Attachment I

CALCULATION M-DSC-373,

"Reactor Pressure Vessel Minimum Boltup Temperature"

CALCULATION TITLE PAGE	ICCN No./ Prelim. CCN No.	Page____ of ____
		CCN CONVERSION: CCN NO. CCN-

Calc No. M-DSC-373 DCP/FIDCN/FCN No. & Rev. 0 --

Subject: Reactor Pressure Vessel Minimum Boltup Temperature Sheet 1 of 33

System Number/Primary Station System Designator 1201/BBB SONGS Unit 2 & 3 Q-Class I

Tech. Spec. Affecting? ○ NO ● YES Section No. 3.4.3 Equipment Tag No. ______

Site Programs/Procedure Impact? ○ NO ● YES, AR No. 980900942

CONTROLLED COMPUTER PROGRAM/ DATABASE	☐ PROGRAM ☐ DATABASE ACCORDING TO SO123-XXIV-5.1	PROGRAM/DATABASE NAME(S) ☐ ALSO, LISTED BELOW	VERSION/RELEASE NO(S).

RECORDS OF ISSUES

REV. DISC.	DESCRIPTION	TOTAL SHTS / LAST SHT.	PREPARED (Print Name/Sign/Date)	APPROVED (Signature/Date)	
0	Initial Issue	33	ORIG. Russell Cipolla / [signature] 3/1/00	FLS [signature] 3/10/00	Other 90034 R.6
		33	IRE. [signature] Michael T. Crowin 3/10/00	Other	Other
			~~ORIG.~~ Jun Gao / J.G. 3/10/00	FLS	Other
			IRE.	Other	Other
			ORIG.	FLS	Other
			IRE.	Other	Other
			ORIG.	FLS	Other
			IRE.	Other	Other

Space for RPE Stamp, identify use of an alternate calc., and notes as applicable.

Note: This calculation provides minimum boltup temperature calculations for the RPV flange for SONGS 2 and 3 performed by Aptech Engineering Services, Inc. (APTECH)

This calc. was prepared for the identified DCP/FCN. DCP/FCN completion and turnover acceptance to be verified by receipt of a memorandum directing DCN Conversion. Upon receipt, this calc. represents the as-built condition. Memo date ______ by ______

CALCULATION CROSS-INDEX

CCN NO./ PRELIM. CCN NO.	PAGE ____ OF ____
	CCN CONVERSION: CCN NO. CCN-

Calculation No. M-DSC-373 Sheet No. 2 of --

Calc. rev. number and responsible FLS initials and date	INPUTS These interfacing calculations and/or documents provide input to the subject calculation and if revised may require revision of the subject calculation.		OUTPUTS Results and conclusions of the subject calculation are used in these interfacing calculations and/or documents.		Does the output interface calc/ document require change?	Identify output interface calc/document CCN, DCN, TCN/Rev., FIDCN, or tracking number.
	Calc / Document No.	Rev. No.	Calc / Document No.	Rev. No.	YES / NO	
0 [signature] 3/6/00	SO23-901-C251	0	Tech Spec 3.4.3 DBD-SO23-360 M-0011-063	-- 6 1	Yes Yes Yes	AR 980900942 AR 980900942 AR 980900942

SCE 26-424 REV. 3 8/99 [REFERENCE. SO123-XXIV-7.15]

CALCULATION COVER SHEET

M-DSC-373 SH. 3

Calculation No.: AES-C-3865-1	**Client:** Southern California Edison Company
Title: Reactor Pressure Vessel Flange Temperature Limit for Boltup — SONGS Units 2 and 3	**Project No.:** AES 99123865-1Q
	APTECH Office: Sunnyvale
	Sheet No. 1 of 20
☐ **Uncontrolled** ■ **Controlled**	**Document Control No.:** I-2

Purpose: The purpose of this calculation is to determine the minimum metal temperature for the reactor pressure vessel flange for initial head boltup for compliance with ASME Section XI, Appendix G, requirements.

Assumptions: The analysis assumptions are described in Section 3.

Results: The limiting location for the flange is the flange-to-shell weld. The minimum boltup temperature (MBT) is computed to be 59°F based on the ASME Section XI, Appendix G, computed MBT and includes uncertainties in temperature measurement (i.e., instrument error).

Revision No.	Prepared By / Date	Checked By / Date	Verified By / Date	Approved By / Date	Revision Description
0	[signature] 3/6/00	MTC 7Mar00	MTC 7Mar00	[signature] 3/7/00	Initial Release

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QAN45
REV. 8/96

APTECH® ENGINEERING SERVICES, INC.

M-DSC-373 SH 4

Calculation No.: AES-C-3865-1	Made by: RCC	Date: 3/6/00	Client: SCE
Title: Reactor Pressure Vessel Flange Temperature Limit for Boltup — SONGS, Units 2 and 3	Checked by: MTC	Date: 7 Mar 00	Project No.: AES 99123865-1Q
	Revision No.: 0	Document Control No.: I-2	Sheet No.: 2 of 20

STRESS REPORT CERTIFICATION STATEMENT

The undersigned, a Registered Professional Engineer competent in the field of design and stress analysis, certifies that the evaluation report complies with the requirements of the Design Specification, Section III of ASME Boiler and Pressure Vessel Code 1971 Edition through Summer 1971 addenda, and Section XI of the ASME Code 1989 Edition, is correct and complete with respect to the design calculations set forth in this report.

