



Load Combinations and Stress Limits for the Pressure Boundary Design

(Non-proprietary Version)

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Presentation to US Nuclear Regulatory Commission

Washington DC

March 04, 2004



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Reactor Coolant Pressure Boundary

- **The Reactor Coolant Pressure Boundary (RCPB) includes the following components:**
 - **2 Steam Generators**
 - **4 Heat Transport Pumps and Motors**
 - **284 Reactor Inlet Feeders**
 - **284 Fuel Channels with End Fittings**
 - **284 Reactor Outlet Feeders**
 - **2 Reactor Inlet Headers**
 - **2 Reactor Outlet Headers**
 - **Connecting Piping**
 - **Pressurize**
 - **Condenser**
 - **(On-Channel) Fueling Machine**



RCPB Analysis

- **RCPB detailed analysis is performed per ASME Section III, NB-3000**
- **Fatigue calculations performed considering seismic motion smaller than the Safe Shutdown Earthquake (SSE)**
 - **Use either 20 maximum stress cycles from SSE**
 - **Or five events of 63 full stress cycles with magnitude equal to one-third that of SSE response**
 - **Design life is 60 years**
 - **For the Pressure Tube /Channel, design life is 30 years**

RCS Transients



	Overpressure Protection Transients	Design cycles
Test	Commissioning	
	Hydrostatic Test	10
	Leak Test	10
	Secondary side leak test	
	Hot Conditioning	25
	Commissioning Without Fuel	25
Level A	Normal Operating Condition (Level A Service Limit)	
	Warmup and Cooldown	200
	Startup and Shutdown	1000
	Power Manoeuvring	10000
Level B	Upset Conditions (Level B Service Limit)	
	Turbine Trip / Loss of Offsite Load	500
	Reactor Stepback	500
	Reactor Trip from 100% FP	200
	Loss of Class IV Power	50
	Reactor Overpower / Loss of Regulation	200
	Total Loss of Feedwater	100
	Total Loss of heat sink (cooldown with HT pump)	10
	Two HT pump trip	50
	Rapid Cooldown	15
	Loss of pressure and inventory control during warmup	15



RCS Transients (cont.)

Level C	Emergency Conditions (Level C Service Limit)	
	System Overpressurization	1
	Small Loss of Coolant Accident (Small break)	5
	Loss of SDC in maintenance mode	1
	HT Pump Shaft Seizure	1
	Level B Transients with SDS1 Failure	1
	Small feedwater line break	5
	Small SG tube leak	5
Level D	Faulted Conditions (Level D Service Limit)	
	Steam Line Break	1
	Large feedwater line break	1
	Loss of Coolant (Large break - LOCA)	1
	Level C Transients with SDS1 Failure	1
	Safe Shutdown Earthquake SSE	
	LOCA + SSE	



RCS Equipment

- **Supplier equipment: Steam Generators, Pressurizer, Condenser, Headers, Pumps, Valves, etc.**
- **AECL prepares specifications per ASME to meet ASME design criteria**
- **Designed / manufactured per Section III, Class 1 rules of ASME, following 10 CFR 55a**



Feeder Tubes – Design per ASME, Section III NB-3600

(ASME Code is 2001 or later)

Design Conditions (NB-3652)

Equation 9

Level A Service Limits (NB-3653)

Equation 10 Primary Plus Secondary Stress Range

Equation 11 Peak Stress Intensity Range

Equations 12 & 13 Simplified Elastic-Plastic Discontinuity Analysis

Level B Service Limits (NB-3654)

the conditions of Eq. (9)

The allowable stress to be used for this condition is $1.8S_m$, but not greater than $1.5S_y$.



Feeder Tubes – Design per ASME, Section III NB-3600 (cont.)

Level C Service Limits (NB-3655)

the conditions of Eq. (9)

The allowable stress to be used for this condition is $2.25 S_m$, but not greater than $1.8S_y$

Or Alternatively use NB-3656 modified as per 3655.2 (b)
(70% allowable stress, 70% allowable load)

Level D Service Limits (NB-3656)

The sustained stress due to weight loading

NB-3656 (b)(2) (Sustained stress due to weight)

NB-3656 (b)(3) (Stress due to weight + inertial loading due to reversing dynamic loads + level D pressures)

NB-3656 (b)(4) Range of moments due to anchor motions due to earthquake and other reversing dynamic loading



