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RAPPORT DAS N° 535e

SAFETY ASPECTS OF NUCLEAR POWER PLANT COMPONENT AGING

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International nuclear power plant aging symposium.
(Bethesda (USA), 30 août-1er septembre 1988)

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1. INTRODUCTION

The safety of nuclear plants depends on the capacity of the systems they are composed to perform, throughout their planned service life and under all operating conditions allowed for in the design of the installations, the functions they were designed for.

The identification and understanding of phenomena liable to degrade this operational capacity thus constitute one of the safety problems for which allowance must be made at the earliest stage of a project.

Aging, a natural and hence unavoidable process affecting all the components of an installation, was identified at a very early stage as being one of these phenomena.

The investigation and implementation of solutions to the safety problems associated to aging make it necessary to:

- defining the domain in which the consequences of aging are to be evaluated,
- identifying the parameters involved,
- identifying the components sensitive to these parameters,
- understanding the mechanisms which govern its evolution.

The results of qualification tests, and of tests and checks carried out at different stages of construction and operation, as well as allowance for operating experience, constitute the necessary basis for establishing or improving the regulatory requirements. The procedures for validating components and systems of the installation are also drawn up on the basis of these tests.

Finally, the actions initiated within the scope of research and development programmes supply the additional data necessary for such validation, and provide the indispensable support for knowledge improvement.

2. SCOPE OF EVALUATION OF THE CONSEQUENCES OF AGING

2.1 Aging considered

The properties of all materials change with time. This change, which occurs at varying rates, essentially depends on the suitability of the initial properties of the material to its actual conditions of use.

Within the scope of the current studies, aging is assimilated to the evolution of the properties of safety related components during normal operation of the plants.

Operating discrepancies due to errors or to design inadequacies are not considered to be linked to aging of components.

2.2 Life-time taken into account

The operating authorizations for French nuclear plants are based on the demonstration of the safety of the installations.

The technical solutions proposed by the utility at the design stage are intended to provide safe operation of the installations for 40 years. It is this value of 40 years which was adopted for evaluating the consequences of component aging.

3. PARAMETERS CONTRIBUTING TO AGING

The parameters which contribute to aging derive from the operating conditions and from the technical solutions adopted in the design of the plant.

They can be divided into two categories:

- **ambient conditions**

These are defined by the physical parameters which characterize the atmosphere prevailing in the areas where the components are located.

Three categories of facilities are considered:

- containment,
- contaminatable areas,
- non-contaminatable areas.

The parameters considered relate to pressure, temperature, humidity, chemical composition and degree of radioactivity of the atmosphere prevailing **in these areas.**

- **the operating conditions**

These are essentially characterized by:

- the mechanical stresses (vibration, transients and water hammer). They result from normal operation and from loading characteristics of the systems during startup or shutdown of active components, as well as interaction phenomena between components of a given system and between systems and structures of the building.
- the stresses linked to the parameters of fluids carried by the systems (water, effluents etc.), and to fluids supplying the active components (compressed air, electric power etc.).

It is the **cumulative effect** of the parameters resulting from these operating conditions which will modify the initial properties of the components and thus age them. This aging must not, in particular, compromise the functional capability of the systems required under accident conditions.

The synergies of the phenomena which govern aging are extremely complex and are not yet fully understood, at the present state of art.

4. COMPONENTS SENSITIVE TO AGING

4.1 General remarks

It is customary to use the term "component" for all materials (concrete, paint, polymer, steel etc.) or equipment (cable, valves, pumps etc.) constituting an elementary system. It is in this sense the word "component" is to be understood in this paper.

4.2 Components concerned by aging studies

4.2.1 General identificaton of the components

The effect of the parameters contributing to aging must be evaluated for all the components necessary for the prevention of accidents and the mitigation of their consequences.

• **Prevention of accidents**

For the purposes of the prevention of accidents, all components of safety-related systems in process under normal operation of the installation must be identified.