Russell C. Cipolla — 3/6/00

Registered Professional Engineer — Date

State of California

Certificate Number 17973 (9/30/01)

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1.0 INTRODUCTION

The pressure-temperature (P-T) limits for the reactor coolant system (RCS) are governed by the Technical Specification (TS) for the plant (Ref. 1). A minimum temperature of 86°F is required to tension the reactor pressure vessel (RPV) head studs. Hence the TS requires that the RCS temperature (i.e., flange metal temperature) cannot be less than 86°F when the RPV head studs are tensioned. This limit is based on original design calculations to Appendix G of American Society of Mechanical Engineers (ASME) Section III for the establishment of the P-T curves for operation, including conditions for flange boltup (Ref. 2).

The purpose of this calculation is to determine an updated flange temperature limit for boltup based on Appendix G of ASME Section XI (Ref. 3). It is the objective of this calculation to justify a lower temperature limit for boltup than the current value of 86°F.

This calculation makes use of material nil ductility (RT_{NDT}) data. The calculation also verifies the available safety margins, as determined by fracture analysis using stress distributions for pressure and boltup loadings that are adequate to the guidelines of ASME Section XI (Ref. 4). These verification calculations are included in Appendix A.

The RPV geometry showing the upper head, head flange, shell, and nozzles is given in Figure 1-1 (Ref. 5). The areas of interest are the RPV flange, closure head flange, and associated weld regions. The design specification for the RPV is given in Ref. 6.

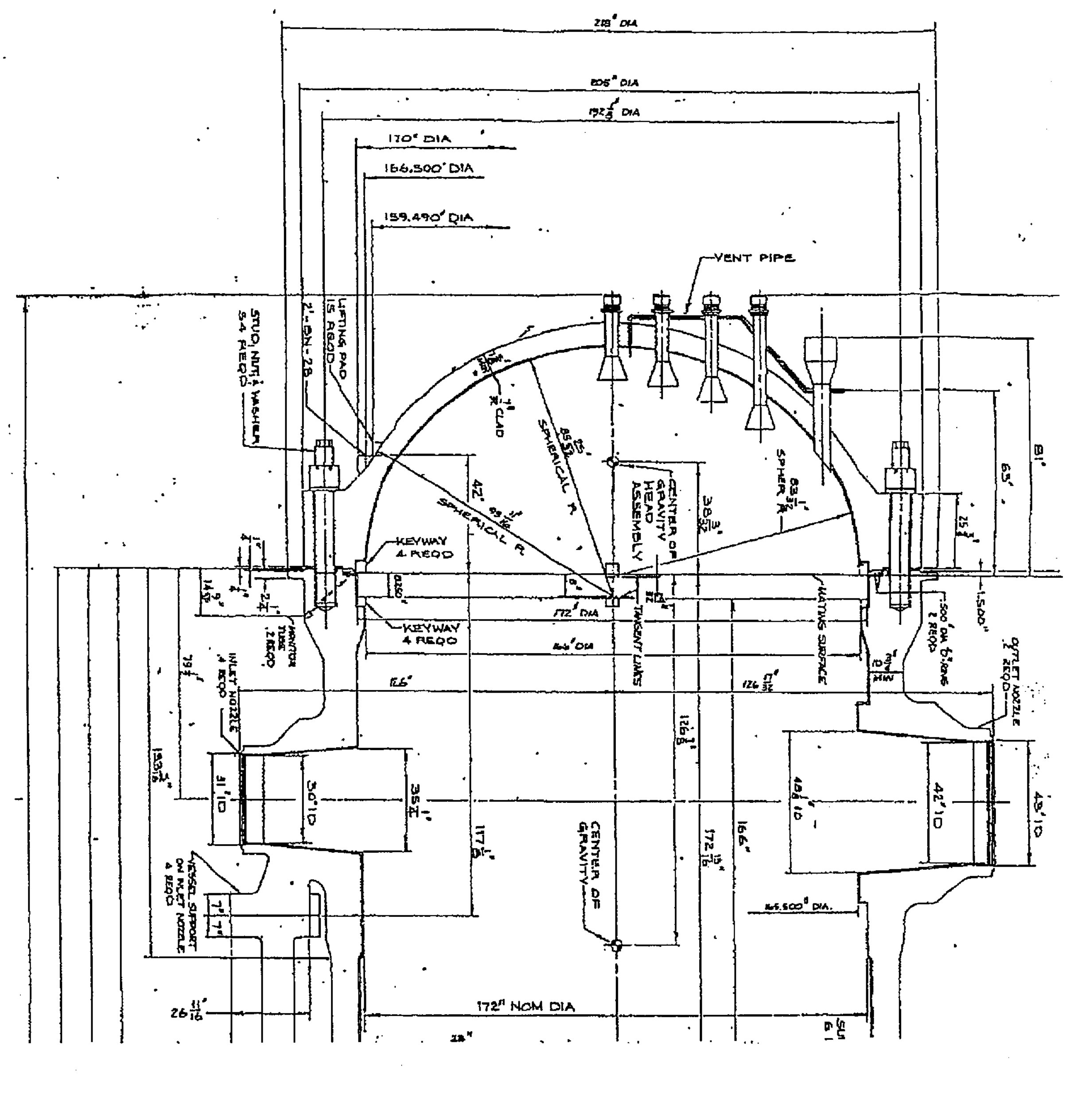

Figure 1-1 — Reactor Vessel Head Flange Geometry.

2.0 SUMMARY

The minimum boltup temperature (MBT) was determined from the RT_{NDT} of the flange materials; specifically, base material and welds for the RPV flange, shell, closure head flange, and torus ring. In applying the recommendation of Article G-2222(c) of ASME Section XI, Appendix G (Ref. 3), an MBT of 59°F was established. This minimum temperature limit includes a maximum temperature measurement error of +19°F based on RCS total loop uncertainties.

