IA-1ca

TASK CLOSE OUT DOCUMENT

Task Scope Modes of Operation During Long-Term Cooling

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MODES OF OPERATION DURING

LONG TERM COOLING

THREE MILE ISLAND

INDUSTRY ADVISORY GROUP

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SUMMARY

Three modes of long term cooling are seen as possible without taking benefit for RHR with, natural circulation being the most desirable of the three modes. The three modes are: (1) natural circulation without boiling, (2) boiling with a closed system and (3) boiling with an open system. Water makeup to the primary of some amount would probably be required for both 2 and 3 because of system leakage. As long as the system remains in natural circulation there should be no bulk boiling. Changes in the rate of heat removal from the primary system; e.g., failure/loss of both A and B loop secondary closed cooling systems, could cause loss of natural circulation and lead to a boiling mode. Other factors, such as reverse flow in the B loop (primary side), may influence the transition to natural circulation and/or may actually ultimately result in loss of natural circulation once established. Thus moving into a boiling mode is not necessarily unlikely in the long-term. It is believed that the possible boiling modes represent a viable way to operate the primary system if natural circulation cannot be maintained. In fact, if primary system pumping is lost altogether, it is believed that the plant should be allowed to go into natural circulation, and if necessary, a boiling mode instead of using the High Pressure Injection to provide forced cooling.

The major uncertainty with going into the boiling modes of cooling is the concern for the effect of non-condensables and whether they will block the flow process of steam from the core to the heat exchanger. This effect was evaluated and reported in the IAG Memo Report #IA-10c. Based on that report, it was concluded that non-condensables will not prevent achievement of an acceptably stable boiling mode.

SUMMARY OF COOLING MODES

There are three basic modes of heat removal envisioned for possible long-term cooling of Three Mile Island Unit 2. These configurations are:

1. Natural Circulation - Natural circulation in the primary with all liquid in both the primary and secondary

2. Boiling with a closed system - A boiling mode in the primary system with boiling occurring in the core and condensing in steam generators and the pressurizer relief valve closed.

3. Boiling with an open system - Same as Number 2 with the relief valve on the pressurizer open.

These cooling modes are listed in the order of desirability. The natural circulation mode is the most desirable, however, certain events may cause transition from one of these modes to a less desirable, but adequate mode. All three modes assume that the secondary side of at least one steam generator can continue to function; i.e., even if lost for some period that it could be brought back into service. The boiling modes are, however, less sensitive to the loss of secondary cooling particularly at low decay heat.

SUMMARY OF COOLING MODES (Cont.)

The natural circulation mode might possibly go to a boiling mode if the heat removal capability of both steam generators is lost for a period of time. The pressure in the primary system would build up due to volume expansion so that the relief valve on the pressurizer would have to be opened. The ensuing blowdown from the pressurizer would allow steam formation in the primary system and eventual transition into a boiling (RB) mode.

If makeup water is not supplied to the reactor in the open system boiling mode, the water level will decrease over a long period of time until the core is uncovered. System leakages are such that even the closed system acts somewhat like an open system too. The generated steam may continue to cool the core until the water level goes below the heated length. At this point, a water seal will exist at the bottom of the core which would inhibit circulation of non-condensable gas around the system.

In order to inhibit the change from natural circulation to a boiling mode, the mass flow on the secondary side of one steam generator is required. If the secondary is all liquid, then the flow rate on the secondary must be large enough to remove the heat. A plot of the flow rate required on the secondary (or primary) to remove sufficient heat assuming a $10^{\circ}F$ temperature rise as a function of decay heat is shown in Figure 1.

In order to inhibit the production of non-condensables if the plant is in a boiling mode, the relief valve on the pressurizer should be closed as soon as the steam generators are restored to working order. If the relief valve is left open, the primary system will be in the open and will tend to attain to a lower equilibrium pressure. Eventually, with the valve open, hydrogen and oxygen will be generated by radiolysis, stripped out of solution, and enter the vapor region. Eventually (possibly within a week) enough H_2 will be produced to cause the vapor transfer from the core to the steam generator to be diffusion limited and could possibly stop the steam generators from removing the heat. This case is evaluated in IAG Memo Report #IA-10c.

