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Systematic Analysis of Dependent Human Errors From the Maintenance History at Finnish NPPs
A Status Report

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Abstract

Operating experience has shown missed detection events, where faults have passed inspections and functional tests to operating periods after the maintenance activities during the outage. The causes of these failures have often been complex event sequences, involving human and organisational factors. Especially common cause and other dependent failures of safety systems may significantly contribute to the reactor core damage risk. The topic has been addressed in the Finnish studies of human common cause failures, where experiences on latent human errors have been searched and analysed in detail from the maintenance history.

The review of the bulk of the analysis results of the Olkiluoto and Loviisa plant sites shows that the instrumentation & control and electrical equipment is more prone to human error caused failure events than the other maintenance and that plant modifications and also predetermined preventive maintenance are significant sources of common cause failures. Most errors stem from the refuelling and maintenance outage period at the both sites, and less than half of the dependent errors were identified during the same outage. The dependent human errors originating from modifications could be reduced by a more tailored specification and coverage of their start-up testing programs. Improvements could also be achieved by a more case specific planning of the installation inspection and functional testing of complicated maintenance works or work objects of higher plant safety and availability importance. A better use and analysis of condition monitoring information for maintenance steering could also help. The feedback from discussions of the analysis results with plant experts and professionals is still crucial in developing the final conclusions and recommendations that meet the specific development needs at the plants.

Key words

Maintenance history, human factors, experience feedback, common cause failures, operability.

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Systematic analysis of dependent human errors from the maintenance history at Finnish NPPs - A status report

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December 29, 2002

Summary

The focus in human reliability analysis relating to nuclear power plants has traditionally been on control room operator performance in disturbance conditions. In the area of maintenance activities, the emphasis has been on human reliability of non-destructive inspections. On the other hand, some studies and incidents have shown that errors related to maintenance, which have taken place earlier in plant history, may have an impact on the severity of a disturbance, e.g. by disabling safety related equipment.

Operating experience has shown missed detection events, e.g. such where faults have passed inspections and functional tests to operating period after the maintenance and modification activities during the outage. The causes of these failures have often been complex event sequences, involving human, organisational and technical factors. Especially common cause and other dependent failures of safety systems may significantly contribute to the reactor core damage risk.

The topic has been addressed in the Finnish studies of human common cause failures (HCCFs), where operating experiences on latent human errors have been searched and analysed in detail from the maintenance history. In the Finnish projects, one aim has also been to promote the studies of human factors related to maintenance.

Within the Olkiluoto case study and as a part of the Loviisa plant case study, a detailed classification model for human errors related to maintenance activities was developed and adopted. The purpose of this new classification model was to provide an enhanced basis for identification, appearance and statistical analysis of human and quality errors related to maintenance activities, and especially of human CCF events, utilising the maintenance work order database. According to the review of the bulk of the analysis results of the both plant sites, the instrumentation & control and electrical equipment is noticed to be more prone to human error caused failure events than the other maintenance.

Most errors stem from the refuelling and maintenance outage period at the both sites, and less than half of the dependent errors were identified during the same outage. The review of the analysed set of multiple error events shows that plant modifications and also predetermined preventive maintenance are significant sources of common cause failures. But also the single and more rare errors on the safety related mechanical equipment can be serious and have caused forced plant outages in Finnish nuclear power units.

The dependent human errors originating from the modifications could be reduced by a more tailored and case specific specification and coverage of their necessary start-up testing programs.

The review of the analysed HCCF events shows that maintenance, work and operability planning are very demanding tasks due to the complex planning environment of different objectives, requirements and instructions, and needs of multifunctional plant technical, maintenance and operability knowledge. Improvements could however be achieved by a more responsible, tailored and case specific planning of the installation inspections and functional testing of complicated maintenance works and on maintenance or modification on the objects of higher plant safety and availability importance.

The analyses and classification of the maintenance related errors provide a good plant-specific material for training of the maintenance, operability and technical personnel. Also a check of the coverage of the identified multiple human errors in the common cause failure models and data in the PSA studies of today is recommended.

Additional conclusions and recommendations are also searched. They indicate among others that condition monitoring which is increasingly available at the plants could be implemented in a more agile pace for an equipment responsible and operative condition data diagnosis based maintenance steering. This would thus utilise the personnel responsibility and expertise better for operability verification after maintenance and modification works, too. The analysis of condition monitoring information could also help to reduce the number of error prone and even costly predetermined preventive or disassembling maintenance activities in the cases where the diagnostic capability of the monitoring approach is comprehensive. The necessary changes in the maintenance strategies and planning for the different equipment and systems can be identified and justified by e.g. an experience based reliability centred maintenance and operability planning approach.

A final report of the project on identification and prevention of human failure events in relation to the maintenance activities of the Finnish nuclear power plants will be prepared and submitted for publication in STUK series in 2003. The feedback from discussions on the analysis results with the utility experts and professionals, as well as with authorities, is still crucial in developing the final conclusions and recommendations that meet the specific and generic development needs at the plants.

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1. Introduction

The focus in human reliability analysis relating to nuclear power plants has traditionally been on control room operator performance in disturbance conditions. In the area of maintenance activities, the emphasis has been on human reliability of non-destructive inspections. On the other hand, some studies and incidents have shown that errors related to maintenance, which have taken place earlier in plant history, may have an impact on the severity of a disturbance, e.g. by disabling safety related equipment.

Operating experience has shown missed detection events, e.g. such where faults have passed inspections and functional tests to operating period after the maintenance and modification activities during the outage. The causes of these failures have often been complex event sequences, involving human, organisational and technical factors. Especially common cause and other dependent failures of safety systems may significantly contribute to the reactor core damage risk.

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2. Studies of human common cause failures in relation to maintenance activities in Finland

Pilot studies for identification and analysis of human common cause failures in relation to the maintenance activities have been conducted for both Finnish nuclear power plant sites.

