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"Rest-Lifetime Evaluation of Equipment and Facilities of NPP Kozloduy 3&4 and Development of an Ageing Management Program"

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Summary

Since the liberalization of the European energy market, more and more demands have been voiced that nuclear power plants meet uniform safety standards. A basis of such European standards has been formulated by the IAEA in guidelines generated by international specialists. Starting from this basis, nuclear power plant operators—including Kozloduy NPP (KNPP)—have intensified efforts to adapt their plants in line with the western safety philosophy, in some cases by implementing extensive upgrading measures. Beginning with the WANO 6-Month Program, KNPP was in a position to have essential components of its VVER 440/230 plant Kozloduy 2 reviewed using standard western techniques as early as 1992. In the years that followed, the same components of the other KNPP VVER 440 plants were also evaluated. All units were upgraded in line with these safety analyses.

Over the years the plant operator KNPP cultivated the idea to not only upgrade individual aspects of his plants pertinent to safety, but instead to enhance the safety level of all components and systems relevant for safety. This approach involved various exemplary and innovative efforts, serving as a model for pioneering a new culture of safety (essentially creating a new VVER 440 reactor design). Upgrading that involves a tailored aging management program is in the interest of industrial plants as they age. The plant safety can be kept at a high level over the planned service life of the plant and even beyond. At the same time, it is also legitimate to expect economic advantages resulting from higher reliability and availability.

The task indicated in the title is part of a comprehensive upgrading program for Units 3 and 4 of the Kozloduy plant executed in a Consortium between Framatome ANP (a Framatome and Siemens company) and the Russian company Atomstroyexport. It comprises an evaluation of the residual service life of components/systems/plants subject to acceptance by international experts, identifying the need for further investigations/calculations in certain cases, and finding solutions for improvements that achieve a consensus of safety and economy. The initial results are:

- Walkdowns revealed no clear knock-out point for the plants, however there are preliminary hints for necessary further improvements.
- Investigations of templates taken from the RPV of Unit 1 were started: the results are still preliminary, but can be considered very positive; their transfer to the RPV of Unit 3 would mean that the latest safety analyses of the Unit 3 RPV are conservative.
- The general work program was successfully applied on the batteries as a pattern for the electrical equipment: parameters for the computer database and proposals for an effective aging management program were addressed.

1. Background

Since the liberalization of the European energy market, more and more demands have been voiced that nuclear power plants meet uniform safety standards. A basis of such European standards has been formulated by the IAEA in guidelines generated by international specialists. Starting from this basis, nuclear power plant operators—including Kozloduy NPP (KNPP)—have intensified efforts to adapt their plants in line with the western safety philosophy, in some cases by implementing extensive upgrading measures. Beginning with the WANO 6-Month Program, KNPP was in a position to have essential components of its VVER 440/230 plant Kozloduy 2 reviewed using standard western techniques as early as 1992. In the years that followed, the same components of the other KNPP VVER 440 plants were also evaluated. All units were upgraded in line with these safety analyses.

Over the years the plant operator KNPP cultivated the idea to not only upgrade individual aspects of his plants pertinent to safety, but instead to enhance the safety level of all components and systems relevant for safety. This approach involved various exemplary and innovative efforts, serving as a model for pioneering a new culture of safety (essentially creating a new VVER 440 reactor design). Upgrading that involves a tailored aging management program is in the interest of industrial plants as they age. The plant safety can be kept at a high level over the planned service life of the plant and even beyond. At the same time, it is also legitimate to expect economic advantages resulting from higher reliability and availability.

The task indicated in the title is part of a comprehensive upgrading program for Units 3 and 4 of the Kozloduy plant. The challenging goal is to generate an aging management program that permits detection, evaluation and mitigation of the relevant aging degradation mechanisms including identification of plant locations where they are likely to occur. The contract, executed in a consortium between Framatome ANP (a Framatome and Siemens company) and the Russian company Atomstroyexport, includes an objective evaluation of the residual service life of components/systems/plants subject to acceptance by international experts, shall identify the need for further investigations/calculations in certain cases, and shall find solutions for improvements that achieve a consensus of safety and economy.

