University of Michigan
Michigan Memorial-Phoenix Project
Office of the Director
Ann Arbor, Michigan 48109-2100

May 19, 1994

Docket 50-2
License R-28

United States Nuclear Regulatory Commission
Document Control Desk
Attn: Theodore S. Michaels, Project Manager
Standardization and Non-Power Reactor Project Directorate
Division of Reactor Projects III, IV, V, and Special Projects
Office of Nuclear Reactor Regulation
Washington, D.C. 20555

Re: **Ford Nuclear Reactor License and Technical Specifications, Amendment 39**
Effects of Abnormal Loss of Coolant at 2.2 Megawatts

Dear Mr. Michaels:

The attached analysis addresses an abnormal loss of coolant from the Ford Nuclear Reactor during operation at 2.2 megawatts. While you have requested this analysis, license amendment 39 does not request permission for steady state operation at 2.2 megawatts. Licensed steady state power remains at the current level of 2.0 megawatts; 2.2 megawatts is the licensed power limit.

Sincerely,

Reed R Burn

Reed R. Burn
Manager
Michigan Memorial-Phoenix Project

A020 1/1

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ABNORMAL LOSS OF COOLANT FOR AN OPERATING POWER OF 2.2 MEGAWATTS

Loss of Coolant Flow Rates and Drain Times

Section 14.2 of the Ford Nuclear Reactor Safety Analysis addresses an abnormal loss of coolant from the reactor pool. Abnormal loss of coolant could be caused by a rupture in or damage to I beamtube or the pneumatic sample transfer system. In the event of loss of coolant through I beamtube, the core would always be partially immersed in water. In the case of a total rupture of a pneumatic tube, the leak rate would range from 215 gpm at the time of initiation of the low pool level scram to 105 gpm when the water level receded to the bottom of the reactor core. The emergency makeup water system, with a flow rate of approximately 600 gpm, exceeds the average loss of coolant flow rate by a factor of about four. If emergency makeup were not initiated, the reactor core would remain completely covered for 2.95 hours subsequent to a low pool level scram, and it would remain partially immersed in water for 3.50 hours. (Note that these numerical values for flow rates and drain times vary slightly from the Table 14.1 values in the Safety Analysis based on a calculational error in the original table.)

If the core remains even partially immersed in water, when the boiling temperature is reached, boiling will occur. Since boiling is the most efficient means of heat transfer, excessive fuel temperatures would not be reached

Fission Product Heating

Table 1 is a listing of fission product decay heat for reactor operating times of 1,000 hours and 10,000 hours at various times after reactor shutdown. After 1,000 hours of reactor operation, fission product decay energies have nearly reached the equilibrium level.

A typical fuel element remains in the reactor for approximately 12,000 hours of operation; the average element is, therefore, in residence for approximately 6,000 hours. It is conservative to use the decay heat values for 10,000 hours of operating time.

For a total loss of coolant from the reactor core caused by a pneumatic tube rupture, the pool water level would recede below the bottom of the core in 3.5 hours (12,600 seconds). Making a linear interpolation from Table 1 between decay times of 10,000 seconds and 20,000 seconds yields the following fission product decay heat energy release rates.

Reactor Power	Total Fission Product Decay Heat
2 Mw	16,002 watts
2.2 Mw	17,602 watts

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Table 1 Fission Product Decay Heat For Various Times After Reactor Shutdown

