LATEST EXPERIENCES IN INSPECTING THE INSIDE OF BWR VESSEL SHIELDS

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In the last few years, the owners of BWR nuclear power plants have been forced to address new fuel shield inspection requirements. TECNATOM has responded to this situation by launching the TEIDE projects, which include development of an inspection machine and the corresponding Non-Destructive Tests to examine the inside of the shield. With these projects, TECNATOM has performed more than 12 fuel shield inspections in different countries. This article describes the experience gained in the last three years.

INTRODUCTION

In the last few years, the owners of BWR nuclear power plants have been forced to address new inspection requirements applying to the fuel shield located inside the reactor pressure vessel, the purpose of which is to contain the fuel assemblies and which also serves to support the structures located at the top of the reactor.

This component consists of a 40 to 50 mm thick cylinder made of different stainless steel 304 and INCONEL sleeves joined together by vertical and circumferential welds. It is obvious that the formation of unstable cracks in these welds could directly affect their structural integrity and plant safety as well.

Stress analyses based on service conditions and the materials contained in the shield, which have been corroborated by the experience gained in visual examinations performed in different plants during refueling outages, postulate cracking parallel to the weld cord and open to the inside surface with progression towards the exterior. Two kinds of cracking may occur: IASCC (Irradiated Assisted Stress Corrosion Cracking) or IGSCC (Intergranular Stress Corrosion Cracking), and cracking may appear on both sides of the weld in the thermally affected zone. The need to position, size the length and depth, and reliably evaluate the potential cracks detected by the preliminary visual examination, and to enlarge the range to include any defect present in the component thickness, requires the use of advanced non-destructive testing techniques (ENDs).

From the standpoint of access to the fuel shield and attacking the surface to be examined, there are two alternative approaches: inspection from outside the component, focusing on the area called "annulus" that is located between the vessel walls and the component (OD inspection), or inspection from the inside (ID inspection).

To find solutions to this problem, Tecnatom has in the last few years launched several projects under the generic name of TEIDE, for the purpose of developing inspection machines and non-destructive testing techniques to try to achieve maximum possible coverage of these components.

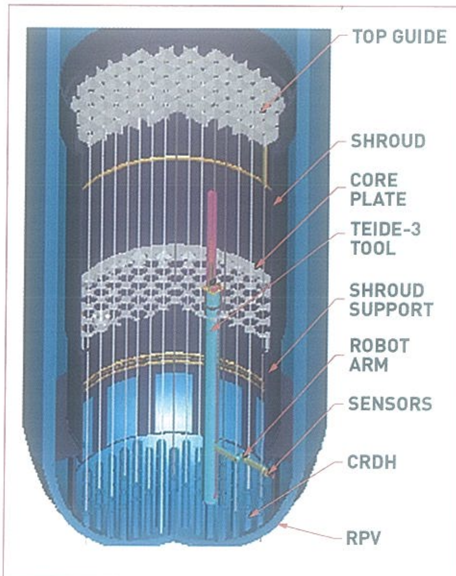
Of these two options, ID inspection was chosen as we believe it provides the following advantages:

- Maximum inspected weld length. It eliminates interferences with the jet pumps and systems present in the annulus that affect OD inspections.

- Repairs made on in-service fuel shields always add new fixed assemblies from the outside, as the space provided for the fuel assemblies must be kept free. This fact ensures the viability of ID inspections and increasingly hinders OD type inspections.

- It shortens inspection time and prevents unexpected occurrences: helps to maintain planning, reduce personnel doses, shorten critical path time.

- Superior features of precision and repeatability, as the fuel assembly cells and upper guide tube can be used as support.

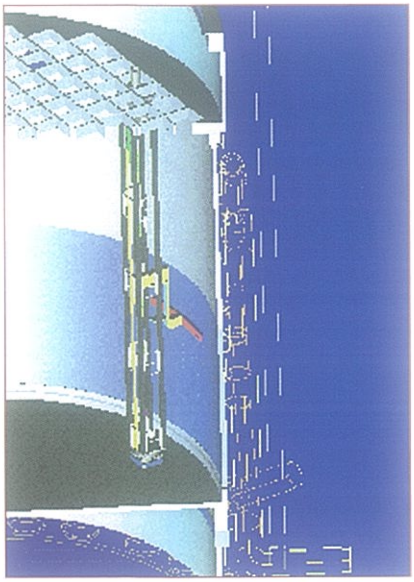


Vessel interior. TEIDE-3 installed.