The analysis of the Olkiluoto units 1 and 2 three- year experience during 1992 –1994 covered 4400 fault repair work orders among which 334 human error cases were identified among which the number of single errors was 206. The number of dependent human error event cases derived and analysed was 14.

In the corresponding study of Loviisa nuclear power plant units 1 and 2 maintenance history during 1995-1997, the number of fault repair work orders was 14091, and the number of single errors 149 and dependent human error cases identified and studied 34.

The numbers of the different plant sites are not directly comparable because in the Olkiluoto case all the 4400 fault repair work orders were studied but the scope of the examined work orders was limited in the Loviisa case by creating a data screening procedure. The screening procedure had a hit rate of 2/3 in error identification in the detailed analysis of the studied fault work orders.

The analysis results of the Olkiluoto plant study and recommendations of actions were summarised and published in 1998 [Laakso, Pyy & Reiman, 1998]. The other aim of the Olkiluoto analysis work was to support PSA be extending the applicability of human reliability analysis to study of the effects of wrong human actions in relation to maintenance [Pyy 2000].

Within the Olkiluoto case study and as a part of the Loviisa case study, a detailed classification model for human errors related to maintenance activities was developed and adopted for a trial use [Laakso 2000]. The purpose of this new classification model was to provide an enhanced basis for identification, appearance and statistical analysis of human and also quality errors related to maintenance activities, and especially of human CCF events, utilising the maintenance work order database.

After the preliminary verification of the dominating human error classes with the plant maintenance and safety staff, the new classification was confirmed for re-analysis purposes. The developed new classification model of human and quality errors related to maintenance was firstly tested and refined in identification and review of about 100 human errors with the Loviisa plant maintenance staff [Laakso, Saarelainen, 2003].

The used classification in Table 1 structures and shows how human error effects appear on equipment level.

Table 1. *A classification of human errors effects on equipment level in relation to maintenance.*

Errors of Omission (missing human action)

1. Restoration errors after work, such as omission of the realignment of process or instrument valves, breakers, fuses or limit settings.
   Omission of refilling of fluid or gas into lines or tanks.
2. Cables or electronic components not connected, settings/adjustments omitted, or omission to install packing or control component.
3. Foreign objects or impurities left behind inside the object of the work. Examples are dirt, garbage, tools, scaffolds or covering material.

Errors of Commission (wrong human action)

Wrong order or direction,

4. Wrong order, such as cables or instrument pipelines crosswise connected.
5. Wrong direction, such as reversed or twisted installation of valve or another sub-component, or wrong positioning of valve.

Wrong selection,

6. Wrong place or object, such as cabling fixed on wrong connection, setting of wrong tripping conditions or draining of wrong pipeline.
   Item installed on wrong equipment place.
7. Wrong or mixed parts, materials, tools, fluids or chemicals selected for work.

Wrong settings/adjustments/calibrations,

8. Wrong settings of trip limits, limit switches, reference, indication or time delay values, or of adjusting devices. Deficient alignment of shaft, stem/spindle or pipe. Wrong setting of pipe support.

Other quality problems,

9. Too little force, e.g. loose connections of bolts, cables or sensors,
10. Too much force, e.g. excessive tightening or greasing,
11. Damaging other equipment e.g. cabling, cable trays or small diameter piping by falling or slugging/contacting. Can be due to carelessness and narrow spaces for work or transport.
12. Other carelessness (if 1-11 are not applicable), e.g. worn tools, falling, dropping or intrusion of foreign material, deficient weld, solder joint or insulation. Unclear trips initiated during testing, installation or maintenance, wrong subtitling or recording, wrong timing.

Apart from the observed and direct error effects on equipment, also the underlying contributing factors are studied and classified for the dependent human errors according to another renewed classification. The root causes of errors could be assigned to one of the following groups:

Table 2. *Classification and definition of root causes of multiple human errors in relation to maintenance.*

1. Planning deficiency: Incorrect, incomplete or unclear maintenance or work and operability planning, procedure, work order or operation order. Deficient decision or definition of work, inspection or functional testing scope. 2. Design deficiency: Error or deficiency in design or documentation of modification, equipment, system, installation or computer program. Documentation not updated. 3. Violation of procedure or order: Violation due to insufficient knowledge or poor information. Deviations from procedure or order due to gradual organisational learning of "bad habits". Or conscious violation. 4. Poor co-ordination, supervision or information transfer: Poor project co-ordination or supervision of subcontractors, poor information transfer due to organisational changes or boundaries. Or weaknesses in experience feedback such as recurrence of events with known phenomena. Or poor quality control. 5. Insufficient knowledge: Lacking training, specialist or cross-functional knowledge.

A good quality of the maintenance history data is helpful in the identification and analysis of errors and missed detection opportunities, e.g. deficient operability verifications [e.g. LOTI].

A structured classification and systematic analysis helps the identification and analysis of the errors which have penetrated the barrier functions such as inspections or functional checks and resulted in latent faults.

One target of the study was to identify the dependent human error mechanisms and search for causes of missed detection of the errors in the operative and organisational defensive barriers. This analysis was done in interaction with plant maintenance and operability experts in order to capture the tacit knowledge, and the equipment place history coming before the fault detection, and to close the feedback loop of operating experience.

The identified dependent human errors were analysed and summarised in condensed maintenance event reports including a qualitative description of the:

- multiple error and its failure consequence,

- originating erroneous or defective work task, e.g. maintenance or modification design, and
- primary missed opportunity for detection, e.g. deficiency in operability verification, allowing the errors or faults to remain latent in the system e.g. throughout the start-up testing program after the plant maintenance outage or during extended time periods.

Table 3. An example of a maintenance event report.

