*GE Nuclear Energy*
*BWR Technology*

GE-NE-523-41-0691
DRF 137-0010
Class II
June 1991

# FULL STRUCTURAL WELD OVERLAY DESIGN
# FOR THE OYSTER CREEK
# SHUTDOWN COOLING AND CORE SPRAY SYSTEM


Prepared By: B.J. Branlund, Engineer, Structural Analysis Services

Verified By: H.S. Mehta, Principal Engineer, Structural Analysis Services

Approved By: S. Ranganath, Manager, Structural Analysis Services

IMPORTANT NOTICE REGARDING
CONTENTS OF THIS REPORT

Please Read Carefully

ABSTRACT

This report documents the technical basis for the design of weld overlays for the Oyster Creek Shutdown Cooling and Core Spray Systems and the subsequent shrinkage analysis. The two following analyses were performed:

- A weld overlay analysis was performed for one weld (NU-3-5) in the Shutdown Cooling System, two welds (NZ-3-43 and NZ-3-44) in Core Spray System 1 and one weld (NZ-3-95) in the Core Spray System 2.

- A shrinkage analysis was performed to determine the effect of the shrinkage from one overlay on the Shutdown Cooling System and the three overlays on the Core Spray Systems.

The overlay designs are consistent with the requirements of the ASME Code Section XI, NUREG-0313, and the NRC's Generic Letter 88-01. The results verify that the weld overlay designs are acceptable for at least one more operating cycle. The NRC has granted approval for plants to operatr for more than one cycle on a case-by-case basis, however, from ar IGSCC viewpoint, full structural overlays have no inherent limitation as to length of service.

Since there are no specific ASME Code requirements regarding shrinkage stresses, the magnitude of the stress was compared to th material yield strength. Since the shrinkage stresses are well below the material yield strength the stresses are judged to be acceptable and will not influence stress improvement. High stresses in the 1 inch sockolet pipe section were anticipated and the sockolet was uncoupled from the bracket during the application of the overlay, thus precluding high stresses in this section of pipe.

In a recent letter distributed by NUTECH, an issue of air gap and set-point changes due to piping repairs or stress improvement was raised. An out-of-tolerance condition can be avoided by performing a piping system support walkdown and resetting air gaps and set-points to the original specifications.

TABLE OF CONTENTS

# 1. INTRODUCTION AND SUMMARY

During the 1990 in-service inspection of the Oyster Creek Unit 1 Shutdown Cooling System and Core Spray Systems, four welds were found that had indications exceeding the ASME acceptance standards. Table 1 contains a summary of the indications for each System. Each of the welds were repaired with a full structural overlay; the overlay designs are shown in Figures 1 through 4.

This report documents the technical basis for the design of the weld overlays and determination of the shrinkage stresses.

Weld overlays were designed to support the entire pressure, dead weight and seismic loading in the pipe with the conservative assumption that the crack extends through the wall of the original pipe for the entire circumference. Therefore, uncertainty in flaw sizing does not influence the weld overlay design. The thickness is specified after the application of the first layer, however, the first layer may be included in the total thickness if the ferrite content is shown to be greater than 8FN. The weld overlay designs are consistent with paragraph IWB-3642 in Section XI of the ASME Code, NUREG-0313, and the NRC's Generic Letter 88-01.

Shrinkage Stress analyses modeled the local axial shrinkage that results from application of the weld overlay. This induced axial shrinkage will produce stresses throughout the piping system up to the first fixed support on either side of the weld. These stresses were reviewed to determine that yield is not exceeded.

The results of the analyses verify that the weld overlay designs are acceptable for at least one more operating cycle. The NRC has granted approval for plants to operate for more than one cycle on a case-by-case basis, however, from an IGSCC viewpoint, full structural overlays have no inherent limitation as to length of service.

TABLE 1 SUMMARY OF THE INDICATIONS AT OYSTER CREEK UNIT 1

| SYSTEM | INDICATION LOCATION (inch) | TOTAL LENGTH (inch) | INDICATION DEPTH (inch) | WELD* SIDE | TYPE** |
|---|---|---|---|---|---|
| Shutdown Cooling - NU-3-5 | 1) 1.70 | 5.20 | 0.22 | upst | circ |
| | 2) 8.00 | 1.80 | 0.34 | upst | circ |
| Five Axials | | | | | |
| Max. Length and Depth | 3) 3.25 | 0.50 | 0.38 | upst | axial |
| Core Spray - NZ-3-43 | 1) 11.60 | 0.30 | 0.12 | dnst | axial |
| | 2) 12.90 | 0.30 | 0.10 | dnst | axial |
| Four Axials | | | | | |
| Max. Length and Depth | 6) 0.20 | 0.48 | 0.22 | dnst | axial |
| Core Spray - NZ-3-44 | 1) 0.70 | 0.80 | 0.10 | upst | circ |
| | 2) 25.20 | 2.40 | 0.22 | dnst | circ |
| Twenty Axials | | | | | |
| Max. Length Downstream | 4) 6.10 | 0.68 | 0.28 | dnst | axial |
| Max. Depth Downstream | 3) 0.70 | 0.44 | 0.30 | dnst | axial |
| Max. Length Upstream | 13) 11.90 | 0.72 | 0.18 | upst | axial |
| Max. Depth Upstream | 15) 15.20 | 0.40 | 0.24 | upst | axial |
| Core Spray - NZ-3-95 | 1) 22.50 | 1.00 | 0.10 | dnst | circ |
| Four Axials | | | | | |
| Max. Length Downstream | 3) 2.85 | 0.35 | 0.15 | dnst | axial |
| Max. Depth Downstream | 4) 25.40 | 0.30 | 0.25 | dnst | axial |
| Max. Length and Depth Upstream | 5) 26.50 | 0.25 | 0.20 | upst | axial |

* upst = Indication is upstream of the weld centerline
dnst = Indication is downstream of the weld centerline

** circ = The indication is a circumferential flaw
axial = The indication is an axial flaw

## 2. WELD OVERLAY DESIGN

### 2.1. Weld Overlay Process

The weld overlay design consists of a continuous 360° band of weld metal deposited over the outside surface of the pipe directly over the indication. The overlay weld metal is Type 308L stainless steel containing low carbon and high ferrite. This material has a very high toughness and is resistant to Intergranular Stress Corrosion Cracking (IGSCC). The weld metal is deposited using an automatic gas tungsten arc welding (GTAW) technique with stagnant water on the inside surface of the pipe. The procedure for application of the overlay is described in Reference 1.

### 2.2. Weld Overlay Design Methodology

In designing a full structural weld overlay, the crack is conservatively assumed to extend through the original pipe wall thickness for the full circumference of the pipe. Making this assumption, the weld overlay design is independent of the size of the indication.

The weld overlay effectively increases the pipe wall thickness with Type 308L stainless steel weld material that is resistant to IGSCC. Therefore, a crack growing through the wall of the pipe is unlikely to extend into the overlay. Growth of the crack into the overlay is also mitigated by assuring that the first layer meets a ferrite content greater than 8FN. If the first layer fails to meet the ferrite requirement, additional layers are deposited until the required ferrite content is obtained. The layers that have a ferrite content less than 8FN are excluded from the overlay minimum thickness requirement. Mitigation of crack growth into the weld overlay will be confirmed by future inspections.

The overlay thickness is designed so that a factor of safety of 3.0 is maintained against net section collapse for normal and upset load condition

(per Paragraph IWB-3642 of Reference 2). A factor of safety of 1.5 must also be met for emergency and faulted load condition. In addition to IWB-3642, the overlay is designed to meet the requirements of NUREG-0313 and Generic Letter 88-01 (Reference 2).

2.2.1. Weld Overlay Thickness

An iterative process is used to determine the required weld overlay thickness. An initial overlay thickness, T, is first assumed. Considering the pressure, deadweight and seismic loading on the pipe, the membrane ($P_m$) and bending ($P_b$) stresses on the uncracked, overlaid section (Section A-A of Figure 5) are then calculated. The bending stress ($P_{bc}$) in the uncracked, overlaid section of the pipe (Section A-A) at the point of net section collapse of the cracked section of the overlay (Section B-B) is next calculated using the methodology described in Reference 3. The stress distribution shown for Section B-B of Figure 5 is assumed at collapse. The flow stress, $\sigma_f$, is defined as 3 $S_m$ as in Appendix C of Reference 2. For the membrane stress calculated previously, the neutral axis angle is determined by Equation 3 of Reference 3 as

$$\beta = \pi ( 1 - d/t - P_m/\sigma_f ) / ( 2 - d/t )$$

The bending stress in the uncracked section (A-A) at net section collapse of the cracked section (B-B) is then calculated according to Equation 4 of Reference 3 as

$$P_{bc} = ( 2 \sigma_f / \pi ) ( 2 - d/t ) \sin(\beta)$$

The net section collapse stresses are then compared against the applied stresses to determine if factors of safety on collapse of 3 for upset loading and of 1.5 on faulted loading are achieved.

$$(P_m + P_{bc}) / (P_m + P_b)_{upset} \geq 3$$

$$(P_m + P_{bc}) / (P_m + P_b)_{faulted} \geq 1.5$$

If these condition are met, the assumed overlay thickness is sufficient. If these condition are not met, the assumed thickness must be increased and the calculations repeated until the required factors of safety are achieved.

2.2.2. Weld Overlay Width

After the required overlay thickness has been determined, the overlay width is considered. The overlay width is sized taking into account several considerations.

First, the overlay must extend along the length of the pipe a distance great enough to ensure it will envelope the extent of cracking. For a circumferential crack, the extent of cracking is confined to a small axial region of the pipe. GE has completed studies (Reference 4) into the minimum overlay width required to provide adequate structural reinforcement of the cracked area and to assure that the stresses in the overlay will be reasonably uniform. These studies have shown that an overlay width of $1.0 \sqrt{Rt}$ (i.e $0.5 \sqrt{Rt}$ on each side of the weld centerline) is adequate; where R is the outside radius and t is the thickness of the original pipe. This width is also adequate reinforcement for axial cracks.

Second, inspection requirements of the indication after the overlay is applied are considered. The UT transducer must be placed flat on the outside surface of the overlay at some distance from the indication. This distance must be great enough to locate a crack tip with a 45° or 60° refracted wave in the outer 25% of the original pipe wall. This requirement usually exceeds the structural requirements for the overlay width described above.

