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

November 9, 1994

MEMORANDUM TO: The Chairman
Commissioner Rogers
Commissioner de Planque

FROM: James M. Taylor
Executive Director for Operations

SUBJECT: REACTIVITY TRANSIENTS AND FUEL DAMAGE CRITERIA FOR HIGH BURNUP FUEL

The purpose of this memorandum is to provide an assessment of the safety significance of new information relating to fuel failure limits for high burnup fuel and to describe the joint efforts of the Office of Nuclear Reactor Regulation (NRR) and the Office of Nuclear Regulatory Research (RES) to assess the need for revised fuel design acceptance criteria for high burnup fuel.

My September 13, 1994, memorandum to you described current activities and gave a summary of recently available test data on reactivity transients for high burnup fuel that indicate that fuel damage enthalpy limits decrease as a function of irradiation exposure. The new data raise concerns about the adequacy of the current fuel damage criteria for reactivity transients. The current criteria are a peak radially averaged enthalpy limit of 280 calories per gram (cal/g) to ensure fuel coolability and 170 cal/g as the measure of fuel rod cladding failure (by boiling transition) for boiling water reactors (BWRs). The more recent data indicate that fuel rod cladding failure may occur at enthalpy conditions of 30 cal/g for high burnup fuel (i.e. fuel with more than 60 giga-watt days per tonne [GWd/t] uranium). These data do not provide information on the enthalpy limits for fuel coolability.

Information Notice 94-64, "Reactivity Insertion Transient and Accident Limits for High Burnup Fuel," cited the new foreign data that indicate higher burnup fuel may fail at lower enthalpy levels than those used in our current acceptance criteria. The new information warrants careful attention, and NRR has assessed its potential impact on public health and safety. To assess the significance of the new data, NRR evaluated the safety significance (Attachment 1) of lower thermal limits associated with fuel rod cladding failure by a pellet/cladding interaction mechanism during reactivity transients. This initial assessment concludes there is no significant risk impact because of the low power associated with high burnup fuel in current fuel management schemes and because of the low probability of reactivity transients of sufficient magnitude to threaten the integrity of the fuel.

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However, lower fuel damage enthalpy limits for high burnup fuel may result in some increase in fuel failure and radiological consequences for some design bases reactivity transients analyzed in the Updated Final Safety Analysis Reports (UFSARs) and may affect conformance to acceptance criteria for safety analyses at high burnup levels. Therefore, we will not approve any further extensions of burnup limits beyond the maximum value previously approved for each fuel vendor until supporting transient data are available. In order to address this issue, the staff has scheduled a meeting with fuel vendors and reactor owners to ascertain whether additional data or analyses are available to resolve the concern. If necessary, the staff will issue generic communications (e.g., bulletins or generic letters) to assure that the safety and regulatory issues are being resolved by licensees.

In light of the new data, we have developed an action plan to determine if further regulatory action is needed. This action plan includes (1) evaluation of the recent and planned test data, (2) detailed study of the most limiting transients to assess the impact of revised burnup limits, (3) coordinated efforts with the industry to develop revised fuel failure limits, and (4) coordinated efforts with foreign experimenters and regulatory representatives. A milestone summary is included as Attachment 2, outlining our action plan to follow the testing activities and to evaluate all available data and the potential impact on fuel burnup limits and acceptance criteria for use in licensing safety analyses.

We have started our transient study which will consist of a detailed analysis of limiting fuel loading patterns subjected to the most challenging transients. This analysis will require about 6 to 8 months for RES to complete. Since the new test data are preliminary and incomplete, more detailed information and additional testing will be needed to determine how it should be applied to define limitations on the use of high burnup fuel in U.S. reactors. Further tests in France are planned during the next year.

We have contacted the fuel vendors and owners groups to alert them to this issue and our plans for future action. We have also notified the public and industry of ongoing test results and the new data at a special session of the October 1994 Water Reactor Safety Information Meeting (WRSM). Following that meeting, we met with industry representatives concerning their plans to evaluate the more recent data and to assess its impact on operating reactors with current fuel exposure distributions. The industry indicated that their preliminary evaluation of the new data indicates low safety significance. EPRI described its program to evaluate the reactivity insertion test results and preliminary evaluations of the high burnup fuel behavior in plant responses to reactivity insertion transients. The plant results were in general agreement with the staff evaluation (Attachment 1). Industry agreed to develop a course of action and further discuss the issue and industry plans during the week of November 14. The staff agreed with this approach.

