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CORE-POWER AND DECAY-TIME LIMITS FOR DISABLED AUTOMATIC-ACTUATION OF LOFT ECCS

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LOFT TECHNICAL REPORT
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SUMMARY

The Emergency Core Cooling System (ECCS) for the LOFT reactor may need to be disabled for modifications or repairs of hardware or instrumentation or for component testing during periods when the reactor system is hot and pressurized, or it may be desirable to enable the ECCS to be disabled without the necessity of cooling down and depressurizing the reactor.

A policy involves disabling the automatic-actuation of the LOFT ECCS, but still retaining the manual-actuation capability. Disabling of the automatic-actuation can be safely utilized, without subjecting the fuel cladding to unacceptable temperatures, when the LOFT power decays to 33 kW; this power level permits a maximum delay of 20 minutes following a LOCA for the manual-actuation of ECCS.

For the operating power of the L2-2 Experiment, the required decay-periods (with operating periods of 40 and 2000 hours) are about 21 and 389 hours, respectively. With operating periods of 40 and 2000 hours at Core-I full power, the required decay-periods are about 42 and 973 hours, respectively. After these decay periods the automatic actuation of the LOFT ECCS can be disabled assuming a maximum delay of 20 minutes following a LOCA for the manual actuation of ECCS. The automatic and manual lineup of the ECCS may be waived if decay power is less than 11 kW.

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TABLE

I. STATEMENT OF PROBLEM

An extension of the analysis of LTR-113-47[1] was requested to determine the LOFT decay-heat power at which the automatic-activation function of ECCS can be disabled, but still retaining the manual-actuation capability. Specifically requested was the determination of the LOFT decay-heat power level at which the automatic ECCS-delivery capability can be disabled for 30 minues without the potential of subjecting the fuel cladding to unacceptable temperatures.

II. SAFETY CRITERIA[2]

"The criteria used for determining when the ECCS would not be needed following a loss of coolant was a maximum (peak) fuel clad temperature of less than 1650°F. This maximum clad temperature (TMAX) is obtained from the damage criteria established for the LOFT Technical Specifications[11] for Infrequent Incidents (Unlikely Faults). Loss of coolant accidents are considered to have a qualitative probability for occurrence less than that for a Limiting Fault (or Extremely Unlikely Fault) for both the LOFT reactor and for the nuclear industry. The damage criteria specified in the LOFT Technical Specifications for Limiting Faults would allow TMAX to be up to 2200°F as long as no more than 244 fuel pins have a clad temperature exceeding 1900°F (see Reference 11 for other limiting conditions for the Limiting Fault damage criteria). Therefore, use of TMAX < 1650°F is a conservative and sufficient criteria for use in determining when ECCS would not be required following a loss of coolant. With a maximum clad temperature of 1650°F a small amount of damage may exist to some of the LOFT fuel pins but any significant fuel pin perforation would not be expected.

III. METHOD OF ANALYSIS

The initial calculational considerations involved the simultaneous natural-circulation air-cooling and the temperature-rise of the LOFT fuel and cladding, during the specified 30-minute period. Reference 4 was to be the basis for evaluating the transient natural-circulation air-cooling. During preparations for this complex transient analysis, it was found that the energy absorption by the fuel and cladding was sufficiently greater than the heat dissipation to the air as to make unnecessary the carrying-out of the combination calculation. The calculation then required is establishing the LOFT decay-heat power which would raise the average fuel-and-cladding temperature from 580 to 1008°F in 30 minutes. The initial temperature of 580°F is the estimated average fuel-and-cladding temperature while the PCS water was removing the decay heat. The average core temperature of 1008°F is based on a limiting clad temperature of 1650°F[2] and a peak-to-average ratio of 2.5[3].