If a boiling mode occurs and the pressurizer relief valve is closed when the steam generators are restored, the vapor region could be made to collapse by removing excess heat and adding makeup water. Due care should be taken to ensure that water hammer does not damage the system during the collapse.

If the non-condensables have built up by the time the steam generators are restored, the pressurizer relief valve could be closed to increase the rate of pressure build up. When the pressure builds up to a sufficiently high value, the solubility of the water to the non-condensables will be increased to the value where a sufficient quantity will dissolve in the water in the steam generator and unblock the steam flow from the core and allow it to condense in the steam generators.

If none of these systems function, a very unlikely event, the core uncovered mode will occur and would probably be unsatisfactory. An analysis of this case is presented in Appendix 1.

A discussion of each of the modes of long-term cooling is presented in the remainder of this report to show how each will function.

NATURAL CIRCULATION MODE

INEL has made calculations of natural circulation with use of the RELAP4 code. These results are summarized in Table 1. On paper, it appears to be difficult to leave the natural circulation mode with the steam generators in operation. A computer run was made where the pressurizer vent was opened during one of the steady state natural circulation runs. The natural circulation remained during the blowdown and the pressurizer was completely voided without any steam being generated in the upper reactor vessel or candy cane. Thus, on paper, it appears difficult to thwart natural circulation. This calculation is, however, not too consistent with naval reactor experience which indicates that such systems are very sensitive changes in rate of heat removal during natural circulation. Thus, loss of the natural circulation mode cannot be ruled out.

BOILING MODE

This mode of heat transfer appears difficult to control. The secondary side should only remove enough heat to offset the heat generated in the core. Excess heat removal will cause the voids to collapse. Insufficient heat removal will cause the void to expand. Basically, this mode will cause the entire primary system to be behave like a pressurizer.

Preferred operation would appear to be with a closed system at 10-20 atmospheres of pressure. Although, operation with the pressurizer relief valve open may accomplish similar results. The basic reason desiring some pressurization is that radiolysis is low, H_2 resolution is higher and boiling is more stable in a pressurized system.

Figure 2 shows the supposed configuration of the liquid and gas phases.

Increasing the pressure on the system will allow the non-condensables to dissolve in the water and allow the process to proceed. The heat transfer coefficient will degrade due to the presence of non-condensables. The required steam generator area is shown in Figure 2.

Other processes which were considered included:

1. Streaming of steam through the center of the candy cane due to buoyancy.

2. Heat loss from the pipe causing condensation.

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These processes do not appear sufficient to aid the process. Subsequent work reported in IAG Memo #IA-10c indicate the non-condensables should not be a long-term problem.

Ted Mott

APPENDIX 1

ANALYSIS OF CORE UNCOVERED MODE

1. Vapor blocks natural circulation.

2. Water in core heats to boiling point and core now generates steam and hydrogen pressure rises and steam and H_2 vent to containment - primary system is loosing mass with no make up.

3. Steam is generated in the core - part is vented and part condenses - water level drops. During this time, hydrogen concentration is low in vent flow, however, hydrogen concentration in steam generator builds since the steam is being condensed there.

$$\dot{m}\,\frac{\text{Core}}{\text{Steam}} \approx \frac{3000\ \text{B/sec}}{1000\ \text{B/\#}} \sim 3\#/\text{sec} \approx 10{,}000\ \#/\text{hr}$$

$$\dot{m}H_2 = 36\ \#/\text{day} = 1.5\ \#/\text{hr}$$

4. As H_2 concentration builds up in SG, condensation slows - core now drys out.

5. Rapient heat transfer from the core evaporated enough water to break seal.

6. At a pressure of 14.7 psia free convection of hydrogen will not cool core.

   At 147 psia free convection will cool core (if loss coefficient $k < 100$) with $3000^{\circ}F$

   ΔT - Fuel surface temp $\approx 4000^{\circ}F$

CONCLUSION

If vapor blocks natural circulation, the system pressure should be raised as high as possible as soon as possible. This would, in the limit, permit natural circulation of hydrogen and prevent a melt down.