It is obvious that all the components of the primary circuit must be taken into consideration, as must those involved in scrams, in bringing back the reactor to various safe shutdown states and in maintaining it there.

• **Mitigation of consequences**

Apart from the components of the engineered safety systems of which the operating capability may be degraded by aging phenomena, the components necessary to guarantee the "radioactivity confinement" function must also be included in this study.

Finally, the list of the main system components must be supplemented with the auxiliary supporting system components necessary for their operation, as well as those of the various supporting elements and links with the containment and the concrete structures of the buildings.

In fact, preparation of such lists involves a detailed design review of each system or of each function which is safety related. This will be used to identify the active and passive mechanical components, electrical components, concrete and miscellaneous materials the degradation of which may induce the failure of a function. The system components provided for automatic or manual startup of the main and supporting auxiliary systems, or for the monitoring of their operation, must also be included in the lists.

4.2.2 Selection of components

The number of safety-related components is too high for considering to study the effect of aging on the operating capability of each of them.

It is therefore necessary to select the components which are to be studied.

The selection is carried out on the basis of design and system operating conditions analyses which make it possible to classify, for each main system, the identical components (same design and same manufacturer), operating under similar ambient conditions (containment, contaminatable area or non-contaminatable area) and operating conditions (stresses).

In selecting the components, particular care must be paid to paints, varnishes, oils, greases, polymers and elastomers which are very sensitive to aging phenomena. It is frequently the degradation of the characteristics of such components which is the origin of the failure of major components such as motors, valves and pumps etc.

The influence of aging is studied on a component representative of the categories thus defined.

Standardization of the French nuclear units facilitates this selection and limits the number of representative components to be considered.

5. ACTION TO CONTROL AGING

Since 1975, the approach adopted in France to control aging is based on a prevention policy oriented towards obtaining and maintaining equipment quality, quality being defined as the capability of equipment to operate correctly in service. This approach, which assists in delaying the consequences of aging, is applied at the different stages of design, construction and operation of the plants.

5.1 At design stage

5.1.1 General principles

At the launch of the French nuclear power programme, regulatory requirements concerning the quality of the installation were laid down for the power plants. These are clearly stipulated in the creation permit of the installations:

"Electricité de France must take measures to obtain for the safety-related structures, systems and components, a level of quality which is sufficient in view of the functions which they perform. An efficient system, enabling the definition of the level of quality to be attained, obtaining it, verifying the results and correcting any errors, must be implemented. This system must include the implementation of a verified series of scheduled and systematic actions, based on written and archived procedures." (Extract from decree 76-59 of 2nd July 1976. Creation permit of the four units of Tricastin Power Plant).

The qualification programmes, the purpose of which is to demonstrate the functional capability of the equipment, constitutes the first step of this regulatory requirement.

The general principle of the qualification sequence is shown in Table 1. Tables 2 and 3 illustrate in a more detailed manner the different tests carried out to qualify the electrical and mechanical components for normal operating conditions of the plant and, in particular, for phenomena occurring in aging mechanisms.

The "aging" tests are always carried out at the start of the qualification sequences. As an accident may occur at the end of the service life of the plant, it is essential to make sure that aging of the components does not compromise the functional capability of the safety systems and of the emergency systems necessary for managing such situations and limiting their consequences into the environment.

5.1.2 Parameters allowed for defining the aging tests

During the aging tests, damage of components must be representative of that occurring in 40 years of plant operation, the period conventionally allowed for.

Predicting the actual conditions of operation of the corresponding components in such a period includes a margin of uncertainty which it is difficult to assess. Consequently, the aging tests are established on the basis of the envelope values of the physical parameters representative of their operating conditions.

Thus, it is considered that:

- the envelope ambient conditions of an area affect all the components located in it,
- the envelope values of mechanical and thermal stress induced by a fluid are sustained by all the components of the system carrying this fluid.

The standardization of French nuclear units and operating procedures, as well as the presence of a unique utility, also facilitate establishing these physical parameters and minimize the number of aging test sequences.

