ON THE ROLE OF THE SAFETY ANALYSIS IN THE PLANT LIFE EXTENSION STRATEGY

JAVIER RIVEROLA GURRUCHAGA, MARISOL CORISCO CARMONA

Department of Nuclear Fuel Operations Engineering, ENUSA Industrias Avanzadas, S.A.
C/ Santiago Rusiñol 12, 28040 Madrid, Spain

ABSTRACT

Most nuclear power plants are reaching the limit of 40 years of operation and, in many cases, are addressing life extensions years. The effects of ageing on and equipment obsolescence may indirectly affect the bases and assumptions of the safety analysis, and therefore it is necessary to ensure proper functionality of the structures, systems and components through preventive maintenance programs, and periodic reviews of plant performance. Occasionally, this practice is not sufficient, and the loss of equipment functionality must be compensated by reviewing that affected portion of the safety analysis of the plant to show compliance with standards and regulations. A number of examples and transients affected are given in this paper. ENUSA has a long experience of cooperation and assessment to customer utilities in updating the safety analysis to address changes due to ageing of SSCs of customer plants.

1. Introduction

The position already established in the industry is that the limit of 40 years of operation is administrative and there is no expiration time implicit in the FSAR chapter 15 analyses. Still, the effects of ageing on materials (embrittlement, properties change, fatigue, corrosion and wear) and equipment obsolescence may indirectly affect the bases and assumptions of the safety analysis, and therefore it is necessary to ensure proper functionality of the structures, systems and components (SSC) through preventive maintenance programs, and periodic reviews of plant performance.

Occasionally, this practice is not sufficient, and the loss of equipment functionality must be compensated by reviewing that affected portion of the safety analysis of the plant to show compliance with standards and regulations. Few explicit mentions about the mission of safety analysis in the life extension strategies of nuclear power plants are made. In general, it is assumed that margins on the safety criteria are analytically guaranteed and that SSC always behave properly and maintain their functionality in all expected circumstances. Actually, this is the consequence of a continuous surveillance effort, attentive study of the operating characteristics, and an adequate policy of maintenance of systems and components by utilities. In parallel, a constant revision of the validity of the Final Safety Analysis Report of reference is carried out, and in certain circumstances, the design modifications are sanctioned by evaluations and revisions of the analysis of accidents. Not surprisingly, there is an intimate relation of the function of the active SSC with the hypotheses and initial and boundary conditions of each one of the analysed transients. Thus, the safety analysis is displayed as a necessary complement in a healthy strategy of extending the plants life.

ENUSA has participated in a series of customer actions well embedded in the history of plants, which are part of the cornerstones for continuous operation to optimize the fuel management strategies, to recover or demonstrate safety margins against major modifications to the reactor coolant system, or as a support to special manoeuvres. This support has allowed maintaining the analysis in a state of permanent renovation of the methodologies of analysis, placing the clients in good position to approach policies of extension of life.

This paper reviews the recent operational experience emanating from the already mature nuclear industry and presents some of the initiatives carried out by our client utilities with given support given by ENUSA in this context.

2. Recent operational experience in effects of SCC ageing

At present, there is a significant accumulated experience of nuclear power plant operation of more than 50 years and there is sufficient knowledge of the different mechanisms of plant ageing and their agents, and of which components are susceptible to obsolescence. There is a number of international studies and guides currently available, for example, those presented in refs. [1], [2], [3], [4] and [5] among others, focusing on the SSC realm, with clear coincident conclusions. Nuclear power plants have implemented preventive maintenance programs focused on the most sensitive parts from the point of view of safe operation. In addition, utilities continuously share their experience, events are openly revealed in their essentials in close contact with regulatory agencies, and they establish periodic review programs to some extent, in close compliance with the guidelines and regulations.

In general, active components such as electrical equipment, valves and pumps can be properly monitored in relation to their operating characteristics so they can eventually be replaced by new components, which it is not always a trivial operation if the original manufacturer has discontinued production. This is not the case for passive components, in which ageing is usually more difficult to detect. The passive components statistically most affected by ageing cause are the piping systems, including main piping, fittings, small bore piping & tubing, sleeves, and pipe supports. Incidents are also frequent in heat exchangers, not only steam generators but also secondary side exchangers and condensers, as well as in the field of reactor pressure vessels, and associated internal components such as the control rod drive mechanism. Other passive components with less relevance are the anchorage, concrete and masonry, containment, filters, tanks and other. Cracking is the most predominant ageing effect. Stress corrosion cracking (SCC), corrosion and erosion are the most significant ageing mechanisms. Also relevant are chemical etching, and thermal and mechanical fatigue.