In addition, we held a meeting on September 8, 1994, with government and regulatory representatives from France, Japan, Germany, and Finland to discuss the safety significance and planned regulatory response to the high burnup fuel transient data. We are continuing our discussions with the international community and will meet with them again in the spring of 1995.

Attachments: 1. Safety Assessment of Recent High Burnup Fuel Reactivity Insertion Transient Tests
2. NRC High Burnup Fuel Action Plan Milestone Summary

cc:	SECY	OGC	PDR
	OCA	OPA	ACRS

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Attachment 1

SAFETY ASSESSMENT OF RECENT HIGH BURNUP FUEL REACTIVITY INSERTION TRANSIENT TESTS

1 BACKGROUND

Recent experiments in France with high-exposure (up to 62 giga-watt days per metric ton (GWd/t)) irradiated fuel have indicated that cladding failure, with some fuel fragmentation and dispersal, may occur at much lower radially averaged fuel rod enthalpy levels than that found for fuel in the 30 GWd/t burnup range as of the result of earlier U.S. experiments in the special power excursion reactor tests (SPERT) test facility. Since all fuel suppliers for U.S. reactors have advanced fuel designs that are approved for operation to exposures of about 60 GWd/t, the staff of the U.S. Nuclear Regulatory Commission (NRC) has assessed the safety significance of the new data on reactors with high burnup cores.

2 DISCUSSION OF NEW EXPERIMENTAL DATA

On June 3, 1994, the Office of Nuclear Reactor Regulation (NRR) staff met with representatives of Electricite de France (EdF) to discuss regulatory issues regarding conversion from 12-month to 18-month operating cycles. EdF currently has 54 operating pressurized water reactor (PWR) plants, all on 12-month refueling schedules. The meeting participants discussed review and approval of increased cycle lengths, including implications of the longer cycles with respect to the required safety analyses and restrictions on fuel thermal limits, burnup, and other core operating conditions during the mixed-core transition cycles. A primary area of interest pertained to requirements regarding fuel rod performance during normal and accident conditions with increasing fuel burnup. EdF described experiments being conducted in a sodium-cooled test loop at the CABRI facility, involving high burnup fuel performance. Results were discussed of an experiment initiated at a coolant temperature of 250°C, involving a fuel rod with an exposure of 62 Gwd/t, and achieving a pulse power insertion (in 0.01 second) from about 16 cal/g to 100 cal/g fuel enthalpy. The fuel rod began to fail at about 30 cal/gm. The significance of the results need to be assessed in light of differences in heat transfer characteristics between sodium versus water coolant. Other sodium tests were discussed, during which fuel rods with 30 to 35 Gwd/t burnup were used. These tests showed no fuel rod failure, which corresponds to Japanese test results for this burnup range. The French were seeking international cooperation for a planned series of tests in a pressurized water-cooled loop to approximate an operating PWR environment.

On September 8, 1994, the NRR and the Office of Nuclear Regulatory Research (RES) staff met with government/regulator representatives from Finland, France, Japan, and Germany to exchange information about high burnup fuel reactivity insertion transient/accident simulation testing and to discuss the safety and regulatory issues concerning the operational behavior of this fuel. The discussions focused on the implications of the French CABRI and other foreign test data for high burnup fuel behavior during design basis transients and the ways that existing safety analyses and regulatory criteria may be affected. Current activities and future plans for testing and evaluation of the data and for analyses to predict high burnup fuel behavior during design-basis transients were also discussed.

The French experimental data for high burnup (62 GWd/t) and intermediate burnup (35 GWd/t) PWR fuel rods under reactivity insertion transient/accident conditions in the CABRI reactor sodium test loop were further described and were publicly presented at the 22nd Water Reactor Safety Information Meeting (WRSM) on October 26, 1994. All participants agreed that the critical fuel enthalpy required for the initiation of fuel rod failure appears to decrease significantly with increasing burnup and that further testing and analysis are required before further extensions of currently approved fuel burnup and rod average enthalpy limits can be justified. As previously stated the maximum approved U.S. burnup limits are about 60 GWd/t; and the French and Japanese limits are somewhat lower.

The French representative presented a schedule for more sodium loop testing of intermediate high burnup fuel rods and plans for future experiments in a pressurized-water test loop. In addition to the information to be presented at the 1994 WRSM, further evaluated test data will be available in January and February 1995, and the participants were invited to France for the next exchange meeting and discussions.

