UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 11, 2014

MEMORANDUM TO: Kathy Halvey Gibson
Director, Division of Systems Analysis
Office of Nuclear Regulatory Research

FROM: Michelle Flanagan ***/RA/***
Fuel and Source Term Code Development Branch
Division of Systems Analysis
Office of Nuclear Regulatory Research

SUBJECT: SUMMARY OF PUBIC MEETING, MARCH 13-14, 2014

On March 13-14, 2014, the U.S. Nuclear Regulatory Commission (NRC) held a public meeting to have technical discussions and an information exchange related to research on fuel fragmentation, relocation and dispersal. The purpose of the public meeting was to discuss fuel research programs and findings. During the meeting, presentations were made by NRC staff, international research organizations, and fuel vendors. The presentations fell generally into three categories: (1) presentations covering details of experimental results from research programs related to fuel fragmentation, relocation and dispersal, (2) presentations covering details of analytical studies to estimate fuel dispersal and (3) presentations on various perspectives on the implications of these research findings. There were multiple opportunities for the public to ask questions, provide comments and give feedback on the topics being discussed. After each category of presentation, an open discussion session provided an opportunity for the NRC staff, panelist, and meeting participants to engage in thoughtful discussion. The meeting included a number of participants who attended in-person as well as a number of participants who connected and engaged through the GoToMeeting and conference bridge line features set up for remote participants..

CONTACT: Michelle Flanagan, RES/DSA/FSCB
301-251-7547

A table below provides the title, speaker and organization for each presentation made during the public meeting. The table includes the Agencywide Documents Access and Management System (ADAMS) Accession number for each presentation.

Title	Speaker, Organization	ML
1. Introduction and Meeting Objectives	Tara Inverso, NRC/NRR	ML14066A476
2. Fuel Fragmentation, Relocation and Dispersal Under LOCA Conditions: Experimental Observations	Michelle Flanagan, NRC/RES	ML14066A483
3. Fuel Fragmentation, Relocation and Dispersal, Current Understanding and Test Results	K.en Yueh, Electric Power Research Institute	ML14078A332
4. LOCA and fuel fragmentation tests in SCIP III	Peter Askeljung, Studsvik Laboratory	ML14071A187
5. Overview of Halden Reactor LOCA experiments (with emphasis on fuel fragmentation) and plans	Barbara Oberlander, Halden Reactor Project	ML14071A197
6. Methodology for Core-Wide Estimates of Fuel Dispersal During a LOCA	Ian Porter, NRC/RES	ML14066A485
7. Analytical Assessment of High-Exposure Fuel Dispersal Potential During BWR LOCA	Kurshad Muftuoglu, General Electric Hitachi	ML14078A381
8. Assessment of Extent of Rupture in a Large Break LOCA	Mitch Nissley, Westinghouse	ML14071A202
9. Potential Impacts on Design Basis Accidents	Paul Clifford, NRC/NRR	ML14066A482
10. IRSN views on fuel dispersion in RIA and LOCA accidents	Marc Petit, IRSN, the French Institute for Radiological Protection and Nuclear Safety	ML14078A346
11. JAEA perspective on fuel fragmentation and dispersal	Fumihisa Nagase, Japan Atomic Energy Agency	ML14078A378
12. AREVA Perspective on Fuel Fragmentation and Dispersal During Design Basis Accidents	Bert Dunn, AREVA	ML14071A180
13. Summary and Conclusions, Next Steps	Michelle Flanagan, NRC/RES	ML14078A374

The purpose of the public meeting was to discuss fuel research programs and findings. There were three “open discussion” slots on the agenda to provide opportunities for the public to ask questions, provide comments and give feedback on the topics being discussed. The open discussion sessions are summarized below.

