IN-SERVICE INSPECTION OF CRITICAL COMPONENTS AS A KEY TOOL FOR THE LIFE MANAGEMENT PROGRAMMES

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Abstract

One of the key elements to assess the life of nuclear power plants (NPP), and to apply for life extension, is to determine the integrity of structural materials more critically subjected to ageing degradation. To accomplish this objective, one of the most comprehensive approaches is the in-service inspection (ISI). In certain occasions in-service inspections have not obtained the expected results. Therefore, it is necessary to qualify inspection systems to verify their performance, and increase the reliability and efficiency of inspections. This paper comments on the approaches applied for in-service inspection of critical components. It will follow the description of the main inspection qualification methodologies. To conclude, examples of actual ISI and inspection qualifications implemented on critical components will be described.

1. Introduction

The standard design life of a nuclear power plant is 30-40 years, however, based on the accumulated experience and multiple assessments carried out on the utilities, it is very likely that many plants will request to the authorities, and will be able, to operate in excess of their design lives. One of the key elements to assess the life of the plant, to apply for life extension, is to determine the integrity of structural materials more critically subjected to ageing degradation. In-service inspection is a powerful and comprehensive approach to achieve this objective.

Safety codes require periodic inspections of critical components. These components are those subjected to the most stringent environmental conditions such as radiation, corrosion, high temperature and pressure. In addition to these facts, the areas to be assessed have a limited and difficult access, and their geometries are complexes.

To answer the requirements imposed by these limitations, ISI systems would be designed with capabilities such as powerful manipulators with several degrees of freedom able to reach locations with limited access and robust enough to cope with radiation doses, miniaturised transducers as phased arrays to minimise interferences scanning the complete inspection volume, real time multi-channel data acquisition system, data analysis system graphic based.

Due to the complexity and stringent requirements of ISI, inspection systems would be qualified to perform with high degree of reliability and efficiency. Inspection qualification means the systematic assessment, by all these methods that are needed to provide reliable confirmation, of an inspection system to ensure it is capable of achieving the required performance under real inspection conditions.

2. ISI Approaches

In-service inspections are intended to identify conditions, such as flaw indications, that are prone to produce structural failures. In the past, ISI were performed based on prescriptive requirements, insurance requirements, utility policy, etc. Most inspection requirements were based on past experience and engineering judgement; aspects such as how, when and where to inspect affect the results and benefits but they were defined having only implicit reference to risk based information (RBI). Elaborating RBI inspection programmes would consider the failure probability and the consequence impacts for the specific material and operation conditions.

Over the last twenty years, based on the gained operation experience and structural materials performance, technologies for risk assessment of components, and progress in inspection technology and the effects of inspection have been developing rapidly. These developments provide the capability of designing different inspection programmes and selecting between them based on quantitative estimates of the risks associated with components failure. The risk is evaluated from the probability and the consequence of component failure, and inspection programmes can be formulated based on managing these risks and related costs.

Currently there is a tendency to assess and implement risk informed processes, instead of prescriptive inspection programmes; the main expected benefits are to improve the effectiveness of inspection of components, to enhance inspection strategies, and to evaluate improvements to plant availability.

Critical components, such as certain areas of reactor pressure vessel, are subjected to stringent environmental conditions and limited accessibility thus standard inspection systems are not appropriate for carrying out ISI. In 1978, supported by the OECD and organised by the Joint Research Centre (JRC) of the European Commission, the Programme for the Inspection of Steel Components (PISC I) showed of that the inspection techniques currently applied did not reach the sufficient effectiveness. Thus, different organisations involved in the round robin tests started to consider the need of performance demonstration of the inspection techniques in test blocks with defects.

The above mentioned facts identified two important questions to take into consideration. The first one, it is necessary to use special inspection systems with powerful features to accomplish the ISI of critical areas and components included in RBI inspection programmes but not included in previous prescriptive inspection programmes. The second one, due to the complexity and stringent requirements of these inspections, it is necessary to qualify the inspection system or, in other words, evaluate its performance under real examination conditions to assure that it is able to achieve the expected results.

