



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

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](mailto:michelle.flanagan@nrc.gov); 301-251-7547)

### **Attachments**

Attachment 1 – Meeting Agenda

Attachment 2 – Meeting Attendee List

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  - 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.
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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<br>(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    |
| <i>BREAK</i>   | -                           |             | 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  |
| <i>BREAK</i>   | -                           |             | 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  |              |
| <i>LUNCH</i>   | -                           | 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

| <b>Name</b>        | <b>Organization</b>            |
|--------------------|--------------------------------|
| 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

| <b>Name</b>        | <b>Organization</b>            |
|--------------------|--------------------------------|
| 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   |