It is not a vain effort to revise time-limited-ageing -analyses, which underlie assumptions of a maximum operating time, sometimes established in the past by economic considerations and market strategy but without a technical reason. At other times, there may be a real technical time limit due to accumulated neutron irradiation, apparition and propagation of fissures, metal fatigue and / or environmental qualification of electrical equipment. Thus, consideration is needed to ensure that safety margins are not eroded under the principles of in-depth defence and minimization of risks to public health. Figure 1 presents these concepts along with the safety analysis review as an added value step.

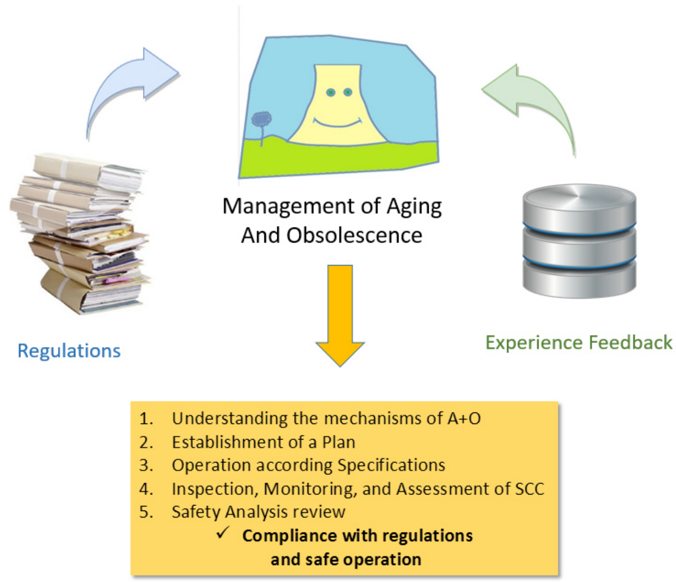

Fig 1. A suitable Ageing and Obsolescence program

3. Transient Analyses Along The Life Of Spanish Nuclear Power Plants

The Spanish plants have been operating for more than 30 years. During this time, the nuclear plants have followed surveillance programs that, in some cases, showed some degradation or lack of effectiveness of various systems. Then it was necessary to demonstrate, by reanalysing the design basis accident, the effectiveness of the system from the concept of defence in depth. In other cases, decisions for replacement were taken in advance before any degradation could occur.

The objective of the Safety Analysis of a plant is to demonstrate that, in normal operational conditions and accident conditions, a sufficient number of barriers are retained to avoid radioactive material release to the environment and the public. During the analysis, the limiting operating conditions, the limiting safety system settings, and design specifications for safety-related components and systems are determined. Then, when some change in one of these systems is needed, a new analysis to demonstrate the same level of safety becomes necessary. Sometimes, new methods or codes, new features or operating condition limits are established to manage it.

ENUSA, sharing responsibility for Core Design and Safety Analysis of Spanish utilities, has been involved in a number of such situations. Different analysis, from part evaluations to complete analysis, with deterministic conservative methodologies or statistical analysis with best estimate codes depending on the case, have been performed to assess the plant managing. In all these cases, careful examination of the fuel and plant thermal limits and suitability of the control and protection systems was verified. Some examples of these circumstances where a reanalysis was deemed convenient, are given below:

- **Steam generator tubes plugging**. The OEM steam generators in some Spanish plants, with Inconel-600 tubes, which is susceptible to Primary Water Stress Corrosion Cracking (PWSCC) were operating with reduced effectiveness because an excessive high plugging level. Thus, specific analysis of the impacted accidents were reanalysed and the margin reduction due to lower heat transfer surface and lower cooling rate was compensated with advanced type of fuel and new operating conditions. The safety analysis showed that all the safety criteria were satisfied despite of the high steam generator plugging.