3. Inspection Qualification Methodologies

As a consequence of PISC results, since mid eighties, the JRC was promoting inspection validation activities. Thus, in 1992 it launched the European Network for Inspection Qualification (ENIQ) and in 1995 the European Methodology for Qualification of Inspection Systems was issued and reviewed in later years. Recommended practices that develop technical details of the European Methodology were also prepared. Two years later, European Regulators of the ten European countries with NPPs issued a consensus document in which the ENIQ qualification approach was accepted. Following this, each European country with NPPs is developing the ENIQ Methodology taking into consideration its legal requirements at national level.

In the USA, as a consequence of PISC results, ASME XI Appendices VII and VIII related to "performance demonstration for ultrasonic examination system" were published. All the NPPs established the "Performance Demonstration Initiative" to give an answer to the new requisites of ASME XI In 1999, the requisites of performance demonstration for ultrasonic examination systems established in ASME XI Appendix VIII came into force.

In the framework of the IAEA's Extrabudgetary Programme activities, the capability and effectiveness of ISI have been identified as one of the most important safety issues for WWER plants. Although efforts to improve ISI were under way at that time, a systematic demonstration of ISI capabilities and limitations was actually lacking. Due to the high safety significance of ISI and also taking into consideration the request and suggestions from several WWER operating countries, in 1996 the IAEA initiated the development of methodology for qualification of ISI systems for WWER NPPs that concluded two years later with the issue of the methodology for qualification. This methodology was developed keeping in mind the approaches and experiences from the European Commission and other western European countries, from the USA, and from several WWER operating countries.

In Spain, in the framework of UNESA (Spanish Association of the Electrical Industry), a Methodology of Validation of NDE Systems utilised in the In-service Inspection of NPPs is prepared following the recommendations of ENIQ. It is approved by the CSN (Spanish Nuclear Safety Council) in 1999, and received favourable valuation for application in 2004.

3.1 ENIQ Methodology Approach

Qualification of a NDE inspection requires the assessment of the NDE system that is made of a combination of inspection procedure, equipment and personnel. This qualification can be considered as the sum of two elements [1]:

- *Practical assessment* (blind or non-blind) conducted on simplified or representative test pieces resembling the component to be inspected.
- *Technical justification*, which involves assembling all evidence on the effectiveness of the test including previous experience of its application, parametric studies, mathematical modelling, physical reasoning, etc. It includes a written statement of the evidence which supports the case that a test is capable of meeting its requirements. It comprises a mixture of experimental evidence and theoretical assessment.

The appropriate weight of the two sources of evidence must be judged for each particular case.

Qualification of inspection procedure / equipment. These can be qualified by technical justification, open trials or both. Qualification of inspection procedures using technical justification includes assessment of technical adequacy, analysis of the essential variables, checking that procedures are written in a sufficiently systematic and unambiguous way.

Qualification of personnel. Personnel should be qualified through one or any combination of: certification through a national NDE personnel certification scheme, theoretical and / or open practical examination, blind trials.

The content of the Qualification Dossier is shown in Table 1.

3.2 IAEA Methodology Approach

Qualification of a non-destructive inspection system (NDE procedures, equipment and personnel) should be carried out through a combination of technical justification and practical trials. The relative weight of each one of these two elements is a matter to be agreed upon between the licensee and the qualification body based on a comprehensive assessment of the TJ prepared either by the licensee or by the inspection organization on behalf of the licensee.

The qualification process is sketched in figure 1 and articulated in the following steps [2]:

Technical specification. It should include the code requirements, area to be inspected and its essential parameters, the NDE method to be applied, inspection conditions and their essential parameters, postulated flaws and their essential parameters, flaw parameters (position, length, depth and their expected ranges), required inspection effectiveness (flaw detection rate, false call rate, sizing errors). This is an input to the inspection organization which allows preparing the bases for the NDE procedure, equipment, evidence and personnel.

Inspection procedure. It would include description of proposed NDE techniques, essential parameters, equipment description, equipment operational conditions, calibration process, indication's reporting and discrimination criteria. Preliminary review of the inspection procedure to provide a preliminary approval/rejection will follow.