5.1.3 Aging test limits

However stringent the definition and execution of the tests may be, the tests cannot simulate actual component aging.

The representativeness of the tests is particularly limited as:

- in the test facilities, a complete system cannot be checked and not all the physical parameters governing the aging phenomena can be taken into account at the same time. The tests are carried out sequentially and the synergy of the phenomena is thus only partially allowed for,

- the duration of the tests may be too long when it is necessary to extrapolate the acceleration laws up to the technological limits of certain components.

Despite this limitation, the lessons drawn from such aging tests are of fundamental importance.

In particular, they make it possible:

- to monitor, at different stages of accelerated aging, the properties of components and identify those which are more sensitive to particular phenomena,
- to constitute a database concerning the foreseeable behaviour of components, the data can then be used together with that obtained during operation of installations to prepare component maintenance systems,
- to eliminate any components which are not suited to the planned conditions of operation.

If, for a given function, there is no component which has passed the aging tests, a request for a concession may be made by the utility. Analysis of the proposals frequently leads to reducing the duration of use of the component to a value compatible with maintaining its functional capability. If necessary, a research and development programme is initiated.

Thus, the presence of components such as seals, insulators, plastic and grease has resulted in limiting the operating period of isolation and adjustment valves pneumatically actuated. 25 valves of this type are used in each French PWR, 12 of which providing the "containment isolation" function. The operability of the most sensitive component, the diaphragm used in the pneumatic actuator, was only guaranteed for an integrated dose of 100 kGy. Therefore, the utility has proposed, for the qualification tests, an integrated dose level compatible with such guarantee:

- Aging irradiation level 35 kGy,
- Accident irradiation level 65 kGy.

In complement of this proposal, the utility commits itself to replace every ten years, the component sensitive to the aging due to irradiation.

In order to evaluate the validity of the utility proposals, the maximum values of the corresponding doses actually integrated by the diaphragms have been estimated on realistic basis; then the potential consequenes of the valve failure have been evaluated.

As the safety analysis has demonstrated the compatibility of these proposals with the safe operation of the plants, the concession has been accepted. Furthermore, in order to maintain sufficient safety margins, the utility commits itself to replace the diaphragms every five years.

5.2 At construction stage

The tests carried out at different stages of construction of the installation constitute the first tests demonstrating the functional capability of the components and systems under operating conditions which are very similar to those occurring during operation. In particular, the synergies associated with the interaction between the components and the interactions between systems and structures are present during such tests. The functional values and parameters specific to the components, recorded under these conditions, are thus characteristic of the state of the installation at the start of operation. They make it possible to supplement the database for aging tests and constitute the "zero point" from which evolution in functional capability due to aging will be monitored.

5.3 At operation stage

The restarting tests, the periodical tests and the in-servive surveillance constitute the principal means of following up of aging. They also make it possible to increase the understanding of the phenomenon.

The action initiated to control aging is based on the results of these tests and on surveillance operations.

6. CONTROL OF AGING

6.1 Principles

The mechanisms which govern aging are not yet fully identified, and control of this phenomenon remains difficult.

The action initiated is intended to limit or delay the consequences of aging of components for the safety of the installations. It is based on analysis of changes in the criteria and performance levels of components and systems as observed during operation of the plants, and consist in replacing or repairing the degraded components.

Although the French nuclear power plants are still relatively young, the older plants yet attained 70 000 operating hours. Current availability of the installations has shown the high quality of operation. Maintaining this performance level will depend greatly on the quality of the maintenance work planned, particularly for the components sensitive to aging phenomena.

6.2 Maintenance

Different types of maintenance are applied on French installations:

- **curative maintenance**:

  this consists in replacing or repairing faulty equipment,

- **preventive maintenance**:

  this consists in schedulling maintenance work on the basis of criteria relating to operating hours or a numbers of startups.