2. General Methodology for Evaluation of Residual Service Life

An economically and technically effective procedure for aging and plant service life management, must consider the plant as a whole. At the end of the 1980s Siemens established a methodology for plant service life evaluation and aging management /1/, which has been successfully applied in the past, continuously updated and further optimized on the basis of feedback from on-site applications. It has also influenced the relevant IAEA methodology, as Siemens was engaged in drafting and reviewing the respective IAEA guidelines /2/. The technical approach of the methodology can be summarized as follows:

3. Adapted Methodology for Residual Lifetime Evaluation of Kozloduy 3 and 4

The task is part of a comprehensive backfitting program for Units 3 and 4 of the Kozloduy plant; it comprises three phases:

- The first phase is evaluation of the residual service life of representative (safety- and availability-relevant) components and systems of the two plants using state-of-the-art techniques.
- The second phase is to elaborate a computerized system structured for handling all relevant component or system data, from plant erection, involving relevant data gathered

during plant operation (loadings and environmental conditions), and in-service inspection and replacement activities as well.

- The final phase consists of generating an aging management program that permits detection, evaluation and mitigation of the relevant aging degradation mechanisms and identification of plant locations where they are likely to occur.

3.1 Evaluation of the residual service life (see Figure 1)

The first step is defining a list of components, equipment and structures considered sensitive to aging degradation. The selection follows the classification of plant components elaborated by the IAEA, as well as our own experience.

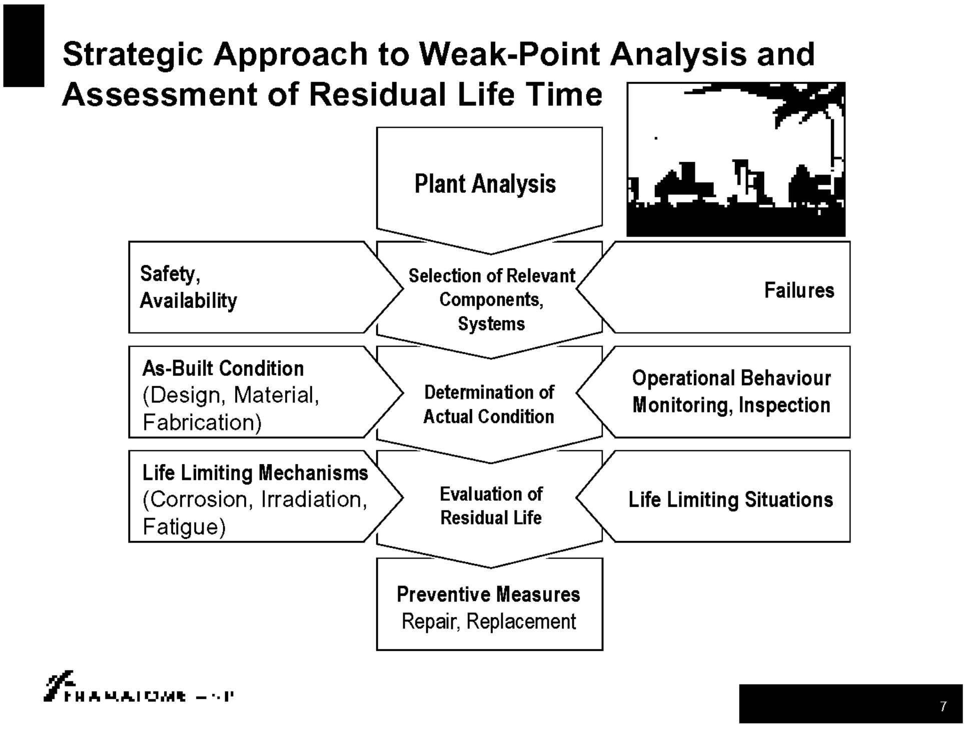
Step 2 is to obtain knowledge on the actual condition of components and structures by comprehensive review of existing information related to understanding of component aging, using all data available (form manufacture, pre-/in-service inspection, walk downs, environmental conditions, operational data, R&D, world-wide experience, etc.).

