LOFT TECHNICAL REPORT LTR 1119-40

RE&C INTERNAL REPORT RE-A-78-068

OCTOBER 31, 1978

FATIGUE LIFE
OF
LOFT REACTOR VESSEL COMPONENTS

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DEPARTMENT OF ENERGY

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RE&C Report # RE-A-78-068
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RESEARCH, ENGINEERING AND CONSTRUCTION REPORT ENGINEERING ANALYSIS DIVISION

APPLIED MECHANICS BRANCH

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FATIGUE LIFE OF LOFT REACTOR

VESSEL COMPONENTS

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In Appendix A, the table of Upset Operating Conditions lists the Operating Basis Earthquake as 0.8 g horizontal and 0.4 g vertical input to the reactor vessel. The list was taken from ANC Specification MS-201, "Reactor Vessel, Loss of Fluid Test Facility". DOE-ID is considering an EG&G recommendation to change the LOFT Operating Basis Earthquake from 0.17 g to 0.015 g. Upon approval, the specification will be revised accordingly. No revision will be made to this LTR; the analysis herein conservatively envelopes the proposed change.

LOFT TECHNICAL REPORT
LOFT PROGRAM

FORM EG&G-229
(Rev. 12-78)

TITLE FATIGUE LIFE OF LOFT REACTOR VESSEL COMPONENTS		REPORT NO. LTR 1119-40
		RE-A-78-068
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PSE RCB Mgr.	FE&OB Mgr. PSB Mgr.	LESD Mgr. P&CSB Mgr.

ABSTRACT

This report provides calculated LOCE lifetimes of the LOFT Reactor Vessel Components. For each component, lifetime is defined as the greatest number of LOCE transient cycles and/or other non-LOCE transient cycles such that cumulative usage factor does not exceed 1.0. The results are presented in tabular form. The results indicate that transients other than LOCE transients govern with or instead of LOCE transients for some components. The other transients are shown in the results.

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FATIGUE LIFE OF LOFT REACTOR VESSEL COMPONENTS

I. INTRODUCTION

The purpose of this report is to summarize the fatigue analyses performed to date on the LOFT reactor vessel. The results will form the basis for re-qualification of reactor vessel components by modifying the design and operating criteria. The scope of this study covers the following components:

- (1) Hot leg nozzle and adjacent shell
- (2) Reactor shell below supports
- (3) Reactor shell above supports
- (4) Instrument penetration head bolts
- (5) Closure head bolts
- (6) ECCS head nozzle
- (7) ECCS head nozzle studs
- (8) CRDM nozzle
- (9) CRDM nozzle studs
- (10) Cold leg nozzle.

The results from the previous analyses are presented in Tables I through X.

TRANSIENT	MAXIMUM STRESS INTENSITY	MINIMUM STRESS INTENSITY	ALTERNATING STRESS AMPLITUDE, S_a	$K_t S_a$	CYCLES, n	ALLOWABLE CYCLES N	USAGE FACTOR $U = \frac{n}{N}$
* HEAT UP/LOCE	229,000	-	114,500	114,500	(260)	808	.322
** OTHER TRANSIENTS *	-	-	-	-	-	-	.003
						> 260 LOCE CYCLES	.325 < 1.0

2 * ALTHOUGH NOT STATED IN DETAIL, THE HEAT UP/LOCE CYCLE IS ASSUMED TO CONTRIBUTE A MAJOR PART OF THE FATIGUE LIFE.

** CONTRIBUTIONS FROM THE OTHER TRANSIENTS ARE ASSUMED TO BE NEGLIGIBLE AND HENCE WERE NOT LISTED IN REFERENCE (1).

TABLE I. HOT LEG NOZZLE - REF(1), PAGE 3.8-30

TRANSIENT	MAXIMUM STRESS INTENSITY (RANGE)	MINIMUM STRESS INTENSITY	ALTERNATING STRESS AMPLITUDE, S_a	$K_c S_a$	CYCLES m	ALLOWABLE CYCLES N	USAGE FACTOR $U = \frac{m}{N}$
OBE (BASED ON FIRST PEAK)	164879	1	82440	103710	30	540	.0555
HEAT UP/LOCE (BASED ON FIRST PEAK)	159234	-	79617	100158	(230)	580	.3966
HEAT UP/COOL DOWN	6819	-	3410	4290	1500	∞	0
HYDROTEST	6245	-	3123	3928	15	∞	0
PLANT UNLOAD	5652	-	2826	3555	2020		
	4653	-	2326	2925	1760		
	3432	-	1716	2158	260		
	2214	-	1107	1392	6960		
HYPOTHETICAL	1555	-	777	977	3750	∞	0
COLD LEAK	1155	-	577	725	290		
PLANT LOAD	899	-	450	566	3750		
	98	-	49	62	7220	∞	0
ZERO TIME STRESS	0	-	0	0	2020		
REMAINING LOCE (4 PEAKS)	94485	-	47243	59431	1040	2400	.4333
REMAINING OBE (4 PEAKS)	5645	-	-	-	120	∞	0
						7260	.8954 < 1.0

