

APPENDIX II

Summary of Stresses for Design Cases for a CANDU 6 Reactor Structure Assembly

II-1 ALLOWABLE STRESSES

Material Properties and allowable stresses for the various service conditions are listed in Tables II-1, II-2 and II-3.

II-2 STRESS SUMMARIES

Summaries of the magnitude and location of maximum stress intensities are given in Tables II-4 to II-16 for the following components, which are divided into several major groups.

II-2.1 CALANDRIA VESSEL - STRESS INTENSITIES - Tables II-4 to II-9

- a. Calandria main shell
- b. Calandria subshell
- c. Calandria annular plate
- d. Calandria side tubesheets of end shields
- e. Calandria tubes (center location)
- f. Calandria tubes (bottom location)

II-2.2 END SHIELD - STRESS INTENSITIES - Tables II-10 to II-13

- a. Fuelling Machine Tubesheets
- b. Lattice Tubes (Center Location)
- c. Lattice Tubes (Bottom Location)
- d. End Shield Shell

II-2.3 END SHIELD SUPPORTS - STRESS INTENSITIES - Tables II-14 & II-15

- a. Support Shell
- b. Support Plate

II-2.4 RCU NOZZLES ON CALANDRIA SHELL - Table II-16

Table II-1
Material Properties

Parameter	Austenitic Stainless Steel ⁽¹⁾	Zirconium Alloy Grade R60802 ⁽²⁾⁽³⁾			
	Type 304L	@68°F 20°C	@200°F 93°C	@225°F 107°C	@260°F 127°C
Ultimate Tensile Strength (min) MPa (psi)	482.6 (70,000)	415 (60,190)	348.6 (50,560)	335.3 (48,630)	315.4 (45,740)
Yield Strength (min) S _y MPa (psi)	172.3 (25,000)	300 (43,510)	257.6 37,360	249.5 (36,180)	237.9 (34,500)
Modulus of Elasticity Transverse, E _T Longitudinal, E _L GPa (psi)	186.16 at 149°C (27.0 x 10 ⁶ at 300°F)	98.9 (14.34 x 6) 94.8 (13.75 x 10 ⁶)	95.1 (13.79 x 10 ⁶) 89.4 (12.97 x 10 ⁶)	94.3 (13.68 x 10 ⁶) 88.4 (12.89 x 10 ⁶)	89.1 (12.92 x 10 ⁶) 87.4 (12.67 x 10 ⁶)
Poisson's Ratio: Transverse, ν _T Longitudinal, ν _L	0.27	.345 .375	.345 .375	.345 .375	.346 .375
Coefficient of thermal expansion, (m/mC° (in/in°F)	17.0 x 10 ⁻⁶ , 21°C to 149°C (9.0 x 10 ⁻⁶ , 70°F to 300°F)	5.3 x 10 ⁻⁶ (2.94 x 10 ⁻⁶)	5.3 x 10 ⁻⁶ (2.94 x 10 ⁻⁶)	5.3 x 10 ⁻⁶ (2.94 x 10 ⁻⁶)	5.3 x 10 ⁻⁶ (2.94 x 10 ⁻⁶)
Density lb/m ³ (kg/m ³)	8030 (.29)	6550 (0.237)	-	-	-

- Notes: (1) ASME Code, 1989 Edition with 1989 Addenda, Section III Appendices, Table I-1.2 and Ref. 2
 (2) CAN/CSA-N285.6 Series 88, Table 7.1, Standard N285.6.7
 (3) Wolsong 2 Design Specification for Calandria Assembly AECL CANDU, 86-31200-DS-001, Rev. 0.

Table II-2
 Allowable Stress Limits
 (Design, Level 'A' and 'B' Service Conditions)

Stress Category	Basic Stress Intensity/Allowable Limits	Austenitic Stainless Steel (Type 304L up to 149°C(300°C))	Zirconium Alloy Grade R60802 at 100°C (212°F)
P_m	S_m	115.14 MPa (16,700 psi)	112 MPa (16,200 psi)
P_L	$1.5 S_m$	172.71 MPa (25,050 psi)	168 MPa (24,300 psi)
P_m or $(P_L) + P_b$	$1.5 S_m$	172.71 MPa (25,050 psi)	168 MPa (24,300 psi)
$P_L + P_b + Q$	$3 S_m$	343 MPa (50,100 psi)	335 MPa (48,600 psi)

