APS

Palo Verde Nuclear
Generating Station

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April 1, 2001

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Mail Station P1-37
Washington, DC 20555-0001

Dear Sirs:

References:

1. Letter from C. D. Mauldin, APS to USNRC, dated September 24, 1999, Request for Code Alternative for the Use of Mechanical Nozzle Seal Assemblies

2. Letter from S. Dembek, USNRC to G. R. Overbeck, APS, dated March 16, 2000,Palo Verde Nuclear Generating Station, Units 1, 2 and 3 – Use of Mechanical Nozzle Seal Assemblies (TAC NOS. MA 7737, MA7738, and MA7740)

Subject: **Palo Verde Nuclear Generating Station (PVNGS)**
Units 1, 2, and 3
Docket Nos. STN 50-528/529/530
Request for Code Alternative for the Use of Mechanical Nozzle Seal Assemblies – Relief Request No. 17

Pursuant to the provisions of 10 CFR 50.55a(a)(3)(i), Arizona Public Service Company (APS) hereby requests NRC approval of an alternative to the repair requirements of 10 CFR 50.55a as implemented through the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI. Specifically, APS requests authorization for alternative use of Mechanical Nozzle Seal Assemblies (MNSAs) for Reactor Coolant System (RCS) pressurizer heater sleeves for a duration not to exceed two operating cycles. As demonstrated in the enclosed request for relief and by extensive industry experience, the use of MNSAs for restoring structural integrity and leak tightness to the RCS provides an acceptable level of quality and safety. As described in references 1 and 2 above, the NRC Staff previously approved a similar APS request for the use of MNSAs for PVNGS Alloy 600 RCS system hot leg pipe nozzles.

PVNGS performs dedicated walk-downs of the RCS Alloy 600 nozzles and sleeves at the start of each outage. Based on the results of these walk-downs, there are currently no identified nozzle or pressurizer heater sleeve leaks at PVNGS. During the recently

A047

completed ninth refueling outage of PVNGS Unit 2, evidence of pressurizer heater sleeve pressure boundary leakage was detected. The cause of the failed heater sleeve appears to be premature Primary Water Stress Corrosion Cracking (PWSCC) associated with past heater sheath swelling experienced by the particular heater sleeve in question. Emergent weld repairs were implemented to correct the Unit 2 heater sleeve problem at the expense of significantly increased personnel doses and extended drained down or de-fueled conditions. Based on experience with Alloy 600 nozzles at PVNGS and throughout the industry, APS believes reasonable potential exists for future pressurizer heater sleeve leakage to occur as the service life of these components increases. Although Alloy 600 cracking is not a safety significant issue (reference NRC Information Notice 90-10, Primary Water Stress Corrosion Cracking of Inconel 600), APS has a proactive plan to mitigate and repair Alloy 600 RCS hot leg nozzles. In addition to the replacement plan for Alloy 600 hot leg nozzles discussed in reference 1, APS is currently evaluating a long-term strategy to repair or replace existing Alloy 600 pressurizer heater sleeves.

To date APS has replaced the Alloy 600 pressurizer instrumentation nozzles (seven per Unit) with Alloy 690 nozzles. Additionally, APS has replaced the Alloy 600 RCS hot leg pressure and sampling nozzles in Unit 2 with Alloy 690 nozzles. As APS continues to implement its long-term Alloy 600 nozzle replacement plans, it is necessary to request NRC approval for the temporary use of MNSAs in the likelihood that pressurizer heater sleeve leakage is identified before plans are in place to repair or replace the sleeves.

APS requests the NRC's review and approval of this alternative request by October 1, 2001, to support the PVNGS Unit 3 ninth refueling outage

The following Commitments are being made in this submittal:

1. As required by IWA-4820, a VT-1 pre-service inspection will be performed on MNSA installations in accordance with IWB-2200.

2. During plant startup (Mode 3) after initial installation and during subsequent plant re-starts following outages, the MNSAs will be pressure tested and inspected for leakage to ensure quality of installation and leak tightness.

3. Prior to exceeding two operating cycles, MNSAs will be removed and appropriate repair or replacement activities will be implemented.

4. APS will verify wall thickness prior to machining MNSA bolt-holes to further assure that adequate vessel wall reinforcement exists.

Please contact Mr. Scott Bauer at (623) 393-5978 if you have any questions.

Sincerely,

David Mauldin

Enclosure

CDM/SAB/RKB/kg

cc:	E. W. Merschoff	[Region IV Administrator]
	J. N. Donohew	[NRR Project Manager]
	J. H. Moorman	[Senior Resident Inspector]

ENCLOSURE

Relief Request No. 17

Alternative Request for the Temporary Use

of Mechanical Nozzle Seal Assemblies on

Pressurizer Heater Sleeves

Second 10-Year Inservice Inspection Interval

Palo Verde Nuclear Generating Station

Units 1, 2 and 3

Relief Request No. 17
Alternative Request for the Temporary Use of
Mechanical Nozzle Seal Assemblies
For Pressurizer Heater Sleeves

Code Class	1
Code Reference	IWA-4170, 1992 Edition, 1992 Addenda
Examination Category	n/a
Item Numbers	n/a
System/Component	Reactor Coolant System (RCS) Pressure Boundary Piping – Pressurizer Heater Sleeves
PVNGS Units	ALL
Inspection Interval	Second 10-Year ISI Interval

Requirement

IWA-4170 of the American Society of Mechanical Engineers (ASME), Section XI, 1992 Edition, 1992 Addenda requires repairs and installation of replacement items to be performed in accordance with the Owner's Design Specification and the original Construction Code. The pressurizer vessel and nozzles were designed and constructed to the rules of ASME Section III, 1971 Edition through and including the Winter 1973 Addenda.

Alternate Requirement

As an alternative under the provisions of 10 CFR 50.55a(a)(3)(i), Arizona Public Service Company (APS) is requesting the use of Mechanical Nozzle Seal Assemblies (MNSAs) as a temporary repair to restore pressurizer heater sleeve integrity and prevent sleeve leakage for up to 2 cycles of operation.

Basis For Relief

The potential exists for RCS leaks to occur in the Alloy 600 pressurizer heater sleeves due to Primary Water Stress Corrosion Cracking (PWSCC). The sleeves are those Alloy 600 pressurizer heater sleeves that are in the ASME Code Class 1 portions of the RCS. These sleeves are welded to the pressurizer bottom head with internal J-groove welds. These have been found to be susceptible to PWSCC. The typical repair of these sleeves utilizes either installing a heater sleeve plug welded to a temper-bead pad using a j-prep configuration, or a half nozzle replacement.

APS performs dedicated walk-downs of the RCS Alloy 600 nozzles and sleeves at the start of each Palo Verde Nuclear Generating Station (PVNGS) outage. Based on the results of these walk-downs,

Basis For Relief (continued)

there are currently no identified nozzle leaks at PVNGS. During the recently completed ninth refueling outage of PVNGS Unit 2, evidence of pressurizer heater sleeve pressure boundary leakage was detected. The cause of the failed heater sleeve appears to be premature Primary Water Stress Corrosion Cracking (PWSCC) associated with past heater sheath swelling experienced by the particular heater sleeve in question. Emergent weld repairs were implemented to correct the Unit 2 heater sleeve problem at the expense of significantly increased personnel doses and extended drained down or de-fueled conditions. Based on experience with Alloy 600 nozzles at PVNGS and throughout the industry, APS believes reasonable potential exists for future pressurizer heater sleeve leakage as the service life of these components increases.

The typical repair methods discussed above are extremely difficult to implement on an emergent basis due to the system conditions required to perform the work and the limited time in which those conditions exist during an outage. These repairs would require the unplanned extension of drained down or de-fueled conditions and the significant increase in worker radiation exposure to perform the work on an emergent basis. However, the temporary use of MNSAs will provide APS with a contingency to address emergent repair of pressurizer heater sleeves. While the APS Engineering staff is evaluating various long-term Alloy 600 pressurizer Heater Sleeve repair / replacement solutions, the use of MNSAs will provide APS with valuable flexibility in managing station resources in the event that emergent pressurizer heater sleeve leaks are identified prior to establishing and implementing such a plan. MNSAs can be effectively installed under various plant conditions and thus would provide outage schedule flexibility while not requiring the scheduled drained down or de-fueled work window to be challenged unnecessarily.

The MNSAs are designed, fabricated and constructed using approved ASME Code materials in accordance with the applicable rules of ASME Section III. The MNSAs are designed to prevent separation of the joint under all service loadings. This is supported by technical analysis and tests that meet the design criteria specified in ASME, Section III. Additionally, MNSA installations would be accessible for inspection, maintenance and removal.

The Westinghouse Electric Company (WEC) Design Report No. PV-PS-DR-006, Rev. 01, Addendum to CENC-1336, 1395 and CENC-1490, Analytical Reports for Arizona Units 1, 2, and 3 pressurizers, is provided in Appendix A. Similar design analyses were provided in

Basis For Relief (continued)

support of APS' alternative request for temporary use of MNSA's for Alloy 600 hot leg nozzles (reference no. 5), which was approved by the NRC per reference no. 6 of this relief request.

This addendum to Combustion Engineering (CE) RCS pressurizer Stress Reports CENC-1336, CENC-1395 and CENC-1490 for PVNGS Units 1, 2 and 3, respectively, has been completed assuring stresses under all service conditions do not exceed the Code allowable values as stated in ASME Section III and that fatigue limits are not exceeded using the conditions in PVNGS Design Specification 00000-PE-130, Revision 06, General Specification for a Pressurizer Assembly, May 1978.

Modification of the RCS pressurizer for MNSA installation has been analyzed in accordance with the Original Construction Code (ASME Section III, 1971 Edition, Winter 1973 Addenda). The analysis included the following items:

- Analysis of the component being built to a later edition of the Code (reference Appendix B of this request).
- Analysis of fatigue to demonstrate that the Code prescribed cumulative usage factor of 1.0 is not exceeded (NB-3222.4).
- Analysis that there is adequate reinforcement in the wall of the pressurizer bottom head for the bolt holes.
- Analysis that the stresses do not exceed the allowable values as stated in the Code.

APS contracted the services of WEC to perform a detailed corrosion analysis to address potential corrosion of the nozzle bore holes, corrosion of the carbon steel surface, galvanic corrosion and stress corrosion cracking (SCC) of the MNSA fasteners. The results of the evaluation are summarized as follows:

- Available laboratory corrosion data and service experience indicate that any corrosion of the carbon steel to Alloy 600 nozzle bore hole (annulus region) will be minor and will not affect the two operating cycle lifetime of the temporary MNSA repair.
- Boric acid corrosion of the materials of construction for the MNSA and the outer surfaces of the vessel have been

Basis For Relief (continued)

assessed by Combustion Engineering Owners Group and through other testing and analysis. With the current ASME Section XI required inspections, a leaking MNSA would be detected before significant corrosion of the pressurizer bottom head occurs.

- There is no history of galvanic corrosion problems in similar applications where carbon steel is in contact with a grafoil seal. This particular combination is used in other applications where the low alloy (or carbon steel) is frequently inspected (for example, steam generator secondary side manway and hand hole applications). This MNSA application is similar and for these reasons significant galvanic corrosion is not expected. In addition, the Grafoil used in the MNSA is Grade GTJ which has been treated with ammonium phosphate to inhibit corrosion. The corrosion protection provided by this inhibitor is comparable to sacrificial inhibitors such as zinc or aluminum. Testing has shown that GTJ Grafoil significantly reduces the galvanic corrosion process. It should also be noted that, in the absence of leakage past the Grafoil seal, the annulus will become stagnant and will not allow replenishment of the boric acid or oxygen.

- Testing in pressurized water reactor environments and concentrated boric acid solutions and service experience indicate that A-286 bolts in the MNSA application will operate indefinitely without failures under normal conditions. If the MNSA device leaks, the bolts may be exposed to borated water or steam under conditions in which deposits or slurries will develop. At stress levels present in the MNSA application, these bolts will operate satisfactorily for more than one fuel cycle. The leaking MNSA will be discovered and repaired as part of the Generic Letter 88-05 walk-down inspections, limiting the exposure to these conditions to a cycle or less.

In summary, there are no potential corrosion or material stress issues associated with the application of the mechanical nozzle seal assemblies to the pressurizer bottom head at PVNGS. The available data indicate that corrosion of the carbon steel to Alloy 600 sleeve bore hole (annulus region) will be acceptable over the requested 2 cycle period of use. These same corrosion analyses were provided in support of APS' alternative request for the temporary use of MNSAs for Alloy 600 hot leg nozzles (reference no. 5), which was approved by the NRC per reference no. 6 of this relief request.

Relief Request No. 17
Alternative Request for the Temporary Use of
Mechanical Nozzle Seal Assemblies
For Pressurizer Heater Sleeves

Additional Information

MNSAs have been used successfully in various applications at the following Nuclear Power Plants: San Onofre Units 2& 3; Waterford Steam Electric Station Unit 3; and Calvert Cliffs Unit 1. The various applications include:

- Pressurizer Side Resistence Thermal Detector (RTD) Nozzles
- Pressurizer Bottom Instrument Nozzles
- Pressurizer Upper Instrument Nozzles
- Hot Leg RTD Nozzles
- Hot Leg Pressure Differential Transmitter (PDT) Nozzles
- Hot Leg Sampling Nozzles
- Steam Generator PDT Nozzles

Two MNSAs were also installed on the Maine Yankee pressurizer before Maine Yankee was permanently shut down. MNSAs have been installed as both a preventative measure and on leaking nozzles to terminate leakage. The MNSAs installed on leaking Alloy 600 nozzles successfully stopped the leaks and allowed the plants to return to power without having to drain the primary system and offload the core to implement repairs.

In addition, APS has been approved for the installation of MNSAs on the Reactor Coolant System (RCS) hot leg instrumentation, sampling and RTD nozzles. However, APS believes this would be the first application of MNSA's for pressurizer heater sleeves.

The MNSAs proposed for use on the pressurizer heater sleeves at PVNGS have completed qualification test programs which include pressure testing at both operating and ambient temperature, thermal cycling, and seismic testing with the results providing a reasonable demonstration of the response of the MNSA design to anticipated service conditions. Any minor deviations in the MNSA design for applications at PVNGS are accounted for in APS' plant specific design calculations for the MNSAs, as provided in Appendix A.

Should APS identify the need to utilize MNSA's for pressurizer heater sleeves, the following actions will be performed.

1. As required by IWA-4820, a VT-1 pre-service inspection will be performed on all pressurizer heater sleeve MNSA installations in accordance with IWB-2200.

Additional Information (continued)

2. During plant startup (Mode 3) after initial MNSA installation and during subsequent plant re-starts following outages, the pressurizer heater sleeve MNSAs will be pressure tested and inspected for leakage. To ensure quality of installation and continued operation with the absence of leakage, a pressure test with visual inspection will be performed on each of the installed MNSAs. The test will be performed as part of plant re-start and will be conducted at normal operating pressure with the test temperature determined in accordance with the PVNGS Pressure and Temperature Limits as stated in the PVNGS Technical Specifications.

3. Prior to exceeding two operating cycles, MNSAs will be removed and appropriate repair or replacement activities will be implemented.

4. APS will verify wall thickness prior to machining MNSA bolt holes to further assure that adequate vessel wall reinforcement exists.

Approval

10 CFR 50.55a(a)(3) states that alternatives to the requirements of paragraph (g) may be used, when authorized by the NRC, if "(i) The proposed alternatives would provide an acceptable level of quality and safety, or (ii) Compliance with the specified requirements of this section would result in hardship or unusual difficulty without compensating increase in the level of quality and safety."

Based on the discussion herein, and in the attached report, APS believes the proposed alternative to use MNSAs on RCS pressurizer heater sleeves provides an acceptable level of quality and safety.

APS will not implement the proposed alternative without prior NRC approval.

References

1. ASME Section XI, Rules for Inspection and Testing of components of Light Water Cooled Plants 1992 Edition and 1992 Addenda.
2. Letter from W. H. Bateman, NRC, to H. B. Ray, Southern California Edison Company, dated February 17, 1998, Use of Mechanical Nozzle Seal Assemblies for the San Onofre Nuclear Generating Station, Units 2 and 3.
3. Letter from G. F. Dick, NRC, to C. M. Dugger, Entergy Operations Incorporated, dated March 25, 1999, Use of Mechanical Nozzle Seal Assemblies at Waterford Steam Electric Station, Unit 3.

References (continued)

4. Letter from J. M. Burger, ABB to R. Meeden, APS, dated July 23, 1999, Corrosion Issues Associated with the Installation of Mechanical Nozzle Seal Assemblies (MNSAs) on Potentially Leaking Hot Leg Nozzles at Palo Verde.
5. Letter from C. D. Mauldin, APS to USNRC, dated September 24, 1999, Request for Code Alternative for the Use of Mechanical Nozzle Seal Assemblies
6. Letter from S. Dembek, USNRC to G. R. Overbeck, APS, dated March 16, 2000,Palo Verde Nuclear Generating Station, Units 1, 2 and 3 – Use of Mechanical Nozzle Seal Assemblies (TAC NOS. MA 7737, MA7738, and MA7740)

APPENDIX A

Westinghouse Electric Company

Design Report

PV-PS-DR-0006, Rev. 001

For

Pressurizer Heater Sleeve

Mechanical Nozzle Seal Assemblies

At Palo Verde Nuclear Generating Station

Units 1, 2 and 3

Report: 10 pages
Appendices: 146 pages
Other Attachments: none

DESIGN REPORT NO. PV-PS-DR-0006, Rev. 001

Addendum to CENC-1336, CENC-1395 and CENC-1490 Analytical Reports for Arizona Units No. 1, 2 and 3 Pressurizers

WESTINGHOUSE ELECTRIC COMPANY
CE NUCLEAR POWER LLC
WINDSOR, CONNECTICUT

VERIFICATION STATUS: COMPLETE

Authored by: [signature] Date: 03/16/01
B. Nadgor, Cognizant Engineer

Reviewed by: [signature] Date: 3-16-01
C. R. Schmidt, Independent Reviewer

Approved by: [signature] for KARL HASLINGER Date: 3-16-01
K. H. Haslinger, Task Manager

It is hereby certified this report is in compliance with the requirements of the ASME Boiler and Pressure Vessel Code, Section III, 1989 Edition, no Addenda.

Certified by: [signature]
Registration No. 15253
State of Connecticut
Date 03-16-01

RECORD OF REVISIONS

Rev	Date	Pages Changed	Prepared By	Reviewed By	Approved By
00	02/28/01	Original	B. Nadgor	T. D. Hammel	K. H. Haslinger
01	03/ /01	Pages 1 - 5, 7, 8, A8, A10, A16-A19, A24, A31, A32, A34-A38, A41, Replaced Attachment B	B. Nadgor	C. R. Schmidt	K. H. Haslinger

ABSTRACT

The Arizona Public Service Company, Palo Verde Units 1, 2 and 3, Mechanical Nozzle Seal Assemblies (MNSA), to be installed on the Pressurizer Heater Sleeves, are designed and fabricated to satisfy the requirements of the ASME Code, Section III.

The components of each MNSA replace the pressure boundary previously assumed to be the J-weld connecting the nozzle to the Pressurizer. Four tapped holes are required in the Pressurizer for the installation of each MNSA assembly. The impact of these holes on the design basis of the Pressurizer is also examined in this design report.

These components are analyzed in accordance with:

1. Design Specification No. V1-NOME-SP-0082, Rev. 0.
2. ASME Boiler and Pressure Vessel Code, Section III, 1989 Edition, no Addenda.

The acceptability of the design is established by the results of the detailed structural and thermal analyses contained in this report.

Revision 01 is primarily performed to address the effect of field measurements (specifically, increased outside diameter) on the Inboard Heater Sleeves.

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LIST OF ATTACHMENTS

1.0 INTRODUCTION

This design report summarizes the analyses performed for the installation of Mechanical Nozzle Seal Assemblies (MNSA) on Pressurizer Heater Sleeves. The MNSA is a mechanical device that acts as a complete replacement of the "J" weld between an Inconel 600 heater sleeve and the Pressurizer. Its function is to prevent leakage and to restrain the sleeve from ejecting in the event of a through-wall crack or failure of a sleeve to Pressurizer weld. The potential for these events exists due to Primary Water Stress Corrosion Cracking.

The components of the MNSA, as well as the impact of the MNSA installation on the Pressurizer, are analyzed in accordance with the ASME Code, Section III, 1989 Edition, no Addenda (Reference 3.6).

Revision 01 is primarily performed to address the effect of the field measurements on the analysis of Heater Sleeve.

2.0 SIGNIFICANT RESULTS

Reference 3.5 defines the current design basis documents for the Pressurizer.

The only Arizona Public Service Company Palo Verde Units 1, 2 and 3 Pressurizer design reports affected by this addendum are CENC-1336, CENC-1395 and CENC-1490 (References 3.1, 3.2 and 3.3). The listed design report addenda below remain applicable to the Pressurizers and are not modified by this addendum.

CENC-1584	(03/83)
CENC-1585	(03/83)
CENC-1586	(03/83)
CENC-1665	(10/84)
CENC-1717	(01/86)

The results of this design report are in accordance with the ASME Boiler and Pressure Vessel Code, Section III allowables (Reference 3.6).

2.1 Heater Sleeve MNSA

Attachment A contains detailed analyses of the Heater Sleeves MNSA components. The following table summarizes the results for the Heater Sleeves MNSA components. The existing design analysis for the Pressurizer Heater Sleeves is not affected by the addition of the MNSA.

