April 16, 2009

MEMORANDUM TO: William H. Ruland, Director
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Paul M. Clifford, Senior Technical Advisor /RA/
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF MARCH 24-25, 2009 MEETING TO COMPARE ANALYTICAL TECHNIQUES FOR MODELING REACTIVITY INITIATED ACCIDENTS

As part of an ongoing program to compare analytical techniques for modeling the phenomena associated with reactivity initiated accidents (RIAs), representatives from the U.S. Nuclear Regulatory Commission (NRC) staff, the French Institute de Radioprotection et de Sûreté Nucléaire (IRSN), and the Electric Power Research Institute (EPRI) attended a public workshop on March 24-25, 2009 at the ANATECH Corporation offices in San Diego, California. Additional attendees included NRC contractors from Pacific Northwest National Laboratory (PNNL) and EPRI contractors from ANATECH. Following a previous meeting to compare computer codes used by EPRI, IRSN and NRC, this public meeting focused on analytical techniques and their supporting empirical database. Analytical models are being employed to scale results from in-reactor RIA test programs conducted at non-prototypical conditions. It is important that any scaling of empirical results be based upon sound engineering principles.

A brief summary of the meeting, along with the workshop agenda and list of attendees, is enclosed. The presentation materials are available in the Agencywide Documents Access and Management System (ADAMS) accession no. ML090890421 (package).

Enclosure:
As stated

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(301) 415-4043

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PUBLIC WORKSHOP
COMPARISON OF ANALYTICAL TECHNIQUES FOR MODELING
REACTIVITY INITIATED ACCIDENTS
MARCH 24-25, 2009

As part of an ongoing program to compare analytical techniques for modeling the phenomena associated with RIAs, representatives from the NRC staff, the French IRSN, and the EPRI attended a public workshop on March 24-25, 2009 at the ANATECH Corporation offices in San Diego, California. Additional attendees included NRC contractors from PNNL and EPRI contractors from ANATECH. Following a previous meeting to compare computer codes used by EPRI, IRSN and NRC, this public meeting focused on analytical techniques and their supporting empirical database. Analytical models are being employed to scale results from in-reactor RIA test programs conducted at non-prototypical conditions. It is important that any scaling of empirical results be based upon sound engineering principles. The agenda for this workshop is provided in Table 1. A complete listing of meeting attendees is provided in Table 2. The presentation materials are available in ADAMS accession no. ML090890421 (package).

During the meeting, differences between analytical solutions and modeling approaches were identified and discussed. To facilitate these discussions, several representative RIA test cases were identified and evaluated with each of the respective models: FRAPTRAN (NRC), SCANAIR (IRSN), and FALCON (ANATECH). Test cased included: HBO-1, HBO-5, HBO-5 (hypothetical hot conditions), HBO-6, REPNa-3, and a postulated Westinghouse 17x17 case. The HBO cases were taken from tests run at the Nuclear Safety Research Reactor (NSRR) in Japan. The REPN a test was taken from the French CABRI test reactor. The results of these benchmarking cases are provided in the presentations, listed in Table 3.

During the meeting, a more theoretical approach was presented by Joe Rashid of ANATECH. This constitutive model treats the cladding as a multi-material composite in which the metal and the hydride platelets are considered separate material phases. The theoretical results show surprisingly good agreement with the stress-strain response of irradiated material, and (remarkably) little temperature dependence of the critical strain energy density method used by ANATECH to calculate cladding failure.

Relative to FRAPTRAN, FALCON includes a non-linear transient cladding heat transfer model which may promote a faster temperature increase during short pulse width RIA scenarios and a corresponding change in cladding mechanical properties (e.g. larger increase in cladding ductility during event). The difference may also be attributed to differences in the cladding nodalization used in the two codes. This difference is apparent in predicted failure strain and requires further study.

With respect to analytical approaches, the largest difference between FRAPTRAN and FALCON is the assumed initial fuel-to-cladding gap and the fuel pellet thermal expansion model. Both the initial fuel-to-cladding gap and thermal expansion model have a first-order impact on predicted fuel rod performance and may be used to calibrate algorithms to achieve measured strains during in-reactor RIA tests. Both codes accurately predict the empirical database. However, with an assumed initial gap size, FRAPTRAN's shell model predicts significantly larger fuel thermal expansion relative to FALCON (with an assumed initial gap size of almost zero). It is important to note that the initial fuel-to-cladding gap size of the fuel rod specimens in the RIA

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test programs is small, difficult to measure, and, therefore, largely unknown. The difference in predicted fuel pellet thermal expansion will have a significant impact on predicted fuel rod behavior for current and new fuel rod designs and requires further study.

