphic depiction of how cause and effect are related to the event being investigated<br><br>Can be used to evaluate complex events with multiple outcomes<br><br>Good method for evaluating equipment failures | Subjective in that all possible causes must be identified in order for this tool to work properly<br><br>Designed for identifying direct causes rather than causal factors<br><br>Technique cannot be used alone to identify root causes |
| **Event tree analysis** | Equipment | High | Single E<br><br>Repeated E | High | Long | Minimal training required<br><br>A specialist in PRA is needed<br><br>Technical knowledge of the issue being investigated is important<br><br>Specialised software | Each outcome is weighted allowing for the prioritisation of corrective actions based on impact on the event or issue being evaluated | Labour-intensive<br><br>Needs to be used with other techniques to populate the event tree |

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| **Why-why (why staircase)** | All | Low | All | All | Once causal factors are identified (depending on other techniques used), process can be completed quickly | Not many resources or training needed<br><br>Most effective when performed by individual with a leadership perspective on the organisation | Can be used for all types of events to identify programmatic and organisational weaknesses<br><br>Simple technique, used to challenge the causes identified by other techniques | Highly subjective<br><br>Difficult to know when to stop asking 'why' (experience needed)<br><br>Does not easily differentiate between root causes and contributing causes<br><br>Needs to be used by an investigator familiar with the specific programmes and organisation<br><br>Needs to be used with other techniques to identify the causal factors |
| **Common cause analysis** | All | High | Trend | Can be used for all levels | High | Training should include using trend reports, understanding causal factors and how they are assigned | Can be used to identify programmatic or organisational weaknesses when trends in causal factors appear<br><br>Can be used with any data sets that causal factors can be assigned to | Quality of the analysis depends on the number and accuracy of the data points<br><br>A successful CCA will only result in the identification of the more dominant common causes for a group of events; a root cause method must be used in order to identify root causes and contributing causes of the trends identified |
| **Current reality tree** | Organisational or programmatic | High | Single E<br><br>Repeated E | Medium/high | Process takes a long time to complete; however, time needed to identify individual causal factors can be moderate | Process expert in the use of this methodology<br><br>Individual with technical knowledge of organisation | Allows common groupings to be found and organises them for many different issues<br><br>Good for identifying organisational factors | CRT could be found too difficult or time-consuming<br><br>Needs to be used with other techniques to identify the causal factors |
| **Failure modes and effects analysis** | Equipment issues | High | Single E<br><br>Repeated E | High | Long | High level of technical expertise related to the failure<br><br>Trained facilitator is needed | Provides a disciplined approach to evaluating possible causes of equipment failures.<br><br>Good method to confirm the cause and support the determination of the most effective CAs | Time-consuming<br><br>Expertise is needed to effectively evaluate possible causes. The team may not recognise all potential causes<br><br>Needs to be used with other techniques to identify the causal factors |
| **Human factor investigation tool** | Human performance | Medium/high | Single E | High | Long | Need for a human factor specialist | HFIT is useful for developing corrective actions related to human performance improvement | Resource-intensive<br><br>The tool relies heavily on the expertise of the specialist in order to get an accurate outcome |
| **Physiological and psychological investigation** | Human performance | Medium | Single E<br><br>Repeated E | High | Medium | Trained medical staff and human factor specialist | Allows proactive identification and correction of a human performance failure mode | Some individuals may consider this tool to be an excessive intrusion of their privacy |

