Abstract:

In the past ten years, the requirements of qualification methodology for NDE examination have been gradually suggested and adopted in the in-service inspection (ISI) codes and standards used in most nuclear power country.

With rapid development of Chinese nuclear power plant and progress of in-service inspection technology, it’s necessary and urgent to carry out inspection qualification in in-service inspection technology of nuclear power plant, to make the non-destructive technology (including the inspection procedure, equipment and personnel certificate etc.) meet the code requirement, which could help to ensure the safety operation of nuclear power plant. Meanwhile forming the localized qualified in-service inspection system will strengthen core competence of inspection technology in nuclear power plant.

This paper reviews the status in requirement and implementation of qualification for qualification methodology for NDE examination used in Nuclear Power Plants. The worldwide technical justification, open test and blind test, etc. methods were investigated in detail to get some reference for the qualification framework construction in China. Consideration and suggestion on establishing inspection qualification platform for Chinese nuclear power industry are given as conclusion.

INTRODUCTION

In-service inspection of complex components in primary loop system of NPP, in certain occasions, has not obtained the expected results. Therefore it is necessary to verify the inspection system to assure it is able to achieve the expected results under real examination conditions. This process is named qualification.

In-service inspection of nuclear power plants safety components are performed according to its relevant code, criterion and guides all around the world, for example, in the American Society of Mechanical Engineers (ASME) code section XI “Rules for In-service Inspection of Nuclear Power Plant Components”, section V “Nondestructive Examination”, relevant guides of United States Nuclear Regulatory Commission (USNRC) French RSE-M code “In Service Inspection Rules for the Mechanical Components of PWR Nuclear Islands” and RCC-M code “Design and Construction Rules for Mechanical Components of PWR Nuclear Islands” section III volume MC “Examination Methods”.

Before ASME code section XI (1989 edition) put forward the Appendix VIII “Performance Demonstration for Ultrasonic Examination Systems” and RSE-M code (1997 edition) put forward the Appendix 4.3 “Qualification Methodology for NDE Application”, or in the past quite a long period, almost all the nuclear power countries among the world used to perform the in-service inspection of nuclear power plants according to above mentioned codes, criteria and relevant guides because they thought that these detailed requirements could insure the reliability of inspection on safety components.

Soon after issuing of the ASME code section XI, PVRC (Pressure Vessel Research Council) carried out the research on the reliability of inspection. The results indicated that it could not detect and size all the flaws correctly in the component and meet the reliability of designing requirement even though the ultrasonic examination procedure specified in the code was strictly performed. So the PISC (Program for Inspection of Steel Component) plan was carried out that European Union, USA,
many Asian research organizations and operation organizations participated in. After several periods of research, the results indicated that:

(1) Conventional ultrasonic examination method described in ASME code could not ensure the validity of detecting flaws which are produced during the operation stage, i.e. executing the code and standard could not entirely ensure the validity of inspection results.

(2) The relating requirement of validity should be described in Code for pre-service and in-service inspection technique.

(3) The ultrasonic examination technique which is used in reactor pressure vessels during in-service inspection should be qualified for performance demonstration.

REVIEW AND IMPLEMENTATION OF INSPECTION QUALIFICATION

In the past dozen years, the requirements of qualification methodology for NDE examination have been gradually suggested and adopted in the respective ISI codes used in each nuclear power country. Meanwhile, some different qualification methodologies are utilized, such as the methods applied in Appendix VIII in ASME code section XI (since 1995 edition), appendix 4.3 in French RES-M code (Since 1997 edition) and Europe Network for Inspection Qualification (ENIQ).

IAEA\textsuperscript{[1-2]}

Safety standard series (No.NS-R-2) “Safety of Nuclear Power Plants: Operation (2000 edition)” and Safety Guides (No. NS-G-2.6) “Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants (2002 edition)” have been issued separately in 2000 and 2002 by IAEA. This Safety Guide definitely specifies the requirements of qualification for non-destructive testing system (i.e. the equipment, procedures and personnel) which is able to implement the required performance under real inspection conditions. This guide also specifies that:

(1) An independent, impartiality and confidentiality qualification body which is the organization to manage, supervise, evaluate and certify an in-service inspection system’s qualification process should be set up.