- Simplification of equipment positioning work (similar to the installation of fuel assemblies).

As regards inspection techniques, it was decided to simultaneously incorporate ultrasound (UT) and induced currents (ET). By means of different sensors clustered on a single test spike, the ultrasound technique provides the length and depth sizing of cracking that preferentially tends to be parallel to the weld, regardless of whether it is open to the interior or exterior surface (main volumetric examination).

The induced current technique, on the other hand, is justified because it guarantees greater precision in sizing



Fuel shield. TEIDE-2 installed.

the length of defects open to the scanned surface (complementary surface examination). In addition, this technique assures high reliability in defect detection and in real-time display.

TEIDE-1 AND TEIDE-2

This mechanical equipment was developed in different phases between 1996 and 1998, as part of fuller scope projects that also included refinement of the techniques and inspection procedures, the manufacture of blocks for laboratory tests and validation, and the final qualification tests for customers. The work has culminated in the design, manufacture and adjustment of two manipulators capable of performing an automated inspection of the vertical welds (TEIDE-1) and circumferential welds (TEIDE-2) located at the height of the core in the shield of BWR type reactor vessels.

This equipment is placed inside the fuel shield, works while immersed and is remotely controlled from outside the contaminated area. Communications are via a fiber optics line of up to two kilometers long, to prevent as much as possible the interferences owing to radio-electric noise.

The TEIDE equipment can be tailored to different versions of the BWR reactor; the inspected weld volume can be maximized, and it can be made compatible with the minimum possible number of insertions into the vessel (reducing inspection times and personnel dose).

TEIDE-1

The TEIDE project was launched in mid-1996 for the specific purpose of inspecting the vertical welds in Sta. M. de Garoña NPP in the spring of 1997. This job was successfully completed and, in view of how well the system worked, the equipment was requested for performing inspections in E.I. Hatch (October '97) in Georgia, USA, and in Nine Mile Point (June '98) in New York, USA; a retest of horizontal welds was also performed in the latter plant, for which the TEIDE-1 was replaced by TEIDE-2.

The TEIDE-1 equipment requires a single insertion into the vessel to inspect each of the vertical core shield welds and it has a range of 90%.

Inspection time has been optimized by simultaneously coupling the UT and CI sensors. In addition, vertical weld inspection is executed in parallel from both sides of the weld with both techniques.

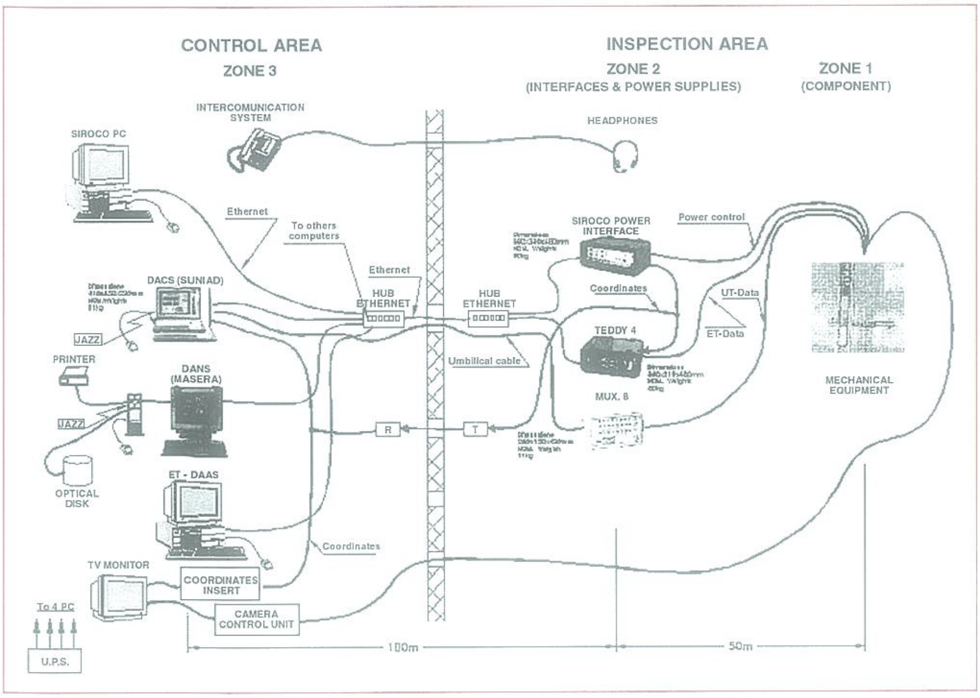
To install the manipulator, the fuel assemblies in the surrounding area should be removed and, in the positions in which it is going to be inserted, the control rod should also be removed. It is operated by suspending it from the polar crane or fuel crane, and then lowering it to the thimble tube of the control rod, at the level of the fuel support plate. In this case, the cart holding the test spikes is manually oriented before inserting the machine, and thus the machine must be completely removed from the vessel when a modification of cart orientation is required.

