PLANT LIFE MANAGEMENT IN REACTOR VESSELS

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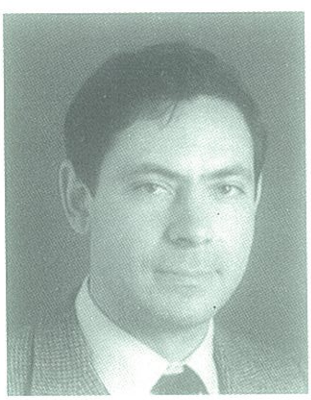

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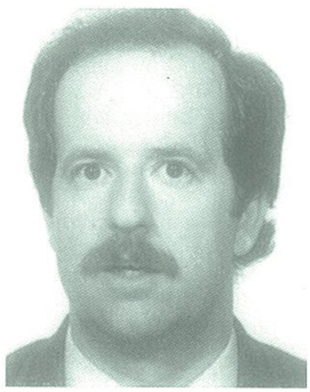
Component remaining increasingly depends on the component's daily performance and on ascertaining/discovering the ailments that can affect it on aging which may limit the appeal of extending it beyond its design life.

In the case of reactor vessels, it is easy to give an example that illustrates the preceding paragraph.

Vessel life has always been measured in terms of neutron, as embrittlement due to neutron radiation is the factor that most limits the life of this component.



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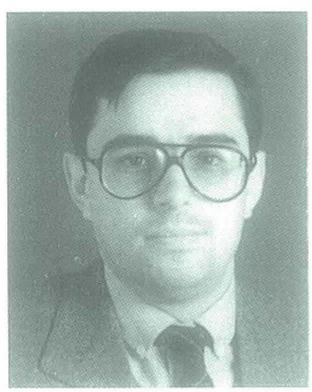

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The recent closure of the Yankee Rowe Nuclear Power Plant in the United States clearly demonstrates how decisive a lack of proper monitoring of this embrittlement can be in a vessel's life. However, when this article is published, possible cracking of the control rod housings in pressurized water reactor vessel head penetrations will surely be of more concern to the operators of our nuclear power plants than the fact that the vessel is becoming embrittled due to neutron radiation.

Since cracking of this type has been detected in French reactors, extensive research has been carried out. Early findings reveal that this may be more of a generic problem than was initially thought.

No one would have thought only a few months ago that plant life management should include investment in the acquisition of a new vessel head. Other solutions are also being considered.

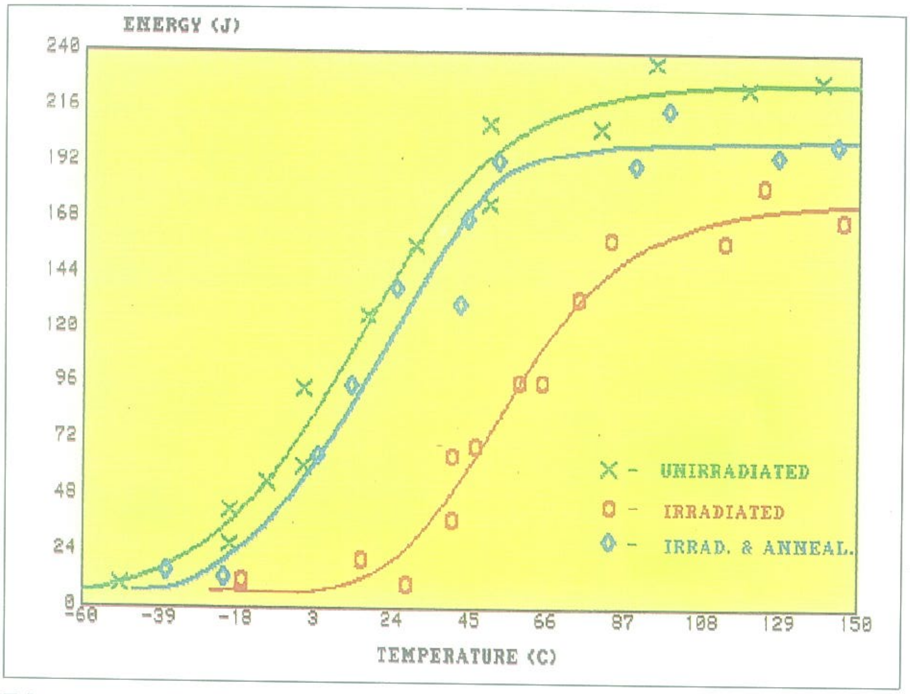
Once the problem became evident from routine hydrostatic tests in the Bugey 2 Nuclear Power Plant, it is clear that only proper monitoring of these vessel areas can guarantee safe reactor operation.