A second calculation was performed based on the same limiting clad temperature of 1650°F, but a peak-to-average ratio of 5.2 to be consistent with the assumptions of Reference 15 for Mode 5 operations. The calculation assumed a local volumetric heat generation rate 5.2 times the core average and computed the power necessary to increase the hot spot temperature from 585°F to 1650°F in 30 minutes.

These two methods, which consider only the sensible-heat absorption in the fuel and cladding, include two areas of conservatism. As mentioned above, no credit was taken for the heat dissipation to the natural-circulation air. In the fuel-and-clad heat-up calculation, the thermal conductivities of the UO_2 and Zr-4 were assumed to be infinite; with the low actual thermal conductivity of UO_2, a significant fraction of the heat produced would still be present in the UO_2 at the end of the 30-minute period.

IV. ANALYSIS RESULTS

The mass of UO_2 in LOFT Core-I is 3256[16] pounds; the mass of Zr-4 in the 66-inch core length is 607 pounds. The heat capacities of UO_2[5] and Zr-4[6], as a function of temperature, are given in Figure 1. Therefore, a decay-heat power of 67 kw and a peak-to-average power ratio of 2.5 would raise the average temperature of the LOFT core from 580 to 1008°F in 30 minutes. A peak-to-average power rato of 5.2 results in an allowable decay power of 33 kw to prevent clad temperatures in excess of 1650°F in 30 minutes.

The 67 kw value of decay-heat power needs to be discounted for the potential inaccuracy in decay power calculations or in measuring reactor power at very low power levels. For shutdown (decay) times between 10^3 and 10^7 seconds, the decay power as calculated by the curves of equations of References 7 and 10, may have an uncertainty of +10% to -20%. The inaccuracy in knowing the reactor power level is unlikely to be significantly greater than this. Because of the conservatisms already present in the method of calculation (Section III), a discounting of 10.5 percent appears adequate. Therefore, the limiting decay-heat power is 60 kw. The 33 kw value of decay power has sufficient conservatism inherent in using 5.2 as the peaking factor.

Decay-power fractions, $P(t)/P_0$, as functions of reactor operating times and decay times and based on ANS Standard 5.1[7], are given in Figure 2[8,10]. The nominal and upper-limit LOFT powers for the L2-2 Experiment are 25 and 28 MW, respectively[9]. The Core-I nominal and upper-limit powers are 50 and 53 MW. Based on the acceptable decay-heat power of 33 kw for peak-to-average power ratio $(P/A) < 5.2$, the $P(t)/P_0$ ratios for the L2-2 and Core-I situations are 0.00118 and 0.000623, respectively. The decay periods required before ECCS-disable, with reactor operating periods of 40, 200 and 2000 hours, are given in Table I. These requirements cover any mode of reactor operation including Mode 5.

Based on the decay-heat power of 60 kw for peak-to-average power ratio ≤ 2.5, the $P(t)/P_0$ ratios for the L2-2 and Core-I situations are 0.00214 and 0.00113, respectively. The decay periods required before ECCS-disable, with reactor operating periods of 40, 200 and 2000 hours, are given in Table II.

Although the above analysis demonstrates that 30 minutes is adequate to prevent fuel clad temperature from exceeding 1650°F, it is recommended that manual actuation of the ECCS be initiated within 20 minutes of a LOCA. This allows 10 minutes for core refill to at least the top of the fuel. This 10-minute period is considered sufficient to allow for core refill in the event that the RABVS are disabled and steam binding is present as is discussed in the following Section V.