Component	Stress Category	Calculated Stress/ Usage factor (stress in ksi)	Allowable Stress/ Usage Factor (stress in ksi)
Tie Rod	Design	26.66	26.8
	Average	27.10	53.6
	Maximum	35.30	80.4
	Thread Shear	7.29	16.1
	Usage Factor	0.921	1.00
Threaded Rod	Design	14.95	26.8
	Average	28.43	53.6
	Maximum	31.15	80.4
	Thread Shear	10.02	16.1
	Usage Factor	0.467	1.00
Top Plate	Shear	4.51	12.0
	Bearing	10.46	22.5
	Bending	26.00	30.0
Compression Collar	Shear	5.05	9.6
	Bearing	9.24	17.7
Upper Flange	Shear	3.78	9.6
	Thread Shear	5.07	9.6
Socket Head Shoulder Screw	Shear	3.57	16.1
	Bearing	6.29	26.8

Lengths of engagement used in analysis:

- Tie Rod - Upper Flange: 0.5 in. (0.264 in. minimum)
- Threaded Rod - Pressurizer: 0.5 in. (based upon bolt thread shear; 0.311 in. minimum).

2.2 MNSAs in Pressurizer

Attachment B contains the detailed evaluation of the attachment locations for the Heater Sleeve MNSA, and maximum allowable loads in Heater/Sleeve and Heater/Pressurizer welds. The results of this evaluation are shown below:

2.2.1 Maximum Allowable Threaded Rod Load and Minimum Allowable Length of Rod Engagement

The allowable maximum load, including preload during MNSA impacting, is limited by shear stress in the threaded rod to

$$F_p = 16.116 \cdot Le \text{ kips}$$

where Le is the length of engagement.

At the conservatively assumed length of engagement Le = 0.5 inch (Section 3.3.2.7 of Attachment A), the allowable bolt load is **8.06 kips** (16.116 x 0.5 = 8.06). This allowable load is greater than the "used in analysis" maximum threaded rod load of 5.0 kips (Section 3.3.2.4 of Attachment A).

Based on a maximum threaded rod load, the minimum allowable length of engagement is **0.310 in.** (5.0/16.116 = 0.310).

2.2.2 Area of Reinforcement Requirements for Nozzle Penetration

For the standard MNSA installation:

Heater Sleeve MNSA, in the plane of the attachment holes:
for outermost heaterwells, Area Available = **5.113 in^2** > Area Required = **4.910 in^2**
for innermost heaterwells, Area Available = **4.681 in^2** > Area Required = **4.513 in^2**

2.2.3 Primary plus Secondary Stress Intensity Range

For the Pressurizer Heater Sleeve MNSA tapped holes:
SI_{MAX} = 26.6 ksi < Allowable 3Sm = 80.1 ksi.

2.2.4 Fatigue Usage Factor

For the Pressurizer Heater Sleeve MNSA tapped holes
ΣU_{MAX} = 0.453 < Allowable = 1.0

2.2.5 Maximum Allowable Load in the Heater Sleeve MNSA

For the Heater/Sleeve weld, the allowable maximum shear load is limited to **6.85 kips**, and allowable maximum bearing load is **15.765 kips**. These allowable loads are greater than the used in analyses maximum load of **5.5 kips** (Section 3.2.3 of Attachment A).

For the Heater/Pressurizer J-weld location, the allowable maximum shear load is limited to **5.29 kips**. This allowable load is greater than the calculated maximum normal operation load load of **4.66 kips** (Section 3.2.1.3 of Attachment A).

3.0 REFERENCES

3.1 "Analytical Report for Arizona Unit No. 1 Pressurizer," Report No. CENC-1336, August 1978.

3.2 "Analytical Report for Arizona Unit No. 2 Pressurizer," Report No. CENC-1395, August 1979.

3.3 "Analytical Report for Arizona Unit No. 3 Pressurizer," Report No. CENC-1490, October 1981.

3.4 Design Specification No. V1-NOME-SP-0082, Rev. 0, "Mechanical Nozzle Assemblies (MNSA) for Pressurizer Heater Sleeves".

3.5 Specification No. 14273-PE-130, Revision 07, "Project Specification for a Pressurizer Assembly for Arizona Nuclear Power Project Palo Verde Units 1, 2 & 3", October 2000.

3.6 American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, 1989 Edition (No Addenda).

ATTACHMENT A

ANALYSIS OF PALO VERDE UNITS 1, 2 AND 3 PRESSURIZER HEATER SLEEVE MNSA

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LIST OF FIGURES

1. INTRODUCTION

1.1 Objective

The objective of this calculation is to present the results of the evaluation of the Mechanical Nozzle Seal Assembly (MNSA) to be installed on the Heater Sleeve at the Arizona Public Service Company, Palo Verde Units 1, 2 and 3 plants.

The MNSA is a mechanical device that acts as a complete replacement of the "J" weld between an Inconel 600 Heater Sleeve and the Pressurizer. Its function is to prevent leakage and restrain the sleeve from ejecting in the event of a through-wall crack or weld failure of a sleeve. The potential for these events exists due to Primary Water Stress Corrosion Cracking.

1.2 Assessment of Significant Design Changes

This report presents the detailed structural and thermal analyses required to substantiate the adequacy of the design of the Mechanical Nozzle Seal Assembly as a replacement of the sleeve "J" weld. This analytical work encompasses the requirements set forth in Reference 5.1 and is performed in accordance with the requirements of the Westinghouse Electric Company CE Nuclear Power LLC Quality Procedures Manual QPM-101 (Reference 5.2).

Addenda to the original Pressurizer Design Reports (References 5.3, 5.22 and 5.23) were reviewed and it was determined that their results have no impact on the current analysis and also that the current analysis does not impact their results.

2. DESIGN INPUTS

2.1 Selection of Design Inputs

2.1.1 Design and Operating Pressures and Temperatures

The Mechanical Nozzle Seal Assembly is considered a pressure-retaining component. The Design Pressure is 2,500 psia and Design Temperature is 700°F. Operating pressure and temperature are 2,250 psia and 653°F, respectively. Ambient design temperature is 120°F (References 5.7 and 5.16).

2.1.2 MNSA Materials

MNSA materials are taken from References 5.8.1 and 5.8.2.

Item	Material
Compression Collar	SA-479, Type 304
Lower Flange	SA-479, Type 304
Upper Flange	SA-479, Type 304
Top Plate	SA-479, Type 304
Threaded Rod	SA-453, Grade 660
Hex Nut	SA-453, Grade 660
Tie Rod	SA-453, Grade 660
Socket Head Shoulder Screw	SA-453, Grade 660

2.1.3 Heater Sleeve Materials

Heater Sleeve material is SB-167 (Reference 5.20).

2.1.4 Material Properties

Material properties used in this analysis include coefficients of thermal expansion (α), Moduli of Elasticity (E), design stress intensity values (S_m), and Yield Strength Values (S_y). These properties are presented below and are found in the Appendices of Reference 5.9.

2.1.4.1 Coefficient of Linear Thermal Expansion, α

The following table presents the temperature-dependent coefficients of linear thermal expansion for various materials:

temperature (°F)	SB-167 (Alloy 600)	SA-479 Type 304 (304 SS)	SA-453, Grade 660 (Alloy 660)
100	6.90	8.55	8.24
200	7.20	8.79	8.39
300	7.40	9.00	8.54
400	7.57	9.19	8.69
500	7.70	9.37	8.82
600	7.82	9.53	8.94
650	7.88	9.61	9.00
653	7.88*	9.61*	9.00*
700	7.94	9.69	9.06

* by interpolation

All coefficients are Coefficient B values from Table I-5.0, where Coefficient B is the mean coefficient of thermal expansion X 10^{-6} in./in./°F in going from 70°F to the indicated temperature.

2.1.4.2 Modulus of Elasticity, E

The following table presents the temperature-dependent Moduli of Elasticity for SA-479 Type 304 and SA-453, Grade 660:

temperature (°F)	E
70	28.3
200	27.6
300	27.0
400	26.5
500	25.8
600	25.3
653	25.0*
700	24.8

* by interpolation

All Moduli of Elasticity values are from Table I-6.0, where E = value given X 10^6 psi.

2.1.4.3 *Design Stress Intensity Value, S_m*

The following table presents the temperature-dependent design stress intensity values for various materials:

temperature (°F)	SA-479, Type 304 S_m	SA-453, Grade 660 S_m
100	20.0	28.3
200	20.0	27.6
300	20.0	27.3
400	18.7	27.2
500	17.5	27.1
600	16.4	27.0
653	16.2*	26.9*
700	16.0	26.8

* by interpolation

The design stress intensity values for SA-479 Type 304 are from Table I-1.2; and the design stress intensity values for SA-453, Grade 660 are from Table I-1.3. All S_m values are given in ksi.

2.1.4.4 *Yield Strength Value, S_y*

The following table presents the temperature-dependent yield strength values for SA-479 Type 304:

temperature (°F)	SA-479, Type 304 S_y
100	30.0
200	25.0
300	22.5
400	20.7
500	19.4
600	18.2
650	17.9
700	17.7

The yield strength values for SA-479 Type 304 are from Table I-2.2. All S_y values are given in ksi.

2.1.5 MNSA Component Dimensions

The threaded rods and tie rods have the following dimensions (References 5.8.8 through 5.8.12, and 5.12):

	Treaded Rods [0.625-18 UNF-2A]	Tie Rods [0.375-16 UNC-2A]
Basic major diameter	0.625 in	0.3750 in
Basic minor diameter	0.5589 in	0.297 in
Basic pitch diameter	0.5889 in	0.3344 in
Tensile stress area	0.256 in^2	0.0775 in^2
Kn max (max minor diam. of internal thread)	0.578 in	0.321 in
Es min (min pitch diam. of external thread)	0.5828 in	0.3287 in
En max (max pitch diam. of internal thread)	0.5949 in	0.3401 in
Ds min (min major diam. of external thread)	0.6149 in	0.3643 in

2.1.6 Heater Sleeve Dimensions

Various component conservative dimensions are taken from References 5.20 and 5.26.

	Heater Sleeve
Pressure Diameter	1.675 in
Length of Sleeve (overall)	15.23 in
Pressure Area = (πr^2)	2.204 in^2

2.2 Assumptions

2.2.1 Loading Conditions

If no crack in the J-weld is present, it is assumed that, except for preloads and thermal expansion, the MNSA components are not loaded during normal operating conditions. Relative thermal growth of the MNSA/sleeve components during normal operating conditions increases the preload caused by the installation compression of the Belleville washers. This increased load is evaluated in the current attachment and its effects onto the Heater Sleeve components are analyzed in Attachment B.

An "impact load" may be experienced if there is a complete and instantaneous failure in the J-weld or a 360° circumferential crack in the sleeve, such that the sleeve would be forced outward against the top plate. After this event occurs, a normal operating load would exist, with the internal pressure holding the sleeve up against the top plate; this load would be cyclical - from essentially zero at Cold Shutdown to a maximum value at normal operating conditions.

For the purposes of this analysis, it is assumed that there is a complete and instantaneous failure of the J-weld (or a 360° circumferential crack in the sleeve) such that the sleeve is ejected outward and impacts against the top plate, which will also then load the tie rods and other components. The impact of the sleeve against the top plate conservatively represents the maximum load that the restraining components would experience.

2.2.2 Consideration of Seismic Loads

Because of the nature of the accelerations from seismic events, only the tie rods will be evaluated for the stress effects of the seismic event. The remaining MNSA components will not be significantly affected. Separate seismic tests on similar MNSA configurations were performed to demonstrate an adequate seal performance (see Reference 5.24).

2.2.3 Friction Force

The effects of any impact of the sleeve against the top plate are dependent upon certain assumptions regarding the determination of the ejection force acting on the sleeve.

In an "ideal" (and worst case) break scenario, the crack would be complete, instantaneous and oriented such that no base or weld metal could interfere with the motion of the sleeve. In this case, the only resistance offered to the sleeve motion would be provided by the attached piping and by the Grafoil seal.

In reality, there are several scenarios that represent a more realistic condition:

(1) Cracking occurs through the J-weld. Since shearing of the J-weld is unlikely, ejection can not occur since the J-weld can not fit through the sleeve hole.

(2) Cracking in the sleeve wall would likely occur at some angle, not exactly perpendicular to the sleeve axis. Thus, the friction factor would then be closer to that of metal to metal, typically 0.3.
(3) The axial elongation of the sleeve as a result of a developing circumferential crack would tend to increase the deflection of the Belleville washers and, therefore, diminishing the effects of full ejection.

Based on all of these more realistic failure scenarios, the methodology used in this analysis to obtain the impact load is very conservative. Thus, a scenario which is somewhere between the "ideal" scenario and the "real" scenario will be used to represent the friction between the sleeve and the seal: it will be conservatively assumed that motion will be allowed but in the presence of an opposing force provided by the crack metal and by the Grafoil seal. This opposing force will be accounted for by applying a coefficient of friction for the Grafoil-to-sleeve contact, as described below, that takes credit for some of the more realistic failure mechanisms:

A coefficient of friction (μ) of 0.30 for Grafoil-to-sleeve contact will be used to determine the force which opposes motion of the sleeve. This value of 0.30 used for the (*kinetic*) motion of the sleeve ejection is higher than the values provided by the Grafoil seal manufacturer in Reference 5.5, which lists (*static*) coefficients in the range of 0.05 to 0.20 (see Table III of Reference 5.5). However, the application of a friction force based upon the coefficient value of 0.3 will be maintained on the basis that the actual force which would tend to limit or prevent motion in the "real" scenario would be higher than the friction provided by the Grafoil seal alone (see discussion above).

2.2.4 Sealing pressure

Compression of the Grafoil creates a radial pressure against the sleeve surface of at least 3,175 psi for a preload of 35 ft-lb, based upon Reference 5.10. (The value of 3,150 psi will be used to determine a friction force on the sleeve from the Grafoil seal).

2.2.5 Preload

Nominal values of tie rod/threaded rod preload are used in this analysis since maximum values of preload will not significantly increase corresponding preload stresses. (A check of the results indicate that use of the maximum preload values will result in stresses which will remain below, or will be on the order of, their respective allowables. Therefore, use of the nominal values is acceptable).

2.2.6 Dimensions

Nominal design dimensions of the parts were used for the calculations of the relative displacement and for the stress analysis, except when noted.

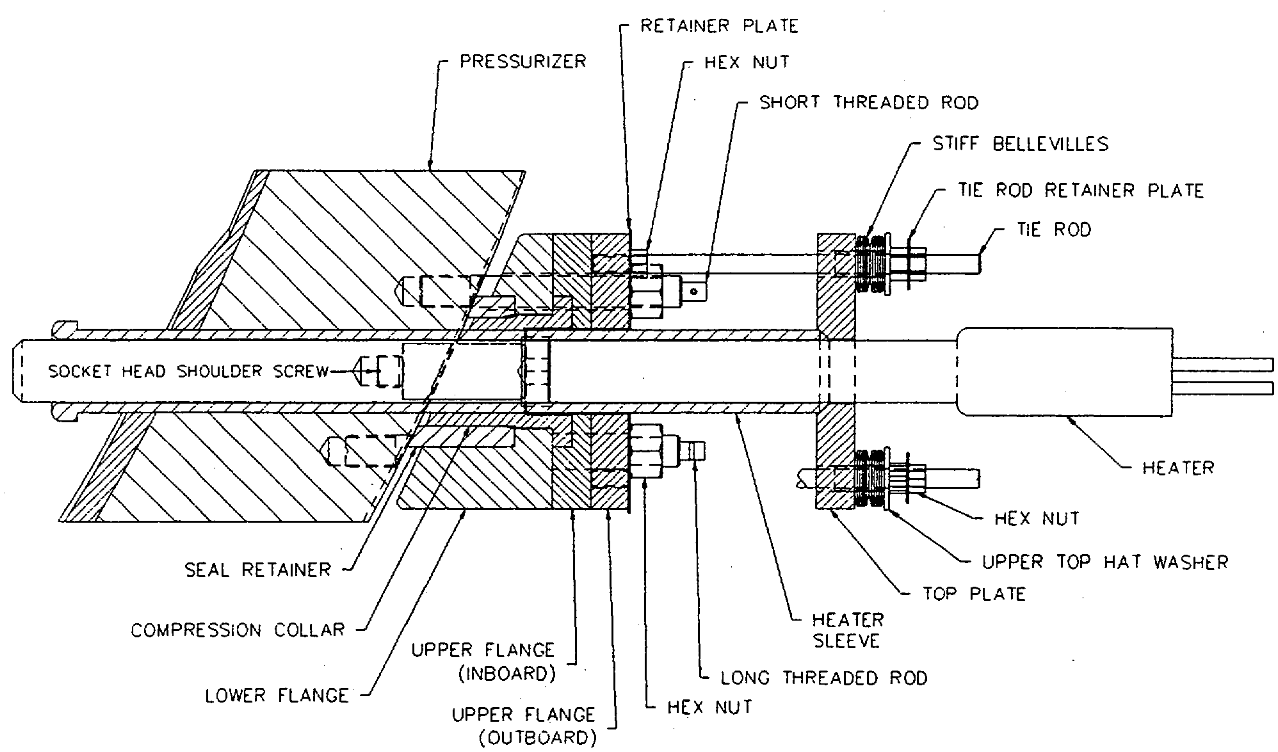
3. ANALYSIS

3.1 MNSA Description

The MNSA is a mechanical device that acts as a complete replacement of the "J" weld between an Inconel 600 sleeve and the Pressurizer. It replaces the sealing function of the weld using a Grafoil seal compressed at the sleeve outside diameter to the outer Pressurizer surface. The MNSA also replaces the weld structurally by means of threaded fasteners engaged in tapped holes in the outer Pressurizer surface, and a restraining plate held in place by threaded tie rods. This feature prevents the sleeve from ejecting from the Pressurizer, should the "J" weld fail or the sleeve develop a circumferential crack.

A general sketch of the Heater Sleeve MNSA is presented in Figure below.

FIGURE 1
Heater Sleeve MNSA



3.2 Consideration of Maximum Load

This section will determine the maximum normal operation load, as well as impact force MNSA/sleeve components experience during any operating condition. Once these forces are calculated, the maximum load will then used to determine stress effects.

3.2.1 Determination of Maximum Normal Operation Load

An installation compression of the Belleville washers creates initial preload in the MNSA/sleeve components. Relative thermal growth of the MNSA/sleeve components during normal operating conditions increases this preload. This section will determine the maximum possible displacement the MNSA/sleeve system experiences with the components at operating conditions. Subsequently, the maximum load the MNSA/sleeve components experience during normal operation conditions will be calculated.

3.2.1.1 Maximum Relative Displacement

The linear thermal expansion displacements of each of the relevant components is calculated using the following equation from Reference 5.17:

$$\delta = \alpha \, L \, \Delta T$$

where:

δ = the displacement (deformation) of a component caused by linear thermal expansion
α = the coefficient of linear thermal expansion
L = the length of the component
ΔT = the temperature change from a reference temperature of 70°F to the applicable operating temperature

*The relative displacement, δ_r is determined by adding or subtracting the displacement of each of the individual components, as follows:

$$\delta_r = \delta_{sleeve} - \delta_{tie\ rod} - \delta_{flange}{}^*$$

(* δ_{flange} in this analysis is taken to mean the combined thermal displacement of the lower and upper flanges)

For determining the maximum relative displacement, it is assumed that the temperature of the flanges and tie rods increases from a reference temperature of 70°F to the ambient temperature of 120°F, and that the sleeve reaches the normal operating temperature of 653°F.

Because of respective component lengths and coefficients of thermal expansion, these assumed conditions produce the maximum relative displacement ($\delta_{r\text{-}max}$) between the sleeve and the MNSA top plate, such that the overall sleeve displacement exceeds the displacement of the top plate by a maximum amount.

Two Heater Sleeves are evaluated in this analysis: Inboard – with the smallest slope at the location of Heater Sleeve penetration into the Pressurizer (Reference 5.8.1), and Outboard – with the steepest slope (Reference 5.8.2).

Inboard Heater Sleeve MNSA Maximum Relative Displacement

component	temperature (°F)	α (10^{-6} in./in./°F)	L* (in.)	ΔT (°F)	δ (in.)
sleeve	653	7.88	7.422	583	0.0341
tie rod	120	8.27	4.022	50	(-)0.0017
flange	120	8.60	3.4	50	(-)0.0015
				$\delta_{r\text{-}max}$ =	0.0309

* Lengths of components are calculated below:
sleeve = 7.422" (Ref. 5.8.1)
tie rod = 7.422"(Ref. 5.8.1) – 3.4" (total thickness of the lower flange and the upper flange, see below) = 4.022"
lower flange thickness = 1.9" (Ref. 5.8.4)
upper flange thickness = 0.75" (upper flange inboard, Reference 5.8.5) + 0.75" (upper flange outboard, Reference 5.8.6) = 1.5"

Outboard Heater Sleeve MNSA Maximum Relative Displacement

component	temperature (°F)	α (10^{-6} in./in./°F)	L* (in.)	ΔT (°F)	δ (in.)
sleeve	653	7.88	6.783	583	0.0312
tie rod	120	8.27	2.934	50	(-)0.0012
flange	120	8.60	3.849	50	(-)0.0017
				$\delta_{r\text{-}max}$ =	0.0283

* Lengths of components are calculated below:
sleeve = 6.783" (Ref. 5.8.2)
tie rod = 6.783"(Ref. 5.8.2) – 3.849" (total thickness of the lower flange and the upper flange, see below) = 2.934"
lower flange thickness = 2.349" (Ref. 5.8.3)
upper flange thickness = 0.75" (upper flange inboard, Reference 5.8.5) + 0.75" (upper flange outboard, Reference 5.8.6) = 1.5"

The value of $\delta_{r\text{-}max}$ defines the maximum relative displacement between the sleeve and the MNSA top plate. However, it is noted that the temperature differences evaluated above are too extreme and would not be seen during plant operations.

3.2.1.2 Equivalent Stiffness of the System

In order to determine the equivalent stiffness of the system, the stiffnesses of the tie rods and of the top plate are first calculated.

