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MAINTENANCE RELATED EVENTS IN NUCLEAR POWER STATIONS

ZDARZENIA EKSPLOATACYJNE W ELEKTROWNIACH JĄDROWYCH

This paper presents the essential results of a study performed by the European Clearinghouse on Operational Experience Feedback, in cooperation with IRSN and GRS, aiming to analyse events where their direct or root cause was an inappropriate maintenance at nuclear power stations. The databases of IRSN, GRS, U.S. NRC and IAEA IRS were screened to select relevant events related to maintenance that took place in the period 2002-2013. The examination of the selected events resulted in their classification into nine categories or groups with sub-division in families and, if necessary, sub-families. In total 921 events were analysed. One of the event classifications performed was according to the type of maintenance (periodic, predictive, planned and corrective). The operational experience data analysis indicated that 47% of the events reported were related to periodic maintenance. The main affected components were „valves", followed by „electric power components". The main root causes observed are „maintenance performed incorrectly" (e.g., improper use of tools, breach of authorization, lapse, etc.), „deficiencies in written procedures or documents" and „deficiencies in management or organization". Regarding the impact on safety, the dominant family is „potential effects on safety function" (57%), followed by „significant effect on operation" (20%). Based on a detailed analysis of selected events, recommendations were developed and some of them are presented in this paper. This study highlights that the continuous analysis of maintenance related events and the efficient utilization of operational experience provide important insights for improving the quality of maintenance and for preventing the occurrence of unusual events and thus helps to enhance nuclear safety.

***Keyword**: operating experience, databases, nuclear power plants, maintenance events.*

W niniejszej pracy przedstawiono najważniejsze wyniki badania dotyczącego informacji zwrotnych na temat doświadczeń z eksploatacji urządzeń przeprowadzonego przez European Clearinghouse we współpracy z IRSN oraz GRS. Badanie miało na celu analizę zdarzeń, których bezpośrednią lub zasadniczą przyczyną była nieodpowiednia eksploatacja urządzeń w elektrowni jądrowej. W badaniu, przeszukiwano bazy danych których operatorami są IRSN, GRS, U.S. NRC oraz IAEA IRS w celu wyłonienia istotnych zdarzeń eksploatacyjnych z lat 2002-2013. Analiza wybranych zdarzeń pozwoliła na sklasyfikowanie ich według dziewięciu kategorii lub grup, które z kolei podzielono na rodziny i, jeśli zachodziła taka potrzeba, także na pod-rodziny. W sumie przeanalizowano 921 zdarzeń. Jedna z klasyfikacji zdarzeń została oparta na kryterium rodzaju utrzymania ruchu (okresowe, predykcyjne, planowe oraz korekcyjne). Analiza danych dotyczących doświadczeń operacyjnych wykazała, że 47% zgłaszanych zdarzeń było związanych z konserwacją okresową. Głównymi elementami, których dotyczyły badane zdarzenia były "zawory", a w drugiej kolejności "części elektryczne" Najważniejszymi zasadniczymi przyczynami zdarzeń były "nieprawidłowo wykonana konserwacja" (np. nieprawidłowe użycie narzędzi, naruszenie autoryzacji, pomyłka, itd), "niedoskonałe procedury pisemne lub niedoskonała dokumentacja" oraz "niedociągnięcia w zarządzaniu lub organizacji". W odniesieniu do wpływu na bezpieczeństwo, dominującą rodzinę zdarzeń stanowiło "potencjalne oddziaływanie na funkcję bezpieczeństwa" (57%), a w drugiej kolejności "znaczący wpływ na pracę" (20%) W oparciu o szczegółową analizę wybranych zdarzeń, opracowano rekomendacje, z których część przedstawiono w niniejszym artykule. Omawiane badanie zwraca uwagę na fakt, iż ciągła analiza zdarzeń eksploatacyjnych oraz skuteczne wykorzystanie doświadczeń z eksploatacji dostarczają istotnej wiedzy na temat możliwości doskonalenia jakości utrzymania ruchu oraz zapobiegania występowaniu zdarzeń, pomagając w ten sposób zwiększyć bezpieczeństwo produkcji energii jądrowej.