Finally, the overlay width may be determined by geometric constraints if located near a tee, valve or other fitting.

The slope of the overlay end was set to one-to-one (width-to-thickness) for geometric considerations and to reduce stress concentration effects. Some

earlier designs used a three-to-one slope, however, the one-to-one slope is fully acceptable from a Code stress concentration and piping fatigue usage point of view. The one-to-one slope also provides greater straight length on the overlay outside diameter surface for UT angle beam examination.

## 3. WELD OVERLAY DESIGN

As stated previously, the weld overlay is designed using an iterative approach. The thickness is adjusted until the structural margins defined by the ASME Code are achieved. For this analysis, the iterations made to arrive at the final overlay thickness are not shown. Only the calculations for the final overlay thickness are included to show that the designed thickness is sufficient, see Tables 2 through 5. Sample calculations for the Shutdown Cooling Weld NU-3-5 are described in detail below.

### 3.1. Weld Overlay Thickness

The minimum overlay thickness was determined to be 0.23 inch excluding the first layer. For this overlay thickness, the important dimensions and cross sectional properties are:

Pipe + Overlay Thickness, $t = 0.760 + 0.225 = 0.985$ inches
Pipe Inner Radius, $R_i = 6.240$ inches
Overlay Outer Thickness, $R_o = 7.225$ inches
Nominal Radius, $R = 6.733$ inches
Cross Sectional Area, $A = 41.667$ inch$^2$
Bending Inertia, $I = 949.365$ in$^4$

#### 3.1.1. Applied Stresses

The pressure for this piping is 1,275 psig, the dead weight axial load is 0 lbs ($F_d$), and the OBE axial load is 0 lbs ($F_s$). The loads were supplied by GPU Nuclear (Appendix A). Therefore, the primary membrane overlay stress is thus

$$P_m = P * R_o / 2t + (F_d + F_s)/ A =$$
$$= (1275 \text{ psig})(7.225 \text{ in}) / 2(0.985 \text{ in}) + 0 = 4,676 \text{ psi}$$

Table 2 - Oyster Creek Shutdown Cooling System

Pipe-to-Elbow Weld NU-3-5

```
**********************************************************************
*                                                                    *
*                                                                    *
*                    PLANT ID:  OYSTER CREEK                         *
*                    WELD ID:   NU-3-5                               *
*                                                                    *
*                                                                    *
*                 PIPE THICKNESS =  0.76 INCH                        *
*                 PIPE DIAMETER  = 14.00 INCH                        *
*                                                                    *
*            PRIMARY STRESSES:                                       *
*                   PRESSURE               =  5.87 KSI               *
*                   DEAD WEIGHT MEMBRANE =  0.00 KSI                 *
*                   DEAD WEIGHT BENDING  =  1.65 KSI                 *
*                   SEISMIC MEMBRANE      =  0.00 KSI                *
*                   SEISMIC BENDING       =  0.21 KSI                *
*                   SM WELD MATERIAL      = 16.95 KSI                *
*                   SM PIPE MATERIAL      = 16.95 KSI                *
*                                                                    *
*                                                                    *
*                                                                    *
*            T                  PB  (KSI)       PM+PB    PM+PB/3     *
*          -----      PM     --------------    --------  -------     *
*   WOT    T+WOT    (KSI)    REMOTE     WOT    (REMOTE)  (WOT)       *
*  -------------------------------------------------------------     *
*                                                                    *
*  0.225   0.772    4.676    1.402   13.599     6.078    6.092       *
*                                                                    *
*                                                                    *
*                                                                    *
*            PRIMARY STRESSES:                                       *
*                          PM       = 4.676                          *
*                        PM+PB      = 6.078                          *
*                                                                    *
*                                                                    *
*   MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.225 INCH             *
*   MINIMUM REQUIRED WEL. OVERLAY WIDTH      =  2.3  INCH            *
*                                                                    *
*                                                                    *
**********************************************************************
```

Tabl. 3 - Oyster Creek Core Spray System

Pipe-to-Elbow Weld NZ-3-43

```
PLANT ID:  OYSTER CREEK
WELD ID:   NZ-3-43

P.PE THICKNESS =  0.53 INCH
PIPE DIAMETER  =  8.63 INCH

PRIMARY STRESSES:
     PRESSURE               =  5.09 KSI
     DEAD WEIGHT MEMBRANE =  0.00 KSI
     DEAD WEIGHT BENDING  =  1.06 KSI
     SEISMIC MEMBRANE     =  0.00 KSI
     SEISMIC BENDING      =  0.31 KSI
     SM WELD MATERIAL     = 16.95 KSI
     SM PIPE MATERIAL     = 16.95 KSI
```

| WOT | T<br>-----<br>T+WOT | PM<br>(KSI) | PB (KSI)<br>REMOTE | <br>WOT | PM+PB<br>(REMOTE) | PM+PB/3<br>(WOT) |
|---|---|---|---|---|---|---|
| 0.135 | 0.797 | 4.180 | 1.072 | 12.083 | 5.252 | 5.421 |

```
PRIMARY STRESSES:
         PM      = 4.180
         PM+PB   = 5.252

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.135 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH     =  1.5  INCH
```

Table 4 - Oyster Creek Core Spray System

Pipe-to-Reducer Weld NZ-3-44

PLANT ID: OYSTER CREEK
WELD ID: NZ-3-44

PIPE THICKNESS = 0.53 INCH
PIPE DIAMETER = 8.63 INCH

PRIMARY STRESSES:

| | | |
|---|---|---|
| PRESSURE | = | 5.09 KSI |
| DEAD WEIGHT MEMBRANE | = | 0.00 KSI |
| DEAD WEIGHT BENDING | = | 3.13 KSI |
| SEISMIC MEMBRANE | = | 0.00 KSI |
| SEISMIC BENDING | = | 0.72 KSI |
| SM WELD MATERIAL | = | 16.95 KSI |
| SM PIPE MATERIAL | = | 16.95 KSI |

| WOT | T / T+WOT | PM (KSI) | PB (KSI) REMOTE | PB (KSI) WOT | PM+PB (REMOTE) | PM+PB/3 (WOT) |
|---|---|---|---|---|---|---|
| 0.175 | 0.752 | 3.978 | 2.813 | 16.765 | 6.791 | 6.915 |

PRIMARY STRESSES:

| | | |
|---|---|---|
| PM | = | 3.978 |
| PM+PB | = | 6.791 |

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.175 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 1.5 INCH

Table 5 - Oyster Creek Core Spray System

Pipe-to-Reducer Weld NZ-3-95

PLANT ID: OYSTER CREEK
WELD ID: NZ-3-95

PIPE THICKNESS = 0.53 INCH
PIPE DIAMETER = 8.63 INCH

PRIMARY STRESSES:

| | | |
|---|---|---|
| PRESSURE | = | 5.09 KSI |
| DEAD WEIGHT MEMBRANE | = | 0.00 KSI |
| DEAD WEIGHT BENDING | = | 2.47 KSI |
| SEISMIC MEMBRANE | = | 0.00 KSI |
| SEISMIC BENDING | = | 2.85 KSI |
| SM WELD MATERIAL | = | 16.95 KSI |
| SM PIPE MATERIAL | = | 16.95 KSI |

| WOT | T / T+WOT | PM (KSI) | PB (KSI) REMOTE | PB (KSI) WOT | PM+PB (REMOTE) | PM+PB/3 (WOT) |
|---|---|---|---|---|---|---|
| 0.200 | 0.726 | 3.863 | 3.742 | 19.346 | 7.605 | 7.736 |

PRIMARY STRESSES:
PM = 3.863
PM+PB = 7.605

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.200 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 1.5 INCH

The normal and upset deadweight moment is 163,667 in-lbs ($M_d$) and the OBE seismic moment is 20,534 in-lbs ($M_s$) as shown in Appendix A. Therefore, the primary bending stress is thus

$$P_b = (M_d + M_s) R_o / I =$$
$$(163667 \text{ in-lbs} + 20534 \text{ in-lbs}) 7.225 \text{ in} / 949.365 \text{ in}^4$$
$$= 1{,}402 \text{ psi}$$

The dimensions and cross sectional properties for the original pipe are as follows:

Pipe Wall Thickness, d = 0.760 inches,
Pipe Inside Diameter, ID = 12.48 inches,
Pipe Outside Diameter, OD = 14.00 inches,
Pipe Cross Sectional Area, $A_p$ = 31.612 inches$^2$, and
Pipe Bending Inertia, $I_p$ = 694.970 inch$^4$.

3.1.2. Net Section Collapse Stresses

The design stress intensity for the base material for Type 308L stainless steel at 550°F is given in Table I-1.2 of Reference 5 as

$$S_m = 16{,}950 \text{ psi}$$

Since the Type 308L stainless steel weld material has a greater strength, the pipe material properties will conservatively be used. The flow stress is defined as three times the design stress intensity, or

$$\sigma_f = 3\ S_m = 50{,}850 \text{ psi}$$

For the 4,676 psi membrane stress calculated above, the neutral axis angle is calculated as

$$\beta = \pi( 1 - 0.760/0.985 - 4676/50850 ) / ( 2 - 0.760/0.985 ) = 0.3490 \text{ rad}$$

as described in Section 3.1. The bending stress in the overlaid pipe at net section collapse of the cracked section is

$$P_{bc} = [\ 2\ (50850)\ /\ \pi\ ]\ (\ 2 - 0.760/0.985\ )\ \sin(0.3490) = 13599 \text{ psi}$$

3.1.3. Factor of Safety to Net Section Collapse

The ratio of net section collapse stresses in the uncracked, overlaid pipe over the applied stresses due to pressure, deadweight and OBE seismic loads, yields the factor of safety of

$$(P_m + P_{bc})\ /\ (P_m + P_b) = (4676 + 13599)\ /\ (4676 + 1402) = 3.01$$

This factor of safety meets the required factor of safety of 3.0 for normal operating and upset condition per Paragraph IWB-3642 of Reference 2. Similarly, a factor of safety of 1.5 was met for the emergency and faulted condition. Therefore, the minimum weld overlay thickness of 0.23 inch excluding the first layer is sufficient. The weld overlay repairs for each weld are shown on Figures 1 through 4.

