Basis of Technical Guideline for FBR Fuel Safety Evaluation in JNES

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International Conference on Fast Reactors and Related Fuel Cycles (FR09) on 7-11 December, 2009
Kyoto International Conference Center, Kyoto, JAPAN

Background

- **LMFBRs were actively developed from 1970s to the 1980s in some countries such as the United States, France, the UK and Germany.**
- **In the following years, the development of LMFBRs slowed down but was revived in the latter half of the 2000s.**
- **Japan still continues to develop LMFBR and the prototype reactor "Monju" is scheduled to resume operation in 2010.**
- **The improvement in the performance of fuel assemblies will be pursued in the future.**
- **Japan Nuclear Energy Safety Organization (JNES) has the mission to establish the base to ensure the nuclear safety in nuclear utilization for energy by performing the safety analysis, evaluation and so on.**

Purpose

- **JNES shall establish the technical guideline for LMFBR fuel safety review.**

- **The purposes are**

  (1) to do an adequate safety review

  (2) to build up the know-how related with LMFBR fuel safety design and safety review into a form of an appropriate document

Review of the Guidelines Related with Fuel

Nations	Guidelines	Standards
USA	SRP	ASME / IEEE / ANSI
FRA	RFS	RCC-C
GER	RSK / KTA	
UK	LC / SAP / TAG	
JPN	Review Guides for Nuclear Safety	JIS / JEAG
IAEA	NS-R / NS-G	
OECD/NEA	Fuel Safety Criteria in NEA Member Countries NEA/CSNI/R (2003)10 (Review Report)	

SRP : Standard Review Plan
RFS : Regle-Fondamentale de Surete
RSK : Reaktor-Sicherheitskommission
KTA : Kerntechnische Ausschuss
LC : License Conditions
SAP : Safety Assessment Principles
NS-R : Nuclear Power Plant Safety Requirement
NS-G : Nuclear Power Plant Safety Guide

ASME : American Society of Mechanical Engineers
IEEE : Institute of Electrical and Electron Engineers
ANSI : American National Standards Institute
RCC-C : Regles de Conception et Construction-Combustibles
JIS : Japanese Industrial Standards
JEAG : Japan Electric Association Guide

Standard Review Plan (SRP)

Chapter 4.2 "Fuel System Design" of SRP of the United States systematically provides items required as fuel technical guidelines.

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SRP will be used as reference for the structure of the technical guideline for LMFBR fuel safety review.

Characteristics of LMFBR

- **Sodium coolant is high temperature but low pressure.**
  No occurrence of rapid withdrawal of control rod
  RIA is not considered in LMFBR.
- **Reactor core is always filled with sodium coolant by guard vessel.**
  No occurrence of exposure of core without sodium coolant
  LOCA is not considered in LMFBR.

Objectives of Fuel Safety Review

- Comparison between LWR and LMFBR -

LWR	LMFBR
(1) Fuel system is not damaged (1-a) fuel rods do not fail (1-b) dimension remains within tolerance (1-c) functional capability are not reduced	(1) Fuel system is not damaged (1-a) fuel elements do not fail (1-b) maintenance of control rod insertion path (1-c) maintenance of coolable geometry
(2) Fuel system damage is never so severe as to prevent control rod insertion	(2) Fuel system damage is never so severe as to lose control rod insertion path
(3) Number of rod failures are not underestimated	(3) Number of fuel element failures is not underestimated
(4) Coolability is maintained	(4) Fuel system damage is never so severe as to lose coolable geometry

Design Bases and Objectives

Comparison between LWR and LMFBR

LWR	LMFBR
Fuel System Damage (1) Fuel system is not damaged (1-a) fuel rods do not fail (1-b) dimension remains within tolerance (1-c) functional capability is not reduced (2) Fuel system damage is never so severe as to prevent control rod insertion	**Fuel System Damage** (1) Fuel system is not damaged (1-a) fuel elements do not fail (1-b) maintenance of control rod insertion path (1-c) maintenance of coolable geometry (2) Fuel system damage is never so severe as to lose control rod insertion path (4) Fuel system damage is never so severe as to lose coolable geometry
Fuel Rod Failure (3) Number of fuel rod failures are not underestimated	**Fuel Element Failure** (3) Number of fuel element failures are not underestimated
Fuel Coolability (4) Core Coolability is maintained	

Since the design bases of fuel coolability for LWR correspond to the LMFBR objectives of (1-c) and (4) as indicated in the previous slide, these two objectives are counted as fuel system damage. Thus the fuel design bases for LMFBR are composed of fuel system damage and fuel element failure.

Objectives and Related Operational Conditions

LMFBR	Operational Conditions		
	Normal Operation	AOO	Accident
Fuel System Damage			
(1) Fuel system is not damaged			
(1-a) fuel elements do not fail	○	○	
(1-b) maintenance of control rod insertion path	○	○	
(1-c) maintenance of coolable geometry	○	○	
(2) Fuel system damage is never so severe as to lose control rod insertion path			○
(4) Fuel system damage is never so severe as to lose coolable geometry			○
Fuel Element Failure			
(3) Number of fuel element failures are not underestimated		○*	○

AOO　Anticipated Operational Occurrence

*　This shall be considered in (1-a).

