TRACKING DEGRADATION AND EVALUATING REMAINING LIFETIME OF NPP COMPONENTS

M. AGUADO - C. CUETO-FELGUEROSO

In recent years, the electrical sector has allocated numerous resources to developing and implementing strategies aimed at optimizing the remaining lifetime of facilities. However, more work needs to be done in this field, in order to more reliably and fully track the status of component aging. In this respect, one of Tecnatom's primary objectives is to optimize, validate and develop new degradation detection and diagnostic techniques, improve remaining lifetime evaluation methods and design integrated tracking tools. The lastest achievements and advances are described in this article.

INTRODUCTION

The electrical sector, both in our country and abroad, has worked extensively on research and implementation of strategies for remaining lifetime management, as it is aware of the need not only of extending the life of facilities, but also of improving these facilities' reliability and availability factors.

In recent years, during which we have spoken successively of life extension, then remaining life management and finally aging or even asset management, studies have been carried out on poorly understood degradation mechanisms in order to develop different methodologies both for selecting and evaluating critical components, to design component inspection or monitoring equipment, etc.

In any event, the main philosophy of life management is still the same, i.e. to focus on providing tools that can be used to ascertain or evaluate component status, and on strategies intended to mitigate aging or even to repair or replace the component. This latter possibility should also be taken into consideration, as evidenced by steam generator, turbine rotor, etc., replacements.

However, although many advances have been made in this field, there is still much work to be done in sevaral areas:

- Research into degradation mechanisms whose influence is still not well understood.
- Development of techniques, equipment or methods to detect, evaluate and reliably track the degradations mechanisms that are considered as having the most significant or limiting effect on effective plant life.
- Development and implementation of tools to assist in the overall interpretation and evaluation of the remaining lifetime of main components.
- Integration of aging management and life evaluation concerns with the operating criteria of facilities.
- Development of criteria to help make decisiones on optimum repair, redesign, replacement, etc. strategies.

As one of the sector companies whose mission is to contribute to improving nuclear power plant operation, Tecnatom has been committed from the very beginning to issues relating to plant life management. From its main areas of activity, it has contributed to developing techniques, methods or tools in general for tracking degradation or evaluating remaining life.

The following paragraphs briefly describe the main recent or ongoing developments in which Tecnatom has been involved, either on its own or in conjunction with other sector enterprises. The purpose of these developments is clearly aimed at optimizing nuclear power plant life management through degradation detection, diagnostic and tracking techniques and methods, as well as through integrated tracking tools that can be used to continuously and realiably monitor the status of material and component aging.

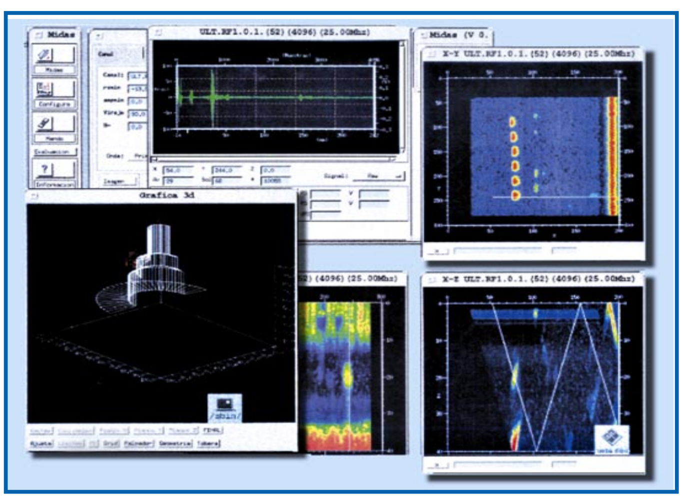
DEGRADATION DETECTION AND DIAGNOSTIC TECHNIQUES