3.2. Weld Overlay Width

As described in Section 3.2, the overlay must be applied for a width of at least 1.0 $\sqrt{(Rt)}$ or 0.5$\sqrt{(Rt)}$ on each side of the weld centerline. Therefore,

$$L = 0.5\ \sqrt{(Rt)} = 0.5\ \sqrt{((7.00 \text{ inch})*(0.760 \text{ inch}))} = 1.15 \text{ inches}$$

on each side of the weld centerline to meet structural requirements. However, to ensure the ability to conduct UT inspection of the indication after the overlay is made, an overlay width of 6.25 inches is specified. The minimum thickness requirement is applied only over the width that is required for structural reinforcement. For the width outside of 1.15 inches on each side of the weld centerline the minimum overlay thickness is optional, however a flat surface for UT inspection is required.

## 4. WELD OVERLAY SHRINKAGE

Shrinkage analyses were performed to simulate the local axial shrinkage that results from application of the weld overlay. This induced axial shrinkage will produce stresses through the piping system.

### 4.1. Method

The analysis was performed using the piping analysis code, PISYS, (Reference 7). Three shrinkage analyses were performed; one for the Shutdown Cooling System and two for the Core Spray Systems (one for each system). These four cases are shown in Table 6 (see Appendix B for piping configurations and weld locations).

### 4.2. Assumptions

The weld overlay shrinkage values are based on measured shrinkages for each weld overlay. The shrinkage values and welds analyzed for each case are summarized in Table 6. The width in Table 6 is the distance along the pipe over which the shrinkage is applied in the model. This distance is the width of the overlay excluding the one-to-one transition on each end of the overlay. The stresses are summarized in Table 7.

### 4.3. Results

Currently, there are no specific ASME Code requirements regarding shrinkage stress. However, weld shrinkage stress is similar to cold spring stress and a measure of acceptability is that the stress be below the material yield strength. The shrinkage stresses shown in Table 7 are acceptable since the stresses are well below the material yield strength. The weld shrinkage stress, which could be considered a sustained stress, only requires special evaluation for crack indications that are recommended for operation "as-is" or for welds on which stress improvement has been applied. However, there are no indications that are operating "as-is" at Oyster Creek and the stresses are to small to influence stress improvement.

It should be noted that the shrinkage stresses in the 1 inch sockolet pipe section in the Core Spray Systems 1 and 2 were quite large. However, this condition was anticipated and the sockolet was uncoupled from the bracket during the application of the overlay, thus precluding high stresses in this section of pipe.

In a recent letter distributed by NUTECH, an issue of air gap and set-point changes due to piping repairs or stress improvement was raised. The issue was motivated by the observation of an out-of-tolerance condition for air gaps and set-points at two nuclear power stations. A root cause analysis concluded that the out-of-tolerance was possibly caused by axial shrinkage on vertical risers. This situation can be avoided by performing a piping system support walkdown and resetting air gaps and set-points to the original specifications.

Table 6 Weld Overlay Shrinkage Cases

Case 1: A shrinkage analysis of the Shutdown Cooling System with shrinkages on the pipe-to-elbow weld NU-3-5

| WELD | SHRINKAGE (inch) | WIDTH (inch) |
|---|---|---|
| NU-3-5 | 0.21 | 6.25 |

Case 2: A shrinkage analysis of the Core Spray System 1 with shrinkages on the pipe-to-elbow weld NZ-3-43 and the pipe-to-reducer weld NZ-3-44

| WELD | SHRINKAGE (inch) | WIDTH (inch) |
|---|---|---|
| NZ-3-43 | 0.28 | 4.27 |
| NZ-3-44 | 0.33 | 5.01 |

Case 3: A shrinkage analysis of the Core Spray System 2 with shrinkages on the pipe-to-reducer weld NZ-3-95

| WELD | SHRINKAGE (inch) | WIDTH (inch) |
|---|---|---|
| NZ-3-95 | 0.34 | 5.03 |

Table 7 Summary of Shrinkage Stresses

Case 1: A shrinkage analysis of the Shutdown Cooling System with shrinkages on the pipe-to-elbow weld NU-3-5

| WELD | NODE | SHRINKAGE STRESS (ksi) |
|---|---|---|
| NU-3-5 | 222 | 0.4 |
| MAXIMUM | 30 | 0.6 |

Case 2: A shrinkage analysis of the Core Spray System 1 with shrinkages on the pipe-to-elbow weld NZ-3-43 and the pipe-to-reducer weld NZ-3-44

| WELD | NODE | SHRINKAGE STRESS (ksi) |
|---|---|---|
| NZ-3-43 | 15 | 1.5 |
| NZ-3-44 | 13 | 1.7 |
| MAXIMUM | 10 | 2.3 |

Case 3: A shrinkage analysis of the Core Spray System 2 with shrinkages on the pipe-to-reducer weld NZ-3-95

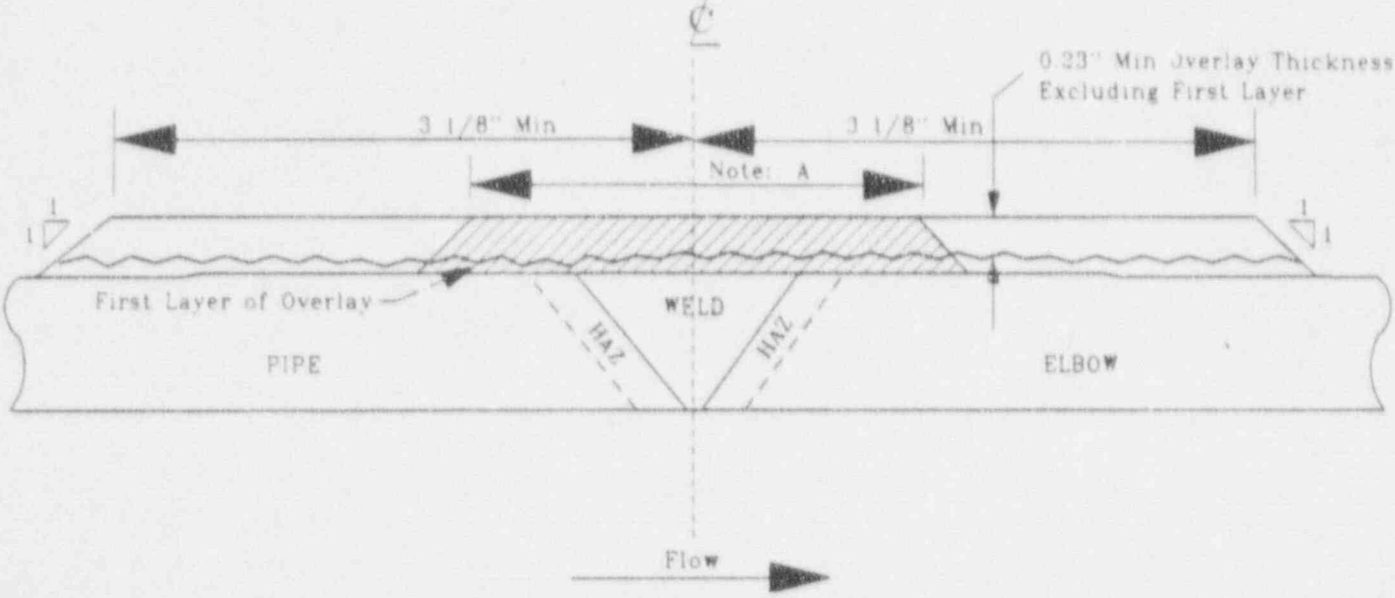
| WELD | NODE | SHRINKAGE STRESS (ksi) |
|---|---|---|
| NZ-3-95 | 13 | 1.1 |
| MAXIMUM | 7 | 1.7 |

## 5. CONCLUSIONS

The weld overlays shown in Figures 1 through 4 are full structural weld overlays and are designed consistent with Section XI of the ASME Code, NUREG-0313, and the NRC's Generic Letter 88-01. The weld overlay designs are acceptable for a least one more operating cycle. The NRC has granted approval for plants to operate for more than one cycle on a case-by-case basis, however, from an IGSCC viewpoint, full structural weld overlays have no inherent limitation as to length of service.

Since there are no specific ASME Code requirements regarding shrinkage stress, the magnitude of the stress was compared to the material yield strength. Since the shrinkage stresses are well below the material yield strength the stresses are judged to be acceptable and will not influence stress improvement. High stresses in the 1 inch sockolet pipe section were anticipated and the sockolet was uncoupled from the bracket during the application of the overlay, thus precluding high stresses in this section of pipe.

In a recent letter distributed by NUTECH, an issue of air gap and set-point changes due to piping repairs or stress improvement was raised. An out-of-tolerance condition can be avoided by performing a piping system support walkdown and resetting air gaps and set-points to the original specifications.

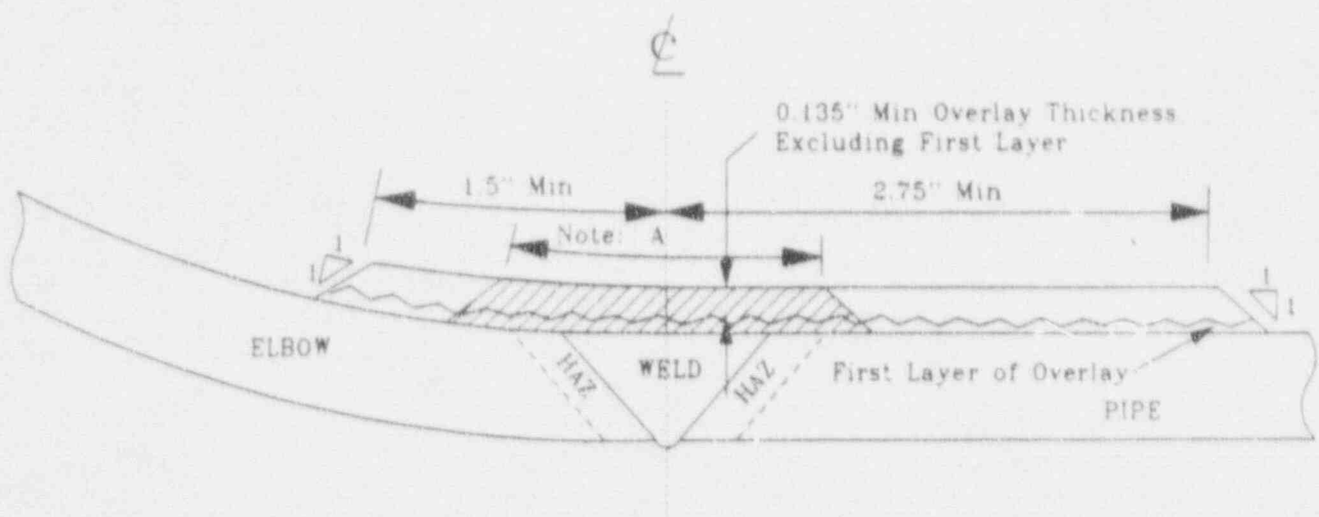



Notes: A. 2.6" min. width required for structural reinforcement; minimum overlay thickness is required for this section.

