APPENDIX 5E

5E.0 REDUCTION IN CONTAINMENT PRESTRESS AND LONG-TERM CORRECTIVE ACTIONS FOR VERTICAL TENDON CORROSION

5E.1 REDUCTION IN CONTAINMENT PRESTRESS

5E.1.1 DESIGN BASIS

The design basis for the Containment Structure is described in Section 5.1.1.

5E.1.2 DESIGN CRITERIA FOR PRESTRESS

In the concept of a post-tensioned Containment Structure, the internal pressure load is balanced by the application of an opposing external force on the structure. Sufficient post-tensioning was applied to the containment cylinder and dome to more than balance the internal pressure. Therefore, a margin of external pressure exists beyond that required to resist the design basis loss-of-coolant accident pressure.

Nominal, bonded reinforcing steel was also provided to distribute strains due to shrinkage and temperature. Additional bonded reinforcing steel was used at penetrations and discontinuities to resist local moments and shears.

The internal pressure loads on the foundation slab are resisted by both the external bearing pressure due to dead load and the strength of the reinforced concrete slab. Thus, post-tensioning was not required to exert an external pressure for this portion of the structure. The post-tensioning system is described in Sections 5.1.2.1, 5.1.4.2, and 5.5.1. Design load combinations are provided in Sections 5.1.2.2 and 5A.3.1.8.

5E.1.3 DESIGN REANALYSIS

As a result of some hoop tendon lift-off values being lower than expected during the third-year tendon surveillance, as required per Reference 1 at the time, a reanalysis of the Containment was performed between 1977 and 1979 to reduce the minimum required prestress. The third year lift-off force values for hoop tendons indicated that there was sufficient post-tensioning to meet design requirements, but that the losses appeared to be more accelerated than originally expected. The results of the reanalysis were used to develop minimum tendon force requirements for continual tendon surveillance.

The basic approach in the reanalysis was to take advantage of conservatism existing in the initial prestressing system and the conventional reinforcing with respect to the allowable stresses provided in Table 5-1. The reanalysis was done to more accurately reflect the expected results of future surveillances without reducing the original intended margins of the design. The strict requirements of the reanalysis were to assure that all the original design criteria was maintained.

The basic approach of the reanalysis was to reduce the prestress on all three major tendon groups by a uniform percentage of 9%. The original containment vertical prestress level of 1.32P would be reduced to 1.2P. Specific load cases, as identified in Sections 5.1.2.2 and 5A.3.1.8 were reanalyzed and those components of the Containment Structure potentially affected by the reduced prestress were reevaluated. The approach was satisfactory for both the hoop and dome tendon groups with all the design criteria satisfactorily met or exceeded. However, the reinforcing steel in the shell/base slab interface was slightly overstressed for the structural integrity test (Containment) working stress design load case. To overcome this localized overstress, the vertical tendon group prestressing level was only reduced to 1.29P. Therefore, all the original design criteria, as outlined in Sections 5.1.2 and 5A.3.1, were completely satisfied, assuring sufficient prestress to be available at the end of the nominal 60-year design life. Those components of the Containment Structure not affected by a reduced prestress level were not reevaluated.

Since the only change made in the 1977-1979 reanalysis was to reduce the prestress level, the reanalysis concentrates on the portion of the analysis/design that was affected by prestress. Otherwise, the original analysis calculations and results remain valid.

The 1977-1979 reanalysis was performed in two parts. One part addresses the base/shell haunch issue and used separate models for the base slab, and the haunch that were analyzed manually using classical plate and shell theory and finite difference methods. Compatibility relationships were used to establish continuity at the slab/shell boundary.

The second part used a finite element analysis (FINEL CE-316) to model the Containment and obtain force and moments as output. Seismic loads were recomputed using a finite element model axisymmetric shells and solids (CE-771), which provided a more exact distribution of seismic loads, compared to those provided in the original seismic analysis. Results of the analysis were post-processed to convert the force and moments on the concrete and reinforcing steel into stresses.

5E.1.3.1 Summary of Calvert Cliffs Containment Reanalysis

The Calvert Cliffs Containment was reanalyzed to check the effect of reduced prestressing forces. The following table illustrates the original design and reanalysis prestressing forces.

