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EXPERIENCE BASED AGEING ANALYSIS OF NPP PROTECTION AUTOMATION IN FINLAND

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Abstract

This paper describes three successive studies on ageing of protection automation of nuclear power plants. These studies were aimed at developing a methodology for an experience based ageing analysis, and applying it to identify the most critical components from ageing and safety points of view. The analyses resulted also to suggestions for improvement of data collection systems for the purpose of further ageing analyses.

1. INTRODUCTION

Nuclear power plant (NPP) ageing analyses are aimed at identifying the important ageing mechanisms and at developing proper ageing mitigation methods in order to ensure the safe operation of the plant to the end of its planned lifetime [1]. Although safety significant equipment have to fulfill strict quality requirements and they have well defined maintenance programmes, the follow-up of ageing is important. For instance changes in operating conditions affect the lifetime of components.

This paper describes Finnish research studies aimed at evaluating the current state of reactor protection systems and identifying the most critical components from ageing and safety points of view. The research work was initiated by a preliminary study of relay failures and cable ageing [2]. In the second study, a methodology for analyzing the ageing of an automation system was developed [3]. The method was applied to selected automation chains of a reactor protection system. In the third study, a similar approach was used but more detailed failure modes and effects analyses were applied to selected items [4].

2. PRELIMINARY STUDY ON AGEING OF I&C EQUIPMENT

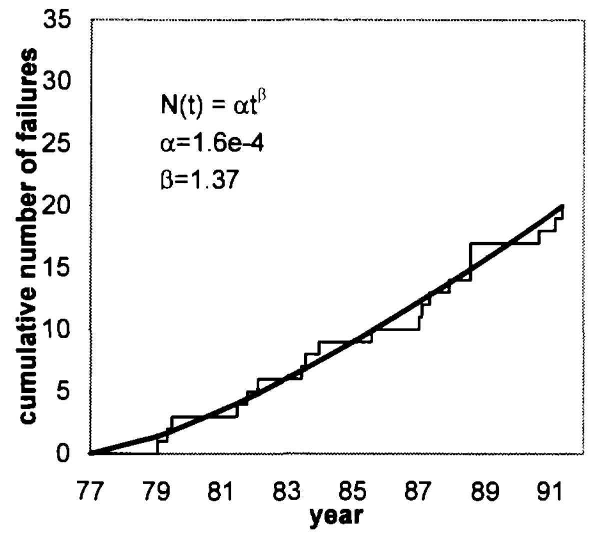
2.1. Analysis of reactor protection system relay failures

The preliminary study was focused on relay failures in the Reactor Protection System (RPS) of Loviisa PWR plant. This study was limited to the analysis of operating experiences collected from work orders at the power plant. One objective of the study was to assess the possibility of using accumulated plant operating experience in ageing analyses.

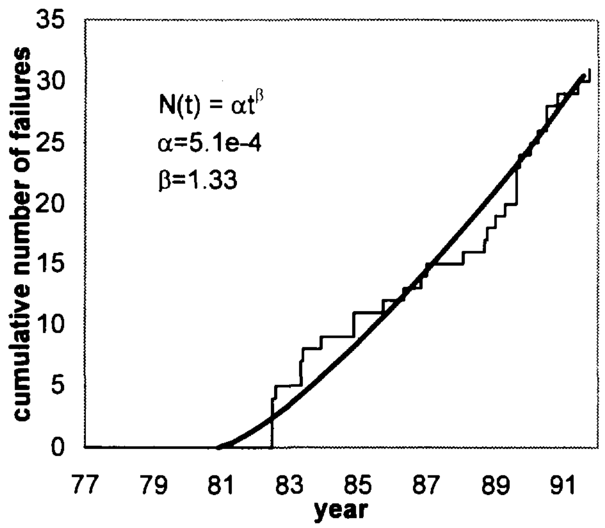
In the study, failure histories of 340 (170 per unit) continuously energized relays in the protection logic of the RPS of the two plant units were collected. The observation period in the study was 15 (11) years at plant unit 1 (unit 2). The numbers of reported failures during these observation periods were 20 at unit 1 and 31 at unit 2. After the data collection, a trend analysis of reported failures was performed and a slightly increasing trend in failure reporting was identified. The trend analysis was done by estimating the parameters of Weibull process from data. The trends are presented in Fig. 1.

The dominating failure mode according to the failure reports was the coil burn out. A more detailed investigation revealed that, at unit 2, most of the failures occurred in relays of two cabinets and especially in relays connected in series with resistors.

Temperatures and voltages were measured in relay cabinets. The voltage measurements showed over voltage due to varying resistance values of the resistors. It was noticed that the ambient temperatures were higher in cabinets of relays connected in series with resistors. Furthermore, it was observed that the temperatures were higher in unit 2 which could explain the higher failure rate in this unit.



a)



b)

FIG. 1. Failure trends of relays. a) unit 1 b) unit 2.