B. Minimum overlay thickness is optional outside the minimum width; however, a flat surface for UT inspection is required.

Figure 1 - Oyster Creek Shutdown Cooling System

Pipe-to-Elbow Weld NU-3-5

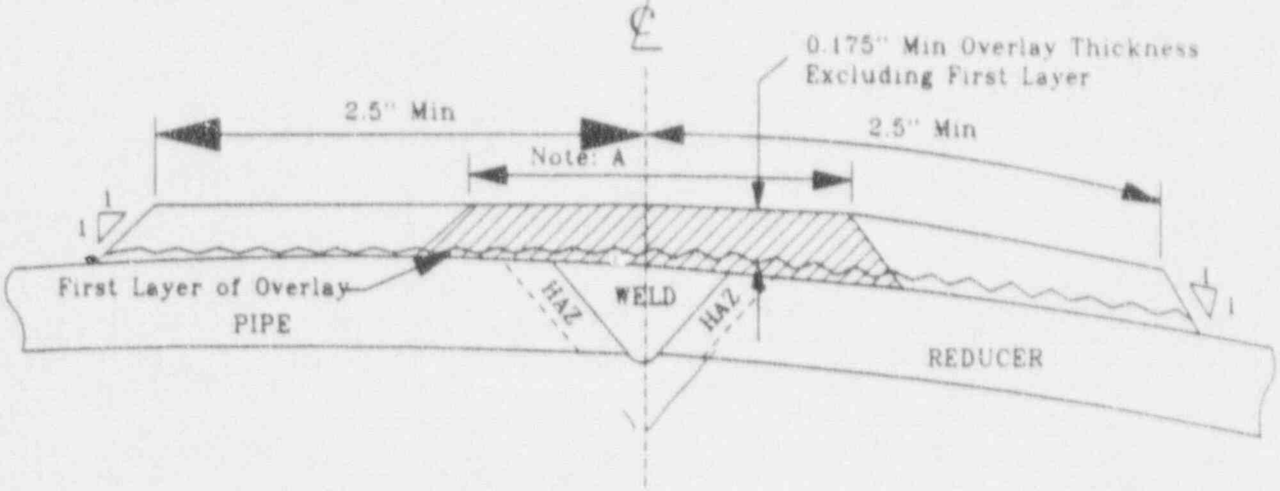



Notes: A. 1.6" min. width required for structural reinforcement; minimum overlay thickness is required for this section.

B. Minimum overlay thickness is optional outside the minimum width; however, a flat surface for UT inspection is required.

Figure 2 - Oyster Creek Core Spray System

Pipe-to-Elbow Weld NZ-3-43

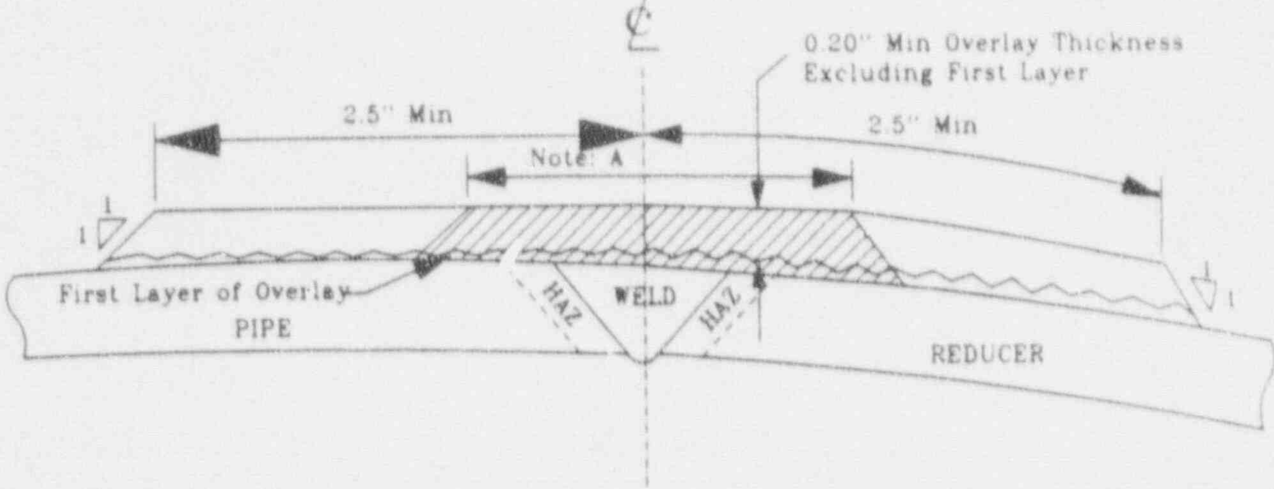



Notes: A. 1.7" min. width required for structural reinforcement; minimum overlay thickness is required for this section.

B. Minimum overlay thickness is optional outside the minimum width; however, a flat surface for UT inspection is required.

Figure 3 - Oyster Creek Core Spray System

Pipe-to-Reducer Weld NZ-3-44




Notes: A. 1.7" min. width required for structural reinforcement; minimum overlay thickness is required for this section.

B. Minimum overlay thickness is optional outside the minimum width; however, a flat surface for UT inspection is required.

Figure 4 - Oyster Creek Core Spray System

Pipe-to-Reducer Weld NZ-3-95

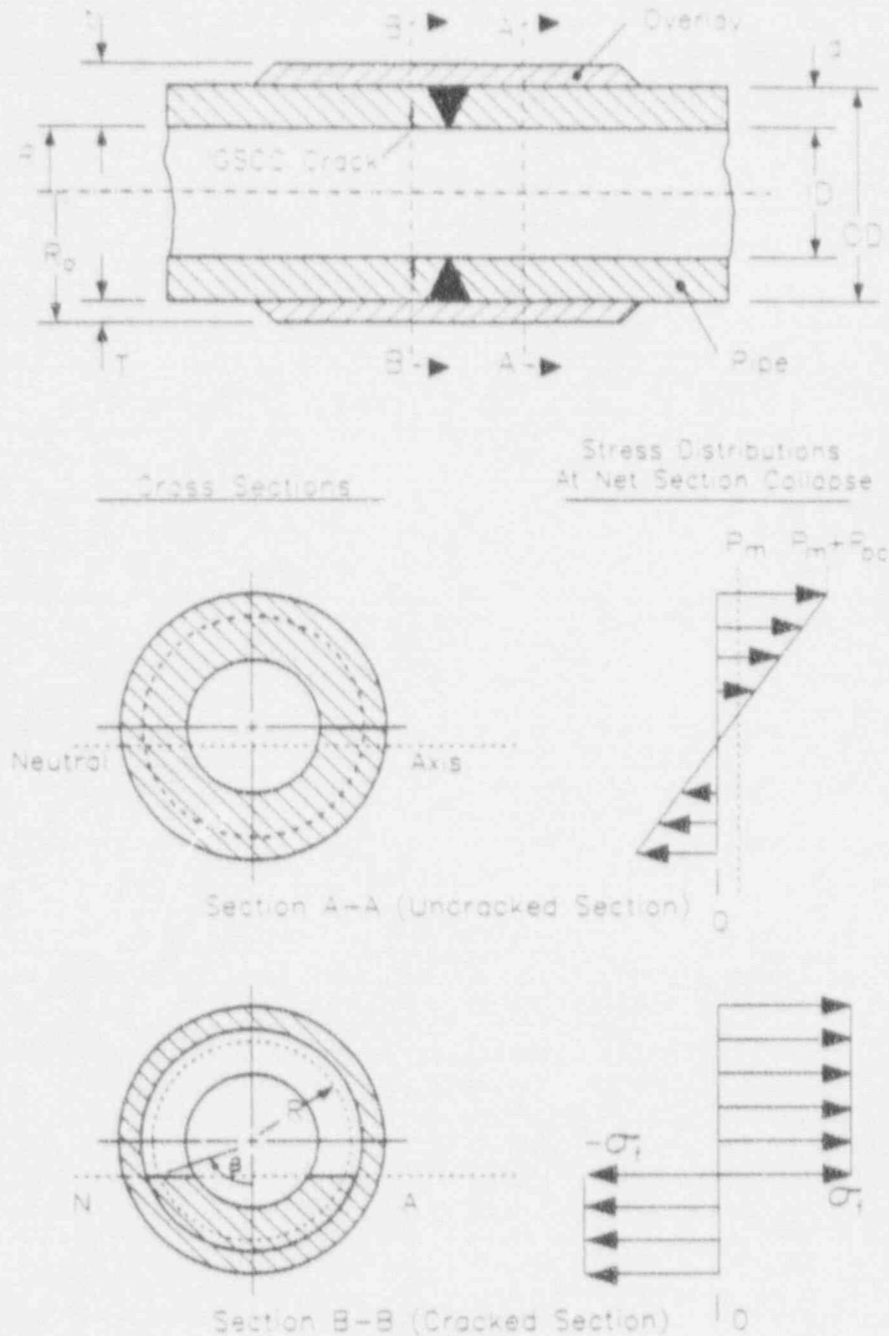



Figure 5 - Weld Overlay Stress Distributions at Net-Section Collapse

## 6. REFERENCES

1) GPU Document #OC-IS-402-585-001, Rev. 4, "Installation Specification for Repair and Replacement of Reactor Coolant System Piping".

2) • 1986 ASME Boiler and Pressure Vessel Code, Section XI.

   • W.S. Hazelton, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping," Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, (NUREG-0313, Rev. 2).

   • US-NRC Generic Letter 88-01, "NRC Position on IGSCC in BWR Austenitic Stainless Steel Piping (Generic Letter 88-01)," US-NRC, Washington, D.C., Jan. 25, 1988.

