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Report No. 2 to the ACRS

NINE MILE POINT NUCLEAR STATION

Power Increase

U. S. Atomic Energy Commission
Division of Reactor Licensing

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ABSTRACT

Our November 23, 1970 report to the Committee, regarding the increase in the licensed power level of the Nine Mile Point Nuclear Station from 1538 MWt to 1850 MWt, indicated that our evaluation of the performance of the emergency core cooling system at the proposed power level of 1850 MWt had not been completed. We have performed extensive additional reviews of the calculational models now used by GE and a model developed independently by INC. Differences between the two models have not yet been fully resolved.

The applicant has provided assurance that the NMP core spray system can achieve rated flow reliably in 35 seconds or less, instead of the value of 60 seconds assumed in previous calculations. Taking this change into consideration, we have determined that, for a loss-of-coolant accident resulting from a recirculation line break, the peak clad temperature calculated by either the GE method or the more conservative INC method is less than 2300°F. For accidents involving small breaks, GE calculates peak clad temperatures of 2226°F.

We have concluded that the ECCS performance is acceptable for operation of Nine Mile Point at a power level of 1850 MWt.

EVALUATION OF ECCS FOR 1850 MWt

NINE MILE POINT

In our evaluation of the Oyster Creek power increase to 1690 MWt, we used the FLECHT BWR test results (Zr-2K) as an experimental basis for assessment of the adequacy of the ECCS. The indicated test conditions for the Zircaloy bundle test (Zr-2K) were essentially upper limits for the 1690 MWt power level, so that the test results could be regarded as a demonstration test. In that case, we did not require additional analytical model formulation as a basis for accepting the adequacy of the ECCS for the Oyster Creek application.

The power increase to 1850 MWt for the Nine Mile Point reactor, however, appears to exceed the test conditions so that a similar approach is not possible. The relationship of the Nine Mile Point conditions to the FLECHT test (Zr-2K) conditions is indicated in the accompanying tables. The total power levels and some of the spray initiation temperatures obtained in the FLECHT bundle test are exceeded by those expected in the Nine Mile Point core at the higher power level, although the linear power density appears favorable. On balance, the indicated differences between the conditions of the test and of the Nine Mile Point reactor at 1850 MWt require a systematic extrapolation of the test results by means of an appropriately developed model formulation based on the full range of experimental data available.

GE had previously presented a spray cooling model development for the Oyster Creek application for 1690 MWt based on the FLECHT tests. At that time, we concluded that there had not been demonstrated sufficient basis on which to completely accept the GE model for spray cooling. Several subsequent meetings have been held with representatives of GE to discuss their model formulation in greater depth. In addition, independent efforts to develop a model have been initiated by INC. Recently, a meeting was held at GE in San Jose between members of the regulatory staff, INC, and GE to discuss detailed calculations obtained from the models and to explore conceptual differences that have been formulated in the two models. Details and differences involved in the models are discussed in the attached appendix.

Both methods represent attempts to produce rational and systematic approaches to a very complicated thermal-hydraulic phenomenon. The models have helped to understand the importance in the spray cooling phenomenon of certain parameters, such as channel quench time, channel film coefficient prior to quenching, heat transfer to the spray fluid, radiation heat transfer, and grouping of the fuel rods. However, several differences in the treatment of these parameters exist between the models that have not been resolved at this time. Numerical evaluations of the Nine Mile Point reactor conditions have been made with both models for a recirculation line break with an assumed 60-second initiation time for the spray system (i.e., achievement of rated flow). These evaluations predict a peak temperature of 2180°F by the GE method and calculations and 2220°F by the INC method and calculations. This comparison of peak temperature alone, however, is not sufficient to appraise the models as the time at which the peak temperature is predicted to occur may also be a significant indication of the intrinsic validity of the model formulation. In the case cited above, the peak is predicted to occur 4 minutes after the break by the GE model and 10 minutes by the INC model, a substantial difference. A similar difference has been exhibited between the model predictions for the Zr-2K FLECHT data; the GE prediction underestimates the time at which the experimental peak temperature occurs while the INC model appears to be substantially better in this regard. Both models predict the peak test temperatures reasonably well but the prediction of an earlier peak temperature is less conservative.