- P_m = General Primary Membrane Stress
 P_L = Local Primary Membrane Stress
 P_b = Primary Bending Stress
 Q = Secondary Stress
 S_m = Stress Intensity

Table II-3
 Allowable Stress Intensity Limits
 (Level "C" Service Condition)

Stress Category	Basic Stress Intensity Limits	Austenitic Stainless Steel (304L) Up to 149°C (300°F)	Zirconium Alloy Grade R60802 at 127°C (260°F)
P_m	$1.2 S_m$ or S_y^*	138.17 MPa (20,040 psi)	237.9 (34,500 psi)
P_L	$1.8 S_m$ or $1.5 S_y^*$	207.26 MPa (30,060 psi)	356.45 MPa (51,700 psi)
$P_L + P_b$	$1.8 S_m$ or S_y^*	207.26 MPa (30,060 psi)	356.45 MPa (51,700 psi)

Table II-4
 Calandria Main Shell
 Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 7558	P_m	115.14 (16700)	10.8 (1572)
	DC 17532	P_L	172.71 (25050)	11.6 (1681)
	DC 17326	$P_m + P_b$	172.71 (25050)	31.1 (4514)
	DC 6867	$P_L + P_b$	172.71 (25050)	28.8 (4184)
Service Level A	LA6 17327	$P_m + P_b + Q$	345.43 (50100)	86.6 (12565)
	LA6 6868	$P_L + P_b + Q$	345.43 (50100)	83.9 (12163)
Service Level B	LB4 17316	$P_m + P_b + Q$	345.43 (50100)	85.8 (12443)
	LB4 6929	$P_L + P_b + Q$	345.43 (50100)	83.7 (12136)
Service Level C	LC3 7904	P_m	138.17 (20040)	101.9 (14784)
	LC3 6969	P_L	207.26 (30060)	179.0 (25960)
	LC3 7899	$P_m + P_b$	207.26 (30060)	179.8 (26079)
Test Conditions	TC1 7966	P_m	115.14 (16700)	43.1 (6244)
	TC1 6928	P_L	172.71 (25050)	48.0 (6966)
	TC2 7966	$P_m + P_b$	172.71 (25050)	55.8 (8097)
	TC2 6932	$P_L + P_b$	172.71 (25050)	60.6 (8788)

Table II-5
Calandria Subshell
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 16250	P_m	115.14 (16700)	9.5 (1385)
	DC 16248	P_L	172.71 (25050)	9.6 (1390)
	DC 16325	$P_m + P_b$	172.71 (25050)	10.4 (1562)
	DC 16034	$P_I + P_b$	172.71 (25050)	14.4 (2093)
Service Level A	LA1 16258	$P_m + P_b + Q$	345.43 (50100)	115.1 (16700)
	LA1 16235	$P_I + P_b + Q$	345.43 (50100)	117.8 (17091)
Service Level B	LB4 16258	$P_m + P_b + Q$	345.43 (50100)	163.8 (23752)
	LB4 16235	$P_I + P_b + Q$	345.43 (50100)	166.5 (24143)
Service Level C	LC3 16256	P_m	138.17 (20040)	57.1 (8277)
	LC3 16247	P_L	207.26 (30060)	127.4 (18479)
	LC3 16242	$P_m + P_b$	207.26 (30060)	66.7 (9671)
Test Conditions	TC1 16262	P_m	115.14 (16700)	29.7 (4305)
	TC1 16348	P_L	172.71 (25050)	29.8 (4329)
	TC1 16210	$P_m + P_b$	172.71 (25050)	38.5 (5580)
	TC1 16142	$P_I + P_b$	172.71 (25050)	38.9 (5637)

Table II-6
Calandria Annular Plate
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 16656	P_m	115.14 (16700)	14.6 (2122)
	DC 6756	P_L	172.71 (25050)	14.8 (2145)
	DC 16702	$P_m + P_b$	172.71 (25050)	15.8 (2285)
	DC 16434	$P_I + P_b$	172.71 (25050)	44.6 (6461)
Service Level A	LA1 16652	$P_m + P_b + Q$	345.43 (50100)	136.2 (19750)
	LA6 16434	$P_I + P_b + Q$	345.43 (50100)	166.1 (24095)
Service Level B	LB1 16652	$P_m + P_b + Q$	345.43 (50100)	140.8 (20417)
	LB1 16434	$P_I + P_b + Q$	345.43 (50100)	160.5 (23284)
Service Level C	LC3 16652	P_m	138.17 (20040)	66.8 (9690)
	LC3 16646	P_L	207.26 (30060)	170.7 (24754)
	LC3 16652	$P_m + P_b$	207.26 (30060)	85.5 (11968)
Test Conditions	TC1 16693	P_m	115.14 (16700)	27.6 (4006)
	TC1 16739	P_L	172.71 (25050)	28.5 (4138)
	TC1 16693	$P_m + P_b$	172.71 (25050)	46.5 (6740)
	TC1 16542	$P_I + P_b$	172.71 (25050)	82.8 (12015)

