REPORT 6460-A

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COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

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STRESS LEVELS AND DESIGN PRACTICES FOR STAINLESS STEEL PARTS IN CONSUMERS POWER, BIG ROCK PLANT, REACTOR VESSEL AND STEAM DRUM

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ABSTRACT

As requested by General Electric, information on stainless steel parts subjected to furnace stress relief and used in the fabrication of the Consumers Power - Big Rock Plant - Reactor Vessel and Steam Drum is presented in this report. Included are stress levels in nozzle extensions in the reactor vessel and steam drum, and in internal brackets in the reactor vessel. In addition, a statement of design practices applied in defining requirements for internal brackets in the steam drum is provided.

SIGNIFICANT RESULTS

Stress levels in each of the parts defined by General Electric (Reference 1) are summarized as follows:

	Stress Intensity (ksi)		
Part Description	Membrane	Peak	Alternating
Downcomer Nozzle Extension	11.2	10.1	13.1
Riser Nozzle Extension	9.9	8.9	5.3
Vent Nozzle Extension	5.1	5.7	10.2
Instrument Nozzle Extension	9.1	8.7	6.2
Steam Outlet Nozzle Extension	10.0	9.6	6.3
Letdown Nozzle Extension	9.0	8.7	6.4
Recirculation Nozzle Extension	10.5	10.1	6.6
Poison Nozzle Extension	9.1	8.8	4.9
Core Support Bracket	4.0	11.8	<11.8
Core Support Plate Bracket	1.4	15.7	<15.7
Diffuser Bracket	0.5	3.9	< 3.9
Vent Nozzle Flange	7.2	5.8	5.7

All calculated stresses are less than the allowable values of of 14.8 ksi for membrane stress intensity, 16.2 ksi for peak stress intensity, and the material endurance limit of 18.1 ksi.

Evaluation of design practices used for the steam drum shows:

1. Design of internals utilizes design concepts developed for conventional fuel power plants,
2. Design, material, and fabrication conforms with ASME specifications applicable at the time of fabrication of the subject unit.
3. The design concept minimizes loads in internals, and their supports by requiring sliding joints between materials of different coefficients of thermal expansion.

TABLE OF CONTENTS

1.0 INTRODUCTION

Information on stainless steel parts subjected to furnace stress relief and used in fabrication of the Consumers Power, Big Rock Plant, reactor vessel and steam drum, as requested by General Electric (Ref. 1) is reported herein. Information included is as follows:

1.1 Stress Levels

Levels of stress in nozzle extension in the reactor vessel and steam drum, and in internal brackets in the reactor vessel are required. Specific parts for which stress levels have been requested are:

Part	P/N	Ref. Dwg.
Steam Drum		
Downcomer Nozzle Extension	103-3	E230-103
Riser Nozzle Extension	103-8	E230-103
Vent Nozzle Extension	104-7	E230-104
Reactor Vessel		
Instrument Nozzle Extension	795-4	E201-795
Steam Outlet Nozzle Extension	795-13	E201-795
Letdown Nozzle Extension	795-17	E201-795
Recirculation Nozzle Extension	796-3	E201-796
Poison Nozzle Extension	796-8	E201-796
Core Support Bracket	802-15/16	E201-802
Core Support Plate Bracket	802-18	E201-802
Diffuser Bracket	802-32	E201-802
Vent Nozzle Flange	807-3	E201-807

1.2 Design Practices

A statement on design practices used in design of internal brackets in the steam drum is required. Specific parts considered in the statement include:

Part	P/N	Ref. Dwg.
Downcomer Baffle Assy.	6 /67A	E230-108
Screen Dryer Hanger Lug	79	E230-108
Feedwater Header Supports	85A	E230-108

2.0 STRESS LEVELS

Categories of stress, and acceptability criteria for each category used in defining stress levels presented in this report are the same as used for original design of the vessels. These stress categories were initially defined by specifications for each of the vessels (Refs. 2 and 3) and further clarified by Combustion Engineering (Refs. 4 and 5).

