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Knowledge Management Aspects in Nuclear Energy

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Abstract. Nuclear knowledge is a fundamental national resource. It is known that knowledge is divided into manifest and implicit. Explicit knowledge is described in the current documents, and implicit knowledge is all important practical, logical, causal knowledge of the operation, maintenance and repair of NPP. They are invaluable because they provide secure and trouble-free operation of the plant and economic prosperity. The bearer of this implicit knowledge are the people – the staff in the NPP. Good practices suggest that this knowledge is extracted, classified, stored and passed on to future generations of energizers. To lose the link between the accumulated own operating experience and the training of young staff means that there is no safe and secure operation of the NPP.

This paper discusses the systematic approach to knowledge management in nuclear energy and specifically its application to knowledge about ageing equipment in the NPP. Criteria for key competencies in the field of ageing management are defined. Processes for capturing, preserving and transferring knowledge are discussed.

Keywords: nuclear power plant, nuclear knowledge, ageing management

1 Introduction

At the beginning of 2024, activities on the construction of new nuclear capacities of Kozloduy NPP, using AP-1000 reactor technology, are undertaken in the Republic of Bulgaria. These capacities are new compared to WWER units. One of the most important conditions for the construction and further development of the nuclear industry is the availability of Bulgarian, trained and competent specialists. Training takes place in technical and physical faculties, but awareness and competencies come with practice. Nuclear knowledge is a fundamental national resource. Without engineering and technical personnel who have a good understanding of the principles of operation of a nuclear unit, to know the possible deviations from the norms of operation and to realize the consequences of an accident, it is impossible to operate and maintain the NPP. Practical operation provides the best lessons for every aspect of service, in all design modes of the block operation. Each work team (shift, brigade) accumulates knowledge that helps it cope with the difficult tasks of daily activities. The specifics of tasks and, accordingly, of the technological and practical skills is very large. Examples much can be given; classically, the order for the implementation of activities in the controlled area of the NPP is so organized that the dose load on the personnel is as small as possible. The knowledge here concerns the coordination of activities between the different structural teams, work on assignment, provision of safety measures, admission to the work site, distribution of activities of perpetrators and observers, efficiency of the work team, activities to be carried out according to the technological regulation of the block and written working procedures, completion of the work, verification of results, records, storage. During my long work experience in the operation of the NPP, I have observed how some brigades always carry out their work in a shorter time than other brigades. My explanation is that the foremen well organize the work process, knowing the nature of the work, the capabilities of each member of the work team in purely human terms, the geography of the area, the access to the sites, the radio load. But this is my opinions, and probably each foreman would give a different explanation for his organization of work. These specific skills represent valuable knowledge, accumulated operational experience, which should be passed on, to the younger generations and applied to new nuclear power plants in order to safely exploit them.

In nuclear energy, knowledge is divided into overt and hidden. Explicit knowledge is that which is subject to norms, regulations, procedures, instructions, methodologies and working cards. Hidden knowledge is all other important skills not recorded in controlled or working documents. A logical "path" of knowledge is presented in Figure 1.

2 Systematic Approach to Knowledge in Nuclear Energy

The principles of a systematic approach to knowledge management are [1]:

- Identification of key competencies;
- Develop effective mechanisms for capturing, preserving and transferring explicit and hidden knowledge;
- Minimizing the risk of knowledge loss;