It was concluded that the probable reasons for the coil burn-out failures are the over voltage due to varying resistance values of the resistors and the elevated cabinet temperatures caused by the heat produced by the resistors. It was recognized that the failure rate of some relays could possibly be decreased by reducing the environmental stresses caused by temperature and voltage. The ventilation in cabinets has been improved.

Recommendations were given also concerning the data collection practices. Although failure descriptions were often missing causing difficulties in the identification of critical failures, and the classification of plant instrumentation components is not very detailed, the analysis showed that failure data was useful in indicating problem areas and trends.

2.2. Cable ageing

In the study of cable ageing, a literature review was made and the ageing surveillance programme of in-containment cables at Loviisa PWR plant were evaluated. In the present surveillance programme, cable samples are taken for measurements with a five year's interval in order to follow the environmental effects on cable materials. However, due to cable replacements, the ageing follow-up from the beginning of the plant operation is possible for only one of the present cable types in safety significant installations. Additional samples were taken for possible further measurements. The results obtained in the surveillance programme could be complemented with accident testing of naturally aged cables. A testing programme to evaluate the possible dose-rate effect is introduced.

3. AGEING STUDY OF REACTOR PROTECTION SYSTEM OF OLKILUOTO BWR

After the preliminary study on relay failures, a more extensive ageing study on reactor protection automation was initiated. One objective of the study was to present an ageing analysis approach and apply it to the automation chains of a reactor protection system of Olkiluoto BWR plant. The second objective was to evaluate the possible ageing effects of equipment and their safety significance.

3.1. Analysis approach

As the aim of the study was to evaluate the effects of ageing on the system safety, the collection and analysis of all relevant plant specific information related to the system was considered important. However, due to limited resources, the study had to be focused on the most important topics. The selected approach is primarily based on the analysis of operating experience, e.g. failure reports and maintenance histories.

The analysis of the system structure is important in order to identify the critical paths where failures could prevent the propagation of the protection signal from measuring devices to the intended valve or pump actuation. Existing PSAs can be used or fault trees can be constructed to indicate the safety importance of components. The analysis of occurred failures is essential for the identification of recurrent failures and trends, and the information on the structure of equipment is needed to understand their failure modes. Qualitative methods, such as failure modes and effects analysis (FMEA), can be applied to analyze both the occurred and other possible failure modes. The environmental and operating conditions, and the maintenance practices are reviewed in order to identify their influence on age-degradation. The steps of the study are presented in Figure 2.

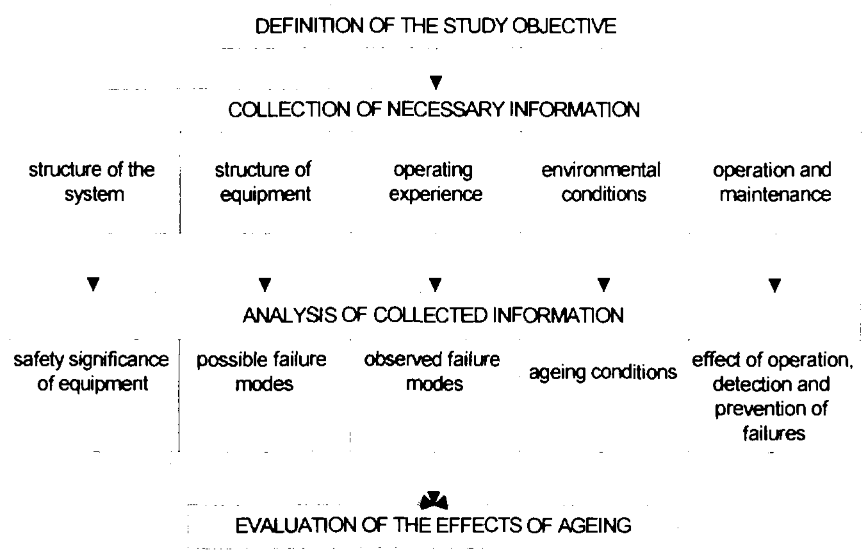


FIG. 2. Steps of the ageing study of reactor protection system.

3.2. Definition of the boundaries of the study and analysis of operating experience

The first step in the study was to select a representative part of the reactor protection system of the plant for the ageing analysis. The reactor trip train components from measurement devices to control electronics were selected as the study objective. The principal scheme of the protection chains is presented in Appendix 1 of this national report. The reactor trip train can be divided into three parts: measurement instrumentation, protection logic, and control electronics. The measurement instrumentation includes sensors, transmitters, neutron flux detectors, room temperature, pressure and float level switches, and other control electronics. The protection logic is based on relays.