In general, the stress criteria conforms to that given in "Tentative Structural Design Basis," Department of Commerce Bulletin PB151987 (Ref. 10) except for nomenclature. The nomenclature used herein has been purposely kept the same as that of the original analysis so as to minimize possible confusion between the stress categories.

Stress categories are expressed in terms of "stress intensity" which is defined as the difference between the algebraically largest principal stress and the algebraically smallest principal stress. The "stress intensity" is numerically equal to twice the maximum shear stress.

Each category of stress reported herein, and its acceptability criteria is as follows:

Membrane Stress Intensity--the stress intensity derived from the average values of principal stress across the thickness of a section that is subjected to internal pressure, mechanical forces, or their combinations (neglecting effects of structural discontinuities and stress concentrations). The membrane stress intensity is limited to the allowable value of stress from Table P-7, Section I, ASME Code (Ref. 7) for the material at the temperature that the loads are applied.

Peak Stress Intensity--the stress intensity derived from the highest values of principal stress at any point across the thickness of a section that is subjected to internal pressure, mechanical forces, or their combinations, including the effects of structural discontinuities but not stress concentrations. The peak stress intensity is limited to 90% of the material yield strength at the temperature at which the loads are applied. Values of material yield strength are taken from Table 5-1, "Tentative Structural Design Basis," Department of Commerce Bulletin PB151987 (Ref. 10).

2.0 STRESS LEVELS (continued)

Thermal Stresses--no stress limitations are applied to thermal stresses. Thermal stresses are considered as transient stresses and are combined with peak stresses for cyclic evaluation.

Alternating Stress Intensity--one-half of the algebraic difference between the maximum and minimum stress intensities at a point in a section during a cycle of transient operation. Maximum and minimum stress intensities are derived from the principal stresses at the point when the structure is subjected to internal pressure, mechanical forces, thermal stresses, and include the effects of structural discontinuities and stress concentrations.

Alternating stress intensity is used to evaluate possible limitations which might result from material fatigue. This evaluation is accomplished by comparing the required number of cycles of an operating condition to the allowable cycles for the maximum alternating stress for the condition. The allowable number of alternating stress cycles is obtained from Figure 5.2-3, "Tentative Structural Design Basis", Department of Commerce Bulletin PB151987 (Ref. 10).

For combinations of operating cycles, the total fatigue effect on the material is calculated as the sum of the ratios of required cycles to allowable cycles for each condition. This sum is defined as usage factor and is limited to a maximum value of 0.8.

2.1 Nozzle Extensions

Since primary loads in the nozzle extensions are limited to internal pressure, membrane stress intensities are calculated by classical equations for a thin walled cylindrical shell subjected to internal pressure.

The Seal-Shell - 2 Computer Program (Ref. 11) is used to calculate peak stress intensities, and the principal stresses needed to determine alternating stress intensities, in the nozzle extensions. Use of this program requires that the actual structure be represented by an analytical model.

2.0 STRESS LEVELS

2.1 Nozzle Extensions (continued)

The model used in analysis of the nozzle extensions (Fig. I) consists of a cylindrical section capped at each end. Geometry of the cylindrical section conforms to the actual geometry of the nozzle body and nozzle extension. Lengths of the sections between the caps and the nearest discontinuity is taken as B. = 3.0 so as to minimize carry over effects. The caps are used to insure proper representation of stresses due to pressure blow-off loads.