Qualification procedure. It describes the entire process of qualification of the inspection system. It contains the description of the: technical justification, practical trials, and evaluation of the qualification results. It is implemented in two steps: 1) procedures and equipment, and 2) personnel.

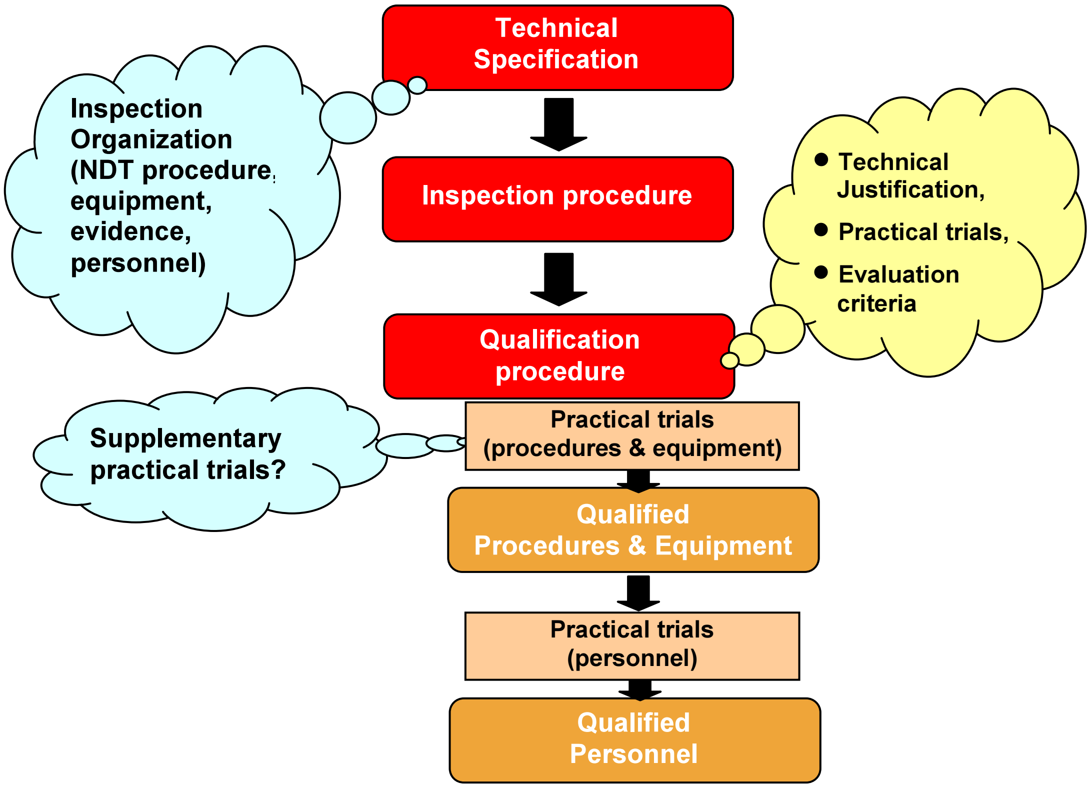


FIG. 1. Flow chart of IAEA's qualification process

Certification and approval. After completion of a qualification process, including a qualification dossier, the qualification body should issue appropriate certificates describing the specific inspection system which has been qualified. The content of the Qualification Dossier is presented in Table 1.

Table 1: Content of Qualification Dossier

ENIQ	IAEA
- Input information: ▪ Details of component and expected defects ▪ In-service inspection performance ▪ Details of NDE system (procedure, equipment) - Technical Justification (TJ) - Qualification procedure: ▪ Objectives ▪ Details on TJ assessment ▪ Details on practical tests, execution & assessment - Conclusions	- Technical specification - Inspection procedure -Preliminary review of inspection procedure - Qualification procedure: ▪ Technical Justification ▪ Description of practical trials ▪ Results of practical trials - Evaluation of the qualification process - Assessments, evaluations and certificates - Conclusions of the qualification

3.3 Spanish Methodology Approach

The Spanish Qualification Methodology [3] of inspection systems takes into consideration the ENIQ European Methodology and, according to the Spanish Law, the requirements of the country of origin of the nuclear power plant.