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| **Ergonomics analysis** | Human performance | Low | Single E | Low/medium | Moderate; however, individual causal factors can be quickly identified | Human factor/ technical expertise | The tool highlights the following aspects:<br><br>- shortcomings of man-machine interfaces<br><br>- inappropriate workload<br><br>- incompatibility with infrequently performed changes<br><br>- incompatibility with usability of documentation | The tool relies heavily on the expertise of the specialist in order to get an accurate outcome |
| **Kepner-Tregoe problem analysis** | Equipment issues | Medium/high | Single E<br><br>Repeated E | High | Process takes a long time to complete; however, time needed to identify individual causal factors can be moderate | Training, experience, licence, technical expertise, team needed | A rational, industry-proven process that allows a focused approach to solving discrete problems. The system approach prevents any aspect of the issue being overlooked | Proprietary technique, expensive licence required, complicated, extensive training in the technique is required and constant practice in its use is necessary<br><br>Significant amount of time, energy and resources may be required for verifying the true causes of the event |
| **Interrelationship diagram** | Complex | High | Single E | High | Long | Team needed | A structured approach that enables complex relationships to be analysed using a non-linear approach | Subjective and complex<br><br>Needs to be used with a method to validate the accuracy of the root causes identified |
| **JNES Organisa-tional Factors List (JOFL)** | Human and organisation issues | Low | Single E<br><br>Repeated E | Recommended for high; can be used for any | Individual causal factors can be identified quickly | Someone with a little training can carry out the analysis using a 'JOFL classification'<br><br>Questionnaires | Provides an illustration of the whole problem and contributing factors. Works very well with barrier analysis | Identifying problems in the timeline is outside its scope (aim of the method is to assess the effectiveness of a root cause analysis)<br><br>Analysts may need to make changes to match the organisation which is the subject of the evaluation |

## 7.3. Recommendations for conducting RCA

The effectiveness of learning from the operating experience feedback process could be increased if root causes of events are properly identified and corrected, allowing lessons to be learned and shared with others in the industry. High-quality event investigation in general, and root cause analysis in particular, could therefore make a substantial positive contribution to improvements in nuclear safety.
In general, successful root cause analysis of an event depends on:

- Appropriate existing infrastructure to support the investigation;
- Adequate preparation for the investigation;
- Whether or not potential barriers and bottlenecks hampering the investigation are removed;
- The safety/quality culture of personnel, and of senior management especially.

Taking into account a great deal of existing advice, recommendations, tips and guides [2] and trying to avoid repeating them, the following specific suggestions can be made for conducting RCA more effectively.

1. The level of investigation necessary (troubleshooting, apparent cause investigation or root cause analysis) should be determined correctly during the event review/screening. Decisions should be properly substantiated and based on a set of objective criteria evaluated against clearly defined thresholds. Attempts, based on personal opinions, to simplify and speed up the investigation of safety-relevant events by avoiding a detailed root cause analysis process should be resisted.
2. Root cause analyses undertaken on ‘near hits, near misses and close calls’ can be just as productive as or even more effective than those done on major incidents. Typically, root causes for ‘near hits, near misses and close calls’ are the same as those for major incidents. Only the consequences or outcomes differ, and they are the result of luck.
3. Preparing properly for root cause investigation is an important prerequisite for success. Preparatory steps such as establishing and implementing an effective event investigation process within the management system, providing appropriate resources, selecting the relevant lead investigator, staffing the investigation team with experienced and adequately trained personnel, drafting in external experts if required, creating favourable conditions for the investigation and protecting it from undue time pressures are necessary to achieve good results.
4. Identifying and describing root causes for most events requires additional competencies from the human and social sciences. These types of competencies are traditionally very rare in a world of technicians and engineers and even amongst managers. Including human performance engineering specialists, psychologists and/or sociologists in the event investigation team should be considered.
5. A typical mistake in conducting RCA should be avoided — namely concentrating on the direct causes or symptoms of a problem instead of the actual root cause, basically because the team stops asking ‘WHY?’ too early. The investigation should not be limited to the technical flaw and/or individual failure such as ‘operator error’. It should go far and deep enough and cover all organisational levels, including senior management.
6. The benefits offered by RCA methods and tools using cause categorisation trees, ready-for-use universal checklists, computer software based on them and so-called ‘expert systems’ suggesting solutions for a given root cause should not be overestimated. Categorisation schemes restrict thinking by causing the investigator to stop at the categorical cause. Checklists give people the false sense that the correct answer must be among the listed items. Cause categorisation trees and computer software based on them create the illusion of finding the best solutions. These shortcomings and the disadvantages revealed by operational experience practices should also be taken into account during event investigation and offset by thorough evidence-based analysis of all causes and their inter-relationships.

