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In-Service Ultrasonic Examination of BWR MC-Nozzles Using Qualified Techniques: Experience in Sweden

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Tecnatom has participated in the qualification of some ultrasonic techniques for the Nuclear Power Plants in Sweden. These qualifications have been performed by means of Technical Justifications and practical trials on test specimens with real defects. Also, ultrasonic simulation software has been used as aid for technical justifications. This paper will describe some of these qualification processes and the experiences on-site.

The methodology used in these qualifications has allowed an increase in the quality of the inspections, minimization of the operation errors, and knowledge of the reliability of the ultrasonic data and the results reported.

This methodology has been extended to the development of inspection techniques for other components (pressure vessel head welds, bottom dome welds), but the process will be presented only for MC-nozzles examination. This paper will also describe the quality procedures and control tools developed, and the advantages obtained by using this methodology.

INTRODUCTION

Since the year 2000, Tecnatom has carried out a series of ultrasonic inspections at Swedish Nuclear Power Plants. These tasks have associated with them the qualification of the inspection procedures and of the people responsible for acquiring and analysing the ultrasonic data. This article shows the development of these qualifications and inspections.

SCOPE

The inspections referred to in this article are those covering the welds of the cover head and bottom dome of the reactor vessel (including the circumferential and longitudinal welds) and the welds of the main circulation nozzles (including the inner radius and the nozzle-vessel and nozzle-piping welds). But the development of the article shall be focused mainly on MC-Nozzles inspection.

Initially, the qualification of the techniques and corresponding inspection was applicable to two Swedish plants. Later, the scope was extended to similar areas at a further two plants. This qualification process has been recently finished, although the on-site inspections are still in action, and it will finalize –at the time of writing this paper- during the summer of 2007.

Consequently, the summer of 2007 will see the end of a cycle that began in 2000.

A LITTLE HISTORY

The tasks relating to qualification to work at the Swedish plants began in 2000. The first phase included qualification of the ultrasonic techniques for inspection of the vessel cover head and bottom dome welds and the second phase for inspection of one type of nozzles.

For all these qualifications mock-ups containing realistic defects were available.

The mechanical equipment, for the inspection of the vessel cover head and bottom dome (WIND), was designed in Tecnatom and was fitted with magnetic wheels. The mechanical equipment used for ultrasonic MC-nozzles inspection (5-STN HC) was manufactured in Sweden. This equipment had three different and independent probe-holding modules for inspection of the inner radius and the nozzle-vessel and vessel-piping welds; these modules were inserted into the nozzle (through a specific built-in guide-pipe for this purpose) and reached the inspection zone by joining a series of tubes.

The ultrasonic data acquisition and analysis equipment was that manufactured at that time by Tecnatom (SUMIAD / MASERA 4.2). Later, this equipment was replaced with a newer system (MIDAS / MASERA 5.0). The adaptation of the inspection procedures and the training of the personnel on the new equipment and programmes were a part of the qualification processes carried out.

The ultrasonic techniques proposed were of the pulse-echo type (and tandem in certain cases), using conventional ultrasonic probes.

For performance of the Technical Justifications, the effectiveness of the detection techniques was simulated for the worst defect cases (Ray tracing) and a parametric study of the error in defect sizing was performed. During the last stage of this qualification process, an ultrasonic simulation software (CIVA) was also used, as the most powerful tool for supporting technical justifications. Human team involved in MC-Nozzles inspections was qualified in data acquisition and analysis using blind mock-ups containing real defects.

INITIAL INSPECTIONS

The first inspections of the vessel cover head and bottom dome were carried out in 2001, and the first MC-Nozzle inspection was performed in 2002.

NEW QUALIFICATION TASKS. NEW INSPECTIONS

In 2003 a request was made for the qualification of the nozzle inspection procedures already developed to be extended to perform the inspection of the same type of nozzles at another plant, and in 2004 a similar request was made to extend the qualification of the inspection procedures already developed for the vessel cover head and bottom dome to perform the inspection of the vessel bottom dome welds at the same plant.

It was postulated that the areas to which the qualification was to be extended were the same as, or at least very similar to, those in which the first qualification was obtained, and that the volume to be inspected and postulated defects were the same.