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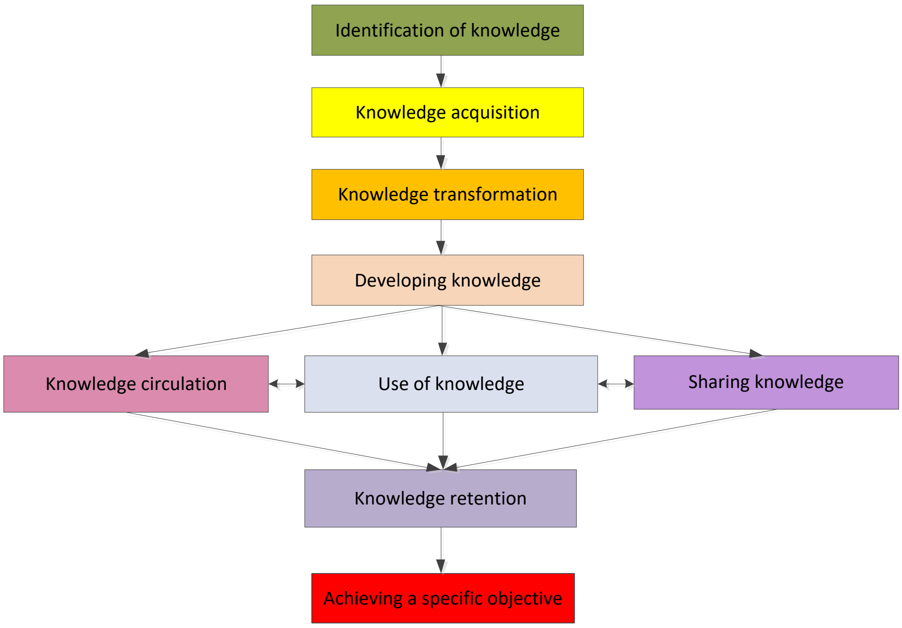

Figure 1. “The path” of Knowledge.

- Mechanisms for the development of young staff;
- Promote a culture of knowledge management.

This systematic approach is applied to the knowledge of: (1) The operation of the NPP; (2) Maintenance and repair. However, knowledge management at the Extension of Life stage of the NPP has not yet been developed. The design life of nuclear power plants is 30–40 years and most of them are at the end of their design term. According to the International Atomic Energy Agency (IAEA), out of a total of 413 reactors in operation worldwide, 282 have been operating for more than 30 years [2]. Knowledge of a causal link to the state of materials, especially at the end of the life of the nuclear power plant will allow safe operation of the plants, scientifically justified extension of their service life (up to 60÷80 years), economic profitability in the production of electricity, meeting the expectations of societies for safe and economically advantageous electrical production and assigning nuclear energy to the directive on “green energies” of humanity.

The presentation of the article below covers the implementation of the systematic approach to knowledge management in NPP.

3 Development of Criteria for Key Competencies

The identification of key knowledge (competencies) should be based on criteria, some of them are listed below.

3.1 Knowledge related to the importance of equipment for the safe operation of nuclear power plants

Safe operation is a basic management policy of the NPP. Any deviations of the operating parameters from the limits laid down in the technological regulation are classified according to the IAEA scale [3]. Knowledge about the safe operation of NPPs and to deal with safety deviations that have occurred can be evaluated by weight factors, Table 1.

Table 1. Criteria for weight factors of knowledge for safe operation of NPP and for activities in deviations, incidents, accidents

Knowledge for:	Weighting factor, value			
	Equipment of safety systems	Equipment of systems important for safety	Second-loop equipment	Other equipment
Accident-free operation for a given period	High	High	High	Low
Deviation	High	High	Medium	Low
Incidents	High	High	Medium	Medium
Accident	High	High	High	Medium

In this sense, each NPP could produce its own rating of the importance of the knowledge to be managed.

3.2 Knowledge related to mechanisms of degradation of mechanical properties of metal

After several decades of operation of a nuclear unit, changes in the mechanical properties of the equipment occur, or in other words – the equipment ages under the influence of operating conditions and operating loads. The facilities in the NPP operate in the conditions of high temperatures and hydraulic effects of fluids, variable loads, radiation environment, corrosion-erosion wear. The degradation mechanisms are neutron and thermal embrittlement, fatigue, corrosion-erosion wear, export in friction [4–6].

Is it important for the personnel operating or servicing a facility to know these mechanisms to understand the importance of ageing? For example, in each routine startup of a nuclear unit after a scheduled annual repair, the operating personnel carry out a series of activities. The automated reactor control systems are actuated, the hydraulic loading of the unit begins, the fluid temperature by the primary circuit rises; as required by the technological regulation - with an average speed not higher than 20°/hour. But sometimes the startup fails and the unit "collapses" before a minimum level of controllable power is reached. After the expiration of technological time, the start-up actions begin again. Staff shall keep operational journals in which activities are recorded. Practice shows – it has been recorded (in past years) that a successful launch of the block has been carried out. So! Neither line was recorded for the number of realized loads on the block. The number of loads, however, is decisive for the resource of the metal by criterion fatigue resistance. Thus, information on the actual number of worked load cycles has been lost over the years. Of course, performing the tired analysis is not within the competence of operatives. Their job is to safely operate the block, follow written instructions. The instructions are developed by competent specialists with engineering education, who worked in an operational unit.