(2) According to successful qualification of a non-destructive testing procedure and the associated equipment, the qualification body should issue a certificate to the licensee and/or inspection organization which clearly identifies the scope of the procedure and the equipment that have been qualified.

(3) For each successful candidate, the qualification body should issue a personnel certificate which should clearly specify its working scope, including applicability and scope of competence (with regard to procedure, detection or sizing, for example).

(4) The power operating organization is responsible for approval of selection of inspection system for nondestructive testing, on the basis of evidence derived from the qualification process and provided by the qualification body.

USA

In ASME code section XI which is compulsory and applicable for in-service inspection of nuclear power plant has been performed by many nuclear power plant countries. Hereinto the ultrasonic examination procedures, equipment and personnel shall be qualified when detecting and sizing flaws on the components or part of components listed below in accordance with Appendix VIII “Performance Demonstration for Ultrasonic Examination Systems”\textsuperscript{[3]}:\n
1) Reactor pressure vessel with more than 2 inches(51mm) thickness
   \(\checkmark\) Shell to dome welds
   \(\checkmark\) Nozzle to shell welds
   \(\checkmark\) Nozzle inner radius section
2) Piping welds
   - Forged austenitic stainless steel piping welds
   - Ferritic steel piping welds
   - Cast austenitic steel piping welds
   - Dissimilar metal welds
   - Overlay

3) Bolts and studs

Furthermore, when eddy current examination is used as a surface examination method, ASME code Appendix IV provides requirements for performance demonstration of eddy current systems. Ultrasonic examination procedure, equipment and personnel are qualified in compliance with relevant provisions. The personnel are qualified on the qualification test specimens (including detecting flaw specimens and sizing flaw specimens). Different inspection objects could either have different detecting and sizing qualification test specimens or the same ones to detect and size. During qualification, the following information shall be prescribed exactly:
   - the shape, size and numbers of qualification specimens
   - the character, direction and numbers of the flaws
   - the character and numbers of the geometry reflector

The reliability and validity of inspection results shall be evaluated comparing with acceptance criteria and if they meet the acceptance criteria, examination procedure, equipment and personnel shall be considered qualified.

Not all the described qualification contents specified in ASME code section XI appendix VIII which is compulsory has been finished by the inspection organization. For instance, cast austenitic piping welds (in the course of preparation), nozzle inside radius section, cladding to base metal interface region, etc., have not developed relevant performance qualification. This is because there are many limits of actual test qualification such as high requirements and quantities to specimens and flaws, high cost and difficulty while manufacturing flaws. So up to now in America ISI fields, the certificate is issued one by one after it is mature and qualified. EPRI (Electric Power Research Institute) could carry out the qualification test and performance demonstration then issue the certification.

So far the qualification has been developed according to the requirement of ASME code section XI Appendix VIII in Japan and Korea, but not all the contents of Appendix VIII, especially the qualification test specimens of detecting and sizing flaws.

Europe

Europe has already formed a regional qualification organization, namely Europe Network for Inspection Qualification (ENIQ) [4-5]. Each member of this organization participates in the qualification of research projects, using the same qualification frame, sharing the results of qualification. Methodology for qualification adopted by Europe which is different from the USA is using the existing technology experience, physical basic analysis and software simulation to confirm whether the inspection technology is met the qualification requirement.

The European Methodology is intended to provide a general framework for development of qualifications for the inspection of specific components to ensure they are developed in a coherent and consistent way throughout Europe while still allowing qualification to be tailored in detail to meet different national requirements.

Along the European Methodology qualification of a non-destructive test may require assessment of any inspection system, composed of any combination of inspection procedure, equipment and personnel. This qualification or assessment can be considered as the sum of the following items:
   - Practical assessment (blind or non-blind trial) conducted on simplified or representative test pieces resembling the component to be inspected.
   - Technical Justification (TJ), which involves assembling all evidence on the effectiveness of
the test including previous experience of its application, laboratory studies, mathematical modeling, physical reasoning and so on. The appropriate mix of the above sources of evidence must be judged separately for each particular case, although the use of technical justification is highly recommended.