Following is a discussion of the elements to be considered in a vessel life management program, which include embrittlement surveillance programs and surveillance/inspection programs for vessel areas in which defects are liable to appear. Lastly, a paragraph is devoted to the methodology for evaluating these defects in terms of plant life management so as to guarantee structural integrity.

EMBRITTLEMENT SURVEILLANCE

Embrittlement of vessel material near the reactor core due to neutron irradiation is a decisive factor in plant life management. This problem led to the decision to close the Yankee Rowe Nuclear Power Plant after approximately 30 years of operation.

Experience in the oldest nuclear power plants indicates the importance of having a complete surveillance program for neutron irradiation embrittlement that helps quantify the degree of the vessel material's toughness.



F I *Recovery of Core Region Shell Mechanical Properties Through Thermal Treatment ("Annealing")*

In order to track the vessel condition and be able to predict the level of degradation caused by irradiation far enough in advance, capsules containing samples both of base and weld materials representing the critical vessel zone are periodically removed and analyzed. The data obtained from these capsules, called surveillance data, are essential for evaluating vessel integrity and provide early indications of the degree of embrittlement that the reactor vessel will reach later on in its design life.

The vessel surveillance program should be directed at the possibility of extending the vessel's lifetime. Thus, it is important to keep the monitoring material from the analyzed capsules and properly file all information obtained. Estimates of the degree of vessel embrittlement should be made for many years of operation and, if necessary, corrective actions should be evaluated and taken in order to lengthen the vessel's lifetime. An example of this would be modification of fuel element distribution in the core in order to decrease peak neutron flux in the vessel.

The operating Spanish reactors have an embrittlement surveillance program. The data provided by the capsules removed to date indicate that the useful life of the vessel in all cases is longer than its design life.

The "Research Project on light water reactor vessel material behavior in the presence of neutron radiation (PIE)", in which nine organizations are participating, is in its final phase. One important project activity is irradiated material recovery, which is of interest in lengthening vessel life.

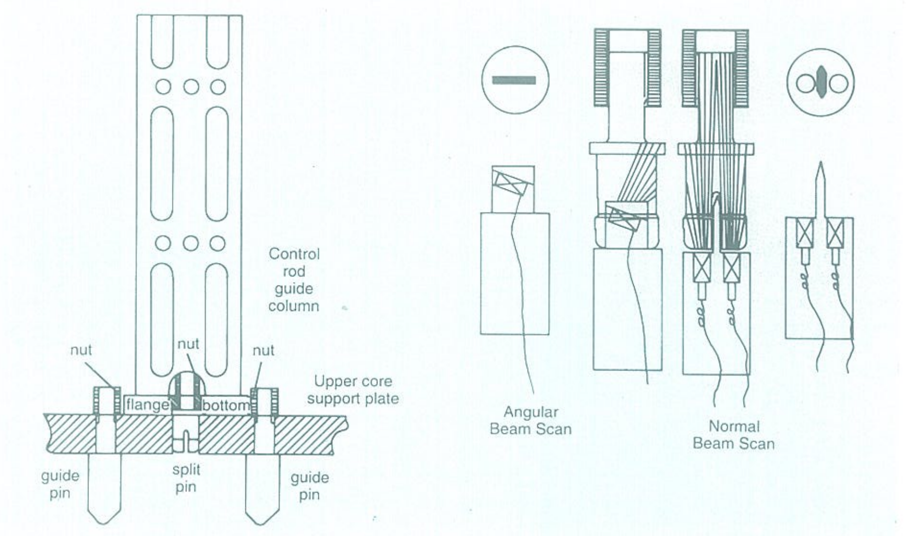
Two new projects that are closely related to vessel life extension are being considered. The first stems from the need to take maximum advantage of available monitoring material by using miniature test specimens and reconstructing Charpy test specimens. The second is to participate in the development of an international embrittlement data base, which would help to reduce inaccuracies in irradiation damage calculations. This would lead to less conservative operating conditions and improved use of the vessel's useful life.

IN-SERVICE INSPECTION

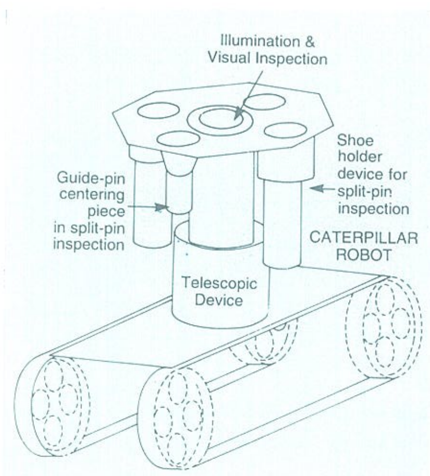
The design of a reactor vessel and its associated systems involves a large number of parts or subcomponents that, although they have no important function in the component's safety analysis as such, should be considered when analyzing life management or setting up remaining lifetime programs in view of the important role they play from the standpoint of plant availability.

