ANSWER TO THE NRC STAFF QUESTIONS ON THE WESTINGHOUSE EVALUATION OF THE EFFECT OF GRID DEFORMATION ON ECCS PERFORMANCE

PREFACE

In Reference (1), it was shown that the mean fuel assembly grid impact strength obtained from dynamic testing of Diablo Canyon-type 17 x 17 grids is [ ]^{a,b,c} pounds at room temperature. A 6% reduction factor may be applied to room temperature grid test strengths to compensate for the effects of reactor operating temperature on impact strength. A grid strength much lower than the mean, the 95 x 95 statistical value at temperature of [ ]^{a,b,c} pounds, must be assumed in order to postulate any permanent distortion. The maximum calculated combined LOCA/seismic load for any Diablo Canyon grid is [ ]^{a,c} pounds, and only three grids in the entire core exhibit computed combined loads equal to or in excess of the 95 x 95 statistical value at temperature. Therefore, no permanent grid deformation is anticipated even if an earthquake occurs coincidentally with a LOCA event.

Although no grid deformation was expected, Westinghouse performed an evaluation of the possible impact of this deformation on ECCS performance. In this evaluation, a steam cooling penalty was estimated due to the effective blockage caused by grid deformation even though the ECCS analysis on record for Diablo Canyon predicts the peak clad temperature to occur when the flooding rate is greater than 1 in/sec. This was done because the approved Westinghouse Evaluation Model does not model blockage for flooding rates greater than 1 in/sec and because it was felt that a steam cooling calculation would bound the Diablo Canyon case. This evaluation showed that the effect of grid deformation blockage on calculated clad temperature was less than 20°F. In addition, it was demonstrated that if this effect was combined with the effect of the reduced power levels existing in the peripheral assemblies and margin in pellet temperature, there would be a net decrease in the calculated clad temperatures.

The NRC staff has asked two questions concerning the above evaluation. Westinghouse feels that the two questions are best answered together.

QUESTIONS:

1. The blockage effect due to deformed grids may be concentrated in one or two rows of rods. Analysis of flow conditions for these rods with bundle average blockage is non-conservative. Provide analyses assuming that the maximum blockage applies to the entire bundle.

2. Provide the basis for assuming that FLECHT data from typical bundles is applicable to deformed bundles.

ANSWER:

To consider making the steam cooling blockage calculation any more conservative is unnecessary since 1) the steam cooling model is overly conservative already, and 2) the peak clad temperature for Diablo Canyon is calculated to turn around during FLECHT cooling (flooding rate greater than 1 in/sec). Therefore, only FLECHT cooling will be discussed.

FLECHT tests have shown that blockage is beneficial to the reflood cooling process since it promotes mixing and atomization of water droplets. However, Appendix K of 10CFR50.46 does not allow Westinghouse to take credit for this additional cooling mechanism in ECCS calculations. By the same token, Appendix K does not require taking a blockage penalty during FLECHT cooling either. This is the basis for applying the Westinghouse design 17 x 17 FLECHT correlation (derived from "typical" bundles) without a blockage penalty in the evaluation of deformed grids for Diablo Canyon. The discussion could stop here; however, in trying to be responsive to the Staff's concerns, the following evaluation is provided:

The October, 1975 version of the Westinghouse Evaluation Model predicts a peak clad temperature (PCT) of 2130°F for the Diablo Canyon limiting break at 96 seconds at 7.5 ft elevation for an F_q value of 2.32. This PCT is calculated to occur during the FLECHT cooling portion of the

transient. The grid distortions postulated to occur will create an increased flow blockage at the grid elevation; FLECHT studies investigating the effect of blockage on post-LOCA heat transfer (Reference 2) have demonstrated that blockage provides enhanced heat transfer to rods in the downstream flow. Nevertheless, no credit is taken during FLECHT for the added grid blockage in this calculation, and none is permitted for rod burst blockage in any 10CFR50.46 Appendix K computation. The percent change in grid cell flow area caused by a given distortion is much greater than the percentage change in grid cell or rod-to-rod pitch dimensions. This is demonstrated below:

Case	% Flow Area Reduction at Grid Elevation	Final* Dimension of Grid Cell, in.	Cell* Compression, in.	% Change* in Cell Dimension
Base	0	.496	0	0
One Impact	[			] a,c
Diablo Canyon Multi-Impact Tests				

*In the direction in which the impact is applied.