***Słowa kluczowe**: doświadczenia operacyjne, bazy danych, elektrownie jądrowe, zdarzenia eksploatacyjne.*

1. Introduction

An in-depth analysis of Maintenance related Events has been carried out in the frame of the activities of the European Clearinghouse on Operational Experience Feedback (OEF) for Nuclear Power Plants (NPP) [7]. This analysis updates and completes a previous study on Maintenance related Events published by the European Clearinghouse in 2009 [10-11]. The updated analysis performed in 2015 covers events registered in 4 different databases for a much longer period of time. The events are reported in the IAEA-IRS database [3-4], the US NRC LER database [8], the French national database SAPIDE [12] operated by IRSN and the German database VERA operated by GRS [6], and are related to the period 2002 - 2013. Since the maintenance related events represent around 30% of the total number of events reported in a typical database it was necessary to establish appropriate criteria with the aim to select the most relevant events. The number of selected events should be significant for a statistical analysis and, at the same time, a manageable number for an in-depth evaluation by the experts. With this in mind, the study was limited to NPP operational incidents which resulted directly (direct cause) from maintenance activities or where maintenance was a root cause of such incidents. The scope of the work was to analyse in depth the causes, root causes, contributing factors and consequences as well as to deduce lessons learned and recommendations. This paper summarizes the results of the topical study "Events related to Maintenance at Nuclear Power Plants", issued by the European Clearinghouse in February 2016 [1].

2. Methodology

For gathering the experience from events related to maintenance at nuclear power plants, four databases were screened. IRSN and GRS analysed information from their respective databases, i.e. France and Germany, while JRC processed information from the IAEA IRS database and US NRC LER database. At the latest stage, JRC integrated all results. No event was counted twice for events reported to the IRS from US, France or Germany.

The databases were firstly searched using specific searching tools (keywords and/or guidewords combined with logical operators) suitable for each database, yielding the first list of potentially relevant events. The event reports contained in this first list were reviewed individually to determine their pertinence for the study, thus obtaining a screened list of relevant events. In total 921 events were selected for analysis.

The events relevant to the topic were classified according to the following categories or groups:

- plant status (on power, hot shutdown, cold shutdown, etc.),
- type of maintenance (periodic, predictive, etc.),
- method for detection of event (in-service inspection, surveillance, etc.),
- affected system in the plant,
- affected component,
- direct cause,
- root causes,
- corrective actions,
- effect on safety (significant effect on operation, effect on safety function, etc.).

For further analyses, the categories were divided into families and, if necessary, into sub-families. The final step includes an in-depth analysis of the causes, root causes, contributing factors, consequences and lessons learned of selected events, in order to identify recommendations to avoid recurrence of similar events. Figure 1 shows the methodology followed in this topical study. This methodology has been applied also in other studies with different topics undertaken by the European Clearinghouse [2, 5, 9, 13].

3. Data analysis

The events are classified according to the type of maintenance as showed in Figure 2. Most of the periodic maintenance consists of servicing while the plant is under normal operation. The difference observed with the German database is just a reflection of a different maintenance philosophy. In fact, in Germany, all events with a replacement of components are assigned to "Planned maintenance". It has to be noted that in the German event description included in the database there is no information whether the component was replaced preventively with or without abnormal behaviour.