	Containment Original Prestress Forces	Containment Reanalysis Prestress Forces	Reduction
HOOP	630 K/Ft	573.16 K/Ft	9%
VERTICAL	300 K/Ft	294.2 K/Ft	2%
DOME	360 K/Ft	327.52 K/Ft	9%

The reanalysis consisted of an elastic finite element analysis of the upper containment shell and dome. The lower part of the shell and base slabs were analyzed using “cracked” section properties in order to incorporate the proper redistribution of stresses. The reanalysis considered applicable dead, thermal, and pressure loadings in addition to the revised prestress forces. The results of the original seismic analysis were used in the reanalysis, as described above. The stresses derived from the reanalysis were checked against the Table 5-1 set of allowables. There is no significant overstressing in either the concrete or the reinforcing steel. The stresses checked include those in the meridional, hoop, and radial directions. The containment stresses from the reanalysis are tabulated in Table 5E-1. The location key, allowable stresses, and general notes are provided in Table 5-1.

5E.1.4 REFERENCES

1. Nuclear Regulatory Commission Regulatory Guide 1.35, Revision 2, Inservice Inspection of Ungrouted Tendons in Prestressed Concrete Containment Structures

TABLE 5E-1

STRESS ANALYSIS RESULTS

CONTAINMENT STRUCTURE – SUMMARY OF CONCRETE AND REINFORCING STEEL STRESSES

REINFORCING STEEL

			COMPUTED (psi)		COMPUTED vs. ALLOWABLE	
SECTION		**LOAD CASE**	σ_m	σ_h	$\frac{\sigma_m}{f_s}$	$\frac{\sigma_h}{f_s}$
A-B	II	$D+F+L+1.15P$	C	C	---	---
	III	$D+F+L+T_O+E$	C	7900	---	0.26
	IV	$D+F+L+T_A+P$	10200	9900	0.34	0.33
	V	$1.05D+F+1.5P+T_A$	3300	7000	0.06	0.13
	VI	$1.05D+F+1.25P+T_A+1.25E$	2900	6900	0.05	0.13
	VII	$D+F+P+T_A+E'$	2200	7500	0.04	0.14
C-D	II	$D+F+L+1.15P$	C	C	---	---
	III	$D+F+L+T_O+E$	8800	15900	0.29	0.53
	IV	$D+F+L+T_A+P$	13900	20800	0.46	0.69
	V	$1.05D+F+1.5P+T_A$	C	21500	---	0.40
	VI	$1.05D+F+1.25P+T_A+1.25E$	8100	21200	0.15	0.39
	VII	$D+F+P+T_A+E'$	17800	20800	0.33	0.39
E-F	II	$D+F+L+1.15P$	C	C	---	---
	III	$D+F+L+T_O+E$	11200	12000	0.37	0.40
	IV	$D+F+L+T_A+P$	C	5600	---	0.19
	V	$1.05D+F+1.5P+T_A$	C	2000	---	0.04
	VI	$1.05D+F+1.25P+T_A+1.25E$	C	3100	---	0.06
	VII	$D+F+P+T_A+E'$	C	5200	---	0.10
G-H	II	$D+F+L+1.15P$	C	C	---	---
	III	$D+F+L+T_O+E$	14900	12100	0.50	0.40
	IV	$D+F+L+T_A+P$	27800	22400	0.93	0.75
	V	$1.05D+F+1.5P+T_A$	35900	30100	0.66	0.56
	VI	$1.05D+F+1.25P+T_A+1.25E$	29200	27800	0.54	0.51
	VII	$D+F+P+T_A+E'$	24700	24500	0.46	0.45
J-K	II	$D+F+L+1.15P$	C	C	---	---
	III	$D+F+L+T_O+E$	8500	10300	0.28	0.34
	IV	$D+F+L+T_A+P$	24200	26800	0.81	0.89
	V	$1.05D+F+1.5P+T_A$	36400	55600	0.67	1.03
	VI	$1.05D+F+1.25P+T_A+1.25E$	31400	36600	0.58	0.68
	VII	$D+F+P+T_A+E'$	25900	27500	0.48	0.51