Another limitation was needed in regard to the safety functions to be included. The control electronics of three safety functions were included:

— closing of isolation valves of main steam lines;
— opening of valves in the relief system;
— starting of pumps in auxiliary feed-water system.

The operating experience was obtained from the plant failure database. Furthermore, calibration histories of pressure and level transmitters, limit signal units and I/U-converters were obtained from a maintenance database. Considering the number of equipment and the time period investigated, the overall number of failures was low. Especially, the failure rate of the relays was very low.

An increase in failure reporting during last years could be identified in room temperature and pressure measurement instrumentation. The failure modes and effects of room control switches were analyzed in order to identify possible ageing-related failure modes that could prevent the progression of protection signal. A simplified FMEA with specific attention to age-related failure modes was applied for this purpose. An example of such an analysis is shown in Table I.

TABLE I. FAILURE MODES, EFFECTS AND AGEING ANALYSIS OF A ROOM TEMPERATURE SWITCH

Component	effect	failure mode	failure cause	age related
Room temperature switch	no signal	setpoint too high	drift, e.g. due to grease hardening	yes
			wrong setting	no
		contact does not open	capillary tube or membrane damaged	no
			switch failed	yes
	unnecessary signal	setpoint too low	drift, e-g- spring has lost elasticity	yes
			wrong setting	no

3.3. Reliability studies of the protection automation

The effect of protection automation failures on plant reliability was studied with a living-PSA code [5]. It was of interest to identify how multiple failures of the system would increase the estimate of the core damage frequency.

The level of detail in PSA models was varying: the reactor measurement circuits were modeled in detail but e.g. room control chains were not modeled with same precision. Failure rates of control electronics were not considered separately but included in failure rates of pumps and valves. Accident sequences were selected for the studies by the following criteria:

— minimal cut sets for which probability exceeds a certain limit;
— sequence includes components of protection automation.

PSA models were used to study the impact of the increased failure rates of protection automation components on accident sequence frequencies. In this connection also the effect of the multiple failures of the system on the core melt frequency was identified. In the sensitivity analyses, the following aspects were considered:

— severity of consequences;
— probability of the accident sequence;
— sensitivity of the accident sequence probability to failures of protection automation.

It was observed that the frequency of the accident sequences, most sensitive to the increase of failure rates of protection automation, does not significantly contribute to the core melt frequency. Investigated cases with simultaneous failures in all four redundant channels were not realistic as result of ageing considering the testing and maintenance of equipment.

3.4. Conclusions

The number of failures was low, and the sensitivity analyses with the living-PSA tool showed that the impact of increase in failure rates of RPS components on plant safety was small. In reactor measurements, typical transmitter failure modes are calibration shifts and response time degradation. A major failure of transmitter or converter is detected immediately. For relays, only few failures had occurred, and critical failures are very unlikely at low voltages. Failures in control electronics may prevent operation of valve or pump but the evaluation of effects of various failures would require a more detailed study. The possible failure mechanisms of room control switches were evaluated with maintenance staff. Measuring switches have been replaced by a different type.

4. AGEING STUDY OF THE ESFAS OF LOVIISA PWR PLANT

In the study of Engineered Safety Features Actuation System (ESFAS) of Loviisa PWR plant, the approach used was similar to the one described above. However, in this study, a more detailed analysis was performed for some items selected on the basis of operating experience and a fault tree analysis. For these selected electronic devices, failure modes and effects analyses were performed. Table II shows the phases on the study and methods used.

TABLE II. PHASES OF THE STUDY AND METHODS IN THE AGEING ANALYSIS OF ESFAS

PHASE	METHOD
evaluation of failure histories	analysis of operating experience
evaluation of equipment safety significance	fault tree analysis
selection of components for more detailed studies	selection based on the results of phases 1 and 2
evaluation of ageing and failure modes for selected components	failure modes and effects analysis

The operating experience was collected from various sources. The failure data was collected mainly from work orders 1977-1990 and from the plant information system since 1989. Furthermore, information was obtained from reports of scheduled inspections and tests, and e.g. laboratory testing reports.

