

# **Design, Maintenance and Lifetime of Nuclear Components: The Contribution of Experience Feedback**

**R. L. Noel**

*Electricité de France, Paris, France*

**D. G. Eisenhut**

*NUS Corporation, Gaithersburg, MD USA*

**J. J. Carey**

*Electric Power Research Institute, Palo Alto, CA USA*

**L. J. Reynes**

*Electricité de France, Villeurbanne, France*

## **ABSTRACT**

Division D of SMIRT deals with experience feedback relating to the in-service behaviour of nuclear components, the design and construction of this equipment, its maintenance and the evaluation and management of its lifetime. The nuclear industry now having reached maturity, with more than 300 units in service worldwide, these problems are now of predominant importance to the activity of the industry and in its development programmes. This applies particularly to the problems relating to the lifetime of nuclear plants, problems which are rightly of such concern both to the utilities, in view of the enormous investments involved, and also to the safety authorities.

All the main issues concerning the mechanical behaviour of nuclear components have been presented at SMIRT conferences since 1981. These issues concerned in particular reactor vessels, steam generators, piping, bolts, containments and diesel generators. The majority of the many and valuable papers presented related to LWRs, which are by far the most numerous.

These contributions have been reviewed for the purpose of analysing the essential points. This analysis highlights the considerable advances achieved during the recent decades in design and maintenance methods and practices.

It also identifies the areas in which progress still remains to be made.

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### 1. A RECENT HISTORY

Division D of SMIRT, which deals with experience feedback relating to the mechanical behaviour of nuclear structures, was created recently. The subject was first discussed in a seminar at the time of SMIRT 6 held in Paris in 1981 but Division D was not set up until SMIRT 7 in Chicago in 1983.

The relatively recent appearance on the scene of experience feedback is not surprising. It follows the natural development of the nuclear industry. First we had the pioneering period, from 1955 to 1965, with its almost infinite variety of reactors and prototypes. Then followed a phase of rapid expansion, geared to "conquering territory", and roughly covering the years from 1965 to 1980, which was dominated by design and construction problems. This growth has now come to a halt which we hope will not last too long. However, it also corresponds to a phase of maturity and industrial operation. More than 330 nuclear power plants are in

operation throughout the world, supplying more than 40% of the electricity produced in many countries, and as much as 70% in France. This being so, the major issues which arise are the proper operation of the installations which result from these massive investments, as well as their maintenance and their lifetime.

During its short lifetime of 6 to 8 years, Division D of SMIRT has benefited from a large number of very valuable contributions dealing with all the major problems relating to the in-service behaviour of nuclear equipment: pressurized thermal shocks on the reactor vessels, corrosion of piping and steam generator tubes, thermal stratifications, bolts, emergency diesel generators, containments etc. We will carry out a brief analysis of the essential points of these contributions in this paper.

More recently, Division D has provided a forum for technical discussions relating to the evaluation and life extension of nuclear plants, a question which is of great importance to all operators.

Lastly, Division D has been honoured with contributions from personalities invited as principal participants. In 1983, Mr. Karl Stahlkopf of EPRI outlined the American studies and conclusions concerning the problem of PTS on PWR reactor vessels.

In 1985, Mr. Richard Volmer of USNRC presented that organization's opinions regarding the optimum compromise between the severity of hypotheses for improbable accidents and the requirements of normal operation.

M. Lucien Bertron of EDF, on the basis of his experience as operator, identified the elements tending to prolong the lifetime of nuclear plants by using ageing indicators, certain of which exist already while others are still to be developed.

## 2. OBJECTIVES OF DIVISION D

The activities of Division D are centred around two poles of interest: experience feedback and maintenance.

It is both **essential and difficult** to incorporate these satisfactorily into an organization such as SMIRT whose basic purpose is research and development in the field of structural mechanics.

We have already explained why issues concerning operation, maintenance and lifetime seem to us to be **essential** to the equilibrium of SMIRT's activities. It is simply because, as of now, in the majority of "nuclear" countries the "maintenance" turnover figures of the nuclear industry are at least as great, if not more than, those of "construction", and it is this turnover which supports R&D.

