ABSTRACT

CANDU nuclear power plants are operated in 3 provinces in Canada for electric power generation. A table in the paper will show the built and operating plants in Ontario, Quebec, New Brunswick and overseas. The regulator for nuclear power in Canada is the Canadian Nuclear Safety Commission (CNSC). The CNSC holds the plant licensees accountable for compliance to CSA N285.4 for periodic inspections. The Standard basically specifies the “what, when, where, how, how much and how frequently” NDE is to be done on pressure retaining systems and components in CANDU nuclear power plants. In inspection methods, the Standard specifies they must be non-destructive. The NDE methods were grouped into visual, dimensional, surface, volumetric and integrative. The Standard also specifies that the licensees are responsible for the performance demonstration (PD) of the adequacy of the procedures and the proficiency of the personnel.

This paper describes the Standard’s requirement in NDE qualification and presents a joint project participated by Canadian and overseas CANDU owners. The sub-project for NDE included providing evidence and technical justification on the adequacy of the procedures and the proficiency of the personnel. The paper describes the qualification methodology followed by the participants. This will be followed by how the participants produced Inspection Specification, tools and procedures, personnel training and qualification programs, test and qualification samples, independent peer reviews and Technical Justification.

INTRODUCTION OF CANDU, ITS REGULATOR AND GOVERNING STANDARD FOR INSPECTION

CANDU is the Canadian designed pressurized heavy water reactor (PHWR) used in Ontario, Quebec, New Brunswick and several countries in the world for electric power generation. As of 2010, there are 25 operating CANDU reactor units in the world. In addition, there are 13 similar design PHWR units operating in India. CANDU users and India’s NPCIL are members of the CANDU Owners Group (COG). There are 2 units in Ontario Power Generation’s (OPG) Pickering A plant that are laid up, and there are 10 other CANDU or PHWR units around the world being refurbished or under construction.
Table 1 below lists the COG member utilities, the number of operating units, laid-up units and under construction or refurbishment units.

Table 1 - List of CANDU and PHWRs

<table>
<thead>
<tr>
<th>COG Members</th>
<th>Operational Units</th>
<th>Laid-up Units</th>
<th>Units under Construction/Refurbishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP(LP) Canada</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HQ Canada</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NBPN Canada</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>OPG Canada</td>
<td>10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>NASA Argentina</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNN Romania</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KHNP Korea</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TQNPC China</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPCIL India (PHWR)</td>
<td>13</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>PAEC Pakistan</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AECL Canada</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>39</strong></td>
<td><strong>2</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>
The nuclear industry is regulated by individual country’s regulator. In Canada, the regulator is the Canadian Nuclear Safety Commission (CNSC).

The Standard that governs periodic inspections of critical components in CANDU reactors in Canada is the CSA N285.4. Although the current version of the Standard is the 2009 version, most plant are in compliance to the 2005 version. In this paper, the terms CSA N285.4-05 and the Standard will be used interchangeably.

PERIODIC INSPECTION FOR CANDU REACTORS

CSA N285.4 specifies the periodic inspection requirements for pressure retaining systems and components such as pipe, nozzle and vessel welds. It also includes mechanical couplings, pump and valve welds and supports. There are also supplementary sections specifically for pressure tubes, feeder pipes and steam generators. Pressure tubes and feeders are uniquely CANDU components not found in PWRs and BWRs.

The CSA Standard calls for inspection methods that are “non-destructive”, hence they include NDE methods such as visual & dimensional (direct or using visual aids), surface test (PT & MT), volumetric (RT, ET and UT) and integrative (leak test, acoustic emission and strain gauge).

When stating NDE requirements, the Standard generally specifies the what, when, where, how, how much and how often for the in-scope components.

NDE QUALIFICATION AND PERFORMANCE DEMONSTRATION

Performance Demonstration (PD) and Inspection Qualification (IQ) will be used interchangeably in this paper. Although the currently preferred term is IQ, the CAN CSA N285.4 Standard uses both “qualify” and the PD words.

In the CSA N285.4-05 Standard, it specifies that NDE must have “performance demonstration” and it puts this responsibility to the licensee (clause 3.6). In other words it holds the power utilities, such as Ontario Power Generation who hold the licenses to operate, responsible for providing evidence that the NDE done on the components are qualified. The responsibilities of the licensees include, in clause 3.6d, verification of the qualification and proficiency of inspection personnel; and in clause 3.6e, PD of the adequacy of the procedures & proficiency of the personnel using assigned equipment, to detect & size flaws. IQ is therefore a dynamic combination of 1) procedure, 2) qualified personnel and 3) equipment; and the capabilities requiring IQ are detecting and sizing.