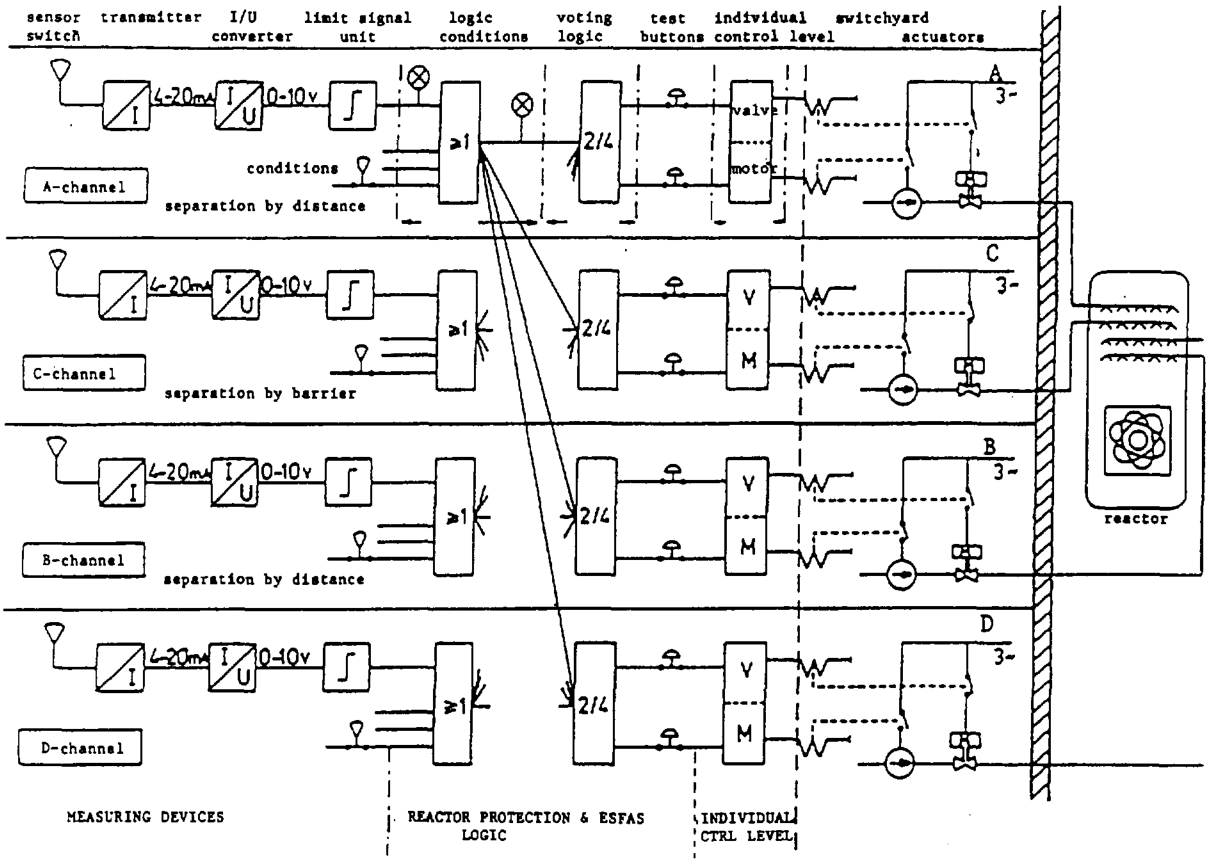


FIG. 3. Principal scheme of the protection chains of the Olkiluoto RPS.

A fault tree analysis was carried out for the safety function: "Starting of emergency feed water pumps if a steam generator level decreases below -140 mm". This was a qualitative analysis with not any failure rates included. The analysis shows which parts of the system are most important for the propagation of the signal. Based on the minimal cut sets, electronic cards were selected for further analyses.

Based on the analysis of operating experience, the limit signal unit and the priority unit were selected for detailed studies. Based on the fault tree analysis, a priority unit, an individual control unit, and a pulse/DC converter were selected for further investigations. An FMEA was performed for these selected cards, at least for those parts related to the paths of the protection signal.

The study showed, that the number of occurred failures is low, and not any clearly increasing trends could be identified. In most cases the failures have caused a false alarm, and only few failures had prohibited the propagation of the safety signal in one channel. These failures were identified mainly in individual control units (relay failures) and in limit signal units. The power supply was not included in the study but it was recommended for further ageing analysis activities.

5. CONCLUSIONS

A methodology for ageing analyses based on operating experience and reliability techniques was developed and applied to protection automation systems. In the cases studied, the amount of failures occurred during the plant operating time was low, and increasing trends in failure occurrence could be observed only for few components. However, as a degradation phenomenon may occur suddenly, it is advisable to inspect regularly failure and maintenance records, e.g. calibrations. The safety importance of age-degradation may be evaluated with PSA models, on conditions that sensitivity analyses can be carried out and that the models are detailed.

Regarding the development of data collection systems, some recommendations were given in order to enable better the utilization of plant experience in ageing studies. The information is often spread in various databases or paper archives, which hinders the efficient use of these records. Integration of various sources of information, such as failure reports and testing, calibration and other maintenance related data, is highly recommended. The system should also provide tools for trend analyses and graphical presentation and, e.g., age-related keywords for data retrieval. The quality of the data may be improved by motivating the plant personnel in filling up more precisely the failure reports.

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