Further analysis, based on fracture mechanics, was performed to verify that adequate safety margins exist at MBT. The verification calculations follow the general procedures for determining P-T limits per Article G-2220 of ASME Section XI, Appendix G, with the objective of computing the available safety margins when metal temperature is equal to RT_{NDT} (i.e., nominal value for MBT). The details of this calculation are given in Appendix A. This analysis was performed for information only and confirms that reasonable margins exist for an MBT of 59°F.

Under the same analysis conditions imposed for P-T curve determination, and with the use of static initiation toughness reference curves, a minimum safety margin of 1.5 was established. It was judged, based on the flaw acceptance criteria of IWB-3613 (Ref. 4), that this margin level is reasonable and adequate for the vessel under boltup loading.

3.0 ANALYSIS ASSUMPTIONS

The following assumptions were made in performing the flange temperature limit calculations:

1. The procedures of ASME Section XI, Appendix G, are used to determine minimum temperature limit for flange boltup conditions.
2. The maximum initial RT_{NDT} (from original construction) for the flange material from either Unit 2 or Unit 3 is conservatively used for both units to represent flange toughness.
3. The maximum initial RT_{NDT} (from original construction) for the weld/shell material from either Unit 2 or Unit 3 is conservatively used for both units to represent weld toughness.
4. Radiation embrittlement is assumed to be negligible since the flange region is remote from the core beltline.
5. In the evaluation of available safety margins, a postulated defect of depth equal to 1/10t (where t is the vessel thickness) was assumed consistent with the original P-T limit calculations of Ref. 7.

4.0 METHODOLOGY

The calculation of minimum temperature limit for flange boltup was developed from the procedures of Article G-2220 of ASME Section XI, Appendix G (Ref. 3). The specific rule for bolt preloading is given in Article G-2222(c):

> "It is recommended that when the flange and adjacent shell region are stressed by the full intended bolt preload and by pressure not exceeding 20% of the preoperational system hydrostatic test pressure, minimum metal temperature in the stressed region should be at least the initial RT_{NDT} temperature for the material in the stressed regions plus any effects of irradiation at the stressed regions."

Therefore, the MBT is established from the RT_{NDT} of the materials (base and weld) in the flange region, both on the vessel side and head side of the closure, with consideration for total loop uncertainties (TLU) in the measurement of temperature of the RCS cold leg. Hence, temperature measurement uncertainty is included so that

$$MBT = RT_{NDT} + T_{TLU} \qquad (4\text{-}1)$$

In order to verify the margins inherent in Eq. 4-1, P-T calculations for the flange are also performed. The P-T calculations are based on principles of fracture mechanics. The temperature limit is computed from the reference fracture toughness curve (K_{IR} or K_{Ic}), and applied stress intensity factor (K_I), with appropriate safety factors from the following:

$$K_I < K_{IR} \qquad (4\text{-}2)$$

For vessel flanges under boltup condition, the K_I value is determined from:

$$K_I = K_{Im} + K_{Ib} \qquad (4\text{-}3)$$

where K_{Im} is the K_I value for primary membrane loading and K_{Ib} is the K_I value for primary bending. The reference fracture toughness curves are defined by the following relationships:

$$K_{IR} = 26.78 + 12.445 \exp[0.0145(T - RT_{NDT})] \qquad \textbf{(4-4)}$$

$$K_{Ic} = 33.2 + 20.734 \exp[0.02(T - RT_{NDT})] \qquad \textbf{(4-5)}$$

Equation 4-4 is the original toughness requirement given in Appendix G of ASME Section XI and is conservatively based on lower-bound dynamic initiation and crack arrest data of RPV steels (Ref. 3). Equation 4-5 is the alternate reference toughness curve in Appendix A of ASME Section XI and is conservatively based on lower-bound crack initiation data for RPV steels (Ref. 4).

The determination of K_I follows the general procedure of Appendix G, with crack shape parameters taken from Article A-3000 of Appendix A. The methods and description for the determination of K_I are given in Appendix A of this calculation.

5.0 DESIGN INPUT

5.1 Component Geometry

The vessel geometry of general interest includes the shell, nozzle, and main flange. A schematic illustration of the vessel geometry is shown in Figure 5-1. The basic dimensions of the vessel components are as follows (Refs. 5, and 7 through 10):

Shell:	R_o	= 96.97 inches
	R_i	= 86.00 inches
	t_b	= 10.75 inches (without clad)
Flange:	R_o	= 102.5 inches
	R_i	= 83.00 inches
	t_b	= 19.28 inches (without clad)
Head Flange:	R_o	= 102.50 inches
	R_i	= 86.00 inches (maximum)
	t_b	= 16.28 inches (without clad)
Head Torus:	R_o	= 93.23 inches
	R_i	= 83.03 inches
	t_b	= 9.983 inches (without clad) (Ref. 7)
Head Dome:	R_o	= 93.62 inches
	R_i	= 85.78 inches
	t_b	= 7.625 inches (without clad)
Nozzle:	r_i	= 17.63 inches
	r_i	= 15.00 inches
Clad:	t_c	= 7/32 inch

The specific areas covered by this calculation are the RPV main flange, the flange-to-shell weld, the head flange, and the head flange-to-torus weld.

5.2 Design Conditions

The design and operating conditions for pressure and temperature are (Refs. 11 and 12):

P_D = 2500 psia

T_D = 650°F

P_O = 2250 psia

T_O = 611.2°F

The hydrostatic test pressure for the vessel is 1.25 times design, or 3125 psia (Ref. 12).