In addition to specifying this IQ requirement, the 2009 version of the Standard specified the requirements for IQ of UT and ET methods. The specified requirements are similar to those included in the European Network of Inspection Qualification (ENIQ) methodology. They included Inspection Specification (IS), Inspection Procedure (IP), Document on how the procedure meets the IS – Technical Justification (TJ), and personnel training and qualification program. For personnel certification, the Standard specified CAN/CGSB 49.9712/ISO 9712 for NDE methods.
DIFFERENT WAYS TO CONDUCT PD/IQ

In different part of the world and in different jurisdictions, NDE IQ has been conducted with various methodologies and approaches in the nuclear power industry. The more significant PD programs are the ENIQ2 and Performance Demonstration Initiative (PDI) administered by Electric Power Research Institute (EPRI) in the USA. Table 2 below lists some key differences between methodologies:

<table>
<thead>
<tr>
<th>Inspection Specification</th>
<th>ASME XI</th>
<th>PDI administration of ASME XI</th>
<th>ENIQ</th>
<th>IAEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Components</td>
<td>Specified</td>
<td>Specified</td>
<td>DBS/DBO</td>
<td>DBS/DBO</td>
</tr>
<tr>
<td>Flaw types/size</td>
<td>Specified</td>
<td>Specified</td>
<td>DBS/DBO</td>
<td>DBS/DBO</td>
</tr>
<tr>
<td>Acceptance Criteria</td>
<td>Specified</td>
<td>Modified to meet technical need</td>
<td>DBS/DBO</td>
<td>DBS/DBO</td>
</tr>
<tr>
<td>Effectiveness / Reliability Criteria</td>
<td>Included in Design</td>
<td>Included in Tech Basis for Code Modifications</td>
<td>Described in IS</td>
<td>Described in IS</td>
</tr>
<tr>
<td>Technical Justification</td>
<td>Embedded in Code *</td>
<td>PDD and Technical Basis</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Practice &amp; Procedure Development</td>
<td>Not addressed</td>
<td>yes –samples provided-(A)</td>
<td>Could use open procedure trial</td>
<td>Could use open procedure trial</td>
</tr>
<tr>
<td>Procedure Trials</td>
<td>Blind</td>
<td>Blind – with feedback</td>
<td>Blind or open</td>
<td>Blind or open</td>
</tr>
<tr>
<td>Personnel qualification</td>
<td>Blind (C)</td>
<td>Blind – with feedback (C)</td>
<td>Blind</td>
<td>Blind</td>
</tr>
<tr>
<td>Independent Qualification Body</td>
<td>Not addressed</td>
<td>Yes</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Documentation of Qualification</td>
<td>To be determined by organization</td>
<td>PDD, Procedure, Essential variables, Demo Records</td>
<td>Dossier -</td>
<td>Dossier -</td>
</tr>
</tbody>
</table>

PDD = Program Description Document (includes compliance comparison, deviations from Code and TJ for deviations)
Open = has knowledge of specific flaw size shape and location
Blind = without knowledge of flaw size, shape, location or quantity
DBS = Defined by Standard
DBO = Developed by Owner
(C) Individuals who qualify the procedure can receive personnel qualification

* Embedded in code – the rationale and evidence of qualification is not on a separate document such as a Technical Justification but within the code’s text.
In a generic sense, the principle of ENIQ’s process should contain at least the following major milestones. The milestones listed below constitute those in the ENIQ or IAEA methodologies. However, other PD processes should include a similar variation of them:

1. An Inspection Specification (IS) written by experts on a component. The expert should have assessed the fitness-for-service (FFS) criteria and determine the extent and detail of NDE results required to conduct the proper assessment. The specified extent and detail should include, but not limited to:
   - “what” and “where” to inspect, including surface and volume coverage requirements,
   - the types of degradations to look for,
   - results repeatability, accuracy, or error tolerance,
   - probability of detection,
   - reportable and rejectable criteria,
   - results recording, reporting requirement and format.

2. Based on the IS, the NDE practitioners develop and write the Inspection Procedure (IP) including specifying the method and equipment. The IP aims to meet the requirements in the IS and it will be tested and qualified in laboratory sessions. The IP should also include essential parameters and industrial experience. During procedure development the NDE practitioners may ask a peer expert to review the procedure. To confirm procedure qualification, the NDE practitioner may conduct witnessed practical trials. Subsequently, NDE personnel training and qualification will be conducted.

3. A Technical Justification (TJ) will be written by the NDE practitioners. The TJ will refer to evidence collected from IP development, training and qualification exercises, field use experiences and destructive examination results (if available); to declare how well the IP, equipment & personnel combination meets the requirements in the IS. The TJ may state exceptions where some of the IS requirements cannot be met, or can only be met partially.

4. Finally, the complete process is subject to an independent peer review. Usually a panel of experts will be assembled to review the IQ process and all of its produced documents. Members of the panel should not have been directly involved in the process of steps 1-3 above. The panel will issue an assessment report based on its observations and the technical arguments in the TJ. There will be back-and-forth interactions between the author(s) of the TJ and the Panel to address comments and questions raised.

**SOME NECESSARY TASKS DURING THE PD PROCESS**

1. During the development of the IS, the FFS experts may or may not consult the NDE practitioners on the limitations of NDE. There are pros and cons in this respect. If NDE practitioners were not consulted, the IS may specify requirements that are not achievable by present or foreseeable NDE capabilities. On the other hand, if NDE practitioners were consulted, the quality of FFS analysis may be limited by whatever results current NDE capabilities can provide.