Reactor Operating Time of 1,000 Hours

Decay Time	Beta Energy	Gamma Energy	Total Energy	Total Fission Product Energy Per Unit Power		
(sec)	(Mev/sec/w)	(MeV/Sec/w)	(MeV/Sec/w)	(watt/watt)	(w/2Mw)	(w/2.2Mw)
100	7.94E+10	9.58E+10	1.75E+11	0.028	56064	61670
200	7.07E+10	8.64E+10	1.57E+11	0.025	50272	55299
400	6.15E+10	7.55E+10	1.37E+11	0.022	43840	48224
1000	4.96E+10	6.15E+10	1.11E+11	0.018	35552	39107
2000	4.03E+10	5.14E+10	9.17E+10	0.015	29344	32278
4000	3.19E+10	4.13E+10	7.32E+10	0.012	23424	25766
10000	2.31E+10	2.92E+10	5.23E+10	0.008	16736	18410
20000	1.76E+10	2.21E+10	3.97E+10	0.006	12704	13974
40000	1.29E+10	1.71E+10	3.00E+10	0.005	9600	10560

Reactor Operating Time of 10,000 Hours

Decay Time	Beta Energy	Gamma Energy	Total Energy	Total Fission Product Energy Per Unit Power		
(sec)	(Mev/sec/w)	(MeV/Sec/w)	(MeV/Sec/w)	(watt/watt)	(w/2Mw)	(w/2.2Mw)
100	8.10E+10	9.77E+10	1.79E+11	0.029	57185	62904
200	7.21E+10	8.81E+10	1.60E+11	0.026	51277	56405
400	6.27E+10	7.70E+10	1.40E+11	0.022	44717	49188
1000	5.06E+10	6.27E+10	1.13E+11	0.018	36263	39889
2000	4.11E+10	5.24E+10	9.35E+10	0.015	29931	32924
4000	3.25E+10	4.21E+10	7.47E+10	0.012	23892	26282
10000	2.36E+10	2.98E+10	5.33E+10	0.009	17071	18778
20000	1.80E+10	2.25E+10	4.05E+10	0.006	12958	14254
40000	1.32E+10	1.74E+10	3.06E+10	0.005	9792	10771

Ref: (1) J. F. Perkins, Report RR-TR-63-11, U.S. Army Missile Command, July 1963.
(2) N. M. Schaeffer, REACTOR SHIELDING FOR NUCLEAR ENGINEERING, Appendix A, 1973.

Those energy release rates are the maximum that would occur. The rates would decrease as time passed and further fission product decay occurred.

Oak Ridge Reactor Loss of Coolant Studies

In 1962, an analysis of fission product heating was submitted to the Atomic Energy Commission by the Ford Nuclear Reactor as part of license amendment 11, a request to increase reactor operating power from one to two megawatts.

In the analysis, Oak Ridge National Laboratory Report 2892 (ORNL-2892) was cited. The report describes temperature profile measurements made on Oak Ridge Reactor (ORR) fuel elements suspended in air. In an element with a power density of 32.5 watts/in^3, the maximum fuel temperature reached was 630 °F.

In the Ford Nuclear Reactor Core containing its normal 40 fuel elements, the active core volume is 8,640 in^3 (24 in x 3 in x 3 in per element x 40 elements). The fission product decay heat power density 12,600 seconds after shutdown is:

Reactor Power	Fission Product Decay Heat Power Density
2 Mw	1.85 watts/in^3 (16,002/8,640)
2.2 Mw	2.04 watts/in^3 (17,602/8,640)

For a reactor core with 25 fuel elements, the active core volume is 5,400 in^3 (24 in x 3 in x 3 in per element x 25 elements). The fission product decay heat power density 12,600 seconds after shutdown is:

Reactor Power	Fission Product Decay Heat Power Density
2 Mw	2.96 watts/in^3 (16,002/5,400)
2.2 Mw	3.26 watts/in^3 (17,602/5,400)

At a power level of 2.2 Mw, the fission product decay heat power density in the Ford Nuclear Reactor Core is approximately ten percent of the power density in the ORR experiments.

In both the ORR element and the Ford Nuclear Reactor core, the fraction of energy dissipated due to direct gamma radiation and as the result of radiative heat transfer would be proportional to the fission product decay heat power density. The ORR element was a single element suspended in air so the convective cooling along the outside surfaces of the element might be expected to be a somewhat greater fraction of total heat removal than the convective cooling off the faces of the Ford Nuclear Reactor core. However, the Ford Nuclear Reactor core would experience some conductive cooling between elements and from the elements to the reactor grid and tower structure that supports the reactor. The fuel and the support structure are constructed of aluminum, and both fuel and structure are in physical contact.