TABLE I

SUMMARY OF INEL NATURAL CIRCULATION CALCULATIONS

	Percent blockage			
	0	40	85	95
Core Mass Flow (lbm/sec)	429	429	318	100
$T_h - T_c$ (^oF)	10.9	10.9	14	47
T_c	244	244	244	244

Secondary side of Steam Generator A is steaming, B is isolated

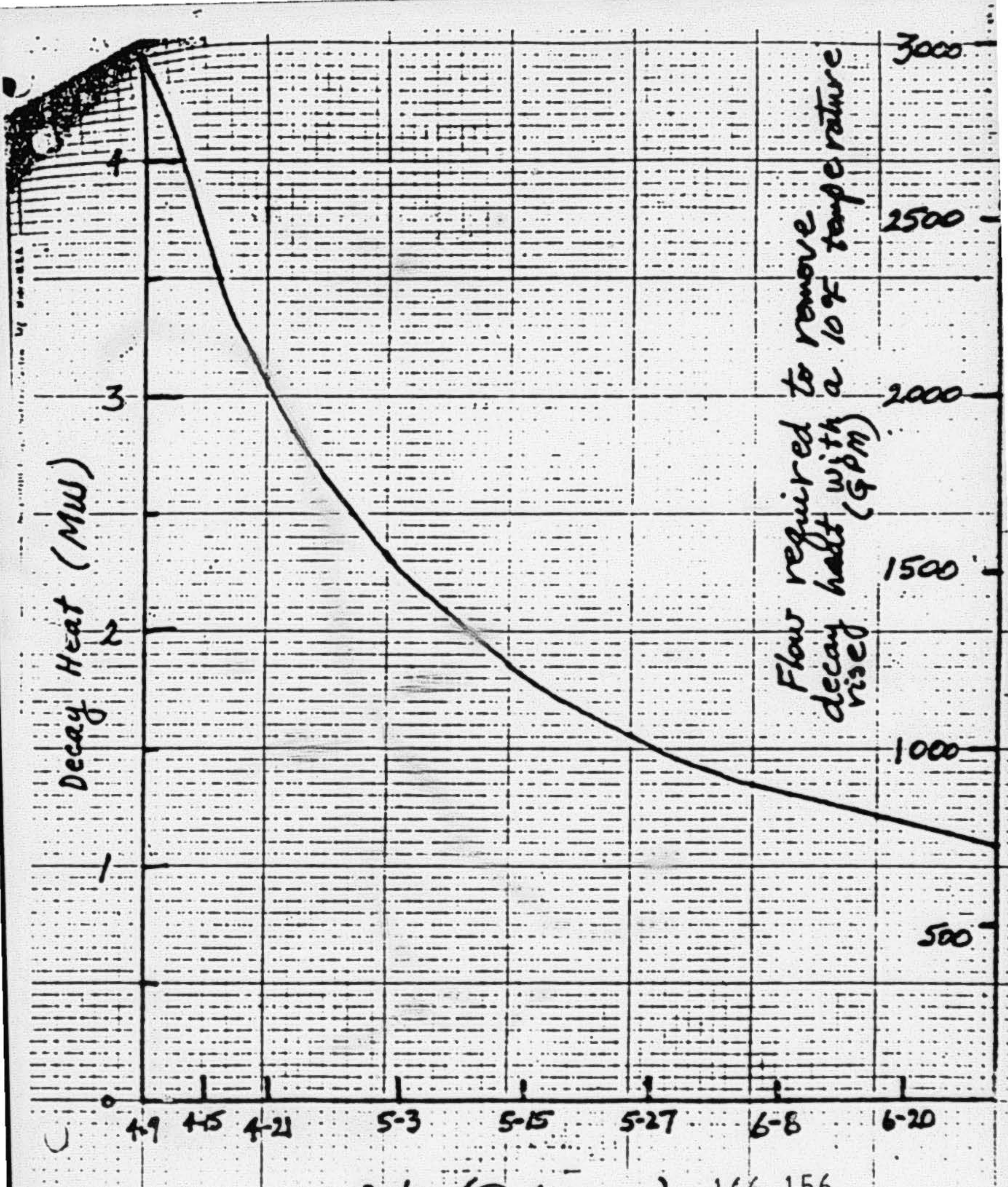

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Figure 1