If somewhat more conservative values of the channel heat transfer coefficient (h) and channel quench time are considered (reducing h from 20 to 10, and increasing the quench time from 3 minutes to 4 minutes), the INC model predicts a peak clad temperature of about 2500°F. GE has made a comparable calculation with the same result, but GE prefers to calculate a "best estimate" by reducing some of the specific conservatisms included in their calculation of a 2180°F peak. The "best estimate" peak temperature is about 2000°F. If the reduced conservatism in this latter calculation were included in the INC calculations, the conservative INC result would be reduced to approximately 2320°F. Although these computations are useful, the uncertainties in the model formulations require additional consideration.

There are significant difficulties in properly modeling the complex phenomena involved in the spray cooling phase of the Nine Mile Point BWR. The different methods of extracting and applying generalized heat transfer parameters from the FLECHT tests as represented by the INC and GE approaches are not unreasonable, but some fundamental differences appear to exist at this time which have not yet been resolved. At present, then, we do not rely solely on the GE model for the evaluation of the spray cooling phase of the recirculation line break in the Nine Mile Point LOCA, but also rely on estimates of anticipated performance based on the more conservative results obtained by the INC calculations.

The calculated peak clad temperatures can be reduced by taking into account the fact that the Nine Mile Point reactor ECCS is to be operated and maintained so that the core spray system can achieve rated flow in 35 seconds or less instead of the value of 60 seconds used in the calculation. Representatives of the Niagara Mohawk Power Corporation have assured the staff that the required startup and operation of the diesels for this purpose is feasible and reliable. Under these conditions, we have concluded that the peak clad temperature calculated by either calculational model will remain below 2300°F; GE estimates a peak temperature of approximately 2000°F, and INC approximately 2200°F.

On the basis of a spray system which achieves rated flow in 35 seconds or less, we conclude that the ECCS for Nine Mile Point reactor should provide adequate core cooling performance in the event of a recirculation line break at power levels up to 1850 MWt.

In Amendment No. 5 to the application for power increase (received 1/26/71), the applicant has documented calculations by GE for small-break LOCAs. The calculated peak clad temperature is 2226°F. We are reviewing these calculations and will report our conclusions orally to the subcommittee.

TABLE 1

NINE MILE POINT LOCA

STAFF EVALUATION AT 1850 MWt (60 sec spray)

Rod Identification	Group Average Peaking Factor		Total Decay Power At Spray Initiation (1)		Power Excess in 9-MP Reactor Bundle Over FLECHT "Zr-2" At Spray Initiation (60 seconds)	Linear Power Density (by GE) - kw/ft	
	FLECHT "Zr-2"	9-MP	FLECHT "Zr-2" (kW)	9-MP (kW)		FLECHT "Zr-2"	9-MP
group 1	0.97	1.30	15.45	23.4	+ 51.5%	12.9	17.5
group 2	1.08	1.11	86.00	100.0	+ 16.2%	13.4	14.9
group 3	0.90*	0.90	57.25*	64.7	+ 13.0%*	11.9	12.1
group 4	0.71	0.80	25.4*	32.4	+ 27.5%*	11.3	10.8

(1) Based on 4.2% decay heat at spray initiation and equivalent peak operating power of 4.65 Mwt for FLECHT Zr-2 and 5.25 Mwt for 9-Mile Point

* Reflects two failed rods in group 4, and one failed rod in group 3, at spray initiation in the FLECHT Zr-2 bundle test

TABLE 2

NINE MILE POINT LOCA

STAFF EVALUATION AT 1850 MWT (60 sec spray)

Rod Identification	Power Excess in 9-MP Reactor Bundle Over FLECHT Zr-2 at Spray Initiation (60 sec.)	Average Initial Temperature °F *		Maximum Temperature *		Channel Box Temperature & Quench Time	
		FLECHT "Zr-2"	9-MP	FLECHT "Zr-2"	9-MP	FLECHT "Zr-2"	9-MP
group 1 (4 rods)	+ 51.5%	1640±0	1930	1780±0	1935	1400 3-4 min	1465 3 min
group 2 (20 rods)	+ 16.2%	1713^{+47}_{-33}	1820	1760^{+80}_{-60}	1930		
group 3 (16 rods)	+ 13.0%	1750^{+90}_{-280}	1695	2017^{+33}_{-27}	2060		
group 4 (9 rods)	+ 27.5%	1677^{+93}_{-217}	1580	2138^{+112}_{-198}	2180		

*At the core midplane (6' level).

APPENDIX

NINE MILE POINT LOCA MODEL

For Nine Mile Point, the loss-of-coolant accident is divided into three time periods: (1) blowdown, (2) core heatup, (3) core spray. The blowdown and core heatup periods of the LOCA presented by GE appear to be reasonable. That is, the use of the 1.8 second dryout time, the experimentally based dryout heat transfer, and no credit for steam cooling are warranted in this case. The derivation of acceptable core spray models and their application to core heatup calculations is of particular concern in this plant.