7. All root causes of an event investigated should be identified the first time wherever possible; it is cheaper, less painful, and more efficient than discovering only one root cause per problem.
8. The degree of independence of the investigation should be increased as much as possible, at least by including independent experts in the investigation team. The final outcome of an investigation depends on the stakeholders' confidence in it, which to a certain extent is linked to the objectivity, integrity and competence of the investigative body. The appointment of members of the investigation team has to find the right trade-off between expertise (i.e. experts who know the field and its culture, technical advances and latest modifications, but are liable to lack impartiality) and independence (members who have no link with the field, but are liable to lack expertise). Investigators (lead and team) require the assurance that taking part in an investigation will not harm their careers in any way.
9. Corrective actions and improvements should be based on reliable root cause analysis results, not on guesses and assumptions derived from ineffective shallow investigations like apparent cause analysis or troubleshooting. This could help avoid wasting time and resources on short-cut investigations and best-guess corrective actions, and improvement programmes will become more cost-effective.
10. Management's approach to and support for event investigation is essential. Management should encourage identification of the real root causes of an event and not limit the investigation to lower-ranking personnel or influence the investigation in a particular direction (especially when underlying causes of incidents are ultimately supervisory and/or managerial and their identification could be uncomfortable).

# 8. Conclusions

1. The appropriateness of the existing training system and the future training needs of event investigation team members remain topical issues and should be considered in future. Since most investigation teams are staffed with formally trained personnel, the prevailing form of training for most survey respondents is participation in short workshops.
2. Event investigation teams are typically composed of technical specialists from the departments concerned in the plant, professional event investigators and representatives of management. The serious shortcoming of current practice in recruiting event investigation teams is that psychologists, human factor specialists and external experts/consultants are rarely included in the team.
3. The event investigation process itself has a positive influence on safety for personnel interviewed or otherwise involved. Besides the final report and recommendations, involvement in the event investigation process seems to be useful in enhancing insight into and attitudes towards safety, increasing awareness and improving competencies, and discovering unknown dependencies between different functions or departments.
4. During the last ten years event investigation practices have not changed much as regards the use of particular methods and tools. The most frequently used RCA methods at European nuclear plants remain HPES, MORT, ASSET and MTO. The choice of RCA tools is heavily restricted by their purpose and the needs of the method used; however, the most 'popular' ones are basic RCA tools (ECFC, barrier analysis, change analysis, task analysis and interviewing), which are used in practically all investigations.
5. In most organisations the same event investigation instruments have been implemented and used for a long time (more than 10 years). Usually RCA methods and tools are obtained for free and there are no obvious trends towards replacing them with new ones.
6. Results of the survey show that to further improve existing practices in event investigation it would be desirable to:
   - develop comprehensive software for further computerising the event investigation process, including RCA methods such as HPES and MORT;
   - resume IAEA technical support for the ASSET method;

- improve the education of event investigators by organising appropriate training, drafting simpler manuals and guidelines, and providing more practical examples;
- organise more intensive exchange of experience among event investigators.