It is provided with two power driven inspection movements, the position and speed of which are controlled by servomechanisms and capable of providing the trajectory required for examining the welds with high precision and speed. Both the ultrasound and induced current sensors are mounted on a single inspection arm, which has a series of pneumatic actuators that locate the sensors opposite the weld and maintain a constant distance from the surface during the examination.

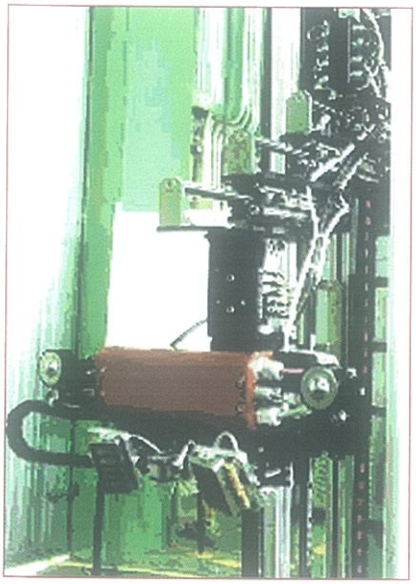
Both the TEIDE-1 and TEIDE-2 equipment are especially protected against a highly radioactive environment and designed for prolonged immersion in water. They are provided with radiation-resistant analog position receivers (resolvers), proximity sensors without semiconductors, shielded motors, and pressurized, watertight cameras. In addition, they have been provided with warning and safety systems in order to ensure proper operation and removal from the core.

TEIDE-2

After developing TEIDE and using it for the first time in a plant, it was seen that, with some small design modifications, the TEIDE system, as of



TEIDE inspection system diagram.



TEIDE-1 inspection arm.

that moment called TEIDE-1, could be valid for horizontal weld inspections while maintaining the advantages of positioning precision and inspection reliability without interferences. It was for this purpose that the TEIDE-2 project was launched in June 1997.

Two kinds of major modifications were made. The first kind were made to provide coverage of horizontal welds, for which purpose a new, bent arm system was designed. This arm was also designed to be interchangeable in order to cover different diameters of shield. In addition, the pneumatic cylinder removal system had to be modified to make it more rigid.

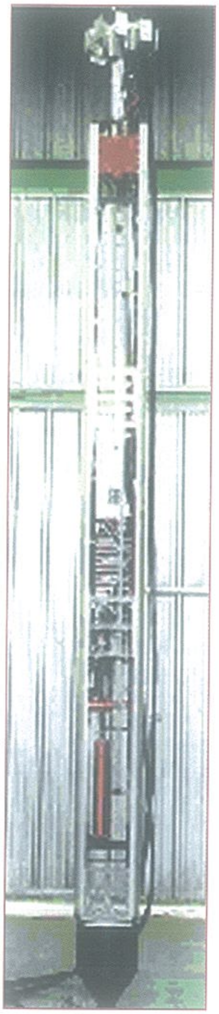
On the other hand, the experience gained was applied to include operating improvements in the new project. Thus the TEIDE-2 is provided with a new coded movement to orient the machine and the inspection arm, so as to support the equipment on the fuel support casting. This made it necessary to reduce the machine section in order to be able to turn it inside the fuel assembly without interferences from the assemblies or false assemblies of the adjacent cells. A new arm rotation system was also incorporated, based on a continuous current motor that was also subsequently coded.

With all these modifications, TEIDE-2 is capable of verifying 100% of horizontal welds H3 and H4. Weld H5, if the model has it depending on the reactor configuration, can be 100% inspected from both sides, from only one side, or it may not be accessible (if it is located at the height of the core support plate). Only eight insertions into the vessel are required, although there could be additional ones depending on the plant.