Identifier marking	Work order time and number	Title and description of event	Operating event identifier
1HCCFYP 12	1996-10-08	<u>Deficient adjustment and testing of the actuators as implementing new motor operated blowdown valves in the pressurizing system</u>	No
	238769D, 238769A 238769B 238769C	The gate valves 12YP12S038, 12YP12S039, and 11YP12S036, 11YP12S037 were not tight in hot state during power operation 1996-10-08. New motor operated gate valves (MOVs) had been installed during the preceding maintenance outage in September 1996. - The MOVs had to be closed as a corrective action by manual operations from the switch-gear during the power operation state at 1996-10-09. - The common cause setting errors had passed from the maintenance outage through to the power operation period, because the setting of the limit and torque switches of the MOVs in the cold state only was insufficient as start-up testing of the modification work.	

In a study of unforeseen effects of wrong human actions in both processes and equipment of nuclear power plants a barrier model was drafted of the birth of an error and its progression into a latent fault and its resulting consequences if an effective barrier not stopped the event.

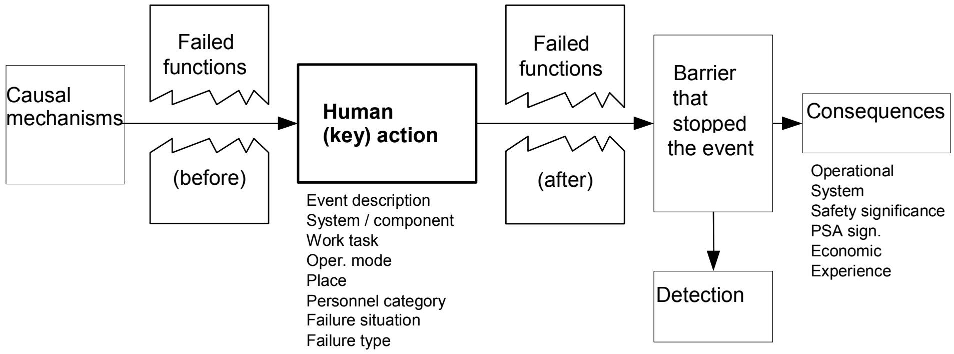
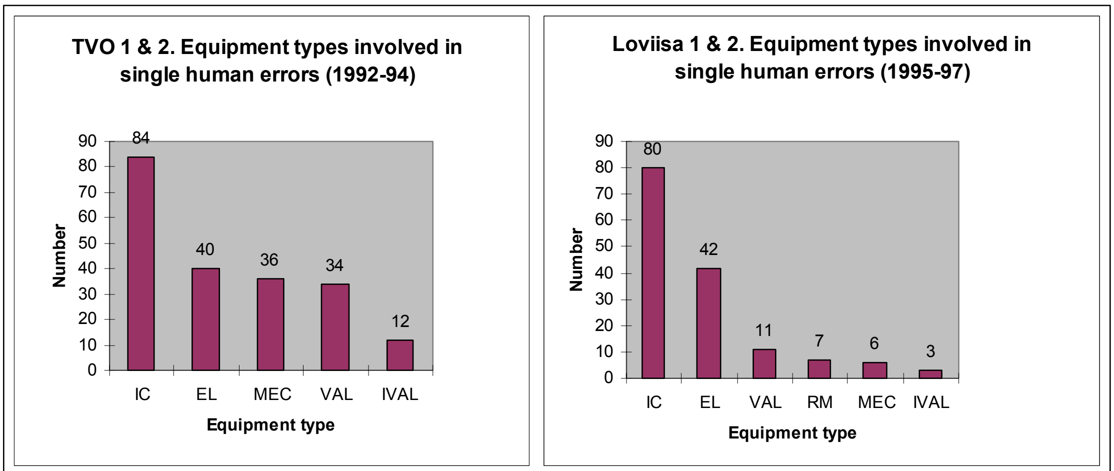


Figure 1. A barrier model [Pyy, Bento, Flodin 2001].

This brief model has been used in analysis and for modelling of various kinds of human failure events for PSA. A similar but a more detailed model, of the operative and organisational barriers including activities before, during and after the human maintenance work actions, was needed for analysis of the operating experiences of the Loviisa NPP human common cause failures in relation to maintenance [Laakso, Saarelainen 2003].

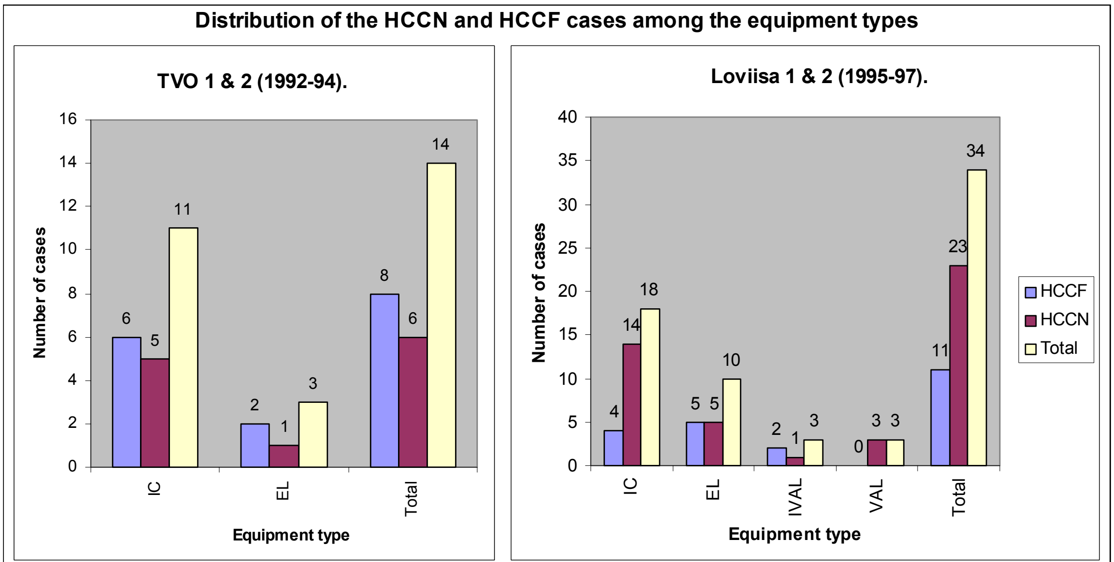
3. Some analysis results conclusions and recommendations for consideration

According to the review of the analysis results of the bulk of the failure events at the both plant sites, the instrumentation & control (IC) and electrical equipment are noticed to be more prone to human error caused failure events than the other maintenance.