As in previous cases, the qualification should be carried out by means of a combination of two elements: technical justification (TJ) and practical demonstration (PD). Their features are similar to the ones described in above sections. One of the main particularities of the Spanish approach is the scope of these two elements, TJ and PD, which depends of the type of defect. Three cases are considered:

- Areas or components with specific defects[1]: An open practical demonstration with mock-ups containing specific defects is required. Technical justification will be prepared in order to complement and generalise the results obtained in the practical demonstration.
  (1): Specific defect refers to a defect already detected in the area or component of the considered NPP.
- Areas or components with postulated defects[2]: Technical justification will in-depth analyse the technical characteristics of the inspection procedure, the essential variables, and similar practical and theoretical evidences. When the TJ provides enough evidence regarding the required issues, the open practical demonstration will not be required. When the TJ does not provide evidence of any of the essential variables, this should be complemented with experimental data of the non justified essential variable.
  (2): this type of defect refers to a defect postulated according to design requisites or according to applicable experiences in similar areas.
- Areas or components with non determined defects[3]: A simplified TJ, which shows that the inspection procedure verifies the actual norms, is required.
  (3): this type of defect refers to a non detected defect and not expected to appear.

The practical demonstration for qualification of inspection procedures and equipment is an open trial, in order to determine their capability and separate the potential influence of the human factor; thus the results of the open trial have to be explained and justified. For personnel qualification blind trial is required. The sequence of the qualification process is sketched in figure 2.