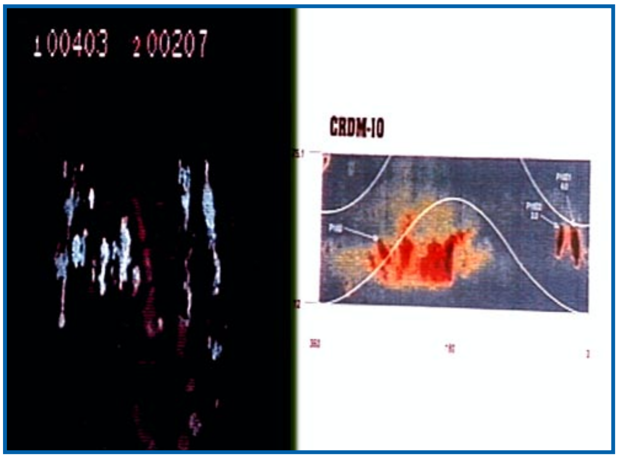
Once a component has been considered as critical for purposes of life management and the degradation mechanisms that can potetially act on this component have been determined, the next step is to select the most suitable technique for detecting the presence and possible influence of these degradation mechanisms. Many factors must be considered when selecting either an inspection or monitoring technique:

- Area and application conditions
- Sensitivity to the degradation mechanism
- Reliability (detection thresholds, degree of incertitude, etc.)
- Periodicity
- Interpretation and evaluation of results
- Cost.

It is extremely important to select a technique that is sensitive to the degradation mechanism

F I - *MIDAS System. Multitechnique data acquisition (eddy-current and ultrasound).*





F II - *Results obtained from visual and eddy-current inspections of a CRDM.*

to be evaluated, in order that this mechanism can be detected from the time it first appears and its influence can be reliably tracked.

Most NPP components are currently checked for aging on the basis of in-service inspections, although monitoring and diagnostic techniques are increasingly being used.

Both techniques - inspection and monitoring - have advantages and disadvantages. The advantages of inspection include greater reliability in detection and the fact that no additional instrumentation is permanently required, whereas the advantages of monitoring include the possibility of tracking on a more continuous basis without the need to shut down the facility.

It is obvious that the two techniques are not mutually exclusive but rather complement each other. The ideal strategy is to establish a balance between the two by accounting for the above mentioned factors, as well as other considerations such as standards, requirements of Regulatory Authorities, plant-specific problems, etc., so as to allow for adequate tracking on the basis of both inspections and monitoring.

Although historically Tecnatom has been a leading in-service inspection firm, it has not overlooked the monitoring aspects that, as mentioned above, will play an important role in the future as a complement to inspection.

As regards each of these techniques, beginning with inspection, the sector has devoted a much time and effort to the following areas:

- **Optimization** of inspection techniques and equipment.

Continuous progress is being made in optimizing techniques and equipment in terms of the following:

- Improving the reliability and repetitiveness of tests using automated equipment, which also contribute to the reduction of personnel dose and inspection times.
- Decreasing the detection threshold in order to evaluate the presence and influence of the degradation mechanism in the early stages of development.
- Simplifying interpretation of results, with additional result processing, storage and evaluation programs, which results in improved historical tracking of defect indicators and the general state of the component.

Examples would include the use of:

- Ultrasound array systems, for monitoring defects associated with BWR plant CRDs.
- Advanced, multitechnique data acquisition systems (MIDAS) with complete signal storage for optimizing material degradation tracking. (Fig. I)

- **Development** of new inspection techniques and equipment.

The emergence of degradation mechanisms in zones where they were not initially expected, as well as the need for better control of component aging, are resulting in the development of new inspection techniques and equipment for application to zones or components that are hard to access or require complete disassembly.

