Qualification of NDT Systems in Hungary

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Abstract: The in-service inspection in nuclear power plants plays significant role in ensuring the structural integrity of pressurized components, therefore the reliability and effectiveness of NDT systems (equipment, procedure and personnel) have important impact to the nuclear safety.

The paper describes the scheme of national qualification; the most important elements of the Hungarian qualification strategy such as determination of qualification levels, the simplified qualifications when transferring foreign qualification results; and also the inspection qualification activity performed in Hungary since 2001 to date as well as planned for the future.

Introduction

The In-Service Inspection (ISI) in Nuclear Power Plants (NPPs) plays significant role in ensuring the structural integrity of pressurized components, therefore the reliability and effectiveness of NDT systems (equipment, procedure and personnel) have important impact to the nuclear safety.

The first steps in the field of inspection qualification have been made in Hungary in the second half of the 1990s. Paks (Hungary's sole NPP with four 440 MW units) together with other VVER[1] operating countries participated in both International Atomic Energy Agency (IAEA) and European Commission (EC) sponsored projects supporting to establish inspection qualification infrastructure in these countries. In 2000 the Hungarian Nuclear Regulatory Authority requested to start the inspection qualification activities at Paks NPP. Since there was no experience on inspection qualification in Hungary the operating organisation proposed that first a pilot qualification had to perform. The pilot qualification began in 2001 and finished in 2002.

During the pilot qualification exercise Hungary developed its national qualification strategy, involved leading NDT experts in the qualification process, established an independent inspection qualification body operated by the Hungarian Association of Welding Technology and Material Testing, and based on experience gained, determined the future qualification goals and the agenda.

Brief Overview Of Inspection Qualification

The results of PISC (Plate Inspection Steering Committee, later Programme for Inspection of Steel Components) have demonstrated that Ultrasonic Testing (UT) during ISI of NPP components could be quite effective. However, use of standardized procedures has been proved to be inadequate for some flaw types and geometries. This recognition has led both

[1] VVERs are Russian designed pressurized water reactors (PWRs).

to Performance Demonstration Initiative (PDI) in the USA, and to the inspection validation concept introduced first in the UK's Sizewell B NPP. From the latter one, ENIQ (European Network for Inspection Qualification, later European Network for Inspection and Qualification) as a European wide inspection qualification framework came into existence. The objective of both the PDI and ENIQ is to establish confidence that the NDT inspection procedure, equipment and personnel are capable of achieving the inspection requirements in real circumstances [1, 2].

Although the PDI and ENIQ approaches have much in common, there are significant differences in their basic philosophy. PDI is based very heavily on the use of test specimens with both realistic and artificially implanted flaws that are representative of the major inspection sites within the existing ISI program. The size, position and orientation of the flaws are exclusively known by the Performance Demonstration Administrator that is currently EPRI NDE Center. On the contrary, ENIQ thought that the essence of a proper inspection lays in the technical planning, procedure and detailed management of the NDT. Therefore the main emphasis of the ENIQ approach is to demonstrate via technical reasoning within a technical justification that the proposed inspection will achieve what is required of it. It has to be presented to an independent qualification body. The qualification body is assessing the proposed NDT against the requirements, and, if needed, lies down any requirements for practical trials. The most important feature of this approach is the role of the plant operator who specifies the NDT requirements in advance (target flaw configuration, inspection effectiveness), and the inspection team has to prepare and design their inspection against these requirements. The IAEA has prepared a guidance document for qualification of ISI systems in case of the VVER plants [3]. This document is a pragmatic synthesis of the American and European approaches, and seems quite close to ENIQ but not in contradiction to the PDI practice.

Today inspection qualification (performance demonstration) has more and more became an integrated part of the plant operation. Establishment of its legal framework is close to end. It has to be noted that some European countries using ASME Section XI as a mandatory document, follow the ENIQ qualification approach (e.g. Finland, Spain). This means that the two systems may exist together, and nuclear regulators can be convinced about it. An intensive exchange of information is going on, in which the series of the *International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components* seem to play a major role [4-6].

Brief History Of Inspection Qualification In Hungary

The Hungarian Inspection Qualification Body (HIQB) works in the frame of Hungarian Association of Welding Technology and Material Testing, who is the contractor of Paks NPP for managing and assessing the performance of inspection qualifications. The activity of HIQB is regulated in documents like Quality Assurance Manual, Procedure for Qualification, Working Methodology. All of these documents have been prepared based on the ENIQ and IAEA guidelines.

