APPENDIX I

Design Loads and Load Cases for a CANDU 6 Reactor Structure Assembly

I-1 ANALYSIS METHOD FOR COMBINED LOADS

I-11. LOAD CASES AND LOADING CONDITIONS

For each defined *loading case* that the reactor structure is subjected to, the total load applied is a *combination of the basic loadings*, ie, the weight of structural members and fluids and other components enclosed and supported, plus pressure and buoyancy loads, plus loads due to thermal restraint, plus dynamic loads due to acceleration acting on the mass of the components and contents. Weight loads will be the same for all cases, but other basic loads (eg, temperatures, pressures, seismic loads) will take on different values for the different cases.

The stresses resulting from each of these combinations are the sums of the stresses for each of the basic loads. The method of analysis used therefore, is to calculate the stresses for a *unit load value* for each basic load, using the Finite Element Model (FEM), and then multiply all the stresses by the value of that load, for each loading case. The total stress for that loading case, is therefore the sum of the stresses for all the factored basic loads.

I-1.1 LOAD CLASSIFICATIONS

The loading conditions applied to the calandria assembly are represented by a combination of pressure, thermal, structural weights, buoyancy, imposed and seismic loads. These conditions are classified in accordance with ASME Code, Section III, Division 1, NC–3111.

I-2 BASIC LOADS

I-2.1 Pressure Loads

The analysis takes into account the differential pressure acting on each component; details are given in the Design Specification. The pressure distributions for the calandria assembly are determined for service levels A, B, C and test conditions, while pressure load for Service Level D is determined from the postulated flow blockage accident analysis. The pressure load cases are coded as unit pressure loads and variable pressure loads on the different components. This approach provide flexibility in analysing new loading conditions.

I-2.2 Thermal Loads

The temperature distribution for the calandria assembly was calculated for several normal operating and thermal transient cases. The linearized temperature gradient is used as the input to the finite element program STARDYNE to calculate the thermal stresses.

Figure I-1 shows the temperature distributions for a typical normal conditions which has been considered for the analysis.

Stresses resulting from thermal loads are classified according to the ASME Code as secondary stresses. However in the calandria tube case, thermal stresses are classified as primary stresses and included in the design condition.

I-2.3 Weights

I-2.3.1 Structural Weights

The breakdown of the assembly weight, its contents, and components supported by assembly such as the reactivity control units (RCUs) is given in Tables I-1 & I-1.

I-2.3.2 Buoyancy Loads

The analysis takes into account the buoyancy loads acting on the calandria assembly since the actual hydrostatic loads and deadweight are used.

I-2.4 Imposed Loads

Imposed loads are the forces and moments due to the deadweight, thermal expansion and movements of the attached components such as piping, reactivity control units, fuelling machine loads and fuel channel assemblies.

I-2.5 Seismic Loads

Seismic loads are comprised of two parts: those due to the calandria assembly response, (which are shown in part I-6 of this appendix) and those due to *attached* component responses to an earthquake event, discussed below.

I-3 LOADING CONDITIONS

I-3.1 Design Condition

The design loads are as defined in Section III, Division 1, NC–3112 of the ASME Code. These loads are described in the design specifications, and summarized as follows:

- Weight loads due to all reactor components.
- Pressure loads: the design pressure for the calandria vessel represents the maximum pressure inside the calandria under Level A condition plus 40.7 Kpa(g) (5.9 psig) uniform pressure due to liquid poison injection. The total design pressure of 75.2 Kpag (10.9 psig) acts at the top of the calandria vessel In addition to the design pressure, the hydrostatic loads (varying pressure load) is superimposed to find the total pressure at the bottom of calandria vessel and end shields.
- Imposed mechanical loads such as RCU spring tension loads, piping loads, concrete movements, etc.
- The design temperature for the calandria vessel (except the calandria tubes) and the end shields is 149°C (300°F). The calandria tube design temperature is 93°C (200°F). The

design temperatures are used to establish the allowable stress intensities for design condition.

I-3.2 Service Loading Conditions

The service conditions are classified in accordance with Section III, Division 1, NCA-2142 of the ASME Code. These conditions may designate service limits such as Level A, Level B, Level C and Level D as defined in Subsection NCA-2142.2 (b).

Listed below are those operating conditions under the categories of service Levels A, B, C and D, that have been assessed to cause significant stresses in the calandria assembly. Descriptions of all operating conditions are specified below:

- Service Level "A"

  LA1 - Full power steady state operations

  LA2 - Coid startup

  LA3 - Normal startup after short shutdown (less severe than LA2)

  LA4 - Shutdown using shutoff rods (shutdown system number one)

  LA5 - Reactor Setback Shutdown

  LA6 - Shutdown using poison injection (shutdown system number two)

- Service Level "B"

  LB1 - Loss of Class IV power to whole station

  LB2 - Loss of main moderator pumps

  LB3 - Loss of service water to one moderator heat exchanger

  LB4 - Loss of shield coolant pumps

  LB5 - Loss of service water to both shield coolant heat exchangers (less severe than LB4)

- Service Level "C"

  LC1 - Rupture of one pressure/calandria tube combination (in-core small LOCA)

  LC2 - Reactor header failure (LOCA)

  LC3 - Design basis earthquake

- Service Level "D"

  LD1 - pressure tube and calandria tube failure due to fuel channel flow blockage

I-3.3 Test Conditions

Listed below are the test conditions that have been assessed to cause significant stress in the calandria assembly.