A bounding case will be considered in responding to the questions posed: grids in an assembly are assumed to deform such that the cells of two rows in each grid are reduced in flow area by the amount observed in the multi-impact case of the Diablo Canyon test program. In the Diablo Canyon test program reported in Reference (1), the "energy input was greater than that calculated for Diablo Canyon and the number of impacts substantially greater than the number of impacts calculated for Diablo Canyon." The speed of the hammer in these tests, 17 in/sec, was also greater than the speed of impact calculated for Diablo Canyon.

For conservatism, the same two rows of cells will be assumed to deform in axially adjacent grids; in this way a confined channel of set geometry is postulated to exist in the distorted assembly over a significant length. Additional conservatism is introduced into the calculation by assuming that adjacent cell rows deform within a grid. The rod-to-rod spacing in the impact direction resulting from these assumptions is presented in Figure 1 for the Diablo Canyon multi-impact case; rod pitches in the other direction are unchanged. Flow conditions about a rod in a distorted cell will be analyzed and heat transfer effects will be evaluated.

An analytical approach will be adopted to evaluate the flow heat transfer to an individual rod in the distorted assembly. The zero shear planes between adjacent rods define the flow field and may be used to assign each rod its appropriate flow passage. With this definition, the equivalent diameter for flow about a rod in the most confined channel is as follows, using Figure 1 dimensions:

$$D_e = \frac{4 \times \text{Flow Area}}{\text{wetted perimeter}}$$

[ ] a,c

The equivalent diameter provides a basis for assessing the impact of the distorted geometry on flow (velocity) and heat transfer.

The flow regime within the core rod bundle during reflooding may be determined from the current October, 1975 Westinghouse Evaluation Model limiting break analysis for Diablo Canyon. In the initial stages of reflood (core water level $<$ 1.5 ft.) radiation is the dominant heat transfer mechanism because F_{out}, the mass effluent fraction, is small. When the core water level reaches 1.5 ft., F_{out} = .282 and steam flow through the core has been established. The Reynolds number of the flow

(Re) equals ($\rho VDe/\mu$) using standard nomenclature. Flow density ρ and velocity V are redefined from the continuity equation, $w = \rho VA$: $\rho V = w/A$. Substituting values from WREFLOOD when core level equals 1.5 feet (time = 52 seconds) gives:

$$Re = wDe/\mu A = 6430$$
$$w = 81 \text{ lbm/sec}$$
$$De = .0386 \text{ ft. for a standard channel}$$
$$\mu = .95 \times 10^{-5} \text{ lbm/ft-sec}$$
$$A = 51.2 \text{ sq. ft.}$$

The Reynolds number exceeds 4000, so turbulent flow is assumed. Because the mass effluent fraction increases rapidly to values greater than 0.6, the Reynolds number will remain greater than 6430 for the duration of reflood. Inasmuch as convection is unimportant when the core level is less than 1.5 ft., it is appropriate to consider the impact of distorted rod geometry on the turbulent flow regime.

Between two elevations in a given fuel assembly the same pressure drop will prevail. Consider two flow channels, one of which has a distorted geometry and one of which has maintained the standard geometry. The Darcy-Weisbach equation states:

$$\Delta P_1 = \frac{\left(\frac{f_1 L}{D_1}\right) \rho u_1^2}{2g_c} = \Delta P_2 = \frac{\left(\frac{f_2 L}{D_2}\right) \rho u_2^2}{2g_c}$$

$$\left(\frac{f_1 L}{D_1}\right) u_1^2 = \left(\frac{f_2 L}{D_2}\right) u_2^2$$

since f is a function of $Re^{-0.2}$, over a given distance L one may write

$$\frac{u_1^{1.8}}{D_1^{1.2}} = \frac{u_2^{1.8}}{D_2^{1.2}}$$

$$\left(\frac{u_1}{u_2}\right) = \left(\frac{D_1}{D_2}\right)^{.667}$$

Conservatively considering the most confined channel,

[ ] (a,c)

The velocity about rods in the distorted flow channel is [ ]^{a,c} of the nominal core velocity.

