

SAFETY EVALUATION OF THE
FUEL DENSIFICATION EFFECTS ON THE
MONTICELLO NUCLEAR POWER STATION

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INTRODUCTION

Since the issuance of the Provisional Operating License DPR-22 for Monticello the phenomenon of fuel pellet densification has been observed in operating reactors. Based on the information initially available, the staff issued a report on November 14, 1972, entitled "Technical Report on Densification of Light-Water Reactor Fuels" (Ref. 1). In this report the staff concluded that the effect that densification might have on normal operation, transients, and accidents should be evaluated for all water-cooled nuclear power plants. This conclusion was implemented by letters to the licensee on November 20, 1972 and July 16, 1973, that requested the licensee to provide the necessary analyses and other relevant data needed to determine the consequences of densification and its effect on normal operation, transients and accidents.

On January 17, 1973, General Electric (GE) submitted the topical report "Densification Considerations in BWR Fuel Design and Performance," NEDM-10735 (Ref. 2) which provided the requested information as it applied to GE boiling water reactors generally. Subsequently, GE submitted five supplements (Ref. 3, 4, 5, 6 and 7) to this topical report which provided additional information. Based on this information the Regulatory staff issued the report entitled "Technical Report on Densification of General Electric Reactor Fuels" (Ref. 8). The licensee provided analyses of the effect on densification on steady state operations, operating transients and postulated accidents at the Monticello Nuclear

Power Station (MNPS) in their letter of August 15, 1973, and the referenced GE topical report "Fuel Densification Effects on General Electric Boiling Water Reactor Fuel," NEDM-10735, Supplement 6, August 1973 (Ref. 9). A discussion of our review of fuel densification as it applies to the MNPS and our evaluation of the analyses of steady state operation, operating transients and postulated accidents is presented in subsequent sections of this report.

DENSIFICATION EFFECTS

A detailed discussion of the causes and effects of densification including the results of observations of irradiated fuel in both test and power reactor fuel, an investigation of the possible mechanisms and evaluation of the controlling parameters, is presented in the staff reports on densification (Ref. 1 and 8). At this time the only clear conclusion that can be drawn is that under irradiation fuel pellets can shrink and decrease in volume with corresponding changes in pellet dimensions. Four principal effects are associated with the dimensional changes resulting from densification. A decrease in length of pellets could result in the formation of axial gaps in the column of fuel pellets within a fuel rod. Two effects are associated with axial gaps. First, if relatively large axial gaps form, creepdown of the cladding later in life may lead to collapse of the cladding into the gaps. Second, axial gaps produce a local increase in the neutron flux and generate a local power spike. A third effect, which results from a decrease in pellet length, is a directly proportional increase in linear heat generation rate.

A decrease in pellet radius could result in the increase in the radial clearance between the fuel pellet and the fuel rod cladding. A fourth effect, which results from a decrease in pellet radius, is decreased pellet-clad thermal conductance (gap conductance). Decreased conductance would increase the fuel pellet temperature and stored energy and decrease the heat transfer capability of the fuel rod. Each of these four effects has been considered in evaluating the total effect that fuel densification might have on normal operation, transients and accidents.

Based on experimental evidence that no collapse has been observed in BWR fuel rods and on the results of calculations performed independently by the staff and GE, the Regulatory staff has concluded that typical BWR fuel will not collapse during the first cycle of operation (Section 3.4.2, Ref. 8). GE has also calculated the creep collapse of fuel in later cycles using a model which includes the modifications specified by the staff (Section 3.4.2, Ref. 8). The results of these calculations for fuel in residence up to September 1974 are reported in Supplement 6 of the GE report (Ref. 9) and indicate that clad collapse will not occur. The staff has reviewed the GE calculations and performed independent calculations, which also predict that collapse will not occur. Based on the calculations and experimental evidence, the staff concludes that creep-collapse need not be considered as affecting normal operation, transients or accidents.