TABLE II. REACTOR SHELL BELOW SUPPORTS - REF (2), PAGE 213

TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_c = 1.0$ $K_c S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$	COMMENTS
HEAT UP/COOL DOWN	162328	81164	81164	1500	2500	.6000	C.D.(336), HU(334.2)
HEAT UP/LOCE	140872	70436	70436	(260)	4400	.0591	LOCE(2.0), HU(334.2)
HYDROTEST/LOCE	94768	47384	47384	15	25000	.0006	HYDRO, LOCE(240)
LOADING/LOCE	84400	42200	42200	245	50000	.0049	LOAD(30), LOCE(240)
LOADING/LOCE	82652	41326	41326	260	60000	.0043	LOAD(30), LOCE(30)
LOADING/HYDRO	76868	38434	38434	275	70000	.0039	LOAD(30), HYDRO(0)
LOADING/LOCE	67472	33736	33736	780	150000	.0052	LOAD(30), LOCE(S.S.)
LOADING/LOCE	60836	30418	30418	260	350000	.0007	LOAD(30), LOCE(S.S.)
LOADING/HYPOTH.	37988	18994	18994	3750	∞	0	LOAD(30), HYPO(60)
LOADING/LOCE	37164	18582	18582	260			LOAD(30), LOCE(.025)
LOADING/LOCE	30516	15258	15258	260			LOAD(30), LOCE(.1167)
LOADING/UNLOAD	28924	14462	14462	4910			LOAD(30), UNL(60)
HYPOTHETICAL/UNLOAD	17348	8674	8674	3750			HYPO(1.2), UNL(60)
COLD LEAK/UNLOAD	15144	7572	7572	260			C.L.(85), UNL(60)
LOADING/UNLOAD	14180	7090	7090	2080			LOAD(0), UNL(60)
HEAT UP/HOT LEAK	76	38	38	260			H.U.(S.S.), H.L.(S.S.)
LOADING/UNLOAD	52	26	26	8920			LOAD(S.S.), UNL(S.S.)
LOADING/UNLOAD	0	0	0	1040			LOAD(0), UNL(S.S.)
					>260	.6787 <	1.0

TABLE III REACTOR SHELL ABOVE SUPPORTS - REF (2), PAGE 626

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TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_c = 1.0$ $K_c S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$	COMMENTS
HEAT UP/LOCE	187274	93637	93637	(275)	1150	.2391	H.U./LOCE (334.2)
H.U./LOCE/COOL DOWN	129006	64503	64503	1485	2400	.6188	H.U. LOCE (334.2) COOL DOWN (336)
HYDROTEST/COOL DOWN	42032	46019	46019	15	4800	.0031	HYDRO(0), CD (336)
LOADING/LOCE	32883	16442	16442	260	230000	.0011	LOAD, LOCE (-233)
LOADING/COLD LEAK	32578	16289	16289	780	230000	.0034	LOAD, C.L.
LOADING/HYPOTH.	26046	13023	13023	3750	∞	0	LOAD, HYPOTHETICAL
HYPOTHETICAL HOT LEAK COLD LEAK LOADING UNLOADING	< 26046	< 13023	< 13023	-			
					> 260	.866 < 1.0	

TABLE IV. INSTRUMENT PENETRATION HEAD BOLTS - REF (2) - PAGE 647

TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_c = 1.0$ $K_c S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$	COMMENTS
HEAT UP/LOCE	298349	149175	149175	(275)	480	.5729	
H.U./LOCE, COOL DOWN	238360	119180	119180	1485	700	(2.1214)	
HYDROTEST/C.D.	208318	104519	104519	15	950	.0157	
LOADING, H.U./LOCE	109186	54593	54593	260	3500	.0742	
LOADING, H.U./LOCE	102020	51010	51010	260	3500	.0742	
LOADING, H.U./LOCE	101487	50744	50744	520	4000	.1300	
LOADING, H.U./LOCE	42587	46294	46294	260	4800	.0541	
LOADING, HYPOTHETICAL	55565	27783	27783	3750	19000	.1973	
LOADING/UNLOAD	40799	20400	20400	5950	70000	.0850	
HYPOTH/UNLOAD	28715	14358	14358	3750	600000	.0062	
COLD LEAK/UNLOAD	26870	13435	13435	260	10^6	.0002	
HOT LEAK/UNLOAD	21075	10538	10538	260	∞	0	
					< 260	(3.3318) > 1.0	

