Status of ECCS Acceptance Criteria Revision in U.S. NRC and Perspective

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1. History

In July 1998, the U.S. Nuclear Regulatory Commission (NRC) adopted a research plan to address the effects of high burnup on LOCAs because the licensing fuel burnup was achieved almost twice as great as expected when current regulations were written in 1970s (Executive Director for Operations (EDO) memorandum to the Commissioners, dated July 6, 1998). Subsequently the NRC had conducted a fuel cladding research program to investigate the behavior of high burnup fuel cladding under LOCA conditions. This research program conducted at Argonne National Laboratory (ANL), as well as conducted as jointly-funded programs at the Kurchatov Institute and the Halden Reactor. From these programs, several important technical findings, listed in following section, for rule revision were obtained (RIL-0801).

On March 14, 2000, the Nuclear Energy Institute (NEI) submitted a petition for rulemaking (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 specific zirconium-alloy fuel cladding materials (zircaloy and ZIRLO^{TM}). The NRC resolved PRM-50-71 by deciding that it should be considered in the following rulemaking process.

Meanwhile, on March 15, 2007, Mark Leyse submitted a PRM to the NRC (PRM 50-84) [1]. The petitioner requests that the NRC conduct rulemaking in the following areas:

a) Establish regulations that require licensees to operate light-water power reactors under conditions that are effective in limiting the thickness of crud and/or oxide layers.

b) Amend Appendix K to Part 50 to explicitly require that steady-state temperature distribution and stored energy in the reactor fuel at the onset of a postulated LOCA be calculated by factoring in the role of the thermal resistance of crud and oxide layers.

c) Amend 50.46 to specify a maximum allowable percentage of hydrogen content in the cladding.

The NRC resolved PRM-50-84 by deciding that the petitioner's issues should be considered in the rulemaking process.

On August 13, 2009, the NRC published an Advance Notice of Proposed Rulemaking (ANPR) to obtain stakeholder views on issues associated with amending 50.46(b)[2]. 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 [3], and it was approved on January 7, 2013 with some amendments.

2. Technical Findings for Revision

Major findings of the NRC's research program are as follow and those are summarized in detail in Research Information Letter (RIL)-0801.

- 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.
- Hydrogen, which is absorbed in the cladding under normal operation, has a significant influence on embrittlement during a postulated LOCA. Hydrogen increases both the solubility and the rate at which it is diffused within the metal.
- Oxygen from the oxide fuel pellets enters the cladding from the inner surface if a bonding layer exists.
- 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.
- 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 ECCS Acceptance Criteria; 10CFR50.46c

As listed in the Table 1, comparing to the current 10CFR50.46, significant changes in format and contents are being proposed in the 10CFR50.46c. Full text of the proposed rule can be read in SECY-12-0034. Main characteristics are such that:

- The applicability was not limited to uranium oxide pellets within cylindrical zircaloy or ZIRLO^{TM} cladding by reflecting PRM 50-71.
- In cladding embrittlement criteria, current analytical limit, 17 % ECR, was replaced with

Table 1. Structure of newly proposed ECCS acceptance criteria; 10CFR50.46c

Proposed 10CFR50.46c			**Note**
(a) Applicability			The applicability expanded beyond uranium oxide pellets within cylindrical zircaloy or ZIRLO^{TM} cladding.
(b) Definitions			Breakaway oxidation was newly added
(c) Relationship to other NRC regulations.			
(d) Emergency core cooling system design.	**(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***	Analytical requirements specifically require that the ECCS performance be demonstrated for both the accident, and the post-accident recovery and recirculation period. Modeling requirements listed in (g)(2) were newly added.
	(3) *Required documentation*		The same as currently provided in Appendix K
(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 cladding embrittlement criteria current analytical limit, 17 % ECR, was replaced with performance criteria Breakaway oxidation was newly introduced.
	(2) *Fuel system modeling requirements.*		Oxygen ingress from cladding inside and thermal effects of crud and oxide layers was newly added
(k) Use of NRC-approved fuel in reactor			
(l) Authority to impose restrictions on operation			The authority to impose restrictions was expanded. NRO can impose restrictions.
(m) Reporting	**(1)**		Three categories of changes or errors were described for clarity.
	(2)		In addition to the PCT change, definition of significant change or error to ECR was added
	(3)		Breakaway oxidation reporting was added
(o) Implementation			Operating reactors were divided into three groups based on the anticipated level of effort.

performance criteria. And a breakaway oxidation criterion was newly introduced.

- Fuel system modeling requirements such as the consideration of oxygen ingress from inside of cladding and thermal effects of crud and oxide layers were added by reflecting the PRM 50-84.
- In addition to PCT change, ECR change was also added as new reporting criteria, and reporting of breakaway oxidation tests were added
- Three draft regulatory guides were prepared to support the rule, which describe the testing of breakaway oxidation (DG-1261), testing for postquench ductility (DG-1262), and establishing analytical limits (DG-1263).

4. Perspective

Although SECY-12-0034 was approved by Commission, followings are required to be done before requesting Commission's approval of the draft final rule [4].

- The staff should complete its research on fuel fragmentation, relocation, and dispersal, and incorporate any necessary changes.
- Regarding Generic Safety Issue 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.

As rulemaking process is going steadily in U.S., KINS analyzes its impact to domestic nuclear industry when introduced, and thinks following areas seem to be studied or prepared in detail.

- Updates or modifications of thermal-hydraulic system code coupled with fuel code to be able to perform rod exposure study
- Validation of currently utilized realistic evaluation methodology for LOCA analysis, especially for the selection of uncertainty parameter and its range by considering fuel exposure, for example gap conductance, combined with the fuel thermal conductivity degradation issues
- Study of physical property of crud at high temperature condition, breakaway oxidation phenomena of burnt fuel cladding at high steam pressure condition, validation of hydrogen uptake model etc.

REFERENCES

[1] Petition for rulemaking; notice of receipt, "Mark Edward Leyse; Receipt of Petition for Rulemaking", *Federal Register*, Vol. 72, No. 99, May 23, 2007.
[2] Advance notice of proposed rulemaking, "Performance-Based Emergency Core Cooling System Acceptance Criteria", *Federal Register*, Vol. 74, No. 155, August 13, 2009.
[3] SECY-12-0034, Performance-Based Emergency Core Cooling Systems (ECCS) Cladding Acceptance Criteria, ADAMS Accession No. ML12151A238.
[4] Staff Requirement Memorandum (SRM) to SECY-12-0034, ADAMS Accession No. ML13007A478.