Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

Canada

Canadian Regulatory Perspectives on Probabilistic Fracture Mechanics

Session W14: Improving Confidence in Probabilistic Fracture Mechanics – Part 1: Regulatory and Research Perspectives

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Introduction

- *Nuclear Safety and Control Act*

Section 3 of the *Nuclear Safety and Control Act*, which sets out the purpose of the Act, provides for "the limitation to a reasonable level and in a manner that is consistent with Canada's international obligations of the risks to national security, the health and safety of persons and the environment that are associated with the development, production and use of nuclear energy"

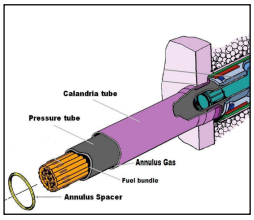
- Fundamental arguments for risk-informed regulation
  - reduction in unnecessary conservatism without compromising safety
  - resources can be used more efficiently to reduce actual risk

Risk-informed assessment

- Incorporates risk insights, probabilistic assessment, new research findings and other sources of information including operating experience
- Allows objective and design intent to be met, and licensing requirements and safety-analysis margins to be maintained
- Demonstrates where excessive conservatism in input parameters or assumptions exists
- Identifies input parameters and assumptions, which are greatest contributors to overall risk
- Should involve a systematic evaluation of uncertainties

Fuel Channels in CANDU Reactors

- A CANDU reactor has a channelized core with a large number of small diameter Zr-2.5Nb pressure tubes



Periodic Inspection Programs for Pressure Tubes

- Canadian licensees follow clause 12 of CSA standard N285.4, *Periodic Inspection of CANDU Power Plant Components*
  - periodic inspections are mandated for flaws, pressure tube to calandria tube contact, pressure tube sagging, pressure tube elongation, pressure tube internal diameter and wall thickness, position of fuel channel on its bearings and for contact with other calandria vessel components
- When inspection findings do not satisfy CSA standard N285.4 then CSA Standard N285.8, *Technical Requirements for In-Service Evaluation of Zirconium Alloy Pressure Tubes in CANDU Reactors* is followed

Required Evaluations for CANDU Reactor Core

- CSA standard N285.8 in clause 7 requires the following evaluations for the reactor core
  - evaluation of service conditions for protection against fracture
    - deterministic or probabilistic approach
  - assessment of degradation mechanism related to flaws
    - deterministic or probabilistic approach
  - assessment of pressure tube to calandria tube contact
    - deterministic or probabilistic approach
  - evaluation of leak-before-break
    - deterministic or probabilistic approach

Probabilistic Fracture Protection

- Probabilistic methodologies for protection against fracture and establishing heatup-cooldown transients limits are under CNSC staff's review
  - developed based on probabilistic core assessment methodology for degradation mechanism related to flaws
  - detailed evaluation of entire reactor core using available reactor specific inspection data and CANDU fleet data
  - uncertainties in the predictions of crack initiation are further discussed
  - acceptance criteria are being developed

Probabilistic Leak-Before-Break

- Two probabilistic leak-before-break (PLBB) methodologies were developed by the Canadian industry to satisfy the requirements of CSA standard N285.8
  - method 1 PLBB based on evaluation of the bounding pressure tube in the reactor core
  - method 2 PLBB based on detailed evaluation of the pressure tubes in entire reactor core
- The CNSC accepted the probabilistic leak-before-break approach with conditions, including evaluation of uncertainties

Development of Probabilistic Methodologies

- Probabilistic methodologies should be technically sound and utilize current best practices
- Probabilistic methodologies should provide realistic estimations
- Independent reviews carried out by subject matter experts from different areas of expertise improve methodologies
- Efforts on validation of probabilistic methodologies

Uncertainties in Probabilistic Assessments – Development of New Annex

- Task Group on Uncertainties in Probabilistic Assessments was established under CSA N285.8 Technical Subcommittee
  - the goal is to develop an annex with the requirements for treatment of uncertainties in probabilistic assessments
  - these requirements are intended for probabilistic assessments performed to satisfy the technical requirements of CSA Standard N285.8
- The requirements for probabilistic assessments and treatment of uncertainties should be defined

Research and Development, and Surveillance Programs

- Experimental programs are carried out by the Canadian nuclear industry and CANDU Owners Group
- Model development or improvements; e.g., new fracture toughness model for pressure tubes with elevated hydrogen equivalent concentrations
- Models validation using laboratory test results and fundamental research
- Surveillance pressure tubes are removed from the reactors and tested to confirm model adequacy and assess actual material degradation
- The CNSC carries out confirmatory research projects

Acceptance Criteria for Probabilistic Evaluations of Reactor Core

- Newly developed allowable pressure tube failure frequencies are being implemented into CSA Standard N285.8
- Acceptance criteria for probabilistic demonstration of fracture protection are under evaluation
- Acceptance criteria for probabilistic pressure tube to calandria tube contact are under evaluation
- Acceptable conditional probability of pressure tube failure for evaluation of leak-before-break is not provided in CSA Standard N285.8
  - planned for future revisions of the standard

Acceptance Criteria for Evaluation of Reactor Core

- The proposed acceptance criteria include the following requirements
  - maximum allowable frequency should not exceed the maximum for the event class the component was designed for
  - pressure tube failure contribution to severe core damage frequency should be less than 10^{-5} occurrences per reactor year
  - contribution to risk increase from a single component should be less than 1% of severe core damage frequency

Quality Assurance for Computer Programs

- Implementation of some probabilistic methodologies into computer programs may result in complex codes and extensive programming efforts
- Systematic approaches in computer code development should be followed
- The requirements for computer code development outlined in CSA standard N286.7 should be satisfied
- Developed computer codes to be benchmarked with other programs when available

Concluding Remarks

- Validation of models, methodologies and assumptions, and uncertainty analysis are important from a regulatory perspective
- The requirements for probabilistic assessments and treatment of uncertainties should be defined
- Further research and development activities, and surveillance programs should be carried out to validate models and assumptions
- Establishing acceptance criteria for probabilistic assessments requires considerable efforts
- Computer codes for probabilistic assessments should satisfy quality assurance standards

Acknowledgements

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