Nevertheless, although it was possible during this new qualification to take advantage of most of the material that had been generated during the previous qualifications, certain difficulties arose and had to be solved. Some of these difficulties are mentioned below:

- Uncertainty regarding the position of the areas to be inspected. Location of the nozzle-piping weld centreline. During nozzle inspections, the dimensions used are taken with respect to the position of the nozzle-piping weld. The position of this nozzle-piping weld with respect to the flange via which the mechanical inspection equipment is introduced is data that is known with some uncertainty. If this uncertainty were not resolved, the volume required to be examined might not be inspected or, if defects were detected, these might not be positioned adequately and not be sized properly if the determination of defect size (depth x length) depended on the position of the ultrasonic probe. In the case of the nozzle qualification to which we refer in this article, this had to be carried out at each of the nozzle-piping welds. For this purpose 0° ultrasonic probes were used which, depending on the plant, located changes in thickness or type of the cladding. The development of this technique required the use of specific mock-ups. The method used to locate the weld centreline using the 0° probe entails a procedure that is independent for each plant and that is not subject to qualification.

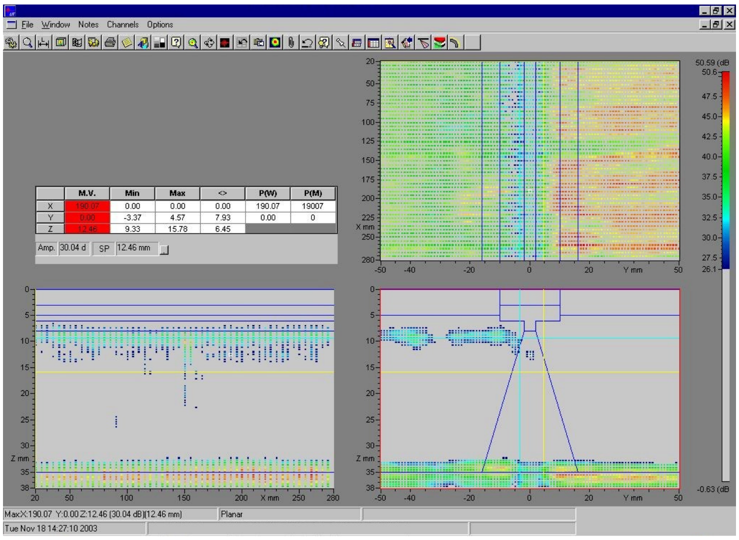
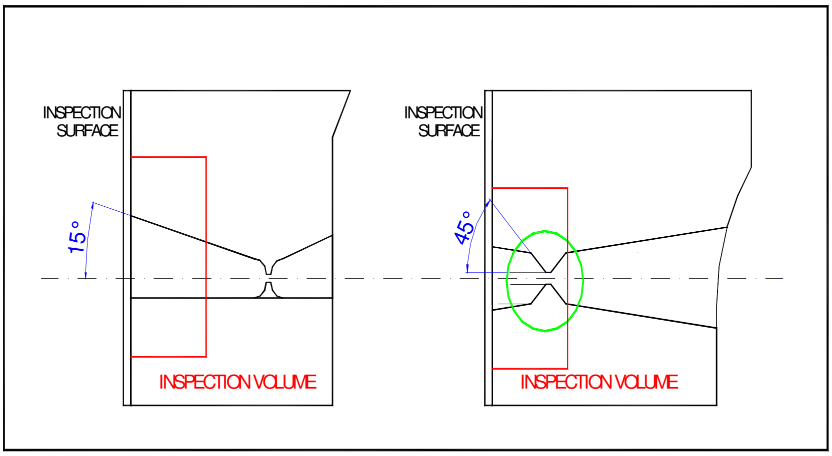


Figure 1 - Location of the weld centre line with a zero degree probe.

- Defects to be detected and sized: tilt and skew margins. The defects are classified by type, location, orientation (tilt and skew), morphology and size. Difficulties may arise even when the same defects are postulated for similar areas. The example presented in the Figure 2 is included to illustrate this situation, showing three nozzle-vessel welds. The left-hand weld has an inspection procedure that is already qualified, while the inspection procedure for the one on the right is to be qualified. Cracking and lack of fusion are postulated for both welds. While the angle of fusion in the weld with the qualified procedure (first sketch) has a maximum value of 15°, in the case of the weld whose procedure was to be qualified (second sketch) the angle of fusion in the areas marked with green circle is 45°. In this case a parametric and practical study was performed in order to determine the capacity of the procedure to inspect cases of lack of fusion with an inclination of 45°, and it was demonstrated that such cases could not be sized using the techniques initially proposed (there were no problems as regards detection). In the last case (third sketch), the fusion face in which the lack of fusion could be generated had an angle of 28º. The detection and sizing here was justified using the properties of the probes and incidence angles onto the defects. This is just an example of the different cases that arose in this qualification.