TABLE V. CLOSURE HEAD BOLTS - REF (2) - PAGE 653

TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_t = 3.33$ $K_t S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$	COMMENTS
HEAT UP/LOCE	131686	65843	219477	(260)	125	2.080	
LOAD, H.U./LOCE	27750	13875	46248	260	31000	.008	
LOAD, H.U./LOCE	23738	11869	39563	260	70000	.004	
LOAD/UNLOAD	17728	8964	29880	10220	350000	.029	
HEAT UP/COOL DOWN	17920	8960	29866	780	350000	.002	
HYPOTHETICAL	16500	8250	27500	980	700000	.001	
HEAT UP/COOL DOWN HYDROTEST HOT/COLD LEAK BOLT UP	9858	4929	16430	2310	∞	0	
					<260 LOCE	(2.124) >1.0	

TABLE VI - ECCS HEAD NOZZLE - REFERENCE (3), PAGE 148-153

TRANSIENTS	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_c S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$
PLANT LOAD / NULL CASE	154930	77465	77465	275	1100	.25000
PLANT LOAD / LOCE	154930	64687	64687	(260)	1500	.17333
PLANT LOAD / COOL DOWN	154930	26482	26482	1500	7500	.20000
PLANT LOAD / BOLT LOAD	154930	23483	23483	275	9000	.030556
PLANT LOAD / DESIGN PRESS.	154930	23432	23432	15	9000	.001667
PLANT LOAD / HYDRO. PRESS.	154930	23420	23420	15	9000	.001667
PLANT LOAD / COLD LEAK	154930	23395	23395	260	9000	.028889
PLANT LOAD / HYDRO LEAK	154930	23385	23385	15	9000	.001667
PLANT LOAD / BOLT LOAD	154930	23329	23329	275	9000	.030556
PLANT LOAD / UNLOAD	154930	17338	17338	8110	15000	.540667
HEAT UP / UNLOAD	147279	13512	13512	1500	25000	.06000
HYPOTHETICAL / UNLOAD	142087	10916	10916	1390	40000	.03475
HYPOTHETICAL	142087	9130	9130	2620	70000	.037429
HYPOTHETICAL	138935	7554	7554	1130	170000	.006647
HYPOTHETICAL	138935	2165	2165	2620	∞	0

TABLE VII ECCS HEAD STUDS - REFERENCE (3), PAGE 174, 175, 192

2260

$U = 1.3978$

1.0

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TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_t S_a$	M CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{M}{N}$	COMMENTS
HEAT UP/COOL DOWN	68709	34355	66320	1500	6000	.25000	
UNLOAD	47229	23615	55580	535	13000	.041154	
UNLOAD	47229	12885	44850	260	30000	.008667	
UNLOAD	47229	12020	43985	10205	30000	.340167	
HEAT UP/LOCE	42385	9598	41563	(260)	50000	.00520	
HYPOTHETICAL	41319	9065	41030	535	50000	.01070	
HYPOTHETICAL	41319	7078	39043	260	70000	.003714	
HYPOTHETICAL	41319	6116	38081	780	75000	.01040	
HYPOTHETICAL	41319	4925	36890	2175	100000	.02175	
HYDROTEST	39864	4197	36162	15	100000	.00015	
HEAT UP/LOCE	36488	2509	34474	1560	150000	.01040	
LOAD	36488	2032	33997	3750	150000	.02500	
HYPOTHETICAL	36488	1637	33602	260	150000	.001733	
HOT LEAK	36488	1306	33271	9700	150000	.064667	
COLD LEAK	35587	855	32820	260	200000	.00130	
COLD LEAK	35587	0	31965	520	200000	.00260	

TABLE VII - CRDM NOZZLE - REFERENCE (3), PAGE 493-498

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TRANSIENT	STRESS INTENSITY RANGE	ALTERNATING STRESS AMPLITUDE, S_a	$K_c S_a$	m CYCLES	N ALLOWABLE CYCLES	USAGE FACTOR $U = \frac{m}{N}$	COMMENTS
HYDROTEST	309545	154773	154773	15	325	.046154	
HOT LEAK	309094	154547	154547	260	325	.80000	
COLD LEAK	303382	29867	29867	260	6500	.04000	
HEAT UP/COOL DOWN	299293	26191	26191	1500	7800	.192308	
HEAT UP/LOCE	299293	25660	25660	260	7800	.03333	
LOAD	298944	25485	25485	275	7800	.035256	
LOAD	298944	25388	25388	275	7800	.035256	
LOAD	298944	23544	23544	260	9100	.028571	
LOAD	298944	11988	11988	3750	34000	.110294	
LOAD	298944	7587	7587	6440	150000	.042933	
HYDROTEST	297443	6836	6836	15	250000	.000060	
	-	-	-	-	∞	0	
					< 260	1.3642 > 1.0	