A fundamental difference exists in cladding failure mode between NRC's FRAPTRAN methods and EPRI's FALCON methods. The FRAPTRAN cladding failure model is based on an irradiated empirical database of uniform elongation (UE); whereas the FALCON model is based on an irradiated empirical database of total elongation (TE). Differences between cladding failure models based upon uniform elongation versus total elongation become significant at higher cladding temperatures and at lower cladding hydrogen levels.

To distinguish between these two approaches, Carl Beyer of PNNL presented a series of movie files showing optical strain measurement of deforming specimens with speckled surfaces. The experimental work was attributed to Curt Lavender of PNNL.

During the meeting, IRSN provided results from their analytical methods based on SCANAIR calculations and fracture mechanics. The IRSN methods accurately predicted results from the VA-1 RIA test specimen (as well other RIA test programs). Applying the critical flaw depth methods to the upcoming VA-3 hot capsule test at NSRR, IRSN predicted cladding failure prior to achieving the anticipated 105 cal/g maximum enthalpy increase. IRSN's estimate of the potential increase in cladding ductility as a result of testing fuel rod specimens at a higher initial temperature is consistent with NRC estimates. However, both the IRSN fracture mechanics failure mode and NRC uniform elongation failure mode yield significant differences from EPRI's total elongation failure predictions.

More work based on upcoming hot capsule tests at the NSRR test reactor is required to evaluate code differences and reach agreement on a proper scaling technique for initial temperature, and changes in cladding properties with temperature. The anticipated NSRR hot capsule test results are important in addressing many of these concerns and finalizing the pellet-cladding mechanical interaction failure criteria. These results are expected to become available in May 2009. EPRI believes that the original RIA Criteria topical report, incorporating the changes discussed above, may be re-submitted as a supporting document rather than a licensing topical report. This would be completed by the end of 2009. Parallel paths may be taken to resolve analytical differences, to re-scale results based on hot capsule tests, and to resolve remaining issues in the interim RIA criteria and guidance (i.e. Appendix B of Standard Review Plan, Section 4.2). A reasonable target for the final criteria and a revision to Regulatory Guide 1.77 is 2010.

In addition to upcoming JAEA hot capsule tests, EPRI is planning on conducting a series of high rate burst-type tests on irradiated cladding segments. The experimental apparatus (under development) uses a mechanical piston to force high pressure oil into a stainless steel sleeve which expands, loading the surrounding fuel rod cladding. The bi-axial loading from the expanding sleeve is expected to be similar to loading due to thermal expansion of fuel pellets. Tests conducted on pre-hydrided, unirradiated cladding have been used to calibrate the experimental apparatus and protocols. Results from future tests on irradiated cladding would be helpful to resolve differences associated with UE versus TE failure modes.

A list of follow-up or action items will be coordinated among attendees following the meeting.

Table 1: RIA Public Workshop Agenda*

Schedule	**Discussion Topics**
March 24, 2009	
8:30 - 8:40 a.m.	Introductory Remarks/Introductions (P. Clifford, NRC)
8:40 - 10:00 a.m.	Results from FALCON Benchmark RIA Cases (J. Alvis, ANATEC)
10:00 - 10:15 a.m.	Break
10:15 - 11:30 a.m.	IRSN Presentation (V. Georgenthum, IRSN)
11:30 - 12:15 p.m.	Lunch
12:15 – 4:45 p.m.	Discussion of Code Algorithms and Analytical Solutions (NRC, PNNL, ANATEC, EPRI)
4:30 - 4:45 p.m.	Public Comment Period
4:45 – 5:00 p.m.	Closing Remarks/Adjourn
March 25, 2009	
8:30 - 8:40 a.m.	Introductory Remarks (P. Clifford, NRC)
8:40 - 10:30 a.m.	EPRI Test Program and Recent Results (K. Yueh, EPRI)
10:30 - 10:45 a.m.	Break
10:45 – 11:30 a.m.	Discussion of Future Testing Requirements for New Fuel Rod Designs and Cladding Alloys (NRC, PNNL, ANATEC, EPRI)
11:30 - 11:45 a.m.	Public Comment Period
11:45 – 12:00 p.m.	Closing Remarks/Adjourn

*** Agenda was modified relative to meeting notice.**

Table 2: Attendees at RIA Public Workshop

Name	Organization	Email Address
Amrit Patel	NRC/NRO	Amrit.Patel@nrc.gov
John Voglewede	NRC/RES	John.Voglewede@nrc.gov
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