Flange stresses due to boltup load were provided by Southern California Edison Company (SCE) in Ref. 7.

5.3 Material Properties

The materials that comprise the RPV, flange, closure head, and inlet nozzle (Refs. 10 through 12) are as follows:

Vessel:	SA 533, Grade B, Class I
Flange:	SA 508, Class II
Closure Head:	SA 533, Grade B, Class I
Inlet Nozzle:	SA 508, Class II
Cladding:	Stainless steel

In the analysis, the cladding is conservatively ignored in the determination of vessel strength. The reference temperature for RT_{NDT} for the base metal (Units 2 and 3) and weldments has been compiled in Ref. 13. A summary of the highest reported values for RT_{NDT} is given in Table 5-1 for base metal and in Table 5-2 for weld metal. Fracture toughness properties for the materials are determined from Eq. 4-3 or 4-4, as appropriate.

TABLE 5-1

RT_{NDT} For Base Metal Components - RPV Head Flange

	Unit 2		Unit 3	
Component	Heat Number	RTNDT (F)	Heat Number	RTNDT (F)
Upper Shell	C7585-2	-4	C4482-2	23
	C7573-1	40	C4472-2	31
	C7573-2	10	C4464-2	10
Vessel Flange	IV3784-264	-10	2L2055-336	-10
Closure Head Flange	123A-293-286	-10	123C278BKW-368	-50
Closure Head Torus	C8288-2	16	C3893-1	30
	C8278-3	18	A2306-3	30
Closure Head Dome	C8279-3	5	C3893-3	40

TABLE 5-2

RT_{NDT} For Weld Seams - RPV Head Flange

	Unit 2		Unit 3	
Weld Seam	Weld Wire Heat Number	RTNDT (F)	Weld Wire Heat Number	RTNDT (F)
Upper Shell Axial	90099	10	4P6052	-50
	90136	10	HAAID	-50
	JADJ	10		
Upper Shell to Flange	10137	10	4P6052	-50
	FOAA	10	30502	-50
			88118	-70
			4P6524	-50
			FAOED	-60
			FAOJE	-60
			JAHB	-40
Closure Head Torus Axial	EOBC	-60	JAOHD	-50
	FABGC	-80	IAOCE	-80
Closure Head Torus to Dome	2P5755	-70	4P6524	-50
	FAAFC	-60	4P6519	-60
	HAAEC	-80		
	HAGB	-40		
Closure Head Flange to Torus	2P5755	-70	4P6524	-50
	FAAFC	-60	4P6519	-60