IC = Instrumentation & control equipment or software, **EL** = Electrical equipment, **MEC** = Mechanical equipment, **VAL** = Process valves, ventilation dampers or channel hatches, **IVAL** = Block or primary valves in instrument lines, **RM** = Radiation monitoring equipment.

Figure 2. Equipment types involved in single human errors in relation to maintenance.

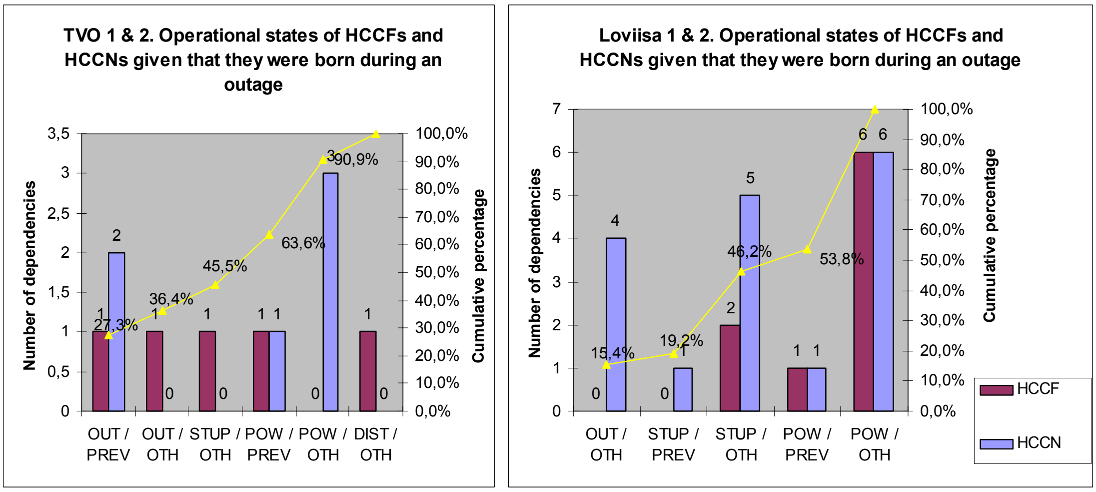


IC = Instrumentation & control equipment and software, **EL** = Electrical equipment, **IVAL** = Block or primary valves in instrument lines, **VAL** = Process valves, ventilation dampers or channel hatches.

Figure 3. Distribution of the functionally critical human common cause failures (HCCF) and non-critical HCCNs among the equipment types.

It should be noticed that also the single and more rare errors on the safety related mechanical equipment can be serious and have caused forced plant outages in Finnish nuclear power units.

The identification of the dominating portion of the IC involved in single and multiple failures does not depend on the IC's error proneness only, but also on the high number of the IC maintenance objects, and the evident functional effects on the equipment and systems of such errors on IC. But this result emphasises as an example the responsibility and requirements of both the versatility and specialisation of the design, maintenance and operability planning, as well as the instrument mechanician’s skills and knowledge of work, on IC and automation.



Type of detection: testing or preventive maintenance (PREV), otherwise (OTH)
Operating states: power operation (POW), refueling outage prior to start-up (OUT), hot shutdown (HOT), cold shutdown (COLD), plant start-up (STUP), plant shutdown (SHDN)

Figure 4. Distribution of the fault detection states of the human related common cause failures born during a maintenance outage.

The more on left in the figure 4 the operational states of the detection of the multiple failure events are, the better is the maintenance planning and operability verification. Most errors stem from the refuelling and maintenance outage period at the both sites, and less than half of the multiple failures were identified during the same outage.

Thus the contents of the figure 4 can represent a direct performance indicator of the quality and responsibility of maintenance and operability planning and verification at the plants.

The review of the analysed set of multiple error events shows that plant modifications and also predetermined preventive maintenance are significant sources of common cause failures, see figure 5 as follows.

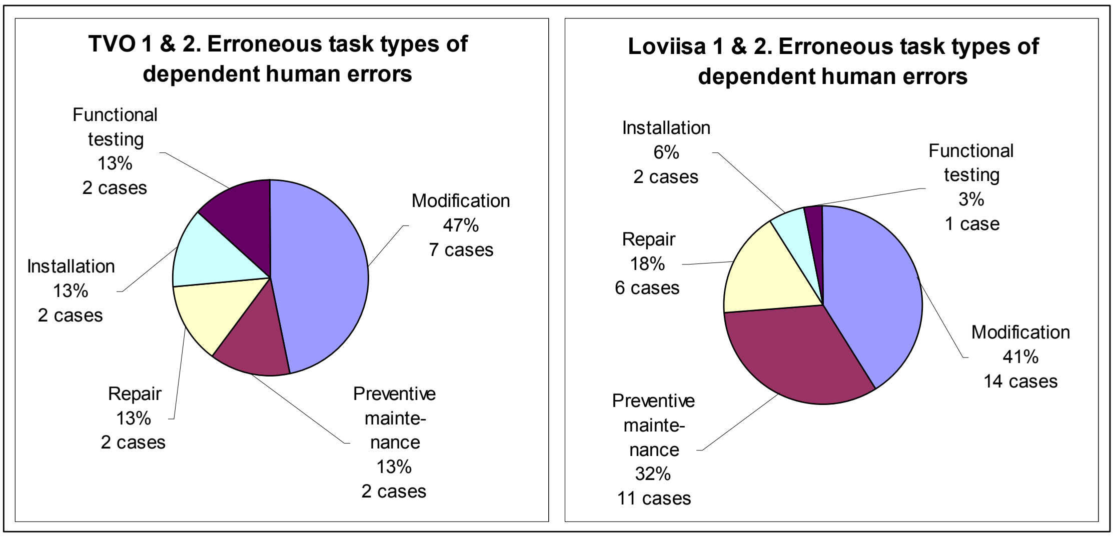


Figure 5. Distribution of the types of the erroneous tasks leading to common cause failures.