3) S. Ranganath and H.S. Mehta, "Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping, "Elastic-Plastic Fracture: Second Symposium, Volume II, Fracture Resistance Curves and Engineering Applications," 1983, (ASTM STP-803), pp. 309-330.

4) M.L. Herrera, "Optimization of Weld Overlay Width for Peach Bottom-2 Recirculation Piping," GE-NE, San Jose, Ca., September 1983, (DRF-137-0010, RSFA 83-58).

5) ASME Boiler and Pressure Vessel Code, Section III, 1986 Edition.

6) PISYS05, GE Piping System Analysis Computer Program, NEDE-24077, April 1979.

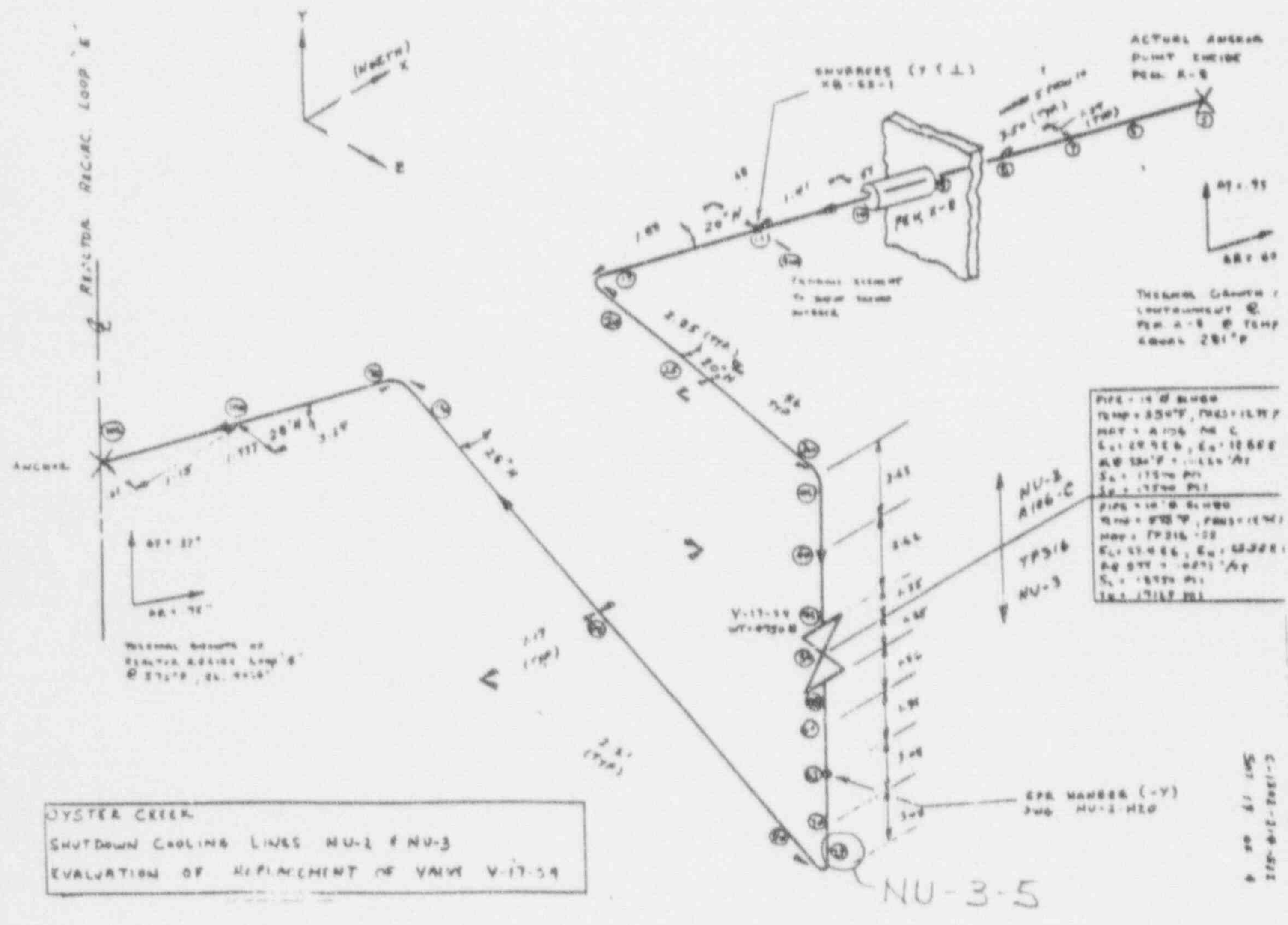
# APPENDIX A LOADS USED IN THE WELD OVERLAY DESIGN ANALYSIS

LOADS FOR THE SHUTDOWN COOLING WELD NU-3-5

**GPU Nuclear** Calculation Sheet

| Subject | Calc. No. | Rev. No. | Sheet No. |
| --- | --- | --- | --- |
| Oyster Creek NSR Piping Analysis Shutdown Cooling (Inside Drywell) | C-1302-214-5320-014 | 2 | ___ of ___ |

| Originator | Date | Reviewed by | Date |
| --- | --- | --- | --- |
| [signature] | 8-19-88 | SAG | 8/22/88 |



B31.1 STRESS REPORT (SSE=EQ. 12E & OBE=EQ. 12U)

## B31-1 1977 S T R E S S  R E P O R T FOR ELEMENT GROUP NO. 2

ABLES- EQ.11 17130, EQ.12U 20556, EQ.12E 30834, EQ.12F 41112, EQ.13 27783, EQ.14 9-

| NODE NO. | SUSTAINED STRESS EQ.11 (PSI) | (OCCASIONAL&SUSTAINED LOADS) UPSET EQ.12 (PSI) | EMERGENCY EQ.12E (PSI) | FAULTED EQ.12F (PSI) | EXPANSION STRESS EQ.13 (PSI) | SUSTAINED EXPANSION EQ.14 (PSI) | BREAK POSTULATION STRESS(STS) (PSI) | A D D I |
|---|---|---|---|---|---|---|---|---|
| 55 | 6907. | 7169. | 7396. | 0. | 1255. | 8162. | 8424. | |
| 60 | 6967. | 7192. | 7388. | 0. | 1143. | 8109. | 8335. | |
| 60 | 6967. | 7192. | 7388. | 0. | 1143. | 8109. | 8335. | |
| 65 | 7033. | 7221. | 7385. | 0. | 1173. | 8205. | 8394. | |
| 65 | 7033. | 7221. | 7385. | 0. | 1173. | 8205. | 8394. | |
| 70 | 7175. | 7322. | 7454. | 0. | 1577. | 8753. | 8900. | |
| 70 | 7175. | 7322. | 7454. | 0. | 1577. | 8753. | 8900. | |
| 75 | 7253. | 7416. | 7565. | 0. | 1883. | 9136. | 9299. | |
| 75 | 7692. | 7911. | 8109. | 0. | 3357. | 11049. | 11267. | |
| 80 | [illegible] | [illegible] | [illegible] | 0. | [illegible] | [illegible] | [illegible] | |
| 80 | 7020. | 7183. | 7331. | 0. | 2004. | 9024. | 9188. | |
| 85 | 6974. | 7131. | 7273. | 0. | 1944. | 8918. | 9075. | |
| 85 | 6974. | 7131. | 7273. | 0. | 1944. | 8918. | 9075. | |
| 90 | 7001. | 7163. | 7308. | 0. | 1809. | 8991. | 9063. | |
| 90 | 7356. | 7572. | 7766. | 0. | 3386. | 10742. | 10359. | |
| 95 | 7352. | 7581. | 7785. | 0. | 2931. | 10284. | 10513. | |
| 95 | 6996. | 7170. | 7322. | 0. | 1644. | 8643. | 8314. | |
| 100 | 6967. | 7138. | 7291. | 0. | 1571. | 8535. | 8716. | |
| 100 | 6967. | 7138. | 7291. | 0. | 1571. | [illegible] | 8716. | |
| 105 | 8123. | 3409. | 8772. | 0. | 2385. | [illegible] | 10054. | |

Stresses for Weld Location #11
4-3-5

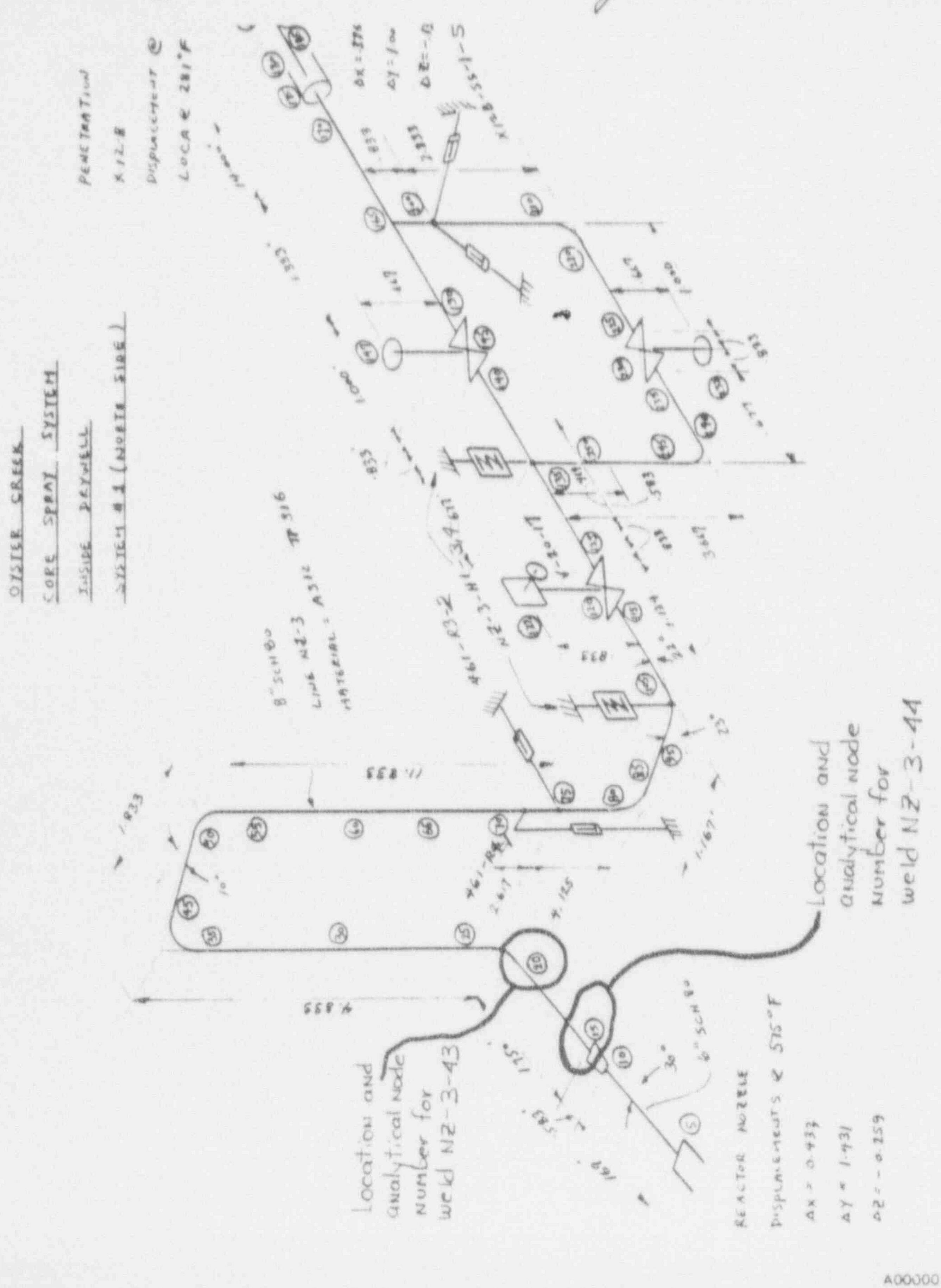
(4)