These components include vessel internals, small diameter vessel connections such as control rod housings, and the fuel proper.

These areas are noteworthy for the lack of detailed standards in the in-service inspections codes, and also for the variety of designs and systems used, which makes it very difficult to establish the different parameters to be considered in an in-service inspection program such as frequency of inspections, exami-

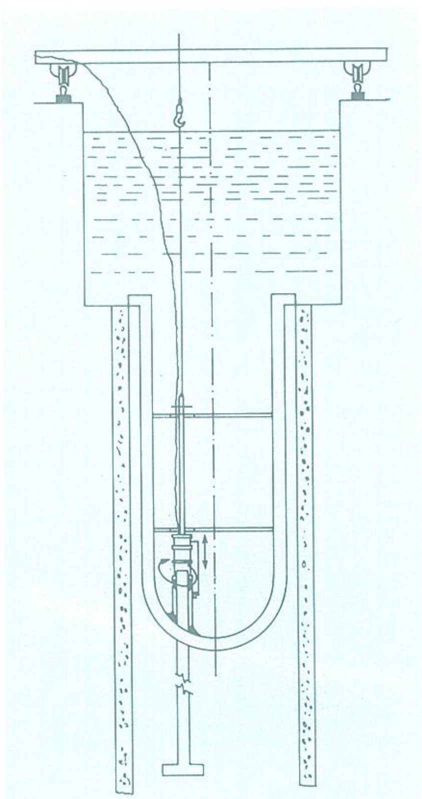


F II *Fuel Element and Control Rod Alignment Pins. Ultrasonic Examination Methodology.*

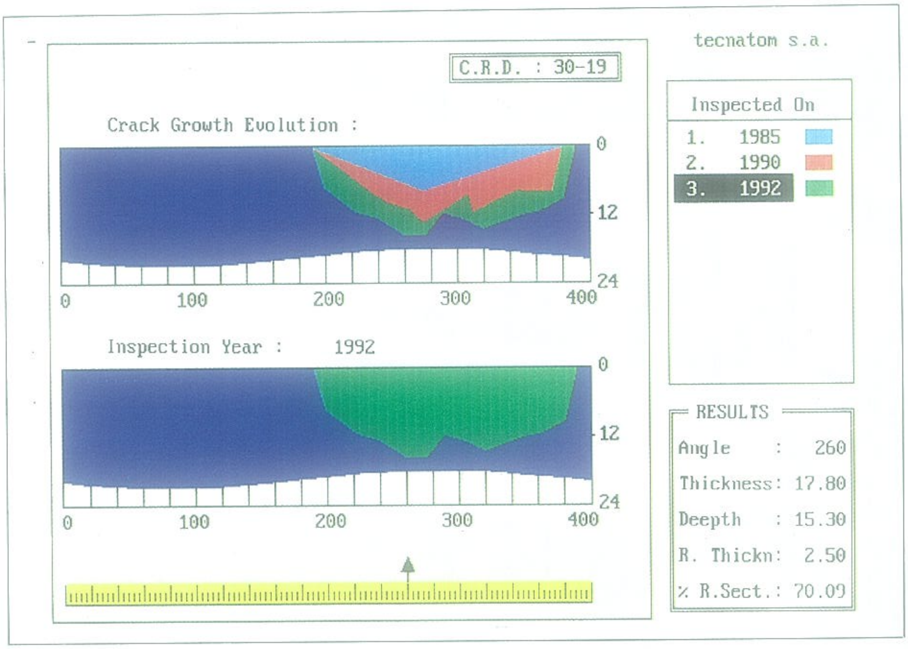


F III *Underwater Robot for Inspection Equipment Manipulation*

nation techniques, inspection equipment, acceptance criteria, etc.
The inexistence or insufficiency of standards that regulate in-service control of this type of component makes it difficult to obtain coherent data to be taken into account in reactor vessel life management studies, and thus the importance of establishing examination criteria and standards for these components as quickly as possible. For example, a new Appendix is being prepared for the ASME Code, Section XI, whose first phase will contain a description of basic examination standards for this type of component and whose publication is scheduled for 1993.
From the standpoint of a supplier of integral in-service inspection services, these problems represent a challenge due to the different factors that must be analyzed when planning and performing an in-service inspection of these components. When undertaking the inspection of this type of component, necessary steps include a preliminary feasibility study, development of specific inspection techniques, design of remote control systems and equipment suited to the component's geometric conditions, preparation of acceptance criteria, and a detailed test and scale model validation plan.
As the Spanish nuclear plants operating lives are consumed, it is obviously ne-