TABLE IX - CRDM NOZZLE STUD - REFERENCE (3). PAGES 536-539

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TRANSIENT	MAXIMUM STRESS INTENSITY	MINIMUM STRESS INTENSITY	ALTERNATING STRESS AMPLITUDE, S_a	$K_c S_a$	CYCLES, m_i	ALLOWABLE CYCLES, N_i	USAGE FACTOR $U = \frac{m}{N}$
* HEAT UP/LOCE	226504	-	113,252	113,252	(260)	880	.29545
ORE	109622	-	54,811	54,811	30	14000	.00214
HYPOTHETICAL	81924	-	40962	40962	1745	65000	.02685
	60850	-	30425	30425	275	350,000	.00079
	47442	-	23721	23721	1700	106	.0017
						> 260 LOCE CYCLES	.3269 < 1.0

* BASED ON TRANSIENT LOCE L1-1 (FOR HOT LEG NOZZLE), RATHER THAN DESIGN LOCE FOR COLD LEG NOZZLE. THE L1-1 TRANSIENT IS MORE SEVERE THAN THE DESIGN CONDITION.

TABLE X. COLD LEG NOZZLE - REF (4) PAGE 45

II. PROCEDURE

The transients used to represent the various design and operating conditions are listed in Appendix A. The method for determining the allowable number of LOCE cycles is outlined in a previous report, Reference (5), and summarized in this report. New stress calculations were not initiated for this report, relying entirely upon the conclusions of References 1, 2, 3, and 4.

The cumulative usage factor, u , is used as a measurement of the fatigue damage due to the various loading conditions. The usage factor is defined by the following relation,

$$u = \sum_{i=1}^{\text{all}} \frac{n_i}{N_i}$$

where

n_i = number of design cycles

N_i = number of allowable cycles based upon the alternating stress intensity, S_a

$$S_a = K_e \frac{S_p}{2}$$

S_p = maximum difference between principal stresses

K_e = stress concentration factor.

The cumulative usage factor must not exceed 1.0 in compliance with the requirements of Paragraph NB-3222.4(e) of the ASME Boiler and Pressure Vessel Code^[6].

To find the LOCE life or allowable number of LOCE cycles for each component, the usage factor is set equal to 1.0. The maximum number of all other transients is assumed to have occurred, therefore, the only unknown factor is the number of LOCE cycles. In certain cases, the dominating transient is limited along with a minimum number of LOCE cycles, as noted in Table XI.

TABLE XI LOCE LIVES

REGION OF VESSEL	TABLE	LOCATION OF MAXIMUM STRESS	FIG.	LOCE CYCLES	OTHER DOMINANT* CYCLES
HOT LEG NOZZLE	I	CUT 3, INSIDE SURFACE	1	805	
REACTOR SHELL BELOW SUPPORTS	II	CUT 2, INSIDE SURFACE	2	262	
REACTOR SHELL ABOVE SUPPORTS	III	CUT 1, INSIDE	3	1673	
INSTR. PENETRATION HEAD BOLT	IV	TOP, INSIDE	4	429	
CLOSURE HEAD BOLT	V	BOTTOM, OUTSIDE	5	37	HEATUP/COOL DOWN 200
ECCS HEAD NOZZLE	VI	CUT 5, INSIDE	6	119	
ECCS HEAD NOZZLE STUD	VII	TOP, INSIDE	6	142	PLANT LOAD 7340
CRDM NOZZLE	VIII	CUT 1, INSIDE	7	10,381	
CRDM NOZZLE STUD	IX	BOTTOM, INSIDE	7	**	HOT LEAK 141
COLD LEG NOZZLE	X	CUT 1 INSIDE	8	852	

* CYCLES LIMITED TO LESS THAN THE MAXIMUM NUMBER.

** 260 CYCLES ASSUMED WHICH ADDS A MINIMAL AMOUNT TO THE FATIGUE LIFE.

Tables XI and XII summarize the LOCE cycles and reference used, respectively. Calculations for the number of LOCE cycles can be found in Appendix B.

Figures 1 through 8 show the finite element models, developed for previous reactor vessel component analyses. Indicated are the respective locations of maximum stress, upon which the cumulative usage factors were based.