# LOADS FOR THE CORE SPRAY WELD NZ-3-43 AND NZ-3-44

**GPU Nuclear** — Calculation Sheet

| Subject | Calc No. | Rev. No. | Sheet No. |
|---|---|---|---|
| Oyster Creek JER Piping Analysis<br>Core Spray (Inside Drywell) | C-1302-212-5320-024 | 2 | ___ of ___ |

| Originator | Date | Reviewed by | Date |
|---|---|---|---|
| [signature] | 11-17-87 | SA Gala [signature] | 10/24/88 |



| Subject | Calc No | Rev No | Sheet No |
|---|---|---|---|
| Oyster Creek USR Piping Analysis Core Spray (Inside Drywell) | C-1302-212-5320-024 | 2 | ___ of ___ |

| Originator | Date | Reviewed by | Date |
|---|---|---|---|
| [signature] | 11-17-87 | S A Gala [signature] | 10/24/88 |

| NODE NO. | X FORCE (LB) | Y FORCE (LB) | Z FORCE (LB) | XX MOMENT (FT-LB) | YY MOMENT (FT-LB) | ZZ MOMENT (FT-LB) |
|---|---|---|---|---|---|---|
| 5 | 155.16 | 82.25 | 135.90 | 361.02 | 284.01 | 280.62 |
| 195 | 305.39 | 61.08 | 107.35 | 211.32 | 217.02 | 200.52 |
| 70 | 0.00 | 174.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| 75 | 173.17 | 0.00 | 99.98 | 0.00 | 0.00 | 0.00 |
| 200 | 34.73 | 387.29 | 85.73 | 0.00 | 0.00 | 0.00 |

--EOR--

B31-1 1977 S T R E S S R E P O R T FOR ELEMENT GROUP NO. 1

-ALLOWABLES- EQ.11 17250. EQ.12U 20700. EQ.12E 31050. EQ.12F 41400. EQ.13 27813. EQ.14 45063.

| ELEM NO. | NODE NO. | SUSTAINED STRESS EQ.11 (PSI) | (OCCASIONAL&SUSTAINED LOADS) UPSET EQ.12 (PSI) | EMERGENCY EQ.12E (PSI) | FAULTED EQ.12F (PSI) | EXPANSION STRESS EQ.13 (PSI) | SUSTAINED EXPANSION EQ.14 (PSI) | BREAK POSTULATION STRESS(STE) (PSI) | A D D I T I O N A L I |
|---|---|---|---|---|---|---|---|---|---|
| <OVER> | | | | | | | | | |
| 1 | 5 | 8559. | 9088. | 9487. | 0. | 2307. | 10866. | 11395. | |
| 1 | 10 | 8287. | 8807. | 9198. | 0. | 2448. | 10734. | 11255. | |
| 2 | 10 | [illegible] | [illegible] | [illegible] | 0. | [illegible] | [illegible] | [illegible] | |
| 2 | 15 | 8673. | 9425. | 9979. | 0. | 5895. | 14568. | 15319. | Stresses for weld NZ-3-44 |
| 3 | 15 | 6681. | 6931. | 7115. | 0. | 1470. | 8150. | 8400. | |
| 3 | 20 | 6230. | 6478. | 6661. | 0. | 1795. | 8025. | 8273. | |
| 4 | 20 | 6504. | 6832. | 7075. | 0. | 3173. | 9676. | 10005. | |
| 4 | 25 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | Stresses for weld NZ-3-43 |
| 5 | 25 | 6261. | 6431. | 6565. | 0. | 2791. | 9052. | 9221. | |
| 5 | 30 | 6269. | 6348. | 6419. | 0. | 3613. | 9882. | 9961. | |
| 6 | 30 | 6269. | 6348. | 6419. | 0. | 3613. | 9882. | 9961. | |
| 6 | 35 | 6290. | 6455. | 6582. | 0. | 4653. | 10943. | 11108. | |
| 7 | 35 | 6952. | 7239. | 7459. | 0. | 10774. | 17726. | 18013. | |
| 7 | 45 | 6353. | 6705. | 6961. | 0. | 11429. | 17782. | 18134. | |
| 8 | 45 | 5945. | 6147. | 6295. | 0. | 4936. | 10881. | 11083. | |
| 8 | 50 | 5848. | 6050. | 6194. | 0. | 4879. | 10727. | 10929. | |
| 9 | 50 | 6185. | 6535. | 6786. | 0. | 11297. | 17483. | 17833. | |
| 9 | 55 | 6474. | 6767. | 6978. | 0. | 10276. | 16750. | 17044. | |
| 10 | 55 | 6014. | 6183. | 6304. | 0. | 4438. | 10452. | 10621. | |
| 10 | 60 | 5873. | 5959. | 6043. | 0. | 2439. | 8311. | 8398. | |
| 11 | 60 | 5873. | 5959. | 6043. | 0. | 2439. | 8311. | 8398. | |
| 11 | 65 | 5766. | 5934. | 6090. | 0. | 434. | 6200. | 6369. | |
| 12 | 65 | 5766. | 5934. | 6090. | 0. | 434. | 6200. | 6369. | |
| 12 | 70 | 5786. | 6003. | 6186. | 0. | 2492. | 8278. | 8495. | |
| 13 | 70 | 5786. | 6003. | 6186. | 0. | 2492. | 8278. | 8495. | |
| 13 | 75 | 5849. | 6093. | 6289. | 0. | 3813. | 9662. | 9905. | |
| 14 | 75 | 5849. | 6093. | 6289. | 0. | 3813. | 9662. | 9905. | |
| 14 | 80 | 6002. | 6150. | 6278. | 0. | 5932. | 11934. | 12082. | |
| 15 | 80 | 6436. | 6692. | 6912. | 0. | 13736. | 20172. | 20428. | |
| 15 | 85 | 6490. | 6774. | 7003. | 0. | 14249. | 20739. | 21023. | |

1

NUCLEAR POWER SERVICES JOB 5000 OYSTER CREEK BY SAG CHKD OE **DYNAP04, V5.3 MOX

CORE SPRAY SYSTEM (INSIDE DRYWELL) PEN.X-12B(NORTH) C-1302-22-5320-024, SYSTEM #1,REV.2

B31.1 STRESS REPORT (SSE=EQ. 12E & OBE=EQ. 12U)

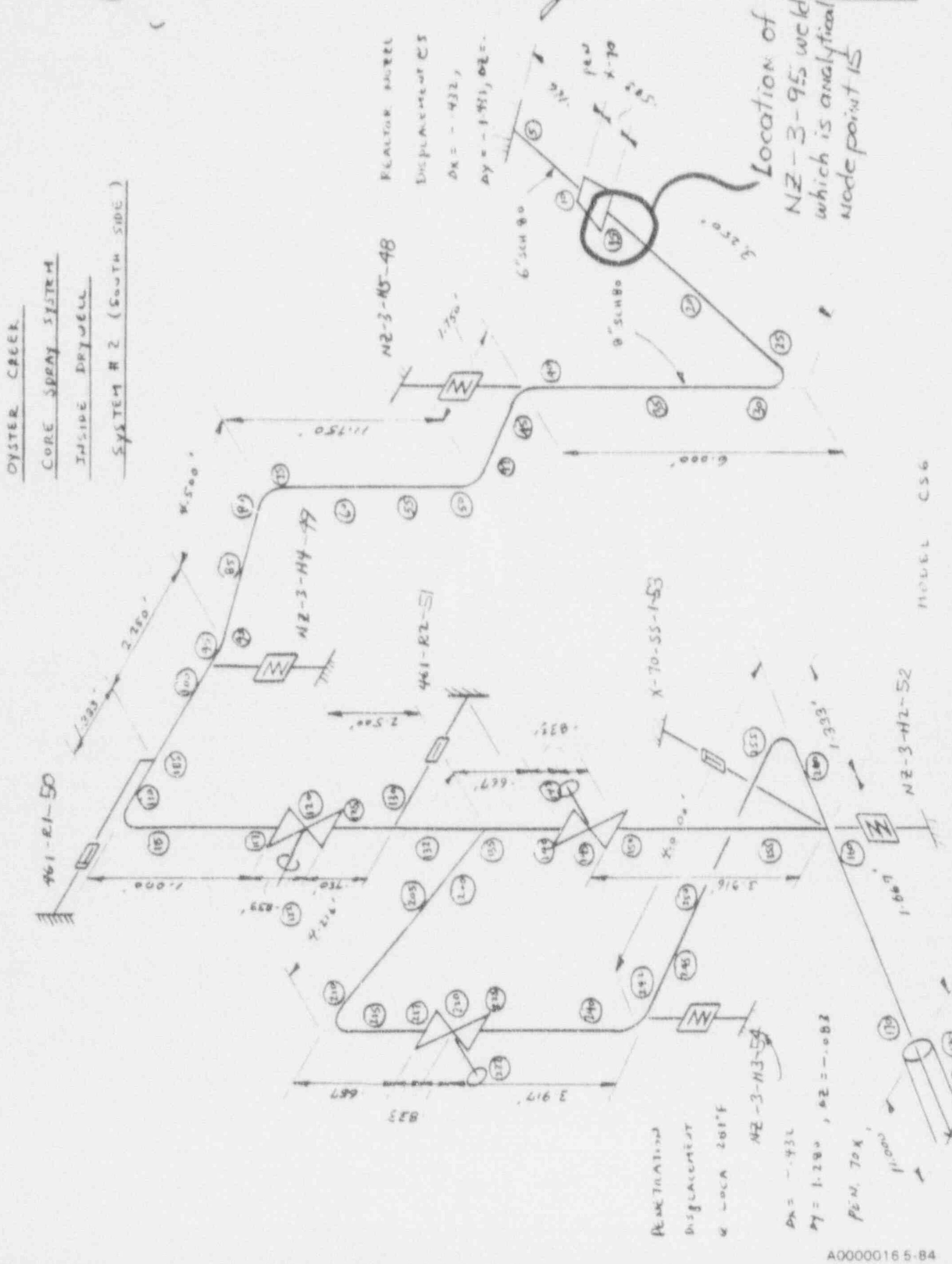
B31-1 1977 S T R E S S R E P O R T FOR ELEMENT GROUP NO. 1