The third step defines the potential aging mechanisms, considering general knowledge and plant-specific information.

Step 4 considers the effects of the relevant life-limiting aging mechanisms. Evident proof must be provided that no life-limiting situation is reached under normal operational or transient conditions during the foreseen service life.

The fifth step determines the residual service life of the component or structure for the leading aging mechanism by appropriate algorithms and/or by linear-elastic fracture mechanics analysis or engineering judgement. By evaluation of the results of all components, equipment and structures the residual service life of the plant can be estimated, also considering economic and safety aspects.

Figure 1



In the final step the remaining service life of the selected key component is evaluated; additionally the analyses yield findings which can be utilized for

- review and integration of preventive maintenance activities,
- measures for plant improvement in terms of safety and availability, and
- further targeted in-service inspection and in-service monitoring tailored to the specific needs of the plant.

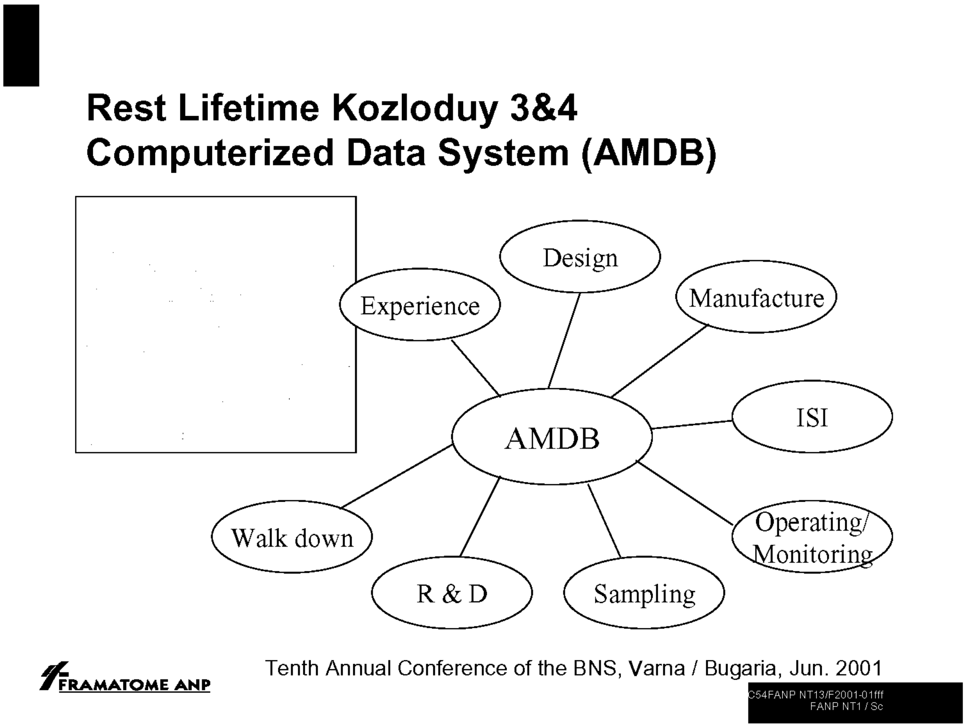
3.2 Elaboration of a computerized system

The work defined in the contract shall representatively reflect—as already mentioned—the situation of the entire plant. In order to determine and monitor the actual physical status of the components, systems and equipment in question for evaluation of the residual service life and use this for an optimized aging management program, it is beneficial to collect the relevant data (such as materials data, operation and water chemistry data, etc.) in a database that will have to be maintained and updated regularly in the future as further data become available.