TABLE XII SUMMARY OF REFERENCES USED

TABLE	REGION OF R. VESSEL	REF.	PAGE LOCATION OF REF.		
			TRANSIENT	LISTING	ORDERING
I	HOT LEG NOZZLE	1	3.8-3 to 3.8-16	3.8-22	3.8-30
II	REACTOR SHELL BELOW SUPPORTS	2	202, 203	206-209	213
III	REACTOR SHELL ABOVE SUPPORTS	2	623, 624	625	626
IV	INSTR. PENETRATION HEAD BOLTS	2	646	647	647
V	CLOSURE HEAD BOLT	2	649, 650	652	653
VI	ECCS HEAD NOZZLE	3	1149	149-152	153
VII	ECCS HEAD NOZZLE STUDS	3	173	174, 175	192
VIII	CRDM NOZZLE	3	468-472	493, 494 497	498
IX	CRDM NOZZLE STUDS	3	525	536-8	539
X	COLD LEG NOZZLE	4	39-43	44	45

FIGURE 1

LOFT REACTOR VESSEL NOZZLE
ANALYTICAL MODEL
DETAIL & NOMENCLATUREMAXIMUM
STRESS
(INSIDE
SURFACE)EL. 40
EL. 49

316 STAINLESS STEEL

(ITEM 1)

INCONEL FORGING

EL. 152

EL. 167

EL. 175

EL. 183

EL. 191

CUT 6

INCONEL WELD

ALLOY STEEL VESSEL

FIGURE 2.
REACTOR VESSEL
BELOW SUPPORTS
(ITEM 2)

FIGURE 3

REACTOR VESSEL
ABOVE SUPPORTS
(ITEM 3)

IP HEAD BOLT (NOT TO SCALE)

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STRUCT MODEL

579	580	582
576		525
492	491	494
473	457	475
456	438	458
439	423	441
422	408	424
391	393	393
346	378	348
288	359	290
234	254	236

FIGURE 4.

INSTRUMENT PENETRATION
HEAD BOLT
(ITEM 4)

CLOSURE HEAD BOLT (NTS)

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STRUCTURAL MODEL

FIGURE 5
CLOSURE HEAD BOLT
(ITEM 5)

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ECCS HEAD

11/09/71

ECCS HEAD NOZZLE STUD
(ITEM 7)

ECCS HEAD NOZZLE
(ITEM 6)

CUT 5

Z-AXIS

FIGURE 6.
ECCS HEAD
(ITEMS 6 & 7)

CRDM STU.D
(ITEM 9)

CRDM
NOZZLE

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CUT 5
CUT 4
CUT 3
CUT 2
CUT 7

OVERALL MODEL WITH POLYIN
CUTS SHOWN; CUTS 3, AND 4 ARE
VERTICAL CUTS

CRDM NOZZLE (ITEM 8)
(CUT 1)

CUT 6
CUT 1

FIGURE 7.

CRDM NOZZLE
(ITEMS 8 & 9)

FIG. 8

NOZZLE-VESSEL TRANSITION
(ITEM 10)

INSIDE
SURFACE
(ITEM 10)

III. DISCUSSION OF RESULTS

The results of the fatigue lifetime studies performed on the reactor vessel components are summarized in Table XI. The results in Table XI indicate that the LOCE cycle is not the only transient limiting the fatigue life of the reactor vessel components.

An example of another limiting transient is the heatup/cooldown cycles for the closure head bolts, as found in Table XI. If either 37 LOCE cycles or 200 heatup and/or cooldown cycles are accumulated, then a re-evaluation of the fatigue life of the closure head bolts should be performed.

IV. REFERENCES

1. J. G. Arendts, et al, "Elastic-Plastic Stress Analysis of LOFT Reactor Vessel", LOFT Technical Report LTR 1119-26, Aerojet Nuclear Co., May 15, 1974.
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4. T. C. Yen, "Stress Analysis of the Cold Leg Nozzle of the LOFT Reactor Vessel for LOCE L1-1 Coolant Transient", LOFT Technical Report LTR 1119-36 (RE-A-78-023), to be issued.
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6. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components", Subsection NB, 1977.

APPENDIX A
PRESSURE AND THERMAL TRANSIENTS

1. Normal Operating Conditions
2. Upset Operating Conditions
3. Emergency Operating Conditions
4. Faulted Operating Conditions

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TABLE IIPRESSURE & THERMAL TRANSIENTS
NORMAL OPERATING CONDITIONS

<u>Transient</u>	<u>Rate or Value</u>	<u>No. of Cycles</u>	<u>Figure</u>
Heatup and Cooldown	100°F/hr	1,500	1
Opening and Closings	--	260	N/A
Steady-State Fluctuations			
Temperature	+6°F	10 ⁶	N/A
Pressure	+100 psi	10 ⁶	N/A
Flow	+5%	10 ⁶	N/A
Load Change	0 - 100%-0	11,000	2