The increase in linear heat generation rate (LHGR) resulting from contraction of the fuel is offset by compensating factors. Although pellets

with initial densities less than the mean initial density will contract more than the average pellet, such pellets also contain correspondingly less fuel and produce less power in a given neutron flux. Therefore, only contraction from an initial mean pellet density need be considered in determining the LHGR. This contraction is offset by thermal expansion, as shown by calculations summarized in Table 3-1 of Supplement 6 of the GE report (Ref 9). Since the increase in fuel column length due to thermal expansion was not considered in the original design calculations or transient and accident analyses, and since the effect of thermal expansion offsets the effect of densification on LHGR, it is appropriate to use the design LHGR in the analyses of normal operation, transients and accidents when considering the effects of densification. This was done in all the analyses presented by GE in Supplement 6 of the topical report (Ref 9).

Calculations by GE of power spikes resulting from possible axial gaps in the fuel take into account the peaking due to a given gap, the probability distribution of peaking due to the distribution of gaps, and the convolution of the peaking probability with the design radial power distribution. Based on an examination of the methods used, comparison with requirements and approved models given in the staff densification report, and check calculations performed for the staff by Brookhaven National Laboratory, the staff concluded in their report (Ref 8) that, if appropriate gap assumptions are made regarding sizes, the GE calculational method is acceptable. The results of calculations of power spikes using acceptable

gap sizes are summarized in Figure 3-6 of Supplement 6 of the GE report (Ref 9). During normal operation there is a 95% confidence that no more than one rod would have a power spike greater than approximately 4% at the top of the fuel. At the midplane the corresponding power spike would be approximately 2%. When the reactor power is low and there are no voids, the spike could be greater. Under these conditions, there is a 95% confidence that no more than one rod would have a power spike greater than 5% at the top of the fuel.

Pellet-clad thermal conductance is a function of gap size and linear heat generation rate. The staff has reviewed the experimental data and analyses that GE has submitted to justify their correlation of gap conductance, examined the uncertainties in the data, and performed independent calculations with a fuel thermal performance computer program. The pellet-clad thermal conductance correlation used by GE is depicted in Figure 3-10 of Supplement 6 of the GE report (Ref 9). It is based on experimental data and predicts with a 95% confidence that 90% of the total population of pellet clad conductances exceed the prediction. The staff concludes that this correlation when used with a gap size adjusted for the effects of densification is acceptable.

EVALUATION OF EFFECTS OF DENSIFICATION

Normal Operation

The design limits affected by fuel densification are the design values

of linear heat generation rate (LHGR) and minimum critical heat flux ratio (MCHFR). The power spike resulting from axial gaps is considered in limiting operation of the reactor. The Technical Specifications will require that the LHGR in any rod at any axial location be less than the design value of 17.5 kw/ft by a margin equal to or greater than the power spike calculated using the accepted model. As discussed previously, this power spike penalty will assure at the 95% confidence level that no more than one rod will exceed the design value LHGR. Since the random occurrence of local power spikes will have no effect on coolant flow or quality, the uncertainty in calculation of the critical heat flux is unchanged. Therefore, if the calculated MCHFR is maintained above the steady state design limit of 1.9 and the margin to the design value of LHGR is also maintained, the probability of reaching a MCHFR of 1.0 is essentially unchanged from that calculated in the FSAR.

Transient Performance

The key transients for evaluation of BWR performance are those associated with overpressurization, which might imperil the integrity of the primary coolant pressure boundary, and with reduction of coolant flow, which might imperil the integrity of the fuel clad. The transient resulting from a turbine trip without opening the bypass valves is representative of transients that might result in overpressurization. The transient resulting from the simultaneous trip of both recirculation pump drive motors is representative of transients that result in a rapid reduction of core flow.

Following isolation of a BWR, such as would result from closure of the turbine stop and bypass valves, stored and decay energy from the core increases the coolant temperature and pressure. Since densification might reduce the pellet-clad conductance and increase the stored energy, densification could effect the peak pressure following a transient. GE has calculated the increase in heat flux, fuel temperature and peak pressure in the primary coolant system following a turbine trip transient without bypass using gap conductances as low as $400 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ (Ref 9). A conductance of $400 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ is representative of the average fuel rod and its use is appropriate since the average fuel rod stored energy is the appropriate parameter to use when evaluating coolant system pressure. The calculated peak pressure is increased only 5 psi and is not significantly greater than the system pressure calculated using the value of $1000 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ for gap conductance. Using a conductance of $400 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$ increased the calculated fuel temperature 13°F and the heat flux 1%. These increases are also insignificant.

