USAGE FACTOR CURVE AS THE TOOL FOR AN ASSESSMENT OF A REST LIFETIME OVER 40 YEARS DESIGN LIMIT FOR COMPONENTS OF NUCLEAR POWER PLANTS (NPP)

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Summary

In introduction the short overview on the actual importance of the Nuclear Power Plants (NPPs) Ageing-Plant Life Extension (PLEX) problem is presented. The proposed forecast for the rest of life span of a pressurized NPP-component based on the calculated Usage Factor Curve can provide less conservative results than the normally used standard usage factor calculations. The main task of the presented Usage Factor Curve approach is the statistical interpretation of the recorded reactor transients and evaluation of load condition of the component resulting from these transients. Such analytical procedure applied during exploitation of NPPs is showing more realistic status of facility and can diagnose existing reserve in lifetime of pressurized NPP-components.

Keywords: Nuclear Power Plants, lifetime extension prediction, usage factor.

KRZYWA WSPÓŁCZYNNIKA ZUŻYCIA, JAKO NARZĘDZIE OCENY POZOSTAŁEGO CZASU EKSPLOATACJI ELEKTROWNI JĄDROWYCH (EJ) PONAD 40 LETNI OKRES PROJEKTOWY

Streszczenie

Na wstępie krótko przedstawiono aktualne znaczenie problematyki przedłużenia projektowego okresu eksploatacji Elektrowni Jądrowych (EJ). Znormowane ustalenie przewidywanego projektowego okresu eksploatacji EJ, opierające się na obliczaniu tzw. współczynnika zużycia dla ciśnieniowych elementów konstrukcyjnych, może prowadzić do niedoszacowania dozwolonego okresu pracy EJ. Zaproponowana w artykule metodologia Krzywej Współczynnika Zużycia może wykazać lepszą ocenę pozostałego czasu eksploatacji. Zasadniczym elementem przedstawionej procedury ustalania Krzywej Współczynnika Zużycia w czasie eksploatacji EJ jest wykorzystywanie statystycznie zbieranych danych o rzeczywistej historii obciążeń elementów konstrukcyjnych i cząstkowe okresowe obliczanie przebiegu współczynnika zużycia. Zastosowanie takiego analitycznego narzędzia pozwala na diagnozę stanu zużycia i realniejszą prognozę pozostałego dozwolonego czasu eksploatacji elementów konstrukcyjnych EJ.

Słowa kluczowe: Elektrownie Jądrowe, ocena pozostałego czasu eksploatacji, współczynnik zużycia.

1. INTRODUCTION

The European know-how and experience in life assessment and life extension of nuclear power plants (NPPs) components is recognized world-wide, and is in great demand. These topics have become increasingly important during the last few years, because of economical as well as political reasons and incoming prolongations of operating licence over old 40 years standard's design limits are going to presently used 60 years design licence limits and in some postulated cases from USA even higher to 80 years. In the USA, as has been pointed out above, some licenses for life extension have already been granted. Life extension (from 40 to 60 years) could be an attractive option for the operators of up to 80 % of US NPPs if it can be performed without major replacements. In France, life extension is being studied with increasing emphasis. 'Hidden' life extension has already taken place, 40 years is today as nominal plant lifetime, in contrast to the span of about 20 to 30 years usually given earlier [1]. In Switzerland the Swiss Nuclear Society [2] has created scopes for the permanent collecting and analysing the Ageing-Plant Life Extension (PLEX) experience of Swiss NPPs operating companies and actual information from this internet source could be interesting for readers.

In the following we would like to refresh the idea from [3] and show a simple method which promises to obtain less conservative assessment of the rest of life of pressurized NPP components, by slightly increased calculating effort. Of course it has to be seen as a part of extensive multi-disciplinary survey for long term operation of pressurized NPP components.