These new developments would include the following:

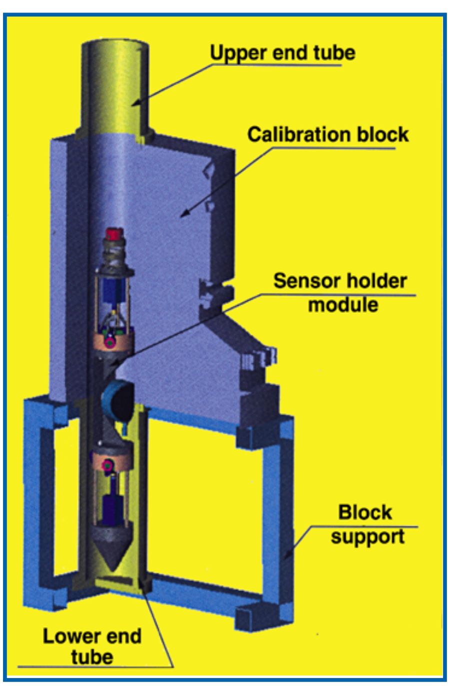
- New device for ultrasound inspection (UT-GAP) of CRDM's without having to cut the thermal sleeve, developed in the framework of the electrical sector's PETAVA Project (Vessel Head Penetrations). (Fig. II)
- Turbine Gear Inspection System (SIRENA) using array focalization techniques, the main advantage of which is that they avoid blade destruction, which up to now had been necessary for inspecting gears, according to the recommendations of some suppliers. (Fig. III)
- Laser vision techniques, to be used as a supplement to eddy-currents in inspecting steam generator tubes, in order to optimize surface crack characterization. (Fig. IV)
- System for eddy-current inspection of control rods. (Fig. V)

- **Validation** of inspection techniques.

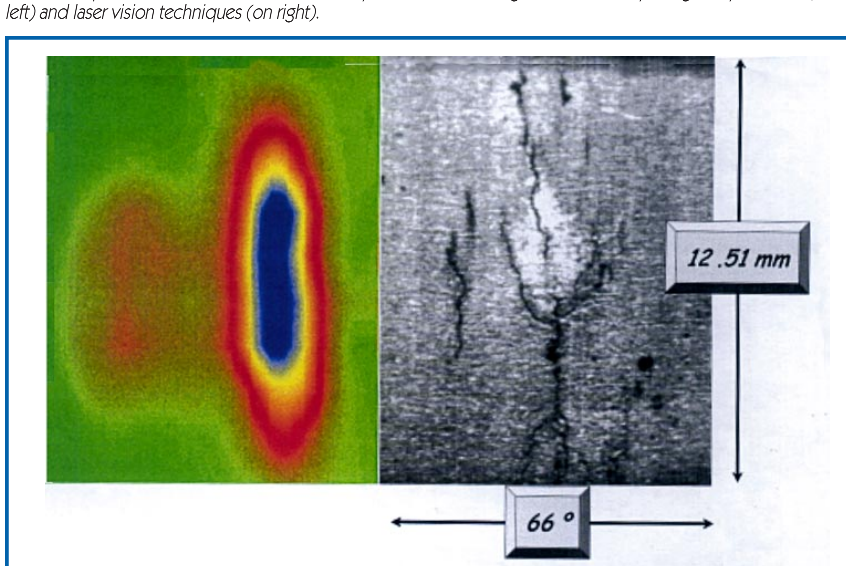
It is particularly important to focus not only on the techniques and equipment as such, but also on their validation in order to ensure that they can be reliably applied to inspection techniques.

As a result, many resources are allocated to mock-up training for personnel, preparation of

F III - *SIRENA system for inspecting turbine gears. Inspection Module and Calibration Block.*



F IV - *Comparison of results obtained from inspection of a steam generator tube by using eddy-currents (on left) and laser vision techniques (on right).*



technical justifications, etc. (Fig. VI)

As concerns monitoring, which is becoming increasingly relevant, both suppliers and service firms are making many advances, and many plants now have such a system. One of the more common ones is to monitor vibrations or the main operating parameters, in order to determine whether they fall within the normal acceptable performance range of the component or system.

These systems vary in complexity, ranging from systems that monitor only whether the parameters vary inside their acceptable limits as mentioned above, to systems that perform more complete diagnostics, determining the possible causes of deviation from normal behavior or even providing recommendations to the operator.