The first version of the European Methodology document has been issued by the PISC III Action 8 Group, dealing with support for codes and standards. The document has been further developed and finalized by ENIQ. The first issue was approved by the Steering Committee of ENIQ at its meeting of 15 March 1995 in Petten and was published as ENIQ Report 1. This document was the first to be published in Europe on this issue and contained a number of innovative proposals such as the use of technical justification, the separation between procedure/equipment and personnel qualification and the use of non-blind trials for procedure and equipment qualification.

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The European regulators issued in April 1996 a common position document on qualification of NDT systems for pre- and in-service inspection of light water reactor components. This official report of the Nuclear Regulator Working Group (NRWG), sponsored by DG XI, considers also the essential elements of the European Methodology and is, in general, in good agreement with it. This means that in Europe there is a remarkable consensus of opinion between the major parties involved on the general principles of inspection qualification. Since the first issue of the European Methodology the concept of inspection qualification has also been discussed widely both at national and international level and some evolution in thinking has occurred.

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The Steering Committee of ENIQ has decided to conduct a pilot study to fully analyze the feasibility of the European Methodology and to explore ways of its implementation for the inspection qualification to a specific component. All this has led the Steering Committee of ENIQ to issue a second version of the European Methodology. Many EU countries are already implementing the general principles of the European Methodology in their national qualification programmes. France has its in-service inspection code (RSE-M) and inspection qualification along the European methodology is now formally required. Sweden introduced formal requirements for inspection qualification in 1995 and has set up a qualification body. Germany has set up a national ENIQ committee in order to issue German guidelines for inspection qualification. Spain, Finland and Belgium are countries that have to follow by law the ASME code. However, for inspection qualification, Spain has decided to follow the ENIQ approach. Finland and Belgium have an ad hoc approach following basically the ENIQ approach for inspection qualification.

France

The requirement of qualification for NDE in which is optional, not compulsory, is specified in RSE-M Code (1997 Edition) Appendix 4.3. The RSEM Code defines the following three types of qualification which depend on the potential damage on the plant safety:

- Applications with conventional qualification: It may be necessary, according to the “defense in depth” principle, to examine some zones of these components. This examination is required even though no design or operational data give cause to suspect the presence of any defect that could affect the plant integrity. The purpose of conventional qualification is to clarify the performance of the NDE application.
- Applications with general qualification: The damage mechanism is presumed but no occurrence has been reported. The purpose of a general qualification is to demonstrate that the NDE application will enable to detect, to locate and to characterize the potential suspected defects.
- Applications with specific qualification: A specific qualification is required on components with identified defects: actual occurrences are reported. The purpose of a specific qualification is to demonstrate that the NDE application will enable to establish the absence of a defect over a given limit and to locate and characterize the identified defect.

Adopting the technical justification (TJ), the qualification is made use of former application experience, experiment research, mathematical models, evaluation of physical deduction and simulation software set up according to the theoretical of math and non-destructive test to analyze the
reliability and validity of inspection techniques, or along with the powerful evidence using the actual
test evaluation to prove that the inspection techniques on detecting and sizing flaws has met the
expected performance objective. From 1999 until today, 70 applications have been qualified. Among
them 60 NDE applications qualified in UT, RT and ET methods, a distribution of 50 % between
manual and automated NDE process, a good know-how of the ultrasonic applications and a better
know-how of radiographic qualifications after some difficulties. The experience feed-back reveals a
strong file treatment capacity increase as well as an increasing efficiency.

RAPID DEVELOPMENT OF NPP IN CHINA MAINLAND

Mainland China has eleven nuclear power reactors in commercial operation, 12 under construction,
and at least 12 more about to start construction in 2009. Additional reactors are planned, including
some of the world’s most advanced, to give a sixfold increase in nuclear capacity to at least 50 GWe or
possibly to 60 GWe by 2020 and then a further three to fourfold increase to 120-160 GWe by 2030.
The country aims to become self-sufficient in reactor design and construction, as well as other aspects
of the fuel cycle. Electricity demand is growing very rapidly.