Open Discussion on the Subject of LOCA Experiments

Following presentations 1-5, an open discussion session included discussion of:

- Which parameters seem to control behavior with respect to the phenomena of fuel fragmentation, relocation and dispersal.
  - Burnup, cladding alloy, cladding strain, rod internal pressure, plenum size, fission gas release during operation, effect of grid spacers, effect of fuel/cladding bonding, burst opening size and fuel pellet temperature.
- Which parameters are important for modeling these phenomena
  - Packing fraction of relocated fuel, the possible effect on thermal conductivity, fine resolution of the fuel temperature profile.
- Testing conditions with respect to their applicability to both PWR and BWR LOCA conditions
- The results and behavior observed in different testing methods, e.g. external heating and nuclear heating may need to be further evaluated for applicability to reactor conditions.
- A proposal for new terminology to distinguish between fuel fragmentation that occurs during operation, and the fuel fragmentation discussed here that is proposed to occur during a LOCA.

During the discussion session, presenters and audience members noted that many of the parameters that may be important to control or model the fuel fragmentation, relocation and dispersal phenomenon are already included in the plans for research programs presented at this meeting. Notably, the following items were discussed that do not seem to be addressed in planned research programs:

- The effect of these phenomena on thermal conductivity, a detailed quantification of packing fraction as a function of burnup and/or strain, a detailed picture of the rod axial and fuel radial temperature profile during the testing and comparison of this profile to in-reactor predictions, a fine resolution of the impact on cladding temperature of relocated fuel that accounts for the complex synergistic effects of both the potential increased heat load and the potential increased cooling effects of the balloon.
- Pellet doping, “accident tolerant fuel” were also mentioned.
- It appears that none of the planned research programs are designed to measure the consequences of fuel dispersal.

Open Discussion on the Subject of LOCA Analysis

Following presentations 6-8, an open discussion session included discussion of:

- The general consistency of the various analyses presented, which all suggested that under best estimate predictions, fuel dispersal may not occur because the rods vulnerable to fine fragmentation are not predicted to rupture.
  - Thermal-mechanical limits, core loading patterns and exposure plans create an envelope that result in this behavior.
- The difference between ECCS analysis for Licensing Basis / Analysis of Record / Design Basis Analysis vs. realistic operation parameters.
  - Presentations and discussions highlight the significant differences.

- The implications of the fragmentation size distribution from high burnup rods (and other empirical observations) being conservatively applied to lower burnup fuel in analytical studies
  - Comments pointed to the lack of empirical observations for low burnup fuel, SCIP-III may provide more information that could be used.
  - Comments pointed to the complexity of a mechanistic model for fuel fragmentation behavior
- How burnable poisons may influence the analysis.
- A proposal to consider an analysis benchmark so that differences in approaches and results can be identified and evaluated.
  - Participants pointed to the need to define guidelines and objectives, for example: Should studies focus on design basis evaluation conditions or realistic conditions and whether the objective is burst population or fuel dispersal quantity?
  - Some expressed concern that this would not be productive. The proposal was further discussed in the third open discussion session, summarized below.
- A proposal to start further analytical efforts on the topic of consequences of fuel dispersal.

Open Discussion on Perspectives on Experiments and Analysis

Following presentations 9-12, an open discussion session included discussion of:

- The need to understand the consequences of fuel relocation and dispersal for both LOCA and non-LOCA scenarios.
- How and when the NRC will communicate any new regulatory actions related to fuel fragmentation, relocation and dispersal.
  - NRC staff clarified that any new regulatory action would follow the normal, rigorous public comment and engagement standards for new regulatory actions.
  - Some asked for clarification on whether there would be an expectation that this subject is addressed in topical reports.
- Challenges with benchmark calculations for this applications
  - Participants noted that traditionally there is an experimental data set available to compare results to, however that is not the case in this instance.
  - Participants noted that the phenomena are very complex and both the thermal-hydraulic and thermo-mechanical models may need to be isolated and examined in detail.
  - Participants noted that code comparisons could focus on specific behavior, such the approach to modeling ballooning and burst behavior.
- A proposal that there is a growing need to study specific parameters to better estimate important aspects of these phenomenon with analytical methods.
  - Noted thermal conductivity, packing fraction etc.
- The value of sensitivity studies related to ECCS performance, fuel parameters, etc.
- The value of more modeling efforts to complement experiments.
- Participants noted that some may be interested in a detailed review of the NRC's calculations.