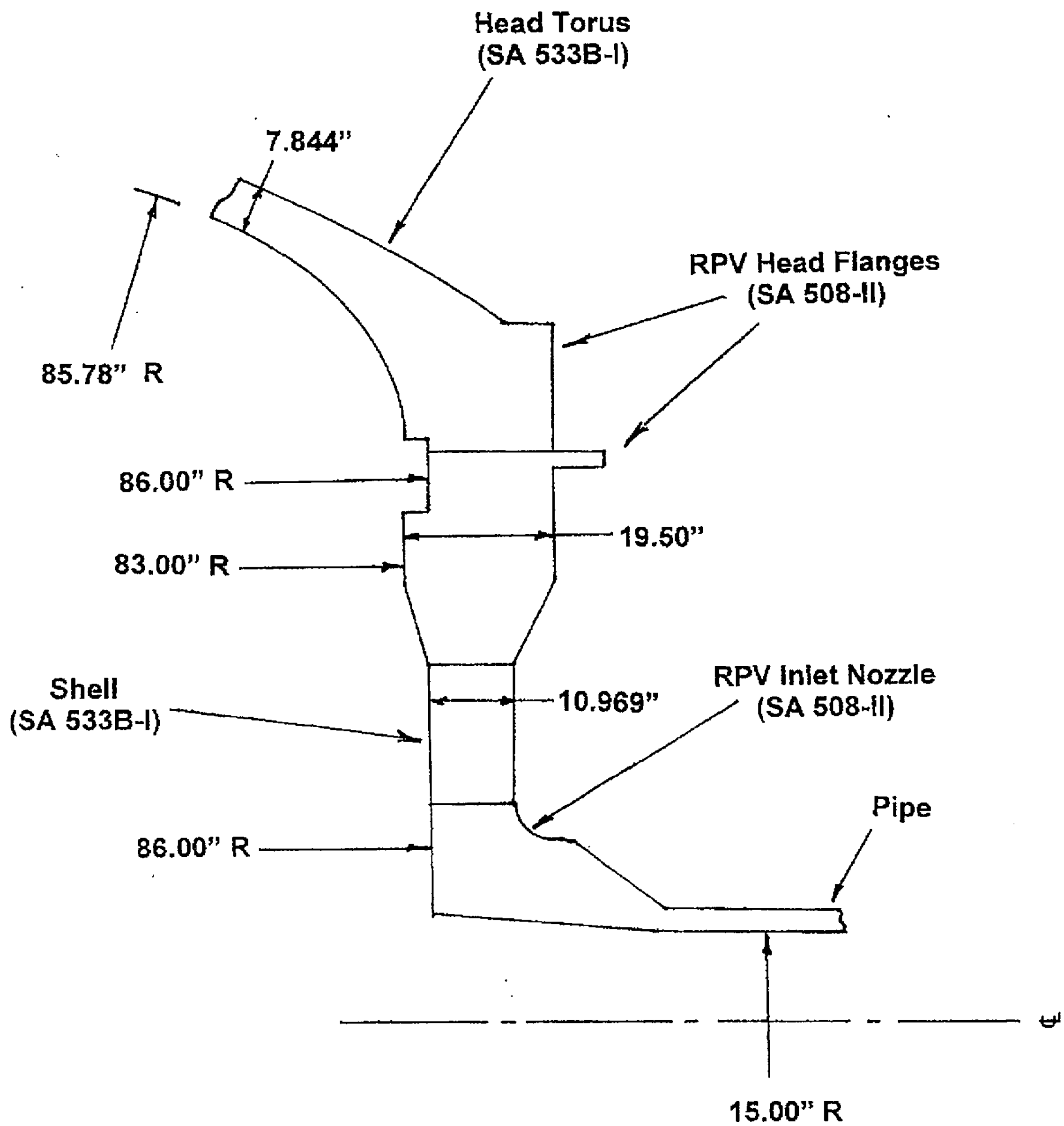

Figure 5-1 — Illustration of Reactor Pressure Vessel Flange Geometry.

6.0 REFERENCES

1. "RCS P/T Limits," 3.4.3, Technical Specifications, Amendment No. 116, San Onofre Unit 3; and "SDC and Coolant Circulation — High Water Level," 3.9.4, Technical Specifications, Amendment 153, San Onofre Unit 2 (ECD-22 from APTECH Project AES 99063721-1Q).

2. ASME *Boiler and Pressure Vessel Code*, Section III, "Rules for Construction of Nuclear Power Plant Components," (1971 Edition, 1971 Summer Addenda).

3. ASME *Boiler and Pressure Vessel Code*, Section XI, Appendix G, "Fracture Toughness Criteria for Protection Against Failure," American Society of Mechanical Engineers, 1989 Edition.

4. ASME *Boiler and Pressure Vessel Code*, Section XI, Appendix A, "Evaluation of Flaws," American Society of Mechanical Engineers, 1989 Edition.

5. Drawing 234-650, Revision 2, "General Arrangement (Elevation) 172″ ID PWR," SO23-901-205-0 (August 7, 1977) (ECD-5 from APTECH Project AES 99063721-1Q).

6. "General Specification for a Reactor Vessel Assembly," Specification No. 00000-PE-110, Revision 1, Combustion Engineering (August 11, 1971) (ECD-4 from APTECH Project AES 98063465-1Q).

7. Calculation No. RS-706, "Appendix G Evaluation," CE Power Systems (August 13, 1981) (ECD-11).

8. Drawing 234-554, Revision 7, "Nozzle Details," SO23-901-44-4 (March 15, 1975) (ECD-5 from APTECH Project AES 99063721-1Q).

9. "Structural Analysis of the Closure Head and Vessel Assembly," Combustion Engineering Company Report, Appendix A, p. A-61 (ECD-11 from APTECH Project AES 99063721-1Q).

10. Drawing 234-651, "General Arrangement (Plan) 172″ ID PWR," SO23-901-204-0 (March 3, 1976) (ECD-5 from APTECH Project AES 99063721-1Q).

11. "Project Specification for A Reactor Vessel Assembly for San Onofre Units No. 2 and No. 3," Specification No. 01370-PE-110, Revision 4, Combustion Engineering, (May 7, 1976) (APTECH Project AES 98083465-1Q, ECD-2).

12. "Analytical Report for Southern California San Onofre Unit 2 Reactor Vessel," Report CENC-1269, Combustion Engineering (October 1976) (APTECH Project AES 98083465-1Q, ECD-3).

13. Letter to J. Gaor (SCE) from ABB/CE, "San Onofre Unit 2 and 3 Minimum Boltup Temperature," S-PENG-99-023 (December 28, 1999) (ECD-13).

14. "Revised P-T Curves for 20 EFPY, SONGS 2 & 3," Calc No. M-0011-063, Southern California Edison Company (May 31, 1994) (APTECH Project AES 99063721-1Q, ECD-10).

7.0 NOMENCLATURE

a	=	Postulated defect depth, inch
E	=	Modulus of elasticity, psi
G_0	=	Free boundary correction factor for uniform stress
G_1	=	Free boundary correction factor for linear stress
K_I	=	Stress intensity factor, ksi $in^{1/2}$
K_{Im}	=	Stress intensity factor for membrane stress, ksi $in^{1/2}$
K_{Ib}	=	Stress intensity factor for bending stress, ksi $in^{1/2}$
ℓ	=	Postulated defect length, inch
MBT	=	Minimum boltup temperature, °F
υ	=	Poisson's ratio
P	=	Pressure, psi
P_D	=	Design pressure, psi
P_O	=	Operating pressure, psi
Q	=	Flaw shape parameter
r	=	Mean nozzle radius, inch
r_o	=	Outer radius of nozzle, inch
r_i	=	Inner radius of nozzle, inch
R_o	=	Outer radius of vessel, inch
R_i	=	Inner radius of vessel, inch
σ	=	Applied stress, psi
σ_m	=	Primary membrane stress, psi
σ_b	=	Primary bending stress, psi
t	=	Wall thickness, inch
t_b	=	Base metal thickness, inch
t_c	=	Clad thickness, inch

T = Temperature, °F

T_D = Design temperature, °F

T_{TLU} = Temperature measurement uncertainty for total system loop, °F

T_O = Operating temperature, °F

8.0 CALCULATIONS

The determination of MBT requires the solution of Eq. 4-1. Per Article G-2222(c) of Appendix G, it is recommended that the minimum metal temperature be at least the initial RT_{NDT} of the material plus any effects of radiation embrittlement. Since the flange region is remote from the vessel core beltline, it is assumed that the embrittlement effects on RT_{NDT} are negligible.