7. The need for an independent investigation, free from any interference by vested interests (such as line management, supervisory authorities, certification bodies or commercial partners), has increasingly been recognised on account of its contribution to the overall quality of the investigation. However, the principle of the independence of event investigations is not in practice considered as an important and necessary feature.
8. Existing practices demonstrate that event investigations frequently continue to remain focused on analysing the direct and immediate causes of events instead of attempting to dig deeper to identify latent root causes, such as human, organisational and management-related factors. Although the importance of correctly identifying these HOF-related causes is commonly understood, there is still a tendency for the analysis to focus solely on the technical issues of the event.
9. The effectiveness of the event investigation and operational experience feedback process mostly depends on the safety culture of an organisation's personnel, and of its senior management especially. Management should not just pay lip service to safety but demonstrate and confirm their commitment in the practical decisions they take during the preparation and conduct of an investigation, in evaluating its results as well as in generating, approving and implementing the corrective actions.
10. During this study, some existing barriers, bottlenecks and emerging traps in the event investigation process were identified and analysed; some methodological and practical recommendations were put forward as to how these obstacles could be overcome.

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# Annex A1

# Survey
# of existing practices regarding nuclear event investigation methods, tools and techniques

## 1. Introduction/background information

Since recently, the EC JRC-IE has been working on a study of methods and practices currently applied in the investigation of abnormal/unexpected events at nuclear power plants.

To collect information on practical experience with the individual investigation methods currently used in the nuclear industry, the following questionnaire has been prepared. The data obtained from the questionnaire will be used in drawing up conclusions and recommendations on the most effective investigation methods. It should help current and prospective investigators to choose the most suitable method for their particular needs. Data contained in the answers should be based on the real situation and reflect the personal opinion of respondents. The data obtained from the questionnaire will be kept confidential and used for the above purposes only.

The questionnaire is to be filled in primarily by specialists — licensee or utility staff members directly involved in the nuclear event investigation on a full-time or part-time basis. If applicable, the questionnaire could be completed also by competent specialists from regulatory bodies, technical support organisations, research or consulting institutions or by individual experts directly participating in nuclear event investigations or involved in developing appropriate investigation methods and tools**.**

## 2. Questionnaire on nuclear event investigation practices

Please answer the questions in parts A, B and C below, omitting any questions that are irrelevant or confusing. Where applicable, tick the appropriate boxes. If there is not enough space available for your answer to a specific question in parts A or B, please use the space provided in part C, indicating the part/question number. For questions not relevant to you, please enter '***N/A***'.

**Part A. PERSONAL AND BACKGROUND INFORMATION**

This part of the questionnaire is aimed at collecting basic information on the specialists participating in nuclear event investigations and how this activity is managed in various countries.

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| **A1.** | **Organisation ……………………………………………………………………………………………**<br>**………**<br><br>**Address ……………………………………………………………Country**<br>**…………………………** |
| **A2.** | **Name of person completing the**<br>**questionnaire ………………………………………………**<br>**Position ………………………………………………….....................................................**<br>**......**<br><br>**Email**<br>**address ……………………………………………………………………………………** |

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| **A3.** | **Number of years employed as an incident investigator:** | |
| **A4.** | **How long did you work in the nuclear/nuclear safety area before you became an event investigator? (number of years)** | |
| **A5.** | **Percentage of your total working time devoted to incident investigations and associated activities:** | |
| **A6.** | **Number of incident investigations in which you have been involved:** | |
| **A7.** | **Have you received formal training in event investigation/root cause analysis methods? yes☐ no☐**<br><br>**If so, please specify the type and duration of the course:**<br>**......................................................................................................................................................................................................................................................................................................................................................................** | |
| **A8.** | **Number of investigators typically participating in an event investigation in your organisation:** | |
| **A9.** | **What is the most common composition of an investigation team (please specify roles, functions, positions) (1)……………………………..;**<br>**(2)…………………..……………….; (3)…………….……………;**<br>**(4)…………….…………………; (5)…………………………………** | |
| **A10.** | **Are external specialists involved in establishing/performing event investigations in your organisation?**<br><br>• **outside experts/consultants from other organisations: ☐yes, always; ☐ no; ☐ sometimes, depending on the type of incident;**<br><br>• **corporate investigators from the utility's central department: ☐yes, always; ☐ no; ☐ sometimes, depending on the type of incident** | |
| **A11.** | **Average duration of an event investigation in your organisation (days) ………………. (limited apparent cause/specialist/supervisor's investigations of near-misses and low-level events should not be taken into account)** | |
| **A12.** | **Time spent on different activities during the investigation (as a percentage of the overall duration of the investigation):**<br><br>**Planning**<br>**Data collection**<br>**Analysis**<br>**Drafting recommendations/corrective actions**<br>**Writing the report** | |