Table II-7
Calandria Tubesheet
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 13764	P_m	115.14 (16700)	21.2 (3079)
	DC 13775	P_L	172.71 (25050)	21.1 (3060)
	DC 13469	$P_m + P_b$	172.71 (25050)	43.4 (6289)
	DC 13470	$P_I + P_b$	172.71 (25050)	50.8 (7371)
Service Level A	LA3 11496	$P_m + P_b + Q$	345.43 (50100)	217.4 (31527)
	LA1 13470	$P_I + P_b + Q$	345.43 (50100)	223.5 (32419)
Service Level B	LB4 11496	$P_m + P_b + Q$	345.43 (50100)	241.6 (35047)
	LB4 13470	$P_I + P_b + Q$	345.43 (50100)	265.0 (38440)
Service Level C	LC3 11515	P_m	138.17 (20040)	118.7 (17220)
	LC3 13773	P_L	207.26 (30060)	136.5 (19795)
	LC3 11496	$P_m + P_b$	207.26 (30060)	182.7 (26493)
Test Conditions	TC1 13426	P_m	115.14 (16700)	21.3 (3088)
	TC1 13405	P_L	172.71 (25050)	21.1 (3062)
	TC2 13469	$P_m + P_b$	172.71 (25050)	45.2 (6550)
	TC2 13470	$P_I + P_b$	172.71 (25050)	52.8 (7651)

* The maximum stress intensities reported in this table envelopes the maximum stresses in local lattice pitch model at centre and bottom locations.

Table II-8
 Calandria Tube (Center Location)
 Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 10486	P_m	111.70 (16200)	109.0 (15811)
	DC 10402	P_L	167.54 (24300)	104.8 (15198)
	DC 10486	$P_m + P_b$	167.54 (24300)	145.5 (21109)
Service Level A	LA6 10486	$P_m + P_b + Q$	335.09 (48600)	146.1 (21189)
	LA6 10411	$P_L + P_b + Q$	335.09 (48600)	146.3 (21226)
Service Level B	LB1 10486	$P_m + P_b + Q$	335.09 (48600)	156.5 (22705)
	LB1 10411	$P_L + P_b + Q$	335.09 (48600)	157.1 (22780)
Service Level C	LC1 10486	P_m	237.87 (34500)	159.7 (23166)
	LC1 10411	P_L	356.46 (51700)	135.7 (19675)
	LC1 11095	$P_m + P_b$	356.46 (51700)	243.6 (35330)
Test Conditions	TC1 11679	P_m	111.70 (16200)	38.9 (5643)
	TC1 11015	P_L	167.54 (24300)	34.9 (5060)
	TC1 10919	$P_m + P_b$	167.54 (24300)	113.3 (18295)

Table II-9
 Calandria Tube (Bottom Location)
 Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 11841	P_m	111.70 (16200)	110.3 (15999)
	DC 11780	P_L	167.54 (24300)	115.3 (16717)
	DC 11841	$P_m + P_b$	167.54 (24300)	146.3 (21216)
Service Level A	LA6 11846	$P_m + P_b + Q$	335.09 (48600)	147.8 (21441)
	LA6 11858	$P_L + P_b + Q$	335.09 (48600)	151.0 (21914)
Service Level B	LB1 11846	$P_m + P_b + Q$	335.09 (48600)	154.6 (22427)
	LB1 11862	$P_L + P_b + Q$	335.09 (48600)	160.2 (23230)
Service Level C	LC1 11862	P_m	237.87 (34500)	171.4 (24861)
	LC1 11780	P_L	356.46 (51700)	178.3 (25865)
	LC1 10919	$P_m + P_b$	356.46 (51700)	271.3 (39344)
Test Conditions	TC1 11679	P_m	111.70 (16200)	40.6 (5893)
	TC1 11783	P_L	167.54 (24300)	40.4 (5861)
	TC1 10919	$P_m + P_b$	167.54 (24300)	126.7 (18386)