Nowadays, the situation is quite different, there is a lot of accumulated and rethought specific knowledge on the ageing of metals. By the way, the number of load cycles is reported by software additionally introduced as an overdesign system for the unit; the influence of the human factor is eliminated.

From personal experience, I can say that every NPP ages differently. There are different national approaches to ageing management [7]. In order to ensure successful exploitation in the future, it is necessary that knowledge of the mechanisms of ageing in one's own nuclear power plant is accumulated, assimilated by staff and transmitted, both within the plant and as an information exchange with other countries.

3.3 Knowledge relating to the operation of equipment with defects

Under the influence of the loads and during the prolonged operation of components, systems and structures (CSSs) in the NPP, a change in the mechanical properties of the metal occurs. Areas of potential risk for fracture are formed, and under the influence of operational loads defects increase in size and can be indicated by the methods of nondestructive testing of the metal [8–22]. Examples of such zones are reactor vessel welded joints, welded joints of main circulation piping, steam generator heat exchanger tubes, etc. Defects in the metal of equipment are divided into permissible and inadmissible [12]. The presence of incompleteness in the structure lowers the bearing capacity of the structures.

Knowledge of this criterion can be (conditionally) divided into two main groups:

- Knowledge on the operation of CSSs with defects (or "monitored equipment"). It is assumed that in the operation of these CSSs some operating parameters should be adjusted, in a way that spares the resource - for example - to provide a lower pressure in some mode of the unit;

- Knowledge of maintenance, control and diagnostics of CSSs. The knowledge of defects, their location and the follow-up of development trends under the influence of operating conditions constitutes very valuable knowledge. It must necessarily evolve by accumulating data on defects, their behaviour over the years of operation (change in number, growth of size or area, direction of increase). The difficulties here are related to several problems:

  - Some equipment is not "defectoscope"; the control object (testing, monotoring) is difficult to access for direct observation or for the deployment of sensors, probes or telescopic systems;

  - In order to trace the trend of development of already found incompleteness in the metal, its coordinates must be clear and confirmed in the next operational control after 1÷6 years.

Below is an example of the tracking of the registered incompleteness (defects) in the metal of a pressurizer (P) during the years of operation of the NPP. After conducting the NDT at the established main critical locations and elements of the P, the location of the defects and their dimensions are found, Figure 2.

In Figure 2 it is observed that in 2000 there were 19 indications of defects from ultrasonic control, their dimensions being up to 150 units. In 2012, there were 36 indications of defects with sizes up to 380 units. Defects propagate to the interior of the seam and can only be manifested and controlled with an ultrasonic method.

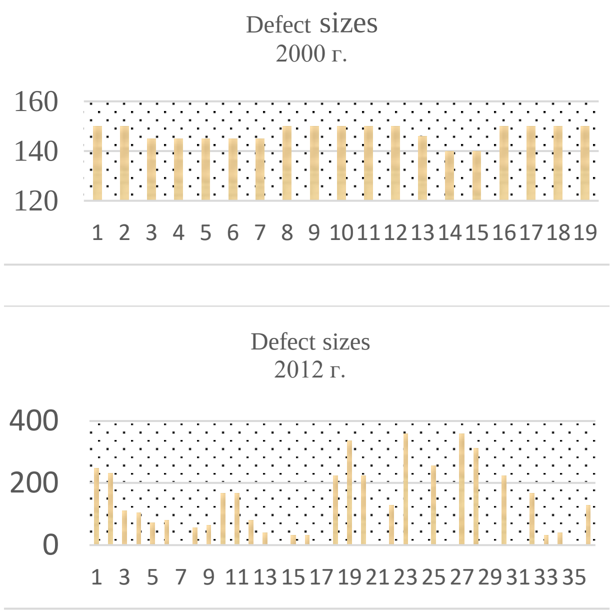

Figure 2. Comparative analysis of the development of incompleteness in the metal of welded joint "XX" of the pressurizer.