To install the manipulator, it is recommended that the fuel assemblies be removed from the vicinity and, in the positions in which it is going to be inserted, the control rod should also be removed. It is operated by suspending it from the polar crane or fuel crane and then lowering it to the fuel support casting on which it is supported, at the level of the fuel support plate. In this case, it does not have to be removed from the water to orient the arm, as this movement is automatic.

The outside dimensions of both equipment units are similar to those of a fuel assembly, and the most notable features are:

- Total weight: 150 kg
- Inspection speed: up to 70 mm/s for both movements
- Resolution: 0.1 mm
- Repeatability error: less than 1 mm for both movements.



TEIDE-1

Acceptance of these inspection systems was done by first qualifying the inspection techniques in EPRI-NDE (USA), and then validating the mechanical equipment with its sensors in full-size mockups under water, in order to verify performance before using them in a plant.

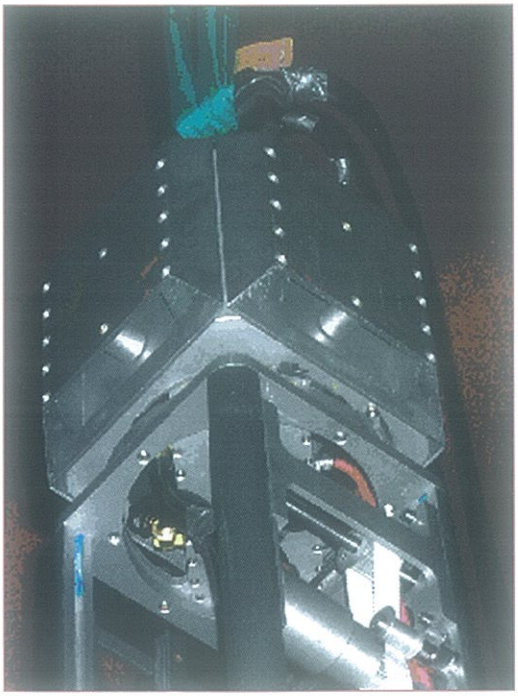
Both TEIDE-1 and TEIDE-2 have been used in the field, performing the required inspection in parallel with fuel movements and/or visual inspections of the vessel internals so that the impact on the refueling outage planning would be kept to a minimum.

IN-SERVICE INSPECTION EXPERIENCES

During this time, in-service inspections have been performed in Spain (2), Switzerland (3) and United States (7). These inspections have covered different ranges of both vertical and horizontal welds, and they have been performed in different types of BWR plants (type -3, type -4, type -5 and type –6) with different powers and core configurations.

From these experiences we can infer some operating and vessel occupation times, although in practice these usually vary because the inspection is performed in parallel with other jobs on the refueling platform.

Teide-2 ready for inspection on refueling platform.

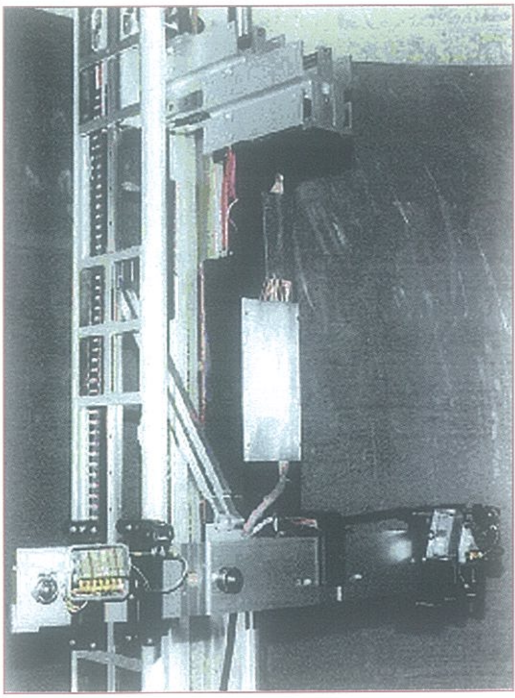


Detail of the TEIDE-2 head.

- Inspecting 3 vertical welds between H3-H4 (arm lowered): 12 hours
- Inspecting 3 vertical welds between H4-H5 (arm lowered): 15 hours
- Changing to configuration for horizontal welds: 8 hours
- Inspecting 5 sectors (approx. 180º) of welds H3 and H4: 20 hours

These times are averaged from the time already spent, as they depend on the positions where the welds are located.