From Tables 5-1 and 5-2, the maximum RT_{NDT} is established from base metal nil ductility temperature properties. The maximum RT_{NDT} is 40°F (upper-shelf) for Unit 2 and 31°F (upper-shelf) for Unit 3. It is assumed that the closure head dome is remote from the flange and, therefore, not subject to peak boltup stresses. From Eq. 4-1,

$$MBT = RT_{NDT} + T_{TLU} = 40 + 19 = 59°F$$

where the TLU on temperature (T_{TLU}) is equal to ±19°F (Sheet 20 of Ref. 14). Therefore, the MBT for the RPV flange for Units 2 and 3 is 59°F.

Appendix A
VERIFICATION OF SAFETY MARGINS

A.1 PURPOSE

To confirm that adequate safety margins exist at the minimum boltup temperature (MBT), a fracture mechanics analysis is performed. This evaluation follows the general procedures for determining the P-T curves per Article G-2220 of ASME Section XI, Appendix G (Ref. A-1). The objective of this calculation is to compute the available safety margins when flange temperature is equal to nominal MBT:

$$T = MBT \equiv RT_{NDT} = 40°F$$

This calculation is provided as background information and verification for the determination of MBT.

A.2 Analysis Locations

The calculation for available margin was performed for four locations: (1) the flange-to-shell weld, (2) the RPV flange base metal, (3) the closure head flange, and (4) the flange-to-torus weld. The locations are shown in Figure A-1.

The postulated defect is a 1/10t deep surface crack with an aspect ratio (length-to-depth) of 6 to 1. The defect is postulated on the outside surface and oriented circumferentially. This flaw location and orientation will be bounding since the highest combined stresses will be axially oriented (i.e., normal to the plane containing the postulated defect).

A.3 Flange Stresses

The flange stress at the four analysis locations included the full bolt preload and a pressure of 20% of the preoperational hydrostatic test pressure. From Section 5.2, the hydrostatic test pressure is 3125 psia.

A.3.1 Pressure Stress

The pressure stress is assumed to be a primary membrane stress equal to the end cap pressure load divided by the cross-sectional area:

$$\sigma_m = \frac{p\,R_i^2}{(R_o^2 - R_i^2)} \qquad \textbf{(A-1)}$$

The internal pressure is computed as:

$$p = 0.20 p_h = 0.20(3125 - 14.7)$$

$$p = 622 \text{ psig}$$

From Section 5.1, the inside and outside radius (conservatively excluding the clad) and wall thickness of the flange locations are summarized below:

	R_o (inch)	R_i (inch)*	t_b (inch)	t (inch)
Flange-to-shell weld	96.97	86.22	10.75	10.97
RPV flange	102.5	83.22	19.28	19.50
Head flange	93.23	83.25	9.983	10.20
Flange-to-torus dome	93.62	85.78	7.625	7.844

* Inner radius to base metal

From Eq. A-1, the pressure stress for each location is summarized below:

Section	Location	σ_m (ksi)
1	Flange-to-shell joint	2.35
2	RPV flange	1.20
3	Head flange	2.45
4	Flange-to-torus joint	3.25

A.3.2 Boltup Stress

The primary membrane and bending stresses due to boltup were obtained from stress information provided by SCE (Ref. A-2). The membrane and bending components were determined by linearization of the stress distribution across the wall. Peak tensile stress occurs at the vessel outside surface. The corresponding σ_m and σ_b values are listed below:

Section	Location	σ_m (ksi)	σ_b (ksi)
1	Flange-to-shell joint	0	19.4
2	RPV flange*	0	6.03
3	Head flange	1.19	24.4
4	Flange-to-torus joint	1.27	23.9

* Bending stress was estimated by scaling σ_b at Section 1 stress based on the square of the thickness ratio between Section 2 and Section 1.

A.4 Available Toughness at MBT

The verification of the minimum temperature is determined from Section 4.0 for the two separate fracture toughness reference curves. For temperature equal to minimum possible temperature, T = 40°F (i.e., MBT – T_{TLU}), the reference toughness levels are given by:

$$K_{IR} = 26.78 + 12.445 \exp[0.0145(40 - RT_{NDT})] \qquad \text{(A-2)}$$

and

$$K_{IR} = 33.2 + 20.734 \exp[0.02(40 - RT_{NDT})] \qquad \textbf{(A-3)}$$

Equation A-2 is based on the original K_{IR} curve (Ref. A-1) and Eq. A-3 is the alternate definition for K_{IR} (based on K_{Ic} in Ref. A-3) as permitted by Code Case N-640 (Ref. A-4). For the maximum RT_{NDT} for each region, the available toughness at MBT is computed from Eqs. A-2 and A-3, as summarized below:

			K_{IR} (ksi in$^{1/2}$)	
Section	Location	RT_{NDT} (°F)	Eq. A-2	Eq. A-3
1	Flange-to-shell joint	40	39.2	53.9
2	RPV flange*	–10	52.5	89.6
3	Head flange	–10	52.5	89.6
4	Flange-to-torus joint	30	41.2	58.5