I. CORE SPRAY MODELS

Starting with the FLECHT SS-2N data, General Electric and Idaho Nuclear Corporation have embarked on similar procedures. Each has developed computer programs to "extract" generalized heat transfer parameters from the data. These parameters were then used to develop heat transfer correlations. These correlations for heat transfer coefficient and channel wetting time are used in computer codes to predict the results of the FLECHT stainless and zircaloy tests, as well as the LOCA for NMP.

A. Extracting Core Spray Heat Transfer Parameters

The first step in GE's extraction procedure is to calculate grey body factors for the 49 rod plus channel box array for a constant emissivity using their GREY code (for SS-2N, ϵ =0.6). These grey body factors are then combined to match the desired grouping of rods for which grey body factors are needed.

Next, the code FILMCO is used to solve the rod energy balance, the only unknown now being the heat transfer coefficient, since rod surface temperatures are known and the fluid temperature is assumed to be at saturation. FILMCO neglects conduction and does not calculate channel box heat transfer coefficients. For extracting coefficients from SS-2N the 16 "northwest" rods in the bundle were considered and grey body factors combined accordingly.*

The INC extraction procedure begins by using the DATAR code to solve for a "total" heat transfer coefficient from each rod and channel surface. The coefficient includes all energy leaving the surface including any radiation. It is the total heat flux divided by the temperature drop between the surface and the same saturation temperature that GE uses. An inverse conduction model is used in DATAR. Since all experimental temperatures are not recorded simultaneously, the values used in calculating are interpolated from the data to the time desired.

The RADHT code uses the DATAR results and the experimental surface temperatures to extract coefficients from surface to fluid. The rod matrix used in RADHT is the entire bundle plus

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* This entire procedure is explained more fully in the appendix of GEAP-13086-"Heat Transfer in a Simulated BWR Fuel Bundle Cooled by Spray Under Loss-of-Coolant Conditions," June 1970.

the channel box. If temperatures are not available for each rod, its "mirror image" along the northwest to southeast diagonal is used. A temperature-dependent emissivity is programmed into RADHT and the matrix solution for body-to-body radiation solved for each body for each time step. The emissivity calculated for stainless in RADHT is almost always about 0.89.

The INC method is somewhat more rigorous than the approach adopted by GE since it includes a conduction model, a temperature interpolation routine, a variable emissivity, a radiation solution for the entire matrix for each time step, and extracts channel box heat transfer coefficients. In general, the INC method yields lower h's than the GE method especially for the outer rods and the channel box. For these reasons, it seems a more conservative method and, therefore, preferable at this time.

B. Correlation of Extracted Heat Transfer Parameters

GE was able to correlate their results as a temperature function (Roger's correlation) strongly dependent on rod location, the outer rods yielding higher coefficients. INC did not find a strong temperature or location dependency but rather a dependence on channel wetting time. After can quench, INC h's were between about 0.5 and 1.5; GE values were between about 0.5 and 10. The ability of GE to correlate well with the temperature function $(T^4 - T_s^4)/(T - T_s)$ indicates a strong radiation component of the heat transfer coefficient (T_s is the sink temperature, assumed to be saturation). This component is too large to be accounted for as radiation to steam or droplets, so GE claims it is radiation to the water film around the wetted channel. Even though some radiation is now absorbed by water surrounding the channel, an appropriate decrease in the amount of radiation to the channel is not made. That is, body-to body radiation is not properly decreased to account for radiation to the film. Conservation of radiant energy requires that the sum of all shape factors for a given body to all other bodies is 1.0. This is maintained prior to channel wetting. However, after channel wetting, the radiation portion of the Roger's correlation causes the sum to be larger than 1.0 for all rod groups. INC estimates that in the GE case of a corner rod, the sum of the shape factors can be as high as 1.5 to accommodate the additional rod-to-film radiation. It can be argued, however, that a high total view factor is compensation for a low value of emissivity. But without a calculation to demonstrate that hypothesis, the issue remains unresolved. The procedure of allowing an excess amount of radiant energy to be transferred to a constant sink appears non-conservative.

INC did a parametric study of the effect of emissivity using their method. It appears that about half the difference in extracted h's between the GE and INC methods can be attributed to the values chosen for emissivity. The intrinsic method of extraction then appears to account for the balance of the difference.