In 2001-2002, a pilot qualification exercise has been completed in Hungary. It has covered the detection and sizing of flaws in the threaded holes of Steam Generator (SG) primary collector using phased-array UT technique. During this pilot qualification the HIQB was organized as a Type B inspection body according to EN 45005. After successfully completing the pilot qualification, a program until 2006 was developed; also the qualification body was restructured. Since 2003 the HIQB organized as a Type A inspection body according to EN 45005. Currently the HIQB has two permanent members (chairperson and his deputy), and one to three temporary members composing a dedicated Qualification Group (QG). The QGs are established on a case by case basis for each inspection qualification ensuring the right experts for the area to be qualified. The scheme of the HIQB is shown in Figure 1.

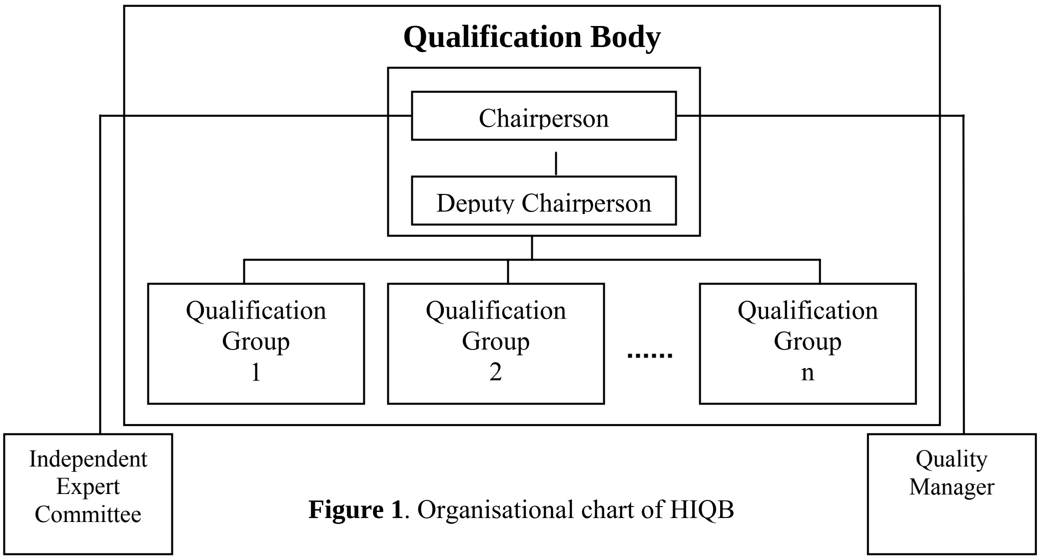

Figure 1. Organisational chart of HIQB

For the period of 2003 to 2005 the following qualifications have been initiated and scheduled:

- Eddy Current Testing (ET) of SG heat exchanger tubes (completed in 2004),
- Liquid Penetrant Testing (PT) of small diameter tubes (completed in 2004),
- Magnetic Particle Testing (MT) of pressure retaining bolts (completed in 2005),
- Mechanized UT of cladding and base metal interface of the reactor pressure vessel (RPV) on the basis of foreign qualification ("simplified" qualification, completed in 2004),
- Mechanized UT of the RPV circumferential welds on the basis of foreign qualification ("simplified" qualification, completed in 2005),
- Mechanized UT of the circumferential welds of main coolant loop piping (started in 2005).
- Mechanized UT of the RPV primary nozzle inner radii on the basis of foreign qualification ("simplified" qualification, started in 2006).

Hungarian Pilot Qualification Project

When preparing the pilot inspection qualification the following aspects were considered:

- the component or weld to be inspected should be significant from safety point of view,
- the inspection to be qualified should have an existing NDT procedure and equipment,
- for the selected inspection existing qualification test piece(s) should also be available.

Based on the aspects above three alternatives were proposed. Finally the mechanized UT of SG primary collector flange was selected.

VVER 440 SGs are horizontal units. The main components of their internals are formed by two primary collectors (playing the same role as the tubesheet in the vertical SGs), submerged tube bundle and a built-in steam separator. The shell is equipped with two secondary cover flanges enabling access to the flange joints of primary collectors, see Figure 2. The shell is made of low alloy steel 22K (GOST 2246). The structural material of the primary collectors and the tubing is Titanium stabilized austenitic stainless steel 08Ch18N10T (similar to Type 321 steel). Primary collectors are in the upper part formed by a flange with cover. The flange is equipped with 20 threaded holes of M 48 for tightening the cover with bolts.

Figure 2. Top view of SG primary and secondary collector flanges

Corrosion damage of SG primary collector flange has been occurred in several VVER NPPs included Paks in 1992. In all cases stress corrosion cracks initiating from the threaded holes had been found by NDT. In order to increase the NDT effectiveness in case of SG primary collector flange in 1995 Paks NPP replaced the manual ultrasonic method by mechanized one using phased-array technique.