Tecnatom and the sector in general are also making progress in developing this type of system supported by other tools, such as Process Supervision Systems (SAMO, SPDS, SATA, GAMA-I, etc.), or by specific applications such as the Watchman Optimization System (SOR). (Fig. VII)

Therefore, a suitable combination of inspection techniques and monitoring and diagnostic systems is the key to life management, as it permits the detection, diagnosis and surveillance of material degradation and component defects. Monitoring is the key to examining components in the intervals between inspections, and inspection in turn between other functions, in order to realistically validate the diagnosis provided by the monitoring system.

DEGRADATION AND REMAINING LIFE EVALUATION METHODS

Inspection and monitoring techniques provide information required to ascertain the status of the component under study; however, in most cases, specific evaluation methods are required to determine the component's remaining lifetime.

In other words, detecting signs of a defect during an in-service inspection, for example, would not be sufficient, in terms of remaining lifetime, if a subsequent evaluation is not carried out on the size of the defect admitted by the component, the anticipated rate of growth, etc. We should remember that there may be cracks that, once formed, can spread rapidly, as happened in the alternator rotor check rings with material 18Mn-5Cr, and on the contrary cracks that may stop growing when they reach more favorable stress zones.

As a result, inspection and monitoring techniques must be supplemented with evaluation methods based on fracture mechanics, experimental tests, etc., in order to obtain a reliable evaluation of the component's remaining lifetime.

Major progress has also been made in the preceding fields, which are essential for optimizing remaining life management.

In many case, fracture mechanics methods have been developed in parallel with inspection techniques, as the need arises to detect and evaluate the incidence of certain degradation mechanisms. The latest developments performed by Tecnatom, in some cases in collaboration with other sector enterprises, can be summarized as follows:

- Development of acceptance criteria. One of the most representative examples involves the criteria developed for vessel head and bottom penetrations. Depending on material properties, in-sevice stresses, the predominant mechanism (SCC), compoment geometry and dimensions and location of the indications, fracture mechanics can be used to determine admissible crack sizes and in turn the remaining lifetime. (Fig. VIII)

- Determination of a component's most critical zones and indication evaluation. Both stress analysis and fracture mechanics can be used to determine a component's most vulnerable and critical zones. This information has many uses, from adjusting the scope of an inspection to selecting the zones where a monitoring system should be installed, and even to evaluating the indications of a defect detected during the inspection.

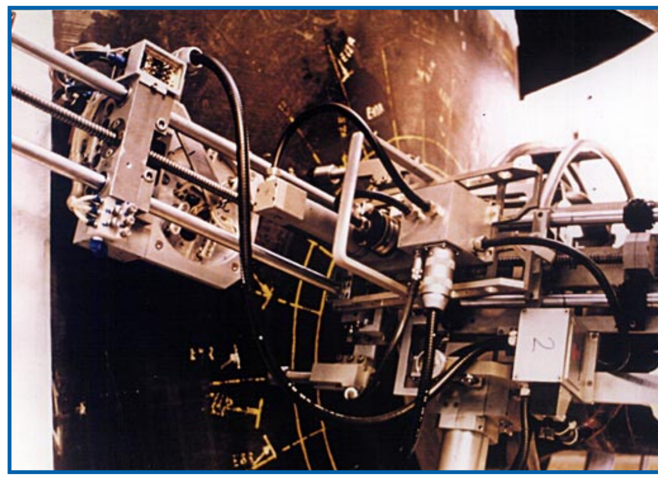
The Indication Evaluation Manuals (MEIs) that Tecnatom has been developing for Spanish NPP vessels and turbines follow the above mentioned philosophy and are continuously optimized in order to provide more reliable, less conservative evaluations. (Fig. IX)

- Development of leak before break criteria.