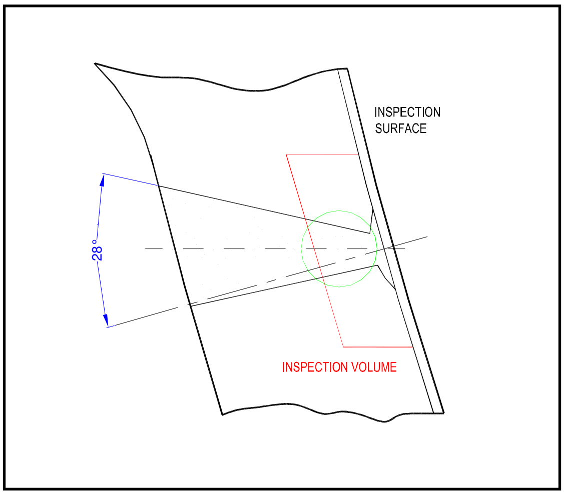


Figure 2 - Different configurations of the nozzle to shell weld.

- Materials. Although similar, at times the materials in the areas to be inspected presented certain differences that had to be resolved. The example shown in the Figure 3 is presented to illustrate this situation. The base material is the same in the areas for which a qualified procedure already existed as in those areas for which the procedure was to be qualified. However, the cladding located on one side of the nozzle-piping weld for which the procedure was to be qualified had been explosively bound. Consequently, it was necessary to demonstrate that this cladding did not affect the inspection, this being accomplished by manufacturing a block exactly reproducing the weld and the stainless steel layers on either side. This same block also served to resolve certain issues posed regarding how to size defects penetrating the cladding from the base material (sometimes opening onto the inner surface of the component).

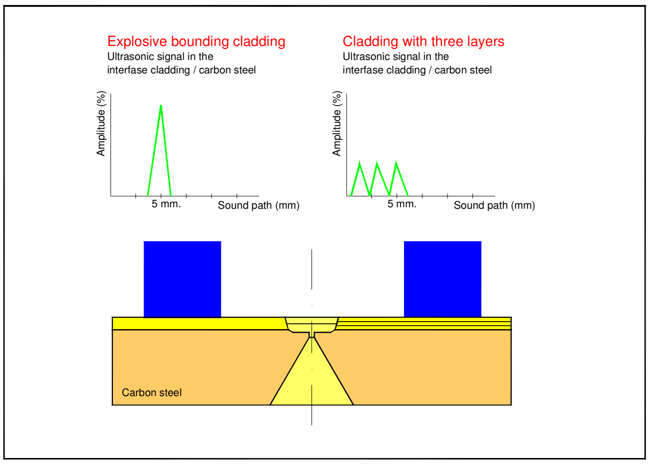


Figure 3 - Two different types of cladding at both sides of a pipe weld.

In other interesting case studied, one of the areas to be inspected in piping had an oblique weld. Cladding layer beads are deposited in circumferential direction, perpendicularly to the pipe axe. Therefore, weld bead is not parallel to the clad beads, having a skew angle of 9º with regard to those (see Figure 4). Consequently, the possible impact of the cladding layer beads on the UT beam was assessed in the technical justification for purposes of detection and sizing of defects. The conclusion was that the impact depends on the cladding type and width of its beads, being more significant when the beam pass through the interface between two cladding bands.

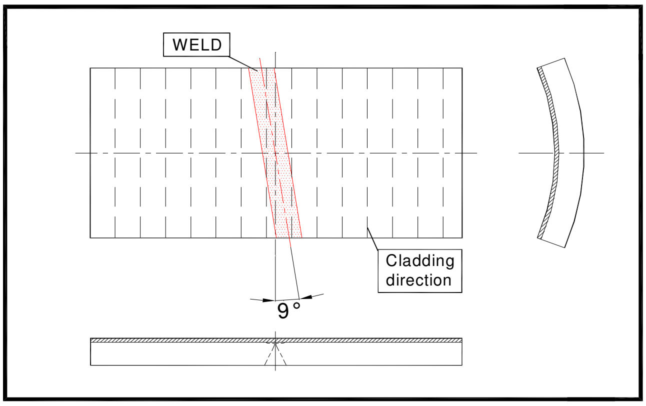


Figure 4 - Oblique weld in pipe connection and cladding beads direction.