3 IMPACT OF LOWER ENERGY DEPOSITION LIMITS ON CORE SAFETY EVALUATIONS

3.1 Thermal-Hydraulic Acceptance Criteria

The NRC Standard Review Plan (SRP, NUREG-0800) provides for the application of approved dryout correlations for the departure from nucleate boiling ratio (DNBR) and critical power ratio (CPR) to define the thermal limits that are assumed to result in fuel rod cladding failure in core safety evaluations. Although overheating of the cladding resulting from critical heat flux (dryout) conditions does not equate directly to fuel failure, it is a condition that can be defined and monitored, using appropriate correlations for core operating parameters such as power and flow, and a reactor scram can be initiated to preserve thermal margin limits in response to anticipated operating transients. For design-basis accidents, including reactivity insertion transients, fuel failures are permitted to the extent that acceptance criteria based on radiological dose calculations can be satisfied. For most of the design-basis accidents, the core design safety evaluation relies on thermal limits as the measure of fuel damage. However, the SRP does provide for the use of a radially averaged peak fuel rod enthalpy criterion of 170 cal/g as the measure of fuel rod failure (by dryout) in the safety analyses for the boiling water reactor (BWR) control rod drop accident initiated at zero or low power. In addition, a fuel energy deposition limit of 280 cal/g for the peak pellet in the core is an acceptance criterion for both the BWR rod drop and the PWR rod ejection safety evaluations. The purpose of this limit is to prevent fuel fragmentation and dispersal, particularly for molten fuel fragments. This limit was developed from transient fuel testing performed at the Idaho National Engineering Laboratory in the SPERT and power burst facility (PBF) test reactors in the 1960's. Dispersion of high enthalpy molten fuel results in rapid transfer of stored energy from the fuel to the coolant, with the possibility of creating a steam pressure pulse that could cause mechanical deformation adverse to continued core coolability. Although the new data are indicative of some fragmentation and dispersal by a pellet/cladding interaction (PCI) mechanism at much lower stored energy levels for the high burnup fuel, the potential for a damaging pressure pulse is small in comparison to the dispersion of lower burnup fuel at high enthalpy (molten and vaporized) with the transfer of fuel latent heat to the coolant. The SPERT data indicate that much less than 1 percent of the thermal energy transferred to the coolant is converted to mechanical energy loads for molten fuel at enthalpy levels up to 400 cal/g.

A study was performed several years ago to evaluate a fuel energy deposition criterion of 140 cal/g as a measure of fuel cladding failures by PCI during a rod ejection accident (REA). The PCI mechanism was believed to be a more realistic failure mode than the departure-from-nucleate-boiling (DNB) criterion for evaluating rapid reactivity insertion transients, and the 140 cal/g limit was selected on the basis of the SPERT transient test data for fuel irradiated to 32 GWd/t (these data were also indicative of declining failure limits for higher burnup fuel). Detailed three-dimensional calculations were performed by Combustion Engineering, Westinghouse, and Babcock & Wilcox for PWR REA cases for actual plants. These calculations showed very few cladding failures (up to 2 percent). The 140 cal/g limit applied to the peak power fuel (at low burnup) in the core. High burnup fuel would be at much lower peak energy levels (peak linear power rate of high exposure fuel is likely about one-third or less that of the fresh fuel), which would tend to mitigate the increase in fuel damage at lower peak enthalpy levels. In contrast to these results, some of the REA analyses based on thermal limits criteria were predicting fuel rod cladding failures in excess of 10 percent, resulting in a challenge to the radiological dose acceptance criteria. From its review of these analytical studies, the staff concluded that safety evaluations based on thermal limits fuel failure criteria (e.g., DNBR) provide a conservative bound of fuel rod cladding failures that might occur by a PCI mechanism for the REA reactivity transient. Therefore, changes to the enthalpy limits to evaluate fuel failures by the PCI mechanism were not required for current core designs. Based on our understanding of fuel performance at this time, it appears likely that, if fuel design enrichments and burnup limits continue to increase, the PCI failure mechanism may become more limiting than the DNB failure mechanism at some undetermined high burnup level because of declining enthalpy limits and higher relative power levels in the high burnup fuel.