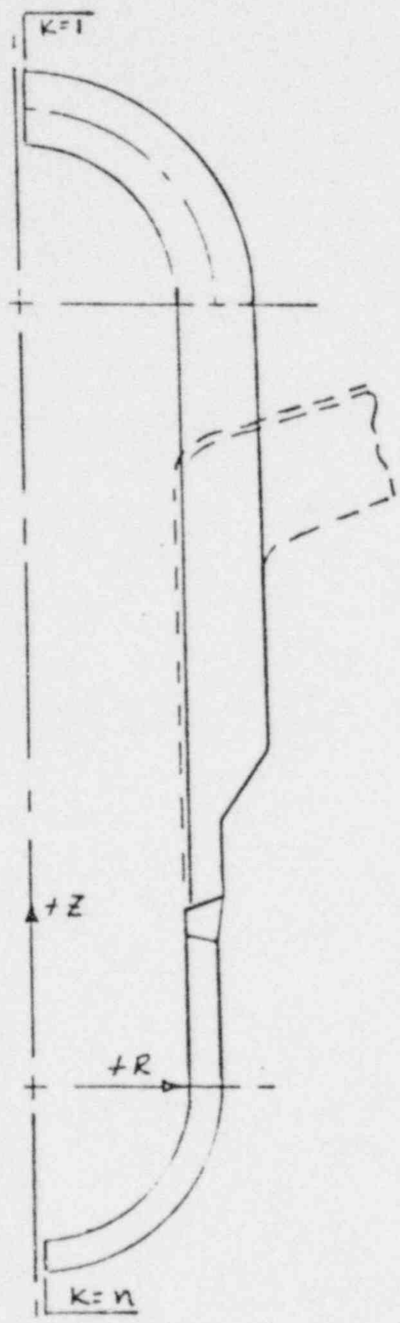

FIGURE I

Typical Analytical Model

The analytical model is divided into nodal segments ($2 \leq K \leq 100$). Radius (R), elevation (Z) and thickness is defined for each node. Physical properties of the nodes are taken from "Tentative Structural Design Basis" (Ref. 10) at the average coolant temperature for transient conditions. The value of coefficient of thermal expansion used is the mean value for steady state conditions and the instantaneous value for transient conditions.

Loading conditions used in calculation of stress levels in the nozzle extensions are as defined by specifications used in design of the vessels except that actual operating pressure of 1350 psia is used.

2.0 STRESS LEVELS

2.1 Nozzle Extensions (continued)

These operating conditions are:

Design Condition

Design Pressure	P = 1700 psia
Design Temperature	T = Saturation (614°F)

Normal Operating Condition

Operating Pressure	P = 1350 psia (1335 psig)
Operating Temperature	T = Saturation (582°F)

Transient Conditions

Normal Startup (2100 occurrences)

Pressure	P = 0 - 1335 psig
Temperature	T = 100 - 582°F at 100°F/hr

Normal Shutdown (2000 occurrences)

Pressure	P = 1335 - 0 psig
Temperature	T = 582 - 100°F at 100°F/hr

Emergency Shutdown (100 occurrences)

Pressure	P = 1335 - 0 psig
Temperature	T = 582 - 212°F at 382°F/hr for steam drum, 300°F/hr for reactor vessel

Since required number of occurences of transient conditions are not defined for the reactor vessel, they are assumed to be the same as for the steam drum.

Pipe reactions were not provided by vessel specifications, and are not available at this time, so have not been considered in this report.

Loads applied to the analytical models are derived from the loading conditions as follows:

Internal Pressure--applied as a uniform load distributed over the inside surface of the analytical model. For transient operations, the applied uniform load is taken as equal to the pressure at the end of the transient.

2.0 STRESS LEVELS

2.1 Nozzle Extensions

Internal Pressure (continued)
Thus, pressure is 1700 psi for design, 1335 psi for steady state operation and for startup, and 0 psi for both normal and emergency shutdown.

Thermal Loads--applied to the analytical model in the form of temperatures across the thickness of each section. For the Seal-Shell program, temperatures are required at the inner surface (T_i), quarter thickness ($T_{1/4}$), half thickness ($T_{1/2}$), three-quarter thickness ($T_{3/4}$) and outer surface (T_o). Temperatures for use in the calculations are obtained from the equation