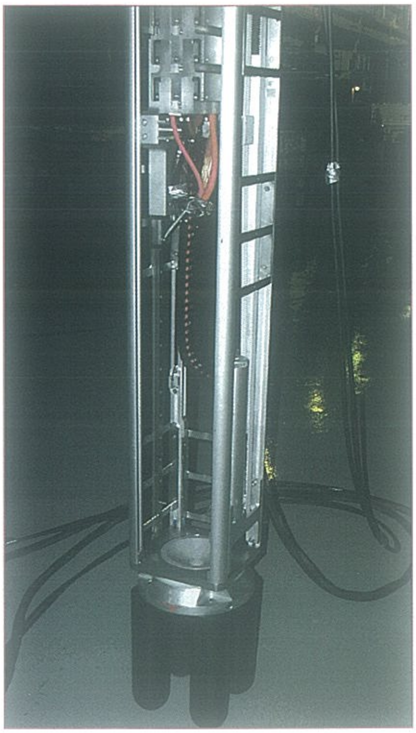
It should also be noted that the time when the polar crane is needed is when the machine must be inserted in/removed from the water, i.e. the first insertion, the last removal, and the beginning and end of the configuration change operations.



Detail of the TEIDE-2 bent arm.

For purposes of reference, we can estimate the following vessel occupation times per task:

- Placing the machine in a position from Platform: 2 hours
- Inspecting 3 vertical welds between H3-H4 (arm raised): 18 hours
- Changing to configuration with arm lowered: 8 hours



Detail of the TEIDE-2 FSC support.

TEIDE-3: THE FUTURE

As a result of the work developed in the shield, EPRI has also begun to study the potential for cracking in its support.

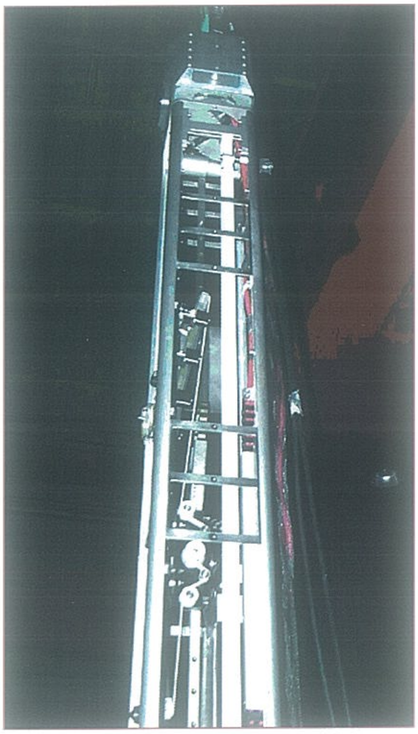
To address the need to inspect shield welds located underneath the fuel support plate (shield support), Tecnatom is developing a new inspection system based on the use of a robotic arm that will allow for inspection of vertical and horizontal welds with the same equipment. Development of this equipment began in 1998, and it is due to be validated during 2001.

TEIDE-3 will have 7 degrees of freedom, all power driven and position coded, and will be able to reach speeds exceeding 100 mm/s.

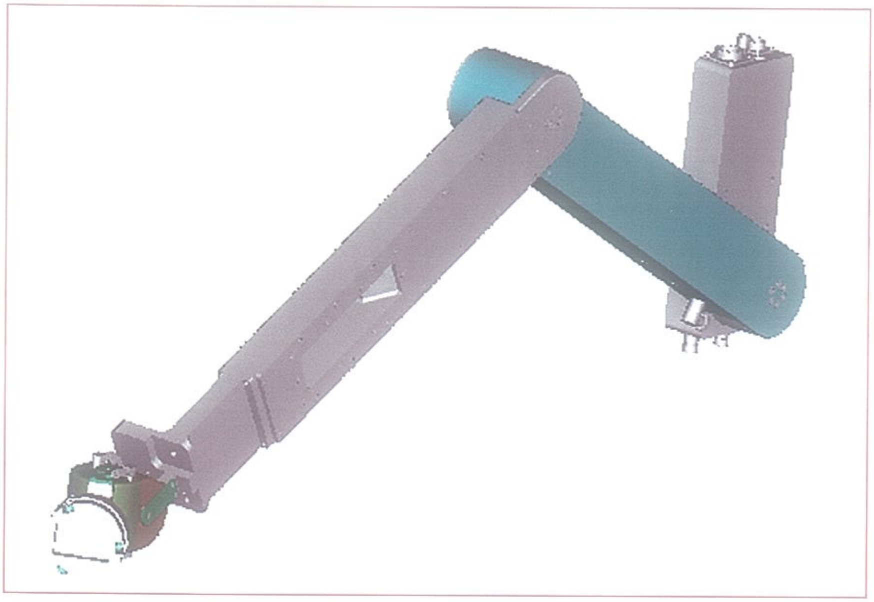
These movements are: one, raising the inspection arm; two, turning the base (machine body) that orients the arm to polar coordinates; three and four are "shoulder" and "elbow" movements, which are test spike extension movements; and finally there are three wrist movements – twisting, nodding and rotating – that keep the test spike continuously perpendicular to the shield.