TABLE 5E-1

STRESS ANALYSIS RESULTS

CONTAINMENT STRUCTURE – SUMMARY OF CONCRETE AND REINFORCING STEEL STRESSES

REINFORCING STEEL

			COMPUTED (psi)		COMPUTED vs. ALLOWABLE	
SECTION		**LOAD CASE**	σ_m	σ_h	$\frac{\sigma_m}{f_s}$	$\frac{\sigma_h}{f_s}$
L-M	II	D+F+L+1.15P	9300	C	0.31	---
	III	D+F+L+T_O+E	15700	27900	0.52	0.93
	IV	D+F+L+T_A+P	C	C	---	---
	V	1.05D+F+1.5P+T_A	16000	C	0.29	---
	VI	1.05D+F+1.25P+T_A+1.25E	400	C	0.01	---
	VII	D+F+P+T_A+E'	C	C	---	---
N-O	II	D+F+L+1.15P	20800	25500	0.69	0.85
	III	D+F+L+T_O+E	9500	C	0.32	---
	IV	D+F+L+T_A+P	18400	24200	0.61	0.81
	V	1.05D+F+1.5P+T_A	39300	44300	0.73	0.82
	VI	1.05D+F+1.25P+T_A+1.25E	25900	40500	0.48	0.75
	VII	D+F+P+T_A+E'	20800	32500	0.39	0.60
P-Q	II	D+F+L+1.15P	19800	25600	0.66	0.85
	III	D+F+L+T_O+E	8100	17200	0.27	0.57
	IV	D+F+L+T_A+P	24400	24300	0.81	0.81
	V	1.05D+F+1.5P+T_A	37600	41600	0.70	0.77
	VI	1.05D+F+1.25P+T_A+1.25E	39900	46300	0.74	0.86
	VII	D+F+P+T_A+E'	32900	39200	0.61	0.73

TABLE 5E-1

STRESS ANALYSIS RESULTS

CONTAINMENT STRUCTURE – SUMMARY OF CONCRETE AND REINFORCING STEEL STRESSES

CONCRETE

			COMPUTED (psi)				COMPUTED vs. ALLOWABLE			
SECTION		**LOAD CASE**	σ_{em}	σ_{eh}	σ_{am}	σ_{ah}	τ	$\frac{\sigma_e}{f_{ce}}$	$\frac{\sigma_a}{f_s}$	$\frac{\tau}{v}$
A-B	II	D+F+L+1.15P	-890	-790	-840	-790	12	0.30	0.56	0.03
	III	D+F+L+T_O+E	-2630	-2810	-1520	-1460	24	0.94	1.01	0.07
	IV	D+F+L+T_A+P	-2770	-2670	-930	-880	27	0.92	0.62	0.07
	V	1.05D+F+1.5P+T_A	-2830	-2590	-640	-540	24	0.63	0.15	0.06
	VI	1.05D+F+1.25P+T_A+1.25E	-3140	-3140	-780	-730	21	0.70	0.18	0.06
	VII	D+F+P+T_A+E'	-3360	-3470	-930	-880	18	0.77	0.22	0.05
C-D	II	D+F+L+1.15P	-480	-300	-430	-240	167	0.16	0.29	0.39
	III	D+F+L+T_O+E	-2660	-1480	-840	-310	131	0.89	0.56	0.31
	IV	D+F+L+T_A+P	-2190	-2410	-480	-250	141	0.80	0.32	0.33
	V	1.05D+F+1.5P+T_A	-2010	-2040	-310	-210	99	0.45	0.07	0.23
	VI	1.05D+F+1.25P+T_A+1.25E	-2670	-2200	-400	-230	94	0.59	0.09	0.22
	VII	D+F+P+T_A+E'	-3270	-2410	-480	-250	94	0.73	0.11	0.22
E-F	II	D+F+L+1.15P	-590	-290	-310	-270	116	0.20	0.21	0.39
	III	D+F+L+T_O+E	-1130	-1270	-480	-310	134	0.42	0.32	0.44
	IV	D+F+L+T_A+P	-2110	-2890	-330	-270	128	0.96	0.22	0.42
	V	1.05D+F+1.5P+T_A	-1870	-2790	-260	-260	88	0.62	0.06	0.30
	VI	1.05D+F+1.25P+T_A+1.25E	-1810	-2820	-300	-260	97	0.63	0.07	0.32
	VII	D+F+P+T_A+E'	-2110	-2870	-340	-270	98	0.64	0.08	0.32
G-H	II	D+F+L+1.15P	-160	-260	-130	-240	30	0.09	0.16	0.18
	III	D+F+L+T_O+E	-2170	-1870	-640	-610	123	0.72	0.42	0.74
	IV	D+F+L+T_A+P	-1570	-1940	-240	-300	40	0.65	0.20	0.24
	V	1.05D+F+1.5P+T_A	T	-530	-40	-120	13	0.12	0.03	0.08
	VI	1.05D+F+1.25P+T_A+1.25E	-630	-930	-140	-170	19	0.21	0.04	0.11
	VII	D+F+P+T_A+E'	-1430	-1540	-240	-250	35	0.34	0.06	0.21
J-K	II	D+F+L+1.15P	-320	-110	-220	-90	21	0.11	0.15	0.15
	III	D+F+L+T_O+E	-1860	-2390	-710	-1060	40	0.80	0.71	0.29
	IV	D+F+L+T_A+P	-2240	-1140	-330	-210	97	0.75	0.22	0.70
	V	1.05D+F+1.5P+T_A	-740	T	-140	T	102	0.16	0.03	0.73
	VI	1.05D+F+1.25P+T_A+1.25E	-1300	T	-210	T	108	0.29	0.05	0.78
	VII	D+F+P+T_A+E'	-1990	-1040	-300	-200	97	0.44	0.07	0.70