The effect of this velocity reduction on the clad temperature computation has been assessed by considering the heatup of a heater rod during a FLECHT test. This calculation was performed by using the Westinghouse approved 17x17 FLECHT correlation and a lumped capacitance model of a FLECHT heater rod. Core pressure, water subcooling, initial clad temperature and rod power input parameters were obtained from the Diablo Canyon limiting break computation; average pressure and water temperature values for the time period from 52-100 seconds were derived, while the clad temperature and power parameters at bottom of core recovery time were taken. With this input the core quench time was calculated based on the actual Diablo Canyon variable flooding rate transient, and the constant core inlet velocity (V_{in}) which gives that same quench time was determined. The impact of a reduced channel flow velocity on heat transfer was then evaluated by reducing V_{in} the corresponding amount. A comparison of the clad temperature at the 6 and 7.5 ft elevations from runs at the Diablo Canyon equivalent constant flooding rate (V_{in} = 1.284 in/sec) and [ ]^{a,c} of this constant rate is shown below. Quench time was held constant in each run at the standard geometry .alue because it will be the same throughout the core.

Elevation	Base V_{in} PCT, °F	[ ]^{a,c} PCT, °F
6.0 ft	2108	2121
7.5 ft	2150	2167

The FLECHT heatup calculation predicts a PCT impact of 17°F for the most distorted (multi-impact) geometry observed in grid impact strength testing.

Heat transfer coefficients predicted by the FLECHT correlation for the reduced V_{in} condition were 96.5% and 96% of the corresponding base values at the clad temperature turnaround time at 6 and 7.5 ft, respectively. As an alternative to the FLECHT analysis, the Dittus-Boelter heat transfer relationship for fully developed turbulent flow may be employed to assess the impact of a flow velocity reduction. Dittus-Boelter states:

$$Nu = \frac{h\,De}{k} = C_1 \, (Re)^{.8} \, (Pr)^{.4}$$

$$\text{so} \quad h \;\alpha\; \frac{(Re)^{.8}}{De} \;\alpha\; \frac{u^{.8}\,De^{.8}}{De}$$

using the previously developed flow relation,

$$u \;\alpha\; De^{.667}$$

$$\text{and} \quad h \;\alpha\; \frac{De^{.533}\,De^{.8}}{De} \;\alpha\; De^{.333}$$

the change in De caused by grid distortion gives

[ ]^{a,c}

This result compares well with the reduced V_{in} FLECHT correlation heat transfer coefficients and confirms that the effect of geometric distortions on reflood heat transfer and calculated clad temperatures is indeed small.

Fuel considerations ameliorate the impact of grid deformation on ECCS performance. Peripheral fuel assemblies incur the greatest grid impact loadings and are the only Diablo Canyon assemblies with calculated loads exceeding the 95x95 statistical strength value. Even though calculated grid loadings are less than [ ]^{a,c} lbs for all fuel assemblies located one row in from the periphery, postulated deformation of this second row has been imposed as a requirement. The Diablo Canyon core loading pattern defined in WCAP-8408[3] is designed in such a way that the highest radial peaking factor (Fxy) of any rod in an assembly on the core periphery is only 85% of the core hot rod value. Similarly, the maximum radial peaking factor of any rod in any second row assembly is 97% of the core hot rod value. This reduction in radial peaking factor from the hot rod value for the limiting rods in the assemblies presumed to be subject to deformation translates directly into a power reduction which will affect calculated PCT.

Modeling the reduced power levels in Diablo Canyon FLECHT heater rod reflood calculations at reduced V_{in} produces PCT benefits of 75°F and 15°F at 7.5 ft for the peripheral and second row locations respectively. An additional PCT benefit results from the lower clad temperature present at the beginning of reflood due to reduced power; the Diablo Canyon October model analysis indicates the clad temperature at 7.5 ft on a rod at 97% hot rod power will be 35°F lower than the hot rod value at beginning of reflood.

