핵연료 안전기준 개정 현황 및 전망

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ECCS Acceptance criteria revision

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1) History

• In July 1998, the U.S. NRC adopted a research plan to address the effects of high burnup on LOCAs.

• This research program conducted at ANL, as well as conducted as jointly-funded programs at the Kurchatov Institute and the Halden Reactor.

• From these programs, several important technical findings for rule revision were obtained (RIL-0801).
• On March 14, 2000, the NEI submitted a PRM requesting that the NRC amend its regulations in 50.44 and 50.46 (PRM 50-71).
  • The NEI petition stated that these regulations apply to only two cladding materials (zircaloy and ZIRLOTM)

• On March 15, 2007, Mark Leyse submitted a PRM to the NRC (PRM 50-84)
  1) Establish regulations limiting the thickness of crud and/or oxide layers.
  2) A postulated LOCA be calculated by factoring in the role of the thermal resistance of crud and oxide layers.
  3) Amend 50.46 to specify a maximum allowable percentage of hydrogen content in the cladding.
• On August 13, 2009, the NRC published an ANPR to obtain stakeholder views on issues associated with amending 50.46(b)

• On March 1, 2012, and subsequently modified by the staff’s June 1, 2012, SECY-12-0034 was submitted to the Commission to obtain approval to publish for public comment

• On January 7, 2013, SECY-12-0034 was approved with some amendments
2) Important technical findings

1) Alloy composition has a minor effect on embrittlement, but that the cladding corrosion that occurs as fuel burnup increases has a substantial effect on embrittlement.

2) Hydrogen, which is absorbed in the cladding under normal operation, has a significant influence on embrittlement during a postulated LOCA.
   - Hydrogen increases the solubility and
   - the diffusion rate of oxygen within the metal.
cont’d (2/2)

3) Oxygen from the oxide fuel pellets enters the cladding from the inner surface if a bonding layer exists.

4) Under some small-break LOCA conditions (such as extended time-at-temperature around 1,000 °C), a phenomenon termed breakaway oxidation can take place, allowing large amounts of hydrogen to diffuse into the cladding, exacerbating the embrittlement process.

5) The research results also confirmed a previous finding that if cladding rupture occurs during a LOCA, large amounts of hydrogen from the steam-cladding reaction can enter the cladding inside surface near the rupture location.
3) Proposed 10 CFR 50.46c

<table>
<thead>
<tr>
<th>Structure of proposed 10CFR50.46c</th>
<th>Note</th>
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<tbody>
<tr>
<td>(a) Applicability</td>
<td>The applicability of the proposed rule remains limited to LWR, but expanded beyond uranium oxide pellets within cylindrical zircaloy or ZIRLO™ cladding.</td>
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<td>(b) Definitions</td>
<td>Breakaway oxidation was newly added. The definition of Loss-of-coolant-accident and Evaluation model would remain unchanged, 50.46(c)(1) and(2).</td>
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<td>(c) Relationship to other NRC regulations.</td>
<td>The same as current regulation founded in 50.46(d)</td>
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<td>(d) Emergency core cooling system design</td>
<td>Define performance requirement such that i) core temperature during and following the LOCA event does not exceed the analytical limits, and ii) the ECCS provides sufficient coolant so that decay heat will be removed for the extended period of time.</td>
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</table>

- (1) ECCS performance criteria
- (2) ECCS performance demonstration
  - (i) Realistic ECCS model
  - (ii) Appendix K model
  - (iii) Core geometry and coolant flow
  - (iv) LOCA analytical requirements
  - (v) Modeling requirements for fuel designs
- (3) Required documentation
  - (iv) Analytical requirements requires most severe LOCA be identified, and specifically require that the ECCS performance be demonstrated for both the accident, recovery and recirculation period.
  - (v) Modeling requirements listed in (g)(2) were newly added.
  - The same as currently provided in Appendix K
**cont’d (2/3)**