- **Replacement of Steam generators**. Later, new generators replaced the old ones coming back to the best behaviour of the plant. ENUSA was involved in the analysis to demonstrate the compatibility of the new generators with the nuclear Plant along with new operating conditions. In this case, the analysis showed than the new steam generator provided an extra safety margin, which could be employed for power uprating. Subsequently, power uprates of plant were done later with the regarded analyses.

- **Change from vessel downflow to upflow**. It was demonstrated that some unwished cross flow at the bottom of the fuel in a Spanish Plant was creating unwanted vibrations and continuous mechanical overload on the baffle structures, was because of the differential pressure existing between the alternate flow directions through the core baffles. The impact of this change (differences in bypass flow, in pressure drop, in flow,...) was analysed.

- **Vessel head changes**. An important issue during the life of the Spanish nuclear plants has been to avoid PWSCC on the vessel head. Two actions were taken: a change to an operation from hot to cold head condition and the change of the units head with Inconel-690 penetrations, less susceptible to PWSCC. The new temperature condition in the vessel head was considered and evaluated in the safety analysis.

- **Zinc Injection** is also a strategy for preservation of the primary loop from the degradation phenomena and for the relocation and clean-up of corrosion products. The impact of a new boron dilution way was considered.

- **Improved fuel loading pattern strategy**: The vessel degradation due to irradiation has been also a preoccupation for Spanish nuclear power plants. In this case, low- low leakage core-loading patterns are used in order to decrease the neutron leakage for enhanced neutronic economy, and lower fluence to the vessel. This way, locating the burned fuel assemblies at the periphery of the core depress the power to avoid that a big number of fast neutrons reach the vessel, lowering the possibility of degradation for irradiation. Potential impacts of the power shifting towards the centre of the core are allocated in the Safety Analysis margins of the plant.

All these strategies and changes have been considered together with other improvements in the safety analyses in order to show that all the safety criteria are complied with.

4. From loss of SSC functionality to the safety analysis

In the previous section, some examples are given on how the Spanish utilities have worked against the degradation during their operating lifetime, and this process has to be continued. If we think on a life extension beyond 40 years, it is important from the point of view of Safety analysis to relate the different systems and components susceptible of degradation as it is established in NUREG -1800 with the accidents affected by those components.

Before this, a discrimination is done considering the possibility of a system to be replaced or repaired in case of degradation. Figure 2 shows an example of the previous needed work. Only those components which are not susceptible of replacement and/or repaired, will be considered for review and analysis.