Evaluation Items (Damage Modes) in LWR and LMFBR

LWR	LMFBR
Fuel System Damage (8 items) • Excessive deformation by stress/strain • Cladding fatigue damage • Cladding damage by fretting wear • Cladding damage by oxidation, hydriding and buildup of corrosion products • Dimensional changes such as rod bowing or irradiation growth of fuel rods, fuel assemblies, control rods and guide tube • Cladding damage by internal gas pressure • Hydraulic loads • Control rod reactivity	**Fuel System Damage** Fuel elements do not fail (7 items) • Excessive deformation by stress/strain • Damage by PCMI • Cladding creep damage • Cladding fatigue damage • Cladding damage by wear mark • Damage by BDI • Damage by DDI Maintenance and no loss of control rod insertion path (1item) • Temperature and radiation induced fuel assembly deformation Maintenance and no loss of coolable geometry (3 items) • Abnormal flow distribution by lifting of fuel assembly • Temperature and radiation induced fuel element deformation • Coolant channel deformation by BDI
Fuel Rod Failure (8 items) • Cladding failure by hydriding ▪ Cladding collapse • Overheating of cladding ▪ Overheating of fuel pellet • Excessive fuel enthalpy ▪ PCI (PCMI, PCCI) • Bursting ▪ Mechanical fracturing	**Fuel Element Failure (3 items)** Number of fuel element failures are not underestimated (3 items) • Mechanical failure by fuel melting in TOP • Cladding failure by internal gas pressure in LOF • Failure by cladding burnout in LOF
Fuel Coolability (5 items) • Cladding embrittlement ▪ Violent expulsion • Generalize cladding melting ▪ Fuel rod ballooning • Structural deformation	

Background of Design Criteria for Damage Modes

[Example]

Design Bases	Damage Mode	Design Criteria used in Monju	Background
Fuel Element Failure	• Mechanical failure by fuel melting in TOP	• Fuel centerline temperature shall be less than melting temperature	Set the limiting temperature by confirming that no failure occurs when centerline temperature reaches melting temperature based on the operational reliability test (ORT TOP test)
	• Cladding failure by internal gas pressure in LOF	• Cladding temperature shall be less than the limiting temperature	Set the limiting temperature based on the result of out of pile experiment of rapid heating using irradiated cladding (Burst Test)
	• Failure by cladding burnout in LOF	• Coolant sodium temperature shall be less than sodium boiling temperature	The possibility of cladding burnout is very low when cladding contacts with coolant sodium

These criteria correspond to specified acceptable fuel design limits applied with Monju Fuel design.

Design Evaluation

Methods verifying compliance with the fuel design bases should be defined. Such methods include

(1) Operating experience

This is a method verifying fuel design bases based on operating experience using a fuel system of an identical or similar design. Compliance with specific fuel design bases to be verified is verified by operating experience.

(2) Prototype testing

If no definitive operating experience, such as when design changes are incorporated, is available, it is very effective to verify the fuel design bases based on prototype testing. Prototype testing includes in-pile and out-of-pile testing.

(3) Analytical prediction

Some of the fuel design bases and related parameters can be evaluated only by calculation. The technical guideline includes considerations in analyzing "normal operation", "anticipated operational occurrences" and "accidents", and evaluation items subject to analytical prediction.

Products (Technical Guideline for LMFBR Fuel Safety Review)

Main Text	Appendices
1. Introduction 1.1 Purpose 1.2 Background 1.3 Scope 1.4 Basis principles 1.5 Definition of terms 2. Objectives of fuel safety review 3. Fuel design bases 3.1 Fuel design bases 3.2 Fuel design criteria 3.3 Background for the fuel design criteria 4. Design evaluation 4.1 Operating experience 4.2 Prototype testing Appendices	1. Domestic Regulatory System for LMFBR 2. History of LMFBR Development in the World 3. Summary of the Review Result of Standard Review Plan (SRP) 4. Characteristics of LMFBR 5. Events to be Considered in the Safety Evaluation 6. LMFBR Fuel Irradiation Behavior under Normal Operation, Anticipated Operational Occurrences and Earthquake 7. Comparison of Fuel Design Bases, Objectives, and Damage Modes between LMFBR and LWR 8. Background for Specifying Fuel Design Criteria for Fuel Damage Modes 9. Achievement of In Pile Experiment with Monju Fuel 10. Knowledge on the Irradiation Characteristics of Materials 11. Example of Analytical Codes for Fuel Performance, BDI and DDI 12. Material Properties for the Fuel Design 13. Flow of the Mechanical Design of Nuclear Fuels 14. Approach to the Fuel Structural Design and the Simple Evaluation Formulas for Stress and Strain 15. Outline of the Fuel Behavior Analysis Codes 16. Outline of the Fuel Element Bundle Deformation Analysis Code 17. Outline of the Core Bowing Analysis Code 18. Procedure for the Integrity Assessment in Earthquake

Summary

- **The draft version of Technical Guideline for LMFR Fuel Safety Review has been finished.**
- **It will be reviewed by the specialists of LMFR fuel in DOE, NRC, IRSN, IAEA and OECD/NEA.**
- **The draft will be revised through the discussion among the specialists all over the world.**