Further reductions in PCT relative to the Evaluation Model value are apparent when one considers radiation effects. In the FAC model, radiation between hot and adjacent rods is computed. In fact, the rods in a deformed row of grid cells may be adjacent to a thimble row. If the hottest rod in the deformed row is next to a thimble tube, a benefit in radiation heat transfer is obtained. The magnitude of this effect has been evaluated for Diablo Canyon by applying hot rod radiative heat fluxes calculated for the geometries shown in Figure 2 at bottom of core recovery time (BOC) at the 7.5 ft elevation to the entire refill transient. A change in heat flux will cause a change in the heatup of

fuel and cladding over the refill period and will affect clad temperature. The Case 2 geometry of Figure 2 exhibits a 14°F benefit in hot rod clad temperature at BOC relative to Case 1; the Case 3 geometry shows a 7°F benefit in hot rod clad temperature relative to Case 1 at BOC. Benefits realized in clad temperature at BOC will reduce the PCT computed during FLECHT cooling.

To summarize, the effects of grid distortion caused by a combined LOCA seismic event have been evaluated for Diablo Canyon even though no permanent distortion is predicted. A bounding case was considered in which an assembly deforms such that the cells of the same two adjacent rows in axially adjacent grids are reduced in flow area to the extent observed for a multi-impact test case. The impact of this altered geometry on reflood heat transfer was evaluated by considering the reduced V_{in} performance of a FLECHT test heater rod. Other phenomena affecting the PCT computation are the lower power of the assemblies postulated to deform and enhanced radiation heat transfer. Considering a second-row assembly to be deformed, the following PCT effects are superimposed on the design basis ECCS analysis at the peak elevation (7.5 ft):

Phenomenon	PCT Effect
Confined Channel Geometry	+17°F
Reduced Power Level:	
Power During Reflood	-15°F
Lower Clad Temperature at BOC	-35°F
Radiation to Thimble Tube	-7°F/-14°F

The peak clad temperature in any assembly being postulated to deform at Diablo Canyon is clearly lower than the peak clad temperature computated for the design basis accident used to establish Technical Specification limits.

REFERENCES:

1. "Diablo Canyon Reactor Coolant System - Response to Combinations of Calculated Loads for Pipe Break and Earthquake," Westinghouse Electric Corporation, December, 1977.

