Forward Alliance – AREVA’s Initiative for NPP’s LTO Projects

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High expectations from a growing reactor fleet worldwide

The total electrical production capacity of nuclear power worldwide continues to grow, with almost 371 GWe currently produced by 434 reactors in operation across the globe and 69 reactors under construction [1]. The Fukushima Daiichi accident in March 2011 certainly slowed this growth, but the need for innovative services for existing reactors continues to grow. The latest IAEA scenarios predict an increase in nuclear production capacity of between 17 % and 95 % by 2030 [2], and the demands of the global market are growing.

In order to meet CO2 and greenhouse gas emission reduction targets, it is vital to maintain a basic source of nuclear power to compensate for the intermittent nature of solar and wind power contributions to the grid. The fact that 80 % of reactors in service are more than 20 years old, with half of these over 30 years old [3], means there is high demand for service life extension across the global nuclear fleet.

Thanks to its integrated model, spanning the complete nuclear cycle from the uranium mines to the recycling of used fuel, reactor design and maintenance, AREVA supplies services to more than 360 reactors of all technology types across the world. To support nuclear utilities in managing LTO projects, AREVA has launched the Forward Alliance initiative, proposing a catalog of the most advanced and efficient products, services and solutions.

Forward alliance

Meeting market demand in this area means, first of all, supporting global operators in their own work to extend plants service life. This involves helping them optimize investment in much-needed fleet modernization work, thereby enabling them to take advantage of the value of current assets in the most effective way. Renewal of operating licenses, periodic safety reviews, service life extension, etc., different approaches are taken depending on the country or continent concerned. However, the end goal is the same: to guarantee the safe operation of plants over the long term.

These processes correspond to the main steps recommended by the IAEA (Figure 1):

- Preliminary studies
- Scoping and screening of components
- Ageing management reviews by component
- Implementation of solutions and new procedures.

Responding to the needs also means proposing an ageing management approach based on the component: vessel, vessel internals, pressurizer, steam generator and primary and secondary pumps, to name just the main systems of the nuclear island. The Forward Alliance approach includes a wide range of skills and experience in material physics and the management of mechanical fatigue, as well as a precise understanding of the behavior of a wide range of components, whether or not they are AREVA-designed. Solutions including sensors to measure transients, which allow a direct fatigue correlation and the use of historical load evaluation to back up component ageing management methods, are also available. Another element is helping utilities combat obsolescence via reverse engineering or replacement with new components, a major success factor in extending service life. Modernizing instrumentation and control systems is without doubt the most relevant example, with digital systems able to deal with obsolescence issues in analog systems whose maintenance cost becomes too high. Finally, it involves providing nuclear operators with fuel cycle management solutions that are effective until the end of plant service life. This can be done by implementing management solutions for unloading pools, dry storage and spent fuel recycling.

These efforts to extend operating licenses are accompanied by a growing demand for assistance in staff training. Managing and anticipating the age and skill distribution of the workforce, as well as guaranteeing the quality of personnel, are vital elements in such an approach. By sharing experience, these projects can be managed in an optimum manner, minimizing investments through wise choices and controlling project costs by maximizing the value of existing assets through service life extension.

Within the ageing management scope, the damaging process caused by fatigue mechanisms is one major concern. It will be escorted by the tightening of fatigue rules due to the consideration of environmentally assisted fatigue (EAF) within the fatigue process. The AFC and its major tool FAMOSI offers solutions therefore [4].

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Fig. 1. Major phases of an NPP LTO project.
AREVA Fatigue Concept:
General overview

In terms of the nuclear industry, the ageing management of power plant components is nowadays a main issue for all actors: states, regulatory agencies, operators, designers or suppliants. As regards fatigue assessment of nuclear components stringent safety standards imply the consideration of new parameters in the framework of the fatigue analysis process: new design fatigue curves, consideration of EAF parameters and stratification effects. Modern state-of-the-art fatigue monitoring approaches gain in importance as part of these ageing management requirements of NPP components. Consequently, lots of operators have to deal with demanding security requirements to ensure the safe operation of power plants. The core challenge is the identification and qualified processing of realistic load-time histories.

In this general context AREVA developed the integral approach AFC with new tools and methods in order to live up to operators’ expectations. The basic principles of the concept are depicted in Figure 2.

The methods are both valid for the erection and the operation phase. In other words, the first fatigue analyses are based on specified design transients. During operation, it is recommended to rely on realistic operational data as input for the fatigue loading. In this sense, the central module is the Fatigue Monitoring System FAMOSi as a data logging system for thermal loads like thermal stratification, plug flows or leakage flows. The simple workflow is a two step workflow consisting of load determination by local measurement (FAMOSi hardware) plus qualified processing of realistic load-time histories.

Fatigue analyses are usually based on a set of model transients from a catalogue as it is shown in Figure 2. Fatigue calculations are usually carried out as simplified elasto-plastic or elasto-plastic analyses based on appropriate material models. Note that EAF is considered both in stages 2 and 3 approaches according to the latest international rules and guidelines [5 to 10]. The strain rate and thus time dependent consideration of partial EAF \( F_{EA} \) for each time step \( i \) (1s according to the frequency of measured data logging) is implemented by combining the modified strain rate approach [11] with the rainflow cycle counting algorithm according to Clormann and Seeger [12]. The latest requirements regarding fatigue within the German safety standards are equally respected and implemented [13]. In fact, usage factors with and without consideration of EAF are calculated for operational load histories considering the requirements of different design codes: ASME, KTA [13] and expected amendments in RCC-M [14].