The data analysis shows that the essential reactor auxiliary systems and the electrical systems are the systems prone to be affected by maintenance failures. This could be explained by the fact that these systems are essential for the smooth operation of the plant, and their rate of allowed unavailability per year is among the lower rates of the

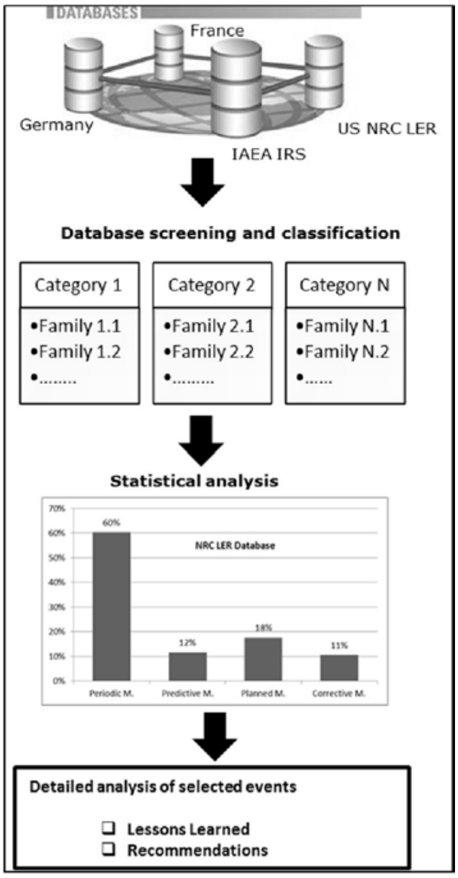

Fig. 1. Methodology

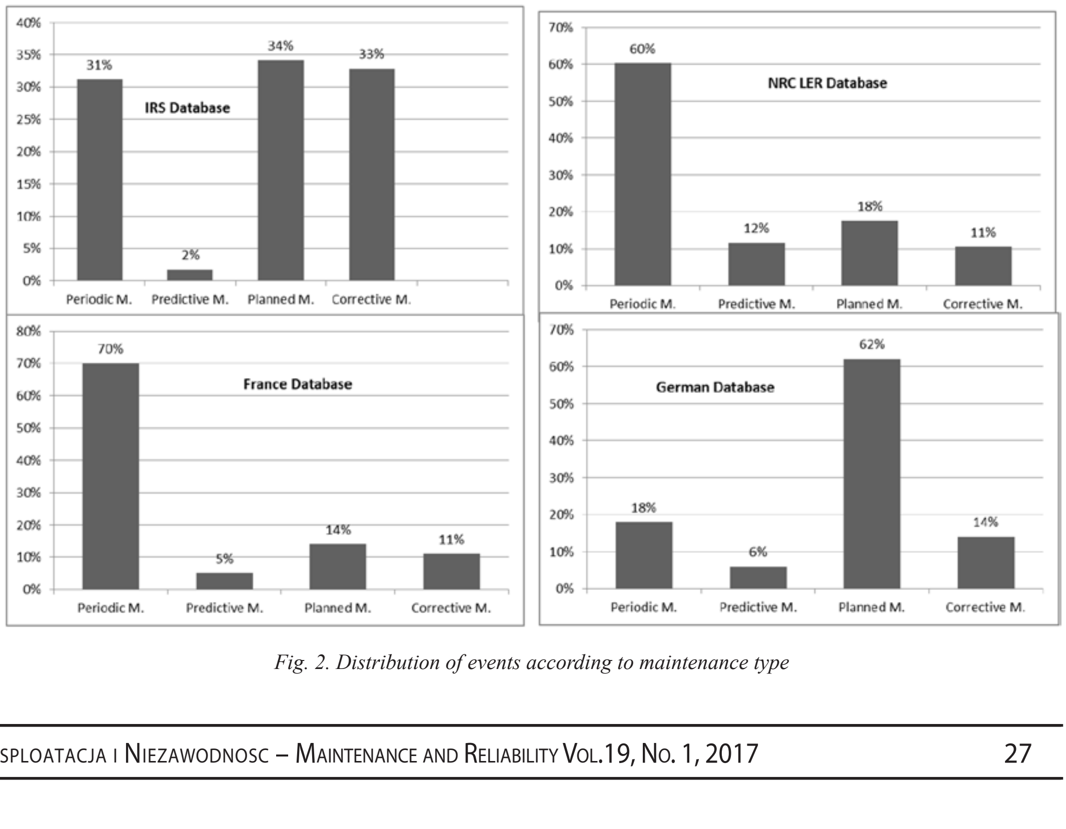

Fig. 2. Distribution of events according to maintenance type

Table 1. Root cause distribution of the events analysed in the IRS database

Root cause	Percentage
Wrong material has been used	5.84%
Corrective maintenance did not correct the problem	4.62%
Preventive maintenance inadequate	13.14%
Maintenance performed incorrectly	16.30%
Deficiencies in post maintenance testing	4.38%
Failure to exclude foreign material	2.92%
Deficiencies in written procedures or documents	19.46%
Deficiencies in management or organization	15.57%
Deficiencies in training or lack of knowledge	17.27%
Others	0.49%

plant systems. Reactor auxiliary systems and electrical systems are a priority for the maintenance activities, and they are often subjected to operational tests and in-service inspections – thus much more exposed to maintenance related failures.

Regarding the category „affected component", the valves and the electrical power components are the components most affected by week maintenance. This is in accordance with the results obtained in the analysis of most affected system. Taking into account that pumps is in the third place in the ranking of most affected component, it may be raised the idea that, apart from the electrical power components, the other most affected components are just those components more frequently subject to manoeuvring during operations and testing.

The results of the type of direct cause of the events show that in around 80% of the cases the most immediate cause triggering the event was of a technical nature (mechanical, electrical, I&C, structural or others) against a ~20% of events caused by human factors. Besides that, these results corroborate with the previous results regarding the most affected components and systems: The overwhelming part the technical failures were mechanical failures (and this is extremely plausible when thinking that the most affected components were those subjected often to manoeuvring, or put into special test or inspection configuration), followed by electrical failures (and the rate of electrical failures with respect to the total number of technical failures of any type is quite proportional to the corresponding rate of electrical components affected by maintenance-related events).

