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Maintenance Optimization of NPPs

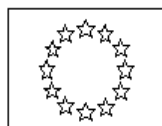
NUCLEAR POWER PLANT MAINTENANCE IN THE CIS AND CEEC

A Brief Evaluation Report

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SENUF

Safety of Eastern European Type Nuclear Facilities



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1. Background, objectives

The goal of nuclear power plant (NPP) maintenance is to allow nuclear operators to use all functions necessary for safe and reliable power production by keeping these functions available and reliable. In order to keep these functions provided by the systems available and reliable, the maintenance tasks have to be achieved on equipment/components related to the systems that are achieving the necessary functions. Plant maintenance includes the aspects of both safety and economy. Maintenance activities of safety systems as well as safety related items have the highest priority, and they are under regulatory control, while that of items not important to safety having influence, however, on plant availability are inevitable taking into consideration the production goals.

Maintenance activities in NPPs are traditionally performed during planned refueling and maintenance outages. Outages are always in the center of attention because they are the biggest reason of plant non-availability, and significant portion of operational & maintenance (O&M) budget has to be spent over this time. In the past one or two decades, significant changes in the electricity generation industry and the markets have been taken place. Privatization and market deregulation have led to a competition among plants and generation technologies. The business drivers are: safety, reliability and cost-effectiveness. This situation increasingly enforces plant and maintenance managers to reduce their O&M budget and sometimes also the number of their staff, to increase plant availability while continuously meeting the more and more rigorous safety requirements.

Although to different extent, the countries of the former Soviet Union known as Commonwealth of Independent States (CIS) and the Central and Eastern European Countries (CEEC) had gone through an economic transition and have still been facing with its consequences. Most of these countries operate Russian-type NPPs (primarily VVERs and RBMKs) the safety of which is under permanent debate. Only Slovenia and Romania has other than Russian design reactor in operation, i.e. a Westinghouse type PWR and a CANDU type RHWR, respectively. Due to the transition economy, these plants need to put more effort to cope with difficulties of the entire situation referred to above. NPPs in question and currently in operation are listed in Table 1 (IAEA, 2002).

The objectives of the current report are to collect and evaluate the available and applied maintenance methods at NPPs of acceding and candidate countries to the European Union (ACCs) as well as of the wider Europe (covering Russian Federation and Ukraine), and based on this evaluation, to identify areas for further collaboration with them. The framework of the collaboration may be the SENUF Working Group on NPP Maintenance. The content of the report relies on a brief survey on the current status of NPP maintenance in some of the plants of the countries referred to. Examples (usually on good practices) illustrating the major tendencies have been collected from Bulgaria (Kozloduy NPP), Czech Republic (both Dukovany and Temelin NPPs), Hungary (Paks NPP), Lithuania (Ignalina NPP), Romania (Cernavoda NPP), Russian Federation (Concern

Rosenergoatom), Slovakia (both Bohunice and Mochovce NPPs), Slovenia (Krsko NPP) and Ukraine (NNEGC Energoatom) from public literature and through TACIS projects experiences.

2. Overview of evolution of NPP maintenance approach

The approach to maintenance during the first and second generation of NPPs (regardless of plant origin) can be seen as somewhat erratic, with no common approach or consistency between different plant designs. Many maintenance activities were based upon the equipment/component manufacturers advice as well as some industrial experience, and were seldom based on the function of system and/or operation of component or linked to any safety cases or design codes. The maintenance programs were, therefore, largely based on conservative approach where many plant items have been over maintained. Until 1980s or so, many maintenance works were based on intrusive methods, and it was not unique to experience plant unavailability and outage program overrun due to post-maintenance defects. A significant portion of these defects was caused by maintenance induced human errors. Also, the historical reasons for the performance of specified maintenance tasks were usually poorly documented, if at all.