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| A13. | **Who initiates the investigation? (a) ☐ investigators themselves; (b) ☐plant management; (c) ☐regulatory organisation; (d) ☐others (e.g. plant committee, commission, group — please specify); (e) ☐it is started automatically as required by the relevant procedure if preconditions are fulfilled** | |
| A14. | **Please evaluate the following (using the scale 'insufficient' 1-2-3-4-5 'adequate'):**<br>**14.1. Human resources (personnel available to conduct an investigation) …….;**<br>**14.2. Time available to perform a good quality investigation …….;**<br>**14.3. Managers' support for investigations ……..;**<br>**14.4. Availability of investigation guidelines/manuals/method (tool) descriptions/software to support the investigation ………** | |
| A15. | **Do you feel that the investigation can be conducted objectively and free of pressures aiming to influence the investigation in a particular direction? Yes ☐ No☐**<br>**If not, please explain why:**<br>**……………………………………………………………………………..…………………**<br>**…………………………………………………………………………..** | |
| A16. | **In your opinion, what influence on safety does the event investigation process itself have for personnel interviewed or otherwise involved (over and above the final report and recommendations)? (Enhanced insight into and attitudes towards safety, increased awareness and improved competencies, discovery of unknown dependencies between different functions or departments, etc. should be considered).**<br>**(a) ☐positive; (b) ☐ no influence; (c) ☐ negative** | |
| A17. | **In what area(s) has the event investigation been most beneficial for your plant/organisation: (a) ☐reducing maintenance costs; (b) ☐improving equipment availability; (c) ☐improving equipment reliability; (d) ☐reducing operating costs; (e) ☐increasing nuclear safety; (f) ☐ improving environmental protection; (g)☐ other (please specify)…………………………...** | |
| A18. | **Are there national regulatory requirements of any sort regulating event investigation in your organisation? yes ☐ no☐**<br>**If so, please provide the references of the latest edition of the relevant document (please attach a copy of document or indicate the internet address, if possible)…………………………**<br>**………………………………………………………………………………………………** | |
| A19. | **What international/foreign requirements/guides do you use for event investigation in your organisation? (please give references or the internet address if possible)**<br>**……………………………………………………………………………………………** | |
| A20. | **Which methodologies are used for event investigation in your organisation? Please tick one or more as appropriate: (a) ☐ root cause analysis — RCA; (b) ☐ probabilistic safety assessment — PSA; (c) ☐ deterministic safety analysis; (d) ☐ safety culture assessment; (e) other** | |

**Part B. — INFORMATION ON CHARACTERISTICS AND EFFECTIVENESS OF SPECIFIC ROOT CAUSE ANALYSIS METHODS, TOOLS AND TECHNIQUES USED FOR NUCLEAR EVENT INVESTIGATION**

The aim of these questions is to collect information about current practices, in order to identify the strengths and weaknesses of root cause analysis approaches, methods and tools used by nuclear industry organisations for nuclear event investigation.