During the qualification process the Technical Specification (TS) is the document that determines the input data for the inspection qualification. The TS for the pilot qualification exercise distinguished two regions in the SG primary collector flange: the region of thread roots (A) and region of threaded hole cup (B). The following qualification goals have been set up

- for detection
  - A. 5 mm deep cracks shall be detected in 100%,
  - B. 10 mm deep cracks shall be detected in 100 %,
- for sizing
  - A. max. sizing error is 3 mm for defects equal or bigger than 5 mm,
  - B. max. sizing error is 5 mm for defects equal or bigger than 10 mm,

- Defect position measurement tolerance max. 5 mm for both regions.

It was decided that in the frame of pilot qualification project the inspection procedure and equipment will be qualified according to ENIQ and IAEA methodology. For the laboratory experiments and for the practical trials existing test blocks were used. These test pieces had been manufactured in the EC's PHARE project No. 1.02/95 in which Paks NPP participated as co-beneficiary thus having the right for free use of these test blocks. Both the laboratory tests and practical trials were organized in the Maintenance Training Centre of Paks NPP, see Figure 3.

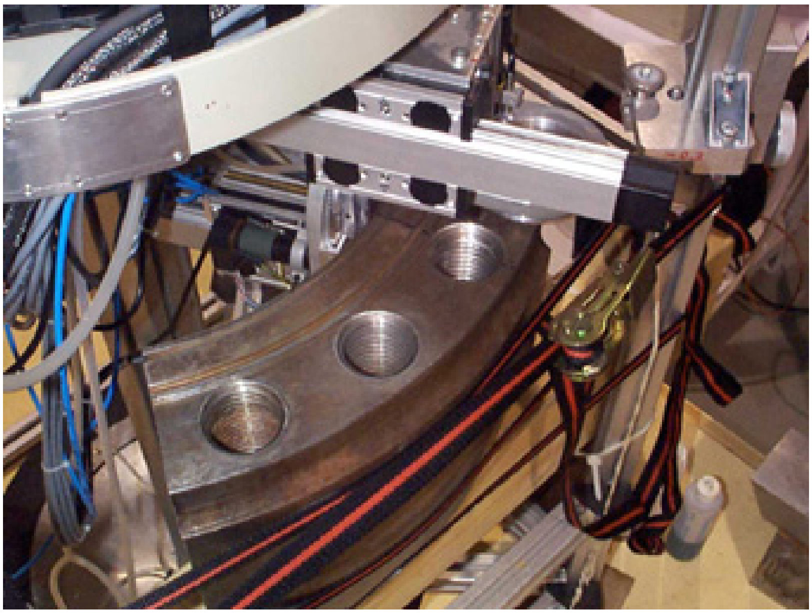

Figure 3. Laboratory tests on qualification test piece at the Paks Maintenance Training Centre

The pilot qualification began in April 2001 and finished in December 2002. Paks NPP played binary role in the pilot qualification. On one hand as the operating organisation (the licensee) submitted the qualification dossier together with the qualification certificate to the Nuclear Regulatory Authority for approval. On the other hand Paks NPP was the inspection organization as well being responsible for performing the ISI of SG primary collectors.

Because in Hungary there was no experience in inspection qualifications, Paks has also contracted with highly competent expert organization to assist the project (AEA Technology, later Serco Assurance, UK). The involved NDT experts helped to develop the national qualification strategy, to establish the Quality Assurance (QA) system of qualification body, and also to solve the problems occurred during the pilot qualification exercise.

Based on the Technical justification (TJ) document and on the results of open trial the HIQB concluded that the inspection was capable to detect the flaws specified in TS with high confidence, since during the trials the detection performance was 100%. For the bottom part the sizing error was shown less than those specified in TS. For the threaded part the sizing error was less than those specified in TS except for defects situated between the outer surface and the threaded hole, where the sizing accuracy was 5 mm. The position accuracy also met the requirements of TS.

Qualification Of Et Of Heat Exchanger Tubes Of Sg

The goal of SG tubing ET is to find any defect which endangers the integrity of the heat exchanger tube system, see Figure 4. The VVER 440 type SG has 5536 pcs of heat exchanger tubes, with the parameters as follows: ∅ 16x1.4 mm; length 9000-14000 mm; U-band type and material is 08Ch18N10T (GOST 5632).