During the last two decades or so, the gradual penetration of the risk considerations into maintenance can be observed. Maintenance has a key role in controlling the risk caused by equipment/component failures or plant disturbances. The historically oldest approach is the corrective maintenance (CM), which still exists in the daily practice, mainly for non-critical components (non-critical means no or little contribution to risk). The CM approach, especially in case of critical components (critical means most contribution to risk, i.e. items important to safety), has been widely replaced later by the concept of the periodically scheduled, i.e. preventive maintenance (PM). Nowadays, risk-aware solutions have been offered to move away from the mostly time-based PM practice to strategies based on component condition, i.e. predictive maintenance (PdM) and associated risk (risk-informed maintenance, RIM). Condition based maintenance (CBM), reliability centered maintenance (RCM), risk informed in-service inspection (ISI) and maintenance can help to improve plant safety and reliability, and to optimize resources by ensuring that maintenance is focused on critical components. The main difference between the risk-informed methodologies and the CBM is that while the latter one is looking for the actual degradation (even in its early stage), the risk-informed approach concentrates to the degradation mechanism (Hüttner, 2000, Jovanovič, 2003,).

The basic approaches of NPP maintenance and some relationships among them are summarized in Fig. 1. It may be possible to identify a loose correlation between the maintenance approaches and the time if we consider the figure below as a co-ordinate system where the symbolic abscissa refers to the time.

A systematic activity to analyze and evaluate the effectiveness of an existing maintenance program, and to carry out modifications on it, in order to eliminate or decrease imbalance between maintenance requirements (legislative, technical,

economic, etc.) and resources used (staff, spares, tools, facilities, doses, etc.), called maintenance optimization, is going on in many utilities or NPPs. This process can lead to maintenance related decisions at various levels, i.e. related to the entire maintenance strategy, the organization of maintenance including the question of outsourcing, the selection of maintenance actions for individual components and the decisions on replacement of major components or even systems.

Outage optimization itself is a key issue, too, which has many options. Reduction in duration of planned outages can mean that more inspection and maintenance works are planned to be done while the plant is on-line. The advantages of the on-line maintenance are counterbalanced, however, that it can render equipment unavailability if needed, which requires a risk modeling and calculation.

3. Maintenance organization features in CIS and CEEC

Maintenance of Russian-type plants shows somewhat different way of the evolution process compared with plant maintenance in the Western world. Usually four (seldom two) units at the same site used to be planned to operate, and during the plant construction and commissioning period, large maintenance department as integrated part of the plant organization used to be established to cover all on-site maintenance related activities. The main reasons behind this approach were that, first, the plant supplier and the component manufacturers were not prepared for continuous service during the coming operation and, on the other hand, no Western type maintenance vendor companies existed in the "market". Thus, the maintenance department was dedicated to be prepared for regular maintenance and repair works and, moreover, for manufacturing spare parts, etc. As a consequence, the staffing of the maintenance department in these NPPs was three or four times larger than the world average. As it can be seen in Fig. 2 this tendency is still valid at the second half of the 1980s (IAEA, 1998).

The changes of the economic and political system occurred in the past decade in the region affected the electricity industry and, thus, the NPPs in the region, too. First, this process has had an influence on the size of the maintenance organization; in most cases the number of staff had to be reduced. In some plants, services of low impact on safety and/or production had been sold (e.g. transportation, housekeeping), in some other plants, only core maintenance competences remained under the plant control, and simple and repetitive services like insulation, scaffolding, radiological clothing laundry, and also those services requiring advanced professional knowledge like welding, non-destructive examination (NDE), computer service and operation, have been usually outsourced. In countries, where nuclear units are in operation at more than one site, there is nowadays one single state-owned utility does exist (Czech Republic, Russian Federation, Slovakia and Ukraine), and usually, a centralized maintenance management has been created in the headquarters of this utility. Maintenance documentations are also developed and issued at that level. For

example, in case of the Concern Rosenergoatom, the Russian utility, an institute of the concern named VNIIAES provides special support on operation and maintenance and prepares even plant maintenance programs. In case of sole plants (like the situation in Bulgaria, Hungary, Lithuania, Romania and Slovenia) the maintenance management is fully integrated into the plant structure.

Maintenance as a whole had been outsourced in the Czech NPPs, and establishing a long-term contractor's policy has become the strategic goal of the maintenance management in both Dukovany and Temelin plant. In case of the Temelin NPP, the situation is that some 65 long-term maintenance contracts cover about 95 % of maintenance works and, within this, 10 main contractors are responsible for around 80 % of the overall scope. The goal of the outsourcing strategy is to reduce cost and to enhance quality and timeliness, supporting by a strategy of building "alliance" with major contractors and sharing economic risk.