The definition of K_I, excluding a safety factor on primary loads, is

$$K_I = K_{Im} + K_{Ib} \qquad \textbf{(A-4)}$$

Therefore, the safety factor margin (SF) is defined as:

$$SF = K_{IR}/K_I \qquad \textbf{(A-5)}$$

A.5 Determination of K_I

A.5.1 Analysis Equations

The determination of K_I follows the procedures of ASME Section XI, Appendix G (Ref. A-1), with crack shape parameters taken from Article A-3000 of Appendix A (Ref. A-3). The basic equations for K_I are:

$$K_{Im} = \sigma_m G_0 [\pi a/Q]^{0.5} \quad \text{(A-6)}$$

$$K_{Ib} = \sigma_b [G_0 - 2G_1 (a/t)] [\pi a/Q]^{0.5} \quad \text{(A-7)}$$

$$\sigma_m = P R_i^2/(R_o^2 - R_i^2) \quad \text{(A-8)}$$

$$Q = 1 + 4.593 (a/\ell)^{1.65} \quad \text{(A-9)}$$

where σ_b is the bending stress across the flange section due to boltup. For the purpose of this evaluation, bolt preload stresses are considered primary. The crack parameters G_0 and G_1 are defined in Article A-3320 for surface cracks in a linear varying stress field. The pressure P is defined as 20% of the preoperational hydrotest pressure per Article G-2222(c).

The calculation of K_I was completed using the 1995 Edition of ASME Section XI as guidance. The current approved Code for SONGS is the 1989 Edition of ASME Section XI. However, the flaw evaluation methods and criteria are very similar in both the 1989 and 1995 Codes. The 1995 Edition is used herein because the equations and information are more complete and direct in application to the problem being evaluated. For these reasons, the 1995 Edition is technically equivalent to the 1989 Edition and can be used in the assessment of safety margins.

A.5.2 Flange-to-Shell Joint

The calculation of K_I for the flange weld region uses the following parameters for solving Eq. A-4:

$a = 0.10t = 1.097$ inches

$a/\ell = 1/6$

$\sigma_m = 2.35$ ksi

$\sigma_b = 19.4$ ksi

The total wall thickness (including clad) is conservatively used to define defect depth (a). The flaw parameters for use in computing K_{Im} (Eq. A-6) and K_{Ib} (Eq. A-7) are developed from Article A-3320 and Table A-3320-1 of Appendix A. For $a/t = 0.10$ and $a/\ell = 1/6$:

$$G_0 = 1.1015$$

$$G_1 = 0.6803$$

$$Q = 1 + 4.593(1/6)^{1.65} = 1.239$$

and

$$K_{Im} = (2.35)(1.1015)[\pi(1.097)/1.239]^{1/2}$$

$$K_{Im} = 4.32 \text{ ksi in}^{1/2}$$

$$K_{Ib} = (19.4)[1.1015 - 2(0.6803)(0.1)][\pi(1.097)/1.239]^{1/2}$$

$$K_{Ib} = 31.24 \text{ ksi in}^{1/2}$$

$$K_I = 4.32 + 31.24 = 35.6 \text{ ksi in}^{1/2}$$

A.5.3 RPV Flange Base Metal

The flange head is thicker than the weld region, but at a lower stress. The calculation of K_I follows below:

$$a = 0.10t = 1.95 \text{ inches}$$

$$a/\ell = 1/6$$

$$\sigma_m = 1.20 \text{ ksi}$$

$$\sigma_b = 6.03 \text{ ksi}$$

$$K_{Im} = (1.20)(1.1015)[\pi(1.95)/1.239]^{1/2}$$

$$K_{Im} = 2.94 \text{ ksi in}^{1/2}$$

$$K_{Ib} = (6.03)[1.1015 - 2(0.6803)(0.1)][\pi(1.95)/1.239]^{1/2}$$

$$K_{Ib} = 12.94 \text{ ksi in}^{1/2}$$

and

$$K_I = K_{Im} + K_{Ib} = 2.94 + 12.94 = 15.9 \text{ ksi in}^{1/2}$$

A.5.4 Head Flange Base Metal

The head flange is not as thick as the RPV flange in the ring section evaluated in Ref. A-2. The calculation of K_I is given below:

$$a = 0.10t = 1.02$$

$$a/\ell = 1/6$$

$$\sigma_m = 2.45 + 1.19 = 3.64 \text{ ksi}$$

$\sigma_b = 24.4$ ksi

$$K_{Im} = (3.64)(1.1015)[\pi(1.020)/1.239]^{1/2}$$

$$K_{Im} = 6.45 \text{ ksi in}^{1/2}$$

$$K_{Ib} = (24.4)[1.1015 - 2(0.6803)(0.10)][\pi(1.020)/1.239]^{1/2}$$

$$K_{Ib} = 37.9 \text{ ksi in}^{1/2}$$

and

$$K_I = K_{Im} + K_{Ib}$$

$$K_I = 6.45 + 37.9 = 44.4 \text{ ksi in}^{1/2}$$

A.5.5 Head Flange-to-Torus Joint

The calculation of K_I for the head flange-to-torus weld location is given below:

$a = 0.10t = 0.7844$

$a/\ell = 1/6$

$\sigma_m = 1.27 + 3.25 = 4.52$ ksi

$\sigma_b = 23.9$ ksi

$$K_{Im} = (4.52)(1.1015)[\pi(0.7844)/1.239]^{1/2}$$

$$K_{Im} = 7.02 \text{ ksi in}^{1/2}$$

$$K_{Ib} = (23.9)[1.1015 - 2(0.6803)(0.10)][\pi(0.7844)/1.239]^{1/2}$$

$$K_{Ib} = 32.5 \text{ ksi in}^{1/2}$$

and

$$K_I = K_{Im} + K_{Ib}$$

$$K_I = 7.02 + 32.5 = 39.5 \text{ ksi in}^{1/2}$$

A.6 Evaluation of Margins

The available margins when metal temperature is equal to 40°F (i.e., MBT – $T_{TI,U}$) was calculated from Eq. A-3. From the previous analysis for K_I and K_{IR}, the following results were obtained:

Location	K_I (ksi in$^{1/2}$)	K_{IR} (ksi in$^{1/2}$) App. G	K_{IR} (ksi in$^{1/2}$) N-640	Safety Margin App. G	Safety Margin N-640
Flange-to-shell joint	35.6	39.2	53.9	1.10	1.51
RPV flange*	15.9	52.5	89.6	3.30	5.64
Head flange	44.4	52.5	89.6	1.18	2.02
Flange-to-torus joint	39.5	41.2	58.5	1.04	1.48

Given the conservative assumptions of a large flaw located in the highest stressed region and lower bound fracture toughness, the safety margins exceed 1.0 for dynamic toughness and 1.5 for static toughness (as permitted by Code Case N-640). The limiting location is the closure head flange-to-torus region. A safety factor of two is specified in ASME Section XI, Appendix G for P-T limits during plant operation. However, a safety factor of $\sqrt{2}$ is specified for flaw acceptance criteria for boltup under IWB-3613 of ASME Section XI.

Given the fracture toughness provisions of Code Case N-640 and a $\sqrt{2}$ safety factor, the computed margins for MBT are reasonable and adequate. Therefore, the MBT derived from Article G-2222(c) has acceptable margins for SONGS Unit 2 and 3 flange component materials.

A.7 References

A-1. ASME *Boiler and Pressure Vessel Code*, Section XI, Appendix G, "Fracture Toughness Criteria for Protection Against Failure," American Society of Mechanical Engineers, 1989 Edition.

A-2. Calculation No. RS-706, "Appendix G Evaluation," CE Power Systems (August 13, 1981) (ECD-11).

A-3. ASME *Boiler and Pressure Vessel Code*, Section XI, "Rules for the Inservice Inspection Requirements of Nuclear Power Plant Components," American Society of Mechanical Engineers, 1995 Edition.

A-4. Code Case N-640, "Alternate Reference Toughness for Development of P-T Limit Curves," (February 26, 1999).

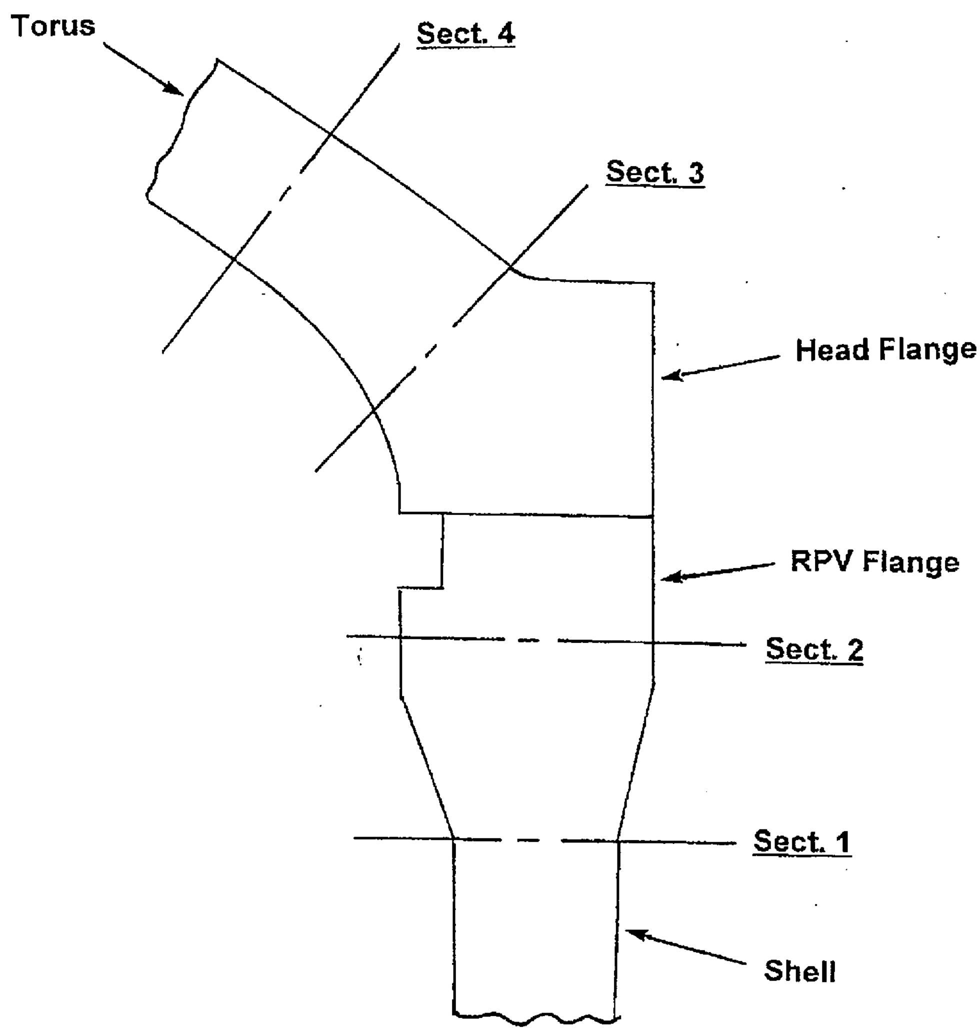

Figure A-1 — Analysis Locations for Minimum Temperature Calculations.