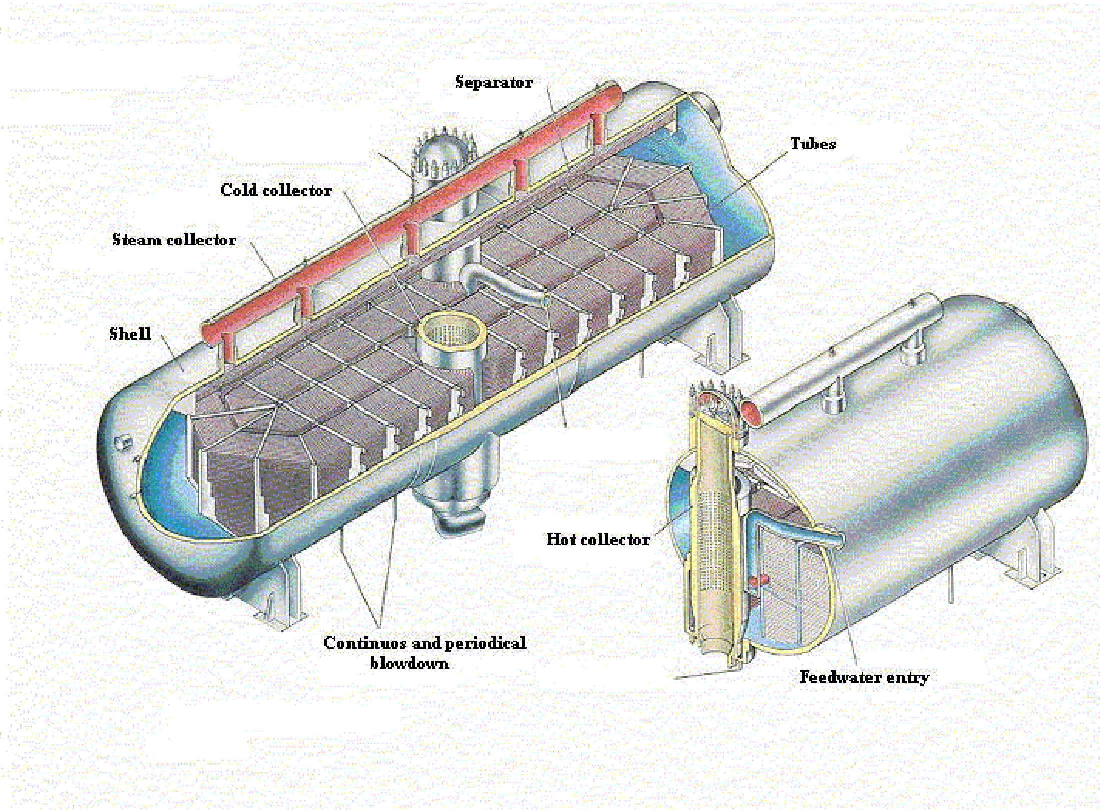

Figure 4. Steam generator and heat exchanger tube system

In Paks, in most cases (at three units out of four) the indications were found beneath or on the edge of the tube support plates, except one unit, where relatively high number of indications was found on the free spans.
Both legs (hot and cold) were affected. Five tubes with defects were pulled out from the first row of the tube bundle in order to study the type of defects by means of metallographic examination and to make a comparison between the analysis of ET and the results of destructive test (DT) [7]. The metallographic examination showed that the defects were usually stress corrosion cracks (transgranular) on the outer surface of the tube, see Figure 5. The comparison between the ET analysis and the results of destructive method gave a very good result, see Table 1.

Although the earlier experiences and the TJ gave a great deal of evidences which supported an assessment of the capability of NDT, the decision of Paks NPP was to complete it with practical trial. As a first step an open trial was performed to qualify the equipment with approved testing procedure. The pilot blind trial (personnel qualification) was organized according to ENIQ and IAEA methodology and to the principles of EN 473 in a separated time period.

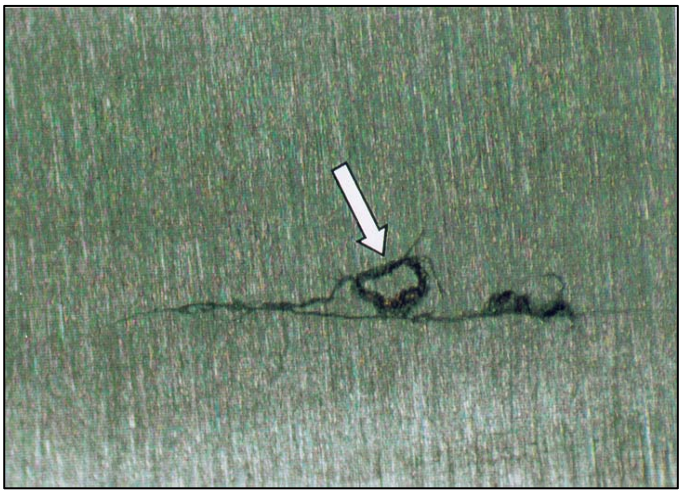

Figure 5. A typical defect on the tube outer surface (length of crack is 2.2 mm)