F IV *Control Rod Penetration Inspection Equipment*



F V *Evolution of Defects on the Basis of Successive CRD Inspections*

cessary to more frequently perform in-service monitoring/inspection of these types of components due to their increasing importance in the overall plant status analysis, as opposed to the areas that are totally regulated in the standards and thus are subject to standardized inspection and control programs.
Following are two examples of components/areas that involve the problems set forth above:

Fuel/Control Rod Alignment Pins

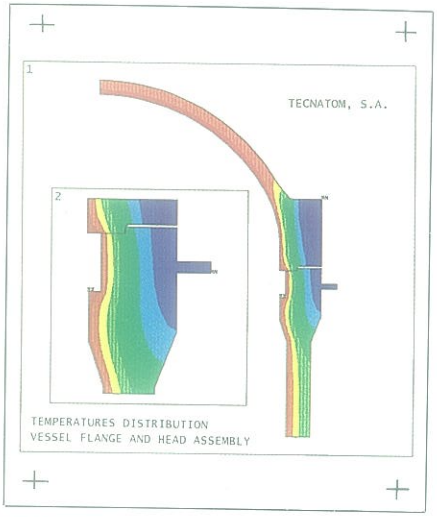
In the upper internals of PWR type plants, there are families of pins that are provided to keep the fuel elements and control rods aligned. In most cases, these pins are made of inconel that can be affected by the stress corrosion phenomenon, produced by residual stresses generated during the erection process, material sensitization and the aggressive medium, plus the prolonged effect of neutron irradiation. The malformations can lead to deterioration of these components, affect the internals' structural integrity, and possibly cause parts to loosen. Thus it is important to set up surveillance programs to learn the rate of occurrence of these problems in each plant and to take corrective measures that will help to provide medium or long-term integrated solutions such as replacement or stress relieving. However, it is first necessary to set up an inspection program to evaluate the specific situation in each plant. The accompanying figures show a diagram of the ultrasonic examination methodology used on these components, and the underwater robot used to manipulate the inspection equipment.

Control Rod Penetrations

In BWR plants and recently in PWR plants as well, stress corrosion phenomena may occur in control rod drive housings or their guide-tubes. Depending on the affected portion and the type and orientation of the specific defect, the problem can affect plant availability to a greater or lesser extent. The requirements specified in the ASME Code are obviously insufficient to perform a detailed evaluation of the problem, and thus it is necessary to complement them with inspection and analysis programs to ascertain the extent of influence and evolution thereof.
Due to the singular configuration of these components and their location in the reactor vessel, it is necessary to design specific equipment to access the inspection zones, and to develop highly reliable examination techniques not only for detecting possible indications but also to learn how the defect evolves, which can be a determining factor when adopting medium- and/or long-term corrective measures.

DEFECT ACCEPTANCE CRITERIA

As indicated above, in order to ensure structural integrity of nuclear reactor vessels, the most critical zones are periodically inspected by means of nondestructive tests, and the neutronic irradiation is



F VI *Thermal Stress Analysis of the Vessel*

monitored to control material embrittlement.

The various NDT techniques are intended to detect possible existing defects that can endanger the structural integrity. Therefore, once a defect is detected, it is sized and subsequently compared to the acceptance criteria established in the codes and standards applying to in-service vessel inspection.

If there are signs of defects that exceed these standards, it may be necessary in principle to eliminate the defect or replace the affected component zone before plant startup, with the resulting economic disadvantages that this would entail.

However, the above indicated codes permit the plant to be put back into operation without repairing the defect, provided that an analytical fracture mechanics study, performed in accordance with the requirements established in the applicable code, proves that the defect's dimensions will not grow during a specific period of time, called evaluation period, up to a certain critical value that depends on the material's properties, in particular the fracture toughness and the stress field of the structure, specifically at the tip of the crack.

Therefore, the advantages of this analytical study are obvious, as it is possible to extend the defect acceptance criteria while maintaining the safety margins required by the applicable codes and standards, and to avoid repairing the defect or to postpone it until the most suitable time within the evaluation period that has been defined.

However, a fracture mechanics analysis is a fairly complex analysis that requires having input data on stress and temperature distributions in the different zones subject to in-service inspection throughout the different transients included in the design specifications. For this reason, it may not be feasible to perform the analytical study before the date scheduled for plant restart, with the resulting economic consequences that a potential delay could have.