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\xi}\frac{\partial T}{\partial \tau} = 0 \text{ which has the solution } T_x = T_o + \Phi m \tau$$

where

T_x = Temperature at point x (^oF)
T_o = Uniform initial temperature (^oF)
t_e = Effective thickness (ft)
= t for one material slab
= $\sqrt{t_1^2 + t_2^2\ \xi_1/\xi_2 + 2t_1t_2\ k_1/k_2}$ for bi-metal slab
= $\sqrt{t^2 + 0.79375t + 0.06138}$ for carbon steel clad with 5/32" of 304 S.S. at 350^oF
ξ = Thermal diffusivity of slab (ft^2/hr)
m = rate of coolant temperature change ($^oF/hr$)
τ = Time from start of transient (hr)
N_{Fo} = Fourier Modulus = $\xi\tau/t_e^2$

and

$$\Phi = \frac{1}{N_{Fo}}\left[N_{Fo} - \frac{x}{t_e}\left(1 - \frac{x}{2t_e}\right) + \frac{2}{\pi^3}\sum_{n=0}^{\infty}\frac{e^{-(n+\frac{1}{2})^2\pi^2 N_{Fo}}\sin(n+\frac{1}{2})\pi\frac{x}{t_e}}{(n+\frac{1}{2})^3}\right]$$

2.0 STRESS LEVELS

2.1 Nozzle Extensions

Thermal Loads (continued)

This solution involves the following assumptions:

1. One dimensional heat flow.
2. Thermal properties constant and uniform throughout the structure at the average coolant temperature.
3. Infinite heat transfer at surface in contact with coolant. Other surfaces perfectly insulated.

In addition, application of this method of solution to the structure being analyzed include the assumptions that the axial temperature distribution in each section of constant thickness is uniform along the length of the section and that changes in temperature distribution between sections of different thickness is uniform along the length of the structural transition.

In applying this temperature solution, it can be seen that the temperature difference across the thickness of a section decreases with increasing value of Fourier Modulus (N_{Fo}). Thus, since for a value of N_{Fo} of 40, the temperature difference across the section is only 1.25% of the total coolant temperature change, it is within the accuracy of the solution to assume the temperature across any section with a value of $N_{Fo} \geq 40$ to be constant at the coolant temperature.

Mechanical Load--limited to pipe reactions which are not available at this time. Thus, mechanical loads are not considered in the calculation of stress levels in the nozzle extensions.

Stress levels in the nozzle extensions are determined as follows:

Membrane Stress Intensities--as previously stated, limiting primary loads in the nozzle extensions to internal pressure allows membrane stress intensities

2.0 STRESS LEVELS

2.1 Nozzle Extensions

Membrane Stress Intensities (continued)

to be calculated by use of classical equations for a thin-walled cylinder subjected to internal pressure. Thus, where

$$\sigma_z = \frac{PR}{2t} \qquad \sigma_\theta = \frac{PR}{t} \qquad \sigma_r = -\frac{P}{2}$$

maximum stress intensity is

$$S_m = \sigma_\theta - \sigma_r = P \quad \frac{2R + t}{2t}$$

Peak Stress Intensities--values of peak stress intensities due to internal pressure are obtained directly from Seal-Shell-2 output data.

Alternating Stress Intensities--principal stresses (σ_z, σ_θ, and σ_r) are obtained from Seal-Shell-2 output data for each node at each operating condition. Stress intensities are calculated as the algebraic differences between principal stresses, or

$$S_{x\theta} = \sigma_x - \sigma_\theta \ , \quad S_{xr} = \sigma_x - \sigma_r \ , \ S_{\theta r} = \sigma_\theta - \sigma_r \ .$$

Although stress intensities are directionless, signs are maintained in the above calculations so as to insure proper combinations of stress intensities when determining stress range. Then, stress intensity range and alternating stress intensity are:

$$(S_{ij})_R = (S_{ij})max - (S_{ij})min \qquad (S_a)_{ij} = 1/2\ (S_{ij})_R.$$

Results of calculations, attached to this report as 6460-1 through 8 are summarized as follows:

Nozzle Extension	Stress Intensity: Membrane S_m (ksi)	Peak S_p (ksi)	Alternating S_a (ksi)
Downcomer	11.2	10.1	13.1
Riser	9.9	8.9	5.3
Vent	5.1	5.7	10.2
Instrument	9.1	8.7	6.2
Steam Outlet	10.0	9.6	6.3

2.0 STRESS LEVELS

2.1 Nozzle Extensions

Alternating Stress Intensities (continued)

Nozzle Extension	Membrane S_m (ksi)	Peak S_p (ksi)	Alternating S_a (ksi)
Letdown Cooling	9.0	8.7	6.4
Recirculation Inlet	10.5	10.1	6.6
Poison	9.1	8.8	4.9

Each of the above values are less than the allowable stress values for the extension material of

$S_m = 14.8$ ksi $\quad S_p = 16.5$ ksi $\quad S_{ae} = 18$ ksi

where S_{ae} is endurance limit for the material.