A summary of the present criterion for key knowledge related to the operation of equipment with defects is given in Table 2.

3.4 Knowledge on ageing equipment management

The study of materials demolition processes in a nuclear power plant is extremely important because knowledge of the causes and mechanisms of demolition leads to an increase in the reliability of nuclear power plants. Variable

Table 2. Knowledge relating to the operation of equipment with defects

Established state of the KSK	**Knowledge for:**	
Equipment without critical areas and defects	Operation by Technology Regulation	Maintenance and Repair by Technology Regulation
Equipment with defects	Operation Operating load parameters in a resource-wasting mode (if possible).	Maintenance and Repair Reduce the period between consecutive controls (trial) / or increase the frequency. Application of qualified control (testing) procedures [23]. Study of changes in defects or mechanical properties of metal.

thermo-hydraulic loads, radiation effects and aggressive working environment contribute to the natural ageing of materials. The technological reasons for demolition are the degradation of mechanical properties of the metal during the operation of NPP. The description of the critical areas in the sites to be assessed shall be based on:

- The assessment of the current physical condition of the site;
- Results of previous ageing management activities, strength analyses;
- Defect and failure data for the site (operation history);
- Knowledge of typical ageing management mechanisms in NPPs.

Knowledge management on ageing must follow a logical path:

Degradation mechanisms → Manifestation of mechanisms → Ageing effects → Test methods for objects to be sensitive to these methods.

A specific description of knowledge management activities are presented in Tables 3–6.

Table 3. Preventive measures to minimize and control ageing

Degradation Mechanism, code	**Description of the mechanisms**	**Description of Ageing effects**	**Indicators of ageing effects**	**Methods of control/ monitoring**	**Input data required**	**Indicator Data Flow**
				Procedure for: operation, maintenance, monitoring, control, testing methodology Period between monitoring, control and testing Responsibilities Data	For indicator xx What data (data type)? Where they are collected, systematized and stored? Intervals between data input, Responsibilities	Input requirements What? By whom? Output requirements What? By whom?

Table 4. Monitoring of ageing effects

From Table 3.	**Data**	**Methods of analyses**	**Ageing effect trend**
	Type 1 data Type 2 data	Type 1 Data Analysis Methods Type 2 Data Analysis Methods	Trend of data type 1 Trend of data type 2 General trend (rate)

Table 5. Activities to reduce ageing effects

From Tables 3, 4	**Activities to reduce the effects of ageing**
	Exploitation (programme, responsibilities, activities, data, data storage) Maintenance, monitoring, control (program, responsibilities, activities, data, data storage) Replacement

Table 6. Acceptance criteria and corrective activities

From Tables 3, 4, 5	**Acceptance criteria**	**Fulfilment of acceptance criteria**	**Corrective activities**	**Defects / Failures Data base**
	Criteria concerning exploitation Criteria concerning maintenance, monitoring and control	Fulfilment of acceptance criteria concerning exploitation Fulfilment of acceptance criteria concerning maintenance, monitoring and control	Activities concerning exploitation Maintenance, monitoring, control activities Repair Replacement	

4 Knowledge for Accumulation of Data on Ageing

My observations on the topic of data accumulation for ageing management in NPPs in different countries shows that there are two main ways to develop knowledge:

- Extension of tests (control) of CSSs sites;
- Introduction of software modules that will predict the future state of the equipment metal.

4.1 First way – extension of tests (control) of objects

In the technological regulation of the NPP are prescribed the volumes of the controlled equipment and the methods for control (testing) of the condition of the metal. The extension of the control (tests) can be in two directions:

- Increase in the volume of controlled equipment compared to that required by the technological regulation. For example, it turns out that the polar crane and the refueling machine (equipment used to refuel nuclear fuel in the reactor) are not controlled (tested) at all during the entire service life of the plant, because this is not required by the technological regulation. The regulation is prepared by the manufacturer of the unit and is made available to the owner of the NPP at the time of delivery of the equipment. For most power plants in Central and Eastern Europe, this period is 40 years old. Since then, there has been accumulated knowledge about ageing mechanisms for these specific facilities, an understanding of the need to perform periodic control (testing), an awareness of the danger of a possible accident.
- Increase the sensitivity of the control (test). On the one hand – the increased permittivity of the apparatus is in the priority of the manufacturing companies and is not the subject of discussion in this publication; on the other hand – more thorough controls should be applied to systems important for safety.