Fuel Channel and Fueling Machine

- **Fuel channel includes: pressure tube, end fitting, rolled joint, channel closure, feeder connection**
- **Analysis is per per ASME, Section III, NB-3200**
 - Design Condition
 - Level A
 - Level B
 - Level C
 - Level D
 - Test Conditions



Fatigue Analysis/Stress Limits per ASME Section III

Stress Category	Loading Conditions					
	Design Condition	Service Condition Level A	Service Condition Level B	Service Condition Level C	Service Condition Level D	Testing Condition
P_m	S_m	-	$1.1 S_m$	Larger of $1.2 S_m$ or S_y	Smaller of $2.4 S_m$ or $0.7 S_u$	$0.9 S_y$
P_L	$1.5 S_m$	-	$1.65 S_m$	Larger of $1.8 S_m$ or $1.5 S_y$	Smaller of $3.6 S_m$ or $1.05 S_u$	-
$P_m(P_L)+P_b$	$1.5 S_m$	-	$1.65 S_m$	Larger of $1.8 S_m$ or $1.5 S_y$	Smaller of $3.6 S_m$ or $1.05 S_u$	$1.35 S_y$ or $2.15 S_y - 1.2 P_m$
$P_m(P_L)+P_b + Q$	-	$3 S_m$	$3 S_m$	-	-	-
$P_m(P_L)+P_b + Q + F$	-	Cumulative fatigue usage factor not to exceed 1.0		-	-	-
Triaxial Stress $(\sigma_1 + \sigma_2 + \sigma_3)$	$4 S_m$	$4 S_m$	$4 S_m$	$4 S_m$	-	$4 S_m$



(Preliminary) Temperature and Pressure Profile in Fuel Channel



Generalized Level A Condition System Pressure/Temperature Data at Fuel Channel Outlet



FM Design Loads

- **Pressure**
- **Temperature**
- **Maximum ram axial thrust force (fuel pushing)**
- **Maximum latching operations ram force**
- **Maximum z-motion force (effected by the fueling machine carriage)**
- **Maximum mechanical load applied by fuel string**
- **Radial force applied to snout during normal homing operations**
- **Occasional misalignment forces and moment at snout during clamping**
- **Maximum misalignment forces at the fueling machine (FM) snout during clamping with a spurious movement of a FM homing drive mechanism (abnormal occurrence)**
- **Internal force within snout assembly due to clamping force on an end fitting**



Typical Level A (Normal) Operating Condition Loads

- **FM homing onto end fitting**
 - **Snout Clamp**
 - **Pressure**
 - **Temperature**
 - **Temperature of FM Magazine Coolant**
 - **Fuel Pushing Ram**
 - **Latching Operations Ram**
 - **Separator System**
 - **Fuel Bundle**



Typical Level B Service Condition Parameter

Reactor inlet level B transient (upstream FM on reactor)

Pressure:	13.2 – 14.6 – 13.2 MPa(g) (1915 – 2118 – 1915 psig)
Temperature:	57 – 291 – 57 °C (135 – 556 – 135 °F)



Typical Level C Emergency Condition

FM on reactor

	1) DBE	2) Loss of Class III Power
Pressure (upstream FM)	13.2 MPa(g) (1915 psig) decreasing	13.2 MPa(g) (1915 psig) decreasing
Pressure (downstream FM)	12.4 MPa(g) (1800 psig) decreasing	12.4 MPa(g) (1800 psig) decreasing
Temperature	38 – 320 °C – [tbd] (100 – 608 °F – [tbd])	38 °C – [tbd] – [tbd] (100 – [tbd] – [tbd])



FM Test Conditions (Preliminary)

Pressure:	19.4 MPa(g) (2814 psig)
Temperature:	21 °C (70 °F)



Allowable Service Stress Limits for Specified Service Loading Combinations for RCPB

Plant Event	Operating Condition	Loading Combination	Service Limits
Normal Operation	Normal	Sustained Loads	A
Plant/System Operating Transients (SOT) *	Upset	Sustained Loads + SOT	B
Small LOCA	Emergency	Sustained Loads + DBPB	C
MS/FWPB	Faulted	Sustained Loads + MS/FWPB	D
SSE	Faulted	Sustained Loads + SSE	D
LOCA	Faulted	Sustained Loads + LOCA	D
LOCA + SSE	Faulted	Sustained Loads + LOCA + SSE	D

(* OBE equivalent considered for fatigue calculations)



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