The various sources of degradation of life of NPPs components can be divided into six groups from Table 1 e.g. according [4]. Generally, NPPs Ageing-Plant Life Extension (PLEX) problems are permanently present in publications and are in focus of interest of scientific societies (e.g. International Association of Structural Mechanics in Reactor Technology IA-SMIRT) and regulatory and experts organisations (e.g. International Atomic Energy Agency IAEA in Vienna). The PLEX primarily concern passive components, i.e. components without moving parts. Regarding active components like pumps and valves, deterioration usually manifests itself in a more obvious manner, and exchange of components can often be performed during regular maintenance work. Nevertheless, ageing of active components cannot be completely neglected as a risk factor. There is no generally recognised procedure to determine the admissible lifetime of a nuclear power plant. Decisions are usually based on economic reasons as well as on general engineering practice. Various individual ageing-related problems have been studied in some detail in the past. A number of mechanisms are known; nevertheless, they are not completely understood. For example, the so-called dose rate effect in steel irradiation embrittlement has been known for years; but it still cannot describe reliably and quantitatively today, giving rise to an increased risk of pressure vessel failure in older NPPs. Another problem not fully understood is the propagation of fatigue cracks in austenitic steel pipes. All in all, it is clear that the global risk of a reactor accident grows significantly with the number of nuclear power plants which are in operation longer than about 20 years. The knowledge on PLEX is well summarized in many IAEA publications, on this place we would mentioned the positions [5] and [6] listed in **REFERENCES**. The summary of identified research and developments needs connected with PLEX is recently giving in the paper [7] of the SMIRT 20 Conference.

Of these six destructive mechanisms from Table 1, the fatigue and creep have the most important influence on the long term strength of materials pressurized component.

For the NPPs owners it is of the upmost importance to obtain as much information as possible about the fatigue usage factor of essential components, as a basis for decisions regarding in service inspections, replacements or manner of operation of the plant.

Table 1. Sources of Ageing Degradation

NO	DEGRADATION MECHANISM	INFLUENCED COMPONENTS AND SYSTEMS	CAUSED BY
1	IRRADIATION AND EMBRITTLEMENT	REACTOR PRESSURE VESSEL (RPV) INTERNALS OF RPV	DESIGN, MATERIAL, IMPURITIES IN STEEL (COPPER, PHOSPHOR)
2	FATIGUE CORROSION, CREEP	PIPING AND ITS FITTINGS AND SUPPORTS. NOZZLES, VALVES, MIXING REGIONS OF FLUIDS WITH DIFFEREI\1T TEMPERATURES	RESULTING LOCAL STRESSES, OPERATIONAL LOADING, SYSTEMS ENGINEERING
3	GENERAL CORROSION, PITTING, WASTAGE	SYSTEMS WITH LOW VELOCITIES OF FLUIDS, CONDENSATE IN STEAM LINES, SERVICE WATER SYSTEMS. SAFETY INJECTION SYSTEMS INTERNALS OF PUMPS AND V AL VES	SYSTEM ENGINEERING, OPERATIONAL INFLUENCES SERVICES (DESIGN), MATERIALS
4	STRESS CORROSION CRACKING	WELD VINCINITY IN COMPONENTS; (STAINLESS STEELS), STRAIN INDUCED FERRITIC PIPING (HIGH TEMPERATURE AND OXIGENCONTENT OF FLUID)	MATERIAL, OPERATIONAL CONDITIONS, CHEMICAL CONDITIONS, INSULATION AND GASKET MATERIAL
5	WELD RELATED CRACKING, HYDROGEN EMBRITTLEMENT	ALL KIND OF WELDS, INTERFACE BETWEEN STAINLESS STEEL CLADDING AND VESSEL'S MATERIAL	STEEL-COMPOSITION AND MANUFACTURING PROCESS
6	EROSSION-CORROSION	STEAM AND FEED-WATER PIPING, STEAM SEPARATORS, HEAT EXCHANGES, TURBINE BLADES	CHEMICAL CONDITIONS (PH-VALUE), MATERIALS, SYSTEMS ENGINEERING

2. DAMAGE ASSESSMENT BY ANALYSIS

Analytical methods of determining the usage factor are set forth in the following accepted worldwide codes: from USA in ASME Section III, Subsection NH and NB, and from Germany in KTA 3201.2.