The available worldwide reactivity insertion experimental data show considerable scatter in failure results for multiple points at a given burnup level, but clearly indicate a declining energy deposition failure limit as fuel irradiation exposure is increased. The continuing experimental program appears likely to lead to the conclusion that more restrictive burnup-dependent failure limits are needed to limit the number of fuel failures for design-basis accidents. The staff has evaluated the impact of revised limits on the core design safety evaluation for reactivity insertion events as a first step in assessing the safety significance. The bounding data point for the tests suggests fuel cladding rupture and possibly some fragmentation at 31 cal/g with a reactivity insertion of only 15 cal/g.

3.2 Review of FSAR Design Basis Accident Analyses

The staff has performed a preliminary review of the Final Safety Analysis Report (FSAR) Chapter 15 accident analysis results for a typical BWR and a typical PWR to identify the transients that are likely to result in reactivity insertion levels of concern. For the study, it was assumed that the average power traces presented in the analyses results are representative of the power transients experienced in limiting high burnup (60 GWd/t) fuel, since the highest relative power of high burnup fuel bundles is usually near or less than the core average. It was found that only a few of the FSAR transients would result in any fuel approaching or exceeding 15 cal/g radially averaged energy deposition. The following transients were identified:

- BWR rod drop
- PWR rod ejection
- BWR flow controller failure with recirculation flow increase
- BWR power oscillations

3.3 Safety Significance of Identified Transients

Based on system design features and operating experience the staff concludes that the BWR rod drop and PWR rod ejection transients are low probability events that are not expected to occur during the lifetime of a reactor. For a BWR rod drop to occur, the rod would have to be unlatched from the drive mechanism and stick in its inserted position when the drive mechanism is withdrawn. In the unlikely event that this event were to occur and not be detected by the operators, the rod could become unstuck and drop out during power operation. A PWR rod ejection could only occur in the unlikely event of a complete circumferential severance of the control rod drive housing boundary.

To fully assess the impact of lower enthalpy limits on fuel failure estimates for these transients, a detailed three-dimensional (3-D) study is needed. The study would determine if the fuel damage for high burnup fuel in the vicinity of a dropped (ejected) rod could be greater than that already determined for fresh (high power) fuel. Although this study may conclude that there is some increase in predicted fuel failures over current values with a corresponding increase in radiological consequences, no action is needed until this study can be completed based on the low probability of the initiating events and limited safety significance of increased fuel failures in the vicinity of the dropped (ejected) rod. Probabilistic risk assessment studies, including individual plant examinations, have never identified BWR rod drop or PWR rod ejection as risk significant events and we do not expect that assessment to change.

The BWR flow controller failure transient and power oscillations due to density wave instability are much slower power pulses (2-second period) than most of the test conditions (<0.1 seconds), and this may increase the fuel rod mean enthalpy required for cladding rupture. The BWR flow controller failure transient would result in a single power pulse before reactor shutdown and might result in a few fuel failures that would be inconsequential. The BWR power oscillation transient was not originally identified in the FSAR but has since been identified in a 10 CFR Part 21 evaluation for potential violation of thermal safety limits without scram protection. This has been reviewed as a generic issue, and thermal limits scram protection is being provided as a long-term solution compliance backfit. The thermal limits scram will also prevent the fuel from reaching high enthalpy levels caused by power oscillations. Generic Letter (GL) 94-02 was issued to document our actions. Until the GL 94-02 long term solution to the BWR oscillation issue is implemented, the BWR owners are strengthening interim administrative measures to reduce the probability of unstable power oscillations. Even if oscillations should occur, the probability of asymmetric power oscillations that is undetected by the operator is small. If oscillations are detected, operators have been trained to take prompt corrective actions.

For a highly improbable complete scram failure during an anticipated transient without scram (ATWS) event, oscillations may occur and will place high exposure fuel in jeopardy of PCI failure with possibly significant fragmentation and dispersal of fuel. The dispersal of solid fuel at low energy levels is not expected to result in a damaging pressure pulse that could affect core coolability. The emergency procedure guidelines require that water level be lowered promptly and that action will damp the oscillations.

Further study of high burnup fuel behavior during a loss-of-coolant accident (LOCA) is also planned, but no impact on LOCA analyses results is expected.

4 SUMMARY

In summary, the staff has evaluated the safety significance of lower fuel failure limits for high burnup fuel. The evaluation indicates the following:

(1) Lower enthalpy fuel rod cladding failure limits may result in some increase in fuel damage fraction for a few design-basis events.