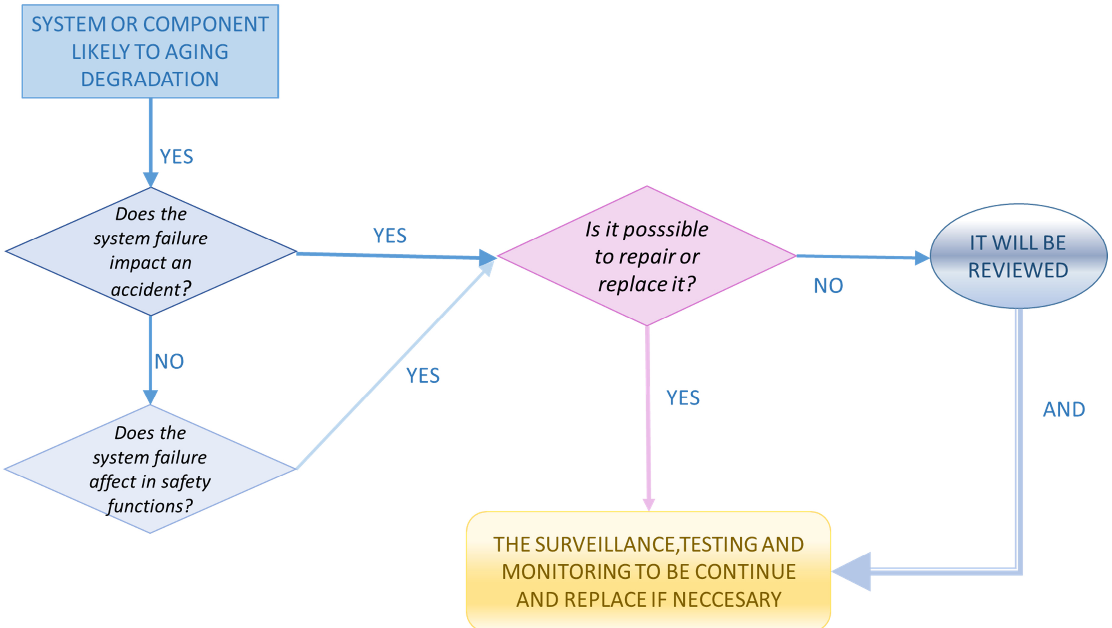

Figure 2. The decision process

After this discrimination process, the accidents turn out to be related to the components and systems so that they will be affected to some extent. Consequently, it will be helpful reanalysing those affected accidents to confirm that the barriers will not fail when a component has been degraded or changed. Table 1 includes some components and systems that are susceptible to degradation as they are related to the accidents resulting from or affected by these faults. Besides, it might be necessary to review if there is a subsequent new accident, which is not on *design basis* or if some of the accidents after degradation change the category and whether or not the safety criteria is more (or less) restrictive.

	Secondary Side Heat Transfer				**RCS Flow Reduction**		**RCS Mass Inventory**			**Reactivity**				
Aging Component	SLB	LLTT & LOAC	LNFW & MFLB	FWM	LOF & LR	SIS	PSV	LOCA	SGTR	RWFS & RWAP	RMIS	SUIL	BDIL	REJ
RCS Piping & Valves														
CVCS, SIS, RHR														
Steam Generators Geometry														
Secondary side Heat Exchangers and Condenser														
RVessel, internals, CRDM														

Tab 1. Impacts of component modifications on transients and accidents analysis (*red - direct impact, yellow - indirect / deferred impact*)

It is worth mentioning the special case of **Reactor pressure Vessel degradation Reduction**. The most important cause for degradation in the vessel is the neutronic irradiation. Different solutions are being proposed in order to reduce the fast neutron fluence. Some of these are the Power Suppression Rods and Shielding Fuel Assemblies. Both require a study from the point of view of thermalhydraulic and transient analysis. Because of the power reduction at the periphery, the power distribution is shifted towards the core centre, so that skewed power distributions have to be considered. If shielding fuel assemblies are located in the periphery, the replacement of UO2 rods by SS rods will increase the maximum linear heat rate (kW/m). The new distribution and the new peaking factors limits have to be considered in the safety analysis and the thermal margin penalty has be compensated for example using an improved fuel assembly design (with IFM) or by adopting improved analytical methodologies.

5. Conclusions

There is no expiration time implicit in the FSAR chapter 15 analyses. Still, the effects of ageing on materials have to be addressed in preventive maintenance programs. Eventually, this practice may not be sufficient and a safety analysis of the plant to show compliance with standards and regulations is needed. Thus, the safety analysis is a necessary complement in a healthy strategy of extending the plants life.

The Spanish plants have been operating for several decades and the effects of ageing have been tackled by replacing some of the SSC, performing a safety analysis to compensate the eventual penalties on thermal and fuel margins, or both actuations together. Depending on the case, a quite significant number of transients was involved. The accomplishment of these works and determination of the impact, allowed to approach the changes or to solve the questions related to ageing, and even helped to determine some of the operation characteristics of equipment before its incorporation to the plant.

Each utility deals with the challenge with a different combination of solutions, but in any case, keeping an updated safety analysis in good harmony with the regulation is always a good strategy to address the extension of plant life.

6. Acknowledgments

Authors wish to thank ENUSA for the support and availability of tools and time needed for this research work.

7. References

[1] NUREG-1801 rev.2, Generic Aging Lessons Learned (GALL), NRC, December 2010.

[2] In-Kil-Choi *et al*, Identification and Assessment of Aging-Related Occurrences in Nuclear Power Plants, KAERI, July 2011

[3] IAEA Safety Standards, Safety Guide No. NS-G-2.12 “Ageing Management for Nuclear Power Plants”

[4] 10CFR 54: Requirements for renewal of Operating licenses for NPP

[5] IS-22, de 1 de julio de 2009, del Consejo de Seguridad Nuclear, sobre requisitos de seguridad para la gestión del envejecimiento y la operación a largo plazo de centrales nucleares