DEVELOPMENT AND EXPERIENCES OF THE ARTIFICIAL VISION AND EDDY CURRENT FUEL INSPECTION SYSTEM (SICOM)

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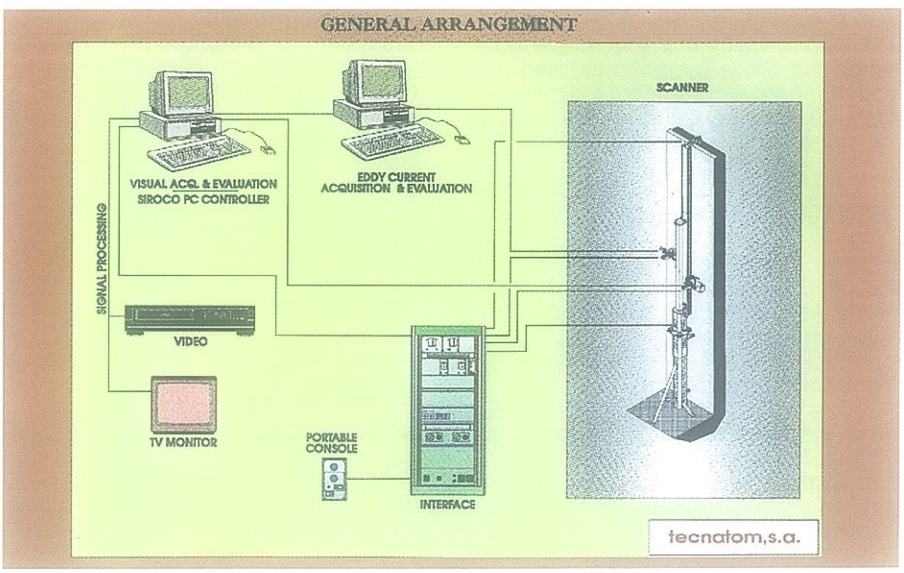
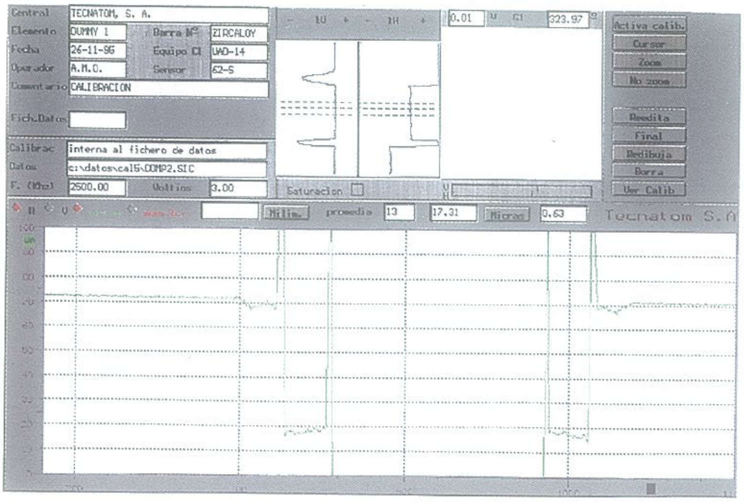
INTRODUCTION

Nuclear fuel undergo evolution in its properties and characteristics as result of the operation in the nuclear reactors. Knowledge of this evolution is necessary to guarantee the behaviour and safety in the operation, as well as to optimize the economic performance of the fuel cycle. For this reason, fuel manufacturers develop fuel behaviour models readily validated.
On the other hand, when with the objective of improving the performance of fuel, some important modifications are made, it is necessary to prove the effect on the behaviour and evaluate the influence in each of the critical characteristics of the fuel assemblies. In this cases, before a complete refuelling with new designed fuel is inserted, it could be necessary, in accordance with the importance of the modification, to burn a reduced number of fuel assemblies of the new design. This kind of fuel assemblies are known as demonstration

F I - *Representation of SICOM equipment*





F II - *Main sub-assemblies of the mechanical equipment.*

assemblies. During the demonstration process, some characterization of the behaviour of the fuel is made, usually at the end of each cycle. The information obtained would be used to assess the criteria for commercial operation of the new designed fuel.

An important part of this characterization is made using NDE methods, applied at the nuclear plant during the refuelling outages. The features to be checked in these circumstances are usually be the following: general condition of the assembly and its main parts, dimensional variations, corrosion layer thickness and fuel rod tightness.