There are differences within the identified root causes of the events. While in France and in Germany the written procedures and documents appear to be quite consistent (15% in France and 11% in Germany), the situation is quite opposite in the US, where the main root cause registered was the imperfection of the written procedures and documents guiding the maintenance activities (29%). Besides that, while in the US the category „maintenance performed incorrectly" (e.g., improper use of tools, breach of authorization, lapse, etc.) is about 16%, in France and in Germany the incorrect way of performing maintenance occurred between 2 and 3 times more often.

The IRS event distribution, Table 1, shows that most of the events reported have as the most frequent root cause a deficiency in the written procedures and documents (19%), but nearly similar rates were also registered as root causes maintenance performed incorrectly (16%), deficiencies in management or organization (16%), and deficiencies in training or lack of knowledge (17%). There is one feature common to the four databases: the maintenance technicians managed to improve and maintain a better Foreign Material Exclusion Zone, since failing to exclude foreign material has quite a low contribution; the same situation is encountered for the post-maintenance testing.

The data analysis shows that there are two main corrective actions: changes in operating mode documents or procedures followed closely by repair or replacement. The corrective action „repair or replacement" was applied in a little less than half of the events. When linking the corrective actions with the root causes, the analysis shows that changes in maintenance documentation, program and personal training is a common response in the four database to correct any maintenance failure; at least two thirds of the corrective actions focused on three large administrative areas (changes in operating mode documents and procedures, changes in maintenance program and personal training). This is very consistent for the US database since the statistics revealed that in US the largest contributors (with a total of approx. 40%) were deficiencies in written procedures and documents and deficiencies in management or organization.

4. Observations from the analysed events

Lessons learned and specific recommendations from 40 selected events from the 921 events are given in [1]. Some general observations are listed below, resulting also from the events analysed. These insights should help avoiding deficiencies of the NPP´s during maintenance and reducing the number of events, especially with impact on safety.