Year	Unit	SG	Tube ID	depth by ET	depth by DT
1997	2	3	25/1	77%	79%
1998	3	3	33/1	61%	57%
1999	4	1	63/1	77%	85%
2000	2	3	17/1	94%	95%
2002	3	3	61/1	80%	70%

Table 1. Comparison between eddy current and destructive test

The goal of the open trial was to determine if the capability of test (equipment and testing procedure) meets the requirements specified in the TS. The capability requirements were as follows:

- probability of detection (POD):
  - should reach 100% if the depth of defect is higher than 50% of the wall thickness,
  - should be higher than 95% above 20% depth of defect;
- location along the length of tube: ± 20 mm,
- sizing:
  - depth (d) of defect in outer surface:
    if $d \leq 50$ %, than ± 15%,
    if $d > 50$ %, than ± 10%,
  - depth of defect on the inner surface: ±20 %,
- false call:
  - in generally: should be lower than 0.1 % of total evaluated indication,
  - if $d > 50$%: should be lower than 0.01 % of total evaluated indication.

The NDT equipment was consisted of a data collection system MIZ 18A, using bobbin probe type SF 11.5, the EDDYNET 95 software for data evaluation, and a manipulator. The testing procedure was developed by Paks NPP. The HIQB assessed the technical adequacy of the procedure, checked all the testing parameters which might affect the outcome of the test and checked if the procedure was written in a sufficiently systematic and unambiguous way that its application was reproducible.

A wild range of reference test pieces with artificial defects were used. They were collected from the Czech Republic, Croatia and Paks NPP.

The tubes were installed in a mock-up system with three sections and this enabled replacing individual tube segments by another one. So it was possible to locate the tubes in arbitrary position, see Figures 6 and 7.

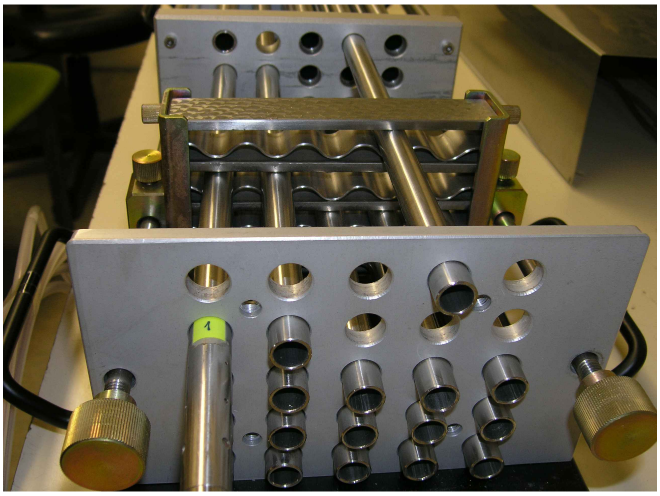

Figure 6. Mock-up system for practical trial (during the assembly)

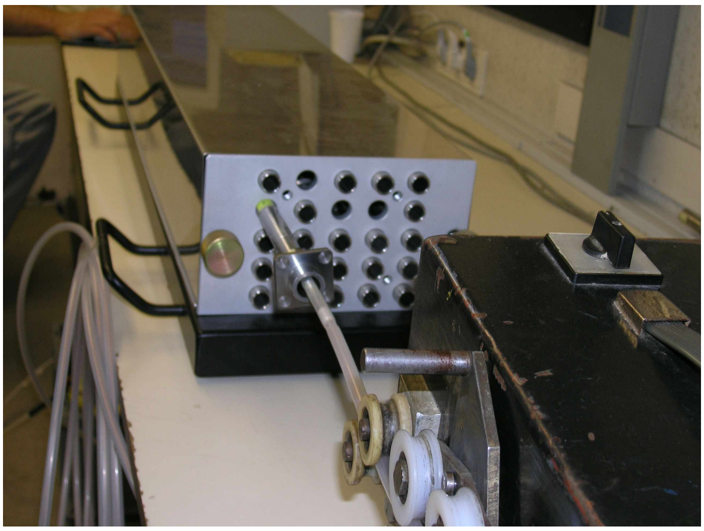

Figure 7. Mock-up system for practical trial (ready for testing)

According to the qualification program, the capability of the test was analyzed in the TJ which was completed with open and blind practical trials. Drawing the conclusion, it could be declared that testing method and the equipment were suitable for purpose, the testing procedure was appropriate to perform the test, and the personnel was well trained. All the experiences and results were summarized in the Summary Report and were documented in the Qualification Dossier.

As a final step of qualification the Qualification Certificate was issued which certified the reliability of ET of SG heat exchanger tubes according to the TS.