(2) Because of the low power associated with high burnup fuel, the impact of reduced enthalpy limits at high burnup is expected to be small.

(3) Although no data exist on fuel dispersion effects at low enthalpy levels, earlier experiments indicate that molten and vaporized fuel is needed to produce damaging pressure pulses. Therefore, the concerns related to high burnup fuel performance do not appear to raise any new concerns for local pressure transients or their consequences.

(4) The only identified events that can result in enthalpy rises large enough to potentially affect the fuel failure estimates of previous safety analyses are very low probability events.

(5) Because of the low probability of reactivity transients that might result in some increase in fuel damage fraction and the high likelihood that core coolability will be maintained, the staff concludes that there is no significant impact on public health and safety.

Even though the immediate safety significance of the new high burnup transient tests is small, the impact on planning for future cores with higher burnup and longer operating cycles may be large. The fuel damage fraction for reactivity insertion transients will tend to increase as the fuel enrichment and burnup limits are increased, and the capability of the fuel to conform to design and licensing acceptance criteria will be challenged. Therefore, it is necessary that the staff evaluate appropriate design limits and burnup limitations for high burnup fuel.

Attachment 2

NRC HIGH BURNUP FUEL ACTION PLAN MILESTONE SUMMARY

MILESTONES	DATE	ACTION * STATUS
1. Issue User Need Letter to RES	10/04/93	(C)
RES Responses:	12/06/93	(C)
• Plan to assess French, Japanese & other transient test results		(A)
• Plan to improve/update fuel rod performance models and audit codes		(A)
• Plan to evaluate fuel failure thresholds for reactivity transients		(A)
2. Contracts issued by RES	03/31/94	(C)
3. Schedule and Coordinate Meetings with Foreign Experimenters and Regulatory Authorities as needed to facilitate review of test results, future test plans, and Regulatory Positions relating to the High Burnup Fuel test data.	(7/94, 09/8/94, 10/26/94, 03/95)	(A)
4. Issue Information Notice (IN 94-64), "Reactivity Insertion Transient and Accident Limits for High Burnup Fuel," and Preliminary Assessment of the French Reactivity Insertion Transient Data.	08/31/94	(C)
5. Present High Burnup Fuel Data at the Water Reactor Safety Information Meeting (WRSM)	10/26/94	(C)
6. Schedule and Coordinate Meetings with Vendors and Owners Groups to Discuss Plans For:	10/27/94	(C)
• Evaluating Reactivity Insertion Data and the Effect of Lower Fuel Enthalpy Limits on Operating Reactors, and		
• Proposing New Burnup Dependent Enthalpy Limits for Fuel Design Acceptance Criteria or Justifying Current Operating Limits		

* C - Completed; A - Active

MILESTONES		DATE	ACTION * STATUS
7.	Determine the Need for Generic Communications (e.g., bulletin or generic letter) to Assure that the Safety and Regulatory Issues are Being Resolved by Licensees	11/94	(A)
8.	Issue letter to Vendors Transmitting High Burnup Data and Need to Assess Impact on Currently Approved Fuel Topical Reports	11/94	(A)
9.	Issue IN 94-64, Supplement 1 providing WRSM information and Letter to Fuel Vendors	12/94	(A)
10.	RES Updates NUREG-0933 on Generic Issues to Document the Issue and Plan of Action for Resolution 1/9/95 Ron Emrit will follow up on this.	01/95	(A)
11.	Assess the Effects of Reduced Fuel Failure Threshold for High Burnup Fuel on the Consequences of Design Basis Accidents	07/95	(A)
	• Perform 3D Transient Analyses to Evaluate BWR Rod Drop & PWR Rod Ejection Events		(A)
	• Evaluate the Effect of Design Basis Transients on High Burnup Fuel		(A)
12.	CSNI Specialists Meeting on High Burnup Fuel	09/95	(A)
13.	RES Completes Response to NRR User Need Letters		
	• Complete INEL Assessment of fuel data, data correlations and uncertainties	05/95	(A)
	• Complete NRC Audit Code modifications by PNL and INEL	12/95	(A)
	• Complete Documentation	12/95	(A)
14.	Complete Review of Available Fuel Transient Data Relevant to Design Basis Transient Effects; Define New Criteria (CRGR Review); Establish Schedule for Final Assessment; and State Need for Further Regulatory Action	12/95	(A)

* C - Completed; A - Active