2. Cadek, F. F. et al, "PWR FLECHT Final Report," WCAP-7665, April, 1971, pages 3-58 through 3-68.

3. D. J. Franks, "The Nuclear Design of the Diablo Canyon Nuclear Power Plant, Cycle 1" WCAP-8408, September, 1974.

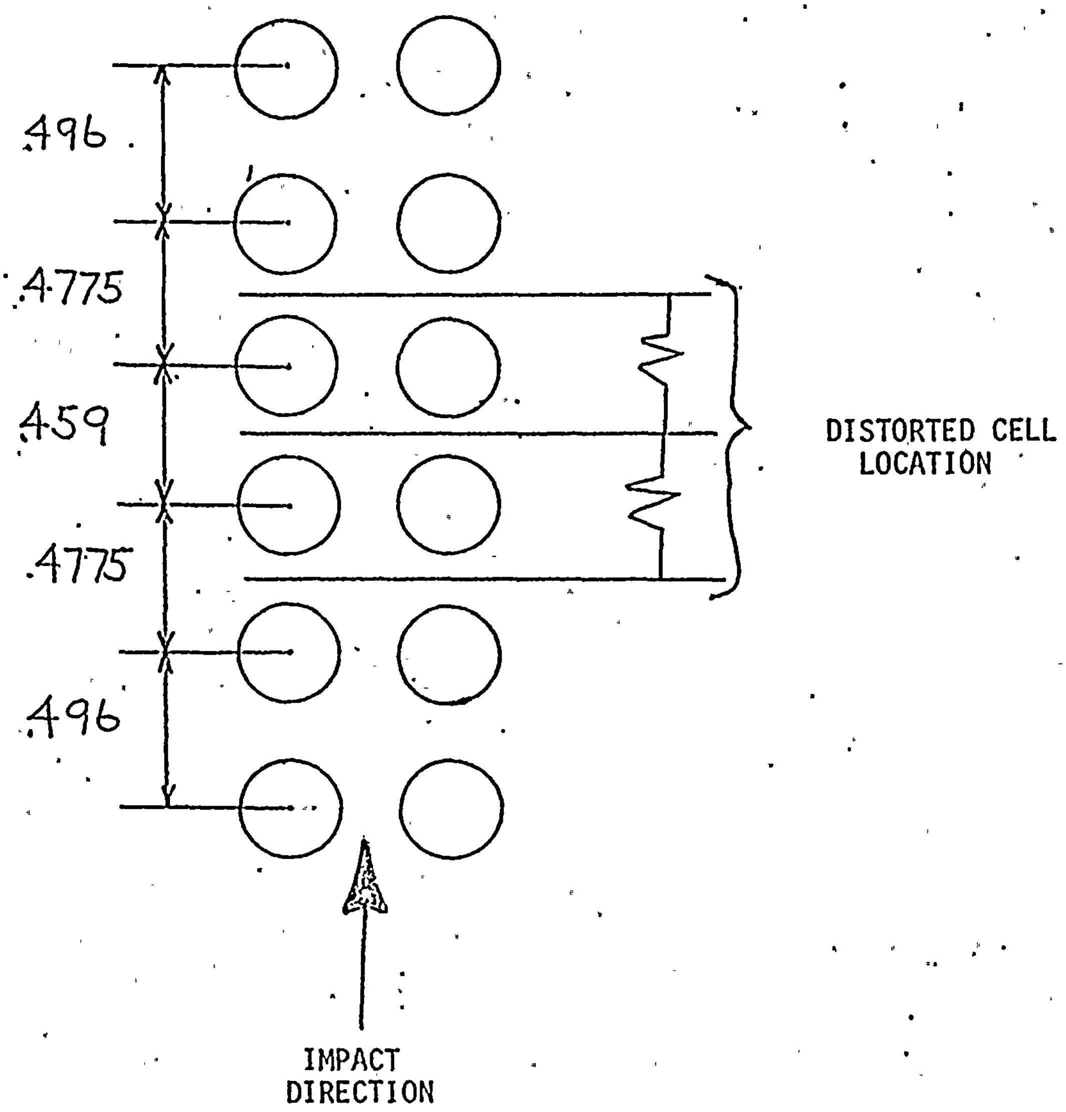
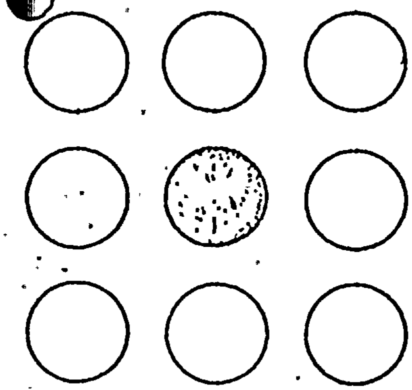
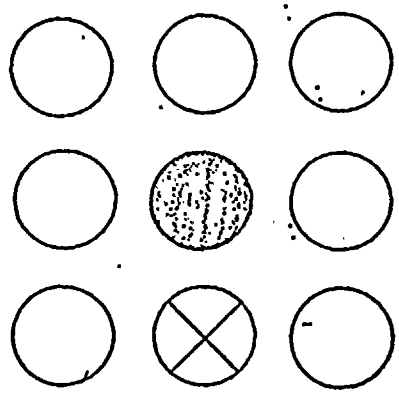


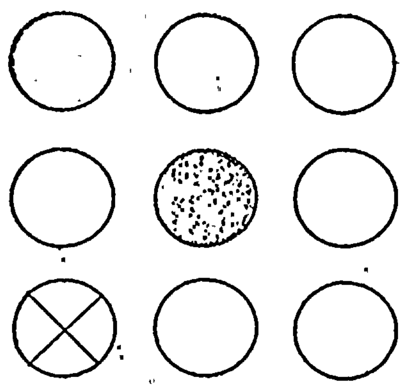
Figure 1: ROD SPACING RESULTING FROM POSTULATED GRID DISTORTION



CASE 1: FAC CONFIGURATION



CASE 2: THIMBLE ADJACENT



CASE 3: THIMBLE ON A CORNER

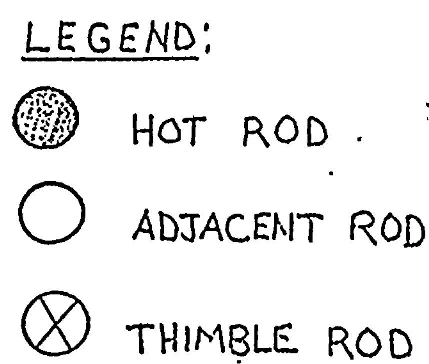


Figure 2: RADIATION COMPUTATION CONFIGURATIONS

[illegible]