Calculation of stresses in the nozzle extensions are shown at the end of this report.

2.2 Internal Brackets

Analysis of the reactor vessel internal brackets is by use of classical equations for equilibrium of forces and determination of stresses in a determinate structure. Equations presented in References 12 and 13 are used for calculation of torsional stresses in a rectangular section.

2.2.1 Core Support Bracket

Loads applied to the core support brackets include gravity loads due to weight of the thermal shield, top plate, and orifice, a pressure blow-off load due to pressure drop through the core, and a horizontal seismic force of 5% of the total weight of the internals. Component weights and C.G.'s, and the pressure blow-off load are from General Electric Data (References 14 and 15). These loads are distributed between the six brackets as follows:

2.2.2 Core Support Plate Brackets (continued)

The total loads, both vertical and horizontal, are assumed to be resisted by two brackets normal to the line of action of the horizontal seismic force. The maximum calculated membrane stress intensity of 1.4 ksi, and peak stress intensity of 15.7 ksi are below the allowable stresses of 14.8 ksi membrane and 16.2 ksi peak stress. The maximum peak stress intensity of 15.7 ksi is also less than the 18.1 ksi endurance limit of the material.

2.2.3 Diffuser Bracket

Loads applied to the Diffuser Bracket include gravity loads, a horizontal seismic force of 5% of the gravity load acting either radial or tangential to the Recirculating Water Inlet Nozzle, and a hydraulic load due to recirculating water flow.

Magnitude of the hydraulic load was determined from the quantity of water flow through the steam drum, as specified by specifications (Ref. 2). From these specifications, 71.8 ft^3/sec of recirculating water is returned to the reactor vessel through two 17" I.D. nozzles. With the quantity of water and the are of opening known, water velocity is then calculated and flow rate determined for the case of flow against a vertical plane.

The maximum membrane stress intensity in the bracket was calculated as 0.5 ksi which is less than the 14.8 ksi. The maximum calculated peak stress intensity of 3.9 ksi is less than the 16.2 ksi allowable peak stress intensity and the 18.1 ksi endurance limit for the material.

2.3 Vent Nozzle Flange

Analysis of the Vent Nozzle Flange requires an interaction solution. For this solution, the nozzle and flange hub deformations are determined by use of the Seal-Shell-2 Computer Program (Ref. 11) in the same manner as for the nozzle extensions. Deformations of the flange are determined from classical equations for a ring. In order to determine effect of bolt loads on the structure, the connecting pipe has been included in the interaction solution where the pipe flange was assumed to be the same as the nozzle flange and the pipe section was taken as equal to the this section of the nozzle.

2.3 Vent Nozzle Flange (continued)

Loading conditions considered, and resulting temperature distributions in the structure were taken to be the same as for the nozzle extensions of Part 2.1.

Maximum calculated stress intensities are:

Membrane Stress Intensity	- $S_m = 7.2$ ksi $< S_{allow} = 14.8$ ksi
Peak Stress Intensity	- $S_p = 5.8$ ksi $< S_{allow} = 16.2$ ksi
Maximum Alternating Stress Intensity	- $S_a = 5.7$ ksi $<$ endurance limit = 18.1 ksi

3.0 DESIGN PRACTICES

Design of internals, and their supports, for the Consumers Power - Big Rock Plant - Steam Drum utilized design concepts originally developed, and used by Combustion Engineering, for use in conventional fuel power plants. These design concepts comply with rules of the ASME Code applicable to the subject vessel, and minimize differential thermal loads in the internals by requiring that materials of different coefficients of expansion be connected with sliding joints.