On the contrary, in Slovakia, NPP management relies on own maintenance capacity. In case of e.g. Bohunice NPP, the maintenance department is indeed able to provide services outside the plant (turbine and condenser repair at thermal power plants, commissioning tests at Mochovce NPP, reactor pressure vessel annealing at foreign NPPs, etc.). In Mochovce NPP, while contractors contribute to extend the plant's own capability, their major role is to provide technical assistance (manufacturers of the most important components).

The maintenance department is usually one of the main departments in the plant organizational structure and is independent from the production department. It used to include all disciplines (mechanical, electrical and I&C maintenance) and associated activities like service, warehouse, etc. In most of the cases surveillance and ISI/NDE related activities belong to it as well. A typical organization scheme, as an example of Krško NPP, is shown in Fig. 3 (IAEA, 2001). In Russia's Kalinin NPP, under the plant's chief engineer, there is a "cross-reference" organization, which means that each workshop is considered to be the owner of its specialist expertise and is, thus, held responsible for both operation and maintenance of the corresponding equipment.

Outage planning is usually, and logically, part of the operation department and represents an important interface between operation and maintenance planning.

NPPs have often experienced problems with the availability of spare parts due to technology development and/or many original suppliers no longer being in the business. Perenniality of the suppliers seems more critical than obsolescence of certain equipment. It is important, thus, in spare part management to be aware of the possible lack of spare parts and to find alternatives or initiate plant modifications.

4. Available methods of maintenance

The evolutionary process of NPP maintenance in CIS and CEEC are very similar to that has occurred in Western plants. As a consequence of this, within the distribution of the various maintenance approaches or strategies, the time based (interval or running hours based) PM and of course the CM are

dominating. Perhaps, due to the large number of NPPs of the same type (VVER-440s, VVER-1000s or RBMKs), reliance on manufacturers' recommendations seems to be much stronger, and somewhat moving away from this approach could be recognized only after the early or mid 90s.

Condition monitoring to support introduction of PdM has been applied in many plants but its full acceptance by plant or maintenance management is still awaited. The most widely used periodic condition monitoring methods (among others in Bohunice NPP, Mochovce NPP, Paks NPP) are:

- Vibration monitoring of rotating equipment (pumps, motors, turbines). It is sometimes performed continuously on main circulating pumps or steam turbines.
- Diagnostics of air operated or motor operated valves performance (e.g. MOVATS or equivalent system).
- Infrared thermographic monitoring of bearings, motors, electrical connections, conductors.
- Oil analysis on the oil system of turbines, generators, transformers, diesel engines, hydraulic systems (e.g. by means of gas chromatography). Also wear debris analysis and ferrography used to apply to determine component wear.
- Endoscopic visual inspection of turbine rotors (without opening the turbine houses).

In a broad sense, ISI and operational surveillance are pertaining to maintenance. They are, consequently, inherent parts of periodic monitoring of component condition in each NPP. The wall thickness measurements by ultrasound of the secondary circuit pipelines and associated calculation of erosion/corrosion degradation became part of the ISI program in many plants.

Among on-line condition monitoring, leak detection methods have gained the broadest application. The main reason of this is that the leak-before-break (LBB) concept in the safety evaluation of passive systems (primarily in case of high energy pipes) has received more and more consideration as an alternative criterion, and introduction of LBB concept requires more than one (usually three) independent monitoring systems working on different physical principles. LBB concept is fully implemented in the Bulgarian, Czech and Slovakian VVER-440 NPPs as well as at Temelin NPP (VVER-1000) and partially in some other plants, and leak detection systems based on monitoring acoustic signals, air humidity and radioactivity have been installed.

Other continuous monitoring systems such as loose part monitoring, reactor vibration and noise monitoring, fatigue monitoring are quite widely spread, too. Table 2 shows the current status for VVER NPPs, at the countries of CIS. Majority of these on-line techniques have been delivered and installed in the frame of either TACIS or bilateral assistance projects.