Following a rapid reduction in core flow, such as would result from simultaneously tripping both recirculation pump motors, the MCHFR will decrease. A MCHFR of 1.0 is taken as a design limit for fuel damage. The slower thermal response of rods with densified fuel can result in a lower MCHFR following a rapid flow reduction. GE has calculated that the heat flux at the time of MCHFR would increase less than 5%, even if the gap conductance were as low as $400 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$. This conductance is representative of the lower bound of the conductance expected at the

axial location where MCHFR occurs.

Based on these calculations, the staff concludes that changes in gap conductance resulting from fuel densification would affect the course of flow and pressure transients. However, the pressure and MCHFR limits would not be exceeded.

Refueling Accident

Since fuel densification does not affect any parameters used in the evaluation of the refueling accident, the consequences of this accident are unchanged.

Control Rod Drop Accident

A generic evaluation by the staff of the control rod drop accident has been underway for the past several months. General Electric has submitted topical reports revising the techniques for analyses of the control rod drop accident including, among other features, a change in the method for modeling the rate of negative reactivity insertion. These topical reports and revised analyses are under review. However, the parameters important to the analysis such as gross power distribution, delayed neutron fraction and the reactivity changes produced by the dropped rod, the scram insertion of the other rods and Doppler feedback are not significantly affected by densification. The parameters affected by densification are initial stored energy and heat transfer. These factors are not important for the control rod drop accident at low reactor power which results in the largest energy deposition, since the analysis assumes low power and adiabatic fuel pins and therefore no stored energy and no heat transfer.

From our independent calculations we have concluded that the transient effects of a rod drop accident while operation at power levels above 20% would also be small.

Main Steam Line Break Accidents

As in the analysis of transients, the effect of reduced gap conductance resulting from densification is an increase in stored energy and transient heat flux. However, calculations demonstrate that a reduced conductance does not result in departure from nucleate boiling during the transient (Ref. 9). As in the calculation presented in the FSAR (gap conductance equal 1000 Btu/hr-ft²-°F) no clad heatup is predicted to occur and consequently the main steam line break accident is unaffected by densification.

Loss-of-Coolant Accident

Small Break

As in the analysis of a transient, the effect of reduced gap conductance resulting from densification is an increase in stored energy and transient heat flux. A higher initial stored energy, when transferred to the coolant during blowdown, maintains the pressure, and increases the break flow rate resulting in a quicker actuation of the Automatic Depressurization System. Therefore, the reactor is depressurized sooner and the low pressure emergency core coolant systems refill the vessel sooner. Since all stored energy is removed during the initial phase of the blowdown, only the decay heat, which is the same in both cases, affects the clad temperature. The net effect is a reduction in peak clad temperature following a small pipe break. Therefore, densification does not adversely affect a small pipe break accident.

Design Basis LOCA

Following a postulated break of a recirculation pipe, densification can affect the hydraulic response of the reactor as calculated by the blowdown analysis and the thermal response of the fuel as calculated by the heatup model. The effect on the blowdown is much less significant than the effect during the heatup.

As discussed in the review the transient analysis, the effect of densification is reduction of gap conductance and a corresponding increase in stored energy and transient heat flux. The increased energy and heat flux result in a slightly modified hydraulic response following the LOCA. However, as shown in figures 4-7 and 4-8 of Supplement 6 to the GE report (Ref. 9), the flow rates are not significantly changed and the time of departure from nucleate boiling is unchanged. Therefore, the convective heat transfer coefficients are not significantly changed as a result of densification.