GE has correlated channel wetting time as a function of a Yamanouchi* parameter containing channel wall temperature and temperature gradient. The GE correlation with this parameter is linear, although the data are insufficient to be definitive and a less favorable correlation conceivably could be supported by the limited data. On the other hand, the approach developed by INC requires that the wetting time be treated arbitrarily and handled parametrically in their predictions. In formulating the heat transfer correlation after spray initiation but before channel wetting, GE calculates the radiation to the water film component and uses a fraction of the fully developed coefficient as expressed by the ratio of $(t - t_s)/(t_q - t_s)$, where t is the time at which the coefficient is being calculated, t_s is the time of spray initiation, and t_q is the channel quench time. Note that $t_s < t < t_q$. Neither the INC nor the GE data correlate too well with time or temperature before channel quench. This is of special concern where temperature turnarounds are predicted to occur at about the same time

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*Yamanouchi, A., "Effects of Core Spray Cooling and Stationary State After LOCA", Journal of Nuclear Science and Technology, October 1968.

as channel quench; that is, most of the transient has occurred during this period before channel quench. The differences in correlation have given rise to different interpretation of the mechanism operating during this period. Inasmuch as the heat transfer improved prior to and just at channel quench, GE believes that the phenomenon is due to improved emissivity of the wetted channel. INC, on the other hand, attributes the improvement to improved convection due to splashing and slaking of the water from the quench front. Without resolving the differences in the two calculational models, it would be difficult to comment on the interpretation of mechanics.

If just the inner can face is considered, GE estimates heat transfer coefficients of about 20 for the channel prior to can quench. INC actually extracts coefficients that are almost always less than 10. The entire GE correlation which allows an additional amount of radiation to be transferred to a low temperature sink prior to and after quench is non-conservative. The higher channel coefficients which result in lower channel temperatures provide a better radiation sink for the hot rods. Most subsequent calculations including some where rod coefficients were zero show that radiation ultimately to the channel even before channel quench is what arrests the temperature transient. Therefore, any mechanism which results in lower channel temperatures prior to quench should be evaluated most conservatively.

II. HEATUP PREDICTIONS

GE uses the code CHAST for bundle heatup calculations. The code can be used for predicting a LOCA or results such as FLECHT. The 49 rod bundle is lumped into 4 groups plus the channel box for ease of calculation. Group 1 is the 4 corner rods, group 2 is the outer rows minus the corner rods, group 3 is the second rows, and group 4 is the center nine. Grey body factors are appropriately combined so that each group and the channel has one interchange factor with each other group, the peaking factors are averaged, and each group has a corresponding heat transfer correlation extracted from the BWR FLECHT tests (Roger's correlation).

INC's revised MOXY code does the heatup calculation. The 49 rods are treated individually in contrast to the simplified GE approach, i.e., individual peaking factors are used and the entire radiation matrix is solved for each time step. This allows variation of emissivity with time for each body. GE uses a single emissivity for the entire matrix for the entire time. The INC method then is more flexible and rigorous. Thus far, INC has treated GE's groups 1 and 2 as a single group with respect to heat transfer coefficient correlations.

A. FLECHT Predictions

Using their respective codes, both organizations have done a good job of predicting temperatures for the stainless steel FLECHT tests from which the data were extracted. Agreement in this "refitting" process is necessary but not sufficient or surprising. In trying to predict the Zr-2 tests, both do surprisingly well in view of the extensive experimental difficulties discussed previously. INC's peak temperature predictions are generally closer to the experiment than GE's, usually slightly higher than the experiment but lower than GE's prediction. The time of turnaround is also usually better predicted by INC. GE's turnaround times are almost always too early by significant factors. The shape of the INC temperature curves are generally flatter around the peak as are the Zr-2 data, but usually this is not the case with the GE predictions which tend to be more sharply peaked near the maximum temperatures.

B. Nine Mile Point Predictions

In predicting cladding temperatures for NMP, GE used the CHAST code by first applying their experimentally based dryout correlations to the blowdown, then an "adiabatic bundle" heatup from end of dryout until the core spray reaches rated flow. "Adiabatic bundle" implies radiant energy interchange among the rod groups and the channel walls but with a convective coefficient of zero. The GE Roger's correlation was then used to model the period of spray cooling which includes the channel wetting time correlation. The results are presented in the NMP addendum 3 cited earlier which indicates the peak clad temperature of 2180°F for the largest double-ended break and 2225°F for the worst intermediate break of 0.14 ft^2.