The review of the analysed HCCF events shows that maintenance, work and operability planning are very demanding tasks due to the complex planning environment of different objectives, requirements and instructions, and needs of multifunctional plant technical, maintenance and operability knowledge.

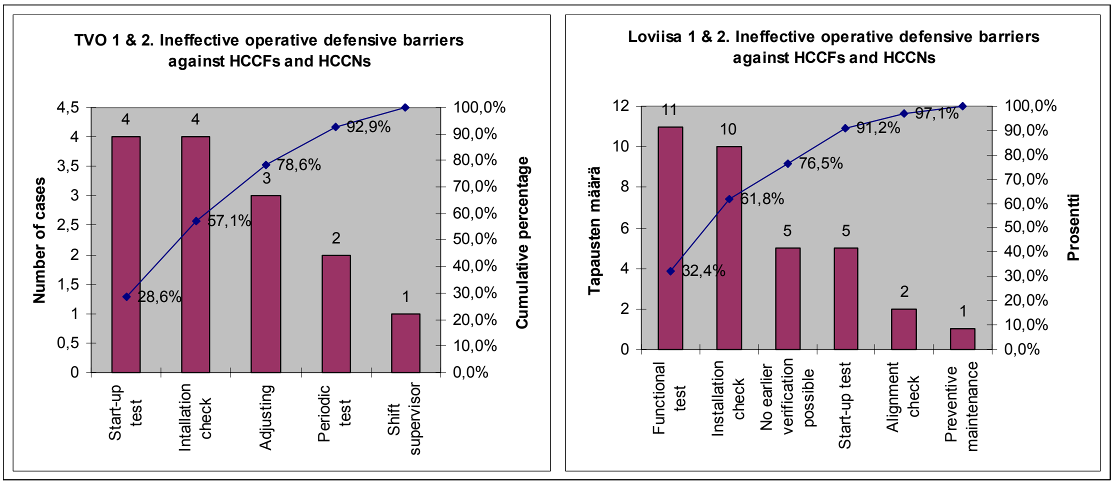


Figure 6. Weaknesses identified in operative defensive barriers against common cause failures.

As can be seen from figure 6 above, the review of the analysed set of human common cause failures showed that the most missed primary opportunities for detection were in the start-up testing, functional testing and installation checks which were thus identified as the most significant contributors to weaknesses in operability verification.

The dependent human errors originating from the modifications could be reduced by a more tailored and case specific specification and coverage of their necessary start-up testing programs. Improvements could also be achieved by a more tailored and case specific planning of the installation checks and functional testing of complicated maintenance works and work on objects of higher plant safety or availability importance.

The analyses and classification of the maintenance related errors provide a good plant-specific material for training of the maintenance, operability and technical personnel. Also a check of the coverage of the identified multiple human errors in the common cause failure models and data in the PSA studies of today is recommended.

4. Searching on additional conclusions and recommendations

Introduction. The detailed classification, analysis and statistical treatment of the maintenance related errors has also provided an information for focusing psychological studies into most relevant aspects in maintenance and operability. The aim of the studies in Finnish nuclear power plants has been to develop a methodology for modelling the maintenance core task and assessing the maintenance culture [Oedewald & Reiman 2002]. The case studies started at the Loviisa nuclear power plant. Maintenance task, its goals, critical demands and the demands for the actual organisation of the maintenance were conceptualised by a core task analysis. The organisational culture of the maintenance department was inspected by interviews, observation, survey and workgroups. The core task model was used to assess the safety and efficiency of the maintenance culture. Results show three critical demands and three instrumental demands to be controlled in all levels of the organisation. The culture must support this.

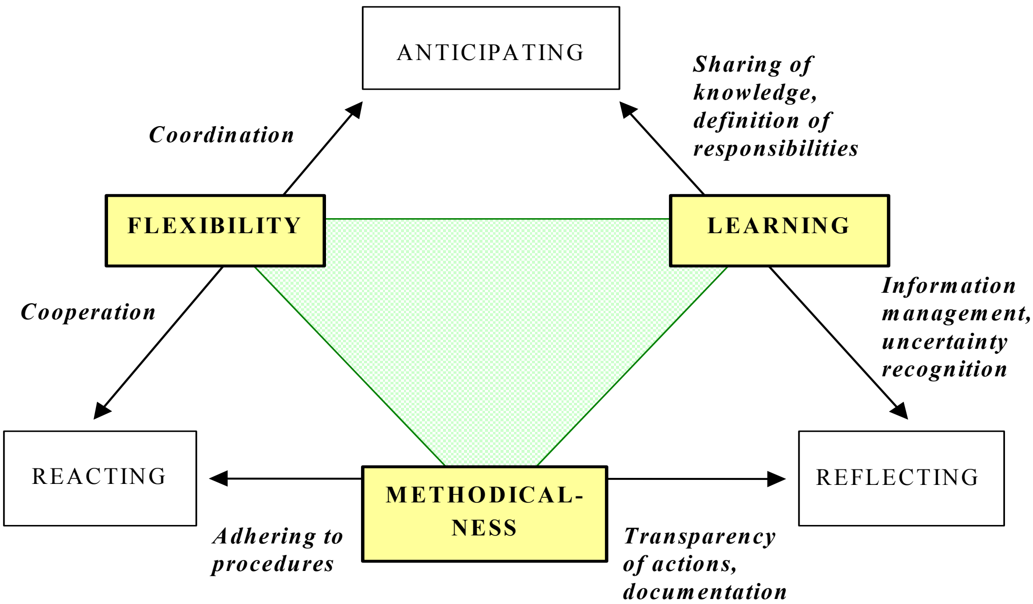


Figure 7. The core task model: Critical demands and requirements of the maintenance task [Oedewald & Reiman 2002].

