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

March 3, 1997

MEMORANDUM TO: Samuel J. Collins, Director
Office of Nuclear Reactor Regulation

FROM: David L. Morrison, Director
Office of Nuclear Regulatory Research *David L. Morrison*

SUBJECT: RESEARCH INFORMATION LETTER No. 174, "INTERIM ASSESSMENT OF CRITERIA FOR ANALYZING REACTIVITY ACCIDENTS AT HIGH BURNUP"

This memorandum describes results of work performed to date to assess fuel damage criteria, which are used by NRC to evaluate reactivity accidents, and to determine the adequacy of those criteria at high burnup. The work was performed by RES staff with assistance from Idaho National Engineering Laboratory, Argonne National Laboratory, and Brookhaven National Laboratory. The results are described in detail in the attached paper, which has been submitted for publication in the journal, Nuclear Safety.

Regulatory Issue

Several reactivity accidents are analyzed in plant safety analyses, and the most severe of these are the rod-ejection accident (PWR) and the rod-drop accident (BWR). Two types of regulatory criteria are used by the NRC in safety analyses to address these postulated accidents. One is a limit of 280 cal/g on peak calculated fuel rod enthalpy, and this limit was intended to ensure coolability of the core after such an accident and to preclude the energetic dispersal of fuel particles into the coolant.

The other regulatory criterion consists of values that are used to indicate cladding failure -- i.e., the occurrence of a breach in the cladding that would allow fission products to escape. This criterion is used in calculating radiological releases for comparison with other limits. For PWRs, a critical heat flux value related to departure from nucleate boiling (DNB) is used. For BWRs, a similar value is used for high-power accidents, but for low-power and zero-power accidents an enthalpy value of 170 cal/g is used.

In late 1993, a test was run in the CABRI test reactor in France, and that test produced cladding failure at an enthalpy of about 30 cal/g. Fragmented fuel particles were dispersed from the fuel rod in the test, and enhanced fission product release was observed. A short time later in 1994, a similar test in the NSRR test reactor in Japan produced cladding failure at an enthalpy of about 60 cal/g. These values were so far below the 170 cal/g failure criterion that the NRC initiated an investigation into this situation and issued an Information Notice to licensees (IN-94-64). NRR then performed a review of the safety significance of this situation and concluded that there was no significant impact on public health and safety because of the low probability of the event and the high likelihood that core coolability would be maintained, although there might be some increase in the fuel damage fraction.

Notwithstanding this conclusion, there is still a question of the adequacy of NRC's regulatory criteria for this type of accident, and there are unanswered questions about the behavior of fragmented fuel particles and fission products released during such an event. Consequently an NRC research program has continued to investigate the behavior of high-burnup fuel rods under conditions of reactivity accidents.

Method

The NRC last tested fuel under conditions of these reactivity accidents in 1978 and does not have an active facility where further tests could be undertaken at a reasonable cost. Therefore, the general method of investigation was to closely examine recent results coming out of the foreign test reactors and to re-examine our own early test results.

More specifically, our method of investigation included several steps. One step was to perform more precise plant calculations, using three-dimensional neutronic models, to determine the potential fuel enthalpy rise during realistic plant transients. Another step was to consider the underlying phenomena that might explain the apparent trend seen in the foreign test data, which contain a lot of uncertainty. We also looked at the mode of cladding failure because there was a variation between different test programs. Then we looked carefully at the test reactor data to interpret those data in light of the above and to make observations and reach whatever conclusions we could.

The findings that are presented below are considered to be interim findings because the current data base is limited and contains uncertainties from atypical test conditions such as test reactor pulse width. However, it will take several years to address these uncertainties in new tests and to accumulate enough new data to substantially improve our knowledge. Therefore, we are on a plateau of understanding at this time and will remain there long enough that this level of understanding should, in the interim, be considered for its regulatory implications.

Findings

Based on the attached paper, our review of the data, and an understanding of the postulated conditions for the rod-ejection and rod-drop accidents, we have the following findings:

1. DNB does not appear to be related to cladding failure for these accidents (except for fresh fuel), and its use as a criterion should be reconsidered for rod-ejection and rod-drop accidents.

2. The amount of cladding oxidation appears to be more important than burnup as the variable controlling cladding integrity.

3. Except as discussed below, 100 cal/g peak fuel enthalpy increase (radially averaged) is a reasonable value below which cladding failure will not occur, and this value could be used on an interim basis for BWRs and PWRs at all burnups above a few GWd/t. This value depends somewhat on the amount of cladding oxide and is subject to further

confirmation; however, it is our best estimate at this time, and it is clearly more realistic than DNB or 170 cal/g as currently assumed in safety analyses.

4. Cladding failure may occur well below 100 cal/g if the cladding contains localized regions of hydrides as were found in the French test, REP-Na1. Continued irradiation of fuel with major oxide spalling or large pellet gaps, which can lead to hydride localization, may not be desirable.

5. If the 100 cal/g value were used as a limit for reactivity-initiated accidents, this would avoid the need to deal with the possible dispersal of fragmented fuel and enhancment of fission gas release (from fuel pellets) as have been observed at high burnup during transient tests. This would also eliminate the need to reassess the previous 280 cal/g limit, which has been revised downward in other countries, by replacing it with a conservative value.

6. If a 100 cal/g limit is established, the use of refined three-dimensional neutronics methods may be needed to demonstrate that fuel enthalpy values remain sufficiently low. Typical safety analyses of record have been performed with licensing methods that overpredict the magnitude of the transient.

Regulatory Application

The findings summarized above could be used on an interim basis in reanalysis of reactivity accidents. Reanalysis might be desirable because the safety analyses of record for operating reactors were based on criteria that no longer appear to be appropriate. Application of these findings to other reactivity transients like ATWS is discussed later.

A 100-cal/g limit should be relatively easy to meet without any plant operating penalties. All vendors, EPRI, and NEI have said that fuel enthalpy during reactivity-initiated accidents will be much lower than 100 cal/g, based on their three-dimensional neutronics calculations. NRC-sponsored three-dimensional calculations performed by Brookhaven National Laboratory also show maximum enthalpy values below 100 cal/g although uncertainties are significant.

The tests upon which the above results are based contained atypicalities that could have affected the results. Therefore, uncertainties in the current data base could be large. Although we have attempted to compensate for these effects in an approximate way, only by obtaining additional data under prototypical conditions will the findings be confirmed.

Future Research

Because of the uncertainties, we will pursue additional research to improve our understanding of fuel behavior under reactivity-initiated accident conditions by using more prototypical test conditions and testing at even higher burnups. We expect this process to take from three to five years.

At the present time, we are not planning any specific research to investigate the consequences of fuel fragment dispersal or enhanced fission product release, which have been observed in the tests. This is based on the expectation that cladding failure will not occur because of low fuel enthalpies in plant transients. A reanalysis by licensees and vendors would be useful to confirm the low fuel enthalpies and to avoid having to deal with these new effects.

Finally, it is our understanding that a 280 cal/g enthalpy limit is being used in the assessment of large power oscillations during a BWR ATWS (anticipated transient without scram). Although the cladding duty may be different for these oscillations than for the prompt critical power pulses of the rod-ejection and rod-drop accidents, it would be reasonable to reassess this ATWS criterion in light of current information. We plan to look into this situation in the near future.

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RES Files
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NUREG No. N/A
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Other NRC PDR
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