- Mechanical equipment movements. In the mechanical equipment used for the inspections there is not always a linear relationship between the movements of the equipment and the position of the ultrasonic probes on the component to be inspected. Knowledge of the exact position of these probes at each moment in time is fundamental to guarantee that the inspection is performed correctly, and also for correct positioning of the defects. For this reason, during the validation processes the movements of the mechanical equipment and of the probes are related (normally by means of tables). If possible, these relationships are calculated using full-scale mock-ups. During the process of extending qualification referred to here, it was known that the tables relating the position of the mechanical equipment to that of the ultrasonic probe in the areas of the inner radius would need to be recalculated in the area of curvature of this radius, due to the change of one dimension, without a full-scale mock-up being available on that occasion. For the performance of these calculations a model of the nozzles was developed by means of a drawing programme, in order to extrapolate the experimental data previously calculated using a 1:1 scale mock-up.

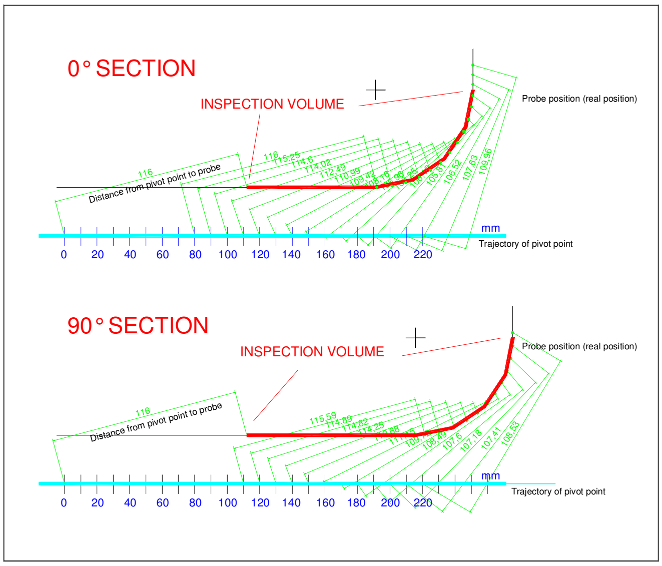


Figure 5 - Mechanical equipment movements.

- Ultrasonic data acquisition equipment. Between the first qualification and subsequent qualifications there is sometimes a period of time sufficient to justify changing the data acquisition equipment for a more modern system. It is necessary to describe how this change in equipment may affect the inspection. In this case the technical justifications need to address issues such as the characteristics of the electronics (pulses, filters, dynamic ranges, etc.) and the relation between the new equipment and the system overall (ultrasonic probes, cables, mechanical equipment (coordinates) and combined acquisition equipment). In addition to the necessary technical justifications, the change of the ultrasonic data acquisition equipment logically has an impact on the inspection procedures, and also requires the training and – in certain cases – the requalification of the personnel participating in the inspection, using the new data acquisition system.

FURTHER QUALIFICATION TASKS. MORE INSPECTIONS

In 2005 a new request was issued for extension of the previous qualifications to cover the inspection of the nozzles at another Swedish nuclear power plant. The new process of qualification of the procedure for inspection of the reactor vessel MC-nozzles has now been completed and the inspection has been also performed at the end of 2006. The main difficulties found in this new qualification was related to a longitudinal pipe weld, which required the use of new probes and a new inspection module, a new parametric study for calculation of sizing errors and the preparation of practical evidence to demonstrate the performance of the new probes. The main part of this qualification was done by means of technical justifications, supported at the same time on ultrasonic simulations. Specifically, the changes in postulated defect tilt and fusion angles were solved using simulation software.