It is perhaps less clear why it is **difficult**, although the authors of this paper, who have been in charge of Division D since its creation, have this very strong impression. The reason for this is that there are two difficulties to be resolved, a minor one and a major one:

a) The **minor difficulty** concerns the **transverse position** which maintenance and experience feedback occupies in relation to all other SMIRT divisions. The handling of a problem relating to in-service behaviour is also that of a reactor component (Divisions E, F or H). The way in which these problems are handled increasingly involves the use of advanced techniques which then become routine: design methods obviously (Div. B), fracture mechanics and non-

destructive examinations almost always (Div. G), probabilistic or reliability analyses (Div. P and Div. M respectively) with increasing frequency. We will therefore find, more and more, that the majority of contributions to SMIRT will concern Division D to some extent, while the majority of papers presented in Division D could equally well be presented in another division.

Up till now, these minor problems have been solved informally, by agreement between the coordinators and the organization of joint sessions, especially between Divisions D, F and G.

For the future, a more stable equilibrium should perhaps be sought. One possibility is that the other divisions could regularly organize one or two sessions D, X, whose purpose would be to deal with experience feedback problems. Division D itself would then only deal with general problems relating to maintenance and lifetime. The general organization would be that shown in Figure 2.1.

b) The **major difficulty** for Division D is to interest the operators and their delegates, constructors and maintenance and service organizations in SMIRT; ie, convince the operators and NSSS vendors that they have something to gain by coming to SMIRT to present all the little problems relating to the mechanical behaviour of their equipment. It is, of course, their duty to do so in order to contribute to the pool of scientific knowledge, but this duty is an exacting one, the disadvantages of which are more obvious than the advantages. When one devotes one's time and energy to trying to convince the public that nuclear power plants are basically very safe, very reliable and very economical (which is in fact absolutely true), it is not easy to follow this up by announcing that copper steel is vulnerable in the face of neutrons, that piping is not totally resistant to thermal stratifications and residual stresses, that rustproof materials are susceptible to almost all forms of corrosion, etc. This is perhaps too paradoxical for our media-dominated society in which everything is for the best in the best of all possible worlds, as has long been proved by Leibnitz.

And yet, it is often through an understanding of what is going wrong that progress is made.

In short, we have no miraculous solution for persuading operators to bring their problems to SMIRT. In the past, we have had only limited success in this respect, obtained with difficulty and most often due to the personality of the coordinators or to the roles which they played.

This point appears to us, however, to be fundamental to the future of SMIRT.

### **3. LIFETIME OF NUCLEAR POWER PLANTS**

#### **3.1 Motivations**

Nuclear power plants are highly efficient, safe and competitive generating tools. For those utilities who have adopted this form of energy production, they represent considerable investments from which it is their duty to obtain maximum return, a consideration which applies also to their potential lifetime. This is especially true given that there is nothing to suggest that in 10 or 20 years time the constructors will be able to market new production equipment which will significantly outclass recent installations in terms of safety, economy or ecology. This situation is very different from the one experienced by the producers of the preceding generation when technical progress was such that equipment put into service during the thirties was completely out of date thirty years later as shown in Figure 3.1.

Programmes for the comprehensive study of "life extension" possibilities first began in the United States, for a very obvious reason which is illustrated in Figure 3.2, from the paper

presented by D.G. Eisenhut at SMIRT 9. In the United States, operating licences are granted for 40 years. For all installations commissioned before 1983 this period is counted from the date of the construction licence, which limits the service life to about thirty years.

If this situation does not change, more than 60,000 MW will be withdrawn from service between 2005 and 2015. As work must now be started 10 years in advance when constructing a power plant, the problem to be solved is an urgent one.

For other countries operating extensive nuclear programmes, the problem does not arise in exactly the same way as, in most cases, there is no official legal limit to the validity of licences, but basically there is not much difference.