Equilibrium

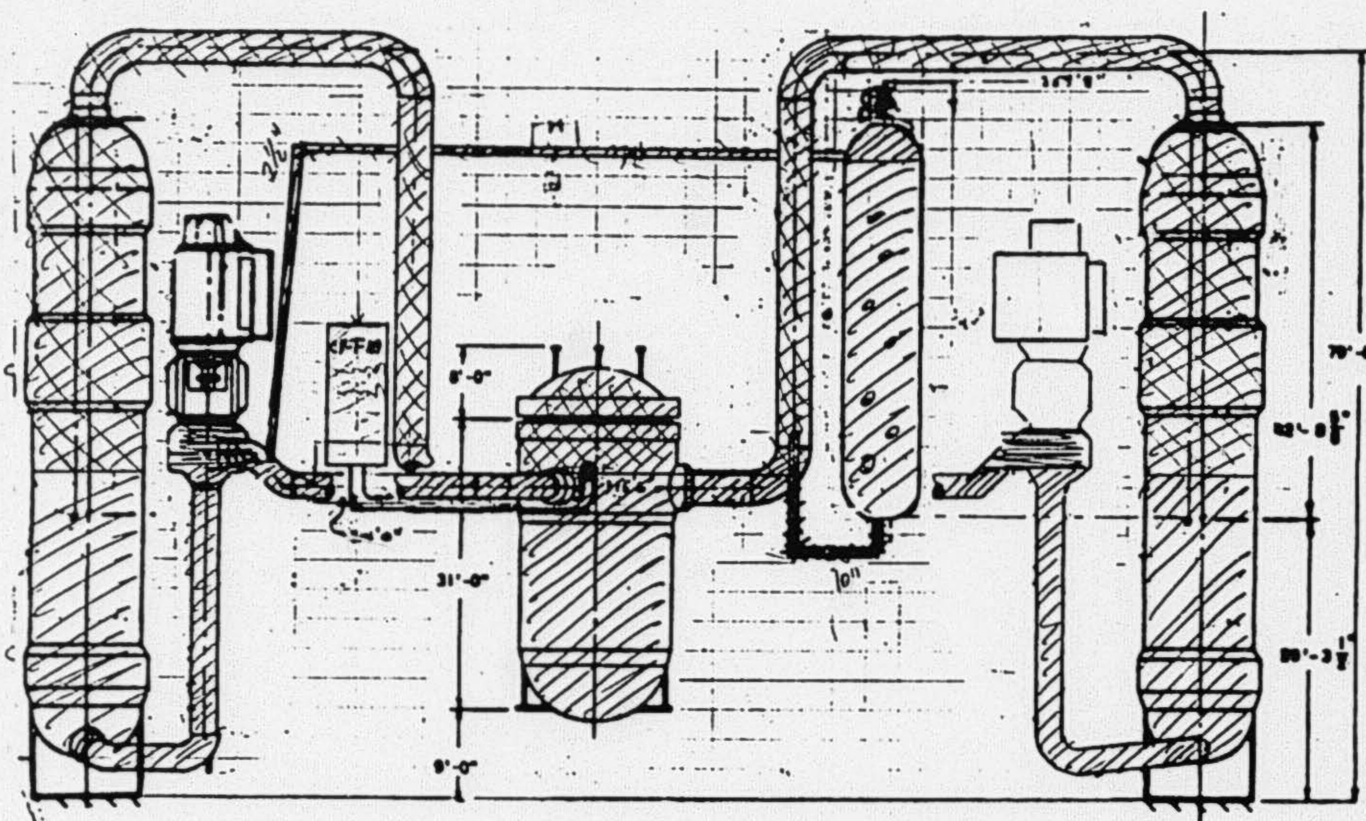

Fig 2

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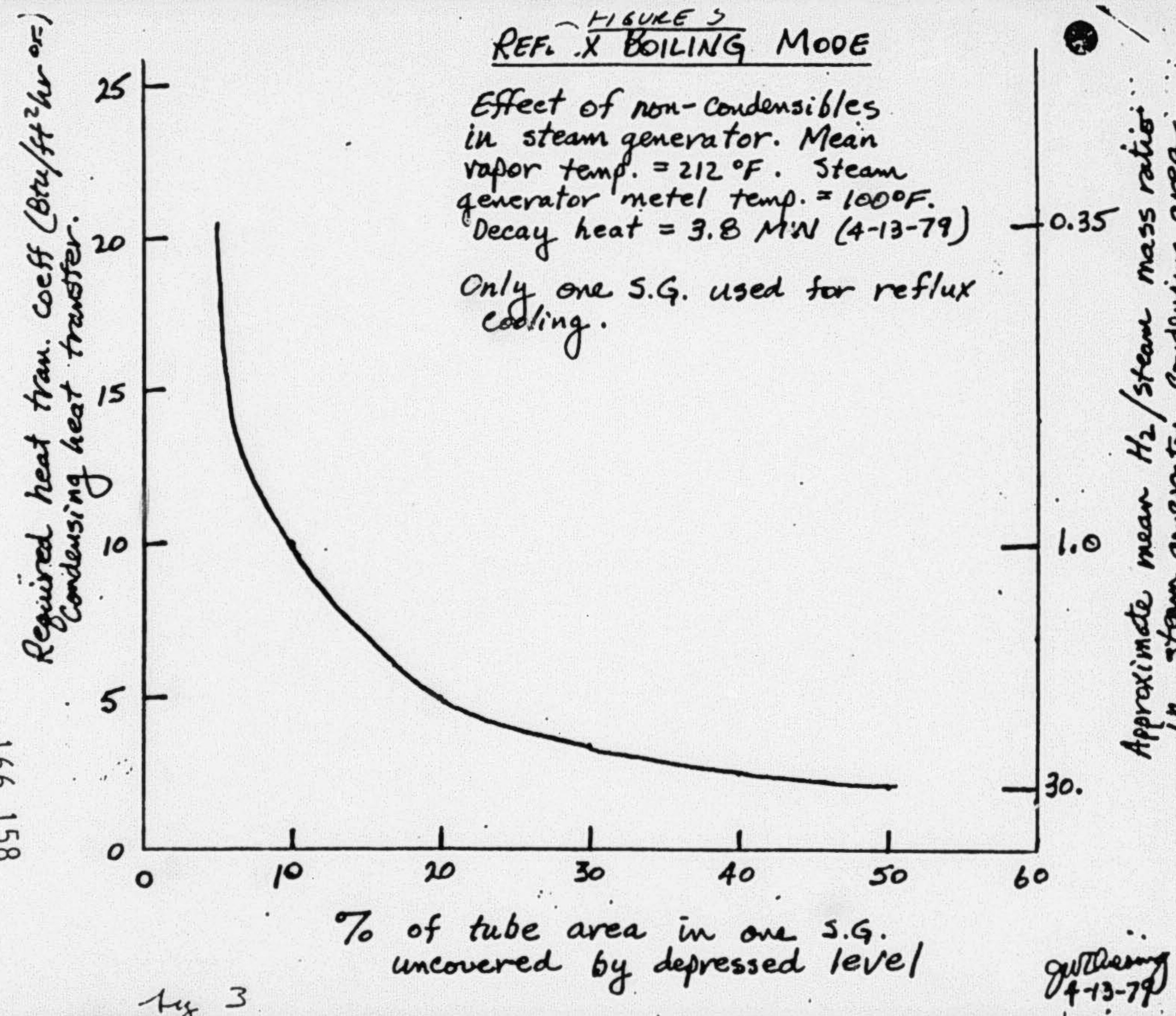
FIGURE 3
REF. X BOILING MODE
Effect of non-condensibles in steam generator. Mean vapor temp. = 212 °F. Steam generator metel temp. = 100°F. Decay heat = 3.8 MW (4-13-79)
Only one S.G. used for reflux cooling.
Required heat tran. coeff (Btu/ft²hr °F) Condensing heat transfer.
25
20
15
10
5
0
0
10
20
30
40
50
60
% of tube area in one S.G. uncovered by depressed level
0.35
1.0
30.
Approximate mean H2/steam mass ratio in steam generator. Condensing area
4-13-79
fig 3

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