  - Commenters noted the importance of a large number of assumptions made during the modeling scheme and open discussions about the choices of these assumptions may be very interesting and useful.
- The need to match calculation assumptions, and resulting temperature and pressure transient, to the conditions of experiments.
- The value of a truly coupled, between thermal-hydraulic and fuel thermo-mechanical behavior, approach to model this phenomena.
  - Participants noted the current approach may over predict burst because the models aren't fully coupled.
  - Participants noted this is a goal of the NRC's efforts, but this is complex and takes some time.
  - Participants noted that sub-channel codes may be available already to examine this as a first cut.
- The need to define a goal for future analytical studies.
  - One proposal was that an objective could be to demonstrate there is no safety issue with respect to fuel dispersal.
  - Another proposal was that an objective could be to develop confidence that multiple analysis can show there is no fuel dispersal concern and thereby reduce need to complete significant research on the sensitivities to these phenomena.

The meeting concluded with a brief review of the open discussion sessions and a summary of NRC's next steps with respect to fuel fragmentation, relocation and dispersal. The NRC presented the following next steps:

- Review results of experiments completed in the last year and remain active and engaged in international collaborative research programs focused on the phenomenon discussed today.
- Continue to perform analysis to develop an improved understanding of the sensitivities of these phenomena with respect to factors including plant design and operation parameters.
- Continue to engage the public on approaches to evaluate the consequences of these phenomenon and regulatory path forward.
- Develop a technical basis and regulatory recommendation that is well informed and comprehensive in scope.

The meeting attendees were reminded that follow up questions could be directed to the meeting contact, Michelle Flanagan (michelle.flanagan@nrc.gov; 301-251-7547)

Attachments

Attachment 1 – Meeting Agenda
Attachment 2 – Meeting Attendee List

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- The value of a truly coupled, between thermal-hydraulic and fuel thermo-mechanical behavior, approach to model this phenomena.
  - Participants noted the current approach may over predict burst because the models aren't fully coupled.
  - Participants noted this is a goal of the NRC's efforts, but this is complex and takes some time.
  - Participants noted that sub-channel codes may be available already to examine this as a first cut.
- The need to define a goal for future analytical studies.
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Attachments

Attachment 1 – Meeting Agenda
Attachment 2 – Meeting Attendee List

ADAMS Accession No.: ML14100A131

OFFICE	RES/DSA/FSCB	BC:RES/DSA/FSCB	D:RES/DSA
NAME	M. Flanagan	R. Lee	K. Gibson (via e-mail)
DATE	4/10/14	4/10/14	4/11/14

OFFICIAL RECORD COPY

Attachment 1 – Meeting Agenda

Topic	Speaker, Organization	Day	Time
1. Welcome	RES/NRR Management	Thursday	12:00 -12:15
2. Ground Rules and Meeting Logistics	Meeting Facilitator		12:15-12:30
3. Introduction and Meeting Objectives	T. Inverso, NRC		12:30-1:00
4. Research on Fuel Fragmentation, Relocation and Dispersal	-		-
a. LOCA Experiments	-		-
i. Fuel Fragmentation, Relocation and Dispersal Under LOCA Conditions: Experimental Observations	M. Flanagan, NRC		1:00-2:00
ii. Fuel Fragmentation, Relocation and Dispersal, Current Understanding and Test Results	K. Yueh, EPRI		2:00-2:30
BREAK	-		*2:30-3:00*
iii. LOCA and fuel fragmentation tests in SCIP III	P. Askeljung, Studsvik		3:00-3:30
iv. Overview of Halden Reactor LOCA experiments (with emphasis on fuel fragmentation) and plans	B. Oberlander, Halden		3:30-4:00
v. Open Discussion*	ALL		4:00-5:00
5. Welcome and brief summary of Thursday's sessions	M. Flanagan, NRC	Friday	9:00-9:15
b. LOCA Analysis	-		-
i. Methodology for Core-Wide Estimates of Fuel Dispersal During a LOCA	I. Porter & P. Raynaud, NRC		9:15-10:00
ii. Analytical Assessment of High-Exposure Fuel Dispersal Potential During BWR LOCA	K. Muftuoglu, GEH		10:00-10:30
iii. Assessment of Extent of Rupture in a Large Break LOCA	M. Nissley, Westinghouse		10:30-10:50
i. Open Discussion*	ALL		10:50-11:15
BREAK	-		*11:15-11:30*
6. Perspectives on Experiments and Analysis			
i. Potential Impacts on Design Basis Accidents	P. Clifford, NRC		11:30-12:00
ii. IRSN views on fuel dispersion in RIA and LOCA accidents	M. Petit, IRSN		12:00-12:20
iii. JAEA perspective on fuel fragmentation and dispersal	F. Nagase, JAEA		12:20-12:40
iv. AREVA Perspective on Fuel Fragmentation and Dispersal During Design Basis Accidents	B. Dunn, AREVA		12:40-1:00
LUNCH	-		*1:00-2:00*
v. Open Discussion*	ALL		2:00-2:30
7. Summary and Conclusions, Next Steps	M. Flanagan, NRC		2:30-3:00