Within the Electrotechnical Research and Development Program (PIE), and with participation by IBERDROLA, TECNATOM and ENUSA, an inspection system (SICOM) has been developed for spent fuel assemblies from pressurized water plants, the aim being to check general condition, apply dimensional controls and measure the oxide layer on the peripheral fuel rods. This equipment was qualified at Tecnatom and Almaraz I NPP during the first quarter of 1995. Subsequently, in September, it was validated for the EDF P'4 plants at C.N.P.E. Belleville.

The objective of this paper is to describe the SICOM equipment and the qualification and validation process. Also, some information is given about the first services performed on site.

GENERAL CONFIGURATION

Figure I is a general representation of the SICOM equipment. The main parts of the equipment are described in the following paragraphs.

Mechanical equipment

From the moment this equipment must be installed in spent fuel pools of different plants, it is necessary to adapt the equipment to fit in the different existing configuration.

Apart from the elements required to fit the equipment to each particular site, the mechanical equipment is designed to safely hold the fuel assembly, make it turn so each face can be inspected and provide precise axial movement of the inspection modules.

The main sub-assemblies of the mechanical equipment (fig. II) are as follows:

- *Upper anti-seismic assembly*: This assembly, from which hangs the rest of the mechanical equipment, is anchored outside the pool and allows the overall assembly to be levelled. It is designed such that the SICOM is capable of withstanding an earthquake, even though a fuel assembly is being inspected at the time.
- *Mast:* This hangs from the upper support and, supported by it, rests on the floor of the pool. The inspection modules are displaced along its faces via linear guides and rack and pinions.
- *Mast support*: This provides the base for support of the equipment on the floor of the pool.
- *Fuel assembly support*: This supports and rotates the fuel assemblies in order for each face to be lined up with the inspection modules.
- *Clamp*: This prevents the fuel assembly from falling, ensuring the security of the assembly during the inspection. The clamp has no contact with the fuel assembly.
- *Displaceable modules*: These transport the eddy current modules, television cameras, lights, etc. to any position along the length of the fuel assembly faces.

The mechanical equipment is designed and manufactured taking into account the high levels of radiation to which it will be exposed and the fact that it will operate under water.

Controller and interface

The controller allows operation of all the assemblies of the mechanical equipment to be accomplished, ensuring also indications of the position of the inspection module and of the fuel assembly during rotation.

The SIROCO-PC controller is made up of a computer equipped with a SIROCO-PC card. The hardware used to govern the equipment depends on the inspection to be carried out. To inspect fuel assemblies using the Eddy Current Module, the SIROCO-PC computer is used, while in the case of inspections performed using the Visual Inspection Module control is accomplished by means of the same computer used to acquire the visual inspection data.

The SICOM interface is in charge of providing the assemblies required for control to be accomplished from the SIROCO mechanical equipment. The characteristics of the equipment and the conditions encountered in operation under water require that the interface provide an infrastructure allowing the receptacles in which the equipment motors operate to be kept pressurized, also providing control of the pneumatic modules and electrical supply for the equipment lights.

The interface is made up of a cabinet which is located at the edge of the pool and from which emerge four pressurized tubes which run to each of the equipment boxes.

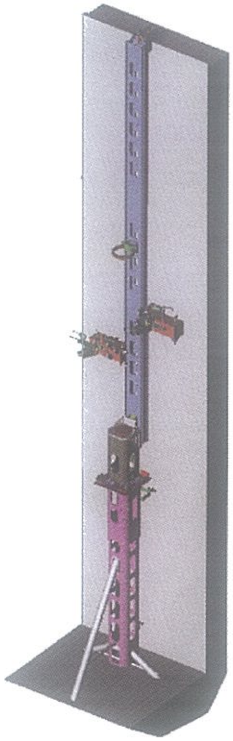
Visual and dimensional inspection system

The visual inspection system is used to check the general conditions of the fuel assembly and carry out dimensional control.

Dimensional control allows the main measurements to be determined, among them the following:

- Distance between fuel rods
- Length of fuel rods
- Length of the fuel assembly
- Distance between fuel rods and nozzles
- Width of grids

Control Screen



F III - *Example of oxide layer thickness data display*

- Fuel assembly bowing
- Twist
- Tilt of the upper nozzle with respect to the lower

For most of these measurements the accuracy is ±0.3 mm, this increasing to ±1 mm for fuel rod and assembly length.
The system is made up of an inspection module and the data acquisition, processing and storage equipment. The inspection module, located on the mechanical equipment, includes a radiation-resistant television camera and four spotlights. The acquisition system is made up of a personal computer including a digitizer card and software for image processing and for automatic calculation of the corresponding measurements by means of artificial vision algorithms.
The movements to be made by the mechanical equipment for data acquisition are also automatically programmed from the visual inspection computer, along with those for the corresponding illumination. The SIROCO-PC controller executes the movements and actions generated. All the information from the visual system may be stored in the computer as well as in the video recorder.