3.2.1.2.1 Stiffness of 4 Tie Rods

The total stiffness of the four (4) tie rods, K_{rods}, is based upon an equation from Reference 5.17 (p. 31):

$$K_{rods} = 4\frac{A\ E}{L}$$

where:

A = 0.0878 in², cross-sectional area of the tie rod, based on the basic pitch diameter

E = 28.0 x 10⁶ psi (at 120°F)

L = 4.2688 in, length between the top of the rigid Belleville washer stack package and upper flange (conservatively, the shorter, Outboard Heater Sleeve MNSA tie rods are used here), where
L = 2.934 (Section 3.2.1.1) + 0.75 (top plate thickness, Reference 5.8.7) + 0.584 (free Belleville washer stack height, Reference 5.4) = 4.268 in

So:

$$K_{rods} = 4\frac{(0.0878in^2)(28.0X10^6\ \frac{lb}{in^2})}{4.268in} = 2.3E6\frac{lb}{in}$$

3.2.1.2.2 Stiffness of the Top Plate

The ANSYS finite element analysis code (Reference 5.18) was used to determine the stiffness of the top plate, which has an irregular shape. A half-symmetry model of the plate is generated using the SHELL93 type element (It should be noted that the model geometry slightly differs from the actual Top Plate geometry. The differences include conservative representation of the Top Plate loading application and small deviation from the actual location of the "flats" that is deemed negligible). The model was restrained at the locations of the tie rods in all directions, with symmetry boundary conditions applied to those nodes on the plane of symmetry, Figure C1 of Attachment C.

To assess the effects of the impact load, a distributed load of 500 lb was applied in the form of pressure to a surface conservatively representing the contact area between the Top Plate and the Heater/Heater Sleeve weld. (Due to the model symmetry, the applied 500 lb load is equivalent to applying 1000 lb. for a full model.) The maximum deflection of the top plate was 0.000502 in.

The stiffness is determined as follows:

$$K_{top\ plate} = F / d = 1{,}000 \text{ lbs} / 0.000502 \text{ in} = 1.99 \text{ E6 lb/in}$$

The output file from the ANSYS evaluation is presented in Attachment C.

3.2.1.2.3 Stiffness of the Rigid Belleville Washer Stacks

In accordance with Reference 5.4, the average spring stiffness of each rigid Belleville stack (consisting of 8 Belleville washers) is approximately 15,874 lb/in. Since four Belleville washer stacks act in parallel, the total stiffness of the Belleville stacks equals 4 x 15,874 = 63,496 lb/in.

Conservatively, use $K_{Belleville}$ = 65,000 lb/in

3.2.1.2.4 Equivalent Stiffness: Tie Rods-Belleville Washers-Top Plate System

The tie rods, Belleville stacks and top plate stiffness act in series against the impact load. The equivalent stiffness of tie rod-top plate system is based upon a series stiffness equation from Reference 5.13 (p. 702):

$$K_{eq} = \frac{1}{\frac{1}{K_{rods}} + \frac{1}{K_{Belleville}} + \frac{1}{K_{top\,plate}}} = \frac{1}{\frac{1}{2.3E6} + \frac{1}{6.5E4} + \frac{1}{1.99E6}} = 6.13E4\frac{lb}{in}$$

3.2.1.3 Maximum Normal Operation Load

The maximum deflection of the Belleville washers during normal operation (δ_{total}) consists of the sum of the maximum installation compression ($\delta_{initial}$) and the maximum relative displacement between the sleeve and the MNSA top plate due to the relative thermal expansion ($\delta_{r\text{-}max}$). Since the installation compression of the Belleville washers is defined as 35 mils (Reference 5.25) with assumed tolerances of ±10 mils, and the maximum relative thermal displacement is 30.9 mils (Section 3.2.1.1 for the Inboard Heater Sleeve MNSA),

$$\delta_{total} = \delta_{initial\ maximum} + \delta_{r\text{-}max} = 45 + 30.9 = 76 \text{ mils} = 0.076 \text{ in}$$

The maximum normal operation load, F_{NOP}, on the top plate and tie rods is then calculated:

$$F_{NOP} = K_{eq}\,\delta_{total}$$

$$F_{NOP} = 6.13E4 \frac{lb}{in}(0.076in) = 4.66kips$$

3.2.2 Determination of Impact Force

At the moment at which an instantaneous break occurs, the internal fluid pressure in the pressurizer will eject the sleeve outward, with the sleeve impacting the top plate. In order to determine the effects of this impact on the top plate, it will be necessary to first determine the net ejection force acting on the sleeve. Once this net force is known, a relation can be defined between the work performed by the ejection force and potential energy stored in the deflection of the affected components (at the point of maximum deflection). Once the deflection of the components is known, the impact force can be calculated.

3.2.2.1 Net Ejection Force, F_e

The sleeve will be forced out of the pressurizer by the internal fluid pressure; this outward motion will be opposed by the friction force which the Grafoil Seal exerts on the external surface of the sleeve. The net ejection force acting on the sleeve, F_e, is the difference between the "pressure force", F_p, and the sum of the seal friction force, F_f, and installation preload caused by the initial compression of the Belleville washers, $F_{initial}$:

$$F_e = F_p - F_f - F_{initial}$$

It should be noted that the maximum net ejection force occurs at the cold conditions because the relative displacement between the sleeve and the MNSA top plate due to the relative thermal expansion increases the compression of the Belleville washers and, thus, reduces the net effects of the ejection.

3.2.2.1.1 Force Due to Internal Pressure

Motion of the sleeve at the moment at which there is an instantaneous break is due to the force created by internal pressure pushing against the entire cross section of the sleeve. This force, F_p, is determined as follows (from Section 2.1.6, the pressure area of Heater Sleeve is 2.204 in^2):

$$F_p = (2500 \text{ psi})(2.204 \text{ in}^2) = 5{,}510 \text{ lbs.}$$

3.2.2.1.2 Friction Force

The determination of the friction force (F_f) provided by the Grafoil seal is made based upon the coefficient of friction for the seal against the sleeve and the radial load provided by the seal against the sleeve (produced by the compression of the seal).

$$F_f = P \mu A$$

where:

P = radial seal load (pressure) = 3150 psi (Section 2.2.4)
μ = coefficient of friction = 0.3 (Section 2.2.3)
A = surface area of the seal in contact with the sleeve surface
= π D h
h = 0.25 in
D = 1.675 in

Therefore:

F_f = (3150 psi) (0.3) π (1.675 in) (0.25 in) = 1243 lbs.

3.2.2.1.3 Installation Preload

The installation preload is created by the initial compression of the Belleville washers. The magnitude of the impact of the sleeve against the top plate is dependent upon this compression - the lesser the compression, the less resistance to the components travel before an impact, the greater the work done by the internal pressure, the greater the deflection of the components, and the greater the load on the components.

The installation preload, $F_{initial}$, is calculated as follows:

$$F_{initial} = K_{eq}\delta_{initial},$$

where:

K_{eq} = 6.13 X 10^4 lb/in (Section 3.2.1.2.4)
$\delta_{initial}$ = 0.025 in (the minimum compression value is conservatively used according to Reference 5.8.25 and assuming tolerance of ±10 mils)

Therefore:

$$F_{initial} = 6.13E4\frac{lb}{in}(0.025in) = 1{,}533 lbs$$

Based upon the forces calculated above, the net ejection force is:

F_e = 5510 - 1243 −1533 = 2734 lbs. Use F_e = 2740 lbs.

3.2.2.2 Deflection of Components Due to Sleeve Ejection

The total deflection of the impacted components due to the ejection of the sleeve is determined below, based upon the conservative understanding that all of the work put in to the system by the net ejection force is converted completely into the potential energy of the deflected components (i.e. there are no losses). The base equation for evaluating the total

deflection is derived from Equation (a) on page 471 of Reference 5.17 and is presented, as follows:

$$F_e\, s = \frac{1}{2} K_{eq}\, \Delta x^2$$

where:

F_e = the net ejection force
s = total distance traveled by sleeve
Δx = total deflection of MNSA tie rods and top plate, and
K_{eq} = the equivalent stiffness of MNSA tie rods, Belleville stacks and top plate

Since the total distance traveled by the sleeve, s, is equal to total deflection of the tie rods, Belleville stacks and top plate (Δx), the base equation may be re-written as follows:

$$F_e \Delta x = \frac{1}{2} K_{eq} \Delta x^2$$

$$\Rightarrow \quad \Delta x = 2F_e / K_{eq}$$

Given:

F_e = 2740 lbs
K_{eq} = 6.13×10^4 lb / in

$\Rightarrow$ Δx = 0.0894 in.

3.2.2.3 Impact Force

The impact force, F_{impact}, on the top plate and tie rods is then calculated:

$$F_{impact} = K_{eq}\, \Delta x$$

$$F_{impact} = 6.13E4 \frac{lb}{in}(0.0894 in) = 5.48 kips$$

3.2.3 Maximum Load

The value of F_{max} = 5,500 lbs will be used in subsequent analysis of the Heater Sleeve MNSA components.

3.3 Stresses in the Heater Sleeve MNSA Components

The Design Loads for the various MNSA components will be a function of either bolt preload, the impact load, and/or thermal expansion loads, depending upon the effects of the source load upon a particular component.

3.3.1 Tie Rod

3.3.1.1 Design Bolt Load Stresses (NB-3231 and Appendix E)

The design bolt load for the tie rod is considered to be the hydrostatic load which results from Design Pressure only, since the tie rod is not used for gasket-joint purposes.

Section 3.4.2.1 determines the service stress in the tie rod for a pressure which bounds the Design Pressure; this stress value is compared to the design bolt load stress allowable:

$26.66 \text{ ksi} < 26.8 \text{ ksi}$ (S_m at 700°F)

The hydrostatic load stress is below the stress allowable, which indicates that the actual bolt area (A_b) exceeds the minimum required bolt area (A_m).

3.3.1.2 Stress Due to Thermal Expansion

The differential thermal expansion between the tie rod and the upper flange will create an additional tensile load on the tie rod. For the analysis of the tie rod, this additional load is assumed to be completely taken up by deformation of the tie rod.
The stress effect of this differential thermal expansion is determined below.
From Reference 5.17:

$$\sigma_{t.e.} = E \, \alpha \, \Delta T$$

The α to be used is the differential in coefficients for the materials of the tie rod and flanges, $\Delta\alpha$. Therefore:

$$\sigma_{t.e.} = E \, \Delta\alpha \, \Delta T$$

Given:

$E = 25.0\text{E}6$ psi at 653°F

$\Delta\alpha = \alpha_{flange} - \alpha_{tie\ rod} = (9.61 \times 10^{-6} - 9.00 \times 10^{-6}) = 0.61 \times 10^{-6}$

(α at 653°F)

$\Delta T = 653 - 70 = 583$

$$\sigma_{t.e.} = 8.9 \text{ ksi}$$

The effective tensile force due to this thermal expansion is determined by:

$P = \sigma_{t.e.} A_t = (8.9 \text{ ksi})(0.0775 \text{ in}^2) = 0.69$ kips

3.3.1.3 *Preload* –

The nuts are being preloaded to 75 in-lbs (Reference 5.8.1). To determine the load in each tie rod, the following equation is used (Reference 5.15):

$T = 0.2 F d$

$\Rightarrow \quad F = T / 0.2 d$

Given:

T = the applied torque = 75 in-lbs
d = is the nominal major tie rod diameter = 0.375 in.

$F = (75 \text{ in-lbs}) / (0.20)(0.375 \text{ in}) = 1.00$ kips.

3.3.1.4 *Impact Load*

The results of the ANSYS analysis of the top plate indicate that the reaction loads at the tie rod locations are not equal and that the load on one pair of rods may be almost three times as high as the load on the other pair, see output in Attachment C.

Algebraically, that may be expressed as:

$X+X+3X+3X = L$
$8X = L$
$X = L/8; \; 3X = 3L/8$

where

X = the reaction load at the lower loaded tie rod
$3X$ = the reaction load at the higher loaded tie rod
L = total load at tie rods

With regard to the average tie rod reaction load ($X_{average} = L/4$), the relationship of the actual tie rod reaction loads may be expressed as follows:

$X / X_{average} = (L/8) / (L/4) = 0.5$
$3X / X_{average} = (3L/8) / (L/4) = 1.5$

For the purposes of analyzing stress in the tie rod (and upper flange threads), the impact load on the tie rod will be taken to be 1.5 times the average tie rod load, or:

$1.5 (5.5/4) = 2.06$ kips

3.3.1.5 *Maximum Tie Rod Load*

The load on the tie rod will be the greater of the load due to preload plus thermal expansion and the load due to the impact:

Preload + thermal expansion = 1.00 + 0.69 = 1.69 kips

Impact = 2.06 kips (> 1.69 kips)

Therefore, the maximum tie rod load is 2.06 kips.

Use P_{max} = 2.1 kips

3.3.1.6 Average Stress, σ_t (NB-3232.1)

The average (axial) stress (σ_t) in the tie rod is due to the maximum tie rod load:

$\sigma_t = P/A_t$

$A_t = 0.0775\ in^2$
$P = 2.1$ kips

$\sigma_t = (2.1\ kips/0.0775\ in^2) = 27.1\ ksi < 2\ Sm = 53.6\ ksi$ (S_m at 700°F)

3.3.1.7 Maximum Stress (NB-3232.2)

The maximum stress in the tie rod is essentially a stress intensity due to a combination of the average stress, bending stress from the OBE (Design Earthquake) event, and the torsional shear stress due to residual torque (from preload).

3.3.1.7.1 Seismic Bending Stress

Prior to any (complete) weld failure, a seismic event could cause accelerations of the MNSA. Most components will experience little or very little effects from these seismic accelerations. However, because of motions associated with the top plate, each tie rod will be subjected to bending stress. This bending stress (σ_b) will be conservatively added to the average and torsional shear stress for determining the maximum stress in the tie rod.

The bending stress at each of the tie rods is determined by applying the maximum acceleration occurring at OBE event to the top plate, following with the even distribution of the resulting force to each of 4 tie rods, and then calculating the stress at the tie rod inboard end.

$\sigma_b = 1/4\ [Mc/I] = 1/4\ [(58.3 \times 0.149) / 3.82 \times 10^{-4}] = 5.69$ ksi,

where

M=FL/2 = bending moment (Reference 5.11, Table 3, Case 1b)
M=FL/2 = (26.52 x 4.397)/2 = 58.3 in-lbs - bending moment
F = W(1+a) = 6.27 (1+ 3.23) = 26.52 lbs - acting force;
$W = W_{top\ plate} + W_{Belleville\ washers}$ = 5.86 + 0.41 = 6.27 lbs (the weight of soft Belleville washers, nuts and retainer plates is negligible)
$W_{top\ plate} = \rho V_{top\ plate}$ = 0.29 x 20.21 = 5.86 lbs - weight of the top plate

$W_{Belleville\ washers} = 32\rho V_{Belleville\ washers} = 32 \times 0.29 \times 0.044 = 0.41$ lbs – weight of 32 rigid Belleville washers

$\bar{a} = \sqrt{G_x^2 + G_y^2} = \sqrt{2.91^2 + 1.4^2} = 3.23g$ - maximum acceleration at OBE. (It is assumed that accelerations in horizontal and vertical direction are applied simultaneously).

$G_x = \sqrt{G_{x1}^2 + G_{x2}^2} = \sqrt{1.9^2 + 2.2^2} = 2.91g$, and $G_y = 1.4g$ – conservatively assumed maximum OBE acceleration values in the horizontal and vertical directions, taken from Reference 5.19 (G_{x1} – maximum acceleration in horizontal direction parallel to Hot Leg; G_{x2} – maximum acceleration in horizontal direction perpendicular to Hot Leg).

$\rho = 0.29$ lb/in^3 - density of the stainless steel

$V_{top\ plate} = \pi/4\ (6.00^2 - 1.3^2)\ 0.75 = 20.21$ in^3 - volume of the top plate, conservatively ignoring notch and flats

$V_{Belleville\ washers} = \pi/4\ (1.1^2 - 0.512^2)\ 0.059 = 0.044$ in^3 - volume of one rigid Belleville washer

$L = 4.022$ (see section 3.2.1.1, Inboard Heater Sleeve, as more conservative) $+0.75/2) = 4.397$ in - length of the tie rod from the top of the upper flange to the center of gravity of top plate

$I = \pi d^4/64 = 3.82 \times 10^{-4}$ in^4 - moment of inertia of the tie rod

$d = 0.297$ in - basic minor diameter of the tie rod

$c = d/2 = 0.297/2 = 0.149$ in

3.3.1.7.2 Residual Torque, T_R

The residual torque due to preload may be calculated using the following equation for standard threads (Reference 5.15, Equation 6):

$T_R = 0.5625\ T = 0.5625\ (75) = 0.042$ in-kips

where:

0.5625 = multiplier based upon a coefficient of friction of 0.15 and standard bolt dimensions

T = 75 in-lb = applied torque

3.3.1.7.3 Torsional Shear Stress, τ_T

The torsional shear stress is determined using the following equation derived from Equation 7 of Reference 5.15:

$\tau_T = 16T_R / \pi d^3 = 16\ (0.042) / \pi\ (0.32)^3 = 6.53$ ksi

where:

d = average of basic pitch diameter (0.3344 in.) and minor diameter (0.297 in.) ≈ 0.32 in.

3.3.1.7.4 Maximum Stress, σ_{max}

The maximum stress intensity (σ_{max}) is determined using the following equation (Reference 5.15, Equation 8):

$$\sigma_{max} = 2\sqrt{\left(\frac{\sigma_t + \sigma_b}{2}\right)^2 + (\tau_T)^2} = 35.3 \text{ ksi} \quad < 2.7\ Sm = 72.4 \text{ ksi} \ (S_m \text{ at } 700°F)$$

$$< 3.0\ Sm = 80.4 \text{ ksi} \ (S_m \text{ at } 700°F)$$

where stresses from the previous Sections:

σ_t = 27.1 ksi

σ_b = 5.69 ksi

τ_T = 6.53 ksi

3.3.1.8 Shear Stress (τ) - Threads

At Top Plate (hex nuts)

The tie rods pass through the top plate and Belleville stack and are held in place with hex nuts at the top and at the bottom. The impact load, in directly loading the top plate and top nut, will create stresses in this section of the tie rod which are in addition to the tie rod/nut preload stresses. The nuts are of the same material as the rods. Therefore, the parameters associated with the external threads of the rod are used (i.e., because of the smaller shear area). It should be also noted that the thickness of just one nut is conservatively used in an analysis.

From Reference 5.12:

$AS_s = \pi$ n Le Kn max [(1/2n) + 0.57735 (Es min - Kn max)] = 0.288 in^2

where:

n = number of threads per inch = 16
Le = the length of engagement (nut thickness) = 0.5 in (Ref. 5.8.18)
Kn max = maximum minor diameter of internal thread = 0.321 in
Es min = minimum pitch diameter of external thread = 0.3287 in

P = 2.1 kips

τ = 2.1 kips / 0.288 in^2 = 7.29 ksi < 0.6 Sm = 16.08 ksi

At Upper Flange

On the other side, the tie rods thread into the Upper Flange. The lower strength Upper Flange threads are evaluated below. (The external tie rod threads in the Upper Flange have essentially the same stress as the external tie rod threads in the top plate region, which were evaluated previously).

From Reference 5.12:

$AS_n = \pi$ n Le Ds min [(1/2n) + 0.57735(Ds min - En max)] = 0.414 in^2

where:

n = number of threads per inch = 16
Le = the length of engagement. Assume equal to 0.5 in
En max = maximum pitch diameter of internal thread = 0.3401 in
Ds min = minimum major diameter of external thread = 0.3643 in

P = 2.1 kips

τ = 2.1 kips / 0.414 in^2 = 5.07 ksi < 0.6 Sm = 9.6 ksi

The minimum allowable length of engagement of the tie rod into the Upper Flange may be calculated as a simple proportion:

Le_{min} = (Shear Stress / Allowable Stress) x Assumed Length of Engagement =
= (5.07/9.6) x 0.5 = 0.264 in.

3.3.2 Threaded Rod

3.3.2.1 Design Bolt Load Stresses (NB-3231 and Appendix E)

Design Bolt Load for the Design Pressure, W_{m1}

$W_{m1} = H + H_p$

H = 5.51 kips (from Section 3.2.2.1.1) - hydrostatic end force

H_p = 2b x 3.14GmP - compression load to ensure a tight joint (Reference 5.9, Appendix E)

b = 0.25 in (width of seal)
G = 1.92 in (average diameter of the biggest inboard seal, References 5.8.14)
m = 1.3 (from Reference 5.5, p. 47)
P = 2.500 ksi

$\Rightarrow H_p$ = 9.8 kips

$\Rightarrow W_{m1}$ = 5.51 + 9.8 = 15.31 kips

Stress due to $W_{m1} = W_{m1} / A_t$
= 15.31 kips / 4(0.256 in^2)
= 14.95 ksi < 26.8 ksi (S_m at 700°F)

Design Minimum Initial Bolt Load, W_{m2}

W_{m2} is taken as the total preload. Rod stress due to preload only ($\sigma_{t\text{-}pl}$) is calculated in Section 3.4.3.1:

$$\sigma_{t\text{-}pl} = 13.13 \text{ ksi} < 28.3 \text{ ksi } (S_m \text{ at } 100°F)$$

The stress due to W_{m1} and W_{m2} are below their respective allowables, which indicates that the actual threaded rod area (A_b) exceeds the minimum required area (A_m).

3.3.2.2 Stress Due to Thermal Expansion

The differential thermal expansion between the threaded rod and the upper flange and compression collar will create an additional tensile load on the rod. For the analysis of the rod, this additional load is assumed to be completely taken up by deformation of the rod.