Attachment 2 - Meeting Attendee List

March 13, 2014; 12:00 p.m. – 5:00 p.m., EDT

Name	Organization
Glenna Lappert	NRC/NRR
Phil Sharpe	GE Hitachi
Pablo J. Garcia	Iberdrola
Kurshad Muftuoglu	GE Hitachi Nuclear Energy, LLC
Lisa Gerken	AREVA
Bert Dunn	AREVA
Fumihisa Nagase	JAEA
Ken Yueh	EPRI
Marc Petit	IRSN
Yang-Pi Lin	GEH/GNF
Joe Rashid	ANATECH
Yun Ho Kim	KHNP
Paul Clifford	NRC
Kurt F. Flaig	Dominion
Ralph Landry	Retired NRC
Michelle Hart	NRC/NRR
Jean Barbaud	EDF
Shanlai Lu	NRC/NRO
Ian Porter	NRC/RES
Dan Collins	NRC/RES
Kevin McCoy	AREVA Inc.
Tom Eichenberg	TVA/EPRI-REG-TAC
Richard Dudley	NRC/NRR/DPR
Robert Florian	Southern Nuclear
Steve Bajorek	NRC/RES
Steve Smith	NRC/NRR
David Boirel	IRSN
Michelle Flanagan	NRC/RES
Tara Inverso	NRC/NRR
Harold Scott	NRC/RES
Ruth Thomas	Public
Marvin Lewis	Public
Farouk Eltawila	FANR
Peter Askeljung	Studsvik
Barbara Oberlander	Halden
Mitch Nissley	Westinghouse
Heinz Sonnenburg	GRS
Martin Zimmermann	PSI
Madeline Feltus	DOE
Stu Richards	NRC/RES

March 14, 2014; 9:00 a.m. – 5:00 p.m., EDT

Name	Organization
Glenna Lappert	NRC
Phil Sharpe	GE Hitachi
Pablo J. Garcia	Iberdrola
Kurshad Muftuoglu	GE Hitachi Nuclear Energy, LLC
Lisa Gerken	AREVA
Bert Dunn	AREVA
Fumihisa Nagase	JAEA
Ken Yueh	EPRI
Marc Petit	IRSN
Ian Porter	NRC/RES
Joe Rashid	ANATECH
Yun Ho Kim	KHNP
Paul Clifford	NRC
Kurt F. Flaig	Dominion
Ralph Landry	Retired NRC
Michelle Hart	NRC
Jean Barbaud	EDF
Shanlai Lu	NRC
Dan Collins	NRC/RES
Kevin McCoy	AREVA Inc.
Tom Eichenberg	TVA/EPRI-REG-TAC
Richard Dudley	NRC/NRR/DPR
Robert Florian	Southern Nuclear
Steve Bajorek	NRC/RES
Steve Smith	NRC/NRR
David Boirel	IRSN
Michelle Flanagan	NRC/RES
Tara Inverso	NRC
Harold Scott	NRC
Farouk Eltawila	FANR
Peter Askeljung	Studsvik
Barbara Oberlander	Halden
Mitch Nissley	Westinghouse
Ruth Thomas	Public
Marvin Lewis	Public
Mark Blumberg	NRC
Richard Lee	NRC/RES
Andrew Proffitt	NRC/NRR
Gordon Clefton	NEI
David Lochbaum	Union of Concerned Scientist
Heinz Sonnenburg	GRS
Ed Lyman	Union of Concerned Scientist