The common task comprises elaborating a suitable database structure, defining the content for the different components, systems and equipment, gathering information on necessary further monitoring and measurement actions and identifying results for the respective components (for example available data on fatigue, thermal aging or radiation embrittlement), and finally establishing a methodology collection and processing of database input.

The basic structure is shown in Figure 2. It will permit collecting all data that are relevant for safety and critical to residual service life evaluation of the respective components in Kozloduy Units 3 and 4.

Figure 2



Rest Lifetime Kozloduy 3&4
Computerized Data System (AMDB)

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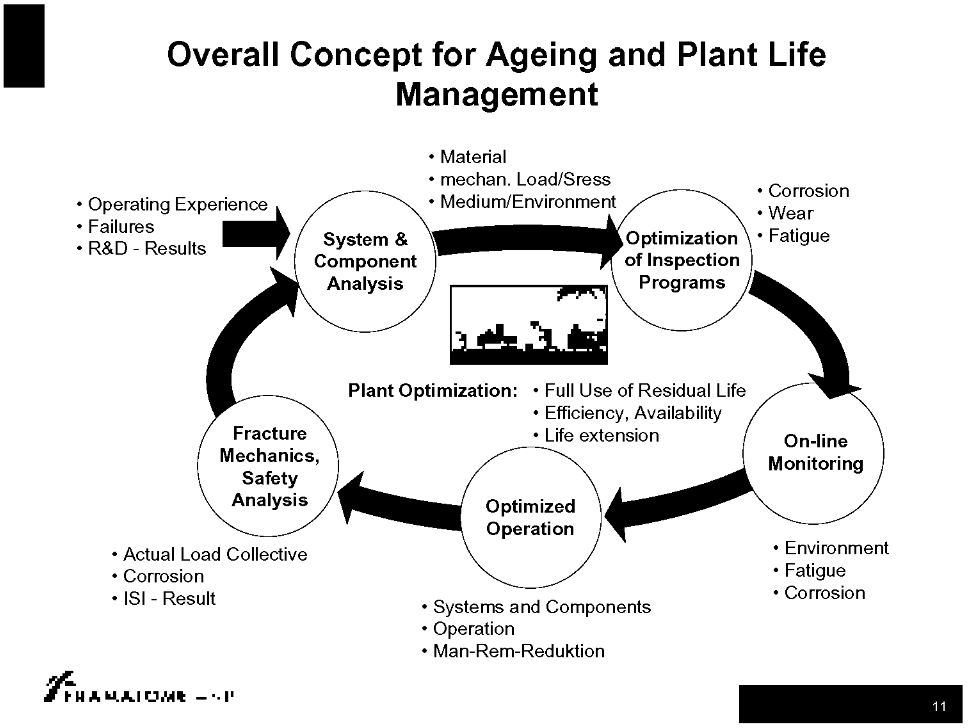
3.3 Generating an aging management program

An effective aging management program (AMP) is dedicated to all components and equipment relevant to safety and critical for the residual service life. It is part of the maintenance program of specific plant units. Such an AMP must be elaborated and implemented on the basis of the methodology applied for evaluation of residual service life and must be continuously updated as shown in Figure 3 using a feedback loop. Timely feedback of experience is essential to ensuring on-going improvement in the understanding of the aging degradation and in the effectiveness of the AMP. The major stages are as follows:

- Stage 1 is the preparation of a realistic, technical analysis of the current status of the selected key components, systems and plant equipment. A comprehensive understanding of the components and equipment, aging degradation thereof, and the effects of the degradation on the ability of components and equipment to perform design functions are the fundamental elements of an AMP. This understanding is derived from a knowledge of the design basis (including applicable codes and regulatory requirements, the design and fabrication (including the material properties and specified service conditions), the operation and maintenance history (including commissioning and surveillance), the inspection results, and generic operating experience and research results. Once the key-components and the main equipment have been analyzed, the relevant degradation mechanisms can be defined. The elaboration of reliable trend curves for future progress of degradation and aging and thus the determination of rest-lifetime (RLT) presumes a steady-state follow up within the following stages:

Figure 3



- Stage 2 is the optimization of the in-service inspection concept (regular or specific in-service inspection).