The stress effect of this differential thermal expansion is considered to be equivalent to that of the tie rod since the respective tie rod - top plate and threaded rod-flange materials are the same:

$$\sigma_{t.e.} = 8.9 \text{ ksi (Section 3.3.1.2)}$$

3.3.2.3 Preload

The threaded rods are being preloaded to 35 ft-lb (References 5.8.1, 5.8.2 and 5.25). To determine the load in each rod, the following equation is used (Reference 5.15):

$$T = 0.2 F d$$

$$\Rightarrow \quad F = T / 0.2 d$$

Given:

T = the applied torque = 420 in-lbs

d = is the nominal major threaded rod diameter = 0.625 in.

$$F = (420 \text{ in-lbs}) / (0.20)(0.625 \text{ in}) = 3.36 \text{ kips.}$$

3.3.2.4 Maximum Threaded Rod Load

Due to the flexibility in the design of the flanged connection between the MNSA and the Pressurizer, the impact from ejection of the sleeve will increase the load on the threaded rods. The stiffness of the flange relative to the stiffness of the rods will determine what percentage of the impact load will be effectively transmitted to the rods.

The total load on the rod can be expressed by the following equation derived from Reference 5.14 (p. 579):

$$F_{max} = \text{Preload} + \left(\frac{K_{rod}}{K_{rod} + K_{flange}}\right) F_{impact}$$

In the above expression, K_{flange} is considered to be the equivalent stiffness of the components which are put in compression due to the torquing / tightening of the threaded rods; these components include the upper flange (top and bottom pieces which are considered to act in parallel with each other), and the compression collar, which act in series with the upper flange.

(The consideration of relationships between the top and bottom pieces of the upper flange represents a condition between two extremes that could be assumed for the components. The first, is that they act together as one solid piece. This would result in an unrealistically high stiffness. The second, is that they are both simply supported rings which act in series. Since the top ring is supported across the entire bottom surface, this would result in an unrealistically low stiffness. The assumption that the two rings act in parallel provides a stiffness that is between these two extremes and is concluded to be reasonable).

It may be concluded (from the above equation) that the greater the stiffness of the rods as compared to the stiffness of the flange components, the greater the increase in load on the rods from the impact (i.e., as $K_{flange}/K_{rod} \rightarrow 0$, the multiplier for $F_{impact} \rightarrow 1$).

The stiffness of the components in the flanged connection between the Heater Sleeve MNSA and the Pressurizer is calculated below

Stiffness of Threaded Rods:

The stiffness of the threaded rods is calculated using the same methods described for the tie rods in Section 3.2.3.2.1. Dimensions are taken from References 5.8.4 through 5.8.6, and 5.8.15.

$$K_{rods} = 4\frac{AE}{l} = 4\frac{(0.272in^2)(25.0X10^6\frac{lbf}{in^2})}{2.92in} = 9.32E6\frac{lbf}{in}$$

where: A = 0.272 in^2, cross-sectional area of the rod, based on the basic pitch diameter 0.5889 in.

E = 25.0 x 10^6 psi (at 653°F)

l = effective length of threaded rod, assuming 0.5 in of thread engagement
= thread engagement + shortest bolt hole length in the lower flange + upper flange (outboard) + upper flange (inboard) + retainer plate
= 0.5 + 0.884 + 0.75 + 0.75+ 0.036 = 2.92 inch
where the shortest bolt hole length is in Inboard Heater Sleeve MNSA and is calculated as
(1.9"- 2.25" tan 24.31°) = 0.884"

Stiffness of Overall Flange:

Heater Sleeve MNSA has three components which represent the flanged connection to the Pressurizer, the upper flange (outboard/top), the upper flange (inboard/bottom), and the compression collar. The stiffness of each of these components is calculated with the use of Reference 5.11. The compression collar is tall and narrow, and therefore is assumed to have only axial stiffness.

Upper flange (top and bottom):

The following equations are found in Reference 5.11, Table 24, Case 1a. All dimensions are taken from References 5.8.5 and 5.8.6.

$$y = \frac{w\,a^3}{D}\left(\frac{C_1 L_9}{C_7} - L_3\right)$$

where:

$$D = \frac{Et^3}{12(1-\gamma^2)} = \frac{25.0X10^6 \frac{lbf}{in^2}(0.75)^3 in^3}{12(1-0.3^2)} = 9.66E5 in - lb$$

C_1, C_7, L_9, and L_3 are constants, and are calculated using the equations of Reference 5.11, using the following dimensions. Since the flanges do not have a rectangular cross section, the following dimensions are selected to produce a conservative flange stiffness.

a = outer radius, 2.25 in
b = inner radius, 0.86 in
r_o = radius of applied load, 0.86 in
t = thickness, 0.75 in
γ = Poisson's ratio, 0.3
E = elastic modulus, 25.0 X 10^6 psi (at 653°F)
C_1 = 0.6299
C_7 = 1.0165
L_3 = 0.0237
L_9 = 0.2961

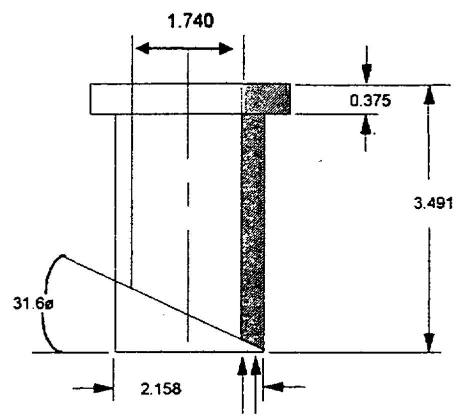
Solving for the stiffness of the upper flange, top and bottom:

$$K_{upper,top} = \frac{W}{y} = \frac{2\pi r_o}{\frac{a^3}{D}\left(\frac{C_1 L_9}{C_7} - L_3\right)} = 2.87E6 \frac{lbf}{in}$$

Compression Collar:

More conservative (since it is taller), Outboard Heater Sleeve MNSA Compression Collar, is used in this calculation (Reference 5.8.16).

FIGURE 2. COMPRESSION COLLAR



$$K_{collars} = \frac{AE}{l} = \frac{(1.28in^2)(25.0X10^6 \frac{lbf}{in^2})}{2.827in} = 1.13E7\frac{lbf}{in}$$

where: A = cross section of collar (conservative) = $\pi/4*(2.158^2 - 1.74^2)$ = 1.28 in^2
l = average effective length,
= (3.491 - 1.079* tan 31.6°) = 2.827 in
E = elastic modulus, 25.0 X 10^6 psi (at 653°F)

Determination of equivalent flange stiffness:

The two upper flange pieces (top and bottom) are considered to act in parallel with each other. The overall flange and the compression collar act in series with the threaded rod. The effective stiffness of the components is calculated below.

$$K_{flange} = \frac{1}{\frac{1}{(K_{upper,top} + K_{upper,bot})} + \frac{1}{K_{collar}}} = 3.81E6\frac{lbf}{in}$$

Therefore, the maximum threaded rod load is

$$F_{max} = 3.36 + \left(\frac{9.32E6}{9.32E6 + 3.81E6}\right)\frac{5.5}{4} = 4.34\text{kips}$$

Use F_{max} = 5.0 kips.

3.3.2.5 Average Stress, σ_t (NB-3232.1)

The average (axial) stress (σ_t) in the threaded rod is due to a combination of stresses from the maximum rod load and from differential thermal expansion:

$\sigma_t = P/A_t + \sigma_{t.e.}$

$A_t = 0.256\ in^2$
$P = 5.0$ kips
$\sigma_{t.e.} = 8.9$ ksi

$\sigma_t = (5.0\ kips/0.256\ in^2) + 8.9 = 28.43\ ksi < 2\ Sm = 53.6\ ksi$ (at 700°F)

3.3.2.6 Maximum Stress (NB-3232.2)

The maximum stress in the rod is essentially a stress intensity due to a combination of the average stress and the torsional shear stress due to residual torque (from preload).

3.3.2.6.1 Residual Torque, T_R

The residual torque due to preload may be calculated using the following equation for standard threads (Reference 5.15, Equation 6):

$T_R = 0.5625\ T = 0.5625\ (420) = 0.236$ in-kips

where:

0.5625 = multiplier based upon a coefficient of friction of 0.15 and standard bolt dimensions
T = 420 in-lb = applied torque

3.3.2.6.2 Torsional Shear Stress, τ_T

The torsional shear stress is determined using the following equation derived from Equation 7 of Reference 5.15:

$$\tau_T = 16T_R / \pi d^3 = 16\ (0.236) / \pi\ (0.5739)^3 = 6.36\ ksi$$

where:
d = average of basic pitch diameter (0.5889 in.) and minor diameter (0.5589 in.) = 0. 5739 in.

3.3.2.6.3 Maximum Stress, σ_{max}

The maximum stress intensity (σ_{max}) is determined using the following equation (Reference 5.15, Equation 8):

$$\sigma_{max} = 2\sqrt{(\frac{\sigma_t}{2})^2 + (\tau_T)^2} = 31.15\ ksi \quad < 2.7\ Sm = 72.4ksi\ (S_m \text{ at } 700°F)$$

$$< 3.0\ Sm = 80.4ksi\ (S_m \text{ at } 700F)$$

where the stresses from the previous Sections are:

σ_t = 28.43 ksi
τ_T = 6.36 ksi

3.3.2.7 Thread Shear Stress, τ

From Reference 5.12:

$AS_s = \pi$ n Le Kn max [(1/2n) + 0.57735(Es min - Kn max)] = 0.499 in^2

where:

n = number of threads per inch = 18
Le = the length of engagement. Assume equal to 0.5 in
Kn max = maximum minor diameter of internal thread = 0.578 in
Es min = minimum pitch diameter of external thread = 0.5828 in

P = 5.0 kips

τ = 5.0 kips / 0.499 in^2 = 10.02 ksi < 0.6 Sm = 16.08 ksi

The minimum allowable length of engagement of the threaded rod into the Pressurizer may be calculated as a simple proportion, based on the rod threads.

Le_{min} = (Shear Stress / Allowable Stress) x Assumed Length of Engagement =
= (10.02/16.08) x 0.5 = 0.311 in.

3.3.3 Top Plate

For the Top Plate, allowable stresses are calculated under the assumption that operating temperature in the Top Plate region does not exceed 300°F.

The assumed operating temperature of the Top Plate is based upon the following justification. The tie rods receive some heat conducted through the upper flange, but are also exposed to ambient temperature. The conservatively selected operating temperature of 300°F is based upon a heat transfer evaluation for the tie rod which assumes a 653°F heat source temperature (conservatively assumed temperature of the top of the upper flange) and heat lost to ambient at 120°F (see Appendix D, page D2). A lowest tie rod length of 2.934 in for the Outboard Heater Sleeve MNSA (Section 3.2.1.1) is used in the calculation.

3.3.3.1 Shear Stress, τ

A_s = (f) πd t = 0.5 (3.91 in) (0.625 in) = 1.22 in^2

where:

f = factor to account for slot in top plate (reduction in area).
Conservatively, use f = 0.5

πd = the perimeter of the contact surface = $\pi \times 1.245 = 3.91$ in
(diameter of the Heater is conservatively used, per Reference 5.21)
t = the minimum thickness of the top plate at the contact area = 0.625 in
(Reference 5.8.7)

P = 5.5 kips

$\tau = 5.5 \text{ kips} / 1.22 \text{ in}^2 = 4.51 \text{ ksi} < 0.6\ S_m = 12.0 \text{ ksi}$

3.3.3.2 Bearing Stress, τ

$A_b = (f)\ \pi d\ h = 0.5\ (3.91 \text{ in})\ (0.269 \text{ in}) = 0.526 \text{ in}^2$

where:

f = factor to account for slot in top plate (reduction in area).
Conservatively, use f = 0.5
πd = the perimeter of the contact surface = $\pi \times 1.245 = 3.91$ in
(diameter of the Heater is conservatively used, per Reference 5.21)
h = the length of the contact area = $(0.19^2 + 0.19^2)^{0.5} = 0.269$ in
(0.19 inch is the weld size, per Reference 5.6)

P = 5.5 kips

$\sigma_{bearing} = 5.5 \text{ kips} / 0.526 \text{ in}^2 = 10.46 \text{ ksi} < S_y = 22.5 \text{ ksi}$

3.3.3.3 Bending stress, σ_b

The top plate finite element model discussed in Section 3.2.1.2.2 was used to determine the stresses in the top plate. The effective applied load of 1,000 lbs generates a stress distribution in the plate, see Figure C1 in Appendix C. The maximum stress intensity in the model is 4,728 psi and occurs at the chamfer radius of the plate on the symmetry plane. Scaling this value produces:

4,728 psi X (5,500 lbs /1,000 lbs) = 26.00 ksi

$\sigma_b = 26.00 \text{ ksi} < 1.5\ S_m = 30.0 \text{ ksi}$

3.3.4 Compression Collar

Dimensions from Reference 5.8.13 (as more conservative).

3.3.4.1 Shear Stress, τ

$A_s = (\pi)(D)(t) = (\pi)\ (2.258 \text{ in})\ (0.375 \text{ in}) = 2.66 \text{ in}^2$
P = 3.36 kips/bolt x 4 bolts = total preload from bolts
= 13.44 kips

τ = 13.44 kips / 2.66 in^2 = 5.05 ksi < 0.6 Sm = 9.6 ksi

3.3.4.2 Bearing stress, σ_b

$A_{bearing} = (\pi/4)(D^2_{comp\ collar\ OD} - d^2_{comp\ collar\ ID}) = (\pi/4)(2.158^2 - 1.675^2)\ in^2 = 1.454\ in^2$
P = 13.44 kips

$\sigma_{bearing}$ = 13.44 kips / 1.454 in^2 = 9.24 ksi < Sy = 17.7 ksi

3.3.5 Upper Flange

Dimensions from References 5.8.5 and 5.8.6.

Shear stress, τ

$A_s = (\pi)(D)(t) = (\pi)\ (3.02\ in)\ (0.375\ in) = 3.558\ in^2$
P = 13.44 kips

τ = 13.44 kips /3.558 in^2 = 3.78 ksi < 0.6 Sm = 9.6 ksi

Due to the proximity of the bolts and support surface, bending stresses are considered to be small and are neglected.

3.3.6 Socket Head Shoulder Screw

Two Socket Head Shoulder Screws are installed through the lower flange to resist slippage of the Pressurizer Heater Sleeve MNSA with respect to the Pressurizer during installation. The total threaded rod preload of 13.44 kips may produce shear and bearing stresses in the two shoulder screws.

Socket Head Shoulder Screw of the Outboard Heater Sleeve MNSA is analyzed in this section since it experiences higher relevant loads due to a steeper slope with respect to the Pressurizer surface (Reference 5.8.17).

(The shear stress in the shoulder screw threads produced by the preload of the shoulder screws is bounded by the shear stress produced in the threaded rod, which is of the same material and the same thread size, and which is preloaded by a higher torque.)

3.3.6.1 Shear Stress, τ

$A_s = (\pi/4)(D^2) = (\pi/4)(1.12^2)\ in^2 = 0.985\ in^2$

P = 13.44 kips (sin 31.6°) / 2 = 3.521 kips (shear load)

τ = 3.521 kips / 0.985 in^2 = 3.57 ksi < 0.6 Sm = 16.08 ksi

3.3.6.2 *Bearing Stress, σ_b*

A_b = D t = (1.12 in.) (0.5 in.) = 0.56 in^2

where:

D = Diameter of unthreaded screw shank = 1.12 in
t = minimum in-contact thickness = 0.5 in (References 5.8.1 and 5.8.2)

P = 13.4 kips (sin 31.6°) / 2 = 3.521 kips (bearing load)

σ_b = 3.521 kips / 0.56 in^2 = 6.29 ksi < Sm = 26.8 ksi

1.5 S_y is the stipulated stress allowable (NB-3227.1). However, S_y is not provided in the Code for this particular screw material. Given that $S_m < S_y$ (per Note 1 of Table I-1.3), the bearing stress allowable of S_m for this component is acceptable.

3.4 Fatigue Analysis

The fatigue analysis of the components will conservatively consider loads which may exist on the components after weld or sleeve failure has occurred. Prior to failure, components will be subjected to loads due mainly to preload and thermal expansion. After failure, and assuming that the sleeve/heater is free to move, certain components will be additionally stressed because of the internal pressure forcing the sleeve/heater up against the top plate. The load on these components would be cyclical, given the change in pressure and temperature that occurs as the plant heats up and then cools down.

The critical components for fatigue analysis purposes are the tie rod and threaded rods, on the basis of:

- preload tensile stresses
- thermal expansion tensile stresses
- stress concentrations in the threaded sections, and
- for the levels of stresses involved, a more restrictive number of allowable cycles (versus the stainless steel MNSA components; see Table I-9.1 of Reference 5.9)

It is noted that, in the fatigue analyses below, the stresses produced by the one-time application of an impact load are not considered since the contribution to fatigue from this one occurrence is not significant.

3.4.1 Normal Operating Pressure Force

The effect of the force acting on the MNSA components due to internal pressure is similar to that of the impact load, only of a smaller magnitude, and it is a function of the internal pressure and the area of the sleeve. The pressure used to determine the force is based on the maximum internal pressure for all Normal and Upset conditions which is bounded, by definition, by the Design Pressure. Therefore, the Design Pressure force of 5,510 lbs calculated in Section 3.2.2.1.1 due to design pressure of 2,500 psi, may be conservatively used as the normal operating force.

This force (F_{nop} = 5.51 kips) will be used to calculate normal operating tensile stresses in the tie rod and threaded rod as part of the Peak Stress Intensity calculation.

3.4.2 Tie Rods

3.4.2.1 Peak Stress

The maximum Peak Stress in the tie rod is calculated, as follows:

Peak Stress = fsrf*(σ_{max}.)

where:

fsrf = fatigue strength reduction factor = 4.0 (from NB-3232.3(c))

σ_{max^*} = maximum stress:

$$\sigma_{max^*} = 2\sqrt{(\frac{\sigma_t + \sigma_b}{2})^2 + (\tau_T)^2}$$

where:

σ_t = $\sigma_{t\text{-}p} + \sigma_{t\text{-}pl} + \sigma_{t.e.}$ (conservatively), and

$\sigma_{t\text{-}p}$ = tensile stress due to pressure (accounting for unequal distribution
= 1.5(5.510 kips/4) / 0.0775 in^2
= 26.66 ksi
(coefficient 1.5 takes into account unequal distribution of the reaction loads at the tie rod locations)

$\sigma_{t\text{-}pl}$ = tensile stress due to preload (preload from Section 3.3.1.3)
= 1.0 kips / 0. 0775 in^2
= 12.9 ksi

$\sigma_{t.e.}$ = tensile stress due to thermal expansion (stress from Section 3.3.1.2)
= (8.9 ksi)*(30E6/25.0E6) (E/E per NB-3232.3(d))
= 10.68 ksi

σ_b = 5.69 ksi (stress from Section 3.3.1.7.1)

τ_T = 6.53 ksi (stress from Section 3.3.1.7.3)

$\Rightarrow \sigma_{max^*}$ = 57.43 ksi

$\Rightarrow$ Peak Stress = 4 (57.43) = 229.7 ksi

Based upon a minimum stress value of 0.0 ksi (this is a conservative approach, since preload never goes away), the maximum Peak Stress Intensity Range (S_p) in the tie rod is:

S_p = 229.7 – 0.0 = 229.7 ksi

3.4.2.2 Usage Factor

The calculation of the usage factor for the tie rod is based upon the maximum Peak Stress Intensity Range of 229.7 ksi:

$S_a = S_p/2$ = 114.9 ksi

This range is considered to occur a total number of 700 cycles, which is the sum of the numbers of cycles for Heatup/Cooldown (500) and Plant Leak Test (200), per Reference 5.16 (seismic loads are conservatively included in a total number of cycles).

For a $S_a = S_p/2$ = 114.9 ksi, the allowable number of cycles per Table I-9.1 (Reference 5.9, for Fig. I-9.4) is approximately 760 (the curve for maximum nominal stress $2.7S_m$ is used). The usage factor (U) is:

$U = 700/760 = 0.921$

There are other Normal and Upset transients which are defined for the Pressurizer (per Reference 5.16), but their contribution to fatigue in the tie rod is not significant.

3.4.3 Threaded Rod

3.4.3.1 Peak Stress

The maximum Peak Stress in the rod is calculated, as follows:

Peak Stress = fsrf*(σ_{max^*})

where:

fsrf = fatigue strength reduction factor = 4.0 (from NB-3232.3(a))

σ_{max^*} = maximum stress:

$$\sigma_{max^*} = 2\sqrt{(\frac{\sigma_t}{2})^2 + (\tau_T)^2}$$

where:

$\sigma_t = \sigma_{t\text{-}p} + \sigma_{t\text{-}pl} + \sigma_{t.e.}$ (conservatively), and

$\sigma_{t\text{-}p}$ = tensile stress due to pressure
= [(5.51 kips/4)] / 0.256 in^2
= 5.38 ksi

$\sigma_{t\text{-}pl}$ = tensile stress due to preload (preload from Section 3.3.2.3)
= 3.36 kips / 0. 256 in^2
= 13.13 ksi

$\sigma_{t.e.}$ = tensile stress due to thermal expansion (stress from Section 3.3.2.2)
= (8.9 ksi)*(30E6/25.0E6) (E/E per NB-3232.3(d))
= 10.68 ksi

τ_T = 6.36 ksi (stress from Section 3.3.2.6.2)

$\Rightarrow \sigma_{max^*}$ = 31.84 ksi

$\Rightarrow$ Peak Stress = 4 (31.84) = 127.4 ksi

Based upon a minimum stress value of 0.0 ksi (this is a conservative approach, since preload never goes away), the maximum Peak Stress Intensity Range (S_p) in the bolt is:

$S_p = 127.4 - 0.0 = 127.4$ ksi

3.4.3.2 Usage Factor

The calculation of the usage factor for the hex head bolt is based upon the maximum Peak Stress Intensity Range of 127.4 ksi:

$S_a = S_p/2 = 63.7$ ksi

This range is considered to occur a total number of 700 cycles, which is the sum of the numbers of cycles for Heatup/Cooldown (500) and Plant Leak Test (320), per Reference 5.16.