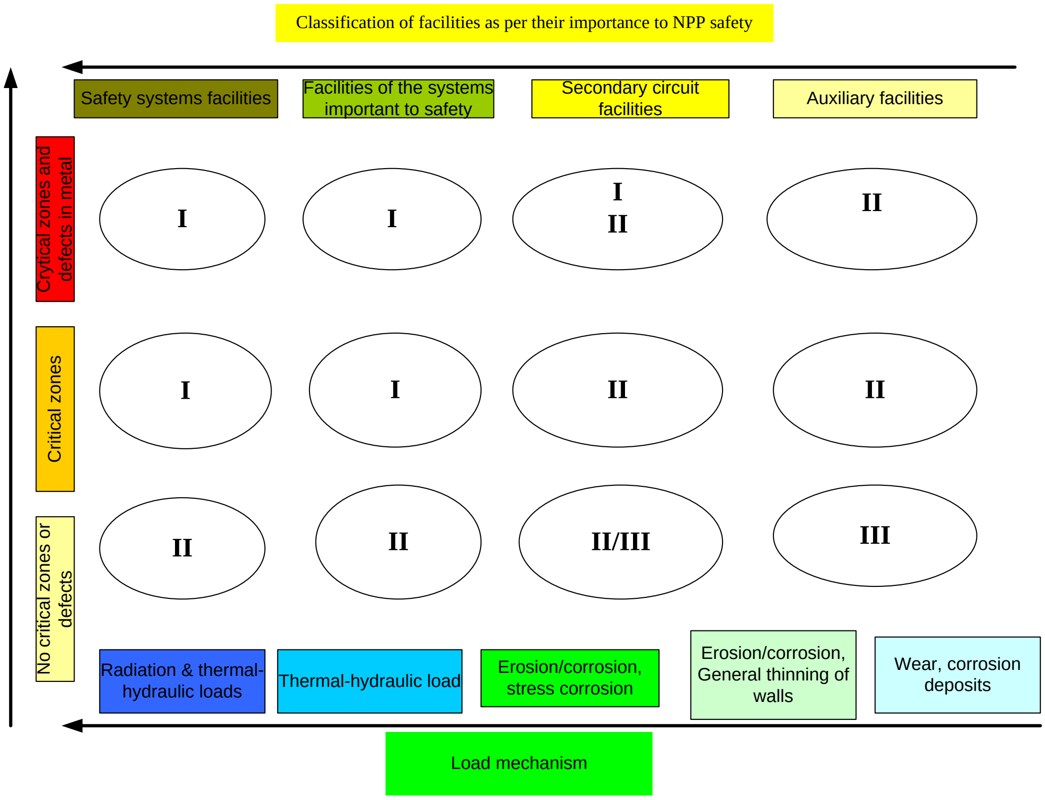

Figure 3. Categorization of control, according to the importance of the facilities for the safe operation of the equipment and the mechanisms of loading.

Figure 3 presents a categorization of the control according to the importance of the facilities for the safe operation of the equipment and the load mechanisms.

Control (test) first level (I) is conducted by qualified control procedures, [23]. Control (testing) second level (II) is carried out according to written procedures, with metrologically verified technical means, with high resolution, and by certified personnel, [8], periodicity of control – no more than 4 years. Control (testing) third level (III) is carried out according to written procedures, with metrologically checked technical means and by certified personnel, and the periodicity of control is 6–12 years.

4.2 Second way – using software products

Software products are developed and put into operation in order to effectively manage the ageing of equipment in the NPP. In general, the tasks set by the use of such software are: (1) Minimizing human interference in processes and hence preventing unintentional human error; (2) Calculation of the parameters of the resource characteristics in an operational order; (3) Management of inspection (testing) data; (4) Easy and quick access to important information by using filters and access rights.