- Stage 3 is to identify missing actual data, necessary for qualitative evaluation of RLT. Then a plan must be established on the basis of the regular outages and in-service inspection programs to allow for the acquisition of missing data by implementation of an overall monitoring concept, instrumentation, specific inspections, measurements, and calculations.

- Stage 4: The evaluation of these results culminates in the definition of necessary preventive measures, additional inspections, repair and replacement work, and systems engineering activities, or any modification of operating modes which are required either individually or collectively to prevent accelerated degradation by the identified aging and wear mechanisms and assure that the component, system or plant reaches its full design service life.

- In stage 5 the current safety margin with respect to the safety or failure criteria for any time during plant operation up to the end of its useful service life will be specified and residual service life will be determined on the basis of current data using established algorithms or linear-elastic fracture mechanics investigations.

The concept and strategy of such an AMP is fully consistent with current IAEA proposed practice and methodology /3/: The main features and interfaces of the key elements of such a component and equipment AMP, which is based on Plan-Do-Check-Act elements, is shown in Figure 4.

Figure 4

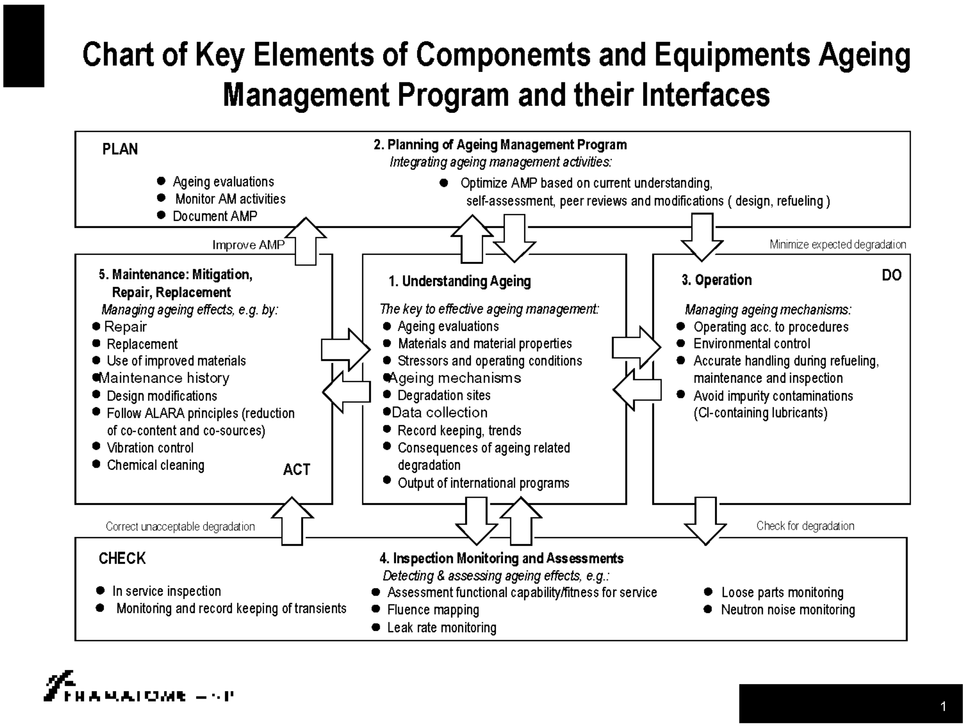


Chart of Key Elements of Componemts and Equipments Ageing Management Program and their Interfaces

2. Planning of Ageing Management Program
Integrating ageing management activities:
- Ageing evaluations
- Monitor AM activities
- Document AMP
- Optimize AMP based on current understanding, self-assessment, peer reviews and modifications (design, refueling)