In France, following the oil crises of the seventies, an enormous effort has been made to establish a programme of nuclear power plants, thus reducing the country's dependence on fossil sources of primary energy imported in vast quantities. Today, EDF operates 48 PWR units, totalling 50,000 MW, the oldest of which has only been in operation for 12 years. The construction of this exceptional production tool continues, albeit it at a slower pace. Its replacement is obviously not yet due, but it is not too early to begin to think about it. In any case, it must be operated in a rational manner, without sacrificing the long term to more immediate matters of efficiency. It is for this reason that EDF also decided, as an extension of the standard maintenance studies, to undertake a programme of systematic evaluation of the potential lifetime of its PWRs and to use it in a rational manner. Figure 3 illustrates the use which EDF could make of the possibilities for extending the lifetime of the PWR units in order to make their replacement much more progressive than their construction.

Other similar study programmes are under way throughout the world, although at SMIRT only those mentioned have been discussed.

### **3.2 Consistency of the lifetime study programmes**

By the nature of things, the programmes are all very similar. They always entail the determination of the technico-economic factors which could limit the period of operation of a nuclear plant, without of course omitting safety considerations.

First of all, an assessment is made of what can reasonably be said regarding the longevity of the principal components of the plant, called "critical components". This is the components for which the cost of major repairs or replacement would be very high, so that these operations are not normally allowed for in the standard maintenance budgets. This is obviously the case, for example, of changing the steam generators of a PWR or the recirculation loops of a BWR.

It should be pointed out here, in order to avoid any ambiguity arising from the use of the term "critical" that we are not making any *a priori* suppositions regarding a probable low longevity for components so called.

On the basis of this selection, we review everything which can be said today regarding the factors affecting lifetime, according to the design studies, manufacture, operating experience, monitoring and in service inspection. The data gathered brings to light certain conclusions which are already quite clear, and also questions the answers to which require additional work.

### 3.3 Preliminary conclusions

From what has already been done, which represents a considerable amount of work, certain conclusions already appear, at least for the LWRs and especially for the PWRs which, being more numerous, have already been the subject of a maximum number of studies.

a) In the majority of cases, it appears that nuclear power plants, with the exception perhaps of the oldest ones, must be able to operate, in a safe and reliable manner, for at least 40 years and sometimes more.

b) This objective is **possible**, because all the “critical equipment” analysed could, if necessary, be repaired or changed, with the exception perhaps of the reactor vessels and the principal containment structures, equipment for which a long lifetime is probable.

c) Operation should be **profitable**, because the corresponding maintenance costs are unlikely to reach an unacceptable level. This can be proved by simple economic calculations, taking into account the cost of constructing, operating and dismantling the present plants and of their probable replacements.

### 3.4 Safety problems

It is obvious that maintaining a nuclear power plant in operation cannot be done at the expense of safety. Safety is a basic requirement which must be respected whether or not the operating licence is officially limited in time. This is a fundamental rule in all studies relating to plant lifetime.

This question raises two main categories of problem:

a) Problems concerning the conformity of a plant to the current general design rules of the “systems”

We must ask ourselves whether the plant which we wish to maintain in service conforms to the rules currently applicable and, if not, how great the deviations are and what the possibilities are of reducing them to an acceptable degree, and at what cost. This applies to the organization of successive barriers, safeguards, resistance to earthquakes and to other exterior impacts etc. This subject can only be examined on a case by case basis. The solution is obviously easier in the case of plants constructed more recently. In the long term, a certain optimism will doubtless be justified, given that the fundamental safety rules in western countries have not been subject to radical change over the past twenty years.

On the contrary, the two dramatic events of this period confirmed the validity of these rules: at Chernobyl because they were not applied and at Three Mile Island because there were no victims.

In these domains, the major developments of the foreseeable future will doubtless concern the problem of the man-machine interface. Even if they result in major revisions to the instrumentation and control systems, as we have already seen in the most recent constructions, the cost of these revisions should remain at an acceptable level.

In the same domain of system studies, in which it is not easy to express in measurable values the “safety level” sought, the progressive development of the probabilistic analyses will doubtless be useful, provided that these analyses are supported by solid data banks established on the basis of experience feedback.