Decay Heat Dissipation Due to Radiative Heating Alone

Following a total loss of coolant from the core, approximately 25 percent of fission product decay heat would leave the reactor in the form of direct gamma radiation. An additional amount would be conducted from the fuel to the reactor support structure. A significant amount would leave the core due to convective cooling by air flow through fuel element water channels and around the outside surfaces of the core.

In addition, decay heat energy would be lost by radiative heating from the exterior surfaces of the core to the surrounding pool walls.

In this analysis, no credit will be taken for direct radiation, conduction, or convection. All cooling will be assumed to be by radiative heat transfer. Based on this, a peak fuel temperature will be determined.

Radiative heat transfer occurs between two mutually exposed surfaces, the core faces and the pool walls. The space between the surfaces is air which absorbs a negligible amount of the radiation. The Stefan - Boltzmann radiative heat-transfer law follows.

$$Q_{rad} = C\ F_e\ F_a\ A(T_{R1}^4 - T_{R2}^4) \qquad (1)$$

where:

Q_{rad} = Radiative heat transfer rate, Btu/hr;

C = Stefan-Boltzmann constant;

= 0.173×10^{-8} Btu/hr ft^2 R^4;

F_e = Emissivity factor depending on nature of the two surfaces;

F_a = Angle factor depending on angle through which a surface sees the other surface;

A = Area of one of the surfaces, ft^2;

T_{R1} = $(T_1 + 460)$, R, where T_1 = temp F of hotter surface;

T_{R2} = $(T_2 + 460)$, R, where T_2 = temp F of colder surface.

The angle factor is one since the core faces are parallel to the pool walls. The emissivity factor varies with the "blackness" of the fuel surface. For this analysis, values of one and 0.5 will be used. The fuel surface area is 16 ft^2 (South core face at 2 ft x 2 ft; east and west faces at 2 ft x 1.5 ft; top and bottom at 2 ft x 1.5 ft. North face contacts a heavy water tank). Pool wall temperature is assumed to be 110 °F (570 °R), the normal pool water operating temperature. The fission product decay energy used is 17,602 watts (60,076 Btu/hr).

Solve equation (1) for T_{R1}.

$$T_{R1} = (T_{R2}^4 + [Q_{rad}/C\ F_e\ F_a\ A])^{1/4} \qquad (2)$$

For an emissivity factor of 1:

$$T_{R1} = (570^4 + [60{,}076/0.173\text{x}10^{-8}*1*1*16])^{1/4}$$

$$= 1{,}228\ {}^\circ R$$

$$T_1 = 768\ {}^\circ F$$

For an emissivity factor of 0.5:

$$T_{R1} = (570^4 + [60{,}076/0.173\text{x}10^{-8}*0.5*1*16])^{1/4}$$

$$= 1{,}452\ {}^\circ R$$

$$T_1 = 992\ {}^\circ F$$

The melting point of aluminum is 1,200 °F.

Conclusion

Based on the ORR experiments, it can be concluded that should the Ford Nuclear Reactor experience an abnormal loss of coolant at an operating power of 2.2 Mw, the peak fuel temperature would remain below 650 °F.

The peak fuel temperature based on radiative heat transfer alone is 992 °F: (1) without taking credit for direct gamma radiation losses, conductive heat transfer from the core to the reactor support structure, or convective heat transfer due to air flow through and around the core and (2) assuming a very conservative emissivity factor of 0.5.

The melting point of aluminum is 1,200 °F.

Fuel would not melt and fission products would not be released as the result of an abnormal loss of coolant from the Ford Nuclear Reactor at an operating power of 2.2 Mw.