Table II-10
 Fuelling Tubesheet
 Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 14165	P_m	115.14	19.0 (2754)
	DC 14170	P_L	(16700)	18.4 (2672)
	DC 4379	$P_m + P_b$	172.71 (25050)	27.4 (3969)
	DC 14036	$P_L + P_b$	172.71 (25050) 172.71 (25050)	47.3 (6863)
Service Level A	LA1 4384	$P_m + P_b + Q$	345.43 (50100)	152.2 (22080)
	LA1 14036	$P_L + P_b + Q$	345.43 (50100)	149.8 (21731)
Service Level B	LB4 4384	$P_m + P_b + Q$	345.43 (50100)	170.5 (24723)
	LB4 14036	$P_L + P_b + Q$	345.43 (50100)	168.1 (24374)
Service Level C	LC3 13135	P_m	138.17	125.1 (18148)
	LC3 14170	P_L	(20040)	193.2 (28028)
	LC3 4384	$P_m + P_b$	207.26 (30060) 207.26 (30060)	154.8 (22453)
Test Conditions	TC1 14361	P_m	115.14	19.7 (2856)
	TC1 14373	P_L	(16700)	19.4 (2821)
	TC2 4379	$P_m + P_b$	172.71 (25050)	48.9 (7086)
	TC2 14067	$P_L + P_b$	172.71 (25050) 172.71 (25050)	50.3 (7301)

* The maximum stress intensities reported in this table envelopes the maximum stresses in local lattice pitch model at centre and bottom locations.

Table II-11
Lattice Tube (Centre Location)
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 12031	P_m	115.14	771.2 (10331)
	DC 12308	P_L	(16700)	103.3 (14977)
	DC 12031	$P_m + P_b$	172.71 (25050)	782.7 (11988)
	DC 12308	$P_L + P_b$	172.71 (25050)	111.0 (16095)
Service Level A	LA6 12339	$P_m + P_b + Q$	345.43 (50100)	118.3 (17155)
	LA1 12308	$P_L + P_b + Q$	345.43 (50100)	111.6 (16190)
Service Level B	LB4 12031	$P_m + P_b + Q$	345.43 (50100)	123.6 (18404)
	LB4 12306	$P_L + P_b + Q$	345.43 (50100)	118.0 (19836)
Service Level C	LC3 12326	P_m	138.17	102.8 (14905)
	LC3 12316	P_L	(20040)	798.9 (14353)
	LC3 12339	$P_m + P_b$	207.61 (30060)	136.3 (19762)
Test Conditions	TC2 12470	P_m	115.14	13.4 (1944)
	TC2 12185	P_L	(16700)	12.7 (1845)
	TC2 12347	$P_m + P_b$	172.71 (25050)	18.0 (2615)
	TC2 12178	$P_L + P_b$	172.71 (25050)	17.3 (2509)
			172.71 (25050)	

Table II-12
 Lattice Tube (Bottom Location)
 Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 12326	P_m	115.14 (16700)	85.2 (12345)
	DC 12308	P_L	172.71 (25050)	76.7 (11122)
	DC 12326	$P_m + P_b$	172.71 (25050)	105.1 (15246)
	DC 12306	$P_T + P_b$	172.71 (25050)	86.8 (12590)
Service Level A	LA1 12326	$P_m + P_b + Q$	345.43 (50100)	126.7 (18373)
	LA1 12306	$P_T + P_b + Q$	345.43 (50100)	147.5 (21391)
Service Level B	LB4 12025	$P_m + P_b + Q$	345.43 (50100)	145.8 (21143)
	LB4 12306	$P_T + P_b + Q$	345.43 (50100)	174.1 (25237)
Service Level C	LC3 12326	P_m	138.17 (20040)	127.4 (18481)
	LC3 12308	P_L	207.61 (30060)	115.6 (16759)
	LC3 12326	$P_m + P_b$	207.61 (30060)	156.3 (22665)
Test Conditions	TC2 12466	P_m	115.14 (16700)	55.3 (8016)
	TC2 12491	P_L	172.71 (25050)	57.2 (8302)
	TC2 12466	$P_m + P_b$	172.71 (25050)	58.3 (8462)
	TC2 12482	$P_T + P_b$	172.71 (25050)	63.9 (9275)