For a $S_a = S_p/2 = 63.7$ ksi, the allowable number of cycles per Table I-9.1 (Reference 5.9) is approximately 1500. The usage factor (U) is:

$U = 700/1500 = 0.467$

There are other Normal and Upset transients which are defined for the Pressurizer (per Reference 5.16), but their contribution to fatigue in the rod is not significant.

3.5 Consideration of Hydrostatic Test Pressure Conditions

Per Paragraph 1.3.1 of Reference 5.7, the deliverable MNSA hardware is not required to be hydrostatically tested. The equivalent "leak" test is conducted at normal operating pressure as part of plant restart. Therefore, stresses resulting from such testing are bounded by conditions analyzed.

3.6 Consideration of Faulted Conditions

Reference 5.16 lists the Faulted Conditions which are identical to the Design Condition except that they also include a Loss of Secondary Pressure, Safe Shutdown Earthquake and Pipe Rupture events. The Loss of Secondary Pressure and the Pipe Rupture events have no effect on the MNSA components.

An assessment is made of the effect of Faulted Conditions by reviewing the maximum stress results for the tie rod (Sections 3.3.1.7.1), which is the component most significantly affected by an earthquake event (either OBE or Maximum/SSE). Conservatively doubling the OBE bending stresses to simulate the effects of the Maximum Earthquake event results in stresses which meet the $3S_m$ allowable for Maximum stress. Therefore, the stresses resulting from Faulted Conditions are acceptable.

4. SUMMARY OF RESULTS

The results presented below were determined using the assumptions defined and justified in Section 2.0. There are no additional contingencies or assumptions that are applicable to these results.

All stresses are satisfactory and meet the appropriate allowable limits set forth in Section III of the ASME Boiler and Pressure Vessel Code (Reference 5.9).

Component	Stress Category	Calculated Stress/ Usage factor (stress in ksi)	Allowable Stress/ Usage Factor (stress in ksi)
Tie Rod	Design	26.66	26.8
	Average	27.10	53.6
	Maximum	35.30	80.4
	Thread Shear	7.29	16.1
	Usage Factor	0.921	1.00
Threaded Rod	Design	14.95	26.8
	Average	28.43	53.6
	Maximum	31.15	80.4
	Thread Shear	10.02	16.1
	Usage Factor	0.467	1.00
Top Plate	Shear	4.51	12.0
	Bearing	10.46	22.5
	Bending	26.00	30.0
Compression Collar	Shear	5.05	9.6
	Bearing	9.24	17.7
Upper Flange	Shear	3.78	9.6
	Thread Shear	5.07	9.6
Socket Head Shoulder Screw	Shear	3.57	16.1
	Bearing	6.29	26.8

Lengths of engagement used in analysis:

- Tie Rod - Upper Flange: 0.5 in. (0.264 in. minimum)
- Threaded Rod - Pressurizer: 0.5 in. (based upon bolt thread shear; 0.311 in. minimum)

5. REFERENCES

5.1 Westinghouse Project Plan No. V1-NOME-IPQP-0367, Rev. 0, "Mechanical Nozzle Seal Assemblies (MNSA) for PZR Heater Sleeves", February 2001.

5.2 Westinghouse Electric Company CE Nuclear Power LLC Quality Procedures Manual QPM-101, Revision 05.

5.3 "Analytical Report for Arizona Unit No. 1 Pressurizer," Report No. CENC-1336, August 1978.

5.4 Dedication Report No. 9481-99-140-1A, Rev. 0, January 2000

5.5 Union Carbide Grafoil, "Engineering Design Manual, " Volume One, Sheet and Laminated Products, by R. A. Howard, 1987.

5.6 CE Drawing No. E-78373-641-002, Rev. 02, "Lower Vessel Final Assembly".

5.7 Design Specification No. V1-NOME-SP-0082, Rev. 0, "Mechanical Nozzle Assemblies (MNSA) for Pressurizer Heater Sleeves".

5.8 Westinghouse Drawing No.

1. E-MNSAAPS-228-006, Revision 03, "Large Heater Sleeve MNSA – Inboard Heaters"
2. E-MNSAAPS-228-005, Revision 02, "Large Heater Sleeve MNSA – Outboard Heaters"
3. D-MNSA-228-050, Revision 01, "Lower Flange – Outboard Heaters"
4. D-MNSA-228-051, Revision 01, "Lower Flange – Inboard Heaters"
5. C-MNSA-228-056, Revision 01, "Upper Flange (Inboard)"
6. C-MNSA-228-057, Revision 01, "Upper Flange (Outboard)"
7. C-MNSA-228-068, Revision 01, "Top Plate"
8. C-MNSA-228-062, Revision 01, "Long Threaded Rod – Outboard Heaters"
9. C-MNSA-228-063, Revision 01, "Short Threaded Rod – Outboard Heaters"
10. C-MNSA-228-067, Revision 01, "Tie Rod"
11. C-MNSA-228-069, Revision 01, "Long Threaded Rod – Inboard Heaters"
12. C-MNSA-228-070, Revision 01, "Short Threaded Rod – Inboard Heaters"
13. C-MNSA-228-072, Revision 01, "Compression Collar – Inboard Heaters, Unit 1, Locations A-5 & A-7"
14. C-MNSA-228-073, Revision 01, "Large Heater Sleeve MNSA Grafoil Seal - Inboard Heaters, Unit 1, Locations A-5 & A-7"
15. C-MNSA-228-060, Revision 01, "Retainer Plate"
16. C-MNSA-228-054, Revision 01, "Compression Collar – Outboard Heater"
17. C-MNSA-228-058, Revision 01, "Socket Head Shoulder Screw – Outboard Heaters"
18. E-MNSA-228-004, Revision 06, "Mechanical Nozzle Seal Assembly Details"

5.9 American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III, 1989 Edition (No Addenda).

5.10 Letter No. NOME-01-V1-0053, K. V. Margotta to J. T. McGarry, "Interim Test Report – Hydrostatic Testing of Steep Slope Large Diameter Heater Sleeve MNSA", February 27, 2001

5.11 "Roark's Formulas for Stress and Strain," Warren C. Young, Sixth Edition, 1989, McGraw-Hill.

5.12 ANSI Standards for Threads, Appendix B, B1.1, 1982.

5.13 "Engineering Mechanics: Statics and Dynamics", F. L. Singer, Third Edition, Harper & Row, New York, 1975.

5.14 "Mechanical Engineers' Handbook", M. Kutz, ed., John Wiley & Sons, Inc., 1986.

5.15 "How to Calculate and Design for Stress in Preloaded Bolts", A. G. Hopper and G. V. Thompson, Product Engineering, 1964.

5.16 Specification No. 00000-PE-130, Revision 06, "General Specification for a Pressurizer Assembly", May 1978.

5.17 "Strength of Materials", F. L. Singer, Second Edition, Harper & Row, New York, 1962

5.18 Report No. MISC-ME-C-274, Revision 00, "Verification and Validation of ANSYS Version 5.5.2 on HP9000/800 Series Machines with the HP-UX 10.20 Operating System", June 1999.

5.19 Specification No. 14273-PE-130, Revision 07, "Project Specification for a Pressurizer Assembly for Arizona Nuclear Power Project Palo Verde Units 1, 2 & 3", October 2000.

5.20 CE Drawing No. E-78373-684-001, Rev. 02, "Instrument Nozzles and Heater Sleeves".

5.21 CE Drawing No. C-STD13-685-031-00, "Heater Pressurizer".

5.22 "Analytical Report for Arizona Unit No. 2 Pressurizer," Report No. CENC-1395, August 1979.

5.23 "Analytical Report for Arizona Unit No. 3 Pressurizer," Report No. CENC-1490, October 1981.

5.24 Engineering Report No. V1-NOME-ER-0122, Revision 02, "Design Evaluation of MNSA for Various Applications at Palo Verde Units 1, 2 & 3", February, 2001.

5.25 Document No. V1-NOME-EP-0335, Revision 00, "Engineering Procedure for the Installation of Pressurizer Heater Sleeve Mechanical Nozzle Seal Assemblies for

Arizona Public Service Co. Palo Verde Nuclear Generating Station Units 1, 2 & 3", February 2001.

5.26 Letter No. NOME-01-V1-0076, J. T. McGarry to K.H. Haslinger, "Arizona Pressurizer Heater Sleeve Nozzles A-5 and A-7", March 16, 2001.

ATTACHMENT B

CALCULATION No. A-PVNGS-9449-1259, Rev. 01
"Evaluation of Attachment Locations for Mechanical Nozzle Seal Assemblies on Arizona Public Service Palo Verde Units 1, 2 and 3 Pressurizer Heater Sleeves"

(32 pages including cover)

SUMMARY OF CONTENTS	
Calculation	23 Pages
Appendices	0 Pages
Attachments	8 Pages
Diskette Attached	_Yes X No

EVALUATION OF ATTACHMENT LOCATIONS FOR MECHANICAL NOZZLE SEAL ASSEMBLIES ON ARIZONA PUBLIC SERVICE PALO VERDE UNITS 1, 2, AND 3 PRESSURIZER HEATER SLEEVES

A-PVNGS-9449-1259, REV. 01

Quality Class: QC-1 (Safety-Related)

Contingencies: None

PURPOSE: To evaluate the structural integrity of the attachment locations for the mechanical nozzle seal assemblies about the pressurizer heater sleeves.

This Design Analysis is complete and verified. Management authorizes the use of its results.

PREPARED BY: B. A. Bell *B. a Bell* DATE: *2/28/01*

VERIFICATION STATUS: COMPLETE

The Safety-Related design information contained in this document has been verified to be correct by means of Design Review using the Checklist in QP-3.4 of QPM-101.

Name J. G. Thakkar Signature *J. G. Thakkar* Date *2/28/01*
Independent Reviewer

APPROVED BY: D. P. Siska *D. P. Siska* DATE: *2-28-2001*

WESTINGHOUSE ELECTRIC COMPANY
CHATTANOOGA, TENNESSEE

CSE-01-020

RECORD OF REVISIONS

NUMBER	DATE	PARAGRAPH(s) INVOLVED	PREPARED BY	INDEPENDENT REVIEWER	APPROVED BY
0	02/21/01	Original Issue	B. A. Bell 02/21/01	J. G. Thakkar 02/23/01	D. P. Siska 02/23/01
1	02/28/01	Sections 5.0, 6.2.1, 7.1, 8.0, and Attachment 2	B. A. Bell B. A. Bell 2/28/01	J. G. Thakkar J. G. Thakkar 2/28/01	D. P. Siska DP Siska 2-28-2001

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1.0 OBJECTIVE OF THE DESIGN ANALYSIS

This report investigates the structural integrity of the attachment locations for the Mechanical Nozzle Seal Assemblies (MNSA) on Arizona Public Service (APS) Palo Verde Units 1, 2, and 3 pressurizer heater sleeves. The MNSAs are described in Reference 3 along with the Project Plan (Reference 5). A MNSA is attached to the outside surface of the pressurizer bottom head by six 5/8-inch bolts/threaded rods, i.e. four regular threaded rods/nuts and two larger shoulder bolts with a shoulder diameter of 1.125 inch. The five objectives of this analysis relate to the machined tapped holes made in the pressurizer bottom head to receive the MNSA attachment bolts/threaded rods as well as the heater sleeves where the MNSA clamp is attached. The objectives are:

1. Establish the maximum permissible bolt load on the tapped holes considering the minimum engagement length for the bolt threads from References 3A and 3B, when using both the threaded rods and socket head shoulder bolts (References 3C thru 3H).
2. Show that the ASME Code (Reference 2) area of reinforcement requirement for the nozzle penetration remains in compliance, when the areas removed by the tapped holes and defective weld are evaluated. Since the defective weld area is only in the cladding (Reference 12A) for which the original reinforcement calculation did not consider, it will not be evaluated in this analysis.
3. Calculate the range of stress intensity in the vessel wall and compare to the ASME Code allowable of 3 Sm for primary plus secondary stresses.
4. Perform a fatigue evaluation for the base of the tapped holes and compare to the ASME Code total usage factor (U) requirement of 1.0.
5. Establish the maximum permissible loads in the heater sleeve considering the minimum shear areas for the heater/sleeve weld and the sleeve/pressurizer J-weld as well as the bearing area for the heater/sleeve weld.

The results of this analysis will demonstrate that the use of a MNSA on the pressurizer heater sleeves will comply with the ASME Code requirements. This analysis can be used for future repair work on any other leaking heater sleeves provided their criteria are the same as those used in this report.

2.0 ASSESSMENT OF SIGNIFICANT DESIGN CHANGES

The "as-designed" configurations for the pressurizer bottom head wall and heater sleeves defined in References 12A through 12D are considered. The design conditions and operating transients (TNS) as presented in Reference 1 are not changed by the results of this analysis.

3.0 ANALYTICAL TECHNIQUES

The ASME Code design force capacity of the shear area is determined for the tapped holes in the pressurizer bottom head wall. The analytical expressions used in this determination are classical to the structural discipline.

The tapped holes in the pressurizer bottom head wall are subtracted from the available reinforcement area about the penetration. The defective J-weld area for the heater sleeves is only in the cladding, Reference 12A, and is not considered in this calculation since the original reinforcement calculation (Reference 1) did not consider the cladded surface area for reinforcement. This calculation follows the rules of the ASME Code, Reference 2, and conforms to the reinforcement limits stated in the pressurizer design report, Reference 1.

The structural evaluation for the base of the tapped hole in the pressurizer bottom head wall is accomplished using acknowledged stress expressions for the outside surface of a spherical shell. The range of stress intensity is evaluated first, followed by the fatigue analysis. In the fatigue evaluation for the tapped holes, a maximum stress concentration factor of five (5) per Paragraph NB-3222.4 (e) (2) of the ASME Code (Reference 2) is applied to the longitudinal (σ_x), circumferential (σ_θ), and radial (σ_r) stresses. The peak stress intensities are then calculated for the respective tapped holes, and the fatigue usage values determined using the applicable ASME Code Sa/N curves.

4.0 SELECTION OF DESIGN INPUTS

The operating conditions for the APS Palo Verde Units 1, 2, and 3 pressurizer at 100% power along with the design conditions from Reference 1, page 3* are as follows:

Normal Operating Pressure:	2250 psia
Normal Operating Temperature:	653 °F
Design Pressure:	2500 psia
Design Temperature:	700 °F

The transient conditions for the Units 1, 2, and 3 pressurizer are from Reference 1, pages 3 and 4*, and are detailed in Section 6.2.

* Throughout this analysis all cited page numbers in Reference 1 refer to CENC-1490, the Analytical Report for the Unit 3 pressurizer; page numbers in the Units 1 and 2 documents listed in Reference 1 may differ.

5.0 ASSUMPTIONS

The assumptions included in this design analysis are:

1. In the determination of the maximum allowable bolt/threaded rod load based on thread shear, the minimum length of engagement is varied over a range of values below the 0.62 in. minimum length thread depth from References 3A and 3B. Lower values for the length of engagement result from the stack-up of tolerances on the bolt and mating compression parts. The use of a lower length of engagement results in a lower value for the allowable load. Also, a conservative maximum torque of 50 ft-lbs. is used in the installation torque calculation, which exceeds the maximum torque of 35 ft-lbs. for installation purposes.

2. In the determination of the bolt installation preload force, the mean coefficient of friction of 0.15 is conservatively used in lieu of the 0.18 given in Reference 10. For a known installation torque, use of a lower value results in a higher preload force.

3. The ASME Code maximum recommended stress concentration factor of five (5) per Paragraph NB-3222.4 (e) (2) of Reference 2 is used to determine the peak stress intensities of the tapped holes in the pressurizer bottom head.

4. The cross sectional areas used in the analysis for the attachment holes are slightly larger than the actual attachment holes (i.e. 0.625 in. drilled hole vs. 0.625 in. threaded profile hole). Also, the maximum heater sleeve diameter of 1.675 in. for penetrations A-5 and A-7 of the Unit 1 Pressurizer (Reference 13) is used in the reinforcement calculation in Section 6.2.1, which will envelope the reinforcement calculation for nominal heater sleeve penetrations.

5. The thermal skin stresses due to the non-linear portion of the through wall thermal gradient are negligible on the bottom head outer surfaces.

6. Longitudinal stresses (σ_x) and circumferential stresses (σ_θ) are conservatively calculated for the pressurizer bottom head outside surfaces rather than at the base of the tapped holes where the stresses are less.

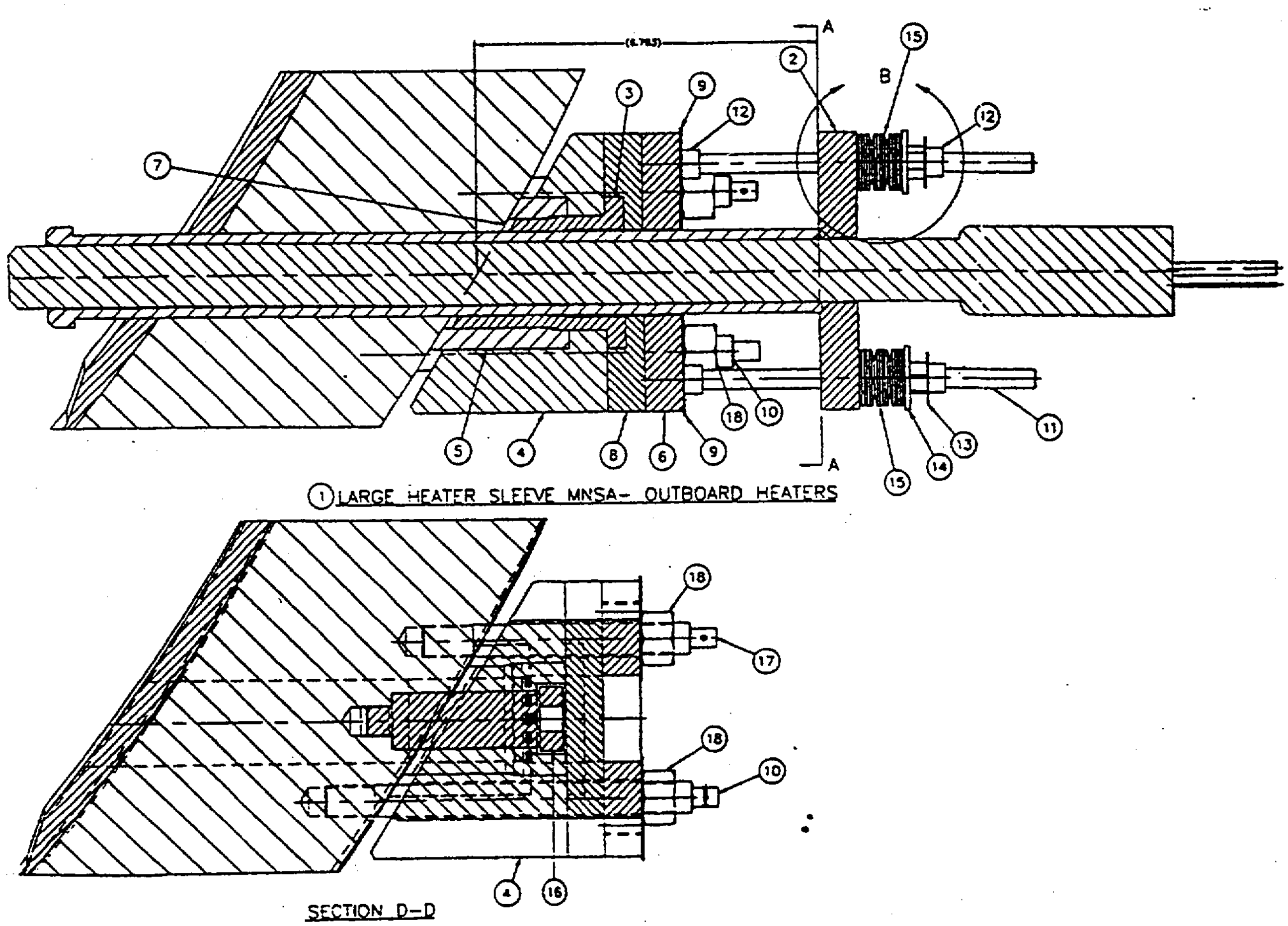
7. The thermal stress imposed on the outside surface of the pressurizer wall by the temperature difference between the linear and non-linear temperatures is conservatively omitted.

8. In the diametrical expansion of the bolt pattern due to thermal growth, there are no additional loads in the vessel since the differences in the diametrical expansions of the flanges and the attachment bolts are well within the bolt hole clearances in the flanges.

6.0 DETAILED ANALYSIS

This section contains the structural evaluation of the attachment locations for the mechanical nozzle seal assemblies (MNSA) on the Palo Verde Units 1, 2, and 3 pressurizer heater sleeves. The evaluation includes comparing the revised available area of reinforcement to the required area, as well as performing a fatigue evaluation on the pressurizer bottom head outside surface with the stress concentration factor due to the attachment stud holes. The following figures from References 3A and 3B show the configuration for the MNSAs and their attachment to the pressurizer bottom head. Stresses due to loads in the stud are concentrated at the upper threads and are negligible at the bottom of the hole.