Simplified Qualification Of Rpv's Ut

RPV inspection at Paks NPP is carried out by vendor in a 4-year cycle. In the tendering document for the fifth inspection cycle (2003-2006) the qualification of UT was a substantial issue. The contractor became the Czech company Skoda, Plzen, and the UT system offered to be applied at Hungary has already been qualified for similar RPVs at the Czech Republic. Taking all these into consideration, the Hungarian Nuclear Regulatory Authority allowed of carrying out a „simplified" qualification, i.e. to transfer the Czech qualification result to possible extent. Since, there has been only limited information and little valuable experience available on how to transfer foreign inspection qualification results, after analyzing the major characteristics and aspects to be considered, on principle, for transferring foreign qualification results, we have concluded that the technical, procedural and legal aspects in the country of qualification and in the country of application have to be identical.

Based on previous considerations, the scheme showed in Figure 8. was established to carry out a simplified qualification of the UT of RPVs. It can be seen that the simplified inspection qualification is a process following ENIQ and IAEA principles that is being carried out on the basis of both the evaluation of foreign qualification results and the comparative assessment of the major inspection parameters with the major inspection parameters of RPVs at Paks NPP. Central element of the simplified qualification is the Comparative Technical Justification (CTJ).

In agreement with the ISI program, subject of the qualification was UT from the inner surface of RPVs at Paks NPP[2]. The scope of the inspection covered the circumferential welds of the nozzle region (Weld Nos.1/2 and 2/3), of the cylindrical part (Weld Nos. 3/5, 5/6 and 6/8) and the bottom weld (No. 8/9,10), furthermore the base material in the belt line region as well as the interface between cladding and base metal/weld, see Figure 9. The complete UT includes the inspection of the nozzle inner radii and the nozzle-to-safe-end dissimilar welds. Qualification of the latter ones is just being carried out recently because the simplified qualification followed the qualification sequences as they were completed in Czech Republic.

[2] The RPVs at Paks NPP can be inspected from the outer surface too.

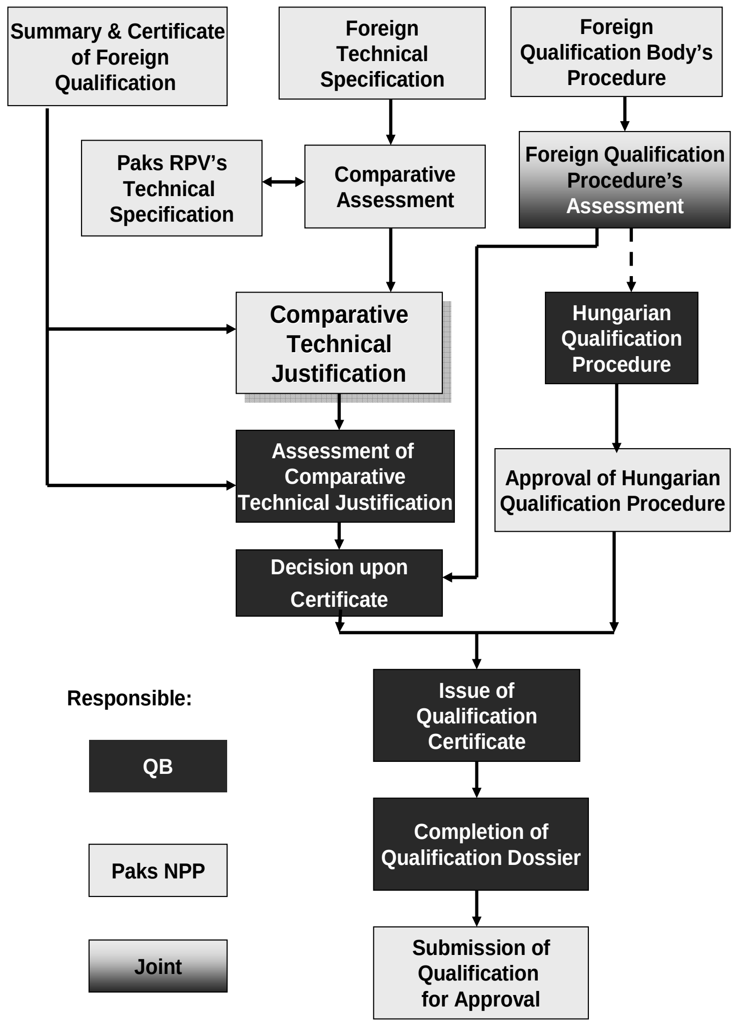

Figure 8. Simplified qualification process

The UT techniques used have been pulse-echo and Time-of-Flight-Diffraction (TOFD). The flaws to be detected were distinguished as specific flaws (under-cladding cracks perpendicular to the cladding/base metal interface and lack-of-fusions parallel with the welding axis), and postulated flaws (fatigue cracks in the welds perpendicular to and parallel with the weld axes and relaxation cracks of undefined orientations). The target flaw sizes and the inspection performance and reliability were basically determined in the framework of the engineering calculations for preparing the long term operation of the Paks NPP, taking in consideration radiation embrittlement of the structural material and assessing crack instability under Pressurized Thermal Shock (PTS) loading.