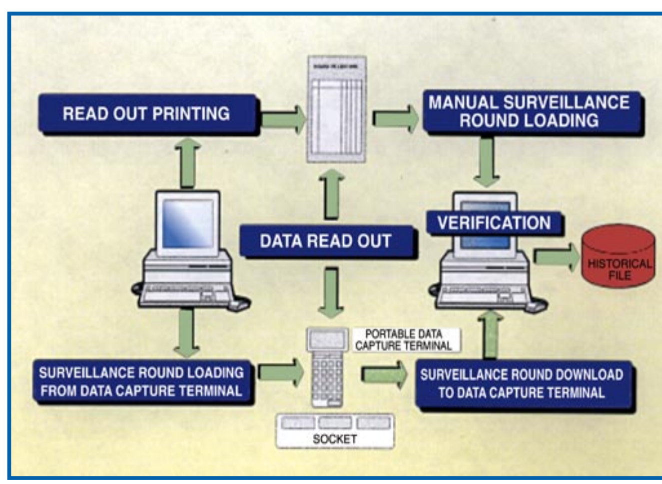
Another application of fracture mechanics is determining whether a component will leak before breaking by comparing the critical crack size with the remaining bond in the component, i.e. by demonstrating that the

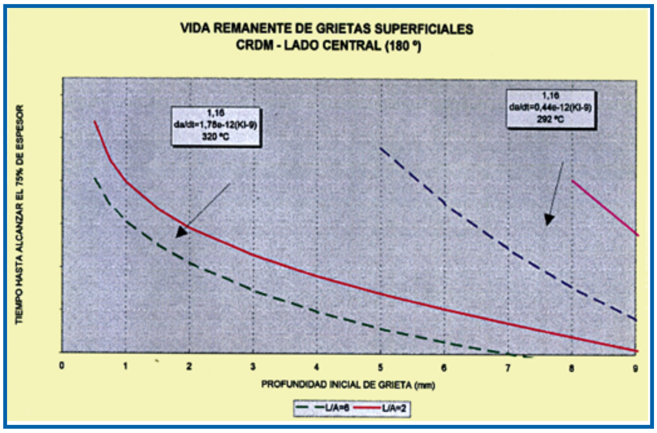
F V - *Eddy-current control rod inspection system.*

F VI -*Nozzle inspection equipment on real mock-up.*

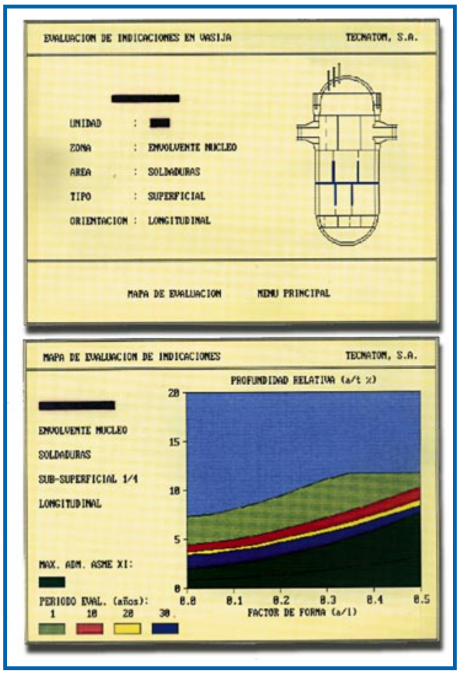


F VII -*Watchman Optimization System (SOR). Operating diagram.*





F VIII -*Remaining lifetime of a CRDM in terms of initial crack depth.*



F IX -*Vessel Indication Evaluation Manual.*

crack can reach the outer wall before becoming critical.

This criterion is of utmost importance for ensuring a component's structural integrity, because if the component meets the leak before break criterion, it can be monitored just by determining whether or not a leak exists.

One of the most important applications of this methodology was in the electrical sector's PISGV Project (Steam Generator Research Project), which has resulted in safe operation of steam generators until they were able to be replaced.

- Evaluation of an aged component's structural integrity.

In addition, fracture mechanics can be used to help evaluate an aged component's structural integrity, in order to demonstrate that this component can continue to operate safely, even with a certain degree of degradation. If this can be demonstrated, the need to carry out inspections on this component can be reduced or even eliminated.