Fig. 1 shows schematically the flow of damage assessment by analysis. As shown in this picture, the stress analysis is the central point of the calculation method. The geometry and the load cases of the components are mostly so complex, that an accurate analysis can only be performed by Finite Elements Method (FEM) computer programs. These programs are used for calculations the six components of stress in selected sections. For assessing the rest of life in accordance with as fore mentioned codes, the stresses must be classified into P_m, P_b, etc.

A postprocessor program suitable for such calculations can be used, e.g. CASAFE [8] , was developed by consulting firm Colenco AG (former well known as part of Motor-Columbus Ing.) from Baden, Switzerland, in cooperation with Firma FIDES Informatik AG years ago. For the both wide used NPPs type of reactors: Boiling-Water Reactor (BWR) and Pressurized-Water Reactor (PWR) according ASME Section III-NB for design temperature below 350°C only fatigue usage factor has to be take into account.

The post processing program CASAFE is capable to calculate fatigue for usage factor, as well as other stress requirements in accordance with ASME Section III. The CASAFE has a standard link with FEM-Programs ANSYS and NASTRAN; other interfaces could be implemented on request. The results output of CASAFE are in the form of tables and/or graphics. One of the most interesting applications of CASAFE (Version ABSI) was for the Project SNR-300, where the design temperature was 450°C and additionally to fatigue the creep has been considered for the usage factor [9].

The experiences of ca. 40 year long lifetime of Swiss NPPs, won during periodical inspections, have shown, that the wall thickness degradation by e.g. erosion occurred; especially for critical components as e.g. elbows or valves made from carbon steel. With other words the periodically measurements of wall thicknesses of critical components by e.g. ultrasonic techniques have to be done and archived. In the cases of such wall thickness degradation it has to be considered the performing of new stress analysis with smaller geometrical dimensions of components. The new stresses will be used for post processing calculations of usage factor. For the components from austenitic steels or using cladding the degradation will be probably smaller, but the measurements of the wall thickness of critical components as well as looking for the cracking have to be performed during each periodical inspection of NPPs.

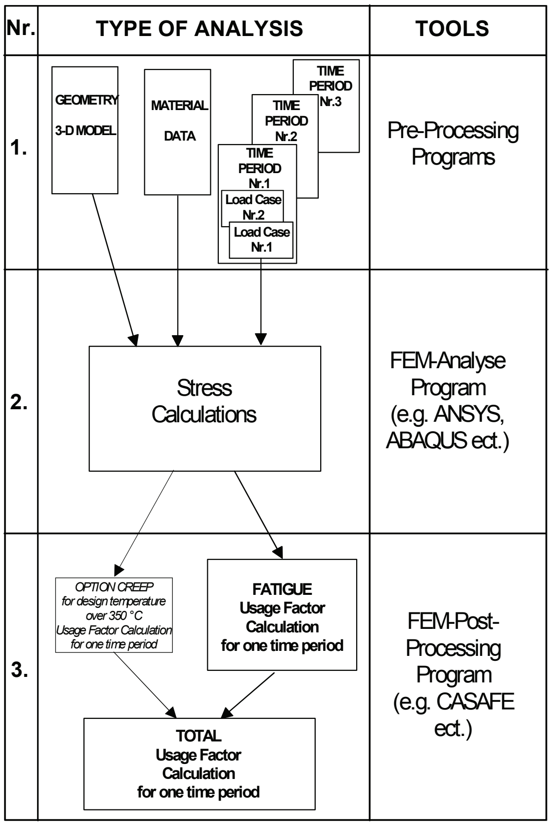

Fig.1. Three steps of analysis for usage factor calculation with examples of analytical tools

3. DEFINITION OF USAGE FACTOR CURVE

As mentioned previously in Pt.1 INTRODUCTION, the usage factors are required to assess the rest of life of NPP components. For this purpose the history of load should be known. Since sophisticated and costly Life Time Monitoring (LTM) Systems are relatively new and still partially in the proving stage, we are looking for an alternative approach to solve this task.