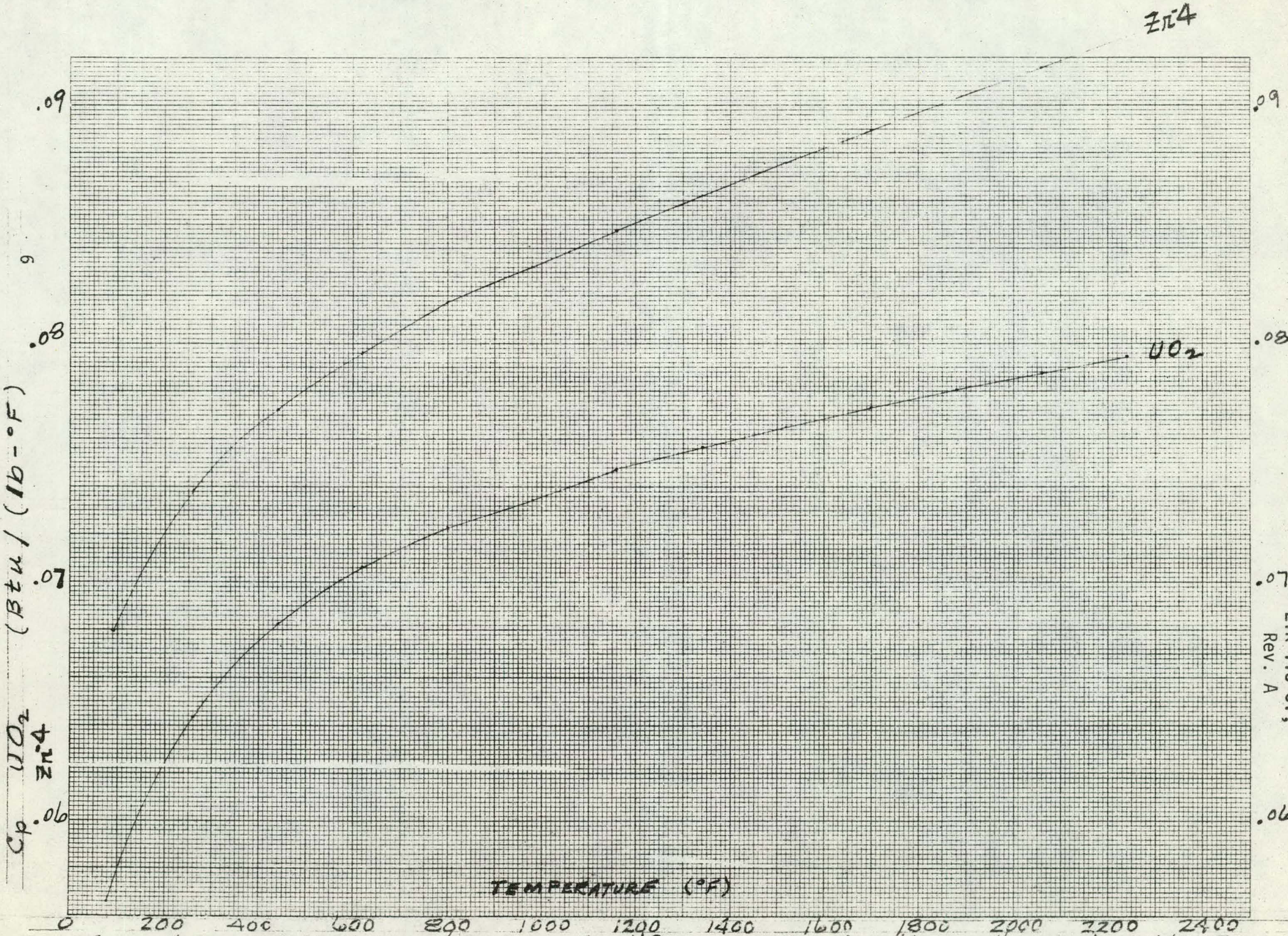

FIG. 1 SPECIFIC HEATS OF UO_2 AND ZR-4 (REACTOR HANDBOOK) GHH 3-78

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FIG. 1 DECAY-ENERGY RELEASE RATES ANS-5.1/N18.6 (OCT 73); H.F.RH 1978