-ALLOWABLES- EQ.11 17250. EQ.12U 20700. EQ.12E 31050. EQ.12F 41400. EQ.13 27813. EQ.14 45063.

LOADS FOR THE CORE SPRAY WELD NZ-3-95

| Subject | Calc No | Rev No | Sheet No |
|---|---|---|---|
| Oyster Creek ISR Piping Analysis Core Spray (Inside Drywell) | C-1302-212-5320-022 | 2 | __ of __ |

| Originator | Date | Reviewed by | Date |
|---|---|---|---|
| [signature] | 11-17-87 | [signature] | 10/24/88 |



![GPU Nuclear] **GPU Nuclear** — **Calculation Sheet**



| Subject | Calc No. | Rev No | Sheet No |
|---|---|---|---|
| Oyster Creek USR Piping Analysis Core Spray (Inside Drywell) | C-1302-212-5320-024 | 2 | ___ of ___ |

| Originator | Date | Reviewed by | Date |
|---|---|---|---|
| D. Lang | 11-17-87 | S A Gala | 10/24/88 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 164.38 | 317.48 | 125.22 | 849.93 | 867.28 | 1885.43 |
| 190 | 452.49 | 688.67 | 196.42 | 902.67 | 456.85 | 3301.05 |
| 105 | 0.00 | 0.00 | 271.13 | 0.00 | 0.00 | 0.00 |
| 130 | 300.07 | -251.89 | 0.00 | 0.00 | 0.00 | 0.00 |
| 160 | -318.65 | 0.00 | 358.96 | 0.00 | 0.00 | 0.00 |

NUCLEAR POWER SERVICES JOB 0 OYSTER CREEK BY SAG CHKD OE **DYNAP04, V5.3 MOD

CORE SPRAY SYS.(INSIDE DRYWELL) SYSTEM #2,SOUTH REACTOR OZZLE N6A,C-1302-212-5320-024,REV.2

B31.1 STRESS REPORT (SSE=EQ. 12E & OBE=EQ. 12U)

B31-1 1977 S T R E S S R E P O R T FOR ELEMENT GROUP NO. 1

-ALLOWABLES- EQ.11 17250. EQ.12U 20700. EQ.12E 31050. EQ.12F 41400. EQ.13 27813. EQ.14 45063.

| ELEM NO. | NODE NO. | SUSTAINED STRESS EQ.11 (PSI) | (OCCASIONAL&SUSTAINED LOADS) UPSET EQ.12 (PSI) | EMERGENCY EQ.12E (PSI) | FAULTED EQ.12F (PSI) | EXPANSION STRESS EQ.13 (PSI) | SUSTAINED EXPANSION EQ.14 (PSI) | BREAK POSTULATION STRESS(STE) (PSI) | A D D I T I O N A L I |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 7986. | 10184. | 11783. | 0. | 2706. | 10692. | 12890. | |
| 1 | 10 | 7735. | 9884. | 11445. | 0. | 2735. | 10470. | 12619. | |
| 2 | 10 | [illegible] | 12429. | [illegible] | 0. | [illegible] | [illegible] | [illegible] | |
| 2 | 15 | 7984. | 10969. | 13129. | 0. | 5686. | 13671. | 16655. | |
| 3 | 15 | 6452. | 7444. | 8162. | 0. | 1418. | 7869. | 8862. | |
| 3 | 20 | 5761. | 6532. | 7089. | 0. | 1634. | 7395. | 8166. | |
| 4 | 20 | 5761. | 6532. | 7089. | 0. | 1634. | 7395. | 8166. | |
| 4 | 25 | 5995. | 6691. | 7200. | 0. | 1734. | 7729. | 8425. | |
| 5 | 25 | 6192. | 7114. | 7789. | 0. | 3064. | 9256. | 10179. | |
| 5 | 30 | 6963. | 7660. | 8180. | 0. | 2949. | 9912. | 10609. | |
| 6 | 30 | 6577. | 7103. | 7495. | 0. | 1669. | 8245. | 8771. | |
| 6 | 35 | 6448. | 6878. | 7192. | 0. | 1216. | 7663. | 8094. | |
| 7 | 35 | 6448. | 6878. | 7192. | 0. | 1216. | 7663. | 8094. | |
| 7 | 40 | 6317. | 6712. | 7005. | 0. | 799. | 7116. | 7511. | |
| 8 | 40 | 6999. | 7670. | 8169. | 0. | 1850. | 8849. | 9520. | |
| 8 | 42 | 7133. | 7794. | 8287. | 0. | 1853. | 8986. | 9647. | |
| 9 | 42 | 7133. | 7794. | 8287. | 0. | 1853. | 8986. | 9647. | |
| 9 | 45 | 7682. | 8328. | 8807. | 0. | 2113. | 9795. | 10441. | |
| 10 | 45 | 6710. | 7082. | 7358. | 0. | 913. | 7622. | 7994. | |
| 10 | 47 | 6287. | 6672. | 6961. | 0. | 743. | 7030. | 7415. | |
| 11 | 47 | 6579. | 7089. | 7472. | 0. | 1314. | 7893. | 8402. | |
| 11 | 50 | 7375. | 7893. | 8277. | 0. | 1719. | 9094. | 9612. | |