TC1 - Calandria internal pressure test (vault empty)

TC2 - Calandria external pressure test (calandria empty)

TC3 - End shield internal pressure test

I-4 LOADING CASES

The design of the calandria assembly is based on appropriate combinations of stresses due to pressure, weight, thermal, imposed and seismic loads in accordance with ASME Code, Division 1, Section III, Subsection NC–3111. Stresses for the following load cases are computed individually.

I-4.1 Pressure Loads

- P_1 - Variable Hydrostatic pressure due to vault water
- P_2 - Uniform external pressure due to vault water
- P_3 - Variable Hydrostatic pressure due to moderator (D_2O) heavy water
- P_4 - Uniform pressure due to moderator (D_2O) heavy water
- P_5 - Variable Hydrostatic pressure due to end shield water and steel balls
- P_6 - Uniform pressure due to end shield water and steel balls.
- P_7 - Uniform external pressure inside containment on fixed side of the calandria assembly
- P_8 - Uniform external pressure inside containment on free side of the calandria assembly
- P_9 - Calandria tube annulus gas pressure

I-4.2 Weights

W1 - Structural weight

I-4.3 Thermal Loads

Service Level "A"

- T_1 - Normal operation - full power steady state
- T_2 - Trip shutdown using shutoff rods - SDS1
- T_3 - Setback shutdown

Service Level "B"

- T_4 - Loss of Class IV power to whole station
- T_5 - Loss of service water to one moderator heat exchanger
- T_6 - Loss of main moderator pumps
- T_7 - Loss of shield coolant pumps

I-4.4 Imposed Loads

- I_1 - Piping, nozzles and RCU imposed loads (cold)
- I_2 - Piping, nozzles and RCU imposed loads (hot)
- I_3 - Feeders imposed loads (cold)
- I_4 - Feeders imposed loads (hot)
- I_5 - Fuel channel, end fitting, pressure tube weights imposed loads

I_6 - Positioning assembly imposed loads

I-4.5 Seismic Loads

S_1 - Feeders seismic loads

S_2 - RCU seismic loads

S_3 - Nozzle, piping seismic loads

S_4 - Structure seismic response loads

In addition to above loads, the vault movements for each loading Condition (Design, Level A, Level B and Level C) were considered in this analysis. Calandria tube ovality load (stresses) are also considered in this analysis

I-5 LOAD COMBINATIONS for the VARIOUS LOADING CONDITIONS

The combination of basic loads for each of the loading cases listed in Section I-4 are summarized in Table I-2. The component stresses due to those basic loads are multiplied by the appropriate factors, taken from the Design Specification. They are then combined using the AECL proprietary computer program STRMAX. The stress intensity values are also then computed within the STRMAX code. This gives the actual stresses for the design, service and test conditions, and are summarized in Appendix II.

Table I-1
Weights of Calandria Assembly and Contents

Component/Item	Unit Weight (lbs)	Quantity Per Reactor	Weight (lbs)	Total Weight (lbs)
1. Calandria Vessel (empty)				
Calandria Shell				
- Main Shell (including nozzles etc.)	53,500	1	53,500	
- Subshell	10,350	2	20,700	
- Calandria annulus	3,250	2	6,500	
Calandria tubesheet	37,500	2	75,000	
Calandria Tubes plus Inserts	56	380	21,280	
Weight of Calandria Vessel (empty).				176,980
2. Balance of End Shield (empty)				
- Fuelling tubesheet	34,000	2	68,000	
- End shield shell	7,500	2	15,000	
- Lattice tubes plus sleeves	100	760	76,000	
Weight of balance of E/S (empty).				159,000
3. End Shield Support				
- Support plate	3,360	2	6,720	
- Support shell	7,300	2	14,600	
Weight of E/S support.				21,320
4. Weights of Contents				
Moderator (calandria)				538,000
Steel Balls (end shields)				385,000
Light Water (end shields).				32,500
5. Weight of Calandria Assembly (full)–w/o attachments.				1,312,800

Table I-2
Weights of Reactivity Control Units and Fuel Channels

Component/Item	Unit Weight (lbs)	Quantity Per Reactor	Weight (lbs)	Total Weight (lbs)
a. Vertical Reactivity Control Units				
- shutoff rods	1,460	28	40,880	
- control absorbers	1,460	4	5,840	
- adjuster rods	950	21	19,950	
- zone control units	300	6	1,800	
- vertical flux detectors	250	26	6,500	
Vertical RCU TOTAL				74,970
b. Horizontal Reactivity Control Units				
- liquid poison injection	100	6	600	
- ion chambers	3,600	6	21,600	
- horizontal flux detectors	90	7	630	
Horizontal RCU TOTAL				22,830
c. Fuel Channels				
- pressure tube	137	380	52,060	
- fuel	53 lbs/bdle	4560	241,680	
- PHT	49 lbs/ch.	380	18,620	
- end fitting plus contents	580	760	440,800	
Fuel channels TOTAL				753,160