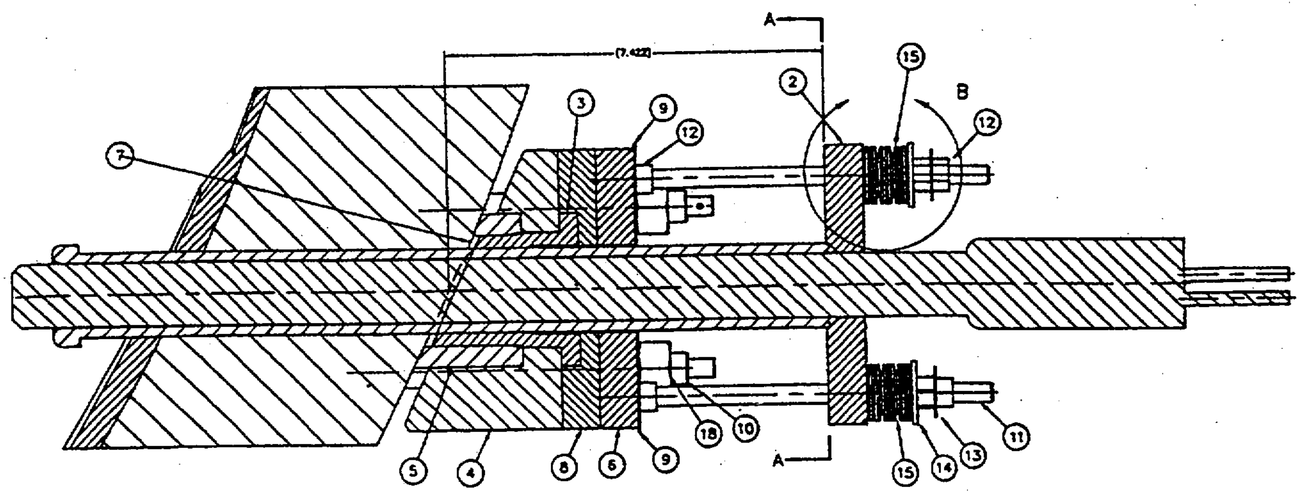
Pressurizer Heater Sleeve Mechanical Nozzle Seal Assembly
Shown at Maximum Angle
(See Reference 3A for details.)

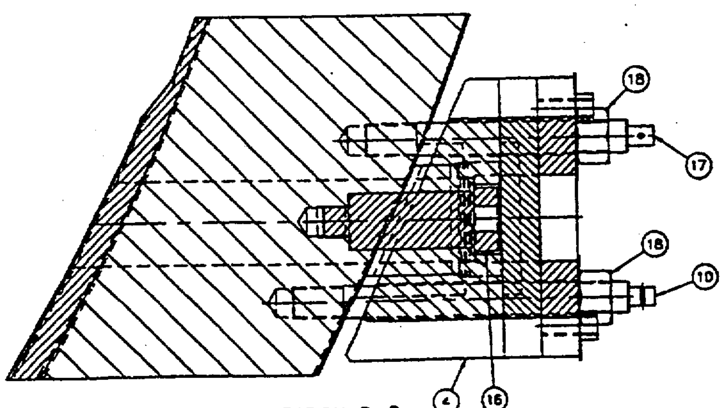


NOTE: The bottom end of the stud holes in this figure are rounded and do not come to a point as shown.

6.0 DETAILED ANALYSIS

Pressurizer Heater Sleeve Mechanical Nozzle Seal Assembly
Shown at Minimum Angle
(See Reference 3B for details.)





NOTE: The bottom end of the stud holes in this figure are rounded and do not come to a point as shown.

6.0 DETAILED ANALYSIS

6.1 Seal Assembly Bolted Connection to Pressurizer Evaluation

6.1.1 Maximum Allowable Load Based on Thread Shear

Reference 2; Paragraph NB- 3227.2(a) and Reference 6, page 59

$$ASn = \pi \cdot n \cdot Le \cdot Ds_{min}\,[1/(2 \cdot n) + .57735(Ds_{min} - En_{max})] = 1.367 \cdot Le\ in^2$$

$$ASs = \pi \cdot n \cdot Le \cdot Kn_{max}\,[1/(2 \cdot n) + .57735(Es_{min} - Kn_{max})] = .998 \cdot Le\ in^2$$

Where: Threads = 0.625-18 UNF-2B; References 3A and 3B
- ASn = Internal Thread Shear Area (Pressurizer Wall)
- ASs = External Thread Shear Area (Bolt)
- n = Threads per Inch = 18
- Le = Length of Thread Engagement = .62 in.(max), see Assumption No. 1
- Ds_{min} = Min. Major Diameter of External Thread = 0.6149 in.; Reference 6, page 14
- En_{max} = Max. Pitch Diameter of Internal Thread = 0.5949 in., Reference 6, page 14
- Kn_{max} = Max. Minor Diameter of Internal Thread = 0.5780 in., Reference 6, page 14
- Es_{min} = Min. Pitch Diameter of External Thread = 0.5828 in., Reference 6, page 14

$\tau = 0.6S_m$ = Thread Shear Stress Allowable (Reference 2; Paragraph NB- 3227.2(a))

For Pressurizer: $\tau_p = .6(26.7) = 16.02$ ksi $S_m = 26.7$ ksi @650°F; Reference 2
Pressurizer Material is SA-533, Gr. B; Cl.1 Ref. 1

For Bolt: $\tau_b = .6(26.9) = 16.14$ ksi $S_m = 26.9$ ksi @ 650°F; Reference 2
Bolt Material is SA-453, Gr.660; Refs. 3C thru 3H

The maximum allowable bolt/threaded rod load based on the available thread area is:

$F_p = \tau_p \cdot ASn$ $F_p = 21.906 \cdot Le$ kips

$F_b = \tau_b \cdot ASs$ $F_b = 16.116 \cdot Le$ kips

The maximum allowable load is governed by shear in the external threads on the bolt/threaded rod. The allowable bolt/threaded rod load is shown for a range of minimum thread engagement lengths in the following table.

6.0 DETAILED ANALYSIS

6.1 Seal Assembly Bolted Connection to Pressurizer Evaluation

6.1.1 Maximum Allowable Load Based on Thread Shear (continued)

Allowable Bolt Load versus Thread Engagement Length						
Le, in.	0.50	0.52	0.54	0.56	0.58	0.60
Fb, kips	8.06	8.38	8.70	9.02	9.35	9.67

For engagement lengths not shown on the above table the allowable bolt/threaded rod load can be calculated from the following equation:

$$F_b = 16.116 \cdot Le \text{ kips}$$

6.1.2 Evaluation of Installation Torque (Preload)

From Reference 7 the equation for the relation between torque and the applied preload P is:

$$T = (P/24)\,[D \cdot v + (d_p \cdot \mathrm{Tan}(\beta + \phi)) / \mathrm{Cos}(\alpha)]$$

Substituting, using the below values and solving for P

$$P = 5019 \text{ lb. for Preload Condition}$$

Where: T = Maximum Torque = 50 ft-lbs., see Assumption No. 1
D = Average Diameter of Bolt Head = .5 (.9375 + .625) = .781 in. (Reference 8)
Lubricant = Neolube or approved equivalent, Reference 11
v = Coefficient of Friction Beneath Bolt Head, 0.18, Ref. 10 (Conservatively, use 0.15)
d_p = Pitch Diameter of Bolt Threads = .5828 in., Minimum value per Reference 6
n = Threads per Inch = 18
β = Helix Angle of Threads = $\mathrm{Tan}^{-1}(1/n)/(\pi d_p) = 1.738^0$
μ = Coefficient of Friction @ Thread Interface = 0.15
ϕ = Thread Friction Angle = $\mathrm{Tan}^{-1}\mu = 8.531^0$
α = 1/2 Profile Angle of Threads = 30^0

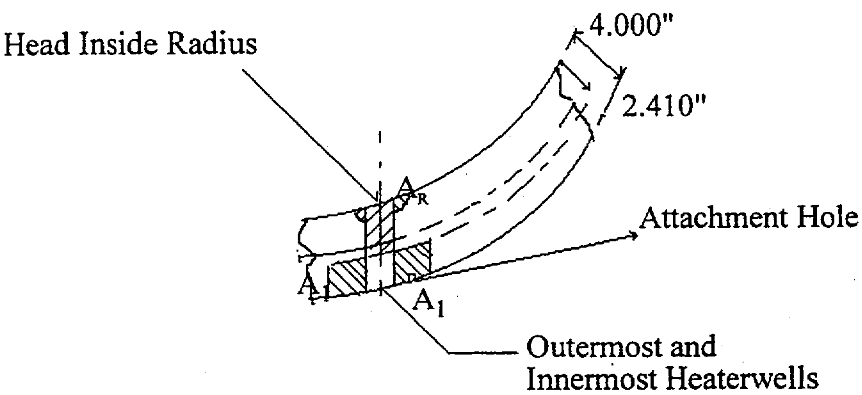
The applied preload of 5.019 kips is less than the allowable bolt load for the minimum expected length of engagement from the above table.

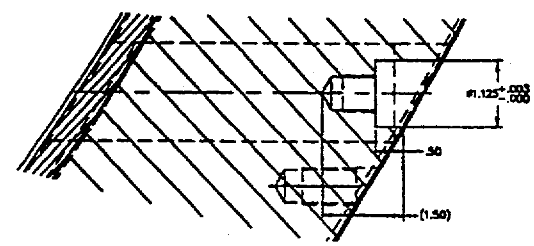
6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.1 Basic Sizing of Heater Sleeve Nozzle Reinforcement

The outermost and innermost heaterwells reinforcement calculation presented in Reference 1 must be modified to account for the area removed by the attachment holes (i.e. shoulder screws give the max. area, Reference 3) in the bottom head. The defective weld area is only in the cladding (Reference 12A) and is not considered in this calculation since the original reinforcement calculation (Reference 1) did not consider the cladded surface area for reinforcement.





Section D-D in Refs. 3A & 3B

Figure from pages A-28 and A-26 for Outermost and Innermost Heaterwells, respectively, of Reference 1

Outermost Heaterwells:

The maximum cross sectional area removed by the attachment holes in Section D-D in Reference 3A with the nozzle angle orientation dimension, θ, of 34.7° from page A-28 in Reference 1 is:

$$A_{hole} := 2\cdot\left[0.625\cdot(1.50 - 0.50) + 1.125\cdot 0.50 + 1.125^2\cdot\tan\left(34.7\cdot\frac{\pi}{180}\right)\cdot 0.5\right] \qquad A_{hole} = 3.251 \quad in^2$$

From page A-29 of Reference 1 for the <u>Outermost Heaterwells</u>, the available area of compensation, A_c, which is 2 times A_1 is recalculated as follows with θ of 34.7° and maximum hole diameter of 1.675", or:

$$A1 := \left(3.00 - \frac{1.675}{2}\right)\cdot\frac{(4.00 - 2.41)}{\cos\left(34.7\cdot\frac{\pi}{180}\right)} \qquad A_c := 2\cdot A1 \qquad A_c = 8.364 \quad in^2$$

Removing the area of the two holes, the available area of compensation, A_c, becomes:

$$A_c := A_c - A_{hole} \qquad A_c = 5.113 \quad in^2$$

The required area of reinforcement on the plane of the MNSA Clamp Holes, A_r, (page A-29 of Ref. 1) is:

$$A_r := (1.675)\cdot\frac{(2.41)}{\cos\left(34.7\cdot\frac{\pi}{180}\right)} \qquad A_r = 4.91 \quad in^2$$

Comparing the two areas, A_c and A_r: $A_c = 5.113 \quad > \quad A_r = 4.91 \quad in^2$

Therefore, the reinforcement area requirement is acceptable for the Outermost Heaterwells.

Note: The ":=" connotation used in this report represents the "=" symbol for an equation. This connotation is used since portions of the report is written with the use of "Mathcad 8.0" (Reference 4)

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.1 Basic Sizing of Heater Sleeve Nozzle Reinforcement (continued)

Innermost Heaterwells:

The maximum cross sectional area removed by the attachment holes in Section D-D in Reference 3B with the nozzle angle orientation dimension, θ, of 26.57° from page A-26 in Reference 1 is:

$$A_{hole} := 2\cdot\left[0.625\cdot(1.50 - 0.50) + 1.125\cdot 0.50 + 1.125^2\cdot\tan\left(26.57\cdot\frac{\pi}{180}\right)\cdot 0.5\right] \qquad A_{hole} = 3.008 \quad in^2$$

From page A-27 of Reference 1 for the Innermost Heaterwells, the available area of compensation, A_c, which is 2 times A_1 is recalculated as follows with θ of 26.57° and maximum hole diameter of 1.675", or:

$$A1 := \left(3.00 - \frac{1.675}{2}\right)\cdot\frac{(4.00 - 2.41)}{\cos\left(26.57\cdot\frac{\pi}{180}\right)} \qquad A_c := 2\cdot A1 \qquad A_c = 7.689 \quad in^2$$

Removing the area of the two holes, the available area of compensation, A_c, becomes:

$$A_c := A_c - A_{hole} \qquad A_c = 4.681 \quad in^2$$

The required area of reinforcement on the plane of the MNSA Clamp Holes, A_r, (page A-27 of Ref. 1) is:

$$A_r := (1.675)\cdot\frac{(2.41)}{\cos\left(26.57\cdot\frac{\pi}{180}\right)} \qquad A_r = 4.513 \quad in^2$$

Comparing the two areas, A_c and A_r: $A_c = 4.681 \quad > \quad A_r = 4.513 \quad in^2$

Therefore, the reinforcement area requirement is acceptable for the Innermost Heaterwells.

Also, in the limits of compensation, the required length, L1, of 3.00 in. (pages A-27 & A-29 of Reference 1) still encompasses the new length of 2.8155 in. (i.e. 2.25 in., bolt circle radius, plus 0.5655 in., shoulder screw hole outer radius) where the shoulder screw hole penetrations will be made.

Therefore, since the reinforcement area requirement is met for both innermost and outermost heaterwells, then the reinforcement area requirement would be met for any intermediate heaterwells, if applicable.

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation

The ASME Code maximum recommended stress concentration factor of five (5) per Paragraph NB-3222.4 (e) (2) of Reference 2 will be applied to the primary plus secondary stresses in the pressurizer bottom head wall at the outside surface for the fatigue evaluation. The transient conditions and respective cycles are defined on page A-413 - 414 of Reference 1. The transient pressures and mean wall temperatures are from page A-418 of Reference 1. The transient wall temperatures are from pages B-150 - 151 of Reference 1. Note that a positive ΔT indicates the outside surface is cooler than the mid-wall which results in tension type of loading. The bottom head material is ASME SA-533, Grade B, Class 1 with material properties from Reference 2.

$k := 0..11$

Transient	ID	Inside Press. (psi)	Outside Press. (psi)	Mean Temp. (°F)	Wall ΔT (°F)	Alpha x 10^{-6} (in/in)	Modulus x 10^{6} (psi)	No. of Cycles
	$i_k :=$	$P_k :=$	$Po_k :=$	$Tm_k :=$	$\Delta T_k :=$	$\alpha_k :=$	$E_k :=$	$N_k :=$
A1 Plant Heat Up, 2.915 hr.	0	2250	15	616	25	7.8524	26.224	500
B1 Plant Cool Down, 1.415 hr.	1	150	15	375	-62	7.5400	27.550	500
B2 End of Cooldown, Ambient	2	15	15	70	0	7.0200	29.200	500
C1 Plant Loading (+ 100 psi)	3	2350	15	653	0	7.9024	25.817	1000000
C2 Plant Unloading (-100 psi)	4	2150	15	653	0	7.9024	25.817	1000000
D1 Reactor Trip, Loss of Flow, Load (75 sec.)	5	2500	15	650	-12	7.9000	25.850	480
D2 Reactor Trip, Loss of Flow, Load (2000 sec.)	6	2220	15	632	14	7.8748	26.048	480
E1 Plant Leak Test, Heatup, 4.0 hr.	7	2250	15	400	0	7.5800	27.400	200
F1 Plant Leak Test, Cooldown, 3.8 hr.	8	2250	15	120	0	7.1000	28.931	200
F2 End of Plant Leak Test, Cooldown	9	15	15	70	0	7.0200	29.200	200
G1 Hydrostatic Test	10	3125	15	70	0	7.0200	29.200	10
G2 End of Hydrostatic Test	11	15	15	70	0	7.0200	29.200	10

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation (continued)

Primary plus Secondary Stress

From pg. A-412 of Reference 1: $R_i := 48.69$ $t := 4.00$ $R_m := R_i + \frac{t}{2}$

Pressure Stresses

$R_m = 50.69$ in

$$\sigma_{\theta p} := \frac{R_i^2 \cdot P}{2 \cdot R_m \cdot t} \qquad \sigma_{xp} := \frac{R_i^2 \cdot P}{2 \cdot R_m \cdot t} \qquad \sigma_r := Po \quad \text{(Outside Surface)}$$

Thermal Stresses $\nu := .3$

$$\sigma_{\theta t} := \overrightarrow{\frac{E \cdot \alpha}{2 \cdot (1 - \nu)} \cdot \Delta T} \qquad \sigma_{xt} := \sigma_{\theta t}$$

Combined Stress $\sigma_x := (\sigma_{xp} + \sigma_{xt}) \cdot 10^{-3}$ $\sigma_\theta := (\sigma_{\theta p} + \sigma_{\theta t}) \cdot 10^{-3}$ $\sigma_r := \sigma_r \cdot 10^{-3}$

$i_k =$	$\sigma_{xp_k} =$	$\sigma_{\theta p_k} =$	$\sigma_{xt_k} =$	$\sigma_{\theta t_k} =$	$\sigma_{x_k} =$	$\sigma_{\theta_k} =$	$\sigma_{r_k} =$
0	$1.315 \cdot 10^4$	$1.315 \cdot 10^4$	$3.677 \cdot 10^3$	$3.677 \cdot 10^3$	16.831	16.831	0.015
1	876.917	876.917	$-9.199 \cdot 10^3$	$-9.199 \cdot 10^3$	-8.322	-8.322	0.015
2	87.692	87.692	0	0	0.088	0.088	0.015
3	$1.374 \cdot 10^4$	$1.374 \cdot 10^4$	0	0	13.738	13.738	0.015
4	$1.257 \cdot 10^4$	$1.257 \cdot 10^4$	0	0	12.569	12.569	0.015
5	$1.462 \cdot 10^4$	$1.462 \cdot 10^4$	$-1.75 \cdot 10^3$	$-1.75 \cdot 10^3$	12.865	12.865	0.015
6	$1.298 \cdot 10^4$	$1.298 \cdot 10^4$	$2.051 \cdot 10^3$	$2.051 \cdot 10^3$	15.03	15.03	0.015
7	$1.315 \cdot 10^4$	$1.315 \cdot 10^4$	0	0	13.154	13.154	0.015
8	$1.315 \cdot 10^4$	$1.315 \cdot 10^4$	0	0	13.154	13.154	0.015
9	87.692	87.692	0	0	0.088	0.088	0.015
10	$1.827 \cdot 10^4$	$1.827 \cdot 10^4$	0	0	18.269	18.269	0.015
11	87.692	87.692	0	0	0.088	0.088	0.015

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation (continued)

Range of Stress Intensity

$S1 := \sigma_x - \sigma_\theta$ $\quad$ $S2 := \sigma_x - \sigma_r$ $\quad$ $S3 := \sigma_\theta - \sigma_r$

$S1_k =$	$S2_k =$	$S3_k =$
0	16.816	16.816
0	-8.337	-8.337
0	0.073	0.073
0	13.723	13.723
0	12.554	12.554
0	12.85	12.85
0	15.015	15.015
0	13.139	13.139
0	13.139	13.139
0	0.073	0.073
0	18.254	18.254
0	0.073	0.073

$Sm := 26.7$ ksi, SA-533, Gr. B, Cl. 1 material at 700 °F (Ref. 2)

$SI1 := \max(S1) - \min(S1)$ $\quad$ $SI1 = 0$ $\quad$ ksi, $\sigma_x - \sigma_\theta$ Range

$SI2 := \max(S2) - \min(S2)$ $\quad$ $SI2 = 26.592$ $\quad$ ksi, $\sigma_x - \sigma_r$ Range

$SI3 := \max(S3) - \min(S3)$ $\quad$ $SI3 = 26.592$ $\quad$ ksi, $\sigma_\theta - \sigma_r$ Range

$$\max\left(\begin{bmatrix} SI1 \\ SI2 \\ SI3 \end{bmatrix}\right) = 26.6 \text{ ksi} < \quad 3 \cdot Sm = 80.1 \text{ ksi}$$

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation (continued)

$Smax := augment(S3, N)$ $Smax := augment(Smax, i)$

$RSortSmax := csort(Smax, 0)$

$$Smax = \begin{bmatrix} 16.816 & 500 & 0 \\ -8.337 & 500 & 1 \\ 0.073 & 500 & 2 \\ 13.723 & 1\cdot10^6 & 3 \\ 12.554 & 1\cdot10^6 & 4 \\ 12.85 & 480 & 5 \\ 15.015 & 480 & 6 \\ 13.139 & 200 & 7 \\ 13.139 & 200 & 8 \\ 0.073 & 200 & 9 \\ 18.254 & 10 & 10 \\ 0.073 & 10 & 11 \end{bmatrix}$$

$$RSortSmax = \begin{bmatrix} -8.337 & 500 & 1 \\ 0.073 & 500 & 2 \\ 0.073 & 200 & 9 \\ 0.073 & 10 & 11 \\ 12.554 & 1\cdot10^6 & 4 \\ 12.85 & 480 & 5 \\ 13.139 & 200 & 8 \\ 13.139 & 200 & 7 \\ 13.723 & 1\cdot10^6 & 3 \\ 15.015 & 480 & 6 \\ 16.816 & 500 & 0 \\ 18.254 & 10 & 10 \end{bmatrix}$$

$$Smax := \begin{bmatrix} RSortSmax_{11,0} \\ RSortSmax_{10,0} \\ RSortSmax_{10,0} \\ RSortSmax_{9,0} \\ RSortSmax_{8,0} \\ RSortSmax_{8,0} \\ RSortSmax_{8,0} \end{bmatrix}$$

$$Smin := \begin{bmatrix} RSortSmax_{0,0} \\ RSortSmax_{0,0} \\ RSortSmax_{1,0} \\ RSortSmax_{1,0} \\ RSortSmax_{1,0} \\ RSortSmax_{2,0} \\ RSortSmax_{4,0} \end{bmatrix}$$

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation (continued)

$$Sn := Smax - Smin$$

$$Smax = \begin{bmatrix} 18.254 \\ 16.816 \\ 16.816 \\ 15.015 \\ 13.723 \\ 13.723 \\ 13.723 \end{bmatrix} \quad Smin = \begin{bmatrix} -8.337 \\ -8.337 \\ 0.073 \\ 0.073 \\ 0.073 \\ 0.073 \\ 12.554 \end{bmatrix} \quad Sn = \begin{bmatrix} 26.592 \\ 25.153 \\ 16.743 \\ 14.942 \\ 13.651 \\ 13.651 \\ 1.169 \end{bmatrix}$$

The maximum recommended stress concentration factor, K, per Par. NB-3222.4 (e) (2) of Ref. 1 is:

$$K := 5.0$$

The allowable number of cycles for each range of alternating stress intensity (modified by the ratio of E) is obtained from Figure I-9.1 of the ASME Code.

