March 31, 2004

MEMORANDUM TO: James E. Dyer, Director
Office of Nuclear Reactor Regulation

FROM: Ashok C. Thadani, Director ***/RA/***
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER No. 0401, AN ASSESSMENT OF POSTULATED REACTIVITY-INITIATED ACCIDENTS FOR OPERATING REACTORS IN THE U.S.

The attached report describes our assessment of postulated reactivity-initiated accidents for operating reactors as called for in the recent updated program plan for high-burnup fuel (W. Travers memorandum to the Commission, August 21, 2003). Hypothetical transients and accidents are used in the design and safety analysis of light-water reactors (LWRs). The postulated events that could challenge the reactor core generally consist of undercooling events (e.g., loss-of-coolant accidents) and overpower events (e.g., reactivity-initiated accidents). The design-basis reactivity-initiated accidents for a pressurized water reactor and boiling water reactor are the control-rod-ejection accident and the control-rod-drop accident, respectively, and they are the subject of this Research Information Letter.

The current fuel enthalpy limit used in safety analyses for reactivity-initiated accidents (RIAs) is 280 cal/g, based on early tests with low-burnup and unirradiated fuel rods. That limit was intended to preclude fuel dispersal by avoiding incipient melting of UO_2. By precluding fuel dispersal, a coolable fuel geometry was ensured and steam explosions could not occur.

High-burnup fuel behaves differently. In late 1993 and early 1994, tests in France and Japan showed that cladding failure with fuel dispersal could occur at fuel enthalpies below 100 cal/g. Since that time, tests in France, Japan, and Russia have confirmed this high-burnup behavior and generated a database that permits an updated assessment of postulated RIAs for operating reactors.

The test reactors in which the data were developed, however, did not reproduce LWR conditions well, and the atypicalities are believed to have biased some of the results. An estimate of this bias was therefore desired. Using NRC's FRAPTRAN fuel rod code, a method has been developed to perform a scaling analysis to adjust raw test data for LWR conditions, and the method has been used to adjust the test results that have the most influence on the cladding failure thresholds. The adjustments range only from -17 cal/g to +27 cal/g, so the final result is still largely empirical and closely related to the measured data. From these adjusted results, RIA cladding failure thresholds have been estimated for PWR and BWR fuels. The adjusted data and the thresholds are shown in Fig. 1. These thresholds apply to Zircaloy-2, Zircaloy-4, Zirlo, and M5 cladding alloys as well as to UO_2 and MOX fuel, all of which were included in the database.

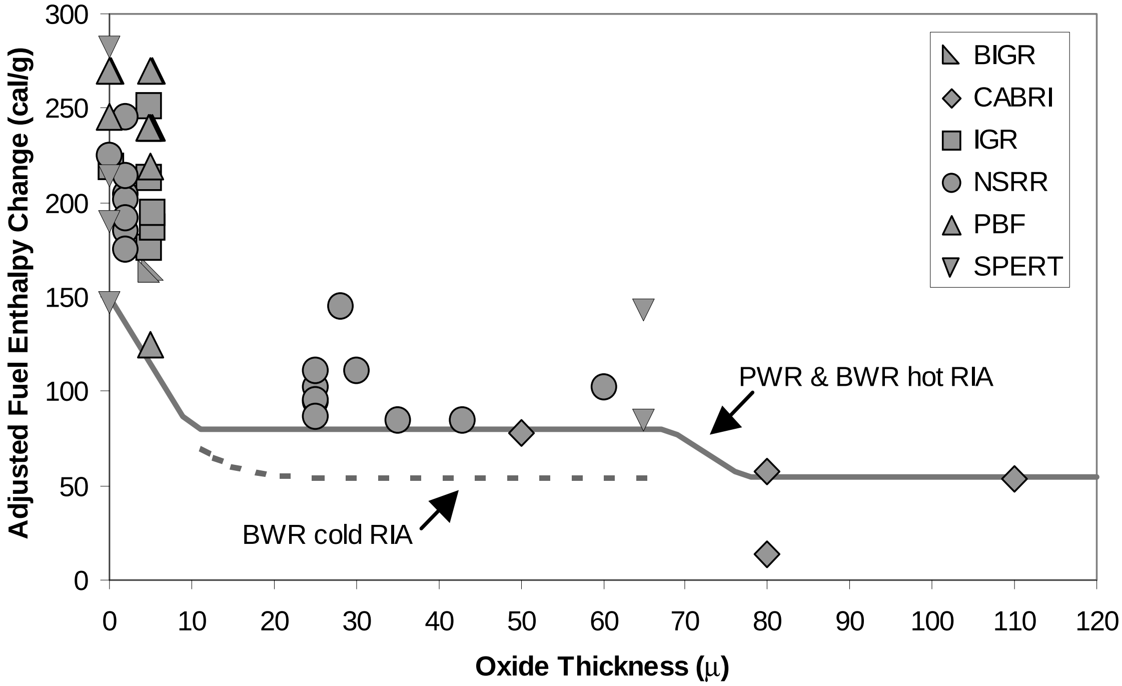

Figure 1. Cladding failure data with adjustments from the scaling analysis and lower-bound failure correlations. The lowest point at 80 microns of oxide thickness is for a test that has been discredited.

In high-burnup fuel, expanding fission gas is able to drive fuel particles out through a cladding breach, whereas fuel melting was needed as the driving force in low-burnup fuel. Thus, many, if not most, cladding failures in high-burnup fuel may be accompanied by fuel dispersal. Consequently, the cladding failure thresholds were used as the enthalpy limits for this assessment, rather than using a higher limit based on fuel melting.

Neutronic analyses were performed for a range of LWR conditions with NRC's PARCS 3-dimensional neutron kinetics code. It was found that control rod worths needed to reach the enthalpy limits are very high (above $1.5). There is no comprehensive database of rod worths in U.S. power reactors. Based on available data, however, it is very unlikely for a rod worth to exceed $1.5. Therefore, it was concluded that current operating reactors are not likely to experience cladding failure during the worst postulated RIAs. Without cladding failure, coolable geometry is ensured and steam explosions cannot occur.

It should be noted that cladding failure thresholds vary only weakly with burnup level. Cladding corrosion (oxidation), which might differ widely for different cladding materials at the same burnup, was found to be the most important variable. The cladding failure thresholds (hence enthalpy limits) in this assessment were developed in terms of oxide thickness, rather than burnup, and were therefore directly applicable to different cladding materials.

The attached report was reviewed by appropriate staff in DET/RES, DSSA/NRR, Argonne National Laboratory, Brookhaven National Laboratory, Pacific Northwest National Laboratory, Pennsylvania State University, Institute for Radioprotection and Nuclear Safety (France), Japan Atomic Energy Research Institute, and Russian Research Center— Kurchatov Institute. Comments were considered and changes were made as appropriate.

We hope the attached assessment will provide NRR with independent information that will help in the review of EPRI's "Topical Report on Reactivity Initiated Accident: Bases for RIA Fuel and Core Coolability Criteria," No. 1002865, 2002. The RES staff are available to assist NRR with that review, and RES is prepared to subsequently revise Regulatory Guide 1.77 on RIA safety analysis as indicated in the updated program plan.

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cc w/att.:
C. Paperiello, EDO

The attached report was reviewed by appropriate staff in DET/RES, DSSA/NRR, Argonne National Laboratory, Brookhaven National Laboratory, Pacific Northwest National Laboratory, Pennsylvania State University, Institute for Radioprotection and Nuclear Safety (France), Japan Atomic Energy Research Institute, and Russian Research Center— Kurchatov Institute. Comments were considered and changes were made as appropriate.

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