It is expected that the repeatability and resolution of TEIDE-3 will be similar to those of the TEIDE-1 and TEIDE-2 equipment. The arm's reach will be 1.3 meters, which means that, in most plants, inspection of the 360º of a horizontal weld will be performed with approximately 8/10 insertions required. A UT test spike and an induced current coil or ultrasound phase array system will be mounted at the end, and they will both make inspections simultaneously.

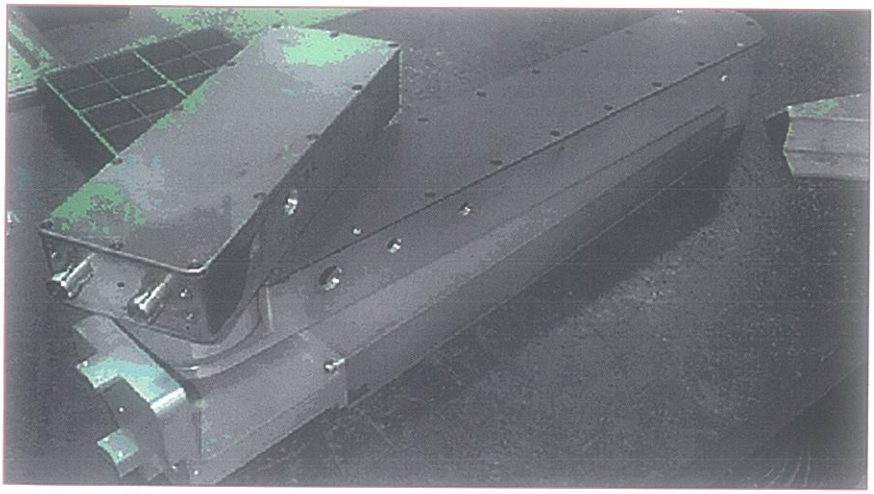
The equipment will be positioned in the same way as the existing TEIDE equipment, the only difference being that the lower support is on the Control Rod Drive Housing (CRDH) and the upper support on the support plate.



Side view of the TEIDE-2 folded up.



TEIDE-3 inspection arm design.



Inspection arm mounting.

Angular orientation will be verified by using the alignment pin of the fuel support casting.

In addition, it is provided with protection and safety systems that ensure safe operation and facilitate tool removal from the vessel.

A new type of real-time controller had to be developed that is capable of simultaneously moving the arm shafts. There are plans to include a computer application in a second phase that will allow the operator to easily generate the desired 3D inspection trajectory and at the same time communicate with the controller in a friendly way.

Because of this equipment's flexibility, it should be able to inspect most welds located below the support plate, such as H7, H8, H10 and H11 of the shield and its support. It will be possible to partially inspect weld H9 on the support of the vessel jet pumps, where there is material continuity or through the supports, welds of the control rod tube housings, etc.

CONCLUSION

With development of the TEIDE projects, Tecnatom became the first company capable of performing automated inspections of vertical fuel shield welds in BWR type nuclear power plants. At present it is the only company that uses non-destructive test techniques to perform a complete volumetric examination of the component's welds from the inside.

Satisfactory results have been obtained with the TEIDE equipment on performing in-service inspections in nuclear power plants in Spain, United States and Switzerland, and the inspection procedures have been approved by the respective National Regulatory Bodies.

This guarantees the suitability of the adopted solutions and Tecnatom's capability to offer owners a set of qualified equipment, procedures and personnel for a complete, mechanized inspection of pressure vessel core shields.

The new TEIDE-3 equipment, currently in the final phase of development, will be able to offer an effective tool to BWR plant owners for fulfilling forthcoming inspection requirements for welds located under the core support plate.

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