Among others, in the analysis of the interview data and group working sessions at the nuclear power plant concerning the core task demands in one's own maintenance work following tensions could be identified:

- situational judgement vs. generally applicable rules
- certainty vs. uncertainty about the impacts of activities
- specialisation vs. maintaining overview.

"The tension between situational judgement and generally applicable rules is manifested e.g. in concrete repair situations where the work broadens so that it is no longer clear if the work is defined in the work order. The question is whether it is acceptable to make a personal judgement and finalise the work, or should it be interrupted until the new work order is given. Correspondingly the dilemma of certainty vs. uncertainty is faced when performing a task for a first time. If the espoused norm forbids you to conduct activities if you are not sure how to do it, how can you ever achieve certainty. The third tension, specialisation vs. maintaining overview, is confronted when considering the role of expertise: what is the best strategy to ensure the reliability of work, to go into details in some areas or to obtain general understanding of the interdependencies".

<u>Reacting.</u> According to the maintenance core task model, one critical demand of maintenance is reacting, i.e. detecting and diagnosing deviations and acting accordingly. A demand for the maintenance work practises is adhering to procedures due to the instrumental demand methodicalness. Flexibility in turn is an instrumental demand between the critical maintenance demands of anticipating and reacting.

A survey of the use of condition monitoring information for maintenance planning and decision making at three Nordic nuclear plants indicates that condition monitoring is increasingly implemented at the nuclear power plants, but very selectively and in a rather slow pace for predictive condition based maintenance. A combined strategy of condition based maintenance and predetermined preventive maintenance is applied for important equipment such as main circulation pumps, generators, steam turbines and turbine condensers at the nuclear power plants [Laakso, Rosqvist & Paulsen 2002].

Predictive condition based maintenance strives to prevent the failure by utilising condition monitoring information, information systems and personnel expertise for maintenance steering of necessary preventive maintenance instead of following the predetermined preventive maintenance program only.

A maintenance data warehouse function aimed for the reliability centred maintenance analysis at a Swedish plant [Laakso & Strömberg 2001] has helped to trace and update the preventive maintenance planning data and complete it with notes from condition monitoring. This function has facilitated for the user an easy way to plan case-specific maintenance actions, i.e. adding planned or deferring predetermined preventive maintenance actions justified by results from condition monitoring.

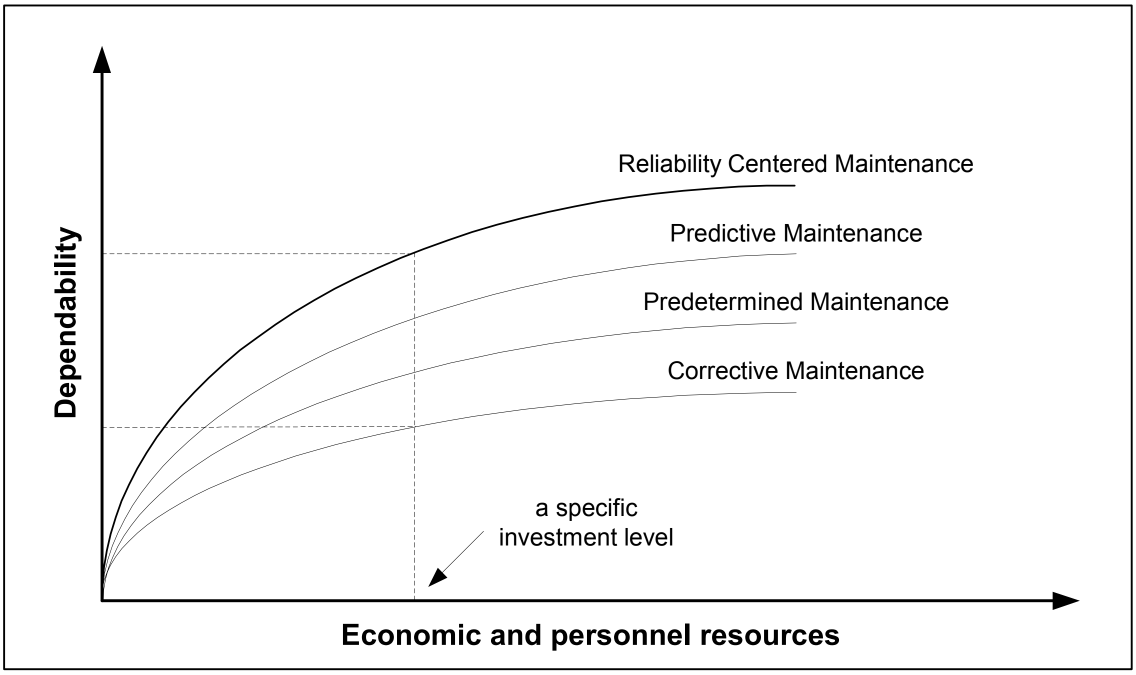


Figure 8. Cost effectiveness of maintenance with respect to dependability for distinct maintenance strategies [Rosqvist & Laakso 2002].