As required by specification, each of the support brackets considered in this report was made of 304 stainless steel conforming to requirements of ASTM A-167-54, which has a maximum allowable carbon content of 0.08%. Attachment of the brackets to the vessel was in accordance with Combustion Engineering Weld Procedure MA-88A. Prior to welding, the stainless steel clad on the vessel weld was subjected to ultrasonic tests using a 1-1/2" grid. Welding was with E308 filler metal conforming to ASME Specification SA 298, E308-15. Maximum interpass temperature was limited to 300°F and the vessel was subjected to a post-weld heat treatment of 1100-1200°F for one hour per inch of vessel thickness. Maximum carbon content of the weld was limited to 0.06%. After welding, the connection was cleaned with wire brushes and visually inspected.

4.0 REFERENCES

1. General Electric letter, R. L. Theis to J. Harper, dated 9-15-70.
2. General Electric Specification DP-19890, Revision 0, Primary Steam Drum.
3. General Electric Specification DP-19889, Revision 1, Specification for Reactor Vessel.
4. "Stress Evaluation Criteria for Steam Drum," CE Report 6460D.
5. "Stress Evaluation Criteria for Reactor Vessel," CE Report 6460R.
6. General Electric Letter, R. L. Theis to J. Harper, dated 10-5-70.
7. Section I, ASME Code (1959), "Power Boilers".
8. ASME Code Case 1270N.
9. ASME Code Case 1273N.
10. "Tentative Structural Design Basis for Reactor Vessels and Directly Associated Components," Department of Commerce, Document PB151987, dated 4-1-58.
11. Freidrich, "Seal-Shell-2 - A Computer Program for the Stress Analysis of a Thick Shell of Revolution with Axisymmetric Pressures, Temperatures, and Distributed Loads," Bettis Atomic Power Laboratory, Pittsburgh, Pa., 1963.
12. Roark, Formulas for Stress and Strain, 4th Edition, McGraw-Hill, New York, 1965.
13. Seely and Smith, Advanced Mechanics of Materials, 2nd Edition, John Wiley and Sons, New York, 1952.
14. General Electric Drawing 114B5283, "Weights and Center of Gravity."
15. General Electric Letter, Olich to St.Cin, dated 8-17-60.

REPORT 6460-A

APPENDIX A

STRESS CALCULATIONS

2.2.1 Core Support Bracket (continued)

1. Each bracket is assumed to resist one-sixth of the total vertical load of gravity load plus pressure blow-off load.

2. The horizontal force is assumed to be resisted by the two brackets 120° away from the line of action of the horizontal force. The force on each bracket is divided into its tangential and radial components.

3. The overturning moment due to action of the horizontal force away from the brackets is assumed to be resisted by vertical forces on the brackets. The magnitude of these forces are taken as a function of their distance along the line of action of the force from the vessel centerline.

Stresses are calculated at weld to gusset attachment lines at both the gusset to vessel weld and the gusset to plate weld. The maximum stress intensities are calculated for the bracket to gusset weld section where

$$S_{membrane} = 4 \text{ ksi} < S_{allow} = 14.8 \text{ ksi}$$

$$S_{peak} = 11.8 \text{ ksi} < S_{allow} = 16.2 \text{ ksi}$$

Alternating stresses are not calculated for the bracket since maximum alternating stresses would be equal to peak stresses and the allowable peak stresses are less than the endurance limit for the material.

2.2.2 Core Support Plate Bracket

Loads considered in the analysis of the Core Support Plate Bracket include gravity loads, a horizontal seismic force of 5% of gravity loads, and a friction load based on an assumed friction factor of 1.0. Gravity loads include weights of internals as defined by General Electric (References 14 and 15). Since the overturning moment due to the horizontal force acting on the weight of the internals is resisted by the Core Support Brackets (Part 2.2.1), effect of the seismic load on the Core Support Plate Brackets is limited to resistance of the shear force.