Equipment of the plants with those systems in CEEC gives a better picture: NPPs in Czech Republic, Hungary and Slovakia have the full set of these

systems. The operational parameters (pressure, temperature, mass flow) are included into the scope of monitoring, moreover, fatigue monitoring system has also been installed in some of these nuclear units. Fig. 4 shows the configuration of the on-line monitoring systems being installed at Mochovce NPP (IAEA, 2003).

RCM is used as pilot application in selected systems of a few plants as a result of an ongoing PHARE project (PHARE, 2000). In Dukovany NPP, RCM analysis was completed on the unit 3 feed water system and continued on the condensate system. In Bohunice NPP, the diesel generators of units 3 and 4 were selected to optimize maintenance strategy and test to RCM applicability. In Mochovce NPP, maintenance engineers have been trained to prepare potential future RCM applications.

Risk informed approach of maintenance has been in stage of consideration. A pilot project to introduce risk-informed ISI to replace the prescriptive program on selected pipelines is going on at the Czech Republic. No on-line maintenance is applied.

In the daily execution of maintenance, work break down and work order systems are quite well developed and do function. Quality assurance of maintenance works and evaluation/assessment of activities against targets (both plant and maintenance targets) tend to be an inherent parts of the entire maintenance. In Ignalina NPP, for example, a comprehensive self-assessment system has been successfully applied. Quality of maintenance tasks completed during outage is evaluated using the results of post-maintenance tests (preliminary assessment, 48 or 72 hours after maintenance completion) and supervised operation period (final assessment, 30 days after post-maintenance test). This assessment can be and is used for evaluation of the maintenance organization and the contractors.

For an effective plant operation and maintenance, computer-aided information management systems are inevitable, in general. It has been recognized and more and more plant introduces integrated management systems. Within such a system, the modules for maintenance management are essential. These modules may support work planning, tagging, maintenance history, malfunction/event reporting, storing and listing of documentation, task scheduling, outage planning, radioactive dose planning, training and qualification updating, spare part management, cost control, etc. Any system works efficiently, however, only if there is a high quality database and plant staff is trained properly.

Training of maintenance personnel receives more and more emphasis. The methodology of training is under change: the systematic approach to training (SAT) is replacing the conventional method of training, which was usually based on the technical information provided by the manufacturer in the equipment/component documentation. SAT is an approach that provides a logical progression from the identification of the competences required to perform a job in an operating NPP, to the design, development and implementation of appropriate training to acquire the necessary competences, and subsequent

evaluation of this training. Specific maintenance training centers, as part of the training setting, recommended by the SAT have been built to facilitate training. Dedicated assistance projects (PHARE, 1992, TACIS, 1993 and 1994) contributed to establishment of the maintenance training centers at Paks NPP, Zaporozhe NPP and Novovoronezh NPP, which all are used to train contractor personnel as well. The maintenance training facility at Paks is unique from that point of view that it has been equipped by original primary circuit components including reactor pressure vessel, internals, main cooling pump, main gate valve and steam generator of the VVER-440 technology. Fig. 5 shows the reactor internals in the training center's "reactor hall".

5. Current maintenance challenges

The challenges NPPs in CIS and CEEC face today do not really differ from those facing the Western plants. These basically are the following:

- Safe and reliable plant operation,
- Outage duration reduction,
- Reduction of maintenance costs, in general.

To meet these challenges the enhancement of maintenance performance, and in some cases a complex optimization of the maintenance program are taking place. In Cernavoda NPP, a Maintenance Enhancement Project is under progress, which is based on the EPRI recommendations and methodology (EPRI, 1998). The cost-effective streamlined version of the methodology covers the following:

- Identification of key components of critical systems and creation of a database.
- Composition of equipment/component groups by type and technical characteristics.
- Expert panel for each type of equipment/component for reviewing PM tasks and intervals.
- Summary of the expert panel recommendations.
- Review of the maintenance procedures accordingly.

The EPRI based approach to optimizing maintenance program has been used in Krško NPP, too. Here, all the systems' functions have been analyzed according to their safety as well as production significance (critical and non-critical equipment/components), and the corresponding maintenance actions were defined accordingly. Also PdM group with multi-discipline teams as equipment "owners" has been established. For assessing maintenance effectiveness, Maintenance Rule is followed (CFR, 1998, US NRC, 1997).