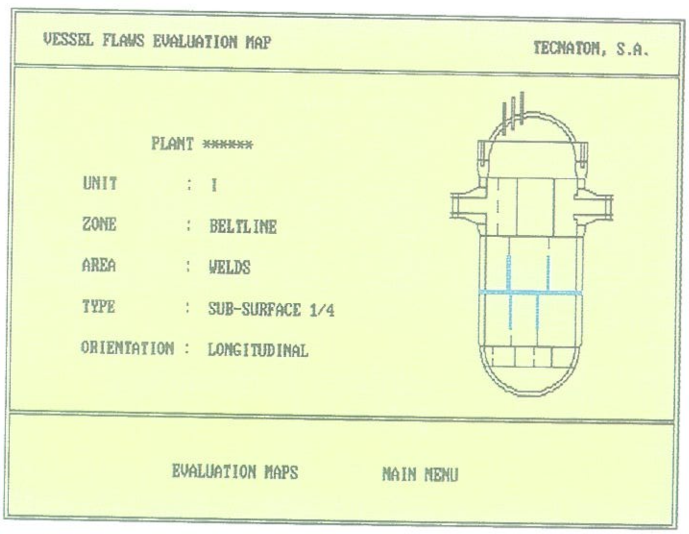
Therefore, it is very advisable to have these defect acceptance criteria in advance. For this purpose, the methodology of the Flaw Evaluation Handbook (MEI in Spanish) has been developed, which essentially consists of a set of graphs or maps to make quick, safe decisions about the acceptability of a given defect.

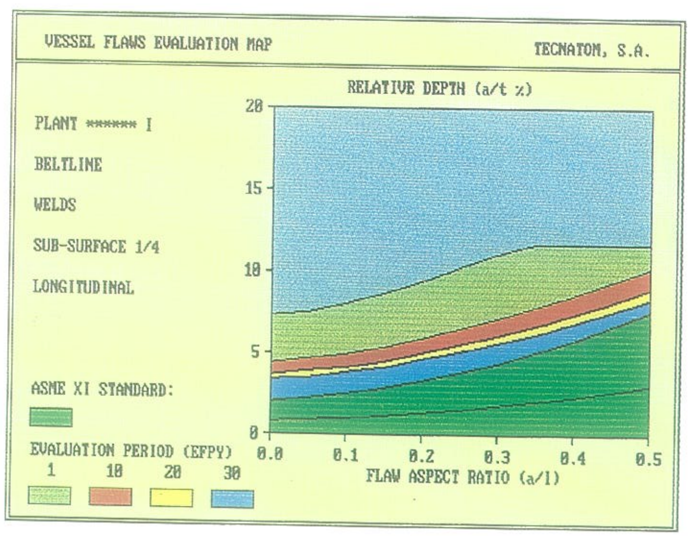
The MEI methodology has been developed on the basis of what have been defined as initial critical crack sizes, i.e. crack dimensions that could potentially evolve toward the corresponding critical crack size of a specific vessel zone during a predefined period of time.

Therefore, the MEI consists of a series of specific decision maps for each zone for which in-service inspection is required and for the most characteristic defects that are potentially found in these zones, characterized by orientation (longitudinal or circumferential) or by type (surperficial or subsuperficial at 1/2 or 1/4 of the thickness). In this way, on the basis of the dimensions of the detected defect, i.e. the flaw shape (a/l) and relative depth (a/t), a decision can be immediately made regarding its acceptability for a certain operating time by comparing it to the corresponding initial critical crack sizes shown in each map.

In some cases, the MEI requires that necessarily conservative simplifications be adopted. For example, within each zone, the maps are prepared for the most critical section both from the stress and from the toughness points of view. Therefore, in the event of very critical defects, i.e. near the MEI acceptance limits or even exceeding them, a specific reanalysis can be performed for the defect in question that in general will enable the acceptance criteria to be extended while maintaining the safety margins required by the codes. This analysis will not require much time, as the stress and temperature distribution study for each vessel zone will have been made beforehand, and thus it can be done without delaying plant restart.

As regards plant life management, another advantage of the vessel MEI is that it gives an overall picture of the effects of material property degradation phenomena, in particular core beltline embrittlement due to neutron irradiation, on the defect acceptance criteria, and provides forehand knowledge of the operating transients and defect types that are most detrimental to the plant's remaining life, so that suitable measures can be taken if necessary to extend plant lifetime.





F VII *Evaluation Map of a Vessel MEI*