Stresses for NZ-3-95

# APPENDIX B PIPING CONFIGURATIONS FOR THE THREE SHRINKAGE ANALYSES

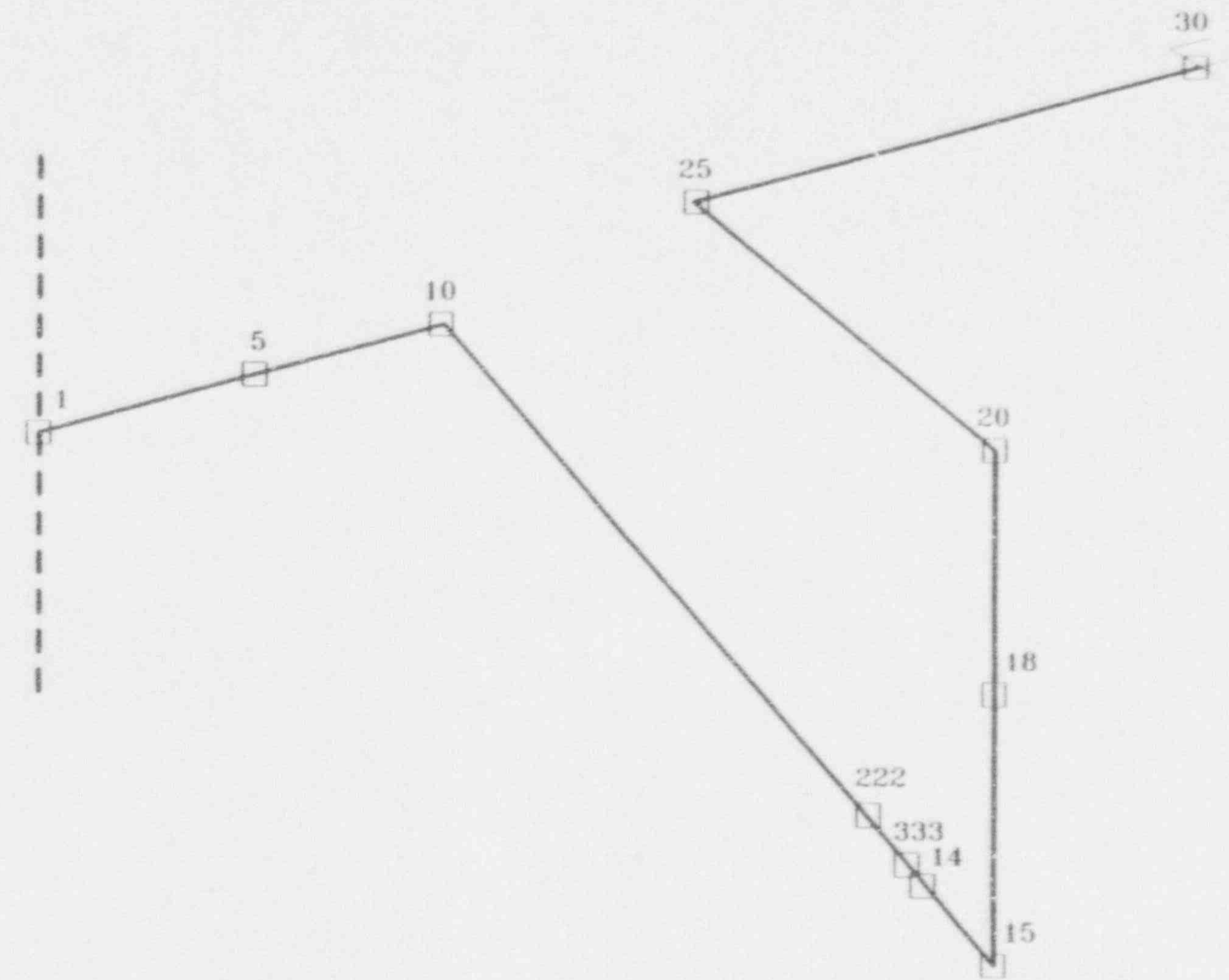



Figure B-1 Oyster Creek Shutdown Cooling System Model

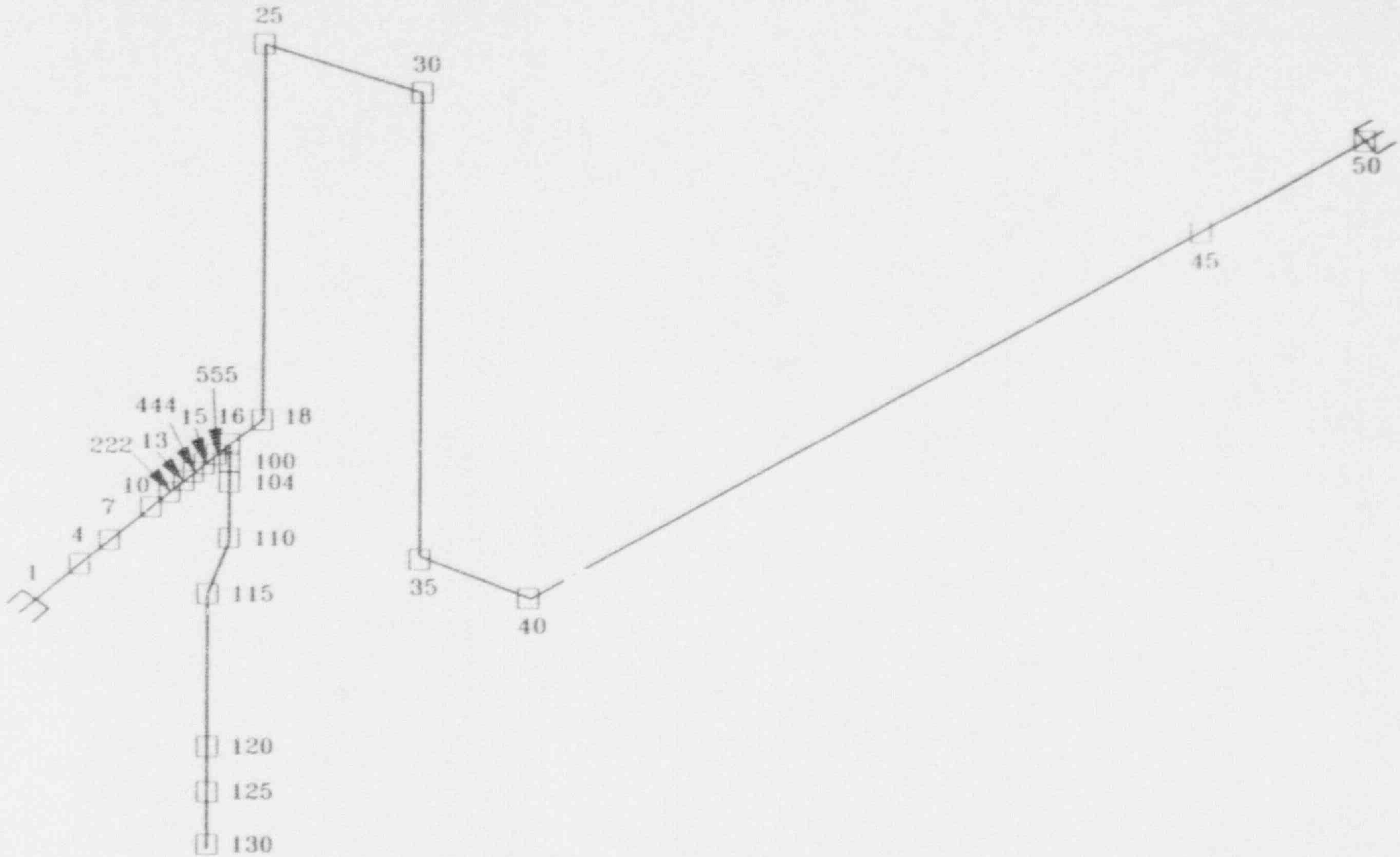



Figure B-2 Oyster Creek Core Spray System 1 Model

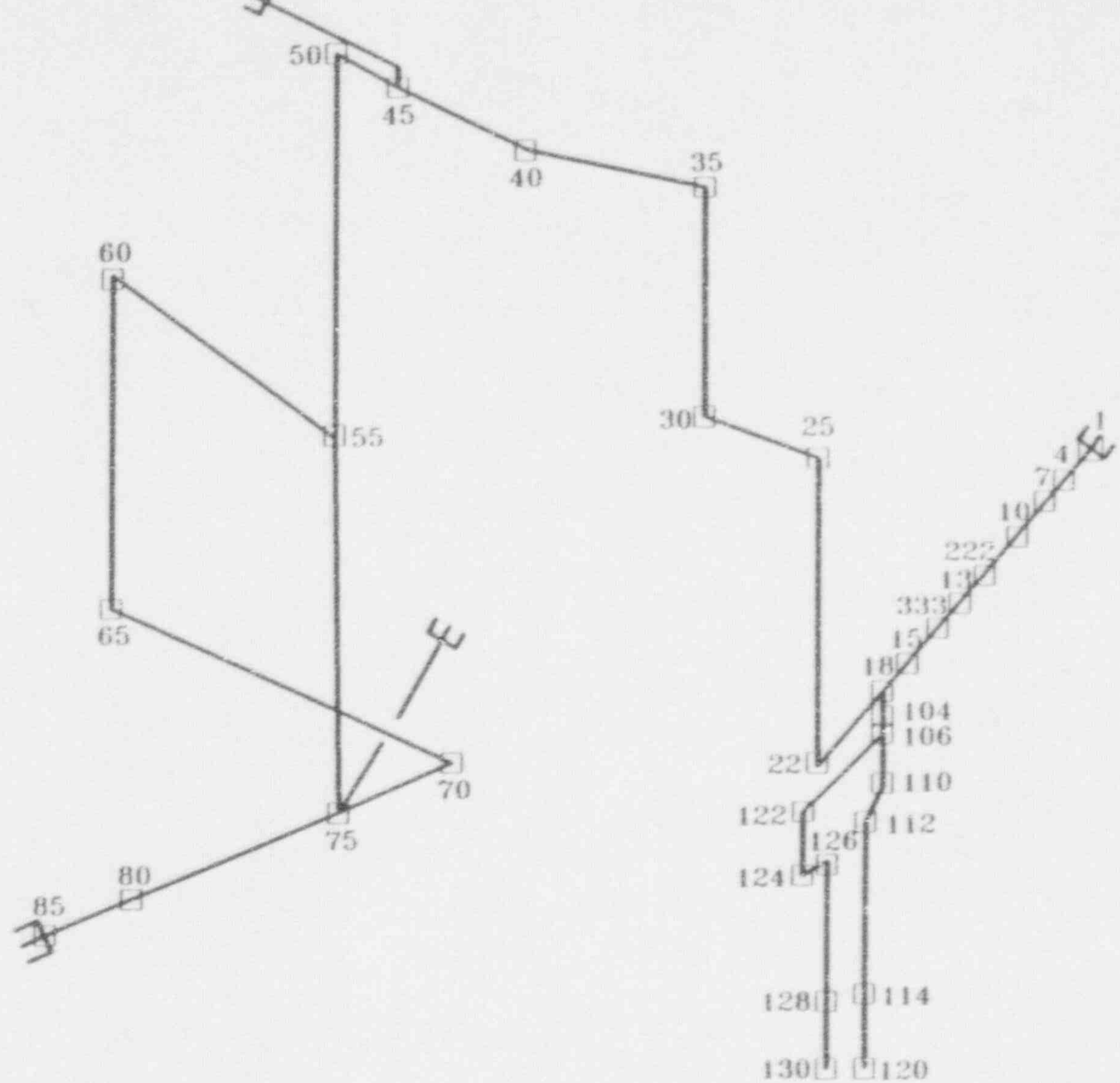



Figure B-3 Oyster Creek Core Spray System 2 Model

## ATTACHMENT 3

Cast Stainless Steel Components
Carbon and Ferrite Analysis

A documentation review was performed to determine the carbon content and ferrite number of the five recirculation pump casings and their connecting suction elbows. The welding records of the five joints between the casings and suction elbows were reviewed to see if welding repairs had been done on these welds. The carbon content of all pump casings and elbows are above 0.035% (see attached Table 1). Three out of five pump casings have reported ferrite numbers higher than 7.5% Ferrite numbers of the remaining two pump casings along with the five elbows are not reported in the material test reports. However, calculations based on figure NB-2433.1-1, delta ferrite content, of ASME III were performed and it was determined that all ferrite contents are above 7.5% Additionally, there were no repairs done on the joints between pump casings and elbows. Therefore, favorable residual stress can be expected at these weld joints.

Based on the above findings and paragraph 2 of "Staff Position on Inspection Schedules" of Generic Letter 88-01, all recirculation pump casing to suction elbow welds (five total) will be upgraded from IGSCC category G to A.

TABLE 1 CARBON CONTENTS AND FERRITE NUMBERS OF RECIRC PUMP CASINGS AND SUCTION ELBOWS

| ITEM | HEAT NO | CARBON(%) | FERRITE(%) | NOTE |
|---|---|---|---|---|
| PUMP CASE | 1634-1 | 0.08 | 12 | 1 |
| PUMP CASE | 1695-1 | 0.05 | 13 | 2 |
| PUMP CASE | 1661 | 0.05 | 12 | 1 |
| PUMP CASE | 3011-3 | 0.06 | 14 | 2 |
| PUMP CASE | 1814-2 | 0.06 | 9 | 2 |
| SUC ELBOW | 2417 | 0.04 | >13.8 | 1 |
| SUC ELBOW | 2436 | 0.04 | >13.8 | 1 |
| SUC ELBOW | 2411 | 0.04 | >13.8 | 1 |
| SUC ELBOW | 2316 | 0.06 | >13.8 | 1 |
| SUC ELBOW | 2427 | 0.04 | >13.8 | 1 |

NOTES

1. CALCULATED FROM FIG.NB-2433.1-1 OF ASME III
2. VALUE FROM MATERIAL TEST REPORTS