Nuclear power has an important role, especially in the coastal areas remote from the
coalfields and where the economy is developing rapidly. In 2007 it provided 62.86 billion kWh - 2.3%
of total, and there is now 8.6 GWe (net) installed. Generally, nuclear plants can be built close to
centers of demand, whereas suitable wind and hydro sites are remote from demand.

The government had planned to increase nuclear generating capacity to 40 GWe by 2020
(of total 1000 GWe then planned), with a further 18 GWe nuclear being under construction then,
requiring an average of 2 GWe per year being added. In May 2007 the National Development and
Reform Commission announced that its target for nuclear generation capacity in 2030 was 160 GWe.
In March 2008 the newly-formed State Energy Bureau (SEB) said that the target for 2020 should be at
least 5% of electricity from nuclear power, requiring at least 50 GWe to be in operation by then. In
June 2008 the China Electrical Council projected 60 GWe of nuclear capacity by 2020. In April 2009
the State Council was reported to be considering raising the 2020 target to 70 GWe installed and 18
GWe under construction.

In-service inspection of nuclear power plants safety components is performed to improve
the safety of nuclear plant. The validity and reliability of the inspection draw more attention of the
nuclear safety authority, plant owner and relative organization. How to find the defect effectively and
efficient during the routine outage and ensure the plant safe operation, is a common problem for
inspection company and owner. Qualification of in-service inspection is more cared that the overall
performance validation to inspection equipment, procedure and personnel is performed qualified in
independent validation body, by which to judge the inspection technology is/or not able to detect and
size the defect validly.

SUGGESTION ON PLATFORM FOR INSPECTION QUALIFICATION

Chinese National Nuclear Safety Authority (NNSA) will soon authorize to establish the safety code
HAF103 (safety of Nuclear Power Plants: Operation) and safety Guide HAD103/06 (Maintenance,
Surveillance and In-service Inspection in Nuclear Power Plants) which means that China will also
push the requirement of qualification methodology for NDE application in nuclear power plants.
As a fact that there are various nuclear power reactor types, e.g., PWR, CANDU, VVER, AP1000 and
EPR, the different inspection technique exists and the requirement for validation is also diverse. The
methodology of IAEA or ENIQ is suggested for basic reference. First to establish the ISI validation
body, according to different specification of code and standard, the relating validation
procedure/outline and input information is compiled as input and implemented gradually in Chinese
domestic nuclear power plant.
This qualification or assessment can be performed as the sum of two parts:
  - Practical assessment (blind or open trial), conducted on simplified or representative test
    pieces resembling the component to be inspected.
Technical justification, assembling all evidence:
- Previous application experience
- Laboratory studies
- Computer mathematical modeling

In order to push the requirement of qualification methodology for NDE application, first an independence, impartiality and confidentiality qualification body which is in charge of and executes qualification methodology for in-service inspection at nuclear power plants should be set up. Under the management of qualification body which should be constituted by regulatory body, safety supervision department and the representatives of operation organizations, then the qualification demonstration is provided with organization, reliability and legality.

Meanwhile, a center of qualification methodology should also be set up. Either it can be transformed by a mature NDE research institute or newly reconstructed. The qualification center is responsible for preparing the qualification laboratory construction, studying or comparing the most reasonable and effective methodology, designing and manufacturing all kinds of qualification specimens, construction of expert team.

The qualification results, the validity and reliability of NDE techniques which is carried out by the qualification body using the resources in the qualification center, shall be evaluated by experts to make sure the capability of inspection organization meets the requirements of qualification. Then the qualification body should issue a certificate to relevant NDE procurement, equipment and personnel.

CONCLUSIONS

The necessity of achieving high levels of reliability in ISI motivated the development of methodologies for inspection qualification. Inspection qualification process, in China, is not implemented that will begin in the near future. An independence, impartiality and confidentiality qualification body which is in charge of and executes qualification methodology should be set up as urgent step. How to combine various reactor type, diverse codes requirement and different inspection technology well is a question for taken into account with the establishment of inspection qualification.

REFERENCES

1) IAEA-EBP-WWER-11, Methodology for qualification of in-service inspection systems for WWER nuclear power plant, Austria, 1998.