4.1. Corrosion management

It should be checked, that existing corrosion protection measures have not been weakened by maintenance activities, especially in case of repairs or exchanges of parts. If an impact on the corrosion protection occurred, it has to be renewed. If a cathodic corrosion protection is used, the post-maintenance testing has to ensure, that the electric connection is still working after the maintenance activity.

After decontamination measures, the corresponding components have to be checked for intrusion of decontamination medium to avoid corrosion effects. Written procedures should include information on how to avoid the intrusion of corrosive medium during the decontamination of components. Additionally, the written procedures should give information about the measures to detect fluid intrusions in decontaminated components and how to clean these components, if necessary.

4.2. Ageing management

Occasionally, the ageing process of components is not in accordance with maintenance programs. Thus, components can lose their ability to ensure their function in accidental conditions. In order to ensure the availability and qualification of equipment, it is advised to:

- Specify a lifetime for the components and equipment selected within the ageing management programme;
- Maintain knowledge on the characteristics and limits of qualification which must be exhaustive;
- Prevent maintenance activities or maintenance program modifications that could prejudice the components qualification.

4.3. Housekeeping project

The housekeeping project concerns operating actors and aims at bringing good practices to plant staff for keeping their installation in a visually good state as if it was their own property. The project also involves the identification and correction of slow deviation phenomena that could impact the reliability of equipment important to safety due to their degradation or bad state of premises where they are located. For this purpose, user-friendly illustrated guides and many displays can help to implement these good practices.

4.4. Temporary device management

Whenever possible, the measurement circuits should be de-energized on relay protection and automatic control system measurement devices prior to performing technical maintenance. Whenever this condition cannot be realized, and for each equipment identified as not being possible to be de-energized before performing work on it, the manufacturer should be contacted with precise intentions to resolve shortcomings in the design of equipment not providing the necessary conditions for the safe conduct of work to remove (or install) devices.

4.5. Steam Generator maintenance

More than several hundreds of SG tube mechanical plugs are installed in each reactor. The loss of a plug can have heavy potential consequences on the safety (breach of a SG tube, migrating foreign material…), leading to a primary circuit breach. This has raised the issue of steam generator plug loss, and emphasises the high attention that must be paid to the installation and periodic check of the plugs. A periodic televisual inspection is advised to check the presence and correct position of the plugs inside the tubes.

4.6. Foreign Material Exclusion

Temporary filters should be thoroughly provided at the time work is being performed within the drywell of a BWR during periodic inspections and for construction work with the generation of a large amount of dust containing iron. In general more attention should be given to reduce the inflow of a large amount of dust containing iron into the system, by e.g. the use of blowers, which can reduce the potential of occurrence of an event. All preventive measures should be specified in the maintenance-related written procedure.

4.7. Risk of internal flooding

From the analysis of OEF, internal flooding is not sufficiently taken into account despite the fact that it could lead to the loss of equipment important to safety with a risk of common mode failures. The risk of internal floods can be induced by maintenance activities. For this purpose, the different scenarios that could damage the water circuit during maintenance activities have to be identified during risk analysis (pre-job briefing) or safety study.

4.8. Preservation of qualification

The operating organisation should ensure that the testing tools and techniques are appropriate to their scope, and whenever possible to benchmark the test results interpretation with a third party, especially when it comes to safety related components. When new developments are implemented related to material research or within the scope of inspection techniques and tools, the maintenance program should incorporate those as fast as reasonably possible.

4.9. Greasing non-compliance

Equipment is lubricated with specific grease for each kind of equipment. However, a human error from maintenance actors could lead to a mixture of these greases and thus to an unknown reaction (e.g. loss of qualification). In order to avoid this, the recommendations are as following:

- To implement in-depth measures such as to ensure proper preparation, execution and monitoring of operations and facilitate the prevention and detection of this type of non-compliance.
- Insufficient lubrication or hardened grease can lead to a stiffness of valves, which can result in the actuation of reactor protection signals. It is therefore necessary to sufficiently lubricate valves and to exchange old grease in an adequate time interval.