The heatup of the fuel is, however, significantly changed primarily as a result of increased stored energy. Although the formation of axial gaps might produce a local power spike, as discussed previously the spike would be approximately 2% at the axial midplane. As discussed in the staff report (Section 4.3, Ref. 8), it is improbable that more than one spike of significant magnitude would occur at any axial evaluation and that a 1% power spike would result in only a 4°F increase in peak clad temperature. Therefore, the effect of power spikes can be neglected in the heatup analysis.

The peak clad temperature following a postulated loss-of-coolant accident is primarily a function of the average heat generation rate and stored energy of all the rods in a fuel assembly at the axial location corresponding to the peak of the axial power distribution. GE has calculated (p. 4-12, Ref. 9) that expected local variations in power distribution within a fuel assembly affect the calculated peak clad temperature by less than $\pm 20^{\circ}\text{F}$ relative to the peak temperature for a typical fuel design. Staff calculations (Table II, Ref. 8) show that variations in individual gap conductances and therefore stored energy within an assembly result in peak clad temperatures approximately 20°F higher than temperatures calculated using only the conductance of the average rod to represent all the rods.

The stored energy is dependent on the LHGR and the pellet-clad thermal conductance. As discussed, the conductance is based on a correlation which underpredicts 90% of the data with a 95% confidence for a selected gap size. The gap size is calculated as specified in the AEC Fuel Densification Model assuming that the pellet densified from the initial density of 96.5% of theoretical density. Since peak clad temperature is primarily a function of average stored energy, the density of 48 rods is taken as the two standard deviation lower bound on the measured initial "boat" pellet density. For the most critical rod, the two standard deviation lower bound on initial density of individual pellets was assumed. The result of calculations of peak clad temperature are presented in Fig. 4-10C of Supplement 6 to the GE report (Ref. 9). The staff concludes that limitation of the average linear heat generation rate of all the rods in any fuel assembly at any axial

location to the values of the curve labeled "Y" in Figures 4-9C1 and 4-9C2 of Ref. 9 will assure that calculated peak clad temperature will not exceed 2300°F.

CONCLUSIONS

The Regulatory staff has reviewed the General Electric Co. report "Fuel Densification Effects on General Electric Boiling Water Reactors Fuel," NEDM-10735 (Ref. 2, 3, 4, 5, 6, 7, & 9) for its applicability to the Monticello Plant. The staff concludes that the following changes in the operating conditions for the Monticello Plant are necessary in order to assure that the calculated peak cladding temperature of the core following a postulated LOCA will not exceed 2300°F taking into account fuel densification effects: (1) the immediate control of steady-state power operation so that the average linear heat generation of all the rods in any fuel assembly, as a function of planar exposure, at any axial location, shall not exceed the maximum average planar linear heat generation rate of 11.5 kw/ft of Section 3.5J of the Appendix I, attached to Order for Modification of License, dated August 24, 1973, and (2) that during steady-state power operation, the linear heat generation rate (LHGR) of any rod in any fuel assembly at any axial location shall not exceed the maximum allowable LHGR as calculated using the equation for maximum LHGR provided in Limiting Condition for Operation, Section 3.5K of Appendix I attached to the Order.

References

1. "Technical Report on Densification of Light-Water Reactor Fuels," by the USAEC Regulatory staff, November 14, 1972.
2. "Densification Considerations in BWR Fuel Design and Performance" NEDM-10735, December 1972.
3. "Response to AEC Questions - NEDM-10735," NEDM-10735, Supplement 1, April 1973.
4. "Responses to AEC Questions NEDM-10735 Supplement 1," NEDM-10735 Supplement 2, May 1973.
5. "Responses to AEC Questions NEDM-10735 Supplement 1," NEDM-10735 Supplement 3, June 1973.
6. "Responses th AEC Questions NEDM-10735" NEDM-10735 Supplement 4, July 1973.
7. "Densification Considerations in BWR Fuel" NEDM-10735, Supplement 5, July 1973.
8. Technical Report on Densification of General Electric Reactor Fuels, August 23, 1973, Regulatory staff, USAEC.
9. "Fuel Densification Effects on General Electric Boiling Water Reactor Fuel," NEDM-10735, Supplement 6, August 1973, General Electric Co.