TABLE 5E-1

STRESS ANALYSIS RESULTS

CONTAINMENT STRUCTURE – SUMMARY OF CONCRETE AND REINFORCING STEEL STRESSES

CONCRETE

			COMPUTED (psi)					COMPUTED vs. ALLOWABLE		
SECTION		**LOAD CASE**	σ_{em}	σ_{eh}	σ_{am}	σ_{ah}	τ	$\frac{\sigma_e}{f_{ce}}$	$\frac{\sigma_a}{f_s}$	$\frac{\tau}{v}$
L-M	II	D+F+L+1.15P	-1100	-900	-250	-730	129	0.37	0.49	0.47
	III	D+F+L+T_O+E	-2790	-260	-680	T	80	0.93	0.45	0.44
	IV	D+F+L+T_A+P	-800	-2410	-310	-650	144	0.80	0.43	0.45
	V	1.05D+F+1.5P+T_A	-1000	-3350	-130	-1700	161	0.74	0.40	0.34
	VI	1.05D+F+1.25P+T_A+1.25E	-20	-3050	-220	-960	258	0.68	0.23	0.54
	VII	D+F+P+T_A+E'	-800	-2600	-310	-810	212	0.58	0.19	0.44
N-O	II	D+F+L+1.15P	T	-540	T	T	72	0.30	[a]	0.46
	III	D+F+L+T_O+E	-480	-20	-180	-150	27	0.27	[a]	0.17
	IV	D+F+L+T_A+P	T	-640	-50	-30	113	0.36	[a]	0.72
	V	1.05D+F+1.5P+T_A	-180	-1440	-50	-20	167	0.40	[a]	0.70
	VI	1.05D+F+1.25P+T_A+1.25E	T	-430	-10	T	170	0.12	[a]	0.72
	VII	D+F+P+T_A+E'	T	-780	-40	-20	150	0.22	[a]	0.63
P-Q	II	D+F+L+1.15P	-540	-660	T	T	4	0.37	[a]	0.07
	III	D+F+L+T_O+E	-590	-990	-270	-100	47	0.55	[a]	0.83
	IV	D+F+L+T_A+P	-950	-980	-170	T	17	0.54	[a]	0.30
	V	1.05D+F+1.5P+T_A	-1850	-1810	-170	T	11	0.51	[a]	0.13
	VI	1.05D+F+1.25P+T_A+1.25E	-850	-1540	-110	T	48	0.43	[a]	0.56
	VII	D+F+P+T_A+E'	-980	-1840	-130	T	58	0.51	[a]	0.68

---

[a] $f_a = 0.3\, f_c'$