5 Capture, Preserve and Transfer the Explicit and Hidden Knowledge of Ageing

Projects aiming at mechanisms for the capture, preservation and transfer of knowledge are being implemented in the different NPPs. Within the IAEA BUL 009/01 project "Manpower Management and the Risk of Nuclear Knowledge Loss" a methodology for identifying and capturing hidden knowledge, tools for realizing the methodology and an internal system for monitoring implicit knowledge has been developed at Kozloduy NPP, Figure 4 [1].

Another CORONA project [24] envisages the creation of a base for education and qualification of VVER technology personnel, unification of existing training schemes; preservation and transfer of nuclear knowledge, application of the European Credit System for Vocational Training and Qualification (ECVET). Kozloduy NPP is also involved in this project.

And what is the application of such a systematic approach to the knowledge about the ageing processes of equipment in NPPs?

Explicit knowledge is:

- The mechanisms of degradation of mechanical properties [4, 5]. The problem here is that each mechanism has been studied only at the laboratory level, without considering the synergistic effect of the interaction of several mechanisms.

- Methods of control (testing), most of them are standardized.

Implicit knowledge (or part of it) is:

- How to determine the influencing mechanisms of ageing of an object. Knowledge extraction can be realized by summarizing the failures and incompleteness (defects in the metal) found for the object.

Figure 4. Information system for monitoring implicit knowledge, AEC Kozloduy.

After 30-40 years of operation, sufficient data on failures and defects are accumulated.

- The processes of conducting the control (test) of the metal in hard-to-reach places. An example of such places are welded joints of equipment located in geometrically complex objects (pockets) – or the so-called "non-defectoscopic" objects. An additional difficulty is represented by the high radiation background at these locations. In the control working documents (instructions, methodologies, procedures, working / technological maps) should be described quite accurately and in detail the way of conducting the control (test) – adjusting the equipment, approach to the object, providing illumination, checking whether the surface has been cleaned to a metallic brilliance, the way the probe (sensor, sensor), benchmark points, duration of the test / measurement, influencing factors, such as probe clamping force, surface roughness, etc.

The exact determination of the coordinates of a given incompleteness. In order to trace the trend of change in already identified incompleteness, its location must be accurately determined and these coordinates confirmed at each subsequent control (test). In some cases, the indication of large incompleteness is defined (detected) as two smaller incompleteness in subsequent control (after 1÷4 years). It is necessary to give in the records of the control (test) detailed descriptions of the area of registered incompleteness, length, coordinates, available benchmark points that will not change in subsequent control, adjustment of the sensitivity of the apparatus.

- The technical diagnostics of the facilities.

Unin-depth knowledge is:

- The complex impact of various ageing mechanisms. For example – the metal of the nuclear block shell is subjected to neutron and thermal ageing, intergranular corrosion, fatigue, wear, embrittlement due to defects in the metal [25].
- Accurate physical-mathematical models for the evaluation of resource characteristics. An example is the neutron and thermal ageing formulae of the reactor vessel metal, which are often changed, due to the many models of research on the specimen-witnesses from the scientific institutes in Russia, Japan, Czech Republic, USA.
- The trends of change in the mechanical and physico-chemical properties of the metal of equipment.

6 Conclusions

The accumulation of knowledge about the ageing of the NPP is undeniably an important factor for the safe and costeffective operation of the plant. The benefits of the acquired knowledge are ensuring reliable operation of the equipment, without failures and emergency situations of the equipment, prevention of incidents and accidents of the nuclear unit, avoidance of economic losses from the downtime of nuclear facilities, trouble-free extension of the service life over the design for the units.

In this context, knowledge management should be part of the management policy of the NPP. In addition to the generally established mechanisms of degradation of mechanical properties, each nuclear power plant ages in its own way. Therefore, it is important to define and develop the criteria for key knowledge, to accumulate data on this knowledge, to develop it. This process must continue while the plant is in operation to ensure its safe operation and the future of nuclear energy in the country.

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