Based on real measured thermal loads (FAMOSi local measurements) and superposed mechanical loads the FFE process allows a highly automated and reliable data processing to evaluate CUF’s of mechanical components. Calculation and management of results are performed within the software frontend FAMOSi, thus impact of operating cycles on components in terms of stress and fatigue usage can be taken into account in order to plan optimized decisions relating to the plant operation or maintenance activities. Figure 3 give an example of measured temperatures, correlating component stresses and fatigue damage accumulation.

The SFE and FFE parts are fully implemented and highly automated in the

![Figure 2. General overview of the AREVA Fatigue Concept (AFC).](image)

![Figure 3. Fast Fatigue Evaluation (FFE) gives a direct correlation between temperature and fatigue.](image)
fatigue assessment software frontend FAMOSi. In the case of increased usage factors the DFC module provides a detailed load case counting and the possible application of realistic material models within the finite element analysis as well as the fulfillment of design code requirements with regard of shakedown and ratcheting [15].

Basically, a local acquisition of load data for the follow-up of fatigue trends is recommended. This way it is ensured, that the local loads at the locations of interest with regard to fatigue (e.g. thick walled nozzles) are captured.

Note that the term “transient” to define the load is used at various occasions. It is useful to exactly differentiate the terms “design transients”, “model transients” and “operational loads”:

- Design transients (see Figure 2) are usually specified in the commissioning phase, i.e. before operation. They are based on plant models and experience and are part of the licensing documents.
- Model transients (see Figure 2) are specified during operation. They are based on operational measurements and/or FAMOSi local measurements.
- Operational loads represent the measured load-time history e.g. based on the FAMOSi software (see Figure 2).

FAMOSi: Hardware and measurement aspects

Thermal load data at the outer surface of the adjacent pipe or directly on elbows are logged by the FAMOSi system by means of thermocouples. The thermocouples are manufactured as measurement sections. In the sense of local fatigue monitoring the measurement sections are located at fatigue relevant locations at the outer surface of pipes and are based on additional temperature measurement by means of thermocouples. The principle of the measurement sections close to the fatigue relevant components is shown in Figure 2.

There are different types of measurement sections installed at the outer surface of the pipe:

- 7 thermocouples in case of stratification,
- 2 thermocouples in case of plug flow / thermal shock.

These measurement sections are connected to the FAMOSi Processing Unit (PU) – small boxes located in the containment. The boxes contain all necessary modules for signal conditioning and digitizing of the thermocouple signals. Further boxes with data acquisition modules are connected via an Ethernet based data bus to the FAMOSi PU. The PU performs the online data reduction, storage and signal analysis functions, as well as the automated fatigue estimation with the SPE.

With the FAMOSi software all data can be displayed in real time and the measurement system can be configured. System warnings like detected thermal transients and high fatigue values will be announced at the sequence display within the FAMOSi software.

Local fatigue monitoring: Application example

The FAMOSi system provides fatigue management solutions for all plants in the sense of a generic solution [16]. The real operating thermal load data give real plant transients at the location of the component of concern (highly stressed/fatigued). These real data deliver real strain rates and thus contribute to eliminate the uncertainty in the EAF F_{\text{Cu}} factor evaluations. Getting the real operational data helps the plant engineer to refine the system level/component level design transients.

By way of example, the temperature measurement at an auxiliary spray line is shown in Figure 5. The FFE module is used to calculate the time histories of inner wall temperature and all stresses of the stress tensor. These are the main input data for the fatigue usage factor calculation including rainflow cycle counting and F_{\text{Cu}} factor determination.

Furthermore, a comparison of measured temperature for start-up versus allocated design transient was carried out. A representative design transient (fluid \rightarrow heat transfer coefficient \rightarrow inner wall temperature) is compared to the FFE calculated inner wall temperature (see Figure 6). Also shown in Figure 6, the differences in the temperature history between the realistic (measured) loading and the model transient take a significant influence on the resulting stresses, stress amplitudes and stress ranges. In this example, the stress amplitude resulting from the model transient is about three times bigger than the stress amplitude resulting from the realistic operational load (temperature) history with the according effects on calculated CUF. Note that the differences between specified design transients and measured temperature histories are usually even much bigger. A similar comparative study was carried out in [18].

LTO project Borssele

For the lifetime extension project of EPZ’s NPP Borssele (KCB) in the Netherlands, detailed fatigue analysis of all major components were required by the Dutch authority. Also thermal transients that were not considered or known during elaboration of the design transients in the 60ies and 70ies...
like thermal stratification shall be taken into account. As the operational plant instrumentation is not sufficient for that purpose, EPZ decided to install the Fatigue Monitoring System FAMOSi with its local measurement equipment during the plant outage in 2010.

Within the following fuel cycles the FAMOSi system was used to collect real thermal transient data at several class 1 components. Detailed fatigue analyses were established and with the real thermal load data conservative assumptions could be reduced efficiently. Sufficient CUF lower than CUF=1 could be demonstrated for all plant components. In 2014 EPZ received its irrevocable license for 20 more years of operation until 2034 [18]. Thanks to the strong partnership between EPZ and AREVA in ageing management related topics, no components had to be replaced for the lifetime up to 60 years.

Conclusions

LTO is very common in NPPs' world nowadays. Utilities can realize a high economic value with low effort within LTO projects. AREVA had launched the Forward Alliance initiative which offers different methods and tools to ensure an optimized support of customer’s LTO projects. It consists of a wide spread catalog which covers typical LTO activities based on AREVA’s experiences. The NPP Borssele had realized a license update to 60 years using Forwards Alliance tools.

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References

[1] IAEA September 2013
[6] ASME Code Case N-792, 2010: Fatigue Evaluations Including Environmental Effects, ASME Boiler & Pressure Vessel Code, Section III, Division 1, American Society of Mechanical Engineers, USA