Oxide layer measuring system

Measurement of the oxide layer on the peripheral fuel rods is accomplished using eddy current techniques based on measuring the separation between the sensor and the cladding material, since the oxide layer is not conductive. Under normal conditions the thickness of the oxide layer to be measured may be between 20 and 60 micra. The accuracy of the measurement to be performed is 3-5 micra.
The system consists of an inspection module and a data acquisition system for data processing and storage. The inspection module includes the sensor (coil) which moves in constant contact with the fuel rod, and a television camera for observation of sensor coupling. The acquisition system is made up of a personal computer including the eddy current equipment and corresponding specific software. The results of the measurements performed may be displayed on screen and printed out. Figure III shows an example of oxide layer thickness data display.

QUALIFICATION TESTS AT TECNATOM

Qualification of the SICOM equipment at TECNATOM was performed using a mock-up of a 17x17 AEF-XL type fuel assembly previously characterized for this purpose at the ENUSA installations.
The inspections were carried out in an 8-metre deep trench full of water, in order to reproduce as closely as possible the inspection conditions existing at the nuclear power plants.
The different phases of the qualification process were as follows: assembly of the equipment, installation of the mock-up on the inspection equipment, inspection and disassembly of the equipment.
During the assembly, mock-up installation and disassembly phases, checks were performed of the difficulties encountered in execution, the times involved and the safety conditions.
The inspection phase consisted of inspecting the following characteristics on the mock-up:
- *Visual inspection of physical integrity.*
- *Dimensional measurements:*
  - Channel spacing
  - Separation between peripheral rods and nozzles
  - Length of peripheral rods
  - Length of mock-up
  - Lateral width of grid
  - Height of upper nozzle
  - Bowing
  - Twist
  - Perpendicularity
- *Corrosion mesurements:*

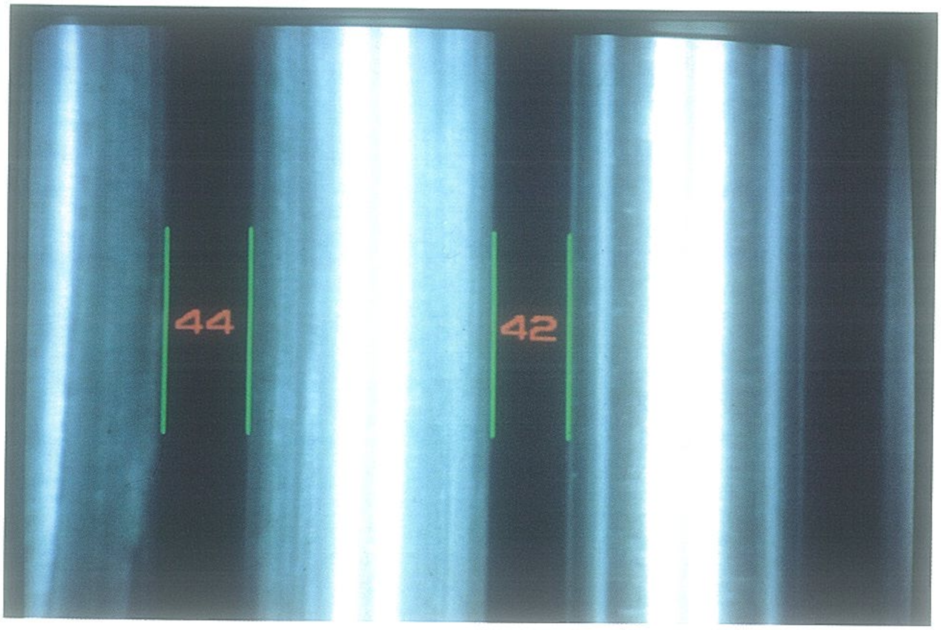
Corrosion measurements were performed on four bushings (two of Zircaloy and two of Zirlo) located on four different mock-up rods.
The results of the qualification process were as follows:
- *Visual inspection of physical integrity.*

The equipment demonstrated its capacity for the performance of this inspection with high quality imaging.
- *Dimensional inspection.*

The equipment obtained the measurements with a degree of accuracy similar to or better than that specified.
The bowing, twist and tilt measurements are qualified by means of a fuel prototype especially conceived for this purpose.
The repeatability achieved in measurement was also very high, the accuracy obtained thus being guaranteed.
- *Corrosion inspection.*

The variations in the values obtained by the equipment, with respect to the

General View. Validation



Dimensional Control

values obtained using metallographic methods, were lower than the specified degree of accuracy of ± 3 micra.