INC used the MOXY code to parametrically study spray cooling effectiveness in NMP. The temperatures at time of spray initiation as calculated by GE were used as initial temperatures in these calculations. The results are shown in Table 3. The result most nearly equivalent to the GE predictions are for a 60 sec spray initiation time, 180 sec quench time, and a channel h of 20. GE predicts a peak of 2178°F with a quench time of 172 sec after spray and a time of peak at 154 seconds after spray. The peak temperature by MOXY is 2220°F at 520 seconds after spray. The longer times predicted by INC are consistent with their Zr-2K predictions and the Zr-2K data. The longer times and flatter profiles are consistent with lower heat transfer coefficients which are not strongly temperature dependent. Since INC's extraction procedure yielded channel h's generally of 10 or less, whereas GE asserts that these values should be in the order of 20, identical calculations were made with channel h's of 10 and 20. In the Zr-2 test, 5 of 6 T/C's on the hot can faces ranged from approximately 1200°F to 1400°F prior to quench, 3 of those 5 quenched at between 3.7 and 4 minutes, the other 2 quenched at about 2.5 minutes, one of those was just barely at 1200°F at quench. The sixth T/C which was about 1000°F quenched at about 3.5 minutes. GE calculates a channel temperature of 1467° at spray initiation for Nine Mile Point reactor which falls to about 1350° at quench under the influence of the constant channel coefficient of 20. When INC uses a constant coefficient of 10 during this period, the can temperature does not fall. Under these circumstances then, a quench time of 4 minutes appears quite reasonable. The MOXY prediction for this case of a 4-minute quench and a can coefficient of 10 yields a peak of 2496°F. Re-calculation of this worst case using the calculated GE clad temperatures at 30 seconds rather than 60 seconds to simulate earlier spray initiation yields a peak value of 2340°F. This INC value is artificially high for a 30-second spray since the channel wetting time was not reduced from 4 minutes to a more appropriate value of about 2 minutes for a 30-second spray. Therefore, it would appear that a 30-second spray initiation will successfully arrest the clad temperature rise with reasonable choices of channel parameters. In fact, the INC prediction using a 3-minute channel wetting time is only 2268°F at 49 sec.

III. NINE MILE POINT MODEL EVALUATION

As was the case with the Zr-2 predictions, the INC temperatures for NMP have a flatter profile near the peak than the GE predictions. Also, as in Zr-2, the predicted times are longer in the INC-MOXY predictions. Although a peak may be predicted at about 500 seconds in MOXY, it typically may have been within 100°F of that peak at 250 seconds or about the time the GE peak is predicted. Experimental work at Oak Ridge* and INC** suggests that extended periods of time, like 8 to 10 minutes, at modest temperatures, like 2200°F, may be just as likely to cause brittle fracture as a short time at a more elevated temperature such as 2700°F.***

If the total amount of heat transferred at the surface of a rod is about the same in the INC and GE extraction methods and both have about the same amount for "pure" convection component, then the GE correlation which has a larger body-to-fluid radiation component is non-conservative. As temperatures are elevated, the strong temperature dependence (roughly T^3) for the Roger's correlation is removing more heat from the bundle. Although the body-to-body component would be larger for the INC extraction method, both prediction methods used the same emissivity for zircaloy.

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*Rittenhouse, P. L., Progress in Zircaloy Failure Modes Research, ORNL-TM-3188, December 1970.

**Herzel & Meservey, Trans. Am. Nucl. Soc. 12 (1), 355-356, 1969.

***Using Baker-Just Kinetics, 8 minutes @ 2200°F or 40 seconds at 2700°F locally reacts about 10% of BWR cladding.

Therefore, the body-to-body component is not as much larger as the INC predictions, if at all, than it was in the extraction procedure. At any rate, a large body-to-body component does not remove heat from the bundle but merely redistributes it within the bundle. A strong temperature dependence for the body-to-fluid radiation component seems to be a non-conservative self-limiting feature.

TABLE 3

MOXY PREDICTIONS FOR NINE MILE POINT

Spray Initiation Time - Seconds	Channel Quench Time After Spray-Sec	Channel Heat Transfer Coefficient-BTU/HR-FT^2°F	Peak Clad Temperature-°F	Time of Peak After Spray-Sec
60	180	10	2317	210
60	180	20	2220	520
60	240	10	2496	240
30	180	10	2268	490
30	180	10	2248	560
30	240	10	2340	260