PHOENIX MEMORIAL LABORATORY

MEMORANDUM REPORT NO. 2

Loss of Coolant During Operation of the Ford Nuclear Reactor

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Abstract

Consideration has been given to the consequences of water leaks in the pool of the FNR reactor. The most likely sources of water leaks have been reviewed and calculations of leakage rates for various size holes have been made. Consideration has also been given to the possibility of fuel meltdown due to fission product heating after operation at 2 MW and after the complete loss of water from the pool. Possible corrective measures following a pool water leak have been listed.

Source and Characteristic Behaviour of Potential Leaks

An investigation of the primary loop piping system and the pool construction details of the FNR suggest the following potential sources of water leaks in order of decreasing probability:

1. Glass window and flow rate indicator in hot de-ionizer system.
2. Beam ports.
3. Pneumatic tubes.
4. Primary loop components.
5. Catastrophic occurrences such as earthquakes and explosions.

These various possibilities suggest leaks ranging from a few inches in diameter to several inches in diameter (neglecting a tank rupture). To obtain conservative estimates of leakage rates and the time to empty the pool, calculations were made using the equation of Torricelli * for exhaust velocity. Since the pneumatic and beam port leaks would probably occur at or near the same elevation as the core, the initial head is assumed to be 21 feet. The equation is written in terms of h (the water head) and is then integrated from $h = h_o$ to $h = 0$ as time varied from $t = 0$ to $t = te$.

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* Vennard, J.K., Elementary Fluid Mechanics, John Wiley and Sons Inc. New York 1952, p. 77.

The solution is given by:

$$te = \frac{Ap}{Ae} \quad \frac{2h_o}{g}$$

where te = time to empty pool

h = water head at any time t

Ap = surface area of pool water

Ae = area of leak

h_o = initial head

g = gravity.

The calculations were made for leaks ranging from 1" diameter to 8" diameter. The results are presented in Table 1B. Friction and flow losses were neglected and the results give the minimum time in which the pool would drain. To aid in designing an early warning leak detector, calculations were made for the instantaneous rate of change of the water level (dh/dt) at heads of 20 feet and 21 feet. The results are given in Table 1A which shows that (dh/dt) is essentially constant during the first foot. A leak detector which annunciates when the water level has dropped by 1 foot will alarm within 20 minutes after a leak of 1" diameter or greater has occurred.

The available time for moving the reactor bridge and installing the gates will depend on the radiation intensity generated as the pool drains.

Hot fuel in the pool storage racks will become exposed when the water level has dropped approximately 10 feet. Thus calculations were made to estimate the time required to expose the storage racks for various leak diameters. The results are presented in Table II. It should be noted that the available time for bridge relocation is limited to the time to expose the hot fuel in the storage racks.

Assuming 30 to 40 minutes is required to move the core into the south pool and install the gates, one may conclude that the largest un-controllable leak which would allow sufficient time for this operation is approximately 2" in diameter.

The corrective measures can be taken for the more probable leaks that have been listed.

1. Should the glass window of the hot D.I. or flow rate indicator be broken, readily accessible valves can be closed to isolate the unit from the reactor pool.
2. The beam ports may rupture in different ways and under different conditions. There could be a complete shearing or uncoupling of the tube or alternatively a small crack in the weld seams. The presence of a plug in the port would reduce the leakage rate in those cases where the port rupture was very large. Also, closing the lead shield door would decrease the leakage rate if it were very large. For cracks which result in rather low leakage rates, blank flanges are available on the beam hole floor for sealing the port opening.
3. Should a leak occur in the pneumatic tubes, the leaking tube can be crimped shut within minutes. A crimping tool is permanently located at the point of intended use in the basement (adjacent to the Hot Sump).

4. The only primary loop component which cannot be isolated from the pool system by valving is the holdup tank.

In all the above cases the rate of drop of the pool level may be reduced by opening a 4 inch city water main to the pool system.

Fission Product Heating

One may postulate several conditions which would result in the loss of all the water from the pool. Thus the effect of fission product heating must be investigated.

The only pertinent data found in the literature is an ORR Report (ORNL-2892) which gives the measured temperature profiles in ORR fuel elements while suspended in air. The maximum temperature recorded was 650°F. in an element producing 111 BTU/hr./in.^{3}

The decay heat for the FNR has been estimated with the aid of decay heat curves in Fig. 7-2 of ANL-6469. A 19 element core operating at 2 MW with fission product equilibrium gives an after heat immediately following a scram of 116 KW. Ten minutes later the level is down to 48 KW. Hence a 19 element core 10 minutes after shut down gives an average power density of approximately 39 BTU/hr./in.^{3} This assumes that all the decay heat is absorbed in the core and that the after heat power density distribution is constant. This power estimate for the FNR is well below the value of 111 BTU/hr./in.^{3} which gave a maximum cladding temperature of 650°F. in stagnant air.

Since the melting point of aluminium is 1200°F., it may be concluded that there is little probability of fuel element meltdown in the FNR resulting from fission product after-heat.

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Table 1A

$\dot{h}$ vs De for h_o = 20 ft. and h_o = 21 ft.

$\dot{h}$ = rate of head drop

Leak Area Ae(ft.^{2})	Leak Diameter De(in.)	$\dot{h}$(h_o=20ft.) ft./hr.	$\dot{h}$(h_o=21 ft.) ft./hr.
.0054	1	3.32	3.40
.0218	2	13.42	13.75
.0491	3	30.2	31.0
.0872	4	53.7	55.0
.1362	5	84.0	86.0
.1961	6	121.0	124.0

Table 1B

te vs. Ae

te = time to empty pool

Leak Diameter de(in.)	Leak Area Ae(ft.^{2})	te(min)
1	.00545	735
1 1/2	.01228	322
2	.0218	187
3	.0481	81
4	.0872	45.8
5	.1362	29.2
6	.1961	21.9
7	.267	14.9
8	.349	11.5

[illegible] calculations are based on a pool surface area of 210 ft.^{2}

Table II

Time to Expose Storage Racks – t

Leak Diameter de(in.)	Leak Area Ae(ft.^{2})	t(min.)
1	.00545	228
1 1/2	.01228	100
2	.0218	56.5
3	.0491	25.1
4	.0872	14.1
5	.1362	9.2