Usually the design calculations of usage factor are based on a hypothetically assumed manner of operation of NPP over its life span of 40 years.

In the Fig. 2, straight line "A" represents design calculation with the usage factor, of 85% at 40 years. Straight line "B" represents the calculation of the usage factor after 20 years of operation, by the same method as for the design calculations, but in calculated the known history of load (e.g. usage factor of 35% at 20 years of operation).

The known history of load of the component allows us to reconstruct the dynamics of time development of usage factor.

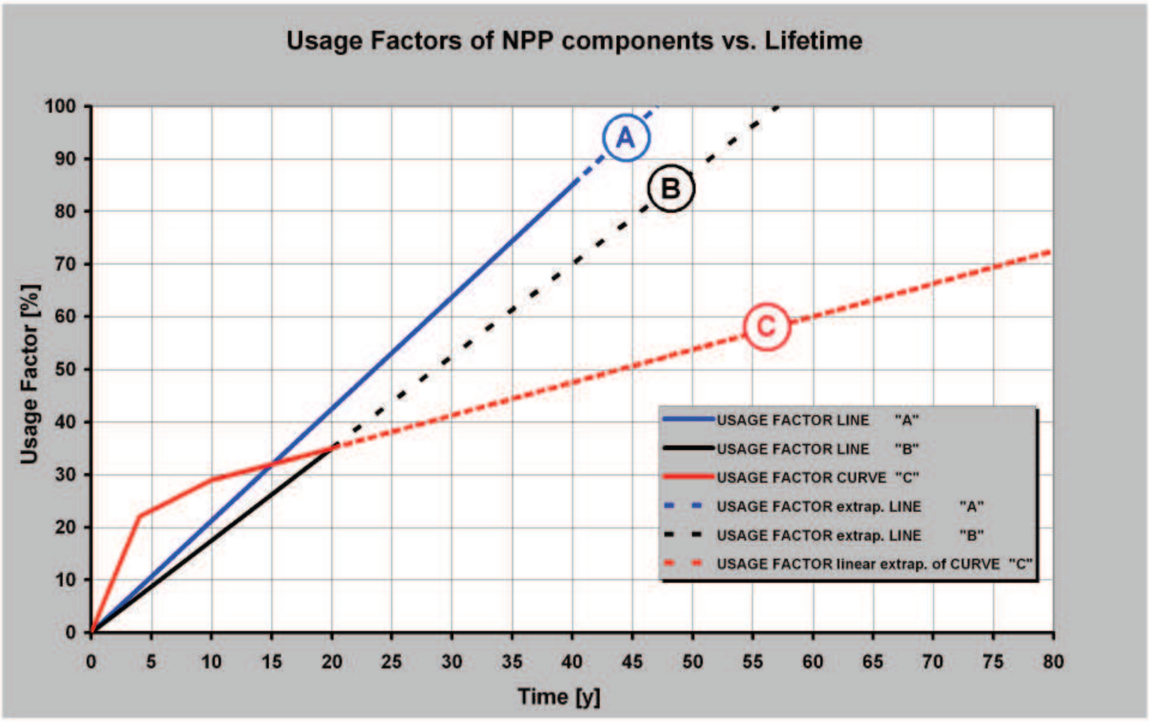

Fig.2. An example of usage factors calculation for the same NPP facility: A-design calculation, B-after 20 years of operation in one time-step calculation, C-after 20 years of operation more detailed calculated in few time-steps. Concluded; taking into account the known 20 years load history in cases B and C, the analytical diagnosis of a longer lifetime tendency can be shown

By dividing the known history of load into a few shorter time periods, for example 2, 4, 10, 15 and 20 years, and calculating the respective usage factor values, we can show the non-linear character of this time development. For example this non-linear reserve has been extensively study in work [10].

The curved line "C" represents this function. As can be seen in Fig. 2 the extrapolations of lines "B" and "C" will forecast different rest of life values. For example at a usage factor of 50% we obtain approximately 28 respectively 44 years of life expectancy, assuming a similar way of operation.