The preventive maintenance programmes include following up of the behaviour, under the operating conditions and, in particular, under irradiation, of the lubricants necessary for preserving the functional capabilities of the systems, as well as their replacement.

The aging laws of these components are not well understood, specific tests have therefore been carried out on simulation testing benches to both select the lubricants best suited to the requirements and also to optimize the frequency of their replacement.

These tests have already made it possible to select greases adapted to operation of the emergency safety system pumps and of the residual heat removal system. Other tests are in progress to identify the lubricants best suited to the operation of other pumps.

- **predictive maintenance**:

  here, the maintenance work is initiated on the basis of physical criteria representative of the state of the equipment in operation. This maintenance, which is considerably more sophisticated, is based on in-service surveillance of the installations.

At the present state of art, predictive maintenance cannot be applied to all the components sensitive to aging. Nevertheless, preventive and predictive maintenance already represent 70% of the activity carried out in French installations in this field.

Generalizing the predictive maintenance necessitates identification of all the physical parameters which are the most sensitive to aging phenomena, and development of the necessary methods for following up their progress.

Research and development programmes are under way to meet these requirements.

7. CONCLUSIONS

Maintaining the quality of the installations, which is necessary to ensure a sufficient degree of safety and availability of the plants, depends on the development of maintenance activities.

The aging of components must be limited or delayed to guarantee that the criteria provided for at the design stage are met throughout the planned service life of the installation.

Should plant life extension be envisaged, the actions and arrangements implemented to control the aging of components will contribute to finding the solutions necessary in attaining this new objective, which can be only reached if the safety of the plants remains demonstrated.

TABLE 1

GENERAL PRINCIPLES OF MECHANICAL AND ELECTRICAL EQUIPMENT QUALIFICATION

LOCATION	NORMAL OPERATION				ACCIDENT PHASE			POST ACCIDENT	EQUIPMENT CLASSIFICATION	
	Aging									
	Thermal	Functional	Irradiation	Mechanical vibrations	Earthquake	Irradiation	Thermodynamic conditions		Electrical	Mechanical
	V_1	V_2								
	V		I	5		1	A	P.A.		
INSIDE	X	X	X	X	X	X	X	X	K1	
CONTAIN-MENT				X	X					M1 Valve: electrically actuated
	X	X	X	X	X	X	X	X		M1 Valve: electricopneu-matically actuated
OUTSIDE		X		X	X				K3	
CONTAIN-MENT				X	X					M2 Valve: electrically or electropneumatically actuated

TABLE 2

TEST PROCEDURE FOR IN CONTAINMENT ELECTRICAL EQUIPMENT

PREPARATION OF PROCEDURE AND REFERENCE TESTS

- Examination of identification dossier and supplementary documents
- Tests of dielectric strength and/or isolation resistance measurement
- Measurement of functional characteristics

TESTS AT FUNCTIONAL OPERATING LIMITS OF EQUIPMENT

- Linked to nature of equipment
- Linked to equipment installation conditions (ambient pressure, ambient temperature etc.)

ASSESSMENT OF EQUIPMENT BEHAVIOUR OVER A PERIOD OF TIME

- Thermal aging test
- Accelerated damp heat test
- Prolonged operating test
- Cumulated radiation during operation
- Mechanical vibrations resistance test

STRESSES DUE TO ACCIDENT CONDITIONS

- Earthquake resistance test
- Cumulated irradiation during an accident inside the containment
- Themodynamic and chemical conditions representing an accident inside the containment

TABLE 3

Qualification of electrical equipment

Accelerated aging

Tests for assessment of equipment behaviour over a period of time

- Thermal aging tests
- Dry heat tests
- Cold tests
- Sudden temperature change tests
- Resistance to mechanical vibrations
- Resistance to mechanical shock
- Accelerated damp heat tests
- Cyclic damp heat tests
- Saline mist tests
- Dust penetration tests
- Cumulated irradiation during operation of reactor under normal conditions
- Prolonged operating tests

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