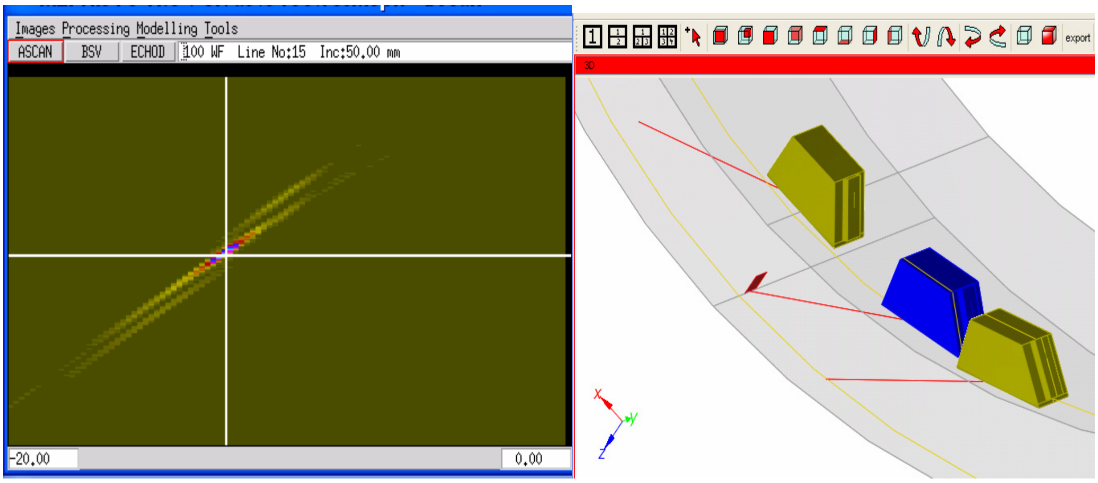


Figure 6 - Ultrasonic simulation software used in technical justifications.

Special interest had the case of a pipe weld, which weld direction is not perpendicular to the nozzle axe (Figure 6). The obliquity of this weld introduced a skew of the defect out of the qualified tolerance margins: given that the scan is performed axially, the postulated defects may present larger orientations regarding the UT beam direction. The technical justification of the inspection in this skewed weld has been supported preparing simulations, as well as with practical evidences obtained from a specific test piece that was manufactured for this purpose, containing implanted defects with the extreme parameters (skew and tilt) that was necessary to qualify.

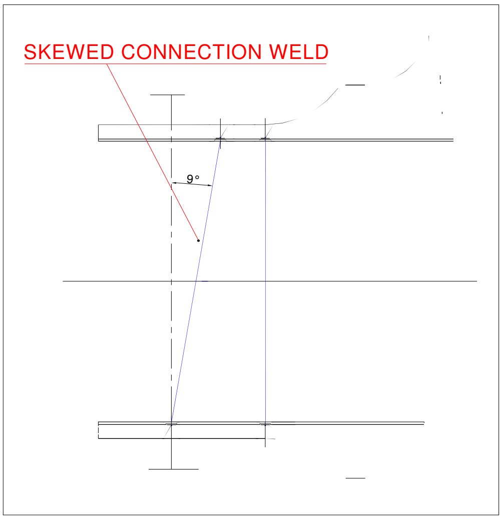


Figure 7 - Skewed weld in a nozzle to pipe connection

On the other hand, the mechanical equipment needed to be modified in length in order to allow the insertion into the nozzle, due to, in this plant, the containment was narrower. Existing internal interferences obliged the equipment to be introduced in certain orientations to avoid such interferences. A previous study of this was done using a 3D modelling program in order to elaborate the best sequence for the equipment deployment into the nozzle, being this task one of the most critical in this inspection.

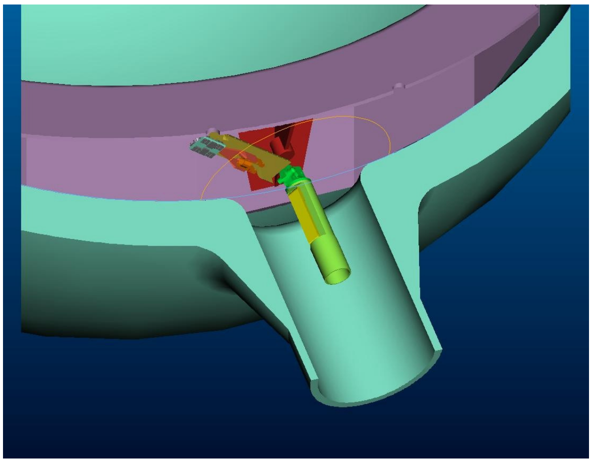


Figure 8 - Study of interferences in nozzles using modelling software.

CONCLUSIONS

By the end of 2007, a total 36 nozzles will have been inspected at four Swedish plants (the total number of inspection areas for these nozzles amounts to 108).

The benefits obtained from this way of work have been:

- Inspection qualification is a solid base for a reliable inspection, based on a rigorous methodology.
- With this background, extension of Qualification provided shorter development period and reduced work load.

- Designed UT techniques were optimized extending the qualification. No new techniques were needed for new weld geometries (fusion face angle, tilt & skew for defects, ...).
- By using technical justifications supported by modern simulation tools, saves time and cost in mock-ups.
- In-Service Inspections are being performed with satisfactory results.

2007 will see the conclusion of a cycle that began in 2000 and has provided those of us who have been fortunate to participate in this process with a rigorous methodology and a wealth of interesting experiences that we have subsequently been able to apply to other aspects of our work.