ON-SITE VALIDATION TESTS

Validation at Almaraz NPP

This phase of the qualification process consisted of repeating the process indicated in section 7 at the Almaraz I Nuclear Power Plant, with the equipment installed in the spent fuel pool.
This validation process also served to qualify equipment packaging and transport.
The main difference with respect to the qualification performed at TECNATOM was that an actual irradiated fuel assembly (17x17 STD) was used for the inspection.
The scope of the inspection was as follows:

- *Visual inspection of fuel assembly physical integrity.*
- *Complete dimensional inspection of a fuel assembly.*
- *Corrosion inspection on 8 peripheral rods.*

The results of this validation were as follows:

- *Visual inspection:*

The equipment demonstrated its capacity for the performance of the inspection on an irradiated fuel assembly, with high quality images obtained.

- *Dimensional inspection:*

The equipment demonstrated its capacity to perform the measurements on an irradiated fuel assembly.

- *Corrosion inspection:*

The equipment demonstrated its capacity to measure corrosion on irradiated rods.
In addition, in this case the values obtained were compared to those measured independently by another unit of equipment homologated for this type of inspection, no significant differences being appreciated.
This test also served for validation of the transport, assembly, inspection, disassembly and decontamination of the equipment at a 900 MW PWR plant (Almaraz).

Blank test at C.N.P.E. Belleville I

The final blank test carried out at the 1300 MW Belleville plant consisted of demonstrating the full operability of the equipment at this plant, for the inspection of 17x17 AEF-XL fuel assemblies.
This test was performed in September, at Unit 1 of the aforementioned plant. Once the equipment had been assembled, the inspection was carried out on a fuel assembly mock-up supplied by the plant, along with different safety tests, all giving satisfactory results.

SERVICES PERFORMED AND FUTURE UNDERTAKINGS

The SICOM Operations Committee was set up for management of the services provided, this including participation by D.T.N., TECNATOM and ENUSA.
During the month of February of this year the first inspection service using the SICOM equipment was performed at Almaraz II NPP.
The inspection was performed on two demonstration assemblies with Zirlo cladding with two burnup cycles and on a spent fuel assembly present in the fuel pool.
Visual physical integrity and dimensional inspections were performed on the three assemblies. In addition, a total 56 Zirlo fuel rods were inspected for corrosion, along with 32 Zircaloy-4 rods, on the two demonstration assemblies. On the other fuel assembly, 15 Zircaloy-4 rods were inspected for corrosion.
During the month of May the second commercial SICOM service was carried out at the Vandellós II Nuclear Power Plant. Initially, within the segmented rod project, four fuel assemblies that had undergone their first burnup cycle were inspected, with general visual, dimensional and oxide layer corrosion controls being performed.
In view of the possibilities offered by the equipment, Vandellós later requested that the service be extended to include the performance of rod corrosion measurements on a further five spent fuel assemblies present in the fuel pool.
This inspection was performed with success in a short period of time.
Finally, in September and following the final blank test, fuel assemblies were inspected at Unit I of C.N.P.E. Belleville.
The scope of the service included visual integrity control, complete dimensional control and measurement of the oxide layer on peripheral rods.
There are currently undertakings to use SICOM in the medium term for the following projects:

- Segmented rods at Vandellós II.
- LFA program at C.N.P.E. Belleville I.
- ADA program at C.N.P.E. Belleville I.
- Gadolinium program at Ascó II.
- Zirlo program at Almaraz II.

CONCLUSIONS

The qualification and validation tests performed, along with the experience acquired in commercial use of the SICOM equipment, has made it possible to demonstrate the capacity of the equipment for the performance of quality inspections on irradiated fuel.
Particularly outstanding is the high degree of accuracy achieved in dimensional measuring and the magnificent image resolution obtained in the visual inspections, along with the large number of rods on which corrosion measurements were obtained.
The advisability of having available an advanced item of equipment for fuel inspections, developed by Spanish industry, is confirmed by the significant medium-term demand foreseen for use of the equipment.