5. Maintenance: Mitigation, Repair, Replacement
Managing ageing effects, e.g. by:
- Repair
- Replacement
- Use of improved materials
- Maintenance history
- Design modifications
- Follow ALARA principles (reduction of co-content and co-sources)
- Vibration control
- Chemical cleaning

1. Understanding Ageing
The key to effective ageing management:
- Ageing evaluations
- Materials and material properties
- Stressors and operating conditions
- Ageing mechanisms
- Degradation sites
- Data collection
- Record keeping, trends
- Consequences of ageing related degradation
- Output of international programs

3. Operation
Managing ageing mechanisms:
- Operating acc. to procedures
- Environmental control
- Accurate handling during refueling, maintenance and inspection
- Avoid impurity contaminations (Cl-containing lubricants)

4. Inspection Monitoring and Assessments
Detecting & assessing ageing effects, e.g.:
- In service inspection
- Monitoring and record keeping of transients
- Assessment functional capability/fitness for service
- Fluence mapping
- Leak rate monitoring
- Loose parts monitoring
- Neutron noise monitoring

4. Contract Description

The contract in principle comprises 2 parts, the general work program and the specific work program .

4.1 General work program

The major tasks of the project are to
- continue evaluation of the actual material and physical status of components, systems and equipment already in progress,
- define the relevant aging mechanisms and proceed with the evaluation of the aging effects and the residual service life of these components, systems and equipment, and
- elaborate a computer database allowing the quantification of the residual service life, thus forming the basis for aging management and for evaluation of the RLT.

The components addressed are all high-safety components and representatively all other components, systems, and equipment. These are:
- all components of the primary circuit,
- components of the secondary circuit (piping, valves and supports),
- spent fuel storage pool,
- lifting equipment,
- electrical equipment (i.e. transformers, batteries, switchgear, and cables) and diesel generators, and
- civil structures (such as the reactor building, turbine building, auxiliary building, diesel generator building, ventilation stack, and pump stations).

4.2 Specific work program

In most cases, the relevant component-specific degradation mechanisms well known from the results of previous projects related to the residual service life of NPP Kozloduy Units 1-4, from experience with the operation of similar plants but also plants in other countries. Those specific degradation mechanisms are addressed within the specific work program, either by investigation of available samples from an RPV weldment (remaining material from sampling in weld No. 4 from RPV Unit 1), by research on possible embrittlement due to neutron radiation (RPV and RPV support structure), by stress and fatigue analyses of possible degradation sites (at the RPV, secondary piping, pumps and valves), or by providing suitable tools to monitor or calculate fatigue (FAMOS), erosion corrosion (COMSY) or radiation fluence levels. Also the main lifting equipment, the electrical equipment (including I&C) and building structures are included by assessing the status quo with respect to possible degradation mechanisms and sites.

The work defined will allow and provide a substantial step forward in the quantitative evaluation of the residual service life on the Units 3 and 4.

5. Initial Results

The evaluation of the plant will be based on walk-down results, input data from the plant, design/manufacture/non-destructive testing of the components/systems/equipment, monitoring operational and environmental conditions, e.g. frequency and level of mechanical loadings, frequencies of transients, temperature, pressure, fluence/radiation dose measurements, on experimental testing and sampling of actual component parts and structures. Necessary information to cover all requirements according to the contract is only partly available. Some could be gained by walk-downs, some (for example as-built piping isometrics) must be reproduced and updated; some must be postulated as a "best estimate" to perform the intended calculation.