$Ecurve := 30.0$ x 10^6 psi, ASME Code Section III, Fig. I-9.1

$E650 := 25.85$ x 10^6 psi, ASME Code SA-533, Grade B, Class 1 material

$$Efratio := \frac{Ecurve}{E650} \qquad Efratio = 1.161$$

Therefore, the alternating stress intensities, Salt, and allowable number of cycles, Na, are:

$$S_{alt} := \overrightarrow{\frac{K \cdot Sn \cdot Efratio}{2}}$$

$$N_1 := 1000 \cdot (2)^{\left(\frac{\log\left(\frac{83}{77.151}\right)}{\log\left(\frac{83}{64}\right)}\right)} \qquad N_2 := 1000 \cdot (2)^{\left(\frac{\log\left(\frac{83}{72.979}\right)}{\log\left(\frac{83}{64}\right)}\right)}$$

$$N_1 = 1215 \qquad N_2 = 1409$$

$$S_{alt} = \begin{bmatrix} 77.151 \\ 72.979 \\ 48.578 \\ 43.352 \\ 39.605 \\ 39.605 \\ 3.392 \end{bmatrix}$$

$$N_3 := 2000 \cdot (2.5)^{\left(\frac{\log\left(\frac{64}{48.578}\right)}{\log\left(\frac{64}{48}\right)}\right)} \qquad N_4 := 5000 \cdot (2)^{\left(\frac{\log\left(\frac{48}{43.352}\right)}{\log\left(\frac{48}{38}\right)}\right)}$$

$$N_3 = 4813 \qquad N_4 = 6764$$

$$N_5 := 5000 \cdot (2)^{\left(\frac{\log\left(\frac{48}{39.605}\right)}{\log\left(\frac{48}{38}\right)}\right)} \qquad N_6 := 5000 \cdot (2)^{\left(\frac{\log\left(\frac{48}{39.605}\right)}{\log\left(\frac{48}{38}\right)}\right)}$$

$$N_5 = 8845 \qquad N_6 = 8845$$

6.0 DETAILED ANALYSIS

6.2 Bottom Pressurizer Mechanical Nozzle Seal Assembly

6.2.2 Bottom Head Wall Fatigue Evaluation (continued)

Fatigue Analysis

$$n := \begin{bmatrix} 10 \\ 490 \\ 10 \\ 480 \\ 10 \\ 200 \\ 999790 \end{bmatrix} \qquad Na := \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \\ N_5 \\ N_6 \\ \infty \end{bmatrix} \qquad U := \overrightarrow{\frac{n}{Na}} \qquad U = \begin{bmatrix} 0.0082 \\ 0.3477 \\ 0.0021 \\ 0.071 \\ 0.0011 \\ 0.0226 \\ 0 \end{bmatrix}$$

$$U_{total} := \Sigma U$$

Therefore, at the Outside Surface: $U_{total} = 0.453$ < 1.0 allowable, per Paragraph NB-3222.4 of Reference 2

6.0 DETAILED ANALYSIS

6.3 Seal Assembly Connection to Heater Sleeve

In the seal assembly connection to the heater sleeves, two areas need to be evaluated for MNSA loading. The first area includes the weld location on the heater sleeve assembly between the Watlow type pressurizer heater and the heater sleeve (Reference 12B). The second area is the J-weld location between the heater sleeve and inside surface of the pressurizer bottom head (Reference 12B).

6.3.1 Maximum Allowable Load Based on Heater/Sleeve Weld Shear

$A_{weld} = \pi \cdot d \cdot w \cdot 0.707 = 0.525\ in^2$

Where: d = heater outer diameter = 1.245 in., Reference 12D
w = weld size = 0.190 in., Reference 12B

$\tau = 0.8S_m$ = Maximum Shear Stress Allowable (Reference 2; Paragraph NB- 3227.2(b))

For Heater/Sleeve Weld: $\tau_w = .8(16.3) = 13.04$ ksi $S_m = 16.3$ ksi @700°F (conservative); Ref. 2
Minimum Strength Heater Material is SA-213, Type TP316 Ref. 1

Since the heater material has the minimum S_m value, it is used in determining the maximum allowable load based on the available shear area:

$$F_w = \tau_w \cdot A_{weld}$$
$$F_w = 6.85 \text{ kips}$$

6.3.2 Maximum Bearing Load on Heater/Sleeve Weld

$A_{brg} = 0.5\ \pi \cdot d \cdot h = 0.525\ in^2$ (one half of the bearing area is used since the MNSA plate only surrounds the bearing surface for 180 degrees, References 3A and 3B)

Where: d = heater outer diameter = 1.245 in., Reference 12D
$h = (0.19^2 + 0.19^2)^{0.5} = 0.2687$ in., Reference 12B

$\sigma_{brg} = S_y$ = Maximum Bearing Stress Allowable (Reference 2; Paragraph NB- 3227.1(a))

For Heater/Sleeve Weld: $\sigma_{brg} = 30$ ksi $S_y = 30.0$ ksi minimum; Reference 2
Minimum Strength Heater Material is SA-213, Type TP316 Ref. 1

Since the heater material has the minimum S_y value, it is used in determining the maximum allowable load based on the available bearing area:

$$F_{brg} = \sigma_{brg} A_{brg}$$
$$F_{brg} = 15.75 \text{ kips}$$

6.0 DETAILED ANALYSIS

6.3 Seal Assembly Connection to Heater Sleeve

6.3.3 Maximum Allowable Load Based on Sleeve/Pressurizer J-Weld Shear

$A_{Jweld} = \pi \cdot d \cdot w = 1.512 \text{ in}^2$

Where: d = heater sleeve outer diameter = 1.660 in., Reference 12A
w = minimum weld length in shear = 0.290 in., Reference 12B

$\tau = 0.1S_y$ = Maximum Shear Stress Allowable (Reference 9)

For Sleeve/Pressurizer J-Weld: $\tau_{Jw} = .1(35.0) = 3.5$ ksi $S_y = 35.0$ ksi minimum; Reference 2
Minimum Strength Heater Sleeve Material is SB-167, Reference 1

Since the heater sleeve material has the minimum S_y value, it is used in determining the maximum allowable load based on the available shear area:

$$F_{Jw} = \tau_{Jw} A_{Jweld}$$

$$F_{Jw} = 5.292 \text{ kips}$$

7.0 RESULTS/CONCLUSIONS

7.1 RESULTS

The objectives and their resolutions are presented below.

Objective (1): Establish the maximum permissible bolt/threaded rod load on the tapped holes in the pressurizer bottom head wall.

Resolution: The allowable maximum load, including preload during MNSA impacting, is limited by shear stress in the external threads of the bolt/threaded rod to $\mathbf{F_b} =$ **16.116·Le kips** where Le is the length of engagement. Values of the allowable bolt/threaded rod load for a range of expected minimum thread engagement lengths are shown in the table below:

Allowable Bolt Load versus Thread Engagement Length						
Le, in.	0.50	0.52	0.54	0.56	0.58	0.60
Fb, kips	8.06	8.38	8.70	9.02	9.35	9.67

Objective (2): Considering the tapped holes, show that the ASME Code area of reinforcement requirement for the Pressurizer heater sleeve penetration is maintained.

Resolution: For the standard MNSA installation for both nominal and oversized heater sleeve penetrations

Heater Sleeve MNSA, in the plane of the attachment holes:

For Outermost Heaterwells, Area Available = $\mathbf{5.113\ in^2}$ > Area Required = $\mathbf{4.910\ in^2}$

For Innermost Heaterwells, Area Available = $\mathbf{4.681\ in^2}$ > Area Required = $\mathbf{4.513\ in^2}$

Objective (3): Calculate the range of stress intensity in the vessel wall and compare to the ASME Code allowable of 3 Sm for primary plus secondary stresses.

Resolution: For the Pressurizer Heater Sleeve MNSA tapped holes

$\mathbf{SI_{MAX} = 26.6\ ksi < Allowable\ 3Sm = 80.1\ ksi}$

Objective (4): Demonstrate that the ASME Code fatigue usage factor allowable of 1.0 is not exceeded for the tapped holes.

Resolution: For the Pressurizer Heater Sleeve MNSA tapped holes

$\mathbf{\Sigma U_{MAX} = 0.453 < Allowable = 1.0}$

Objective (5): Establish the maximum permissible loads in the heater sleeve.

Resolution: For the two weld locations the allowable maximum shear load is limited to **6.85 kips** for the Heater/Sleeve weld and **5.29 kips** for the Heater/Pressurizer J-weld. The allowable maximum bearing load for the Heater/Sleeve weld is **15.765 kips**.

7.2 CONCLUSIONS

Acknowledging the assumptions stated in report Section 5.0 and following the limits stated above, the MNSAs can be attached to the pressurizer at all the heater wells and meets the ASME Code stress requirements.

8.0 REFERENCES

1. CENP Report No. CENC-1336, "Analytical Report for Arizona Unit No. 1 Pressurizer", August 1978.

   CENP Report No. CENC-1395, "Analytical Report for Arizona Unit No. 2 Pressurizer", August 1979.

   CENP Report No. CENC-1490, "Analytical Report for Arizona Unit No. 3 Pressurizer", October 1981.

2. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1989 Edition, No Addendum.

3. CENP Drawings:
   A. E-MNSAAPS-228-005, Rev.02, "Large Heater Sleeve MNSA – Outboard Heaters".
   B. E-MNSAAPS-228-006, Rev. 02, "Large Heater Sleeve MNSA – Inboard Heaters".
   C. C-MNSA-228-058, Rev. 01, "Socket Head Shoulder Screw – Outboard Heaters".
   D. C-MNSA-228-062, Rev. 01, "Long Threaded Rod – Outboard Heaters".
   E. C-MNSA-228-063, Rev. 01, "Short Threaded Rod – Outboard Heaters".
   F. C-MNSA-228-059, Rev. 01, "Socket Head Shoulder Screw – Inboard Heaters".
   G. C-MNSA-228-069, Rev. 01, "Long Threaded Rod – Inboard Heaters".
   H. C-MNSA-228-070, Rev. 01, "Short Threaded Rod – Inboard Heaters".

4. Mathcad 8.0, by Mathsoft, Inc., Cambridge, MA.

5. CENP Project Plan, V1-NOME-IPQP-0367, Rev. 0, "Mechanical Nozzle Seal Assemblies (MNSA) for PRZ Heater Sleeves.

6. USA Standard ASA-B1.1-1960, "Unified Screw Threads", 1960.

7. "Preloading of Bolts", by Bernie J. Cobb; Product Engineering, August 19, 1963.

8. Mark's "Standard Handbook for Mechanical Engineers, 8th Edition, 1978.

9. CENP Letter, "An Advisory concerning a Technical Development Related to the Application or Operation of Nuclear Plant Equipment Supplied by Combustion Engineering", with respect to Instrumentation Nozzle Welds, March 2, 1983.

10. CENP Report No. CR-9448-CSE91-1101, Rev. 1, "Acceptance Criteria for Florida Power and Light St. Lucie #1 and #2 Manway and Handhole Stud Hole Threads", Appendix C - "Good Bolting Practices", Volume 1 issued by EPRI - 3412 Hillview Avenue, Palo Alto, California 94304.

11. CENP Report No. TR-PENG-012, Rev. 00, "Test Report for Verification Testing of RTD Nozzle Seal Assembly", February 1, 1995.

12. CENP Drawings:

A. E-78373-641-001, Rev. 2, "Lower Vessel Assembly and Heater Holes, Arizona Public Service I 96" ID Pressurizer".
E-79373-641-001, Rev. 1, "Lower Vessel Assembly and Heater Holes, Arizona Public Service II 96" ID Pressurizer".
E-65373-641-001, Rev. 0, "Lower Vessel Assembly and Heater Holes, Arizona Public Service III 96" ID Pressurizer".

B. E-78373-641-002, Rev. 2, "Lower Vessel Final Assembly, Arizona Public Service I 96" ID Pressurizer".
E-79373-641-002, Rev. 2, "Lower Vessel Final Assembly, Arizona Public Service II 96" ID Pressurizer".
E-65373-641-002, Rev. 1, "Lower Vessel Final Assembly, Arizona Public Service III 96" ID Pressurizer".

C. E-78373-684-001, Rev. 2, "Instrument Nozzles and Heater Sleeves, Arizona Public Service I 96" ID Pressurizer".
E-79373-684-001, Rev. 0, "Instrument Nozzles and Heater Sleeves, Arizona Public Service II 96" ID Pressurizer".
E-65373-684-001, Rev. 1, "Instrument Nozzles and Heater Sleeves, Arizona Public Service III 96" ID Pressurizer".

D. C-STD-13-685-031, Rev. 0, "Heater Pressurizer".
C-STD-13-685-032, Rev. 0, "Heater Watlow Type Pressurizer".

13. Lotus Notes Memo from R. T. Johnson to K. V. Margotta on "Palo Verde Heater Sleeves", February 26, 2001 (copy in Attachment 2).

ATTACHMENT 1

1. Design Analysis Verification Checklist (4 pages).
2. Reviewer's Comment Form (1 page).

(Copies in Q. A. Records)

Design Analysis Verification Checklist

Instructions: If a major topic area (generally unnumbered, bold face type such as **Use of Computer Software**) is not applicable, then N/A (not applicable) next to the topic may be checked and the check boxes for all items under it may be left blank. Where there is no check box under N/A for a numbered item, such a response is generally inappropriate. If N/A is checked in such a situation, document the basis at the end of this checklist in the Comments section.

	Author		IR
Overall Assessment	Yes	N/A	Concur.
1. Are the results/conclusions correct and appropriate for their intended use?	☒		☒
2. Are all limitations and contingencies on the results/conclusions documented?	☒		☒
Assignment of Cognizant Engineers, Independent Reviewers and Mentors			
1. If there are multiple Cognizant Engineers, has their scope been documented?	☐	☒	☒
2. If there are multiple Independent Reviewers, has their scope been documented?	☐	☒	☒
3. If there will be multiple Management Approvers, has their scope been documented?	☐	☒	☒
4. If an Independent Reviewer is the supervisor or Project Manager, has authorization as an IR been documented?	☐	☒	☒
5. If there is a Mentor, has their scope and responsibilities been adequately documented?	☐	☒	☒
Use of Computer Software			
For software which has been validated under QP 3.13:		☒	☒
1. Is the software listed on an Approved QC-1 Software List?	☐		☐
2. Is the software applicable for this analysis?	☐		☐
For Code-Like Constructs validated under QP 3.14:		☒	☒
1. Is the Code-Like Construct listed on an Approved QC-1 Software List?	☐		☐
2. Is the Code-Like Construct applicable for this analysis?	☐	No	☐
3. Was the Code-Like Construct used directly in the controlled location?	☐	☐	☐
- If No above, is the copy identical to the version in the controlled location? (Leave blank if not applicable.)	☐		☐
4. If changes were made to a Code-Like Construct to meet specific analysis needs, were such changes documented as non-validated software following para. 3.3.3? (Leave blank if not applicable. Complete the next section if "Yes".)	☐		☐
For software excluding spreadsheets which has not been validated under QP 3.13 or QP 3.14:		☒	☒
1. Is the software identification documented?	☐		☐
2. Is a copy of the software included in the Design Analysis?	☐		☐
3. Have tests been documented which are adequate to demonstrate correct operation for the software's intended use?	☐		☐
4. Is the output from the tests included in the Design Analysis?	☐		☐
5. Has the Cognizant Engineer documented the results of the tests and the basis for concluding the software is operating correctly for its intended use?	☐		☐
6. Did the software, as used in this analysis, give correct results?	☐		☐
For spreadsheets which have not been validated under QP 3.13 or QP 3.14:		☒	☒
1. Were spreadsheets used in this Design Analysis in any way – data display, plotting, computations, etc.?	☐	No ☐	☐
- If data display only (no computations or plotting), check "Yes" and skip remaining sub-questions.	☐	☐	☐

Design Analysis Verification Checklist

	Author		IR
Use of Computer Software (continued)	Yes	N/A	Concur.
- If used for computations:	☐	☐	☐
• Are the computations adequately documented and are the results correct?	☐		☐
- If used for plotting:	☐	☐	☐
• Is the data to be plotted correct?	☐		☐
• Are the plots correct in other respects? (titles, scales, labels, etc.)	☐		☐
2. Have tests been documented which are adequate to demonstrate correct operation for the spreadsheet's intended use?	☐		☐
3. Is the output from the tests included in the Design Analysis?	☐		☐
4. Has the Cognizant Engineer documented the results of the tests and the basis for concluding the spreadsheet is operating correctly for its intended use?	☐		☐
5. Has a copy of the spreadsheet file been included in the Design Analysis or has sufficient detail been included in the analysis documentation to permit recreating the spreasdsheet?	☐		☐
Use of software with uncorrected errors:		☒	☒
1. Does any of the software used have uncorrected errors?	☐	☐	☐
2. If yes, is the software identified and documented and has the impact of use been evaluated and documented? (No impact on this analysis)	☐	☐	☐
Objective of the Design Analysis			
1. Has information necessary to define the task been included or referenced?	☒		☒
2. Have the objectives been enumerated?	☒		☒
3. Has the applicability and intended use of the results been documented?	☒		☒
Assessment of Significant Design Changes			
1. Have significant design-related changes that might impact this analysis been considered?	☒		☒
2. If any such changes have been identified, have they been adequately addressed?	☐	☒	☒
Analytical Techniques (Methods)			
1. Are the analytical techniques (methods) described in sufficient detail to judge their appropriateness?	☒	No	☒
3. Are the analytical techniques used or their application governed by an NRC issued SER?	☐	☒	☒
If yes, have the applicable SERs been documented?	☐		☐
If yes, has the basis for concluding the analysis is in conformance been documented?	☐		☐
3. Have analytical techniques incorporated by reference to generic, lead plant or previous cycle analyses been previously verified?	☐	☒	☒
4. Are any modifications or departures from previously approved analytical techniques or Conventional or Automated Procedures documented and justified?	☐	☒	☒
5. If superseded approved analytical techniques or engineering procedures are used, is their use justified and approved?	☐	☒	☒
6. Does the issue date of referenced approved Conventional or Automated Procedures predate their use in this analysis?	☐	☒	☒
Selection of Design Inputs			
1. Are the design inputs documented?	☒		☒
2. Are the design inputs correctly selected and traceable to their source?	☒		☒
3. Are the bases for selection of all design inputs documented?	☒	No	☒
4. Is previously unverified design input used in this analysis?	☐	☒	☒
If Yes, is it treated in accordance with QP 3.2, paragraph 3.4 for use of unverified design information?	☐		☐

Design Analysis Verification Checklist

Selection of Design Inputs (continued)	Author Yes	Author N/A	IR Concur.
5. Is the verification status of design inputs transmitted from customers or Nuclear Systems appropriate and documented?	☐	☒	☒
6. Is the use of customer-controlled sources such as Tech Specs, UFSARs, etc. authorized, and does the authorization specify amendment level, revision number, etc.?	☐	☒	☒
Assumptions			
1. If there are no assumptions, is this documented?	☐	☒	☒
2. Are local assumptions documented, fully justified and verified?	☒	☐	☒
3. Are Internal and External Assumptions which must be cleared by CENP or the customer listed on a Contingencies and Assumptions form?	☐	☒	☒
4. Is the Project Manager responsible for clearing the Assumptions identified on the form?	☐	☒	☒
Results/Conclusions			
1. Are all results contained in or referenced in the Results/Conclusion section? (Where feasible, in the enumerated order of the objectives.)	☒		☒
2. Are all limitations on the results/conclusions and their applicability documented in this section?	☒		☒
3. Are all contingencies on the results that must be cleared listed in the Results/Conclusion section or the Contingencies and Assumptions form referenced?	☐	☒	☒
4. Is the Project Manager responsible for clearing the Assumptions or Contingencies identified on the form?	☐	☒	☒
Other Elements			
1. Has a comparison of the results with those of a previous cycle or similar analysis been documented and significant differences explained?	☐	☒	☒
2. Have applicable Codes (e.g., ASME Code) and standards been appropriately referenced and applied?	☒	☐	☒
3. Is the information from relevant literature searches/background data adequately documented and referenced?	☒	☐	☒
4. Are hand calculations correct and appropriately documented?	☒	☐	☒
5. Is all applicable computer output and input included?	☐	☒	☒
6. Is all computer software used identified by name and revision identification?	☐	☒	☒
References			
1. Are all references used to perform the analysis listed?	☒	☐	☒
2. Are the references as direct as possible and appropriate to the source?	☒		☒
3. Is the reference notation specific to the information utilized, including revision level or date of issue, and where appropriate, identification of the location of the information in the reference, such as page, table or paragraph number?	☒		☒

Independent Reviewer's Statement of Verification Activities:

The IR should describe details of verification activities beyond the obvious on this checklist including, but not limited to the review of new methods, use of software under para. 3.3.3, spreadsheet use, assessment of design and methodology changes, engineering judgments, and use of previously unverified inputs

Checklist Completed by Independent Reviewer: J. G. Thakkar (Printed Name) — J. G. Thakkar (Signature) — 2/28/2001 (Date)

Design Analysis Verification Checklist

The Form and Format section of the Checklist below may be completed by a Checker under the direction of the Independent Reviewer.