An example of the application of this methodology is the case of a cast stainless steel cooling pump shell in a nuclear power plant. It was demonstrated that, even though that the shell was embrittled by temperature, it could resist the crack postulated in the ASME Code.

- Study of optimum operating conditions.

Another possible application is evaluation of optimum operating conditions. It is obvious that in most cases, both material degradation and defect growth are directly affected by operating conditions, as some are more severe than others.

For some components in which operating conditions can be varied slightly without affecting other standards such as performance, production, etc., optimum conditions can be determined by fracture mechanics in order to slow down degradation evolution or increase the component's tolerance to damage. One example refers to steam turbine fatigue cracks. It should be remembered that one of the most critical moments for potential failure of a defective turbine occurs during startup because the material's tensile strength is low, and therefore a crack that may not be critical during normal operation may be critical during startup. The most advisable form of startup, for example by using preheating, can be determined in order to increase the admissible critical defect size and thus guarantee the component's structural integrity.

Therefore, to determine a component's remaining lifetime, evaluating the criticality of defects by fracture mechanics, as explained in the preceding paragraphs, is as important as knowing the influence of degradation on material property evolution.

In nuclear power plants, embrittlement caused both by irradiation and by temperature is one of the most important effects to account for in material property degradation. The two developments described below are examples of activities being undertaken in this area:

- Determination of the tensile strength of temperature embrittled material.

Depending on the material's ferrite content, which is calculated by using a ferrite meter, the material's tensile strength is determined by means of correlations with chemical composition. These analyses are essential for evaluating an aged component, such as in the above mentioned case of the temperature embrittled cooling pump shell.

- Evaluation of vessel irradiation embrittlement.

The embrittlement experienced by the vessel material as a result of neutronic radiation is a well-known phenomenon. This evolution of material properties can be quantified by means of empirical models developed on the basis of data from irradiated material tests in experimental reactors, or on the basis of data from surveillance capsule irradiations in commercial reactors.

Tecnatom, which is responsible for the surveillance programs in most Spanish NPPs, has obtained its own correlation for calculating the RTNDT reference temperature increase that the vessel material will undergo for a given neutronic creep. Surveillance data from analyses of capsules removed from Spanish PWRs have been used for this development.

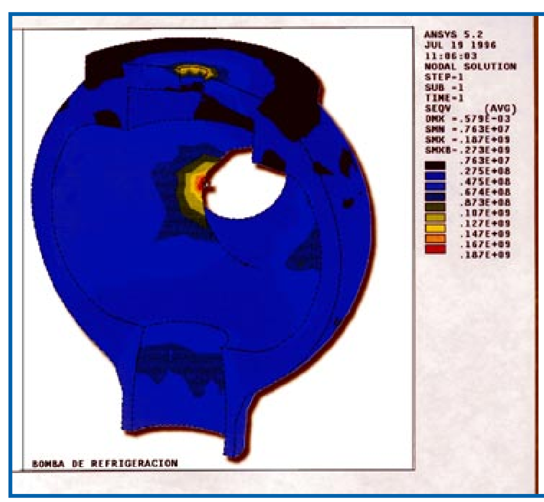
The study concludes that surveillance data from Spanish nuclear PWR plants, when processed as a whole, are very consistent with irradiation embrittlement predictions used in other countries, primarily in the United States. In addition, the use of an embrittlement equation or trending curve specific to Spanish reactors would help to optimize plant operation, increase safety margins and extend effective life. (Fig. XI)

INTEGRATED EVALUATION AND TRACKING TOOLS

The above discussion indicates that there is a high level of development in the area of life management techniques and methods.

Nevertheless, as noted at the beginning,

F X -*Stress distribution in a cooling pump subject to temperature embrittlement.*



though these techniques and methods provide a great deal of information, they only provide a partial view of component status.

It is evident that optimizing management of a plant's aging or lifetime requires a more integrated vision that more thoroughly addresses the most critical components and their most limiting degradation mechanisms.

Metaphorically speaking, although many pieces of the puzzle are available, another more specific piece is required to fit in with the others in order to provide this overall, integrated view.