UPSET OPERATING CONDITIONS

<u>Transient</u>	<u>Rate or Value</u>	<u>Max. No. of Cycles</u>	<u>Figure</u>
Loss-of-Coolant Experiment (LOCE)	Worst case	260	3
Step Load Change	+10% power	1,000	4
Step Load Rejection	100% power	360	5
Reactor Trip (Scram)	100% power	1,000	6
Loss of Flow	100% power	100	7
Loss of Site Power	100% power	360	8
Cold Hydrostatic Tests	3125 psia	15	N/A
Cold Leakage Tests	2250 psia	260	N/A
Hot Leakage Tests	2250 psia and 610°F	260	N/A
Rod Withdrawal Accident	--	100	9
Control Element Drop	--	100	10
Operating Basis Earthquake	0.8g Horizontal 0.4g Vertical	30 Earthquakes 5 Stress peaks each	N/A

N/A - Not applicable.

TABLE II (contd.)EMERGENCY OPERATING CONDITIONS

	<u>Rate or Value</u>	<u>No. of Cycles</u>	<u>Figure</u>
Design Basis Earthquake (DBE)	1.6 g Horizontal 0.8 g Vertical	1 occurrence from 100% power	N/A

FAULTED OPERATING CONDITIONS

<u>Transient</u>	<u>Rate or Value</u>	<u>No. of Cycles</u>	<u>Figure</u>
Loss-of-Coolant Accident (LOCA)	N/A	1 occurrence from 100% power	N/A
DBE (Deleted)			
LOCA + DBE	N/A	1 occurrence from 100% power	N/A
Complete Loss of Flow Accident with a Locked Pump Rotor	N/A	1 occurrence from 100% power	N/A

APPENDIX B

DETAIL CALCULATIONS FOR FATIGUE LIFETIME

- (1) Hot Leg Nozzle
- (2) Reactor Shell Below Supports
- (3) Reactor Shell Above Supports
- (4) Instrument Penetration Head Bolts
- (5) Closure Head Bolt
- (6) ECCS Head Nozzle
- (7) ECCS Head Nozzle Stud
- (8) CRDM Nozzle
- (9) CRDM Nozzle Stud
- (10) Cold Leg Nozzle

FOR HOT LEG NOZZLE, FROM TABLE 1.

$N_1 = 808$ ALLOWABLE HEAT UP/LOCE CYCLES

$m_1 = 260$ HEAT UP/LOCE CYCLES

$\sum U' = .003$ USAGE FROM OTHER TRANSIENTS

$$\begin{aligned} \text{TOTAL } \sum U &= \sum_{i=1}^{\text{ALL}} \frac{m_i}{N_i} = \frac{260}{808} + .003 \\ &= \underline{.325} < 1.0 \quad \checkmark \end{aligned}$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HEAT UP/LOCE CYCLES

$$\sum U = 1.0 = \frac{m_1}{808} + .003 \quad (\text{SOLVE FOR } m_1)$$

$$\Rightarrow m_1 = \underline{805.5} \text{ HEAT UP/LOCE CYCLES}$$

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FOR REACTOR SHELL BELOW SUPPORTS, FROM TABLE 2.

$$N_1 = 580 \text{ ALLOWABLE HEAT UP / LOCE}$$

$$m_1 = 230 \text{ HEAT UP / LOCE}$$

$$* N_2 = 2400 \text{ ALLOWABLE FOR 4 REMAINING LOCE PEAKS}$$

$$* m_2 = 1040 \text{ REMAINING LOCE PEAKS} = \frac{1040}{230} = 4.5217 m_1$$

$$\sum U' = .0555 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\begin{aligned} \text{TOTAL } \sum U &= \frac{230}{580} + \frac{1040}{2400} + .0555 \\ &= .8954 < 1.0 \end{aligned}$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HEAT UP / LOCE

$$1.0 = \frac{m_1}{580} + \frac{4.5217 m_1}{2400} + .0555$$

$$\Rightarrow m_1 = \underline{262.07} \text{ HEAT UP / LOCE CYCLES (FIRST PEAK)}$$

* THE 4 REMAINING LOCE PEAKS PER LOCE CYCLE
CONTRIBUTE A CERTAIN AMOUNT OF FATIGUE NOT
CONSIDERED IN THE PRIMARY LOCE PEAK.