The ratio of corrective to preventive maintenance task rates (total number corrective maintenance work orders divided by preventive maintenance work orders) is about 50 % in the both studied Finnish plant sites. A realistic aim is to reduce the number of costly or error prone predetermined maintenance or disassembling inspection activities by applying condition monitoring for condition based preventive maintenance given that the approach enables a comprehensive fault detection and diagnosis for operative maintenance planning. Systematic follow-up and analysis of the condition monitoring information followed by a case-specific planning and decision making of timely and rightly directed maintenance actions could then justify an extension of the intervals of a number of predetermined inspection, maintenance or periodic testing tasks and thus steer the maintenance to correspond better the real needs. The use of process monitoring information for condition monitoring of equipment would also contribute as a help. An effective use of process information for analysis of the condition of equipment would require a better access of this information to the maintenance personnel.

<u>Co-operation</u>. Co-operation is one of the demands for the maintenance working practises according to the maintenance core task model. Examples of good working practises could be for instance such a co-operation which is applied in certain periodic testing of rotating standby safety equipment where the control room personnel performs the testing and the maintenance personnel the condition monitoring of the equipment simultaneously. Another good practise could be to have cross-functional maintenance foremen or maintenance engineers working in the operating organisation and control room for co-ordination and follow-up of the daily maintenance activities. Installation of modification

works also requires cross- functional working practises and thus the modification work groups can include maintenance personnel from the different maintenance trades in the plant.

Definition of responsibilities. According to the maintenance core task model other demands for the maintenance working practises are sharing of knowledge and definition of responsibilities. A good practise in the different areas of maintenance could be to plan and budget the maintenance properly by help of defined and agreed maintenance strategies in both the short and medium term, and to have a personal equipment level responsibility and accountability for the maintenance performance including the equipment reliability and availability and budget control.

Planning and learning. A critical demand for maintenance is anticipating, i.e. planning and committing planned operations. An instrumental demand of learning is noticed between the critical maintenance demands of anticipating and reflecting. These objectives could be better achieved by implementing in a stepwise fashion an experience based reliability centred maintenance (RCM) planning approach for strategic planning of the necessary maintenance and operability and for experience feedback analysis within the maintenance areas [Hänninen & Laakso 1993, Laakso, Dorrepaal, J., Simola, K., Skogberg, P. 1999, Laakso & Strömberg 2001].

In a Finnish plant the large amount of all the planned preventive maintenance, periodic testing, condition monitoring and NDT actions, which are performed according to different predetermined programs, had been collected and directed to the right equipment places to specify their total preventive maintenance programs. This information had been made visible for the plant personnel in the plant maintenance information system on the actual individual equipment places. This information helps to integrate both the planning and the monitoring of the preventive actions, including repair strategies at the correct maintenance level.

In the systematic RCM operability planning approach the maintenance history and logic tree analyses are combined. The following logic tree in 1988 in Figure 9 helps to identify effective tasks for failure detection and prevention. However the following LTA needs a reconstruction to take into account better the opportunities offered by novel modern condition monitoring, start-up testing of small modifications and a more diversified importance classification of the maintenance objects.

Logic tree (LTA)- for the identification of effective maintenance actions

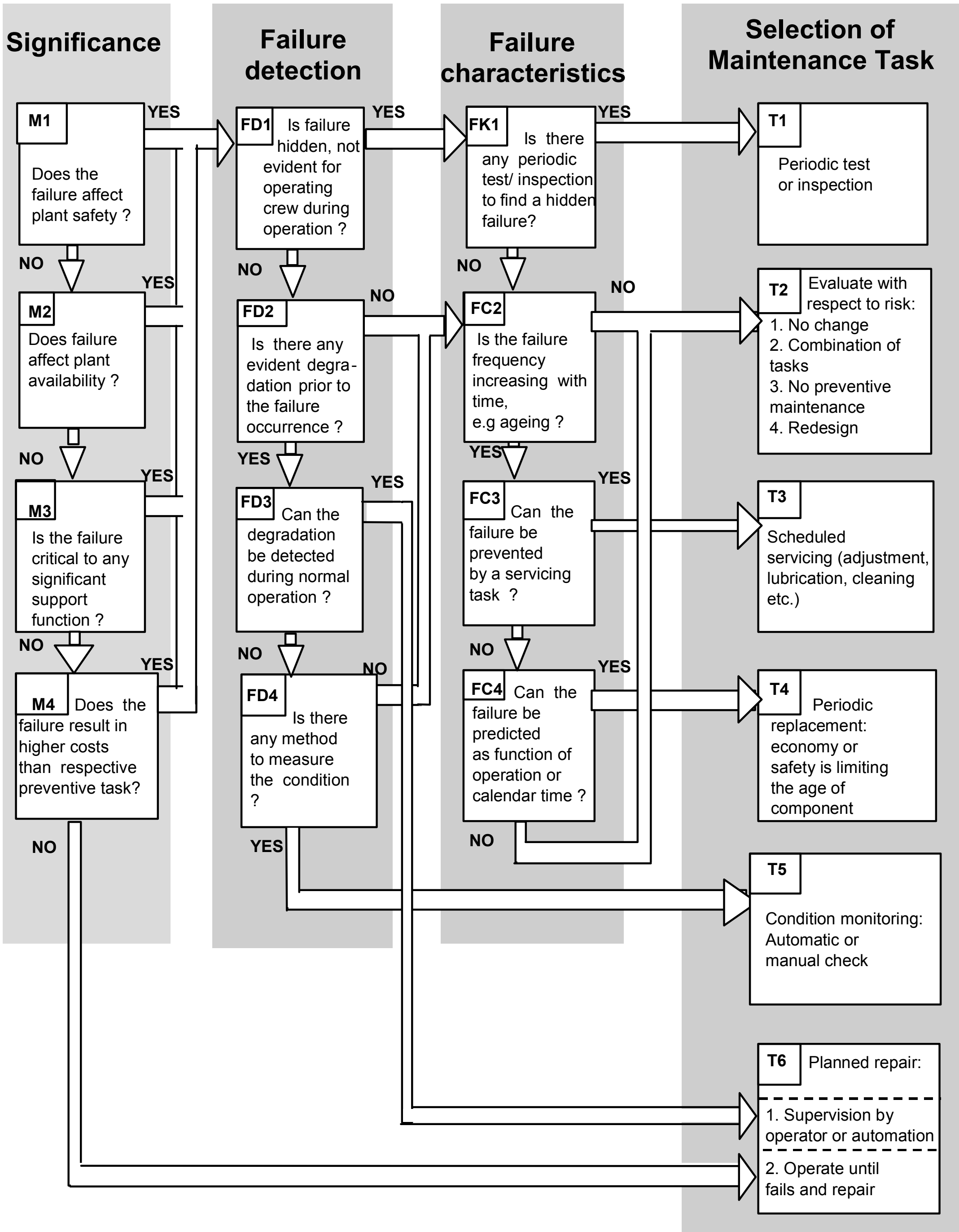


Figure 9. A logic tree of RCM analysis for the identification of effective maintenance actions [MSG-3 1988].