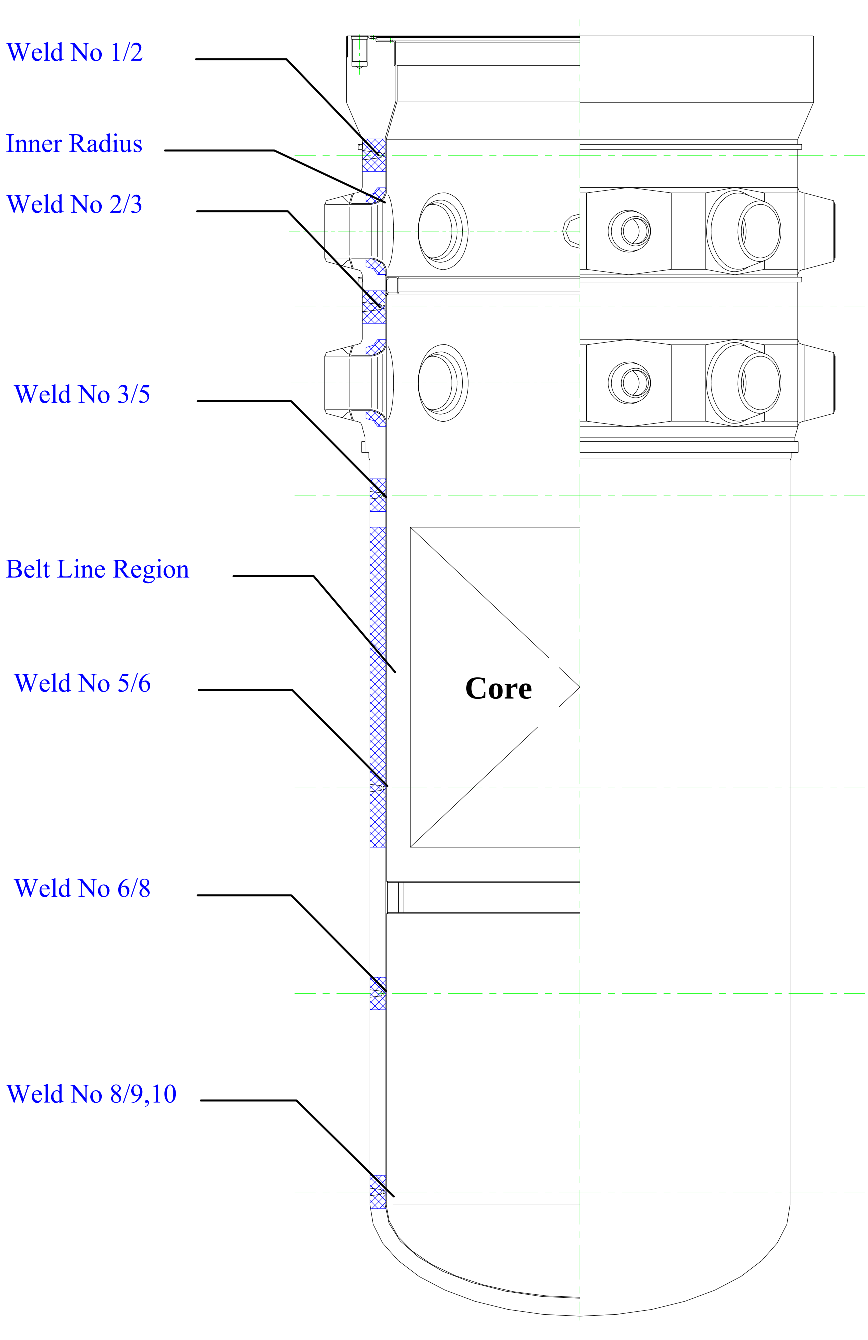

Figure 9. Scope of the RPV UT

The CTJ has summarized and thoroughly analyzed the similarity of the RPVs at both the Czech and the Hungarian NPPs. The four vessels at Dukovany were not only manufactured in the same machinery plant as the four Paks vessels and used the very same design and metallurgical as well as welding technology, but the eight vessels were completed, and the units were started too, at approximately the same period. Thus, the service life of the RPVs up today is also very similar. The conclusion of the CTJ was that the RPVs at Dukovany and Paks from the point of view of UT are identical. The CTJ has then analysed the Czech inspection and qualification objectives and the results of qualifications. The most important part of the justification was the comparison of the Hungarian inspection objectives with the Czech ones. The Czech process has defined 13 mandatory qualification requirements. Nine out of the Hungarian requirements were identical with the Czech ones, and four showed a less strict value. This meant that if the Czech qualification were successful it could guarantee the required level of inspection at Paks as well. The HIQB has concluded that the Czech qualification requirements met the Hungarian requirements and no additional qualification actions like practical trials were necessary.