| | | |
|---|---|---|
| **B1.** | **Which RCA (root cause analysis) method(s)[1] have you used for event investigation in your organisation? ☐HPES, ☐HPIP, ☐HPEP, ☐MORT, ☐ASSET, ☐PROSPER, ☐SOL; ☐MTO; ☐AEB; ☐STEP; ☐PRCAP; ☐CERCA; ☐TRIPOD; ☐HF-RCA; ☐3CA; ☐GO method; ☐Fault Graph method; ☐Markov modelling; ☐DYLAM; DETAM; ☐other (please specify including reference data if available): ……………………………………………………………………………………………………………** | |
| **B2.** | **Which RCA tools and techniques have been used for event investigation in your organisation? ☐Event and causal factors charting; ☐Cause and effect analysis; ☐Interviewing; ☐Task analysis; ☐Why-why chart; ☐Pareto analysis; ☐Storytelling; ☐Change analysis; ☐Barrier analysis; ☐Fault tree analysis; ☐Event tree analysis; ☐Causal factor tree analysis; ☐Kepner-Tregoe problem solving; ☐Human factors investigation tool; ☐Interrelationship diagram; ☐Current reality tree; ☐REASON®; ☐PROACT®; ☐REALITYCHARTING®; ☐TAPROOT®; ☐CAS-HEAR; ☐other (please specify including reference data if available): ……………………………………………………………………………………………………………………………………………………………………………………………………………………** | |
| **B3.** | **How were the RCA methods and tools currently used for event investigation in your organisation acquired (☐obtained for free; ☐purchased from a vendor; ☐developed internally; ☐obtained and then adopted)?** | |
| **B4.** | **If you have developed any new or existing RCA methods/tools in your organisation, please specify the method/tool and briefly describe the development(s): ……………………………………………………………………………………………………………………………………………………………………………………………………………………** | |
| **B5.** | **For how long have the RCA methods and tools been used in your organisation (years)? .......** | |

[1] Explanation of acronyms used: HPES — Human Performance Enhancement System; HPIP — Human Performance Investigation Process; HPEP — Human Performance Evaluation Process; MORT — Management Oversight and Risk Tree; ASSET — Assessment of Safety Significant Event Team; PROSPER — Peer Review of the effectiveness of the Operational Safety Performance Experience Review process; SOL — Safety through Organisational Learning; MTO — Man-Technology-Organisation Investigation; AEB — Accident Evolution and Barrier function; STEP — Sequential Timed Events Plotting; PRCAP — Paks Root Cause Analysis Procedure; CERCA — a computer based event investigation method; 3CA — Control Change Cause Analysis; HF-RCA — root-cause analysis method of GRS (Germany); GO — method for analysis of dynamic systems; DYLAM — Dynamic Event Logic Analytical Method; DETAM — Dynamic Event Tree Analysis Method.

| | | |
|---|---|---|
| **B6.** | **What factors determined your choice of RCA methods and tools? (a) ☐ recommendations of the IAEA, WANO; (b) ☐suggestions of the national regulatory body; (c) ☐suggestions of management of your organisation; (d) ☐suggestions of experienced colleagues; (e) ☐recommendations in literature (please indicate source); (f) ☐your previous experience; (g) there was no need for choice — you used methods and tools which were in place in your organisation.** | |
| **B7.** | **What is the degree of methodological definition of RCA methods used for event investigation in your organisation: (a) ☐ well defined; (b) ☐ loosely defined; (c) ☐ not defined (no methodology — collection of concepts).** | |
| **B8.** | **Is your organisation currently considering changing the RCA method/tool used?**<br><br>**(a) ☐yes; (b) ☐no; (c) ☐don't know. If yes, please indicate the reason for your new choice ………………………………………………………………………………………** | |