A Swedish utility had selected the hydraulic scram system to be the case study object of an experience based reliability centred maintenance analysis (EBRCM) because this important safety system had exhibited a rather high frequency of component failures. The analysis resulted among others in proposals for added preventive predetermined maintenance and a recommendation to consider condition monitoring to partially replace added preventive maintenance to reduce the leaking of pneumatic valves [Laakso, K., Dorrepaal, J., Simola, K., Skogberg, P. 1999, Laakso & Strömberg 2001].

In an earlier EBRCM pilot study on safety related protection automation and cooling system in another but a newer generation Swedish BWR plant, the ratios of the corrective and preventive action rates of some predetermined preventive condition checks of the motor operated valve (MOV) actuators, as well as of the periodic valve motioning test of the MOVs, were zero (0) or very low. Thus it was justified to study the opportunities to prolong these predetermined preventive maintenance action intervals to the next periodicities or to make the corresponding preventive maintenance actions better. The condition monitoring system which was recently added to the preventive action programme could record automatically the actuations of the MOVs, and could thus be credited as a partially substituting preventive condition check and a more effective functional testing, if well registered, documented and diagnosed in this case [Laakso, K, Hänninen, S, Hallin, S. 1995].

Thus an increased use of condition monitoring of equipment for analysis of condition monitoring information and maintenance steering, and a thus more case specific maintenance and operability planning requiring a better utilisation of the personnel expertise and responsibility, is recommended to be considered as a partially substitutive defensive barrier against human failure events to the predetermined maintenance, inspection and testing programs in the maintenance and operability activities.

Reflecting. According to the maintenance core task model, one critical maintenance demand is reflecting, i.e. viewing the effectiveness and results of actions. A modelling of the operability verification process including even small works and modifications in the system during an outage or operation, and comparison with an HCCF event based analysis of missed detection of errors or faults in installation inspections and functional tests, could also help to increase the understanding of the plant practises and identify the weaknesses requiring remedies. A systematic modelling and description of the maintenance and operability planning process of several plants in interaction with plant professionals would help to identify differences between the plant ways of acting and weaknesses or complexities in them. Thus it would help to streamline, simplify and make those accumulated plant routines more transparent and effective.

“Similar” turn-over and acceptance procedures of the technical modifications and their documentation between the modification project phases design, installation, start-up testing and operation, and simultaneously between the responsible organisational units (mostly internal suppliers to internal customers) as has been applied for the technical systems during the installation and start-up testing phases in the latest Nordic BWRs could be considered. Such procedures would act as organisational defensive barriers against common cause failures originating from the modification and renewal projects in the old plants.

A selective reduction of the high number of technical modifications (more than 1000 modifications at Olkiluoto site and almost 3000 at the Loviisa site during the studied 3 years) could possibly be achieved by a risk analysis as a part of the decision making processes of the proposed modifications. Decision analyses have also been demonstrated to provide a more systematic and clear basis and documentation for selecting the best decision option under multi-criteria conditions [Laakso, Sirola, Holmberg 1999].

Concluding remarks. A final report of the project on identification and prevention of multiple human failure events in relation to the maintenance activities of the Finnish nuclear power plants will be prepared and submitted for publication in STUK series in 2003. Detailed reviews of the multiple failure event analysis data, and feedback from discussions on the analysis results with the utility experts and professionals as with authorities, is still crucial in developing the final conclusions and recommendations that meet specific and generic development needs at the plants.

Although these events suggest negative experiences, experts and managers in the nuclear power plants and regulatory body view them as an extremely valuable for experience feedback and the development of safety, operability, maintenance and the manners of proceedings. The aim is to turn the negative experiences of failures and errors by remedial and corrective actions (which have already started) into so uneventful operation as reasonably practicable.

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Abstract

Operating experience has shown missed detection events, where faults have passed inspections and functional tests to operating periods after the maintenance activities during the outage. The causes of these failures have often been complex event sequences, involving human and organisational factors. Especially common cause and other dependent failures of safety systems may significantly contribute to the reactor core damage risk. The topic has been addressed in the Finnish studies of human common cause failures, where experiences on latent human errors have been searched and analysed in detail from the maintenance history.

The review of the bulk of the analysis results of the Olkiluoto and Loviisa plant sites shows that the instrumentation & control and electrical equipment is more prone to human error caused failure events than the other maintenance and that plant modifications and also predetermined preventive maintenance are significant sources of common cause failures. Most errors stem from the refuelling and maintenance outage period at the both sites, and less than half of the dependent errors were identified during the same outage. The dependent human errors originating from modifications could be reduced by a more tailored specification and coverage of their start-up testing programs. Improvements could also be achieved by a more case specific planning of the installation inspection and functional testing of complicated maintenance works or work objects of higher plant safety and availability importance. A better use and analysis of condition monitoring information for maintenance steering could also help. The feedback from discussions of the analysis results with plant experts and professionals is still crucial in developing the final conclusions and recommendations that meet the specific development needs at the plants.

Key words: Maintenance history, human factors, experience feedback, common cause failures, operability

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