Table II-13
End Shield Shell
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition	DC 14616	P_m	115.14 (16700)	32.2
	DC 14619	P_L	172.71 (25050)	(4666)
	DC 14603	$P_m + P_b$	172.71 (25050)	18.6
	DC 14637	$P_L + P_b$	172.71 (25050)	(2698) 52.6 (7631) 31.3 (4537)
Service Level A	LA1 14603	$P_m + P_b + Q$	345.43 (50100)	177.0 (25674)
	LA1 14605	$P_L + P_b + Q$	345.43 (50100)	153.7 (22287)
Service Level B	LB4 14616	$P_m + P_b + Q$	345.43 (50100)	208.7 (30275)
	LB4 14605	$P_L + P_b + Q$	345.43 (50100)	185.4 (26888)
Service Level C	LC3 14616	P_m	138.17 (20040)	78.6 (11395)
	LC3 14619	P_L	207.61 (30060)	143.6 (20824)
	LC3 14603	$P_m + P_b$	207.61 (30060)	103.2 (14973)
Test Conditions	TC2 14613	P_m	115.14 (16700)	28.0
	TC2 14619	P_L	172.71 (25050)	(4057)
	TC2 14603	$P_m + P_b$	172.71 (25050)	17.5
	TC2 14637	$P_L + P_b$	172.71 (25050)	(2533) 46.8 (6785) 30.6 (4440)

Table II-14
Support Shell
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition ⁵	DC 15050	P_m	115.14 (16700)	20.5 (2969)
	DC 15050	$P_m + P_b$	172.71 (25050)	33.2 (4812)
Service Level A	LA6 5225	$P_m + P_b + Q$	345.43 (50100)*	163.5 (23721)
Service Level B	LB3 5225	$P_m + P_b + Q$	345.43 (50100)**	168.2 (24390)
Service Level C	LC3 5225	P_m	172.71 (25050)	140.7 (20403)
	LC3 5225	$P_m + P_b$	259.07 (37575)	210.4 (30516)
Test Conditions	TC2 15050	P_m	153.14 (22211)	21.1 (3060)
	TC2 15051	$P_m + P_b$	229.71 (33317)	39.7 (5762)

Calculated stresses are envelope of all primary loads.

* Minimum of $2 S_Y$ or S_U at temperature, see Table NF-3522 (b) -1, Note 5

** Maximum local stress intensity is limited to $3 S_m$ (50100 psi)

Table II-15
Support Plate
Stress Summary

Loading Condition	Operating Condition and Location	Stress Category	Allowable Stress Intensity MPa (psi)	Maximum Stress Intensity MPa (psi)
Design Condition (4)	DC 15864	P_m	115.14 (16700)	13.2 (1918)
	DC 15505	$P_m + P_b$	172.71 (25050)	21.00 (3049)
Service Level A	LA5 15505	$P_m + P_b + Q$	345.43 (50100)	206.6 (29948)
Service Level B	LB2 15505	$P_m + P_b + Q$	345.43 (50100)	206.5 (29952)
Service Level C	LC3 15881	P_m	172.71 (25050)	101.5 (14727)
	LC3 15612	$P_m + P_b$	259.07 (37575)	148.1 (21486)
Test Conditions	TC1 15863	P_m	153.14 (22211)	16.5 (2397)
	TC2 15505	$P_m + P_b$	229.71 (33317)	38.1 (5531)

Calculated stresses are envelope of all primary loads.

* Minimum of $2 S_Y$ or S_U at temperature, see Table NF-3522 (b) -1, Note 5

** Maximum local stress intensity is limited to $3 S_m$ (50100 psi)

Table II-16
Nozzle Stresses

Stress ¹ Category	Allowable Stress MPa (psi)	Nozzles		
		Adjuster Nozzle MPa (psi)	Pressure Relief Nozzle MPa (psi)	Moderator Inlet Nozzle MPa (psi)
P_m ² (Level C)	$1.2 S_m = 138.17$ (20040)	14.73 (2136)	28.2 (4085)	88.8 (12877)
$P_m + P_b$ ² (Level C)	$1.8 S_m = 207.61$ (30060)	39.9 (5786)	132.6 (19231)	195.3 (28323)
$P_m + P_b + Q$ ³ Levels A and B	$3 S_m = 345.43$ (50100)	(14.1) (2044)	44.4 (6433)	320.6 (46,495)

P_m = Primary membrane stress intensity

P_b = Primary bending stress intensity

Q = Secondary stress intensity (include local stress)

1 Local primary membrane stress intensity (P_L) conservatively taken as P_m

2 P_m and $P_m + P_b$ include DBE nozzle loads for level C

3 $P_m + P_b + Q$ does not include DBE loads (envelope Levels A and B)