FOR REACTOR SHELL ABOVE SUPPORTS, FROM TABLE 3.

$$N_1 = 2500 \text{ ALLOWABLE HEAT UP/COOL DOWN}$$

$$M_1 = 1500 \text{ HEAT UP/COOL DOWN} =$$

$$N_2 = 4400 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$M_2 = 260 \text{ HEAT UP/LOCE}$$

$$\Sigma U' = .0196 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\text{TOTAL } \Sigma U = \frac{1500}{2500} + \frac{260}{4400} + .0196$$

$$= \underline{.6787} < 1.0$$

BASED ON $\Sigma U = 1.0$, FIND NUMBER OF HEAT UP/LOCE

$$1.0 = \frac{1500}{2500} + \frac{n_2}{4400} + 0.196$$

$$n_2 = \underline{1673} \text{ LOCE CYCLES.}$$

FOR INSTRUMENT PENETRATION HEAD BOLTS, FROM TABLE 4.

$$N_1 = 1150 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$m_1 = 275 \text{ HEAT UP/LOCE}$$

$$N_2 = 2400 \text{ ALL}$$

$$m_2 = 1485 \text{ HEAT UP/LOCE, COOL DOWN}$$

$$\Sigma U' = .0076 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\begin{aligned} \text{TOTAL } \Sigma U &= \frac{275}{1150} + \frac{1485}{2400} + .0076 \\ &= .866 < 1.0 \end{aligned}$$

BASED ON $\Sigma U = 1.0$, FIND NUMBER OF HEAT UP/LOCE.

$$1.0 = \frac{n_1}{1150} + \frac{1485}{2400} + .0076$$

$$n_1 = 429 \text{ LOGE CYCLES}$$

FOR CLOSURE HEAD BOLTS, FROM TABLE 5.

$$N_1 = 480 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$m_1 = 275 \text{ HEAT UP/LOCE}$$

$$N_2 = 700 \text{ ALLOWABLE HEAT UP/LOCE, COOL DOWN}$$

$$m_2 = 1485 \text{ HEAT UP/LOCE, COOL DOWN} = \frac{1485}{275} = 5.40 m_1$$

$$N_3 = 4000 \text{ ALLOWABLE HEAT UP/LOCE - LOADING}$$

$$m_3 = 520 \text{ HEAT UP/LOCE, LOADING}$$

$$N_4 = 19000 \text{ ALLOWABLE PLANT LOADING, HYPOTHETICAL}$$

$$m_4 = 3750 \text{ P. LOADING, HYPOTHETICAL}$$

$$\sum U' = .3096 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\text{TOTAL } \sum U = \frac{275}{480} + \frac{1485}{700} + \frac{520}{4000} + \frac{3750}{19000} + .3096$$

$$= \underline{3.3318} > 1.0 \quad \text{EXCEEDS FACTOR!}$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HEAT UP/LOCE

$$1.0 = \frac{n_1}{480} + \frac{5.4 n_1}{700} + \frac{520}{4000} + \frac{3750}{19000} + .3096$$

$$\Rightarrow n_1 = 37 \text{ LOCE CYCLES}$$

$$n_2 = 200 \text{ HEAT UP / COOL DOWN CYCLES}$$

FOR ECCS HEAD NOZZLE, FROM TABLE 6 LTR1119 40

$$N_1 = 125 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$m_1 = 260 \text{ HEAT UP/LOCE}$$

$$N_2 = 31000 \text{ ALLOWABLE HEAT UP/LOCE, LOAD}$$

$$m_2 = 260 \text{ HEAT UP/LOCE, LOAD}$$

$$N_3 = 70000 \text{ ALLOWABLE HEAT UP/LOCE, LOAD}$$

$$m_3 = 260 \text{ HEAT UP/LOCE, LOAD}$$

$$N_4 = 350000 \text{ ALLOWABLE LOAD/UNLOAD}$$

$$m_4 = 10220 \text{ LOAD/UNLOAD}$$

$$\sum U' = .003 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\begin{aligned} \text{TOTAL } \sum U &= \frac{260}{125} + \frac{260}{31000} + \frac{260}{70000} + \frac{10220}{350000} + .003 \\ &= \underline{2.124} > 1.0 \quad \text{EXCEEDS FACTOR} \end{aligned}$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HEAT UP/LOCE

$$1.0 = \frac{n_1}{125} + \frac{260}{31000} + \frac{260}{70000} + \frac{10220}{350000} + 0.003$$

$$n = 119 \text{ LOCE CYCLES}$$

FOR ECCS HEAD STUDS, FROM TABLE 7

$$N_1 = 1100 \quad \text{PLANT LOAD / NULL CASE ALLOWABLE}$$

$$n_1 = 275 \quad \text{NULL CASE} = 275/260 = 1.0576 \quad n_2$$

$$N_2 = 1500 \quad \text{ALLOWABLE PLANT LOAD / LOCE}$$

$$n_2 = 260 \quad \text{LOCE}$$

$$N_3 = 15000 \quad \text{PLANT LOAD / PLANT UNLOAD}$$

$$n_3 = 8110 \quad \text{PLANT LOAD} \quad 8110/260 = 31.19$$

$$N_4 = 40000 \quad \text{HYPOTHETICAL / PLANT UNLOAD.}$$

$$n_4 = 1390 \quad \text{PLANT UNLOAD}$$

$$\Sigma U' = .39908 \quad \text{USAGE FACTOR FROM OTHER TRANSIENTS.}$$

$$\begin{aligned} \text{TOTAL } \Sigma U &= \frac{275}{1100} + \frac{260}{1500} + \frac{8110}{15000} + \frac{1390}{40000} + .39908 \\ &= 1.398 \end{aligned}$$