5.1 Walk-down

A first walk-down in Unit 3 (electrical equipment in Unit 4) was performed; in some cases additional on-site visits may become necessary. The main conclusions can be summarized as follows:

- The isometrics of the main coolant line (MCL) dated 1995 were confirmed, i.e. the leak before break analysis from 1995 was confirmed, provided the assumptions on the accuracy of ISI testing are verified.
- It turned out that the location of supports of the surge lines were changed relative to the situation in 1995; i.e. stress and fatigue analysis must be checked and compared with the assumptions of the leak before break analysis for the surge lines.
- The supports and piping of the main steam line, the main feedwater line, and the emergency feedwater line are in quite good condition; there is no need to consider additional stress concentration factors within the foreseen stress and fatigue analyses of these lines.
- There are no clear defined findings on valves: especially the switch-off behavior of electrical actuators must be checked again, some hardware changes are to be expected.
- No knock-out point was identified in the functional buildings visited (civil structures).
- Although no knock-out point was identified for the spent fuel storage pool, further studies revealed a need for additional on-site visits.
- Walk-down of the electrical equipment in Unit 4 revealed that a major portion of sensitive components was already replaced; there are questions about mechanical or electrical aging situation of the rotary converters, about cable aging; the electrical rooms are generally in good condition, but the temperature is relatively high due to lack of cooling capacity.

5.2 Analyses

5.2.1 RPV 1, template testing

It is well known that the weld metal in RPV weld No. 4 of Unit 4 is in such good condition—with respect to radiation embrittlement—that no practical limitation of lifetime has to be considered. The situation of RPV weld No. 4 in Unit 3 is quite different. Its chemical composition with respect to P and Cu is such that neutron radiation will have a significant impact on the toughness of the weld metal and thus could have an influence on the lifetime of the RPV or at least on the frequency of repeated recovery annealing to restore acceptable toughness. In contrast to the RPVs of Units 1 and 2 the RPVs of Units 3 and 4 are cladded; i.e. there is only very restricted possibility for sampling from the inside of the vessel. But the chemistry factor A_F of weld No. 4 in Units 1 and 3 is comparable despite differences in Cu and P content. For this reason an attempt will be made to use results from sampling in Unit 1 for evaluation of the status of embrittlement in Unit 3.
It is a fact that specimen material from weld No. 4 of Unit 1 was still available after previous testing of Unit 1. These samples (templates No. 5 and 6) were additionally irradiated in the RPV of the Rovno plant. Specimens cut out from these templates are now being used for further evaluation of the possible embrittlement in Unit 1 and simultaneously for evaluation of the possible embrittlement in Unit 3.

Preliminary results are now available and can be interpreted as follows:
Unit 1: The embrittlement due to radiation stays obviously below that tendency which could be very conservatively derived from the already existing results. In other words, the new

value for the Charpy-V notch toughness (valid for a fluence level beyond the forecast lifetime) follows even the so-called lateral shift approach; that means that all calculations related to the safety situation of the Unit 1 RPV made to date are confirmed to be conservative.

Unit 3: When following the Russian Standard, describing the radiation embrittlement analysis on the basis of the chemistry factor formed by the P and Cu content of weld metal to be analyzed, it can be deduced that the Unit 3 RPV, with a nearly identical chemistry factor, will exhibit the same radiation related shift behavior of the toughness properties as the RPV of Unit 1. In other words, all safety calculations made for the Unit 3 RPV /4/ to /6/ are confirmed.

5.2.2 Electrical equipment, batteries

General and allocated specific work program were representatively applied to the batteries of Unit 4. All steps of the program (including collection of basic data, evaluation of the aging mechanisms and effects, evaluation of the remaining lifetime, input for the database system, and aging management program) were individually performed. It can be concluded in principle that the preconditions for an effective aging management are already available. The activities now only have to be transferred into the future management program.

6. Project Status and Further Actions

The contracted work is progressing. Agreed deliverables such as the inception report, fatigue manual, COMSY manual have already been handed over. In spite of some delay in delivery of the input data, the foreseen expiry date should be achieved. The analysis work will start within a short time, either based on input data from the plant or alternatively "best estimate" data.

7. References

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/4/ Schmidt J., Strombach Y., Gledatchev I.: “Reactor Pressure Vessel Integrity Assessment of the Bulgarian NPP Kozloduy Unit 1”, PLIM + PLEX Conference Prague, 1997.

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