The objectives of the maintenance optimization project currently under implementation in Dukovany NPP have included the following:

- Introduction of a differentiated approach to maintenance based on component significance.
- Increased use of PdM at the expense of time-based PM.
- Change from PM to CM in case of functionally and economically 'insignificant' equipment/components.
- Optimization of PM cycles and extent.
- Involvement of operations staff in maintaining and monitoring equipment technical condition.

The optimization projects sometimes have an interface with the plant's overall life management program. Today, almost all plants in question have an explicit policy to extend their service life, thus, component ageing management, modernization and refurbishment actions became much more important. Since carrying out of plant modifications, including cyclic replacement of obsolete I&C components or in extreme case a steam generator replacement, is a permanent task, it can provide a solid work load to maintenance departments. Also these big reconstructions are completed during outage periods and sometimes are even incorporated into a normal outage schedule.

In case of units 3 and 4 of the Bohunice NPP, the main goals of the modernization program are to increase the nuclear safety on higher level according to the newest standard issued by the Slovak Regulatory Authority as well as International Atomic Energy Agency (IAEA) recommendations, and to create preconditions allowing extension of the service life to 40 years in compliance with the national energy policy. The ongoing program deal with the safety issues identified and prioritized by the IAEA.

The Kozloduy NPP has also a safety enhancement and service life optimization program for the units 5 and 6. The goal of the program is to operate the units 15 to 20 years beyond their design life. One of the fundamental part of this program is a 10-year maintenance schedule, which is based on a long-term strategy concerning original design components like reactor pressure vessels, main coolant pumps, steam generators, turbine and electric generators, and the most important electric and I&C systems (e.g. reactor protection). This schedule defines priorities and co-ordinates the maintenance activities. Also important part of the program is the monitoring and analyzing the status of technological systems carried out by operations, maintenance and engineering department staff. Specific ageing management program was developed and being implemented by and expert group under the leadership of operations department during outages. Based on the assessment and evaluation of I&C system reliability and related ageing research, some systems or typical components were selected as a subject of replacement.

Hungary's Paks NPP has decided to follow the American way of license renewal when preparing its own life management strategy. It was identified that the following four major areas have to be managed successfully in the technical justification of the long-term operation:

- 1) Reconstitution of design basis information;

- 2) Implementation of a new regulation for monitoring of maintenance effectiveness, similar to the 10 CFR 50.65 see CFR (1998);
- 3) Completion of environmental qualification for electrical and I&C equipment;
- 4) Introduction of a systematic ageing management program.

The effectiveness of maintenance activities will be evaluated and controlled according to their safety and performance criteria. A complementary measure includes the optimization of the existing ISI program as well, which both inspection qualification and risk-informed ISI will play a role. It has to be noted that the aforementioned tasks do need serious considerations even in case of operating the plant “only” until the design life.

Outage planning and optimization are emerging issues as well. As it was mentioned in the introduction, outages are the biggest reason not to produce electricity and thus the outage lengths may show a correlation with the energy availability figures of the plants. In Fig. 6, which summarizes the energy availability factors in the CIS and CEEC over the past decade, remarkable differences can be seen among different countries.

6. Conclusions, recommendations

The general tendencies of the NPP maintenance evolution process and of the selected approaches as well as the currently applied methodologies in the countries of CIS and CEEC do not differ fundamentally from those in the Western countries and NPPs. The situation and the level of the maintenance activities, however, are strongly affected by the fact that the determining tendencies occurring within the electricity industry and the selling market have found a much less developed basic infrastructure and serious shortage of funds in these countries. The “environmental” conditions thus among which plant and maintenance managers have to meet these challenges are much harsher. Since the countries have still not overcome this situation the further assistance seems quite obvious.

The maintenance approaches followed are not quite homogenous, which can be explained by the differences among countries in size or development of economy however they vary sometimes in countries with very similar circumstances. The maintenance outsourcing policy is e.g. completely different in the Czech Republic and Hungary.