BASED ON $\Sigma U = 1.0$, FIND THE NUMBER OF LOCE CYCLES

$$\begin{aligned} 1.0 &= \frac{1.057 n}{1100} + \frac{n}{1500} + \frac{31.19 n}{15000} + \frac{11000 - (31.19 n + 1500)}{70000} \\ &\quad + .3991 \end{aligned}$$

$$n = 142.64$$

$$\Rightarrow n_1 = 142 \quad \text{LOCE CYCLES}$$

$$\begin{aligned} \text{TOTAL } n_3 &= (142.64)(31.19) + 2890 \quad \left(\begin{array}{l} \text{FIRST 4 LOAD} \\ \text{PAIRS WITH PLANT} \\ \text{LOAD} \end{array} \right) \\ &= 7340 \quad \text{PLANT LOAD.} \end{aligned}$$

FOR CRPM NOZZLE, FROM TABLE 8.

LTR1119 40

$$N_1 = 6000 \text{ ALLOWABLE HEAT UP/COOL DOWN}$$

$$M_1 = 1500 \text{ HEAT UP/COOL DOWN}$$

$$N_2 = 30000 \text{ ALLOWABLE PLANT UNLOAD}$$

$$M_2 = 10205 \text{ PLANT UNLOAD} =$$

$$N_3 = 50000 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$M_3 = 260 \text{ HEAT UP/LOCE}$$

$$\Sigma U' = .2022 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\text{TOTAL } \Sigma U = \frac{1500}{6000} + \frac{10205}{30000} + \frac{260}{50000} + .2022$$

$$= .7976 < 1.0 \quad \checkmark$$

BASED ON $\Sigma U = 1.0$, FIND NUMBER OF HEAT UP/LOCE.

$$1.0 = \frac{1500}{6000} + \frac{10205}{30000} + \frac{N_3}{50000} + .2022$$

$$\Rightarrow N_3 = 10,381 \text{ LOCE CYCLES.}$$

FOR CRDM NOZZLE STUD, FROM TABLE 9. LTR1119 40

$$N_1 = 325 \text{ ALLOWABLE HOT LEAK}$$

$$M_1 = 260 \text{ HOT LEAK}$$

$$N_2 = 7800 \text{ ALLOWABLE HEAT UP / COOL DOWN}$$

$$M_2 = 1500 \text{ HEAT UP / COOL DOWN}$$

$$N_3 = 7800 \text{ ALLOWABLE HEAT UP / LOCE}$$

$$M_3 = 260 \text{ HEAT UP / LOCE}$$

$$N_4 = 34000 \text{ ALLOWABLE PLANT LOAD}$$

$$M_4 = 3750 \text{ PLANT LOAD}$$

$$\sum U' = .2279 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\begin{aligned} \text{TOTAL } \sum U &= \frac{260}{325} + \frac{1500}{7800} + \frac{260}{7800} + \frac{3750}{34000} + .2279 \\ &= \underline{1.3642} > 1.0 \quad \text{EXCEEDS FACTOR} \end{aligned}$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HOT LEAK CYCLES

$$1.0 = \frac{n_1}{325} + \frac{1500}{7800} + \frac{260}{7800} + \frac{3750}{34000} + .2279$$

$$\Rightarrow n_1 = 141 \text{ HOT LEAK CYCLES.}$$

FOR COLD LEG NOZZLE, FROM TABLE 10.

LTR1119 40

$$N_1 = 880 \text{ ALLOWABLE HEAT UP/LOCE}$$

$$m_1 = 260 \text{ HEAT UP/LOCE}$$

$$\sum U' = .03148 \text{ USAGE FROM OTHER TRANSIENTS}$$

$$\text{TOTAL } \sum U = \frac{260}{880} + .03148$$

$$= .3269 < 1.0 \quad \checkmark$$

BASED ON $\sum U = 1.0$, FIND NUMBER OF HEAT UP/LOCE

$$\sum U = 1.0 = \frac{m_1}{880} + .03148$$

$$\Rightarrow m_1 = \underline{852.3} \text{ HEAT UP/LOCE CYCLES}$$