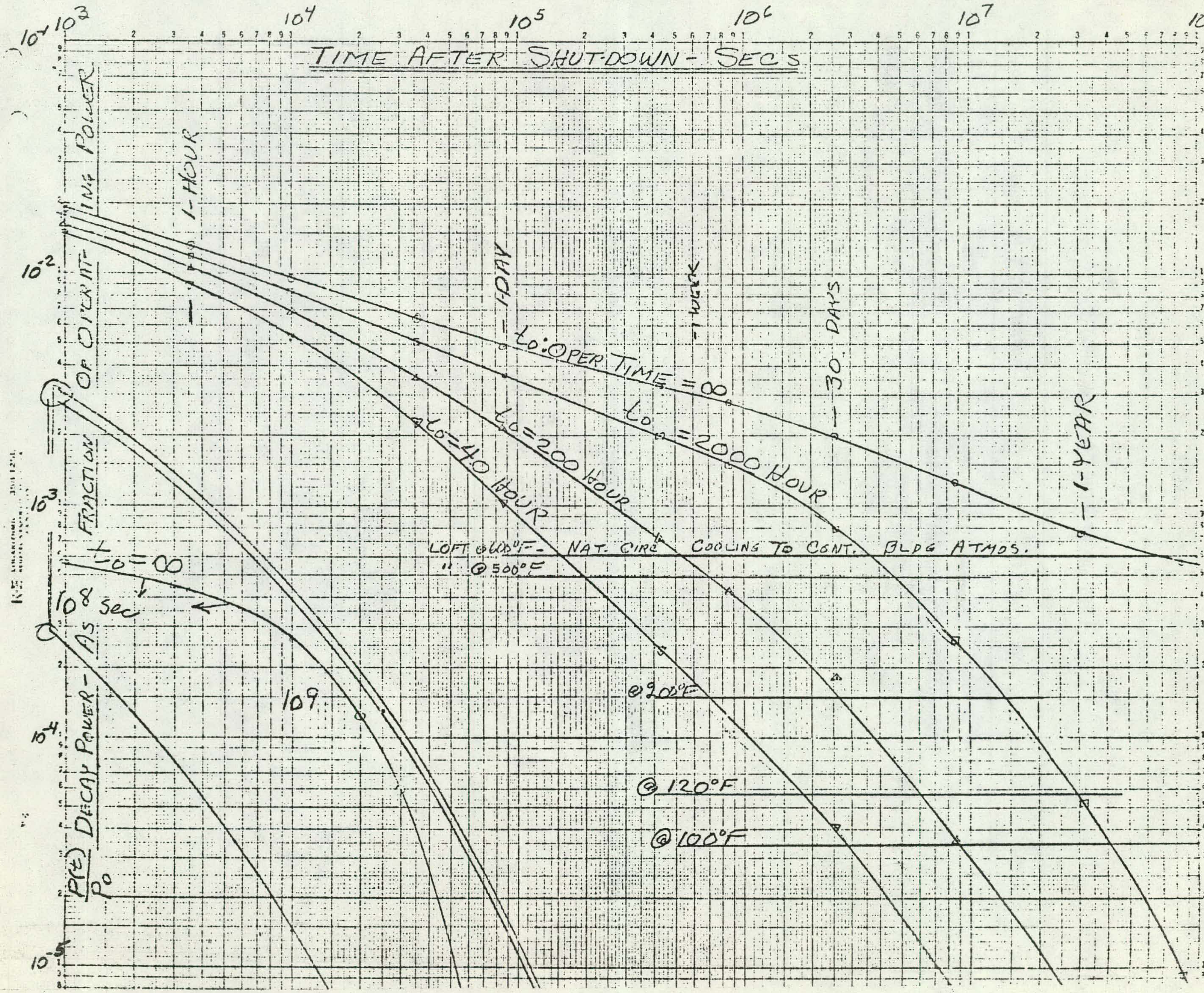

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TABLE I

P/A < 5.2

LOFT DECAY TIME TO 33 KW, HOURS

	OPERATING POWER, MW		OPERATING TIME, HOURS		
	Nominal	Upper Off-Nominal	40	200	2000
L2-2	25	28	20.6	55.6	388.9
Core-I	50	53	41.7	138.9	972.2