The simplified qualification completed has justified the applicability of the special procedure (Figure 8.), which might decrease the qualification costs without compromising safety. The fact that the design, manufacturing (even manufacturer) and operational history of the components to be qualified were identical in the Czech qualification and in the Hungarian one has made easier the process of the simplified qualification. Substantial condition for the successful transfer of foreign qualification results was the proper and timely communication among the parties involved. As a consequence of this exercise, the national qualification bodies have established a cooperation, which has been allowing a continuous exchange of information as well as the participation as observer of a member of the national qualification body in the qualification the result of which is supposed to be transferred. Moreover, the Czech, Slovak and Hungarian qualification bodies decided to create a regional Club of Qualification Bodies, which does exist for 2004.

Further Qualifications And Future Qualification Concept

After successfully completing the pilot qualification exercise the plant came to a decision to continue the qualification of NDT systems following the practice of first qualification. In the first place, it was decided to set up qualification levels in line with the recommendations of ENIQ [8]. The main reason for introducing the concept of different qualification levels was to give those involved in the qualifications process the flexibility to decide and agree upon how much work or evidence is required to qualify a particular inspection. The concept developed for determining the qualification levels proposed three categories: normal (1), high (2) and very high (3), giving at the same time guidance for each level on

- qualification elements to be used,
- type of qualification test pieces to be used, and
- composition of the Qualification Body.

Also the safety importance of the component, the complexity of the component and the type of inspection were taken into consideration.

The future inspection qualifications at Paks NPP will be continued based on the experience gained up to present. The scope and priorities of inspections to be qualified shall meet the requirements of the latest and revised issue of the nuclear safety regulations (July 2005). These regulations deal also with the licensing process for the period beyond the design life. Paks NPP has namely decided to extend the operational life of the units. This life management activity includes a full revision and an upgrading of the ISI program including qualification. In the period of 2006-2008 the following qualifications are planned:

- Mechanized UT of main coolant loop piping circumferential welds,
- Mechanized UT of main coolant loop piping longitudinal welds on elbows,
- Mechanized UT of dissimilar metal weld on pressurizer lower nozzle,
- Mechanized UT of dissimilar metal weld between SG secondary collector and main coolant loop piping.

Experiences, Recommendations

- Inspection qualification infrastructure has been established in Hungary including its legal framework which is embedded in the current nuclear safety regulation.
- Inspection qualification became part of the ISI program. It contributes to both the safe operation of the units and the technical justification of the plant’s long term operability.
- The simplified qualification has justified the applicability of the special procedure for transferring of foreign qualification results. It may decrease qualification costs. It could facilitate the implementation of this kind of qualifications if any authorized European organisation would audit the national qualification bodies and certify that their organisation and procedure meet the ENIQ methodology and recommended practices.
- The introduction of qualification levels allowed to maintain the rigour of the qualifications using risk based approach, which helped to optimize the cost of qualifications
- Using qualified NDT inspection systems at Paks NPP in combination with other safety measures it will be possible to extend the currently existing four year ISI interval to eight years which on long term basis will provide economical benefit as well.

References

[1] Appendix VIII, Performance Demonstration for Ultrasonic Examination Systems, ASME Boiler and Pressure Vessels Code Section XI: Rules for Inservice Inspection of Nuclear Power Plant Components, ASME, New York, 2001

[2] European Methodology for Qualification of Non-Destructive Testing (second issue), EUR 17299 EN, 1997

[3] Methodology for Qualification of In-Service Inspection Systems for WWER Nuclear Power Plants. IAEA-EBP-WWER-11, IAEA, Vienna, 1998

[4] Proc. 2nd Int. Conf. NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, New Orleans, USA, 2000

[5] Proc. 3rd Int. Conf. NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, Seville, Spain, 2002

[6] Proc. 4th Int. Conf. NDE in Relation to Structural Integrity for Nuclear and Pressurized Components, London, UK, 2004

[7] M. Doczi – F. Oszvald: Steam Generator Inspection in Paks NPP. IAEA TM on Steam Generator Replacement and Repair, Prague-Rez, Czech Republic, Feb. 4-6, 2003

[8] ENIQ Recommended Practice 8 on Qualification Levels and Qualification Approaches Issue 1, ENIQ Report Nr. 25 EUR 21761