4.10. Post maintenance testing

The impact of any modification process should be checked against the most restrictive safety requirements that the equipment must fulfil. An independent review of any parameter modification is most welcomed and it should be performed each time when such modification is made to equipment important for safety. Post-maintenance testing should be exhaustive enough to guarantee optimal safety and operation of safety equipment. To avoid cases when equipment important to safety is installed without being properly tested by the manufacturer, especially in the cases when such equipment was repaired, the utility should by default test the equipment against the most limiting performance requirements.

4.11. Subcontractor management

Nowadays, the use of subcontractors for achieving maintenance activities is more and more frequent and is highlighted by a large number of events. Indeed, these events point out essential lacks in communication or surveillance by the operator staff.

Thus, to prevent issues during subcontracted activities, it is essential to facilitate the access to the necessary information and good working conditions. The operator should keep in mind that the subcontractor has generally a lower global knowledge about the state of the plant.

4.12. Calibration management

Many producers and vendors offer equipment with design features that ensure a long maintenance-free life expectancy. When performing ISI or any other kind of maintenance activities for this kind of equipment, the tools used by the licensee should be in accordance with the manufacturer recommendations in order to preserve a long maintenance-free life expectancy. Use of excessive force should be avoided at all times when manually stroking valves.

4.13. Maintenance procedures

All the existing procedures for replacing live relay protection and automatic control system measurement devices should be analysed, and all necessary changes to ensure instrument replacement programmes with respect to an event-free conduct of work should be implemented. This action could be performed as part of a special review of relay protection and automatic control system measurement devices used at NPPs, as a development of measures to ensure the safe removal and installation of measurement devices at live equipment.

4.14. Safety culture

The absence of a safety culture was identified as an accompanying root cause in some events. Disciplinary action, among other corrective actions, was also taken in one particular event. The presence of a strong safety culture in maintenance adds a significant value to the safe operation of the plant. With respect to plant maintenance, safety culture means keeping the maintenance process on track and in control at every stage of plant performance. When there is a strong safety culture, maintenance staff excels in the preparation and execution of the tasks in compliance with the safety, quality and technical specifications.

5. Conclusions

For this study the databases of IRSN, GRS, U.S. NRC and IAEA IRS were screened to select relevant events related to Maintenance that took place in the period 2002-2013. The examination of the selected events resulted in their classification into nine categories with families and, if necessary, sub-families. The definitions of the categories, families and sub-families are based on the preliminary results obtained for the four databases. In total 921 events were analysed.

One of the event classifications performed was according to the type of maintenance (periodic, predictive, planned and corrective). The data analysis indicated that 47% of the events reported were related to periodic maintenance. The main affected components were "valves" (with 33% of the events), followed by "electric power components" (23%). The main root causes observed are "maintenance performed incorrectly" (27%), "deficiencies in written procedures or documents"(19%) and "deficiencies in management or organization" (17%). Regarding the impact on safety, the dominant family is "potential effects on safety function" (57%), followed by "significant effect on operation" (20%).

Some general conclusions based on the analysed events are given below:

- The availability of an advanced plant data collection and storage system of maintenance events is important for trend analysis by NPP staff, which facilitates adequate classification of the types of human errors and components failures.
- The maintenance programme should be defined on the basis of real operating conditions.
- The programme effectiveness should be checked periodically.
- If probabilistic risk assessments are performed, the results can be used to help define and prioritize important systems and components.
- Adequate safety planning and risk assessment should be carried out especially when the conditions of testing or maintenance activity are changed.
- The use of OEF and timely implementation of preventive actions would have prevented the occurrence or recurrence of an event in several cases.
- Learning from plant's own maintenance history and a comprehensive human reliability analysis provide useful tools for identifying weaknesses in plant maintenance practices and procedures.

This study highlights that the continuous analysis of maintenance related events and the efficient utilization of operational experience provides important insights for improving the quality of maintenance and for preventing the occurrence of unusual events and thus helps to enhance nuclear safety.

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