POTENTIAL MATERIAL ISSUES FOR CNSC TO LICENSE ADVANCED REACTORS

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1 Background

- The Canadian Nuclear Safety Commission (CNSC) is performing a pre-licensing review of several advanced reactor designs with various reactor coolants, e.g. high temperature gas, liquid metals and molten salts
- The focus of the review is to provide early identification of:
  - potential regulatory and technical issues in licensing a vendor's design
  - additional regulatory research that may be needed to inform regulatory requirements in specific cases
- This presentation discusses some potential material issues identified/anticipated based on available information to date

2 Scope

- The majority of the vendors propose to use ASME Section III Division 5 “High Temperature Reactors” (Division 5 thereafter) for advanced reactor designs
- HAA-1130 of Division 5 states that the rules “*do not cover deterioration that may occur in service as a result of radiation effects, corrosion, erosion, thermal embrittlement, or instability of the material*”
- The following slides mainly focus on these material issues that are not currently covered by codes and standards

3 Potential Material Issues

3.1 Neutron irradiation embrittlement

3.2 Effect of irradiation on safety margin of using code limits

3.3 Corrosion

3.4 Coating and cladding

3.5 Mechanical connection

3.6 Material development and qualification

3.1 Neutron Irradiation Embrittlement

- ❑ Neutron irradiation embrittlement is a key issue for reactor safety operation.
- ❑ The existing test data or operation experience may not be applicable for advanced reactors due to the differences in:
  - material selection
  - service temperature
  - neutron flux / accumulated fluence
  - interaction of corrosion and neutron irradiation
- ❑ Information/justification is needed to address this non-code issue in the future licence review.

3.2 Effect of Irradiation on Safety Margin of Using Code Limits

- Neutron irradiation affects code limits for load-controlled stresses. For example, the temperature & time-dependent stress intensity limit, S_t, is defined as the lesser of:

  (a) 100% of the average stress required to obtain a total strain of 1%;

  (b) 80% of the minimum stress to cause initiation of tertiary creep;

  (c) 67% of the minimum stress to cause rupture

  S_t values could be lower under neutron irradiation

- Neutron irradiation also affects other code limits, such as S_{mt}, S_o, and limits/values for use-fraction sum analysis associated with the general primary membrane stresses during Level A, B and C Loading

3.2 Effect of Irradiation on Safety Margin of Using Code Limits *(continued)*

- Neutron irradiation also affects the code limits on deformation-controlled quantities

- Irradiation affects isochronous stress-strain curves, stress-to-rupture curves, and therefore affects some key limits for creep and fatigue analysis, for example:
  - S_a in HBB-T-1322 Test No. A-1
  - t_{id} and ε_i in HBB-T-1324 Test No. A-3
  - Σv in HBB-T-1333 Test No. B-3 (Equation 5)

- Vendors will be requested to verify whether there is sufficient safety margin to use Division 5 limits for components under neutron irradiation

3.3 Corrosion

- Corrosion degradations in advanced reactors could be very different depending on the combination of material, environment (coolant, temperature), and stress:
  - general corrosion (molten salt reactors, liquid metal reactors)
  - galvanic corrosion (molten salt reactors)
  - stress corrosion cracking
  - wear and friction
  - flow-accelerated corrosion and erosion corrosion (e.g. heat exchange)
  - environmental embrittlement (e.g. carburization and nitridation in gas-cooled reactor)

3.3 Corrosion *(continued)*

- Under each material/environment/stress combination, the degradation mechanism or corrosion rate could be different. The understanding and prediction of the corrosion effect on structure integrity will be reviewed with a consideration of specific reactor design and operating conditions.

3.3 Corrosion *(continued)*

- Corrosion degradation could be accelerated significantly by other factors, such as:
  - neutron irradiation
  - impurities (e.g. H_2O, O, S in molten salt; H_2O, O in liquid metals; H_2O, O_2 and N_2 in high temperature gas)
  - redox potential (Maintaining mildly reducing condition is key to avoiding significant corrosion and tellurium cracking in molten salt)
- The understanding on irradiation-enhanced corrosion will be reviewed. A Design Manual or Guide for chemistry or impurity control in each advanced reactor should be established. Technology for chemistry control should be demonstrated at an industrial scale.

3.4 Coating and Cladding

- Vendors may use cladding or coating (such as Fe/Al, Ni, carbides, nitrides, borides, phosphides, and refractory coatings) to improve corrosion resistance
- However, coating affects heat transfer capability. Thermal cycling can cause coatings to crack or delaminate. Thin coatings reduce the tendency of cracking or delamination but are more vulnerable to imperfections; radiation-enhanced-intermixing could also be a significant issue for thin coatings
- Qualification or justification on the applicability of coating or cladding to advanced reactors will be assessed.

3.5 Mechanical Connection

- Chemical compatibility of welds need to be investigated:
  - class A materials can be sensitized during welding and become less resistant to corrosion
  - brazing would cause less damage to the base metal microstructure, but is not addressed in nuclear portion of ASME BPVC
- Gaskets may be challenging due to the tendency to develop leaks over time:
  - gasket degradation (e.g. nitriding/carburizing in high temperature gas, corrosion in molten salt or liquid metal)
  - bolt creep
  - sealing-surface deformation

3.6 Material Development & Qualification

- Material qualification and design data validation is important for advanced reactor design:
  - new materials may be developed for meeting design requirements
  - existing materials may be modified to improve component integrity
  - materials with a lower code class (or not in code) may be used for fabrication of higher class components
  - structural ceramic composites remain at a low technology readiness level

3.6 Material Development & Qualification *(continued)*

- Material properties and design data for long-term operation need to be verified and validated

Question: should we allow design to use 100% of non-code stress/deformation limits?

4 Conclusion

Detailed information or justification may be required to address the non-code issues relevant to materials and component integrity in the stage of licence review of advanced reactors

Thank you! Questions?

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