| B9. | **Please evaluate the extent to which RCA methods and tools used for event investigation in your organisation meet the following criteria.** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **RCA methods/tools used[2] →** | | | | | | |
| | **Criteria** | **Evaluations ↓** | | | | | |
| | B9.1. Clear definition of the problem[3] and its significance for safety | | | | | | |
| | B9.2. Clear delineation of the known causal relationships that combined to cause the problem | | | | | | |
| | B9.3. Ability to identify and to establish clearly the causal relationships and interdependencies between the causal factors, the root causes and the problem defined | | | | | | |
| | B9.4. Clear presentation of the evidence used to support the existence of identified causes | | | | | | |
| | B9.5. Clear substantiation of the solutions (proposed corrective measures) and explanation of how they will prevent the problem recurring | | | | | | |
| | B9.6. Ability to document clearly criteria B9.1 to B9.5 listed above in a final RCA report so others can easily follow the logic of the analysis | | | | | | |
| | B9.7. Availability of a mechanism for testing logic in establishing and analysing causal relationships and interdependencies | | | | | | |
| | B9.8. Time needed for constructing an event evolution model (chart, tree, diagram) | | | | | | |
| | B9.9. Accuracy required for constructing an event evolution model (chart, tree, diagram) | | | | | | |
| | B9.10. Extent of influence of subjectivity and emotions on output | | | | | | |
| | B9.11. Suitability to address complex system-wide issues (without need to involve other RCA methods and tools) | | | | | | |
| | B9.12. Extent of training and professional expertise needed for the RCA method to be mastered | | | | | | |
| | B9.13. Level of automation, i.e. availability of specific software for creating charts/diagrams, categorisation, analysing causes, performing integrity checks, generating reports (universal software, such as MS Office, is not taken into account) | | | | | | |
| | B9.14. The potential level of scope of the investigation — suitability to analyse events, influenced by: 1 — the work and technological system; 2 — the staff level; 3 — the management level; 4 — the company level; 5 — the regulator and association level; 6 — the government level | | | | | | |
| | B9.15. How would you rate the effectiveness of the RCA methods/tools used? | | | | | | |

[2] Please enter the names/acronyms of the RCA methods and tools used for event investigation in your organisation in the cells to the right and then your evaluations in the cells below. The scale ‘bad, low’ 1 2 3 4 5 ‘excellent, high’ should be used (except for question B9.14).

[3] A ‘problem’ is not only an incident or event; it can be a deviation, a non-conformance, an ‘issue’ or obstacle that makes it difficult to achieve a desired safety objectives.

**Part C. — ADDITIONAL INFORMATION**

| C1. | What other strengths and weaknesses of RCA methods and tools used could you indicate? | |
|---|---|---|
| **Methods/tools used** | **Strengths** | **Weaknesses** |
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| C2. | Hints for improvement. What further needs for the development or improvement of RCA methods and tools could you indicate? |
|---|---|
| **Methods/tools used** | **Suggestions for development or improvement** |
| | |
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| C3. | Any other comments concerning existing event investigation practices |
|---|---|
| | |
| **C4.** | **Please give your overall opinion and any suggestions concerning this questionnaire** |
| | |

European Commission

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**Abstract**

This final report presents the results obtained in the last phase of a project launched as part of the technical task 'Comparative study of event assessment methodologies with recommendations for an optimised approach in the EU' in 2010-2011. It examines and evaluates existing practices and arrives at some conclusions and recommendations that will help in selecting and applying adequate analysis instruments to improve the quality of nuclear event investigations.

The study is based on the results of a survey involving experts from nuclear power plants and regulatory bodies in 12 European countries and the US. The main focus was on analysing existing practices and organisational aspects of nuclear event investigation, as well as making a qualitative assessment of the event investigation methods, tools and techniques currently employed. Some methodological inconsistencies, barriers, bottlenecks and emerging traps in the event investigation process were identified and analysed more thoroughly.

In order to avoid existing ambiguities and misunderstandings surrounding the terms and definitions used in event investigation in general, and root cause analysis in particular, several improved definitions were suggested. With the aim of better distinguishing between investigation instruments of different levels and applicability, an original system of classification of basic root cause analysis methods and tools was proposed. This system should help in comparing characteristics and selecting the most appropriate instruments for investigating a particular event. Some methodological and practical recommendations were put forward as to how the analysis should be conducted and how the obstacles identified can be overcome. Detailed recommendations for selecting root cause analysis methods and tools are also presented.

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