The main task in calculating the usage factor during a specific time period from the past is that actual life history of component has to be reconstructed on the basis of recorded reactor transients.

Firstly a system specialist has to analyse the mentioned records to recognise the load cases as well as their frequencies.

Secondly it is necessary to recognise the physical connection between the known load cases and stress history of the respective component. We have two possibilities to do this: experimentally and theoretically.

The first possibility is based on experimental tests using mobile instrumentation for measuring and recording the load parameters, similar to that done by LTM Systems.

The second possibility consists of thermo- and fluid dynamic calculations based on real main transient (temperature, pressure) recorded during the operation time of reactor.

On the grounds of these physical connections it is possible to determine the boundary conditions of loading for individual load cases, and the number of occurrences for the respective component.

Finally the entire known operating time is to be broken down into a few time periods for which the individual load cases and their frequencies are to be determined and the usage factor calculated. This procedure is to be repeated for each time period.

It is to be noted, that for the same load cases occurring in different time periods only one FEM Analysis has to be performed (till component's wall thickness stay the same). This means, that for subsequent time periods, usage factors values can be obtained from post-processing program only e.g. CASAFE.

The Usage Factor Curve obtained by these calculations is the basis for an assessment of rest of life of the component. The lineal, (tangential to the last measured and analysed period) extrapolation of this Usage Factor Curve, as shown in Fig. 2, can be used for the lifetime diagnosis of NPP components.

4. CONCLUSION

The forecast diagnosis for the rest of life span of a pressurized NPP-component based on the calculated Usage Factor Curve can provide less conservative results (i.e. longer lifetime) than the normally used standard calculations.

The main task of the proposed approach is the statistical interpretation of the recorded reactor transients and evaluation of load condition of the component resulting from these transients.

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Dr. Patorski currently tenure the Senior Scientist position at PSI in the Target Group in High Intensity Proton Accelerators Division of Large Research Facilities Department and is working on the field of experimental thermo-hydraulics of liquid metals coolants with unconventionally using of Infrared Thermography measurement technique. Simultaneously he is member of Nuklearforum Schweiz (prev. Schweizerische Vereinigung für Atomenergie-SVA) and Swiss Nuclear Society SNS (in German; Die Schweizerische Gesellschaft der Kernfachleute SGK)

Peter HIRT has received the M.Sc. in Mechanical Engineering from Swiss Federal Institute of Technology in Zürich, (Eidgenössische Technische Hochschule Zürich, ETHZ). He began his professional career in 1976 by Motor Columbus Ing. Ltd. Consulting Engineer Inc. /Colenco AG in Baden Switzerland. His activity was connected with the Unit Nuclear Technology, where during his works for many consulting projects on the field of nuclear energy, he has held different and finally company leading positions. In 1998 he has change to the Nuclear Power Plant NPP Beznau in

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Niklaus JAUSSI has received the M.Sc. in Mechanical Engineering in 1964. He began his professional career in 1976 by Escher-Wyss Zürich in the department of closed cycle Helium gas turbines on the position of design engineer. In 1966 he has change and start the international part of his professional at General Atomic in San Diego, Cal., cooperating in the development of a Helium gas cooled high temperature reactor (HTGR). After 6 years of USA proffessionell expirience his coming back to Switzerland in 1972 and starting the job for General Eletric (Getsco) in the group for structure mechanics analysis. He is the author and the peer – reviewer of the stress reports of the mechanical components mostly for the Swiss NPP Leibstadt. In 1977 he has change to Motor Columbus MC Ing. Ltd. Consulting Engineer Inc./Colenco AG in Baden Switzerland with duties for the section of mechanical components. An important example of his consulting activity by MC Ing. was the designing of the additional emergency cooling system for the NPP Würgassen in Germany. From 1987 Niclaus Jaussi has concluded his proffesional career at the Swiss Nuclear Safety Inspectorate (HSK / ENSI), in the section of mechanical components. Since his retirement in 2002 is working in his own consulting firm "Outsource GmbH (Lmtd.) externe dienste" in Basel and serving with his wide know-how for the nuclear industry.