2. During the development of the procedure, test samples will be designed and made and specialized calibration blocks will be made if necessary. After the procedure has been technically qualified, the next task is to train and qualify NDE personnel. To do that, a training package including documents and other materials has to be designed and fabricated. A training program will be developed within which pass/fail criteria will be specified.
3. NDE personnel will be trained and qualified. The qualification process includes open or blind tests although most tests are blind tests. The independent peer review panel may be present during the training and testing. The panel may even select trainees to run through its own set of testing.

4. A dossier of all the documents produced during the PD process will be assembled and file. Finally, a formal submission may be made to the Regulator for its acceptance of the PD evidence and process.

THE CANDU INDEPENDENT QUALIFICATION BUREAU

COG has established a CANDU Inspection Qualification Bureau (CIQB). The quality assurance program of CIQB was based on CAN/CSA Z299.2 and cross referenced to 10CFR50 and ENIQ. CNSC has recognized the COG CIQB as a qualification body. The CIQB has started full operating since 2008.

AN EXAMPLE OF A PD SUBMISSION TO THE CNSC

The example is a project jointly participated by Canadian, Korean (KHNP) and Romanian (SNN) members of COG. The component is the CANDU reactor’s feeder pipes. Feeders of concern are 2” and 2.5” schedule 80 carbon steel pipes circulating primary heat transport (PHT) water in and out of the reactor fuel channels. Flaw types are Flow Accelerated Corrosion (FAC) thinning, and cracking at bends. NDE method used is UT.

Inspection tools are mostly remote controlled or automatic mainly because the inspection is operated in a very high radiation dose rate area (right at the reactor faces). Reliability and accuracy of the results are critical because confirmed rejectable flaws could cause replacement of the feeder – an operation that is expensive and which causes significant outage extension. There is no isolation in the PHT system. Accuracy of wall thickness measurement and location repeatability are crucial because thinning trends need to be monitored to predict remaining life.

INSPECTION TOOLS

The IPs and tools were developed under the COG joint project NDE sub-team. The NDE sub-team consists of representatives from AECL, BPLP, HQ, KHNP, NBPN, OPG and SNN. Photographs of some of the inspection tools are shown below:

*The bend crack crawler (BCC) mounted on a mockup is being tested at the factory*
The BCC mounted on a real feeder pipe about to start a crack detection inspection.

This picture shows the electronic instrumentation operated through a notebook computer.

A thickness measurement crawler. This picture shows drive-wheels, U-joint, an array of UT probe. There is a sample feeder beside the crawler.
The Grayloc Area Inspection Tool (GAIT) for inspecting for wall thickness right adjacent the Grayloc hub wel.

THE COG JOINT PROJECT PD/IQ SUBMISSION

Participants of this joint project have chosen the ENIQ PD methodology. They felt that the method is more flexible, is not component specific and can be logically applied to the target component. A common CANDU industry IS was written by a joint FFS team. The FFS team consulted the NDE team on the IS. Procedures and tools were developed by industry qualified NDE engineers and technicians. Guided practice test pieces and calibration blocks were designed and produced.

Training program and material were developed. Participants and service providers conducted and/or received training of NDE personnel in Canada and from Korea. Trainees passed qualification test. The training and qualification processes was audited and reviewed by CIQB. Numerous real inspection campaigns were subsequently conducted. Many destructive examinations were performed to compare to the NDE results. These field experiences and finding were included or later added to the TJs.
Two TJs were written – one for thickness measurement and one for crack detection. The TJs were reviewed an independent peer team and by CIQB. Comments were addressed and then the TJs were finalized. Two document dossiers were assembled – again, one for thickness measurement and one for crack detection. OPG took the TJs and made a formal submission to CNSC in 2004. CNSC reviewed it and later contracted an external consultant to further review the submission. CNSC accepted the submission.

CONCLUSION

It is a regulatory and CSA N285.4-05 compliance requirement for NDE to be performance demonstrated. Nuclear power plant licensees are responsible for meeting this requirement. COG established the CIQB and it has been recognized by the Regulator. COG administered a joint project to successfully complete the IQ requirement for the NDE of one of the reactor’s most critical component. The ENIQ methodology was proven to be adaptable to a specific development which was suitable for CANDU feeder inspection.

This experience is very valuable to the CANDU licensees and CIQB in executing present and future IQ projects. Subsequent to feeders, the CIQB has since qualified the dry spent fuel storage lid weld phased array UT inspection, Canada’s National Research Universal (NRU) reactor vessel repair and piping UT inspection.

REFERENCES

1) CSA Standard N285.4-05 Periodic Inspection of CANDU nuclear power plant components. Published in June 2005 by Canadian Standards Association.
2) European Methodology for Qualification of Non-Destructive Testing - Third Issue - August 2007 ENIQ Report nr. 31 EUR 22906 EN.