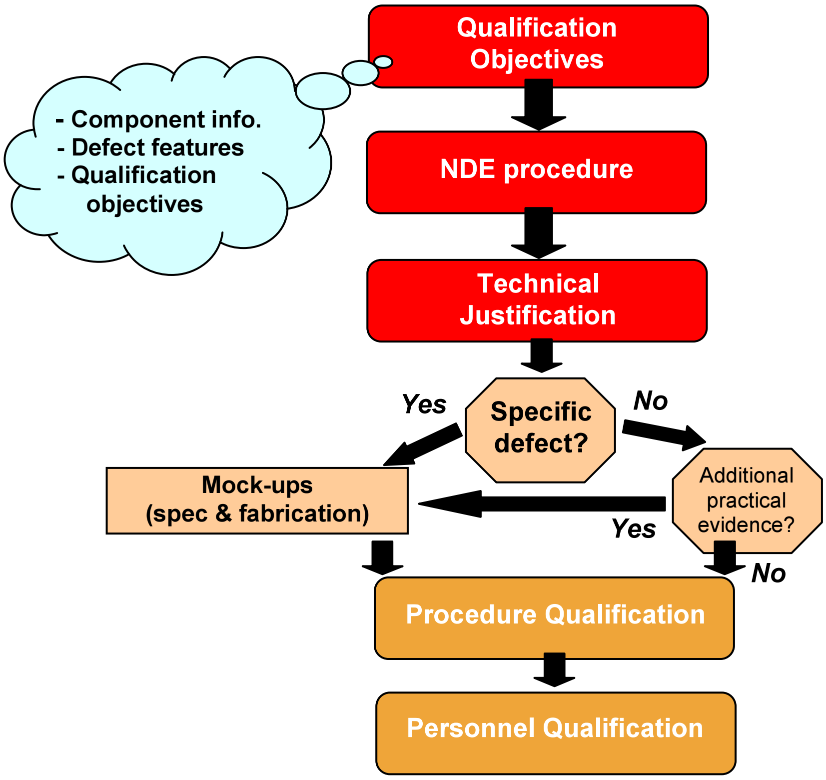


FIG. 2. Flow chart of Spanish qualification process

4. Tecnatom's experience

4.1 Where qualification is applied

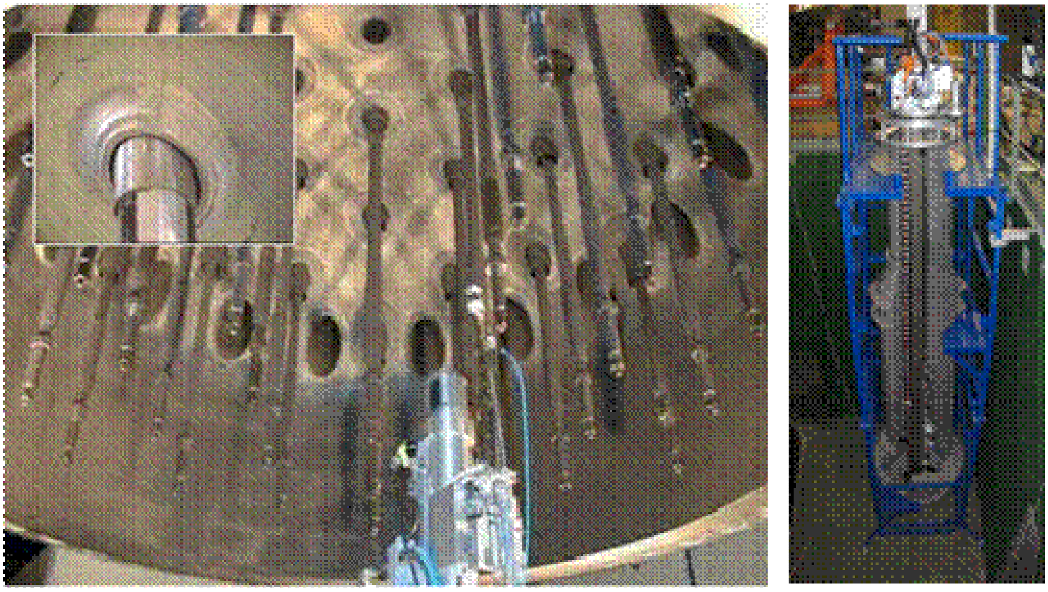
Inspection qualification is currently applied in areas or components required by ISI Codes. However, utilities also apply qualified inspection systems in areas not regulated due to its inherent benefits. In both cases, the main reason is to implement qualification on critical components from the probability and the consequence of their failure.

Tecnatom has a large experience regarding international inspection qualification under different schemes and technologies (PWR, BWR, VVER, etc.). To illustrate this variety, it follows a list of areas in which is required by different organisms, and Tecnatom has obtained, qualification:

- RPV full scope (PWR, BWR)
- RPV shroud stainless steel welds
- RPV head penetrations (see figure 3a)
- RPV bottom penetrations (BMP, ICMH)
- RPV CRDH assembly
- RPV nozzle bimetallic welds
- Primary circuit stainless steels welds (BWR)
- Fuel assembly inspection
- SG collector and tubes (VVER) (see figure 3b)

4.2 Advantages of qualification

The main benefit of inspection qualification is to increase the reliability of in-service inspections. The use of a qualification methodology allows, on the one hand, to have a systematic approach to evaluate the increase of reliability and, on the other, to optimise the inspection system, reduce the number of experimental trials, and optimise the training of personnel. Indirectly, these facts will reduce the associated costs and produce formal materials for additional applications.



a) b)

FIG. 3. a) Tecnatom's RPV head penetration inspection system, b) WWER SG collector and tubes inspection system

5. Conclusions

In this paper we have presented the importance of ISI for life management programmes. This has focussed attention onto the need and the antecedents of inspection qualification. The main principles of different inspection qualification methodologies have been described; they have similar general principles and their developments are adapted to the peculiarity of their regulations and organisations involved. To conclude, examples of areas required to qualification have been presented.

REFERENCES

[1] EUR 17299 EN, European Methodology for Qualification, 1999.

[2] IAEA-EBP-WWER-11, "Methodology for qualification of in-service inspection systems for WWER nuclear power plants", March 1998.

[3] UNESA CEX-120, "Qualification Methodology of NDE systems used in the In-service Inspection of Spanish NPP's", April 2003 (in Spanish).