| (g) Fuel system designs: uranium oxide or mixed uranium-plutonium oxide pellets within cylindrical zirconium-alloy cladding | (1) Fuel performance criteria. | (i) Peak cladding temperature  
(ii) Cladding embrittlement  
(iii) Breakaway oxidation  
(iv) Maximum hydrogen generation  
(v) Long-term cooling | In (ii) cladding embrittlement criteria, the current analytical limit, 17% ECR, was replaced with performance criteria.  
(iii) Breakaway oxidation criterion was newly introduced.  
*Three R.Gs were prepared (DG-1261, 1262, 1263)* |
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<td>(2) Fuel system modeling requirements.</td>
<td></td>
<td>Oxygen ingress from cladding inside and thermal effects of crud and oxide layers was newly added</td>
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<td>(k) Use of NRC-approved fuel in reactor</td>
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<td>(l) Authority to impose restrictions on operation</td>
<td></td>
<td>The authority to impose restrictions was expanded. NRO can impose restrictions.</td>
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* DG-1261: CONDUCTING PERIODIC TESTING FOR BREAKAWAY OXIDATION BEHAVIOR  
DG-1262: TESTING FOR POSTQUENCH DUCTILITY  
DG-1263: ESTABLISHING ANALYTICAL LIMITS FOR ZIRCONIUM BASED ALLOY CLADDING
(m) Reporting

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<th>Three categories of changes or errors were described for clarity. These requirements are unchanged from the current 50.46(a)(3).</th>
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<td>(1)</td>
<td></td>
<td>In addition to the significant PCT change, definition of significant change or error to ECR was added, 0.4 percent ECR.</td>
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<td>(2)</td>
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<td>Reporting of breakaway oxidation test on each reload batch was added</td>
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<td>(3)</td>
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(o) Implementation

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<th>Implementation requirements and schedule for the existing reactor fleet and for new reactor. Operating reactors were divided into three groups based on the anticipated level of effort.</th>
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- **No later than 24 months**: satisfy new requirements without new analyses or model revisions
- **No later than 48 months**: using realistic LBLOCA models requiring new analyses
- **No later than 60 months**: using Appendix K LB and SB models requiring new analyses
4) Perspective

• Followings are required to be done before requesting Commission’s approval of the draft final rule (SRM to SECY-12-0034)
  1) The staff should complete its research on fuel fragmentation, relocation, and dispersal, and incorporate any necessary changes
  2) Regarding GSI-191, the 10 CFR 50.46c proposed rule should contain a provision allowing NRC licensees, on a case-by-case basis, to use risk-informed alternatives without an exemption request

→ takes a year?
5) Required research works

- KINS thinks following areas seem to be studied and prepared in detail for the implementation of the proposed rule

  1) Validation of ‘best-estimate’ ECCS evaluation methodology for high burnup fuel
     - Uncertainty parameter of fuel rod
     - Uncertainty range

leftrightarrow Combined with the fuel pellet thermal conductivity degradation issue
cont’d (2/8)

• Limiting fuel burnup for LOCA analysis changed from BOL to MOL
• For example, **gap conductance approach** is still valid to simulate overall uncertainty of fuel rod even at mid to high burnup fuel?
cont’d (4/8)

cont’d (5/8)

**Beginning of Life LOCA PCT**

- **41 parameters**
- **Gap conductance (0.67~1.5)**
- **Gap conductance (0.67~3.1)**

**Temperature, K**

**Cumulative count**

**Frequency count**

- **GC: 0.67~3.1**
- **GC: 0.67~1.5**

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**Korea Institute of Nuclear Safety**
cont'd (6/8)

30 MWd/kgU LOCA PCT

- 41 parameters
- Gap conductance (0.67~1.5)
- Gap conductance (0.50~2.4)

Temperature, K

Cumulative count
cont’d (7/8)

2) Modifications of TH system code to perform the rod exposure study

• Code coupling between TH code & fuel code
• Two side oxidation
• Crud model in TH code
3) Crud characteristics

• Physical property (e.g. thermal conductivity)
• Crud accumulation modeling

4) Breakaway oxidation

• Environmental effect (e.g. high steam pressure)
• Burnt fuel cladding (hydride and pre-oxide)