Introduction of condition monitoring to support CBM is on the right way, the effective use of PdM, based on monitoring results, is however still to come. This situation shows similarity with the implementation of the CBM in the Western NPPs, i.e. the maintenance managers have some reluctance to change procedures and seem to be resistance to take the risk of investing into new technology and rather wait for experiences. Other advanced methods like RCM or risk-informed ISI and maintenance are under early stage (some pilot applications or only considerations).

Each country has been motivated to improve or optimize its NPP maintenance activity. The scopes of the ongoing projects are different. It is recommended to move into this area and assess the merits and limits of the different ways to help the countries in the region to find the most cost-effective one. Also sharing resources can facilitate to achieve maintenance objectives. It is recommended to try to find the areas where it can work. The most obvious example is sharing of information, which could be done in form of databases.

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Table 1: NPPs currently in operation in CIS and CEEC

Country	NPP	Reactor type	Commercial operation
Armenia	Metsamor-2	VVER-440/270	1980
Bulgaria	Kozloduy-3	VVER-440/230 advanced	1981
	Kozloduy-4	VVER-440/230 advanced	1982
	Kozloduy-5	VVER-1000/320	1988
	Kozloduy-6	VVER-1000/320	1993
Czech Republic	Dukovany-1	VVER-440/213	1985
	Dukovany-2	VVER-440/213	1986
	Dukovany-3	VVER-440/213	1986
	Dukovany-4	VVER-440/213	1987
	Temelin-1	VVER-1000/320	2001
	Temelin-2	VVER-1000/320	2002
Hungary	Paks-1	VVER-440/213	1983
	Paks-2	VVER-440/213	1984
	Paks-3	VVER-440/213	1985
	Paks-4	VVER-440/213	1986
Lithuania	Ignalina-1	RBMK-1500	1984
	Ignalina-2	RBMK-1500	1987
Romania	Cernavoda-1	CANDU-6	1996
Russian Federation	Balakovo-1	VVER-1000/320	1986
	Balakovo-2	VVER-1000/320	1988
	Balakovo-3	VVER-1000/320	1989
	Balakovo-4	VVER-1000/320	1993
	Kalinin-1	VVER-1000/338	1985
	Kalinin-2	VVER-1000/338	1987
	Kola-1	VVER-440/230	1973
	Kola-2	VVER-440/230	1975
	Kola-3	VVER-440/213	1982
	Kola-4	VVER-440/213	1984
	Kursk-1	RBMK-1000	1977
	Kursk-2	RBMK-1000	1979
	Kursk-3	RBMK-1000	1984
	Kursk-4	RBMK-1000	1986
	Leningrad-1	RBMK-1000	1974
	Leningrad-2	RBMK-1000	1976
	Leningrad-3	RBMK-1000	1980
	Leningrad-4	RBMK-1000	1981
	Novovoronezh-3	VVER-440/230	1972
	Novovoronezh-4	VVER-440/230	1973
	Novovoronezh-5	VVER-1000/187	1981
	Rostov-1	VVER-1000/320	2001
	Smolensk-1	RBMK-1000	1983
	Smolensk-2	RBMK-1000	1985
	Smolensk-3	RBMK-1000	1990
Slovakia	Bohunice-1	VVER-440/230	1980
	Bohunice-2	VVER-440/230	1981
	Bohunice-3	VVER-440/213	1985
	Bohunice-4	VVER-440/213	1985
	Mochovce-1	VVER-440/213	1998
	Mochovce-2	VVER-440/213	1999

Country	NPP	Reactor type	Commercial operation
Slovenia	Krsko	PWR (Westinghouse)	1983
Ukraine	Khmelnitski-1	VVER-1000/320	1988
	Rovno-1	VVER-440/213	1981
	Rovno-2	VVER-440/213	1982
	Rovno-3	VVER-1000/320	1989
	South Ukraine-1	VVER-1000/302	1983
	South Ukraine-2	VVER-1000/338	1985
	South Ukraine-3	VVER-1000/320	1989
	Zaporozhe-1	VVER-1000/320	1985
	Zaporozhe-2	VVER-1000/320	1986
	Zaporozhe-3	VVER-1000/320	1987
	Zaporozhe-4	VVER-1000/320	1988
	Zaporozhe-5	VVER-1000/320	1989
	Zaporozhe-6	VVER-1000/320	1996