There is still much to be done on the road to integration, both by the nuclear plants, which will have to optimize or design new strategies for their information management systems, and by service firms and suppliers which are the main providers of information regarding components status, primarily on the basis of inspections and test.

Tecnatom, as a designer and manager of most of the inspection and testing databases, has been working in recent years on optimizing these databases in areas such as the following:

- Ease of use, with more user-friendly environments, the use of sketches and drawings and maintaining a similar, homogeneous structure throughout.
- Introduction of additional utilities to study historical data trending or to evaluate remaining lifetime. (Fig. XII)

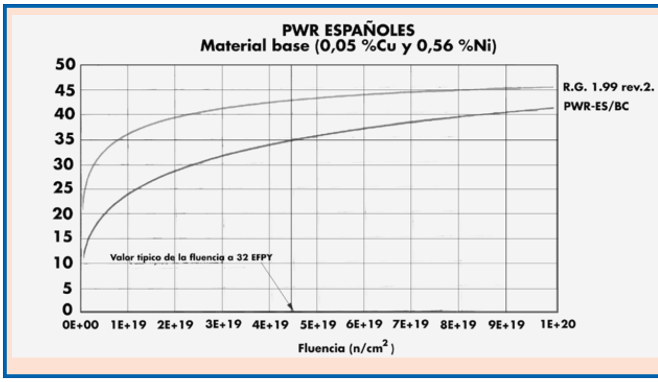
Other improvements, such as risk-based inspection and testing criteria, will soon be available. In addition, there are plans to optimize these databases by integrating more information, which could be the key to component aging and life management.

As a starting point, this will all undoubtedly help to achieve the future integration of different information on life management. However, even more resources will have to be allocated to obtain an integrating platform or system to assist in the hard job of properly tracking a facility's remaining lifetime and its main components.

CONCLUSIONS

Lifetime management of a nuclear power plant requires ongoing work in the development and improvement of inspection and monitoring techniques and of evaluation methods, in order to make it possible to determine the state of component aging in the most reliable, continuous, integrated way. Only in this event will those responsible for nuclear facilities be able to make the best decisions at the right time for optimizing plant operation.

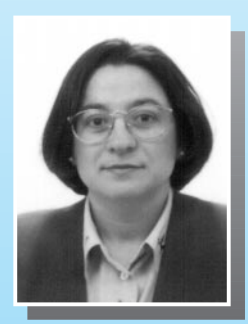
The electrical sector and associated companies have dedicated many efforts to this issue to date, as we have discussed in this article, but it is necessary to examine more thoroughly the influence of some degradation mechanisms, the techniques and methods used to evaluate them, and especially how to integrate the information that can be used to obtain an overall plant evaluation.



F XI -*Evolution curves of RTNDT reference temperature as per R.G. 1.99 Rev. 2, and Tecnatom's own correlation of PWR-ES/BC based on data from capsules removed from Spanish PWRs.*

Carlos CUETO-FELGUEROSO has a Naval Engineering degree from the Universidad Politécnica of Madrid. He joined Tecnatom's Integrity Analysis Unit in 1985, where he has worked on fracture mechanics and remaining life studies of major components in Conventional Thermal and Nuclear Power Plants: vessels, steam generators, turbounits, etc. He has taken part in numerous research projects, including PISGV and PETAVA, in which he was responsible for developing acceptance criteria, remaining life evaluation methodologies, leak before break criteria, etc. At present, he is head of the Component Integrity Unit.

F XII -*Computer application for tracking valve actuation and leak tests.*



Maite AGUADO has an Aeronautical Engineering degree from the Universidad Politécnica of Madrid, and a Master's in Corporate Management from the Instituto de Empresa of Madrid. She joined Tecnatom's Integrity Analysis Unit in 1988, where she worked on steam generator stress analysis and fracture mechanics. In 1990, she was put in charge of Nuclear and Thermal Power Plant Life Management and Extension, taking part in development of methodologies and tools for evaluating compenent and material aging status. At present, she is head of the New Technologies Unit.