TABLE II

P/A ≤ 2.5

LOFT DECAY TIME TO 60 KW, HOURS

	OPERATING POWER, MW		OPERATING TIME, HOURS		
	Nominal	Upper Off-Nominal	40	200	2000
L2-2	25	28	10.6	23.3	97.2
Core-I	50	53	21.4	61.1	430.6

V. CORE-REFLOOD AND PLENUM-REFILL CONSIDERATIONS

Reference 12 shows that the reflood-rate without a bypass (e.g. with RABV disable) would be 0.6 in/sec following a LOCA from full power. The time required to reflood the 66-inch core length is 110 seconds or about 2 minutes. The core volume-reflood-rate is 0.1 ft^3/sec (10.7 ft^3 ÷ 110 seconds).

The above core-reflood rate of 0.6 in/sec is the net result of complex thermal-hydraulic phenomena associated with the introduction of ECC following a LOCA or LOCE.

An analysis for LOFT-structural sensible-heat removal following a LOCA or LOCE and ECC injection is reported in Reference 13. The time-variation of the sensible-heat removal rate from the vessel and vessel structural components, based on information in Table 2[(13)], is given in Table III. The sensible-heat removal rates reported here are 45 to 212 times greater than the core heat generation rate with a core decay power of 60 kW, in the time period of 1 to 12 minutes after ECC injection (reflood) begins. That is, when ECC is injected after a 20-min. delay when core decay power is only 60 kW, the sensible-heat removal rate will dominate the heat transfer to the ECC, and the contribution of the core decay power will be negligible.

Before core reflooding can be accomplished, the bottom plenum must be refilled. The LOFT L1-3 Experiment, representing a 200% cold-leg break with a system temperature of 540°F, showed that the bottom plenum was over half-full following the experiment.[(14)] Applying the core volume-rate-of-reflooding (0.1 ft^3/sec) to the refilling of the 22.7-ft^3 bottom plenum yields a refill-time of 114 seconds (0.5x22.7 ÷ 0.1) or about 2 minutes.

Therefore, a total period of 10 minutes is sufficient for plenum-refill and core-reflood to the top of the fuel, when the RABV's are disabled.

TABLE III

TIME-VARIATION OF SENSIBLE-HEAT REMOVAL

Time	Sensible Heat Removal Rate, MW
3.6 s	24.0
21.6 s	27.0
50.4 s	12.7
2.4 min	8.2
6.0 min	4.3
12.0 min	2.7

VI. CONCLUSION

Disabling of the automatic-actuation of ECCS can be utilized when the LOFT power decays to 33 kw. For the L2-2 Experiment operating power, the required decay-periods (with operating periods of 40 and 2000 hours) are about 21 and 389 hours, respectively. With operating periods of 40 and 2000 hours at Core-I full power, the required decay-periods are about 42 and 973 hours, respectively. After these decay periods the automatic actuation of the LOFT ECCS can be disabled assuming a maximum delay of 20 minutes following a LOCA for manual actuation of ECCS. This 20 minutes includes an allowance for ECCS to refill to above the top of the fuel.

The automatic and manual lineup of the ECCS may be waived if decay power $\leq$ 11 kW. Ninety minutes would be available to lineup and start ECCS before peak clad temperature would reach 1650°F. Since adiabatic heatup of the fuel under the above conditions with a 33 kW heat source results in 30 minutes before the peak clad temperature would reach 1650°F, a heat source of 11 kW with adiabatic heatup would cause the peak clad temperature to reach 1650°F in 90 minutes. This follows directly from the fact that with the 11 kW heat source it takes three times longer to get the same energy input to raise the peak clad temperature to 1650°F as with the 33 kW heat source.

VII. REFERENCES

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