Form/Format	Author Yes	Author N/A	IR Concur.
1. Is the document legible, reproducible and in a form suitable for filing and retrieving as a Quality Record?	☒		☒
2. Except as permitted by 3.1.3.a, are all pages identified with the document number, including revision number?	☒		☒
3. Except as permitted by 3.1.3.a, do all pages have a unique page number?	☒		☒
4. Are all computer disks identified with the analysis number?	☐	☒	☒
5. Are any unverified sections of an otherwise verified analysis clearly indicated?	☐	☒	☒
For a revision to a completed analysis in the "Complete Revision" and "Page Change Package" formats:		☐	☐
1. Where practical, have changes and additions been identified by mechanisms such as vertical lines, etc.?	☒		☒
2. Where practical, have deletions been identified by mechanisms such as strike outs, etc.?	☐	☒	☒
3. Have indications of change in previous revisions been removed?	☒		☒
4. Does the distribution of the revision include those on the distribution of the previous revision?	☒		☒
For a "Complete Revision":		☒	☒
1. Have the title and document number been preserved without change?	☐		☐
2. Has the revision number been incremented by one?	☐		☐
For a "Page Change Package":		☐	☐
1. Are pages numbered in accordance with the original analysis?	☒		☒
2. Are instructions provided for the insertion and deletion of revised pages? Fully assembled report is provided.	☒		☒
3. Has a new Title Page been prepared?	☒		☒
4. Does the Package Contents Page reflect the change package contents?	☒		☒

☒ Form/Format section completed by the Independent Reviewer.

☐ Form/Format section completed by the Checker identified below:

Checker Name: ____________________ Signature: ____________________

Reviewer's Comment Form

Page 1 of 1

Title: Evaluation of Attachement Locations for Mechanical Nozzle Seal Assemblies on Arizona Public Service Palo Verde Units 1, 2, and 3 Pressurizer Heater Sleeves

Document Number: A-PVNGS-9449-1259 Revision Number: 01

Comment Number	Reviewer's Comment	Response Required?	Author's Response	Response Accepted?
1.	Editorial P. 6 &21: Include a statement	NO.	CLARIFICATION MADE	Yes
	clarifying the reinforcement area requirements for nominal size			
	penetration is envelope			
2.	Fully Assembled report is included	NO	NOTE ADDED.	Yes

ATTACHMENT 2

REFERENCES

13. Lotus Notes Memo from R. T. Johnson to K. V. Margotta on "Palo Verde Heater Sleeves", February 26, 2001.

(Copies in Q. A. Records)

Robert T. Johnson/CENO/USNUS/BNFL-TEMP
02/26/2001 09:41 AM (Phone: +423-752-2270, Dept.: FIELD QUALITY OPERATIONS)

To: Kenneth V. Margotta/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
cc: John T. McGarry/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS, Attila Z. Szabo/CENO/USNUS/BNFL-TEMP@ABB_USSEV_IMS
Subject: Re: Palo Verde Heater Sleeves

Security Level:? Internal

Palo Verde Pzr heater sleeve penetration is as follows:

Unit 1-Penetrations A-5 & A-7 have oversize sleeves 1.675 +.000 -.002 diameter.
Unit 2- All penetrations and sleeves standard dia.
Unit 3- All penetrations and sleeves standard dia.

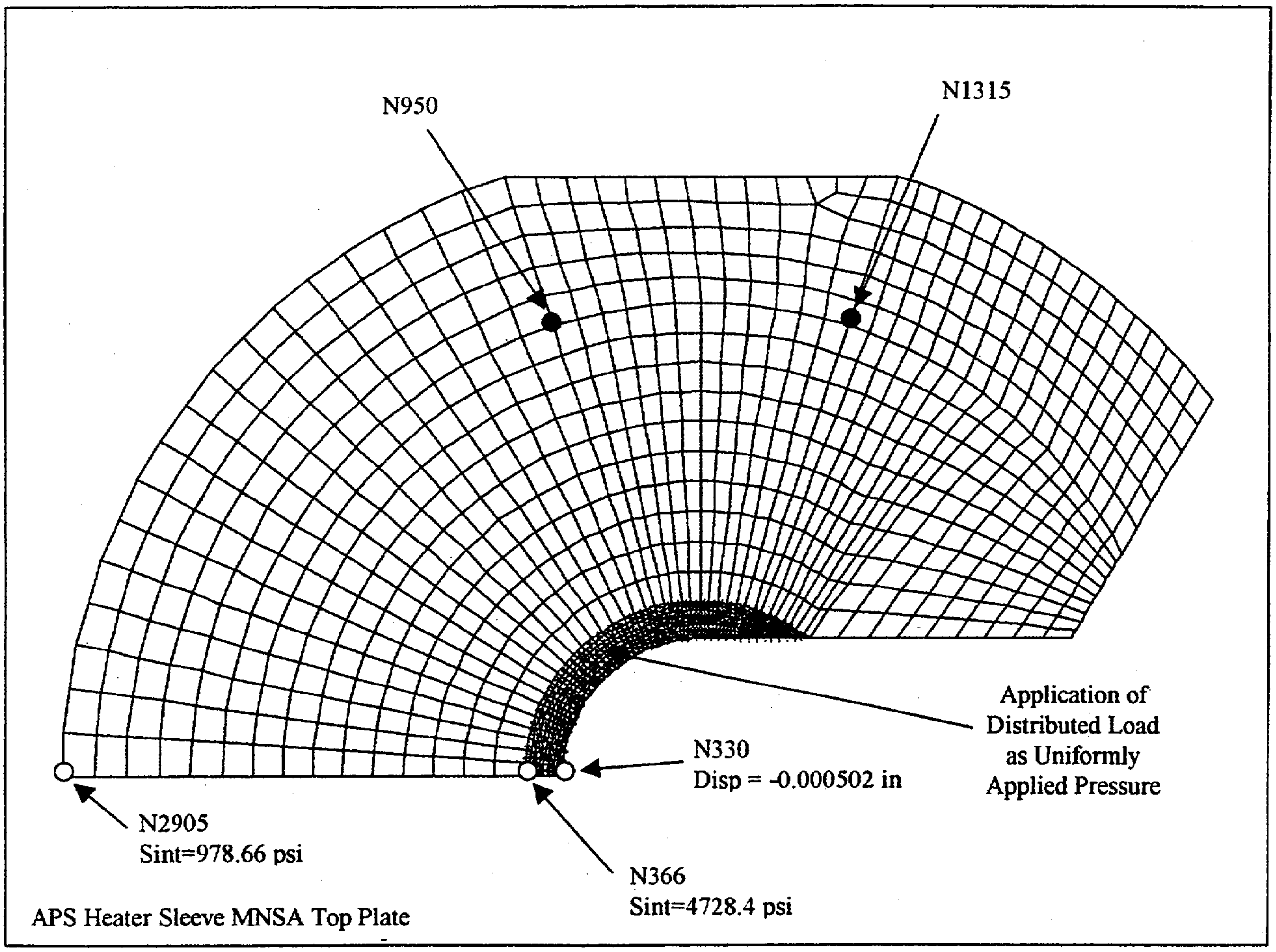
ATTACHMENT C

ANSYS EVALUATION OF PRESSURIZER HEATER SLEEVE TOP PLATE

This Attachment contains the figure of the ANSYS model used to obtain the stiffness and the stresses of the MNSA top plate, as well as the resulting output file from the computer run. The output file printed here contains an echo print of the input file used.

FIGURE C1.

Element Plot of ANSYS Pressurizer Heater Sleeve Top Plate Model



ANSYS OUTPUT FILE

```
    oooo                oooo                oooo
   oooooo              oooooo              oooooo
  oooooooo            oooooooo            oooooooo
   oooooo              oooooo              oooooo
    oooo                oooo                oooo
     WW                 WWWW                 WW
      WW               WW  WW               WW
       WW             WW    WW             WW
        WW           WW      WW           WW
         WW         WW        WW         WW
          WW       WW          WW       WW
           WW     WW            WW     WW
            WW   WW              WW   WW
             WWW                  WWW
              W                    W

           ****************************
          ******************************
           ****************************


                   *
                    **
                     ****
                      ****
COMBUSTION             ****   ENGINEERING
                        **
   NUCLEAR              *          POWER
                       *
                      *
                     *

======================================================================
 E N G I N E E R I N G   C O M P U T I N G   E N V I R O N M E N T
======================================================================
```

```
Date/Time       : Tue Feb 27 17:34:40 EST 2001

User            : schmidt
Group           : v9421me
Project,Task    : default_charge

Job Id          : 2d3i8xt3
Job Name        : 2d3i8xt3
```

```
         Node Name     : twister
         Cpu Type      : HP-UX

         Process ID    : 21186
         Priority      : 8

         Submit Node   : tornado
         Directory     : twister:/PS/schmidt/bn/crs
1

 Job Stream Commands From the File:  twister:/PS/schmidt/bn/crs/sub_2c

     1  ansys55 -m 48 < aps_heater_2c
1

 *-------------------------------------------------------------*
 |                                                             |
 |   W E L C O M E   T O   T H E   A N S Y S   P R O G R A M   |
 |                                                             |
 *-------------------------------------------------------------*
```

```
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ANSYS/Mechanical U

AFTER YOU HAVE READ, UNDERSTOOD, AND AGREED TO THE PREVIOUS NOTICES,
PRESS <CR> OR <ENTER> TO CONTINUE


         *****  ANSYS COMMAND LINE ARGUMENTS  *****
 MEMORY REQUESTED (MB)          = 48

*** NOTE ***                              CP=       0.740   TIME= 17:34:44
There are no parameters defined.

00044163          VERSION=HPPA 7/8XXX     RELEASE= 5.5.2   UP19990107
CURRENT JOBNAME=file  17:34:44  FEB 27, 2001 CP=       0.750


RUN SETUP PROCEDURE FROM FILE= /ansys55/docu/start55.ans


/INPUT FILE= /ansys55/docu/start55.ans  LINE=       0

BEGIN:
      /BATCH,list
      ! aps.inp
      ! Non-standard plate for MNSA
      /filnam,c2c
      /PREP7
      /TITLE,APS Heater Sleeve MNSA Top Plate - Case 2c

      !Variables
      R1=0.65            ! IR of center hole
      !R2=0.83    ! radius of APS
      R2=1.66/2   ! radius for applied force
      R3=4.50/2   ! bolt center radius
      R4=6.00/2   ! OR of plate
      th=0.75            ! plate thickness

      !Materials
      MPTEMP,1,100,200,300,400,500,600
      ! S.S. TYPE 304, 1989 ASME
      MPDATA,ALPX,1,,8.55E-6,8.79E-6,9.00E-6,9.19E-6,9.37E-6,9.53E-6
      MPDATA,EX,1,,28.1E6,27.6E6,27.0E6,26.5E6,25.8E6,25.3E6
      TREF,70

      !Graphical options
      /pnum,area,1
      /pnum,line,1
      /triad,lbot
```

```
!Elements —
ET,1,SHELL93
R,1,th
R,2,th-.25
eshape,3
esize,.15


!Geometry
K,1,0,0,1
K,2,0,0,0
K,3,R1
K,4,R2
K,5,R3
K,6,R4
L,2,3
L,3,4
L,4,5
L,5,6
AROTAT,1,2,3,4,,,1,2,-(90-18)
AROTAT,5,6,7,8,,,1,2,-18
AROTAT,13,14,15,16,,,1,2,-18
AROTAT,21,22,23,24,,,1,2,-(90-18)
ADELE,1,5,4

!Make rectangle to subtract
K,50,R4+1
L,2,50
*get,know_l,line,,num,max
ADRAG,13,,,,,,know_l

! remove slot
AGEN,2,1                ! MAKES A5
ASBA,2,5                ! MAKES A17
AGEN,2,1                ! MAKES A2
ASBA,3,2                ! MAKES A5
AGEN,2,1                ! MAKES A2
ASBA,4,2                ! MAKES A3
ASBA,6,1                ! MAKES A5
! remove 60-deg "corners" from end of slot
L1=1.75
k,100,L1,R1
k,101,R4,R1+(R4-L1)*1.73205    ! 1.73205=tan 60-deg
k,102,R4,R1
a,100,101,102
AGEN,2,1
ASBA,5,1
ASBA,3,4

! delete semi-circle
adele,9,13,4
! merge all "labels"
nummrg,all

!delete section on outer edge of plate
adele,8,12,4
ldele,16
l,10,18
a,9,13,17,18,10

! merge all "labels"
nummrg,all
```

```
! ready for meshing

asel,all
lesize,30,,,8
lesize,47,,,8
lesize,33,,,18
lesize,25,,,6
lesize,3,,,6
lccat,38,43

real,2
asel,s,area,,2,10,8
asel,a,area,,14,17,3

! used later to determine applied pressure loading
asum
*get,ainner,area,,area

amesh,all
allsel
real,1
asel,s,area,,1,3,2
asel,a,area,,6,7
asel,a,area,,11,15,4
asel,a,area,,16
amesh,all
allsel

!Apply B.C.
!symmetry
lsel,,,,30,32
nsll,s,1
DSYM,symm,y,0

!fix bolt locations
ksel,s,,,9,17,8
nslk,s
d,all,all

allsel,all

!solution - apply load
/solu
antype,static
outres,all,all

! apply pressure load totaling 500# to inner areas
! area was determined during meshing

asel,s,area,,2,10,8
asel,a,area,,14,17,3
sfa,all,1,pres,500/ainner

allsel
solve
!post-process results
/post1
/page,300,,300
set
!these are the nodes with displacements more than 0.0001
nsel,s,u,z,-0.001,-0.0001
prnsol,u,z
allsel
```

```
!these are the stress for nodes on the symmetry line
lsel,s,,,30,32
nsll,s,1
prnsol,s,prin
shell,bot
prnsol,s,prin
allsel
!these are the reaction forces at the tie rod locations
prrsol,fz
finish
```

```
 CURRENT JOBNAME REDEFINED AS c2c
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163           VERSION=HPPA 7/8XXX   17:34:45  FEB 27, 2001 CP=       0.850



         ***** ANSYS ANALYSIS DEFINITION (PREP7) *****

 TITLE=
 APS Heater Sleeve MNSA Top Plate - Case 2c


 PARAMETER R1       =     0.6500000

 PARAMETER R2       =     0.8300000

 PARAMETER R3       =      2.250000

 PARAMETER R4       =      3.000000

 PARAMETER TH       =     0.7500000

 *** PROPERTY TEMPERATURE TABLE    NUM. TEMPS=  6 ***
 SLOC=    1      100.0000      200.0000      300.0000
                 400.0000      500.0000      600.0000

 PROPERTY TABLE ALPX  MAT=    1  NUM. POINTS=  6
 SLOC=    1     0.8550000E-05 0.8790000E-05 0.9000000E-05 0.9190000E-05
                0.9370000E-05 0.9530000E-05

 PROPERTY TABLE EX    MAT=    1  NUM. POINTS=  6
 SLOC=    1     0.2810000E+08 0.2760000E+08 0.2700000E+08 0.2650000E+08
                0.2580000E+08 0.2530000E+08

 REFERENCE TEMPERATURE=  70.000  (TUNIF=  70.000)

 AREA NUMBERING KEY =  1

 LINE NUMBERING KEY =  1
 XYZ TRIAD DISPLAY SET TO LEFT BOTTOM

 ELEMENT TYPE       1 IS SHELL93       8-NODE STRUCTURAL SHELL
  KEYOPT(1-12)=     0  0  0     0  0  0     0  0  0     0  0  0

 CURRENT NODAL DOF SET IS  UX     UY     UZ     ROTX  ROTY  ROTZ
  THREE-DIMENSIONAL MODEL

 REAL CONSTANT SET        1  ITEMS     1 TO     6
```

```
  0.75000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

REAL CONSTANT SET       2  ITEMS     1 TO     6
  0.50000       0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00

FOR ELEMENT TYPE(S) ALLOWING MULTIPLE SHAPES:
     PRODUCE ALL QUADRILATERAL OR BRICK ELEMENTS IF POSSIBLE.
     OTHERWISE PRODUCE MIXED ELEMENT SHAPES.

DEFAULT ELEMENT DIVISIONS PER LINE BASED ON ELEMENT SIZE =  0.150

KEYPOINT      1   X,Y,Z=  0.000000E+00  0.000000E+00   1.00000      IN CSYS=  0

KEYPOINT      2   X,Y,Z=  0.000000E+00  0.000000E+00  0.000000E+00  IN CSYS=  0

KEYPOINT      3   X,Y,Z=  0.650000      0.000000E+00  0.000000E+00  IN CSYS=  0

KEYPOINT      4   X,Y,Z=  0.830000      0.000000E+00  0.000000E+00  IN CSYS=  0

KEYPOINT      5   X,Y,Z=   2.25000      0.000000E+00  0.000000E+00  IN CSYS=  0

KEYPOINT      6   X,Y,Z=   3.00000      0.000000E+00  0.000000E+00  IN CSYS=  0

LINE CONNECTS KEYPOINTS       2     3
 LINE NO.=      1  KP1=       2  TAN1=   -1.0000   0.0000   0.0000
                   KP2=       3  TAN2=    1.0000   0.0000   0.0000

LINE CONNECTS KEYPOINTS       3     4
 LINE NO.=      2  KP1=       3  TAN1=   -1.0000   0.0000   0.0000
                   KP2=       4  TAN2=    1.0000   0.0000   0.0000

LINE CONNECTS KEYPOINTS       4     5
 LINE NO.=      3  KP1=       4  TAN1=   -1.0000   0.0000   0.0000
                   KP2=       5  TAN2=    1.0000   0.0000   0.0000

LINE CONNECTS KEYPOINTS       5     6
 LINE NO.=      4  KP1=       5  TAN1=   -1.0000   0.0000   0.0000
                   KP2=       6  TAN2=    1.0000   0.0000   0.0000

ROTATE LINES       1,      2,      3,      4,
     ABOUT THE AXIS DEFINED BY KEYPOINTS       1      2
    DEGREES OF ARC=   -72.00   NUMBER OF SEGMENTS=   1

ROTATE LINES       5,      6,      7,      8,
     ABOUT THE AXIS DEFINED BY KEYPOINTS       1      2
    DEGREES OF ARC=   -18.00   NUMBER OF SEGMENTS=   1

ROTATE LINES      13,     14,     15,     16,
     ABOUT THE AXIS DEFINED BY KEYPOINTS       1      2
    DEGREES OF ARC=   -18.00   NUMBER OF SEGMENTS=   1

ROTATE LINES      21,     22,     23,     24,
     ABOUT THE AXIS DEFINED BY KEYPOINTS       1      2
    DEGREES OF ARC=   -72.00   NUMBER OF SEGMENTS=   1

DELETE SELECTED AREAS FROM       1 TO       5 BY       4

    DELETED    2 AREAS

KEYPOINT     50   X,Y,Z=   4.00000      0.000000E+00  0.000000E+00  IN CSYS=  0

LINE CONNECTS KEYPOINTS       2    50
 LINE NO.=     37  KP1=       2  TAN1=   -1.0000   0.0000   0.0000
```

```
KP2=      50  TAN2=    1.0000    0.0000    0.0000

*GET  know_1    FROM  LINE  ITEM=NUM  MAX   VALUE=  37.0000000

DRAG LINES:
   13,
     ALONG LINES
   37,

GENERATE      2 TOTAL SETS OF AREAS
  SET IS FROM      1 TO      1 IN STEPS OF     1
  DX,DY,DZ=   0.000E+00   0.000E+00   0.000E+00       CSYS=  0

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =          2
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =          5
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =     17

GENERATE      2 TOTAL SETS OF AREAS
  SET IS FROM      1 TO      1 IN STEPS OF     1
  DX,DY,DZ=   0.000E+00   0.000E+00   0.000E+00       CSYS=  0

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =          3
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =          2
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =      5

GENERATE      2 TOTAL SETS OF AREAS
  SET IS FROM      1 TO      1 IN STEPS OF     1
  DX,DY,DZ=   0.000E+00   0.000E+00   0.000E+00       CSYS=  0

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =          4
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =          2
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =      3

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =          6
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =          1
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =      2

PARAMETER L1        =      1.750000

KEYPOINT    100    X,Y,Z=    1.75000      0.650000      0.000000E+00  IN CSYS=  0

KEYPOINT    101    X,Y,Z=    3.00000       2.81506      0.000000E+00  IN CSYS=  0

KEYPOINT    102    X,Y,Z=    3.00000      0.650000      0.000000E+00  IN CSYS=  0

DEFINE AREA BY LIST OF KEYPOINTS
  KEYPOINT LIST =     100    101    102
```

```
    AREA NUMBER =        1

GENERATE      2 TOTAL SETS OF AREAS
  SET IS FROM      1 TO      1 IN STEPS OF      1
  DX,DY,DZ=   0.000E+00   0.000E+00   0.000E+00       CSYS=  0

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =        5
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =        1
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =     6

SUBTRACT AREAS

     AREA NUMBERS TO BE OPERATED ON =        3
     AREAS OPERATED ON WILL BE DELETED
     AREA NUMBERS TO BE SUBTRACTED  =        4
     AREAS SUBTRACTED WILL BE DELETED
     OUTPUT AREAS =     1

DELETE SELECTED AREAS FROM      9 TO     13 BY      4

    DELETED    2 AREAS

 MERGE COINCIDENT NODES WITHIN TOLERANCE OF  0.10000E-03

MERGE IDENTICAL MATERIALS WITHIN TOLERANCE OF  0.10000E-06

MERGE IDENTICAL ELEMENT TYPES

MERGE IDENTICAL REAL CONSTANT SETS WITHIN TOLERANCE OF  0.10000E-06
ZERO REAL CONSTANT SETS WERE MERGED

MERGE IDENTICAL ELEMENTS

MERGE IDENTICAL COUPLED DOF SETS

MERGE IDENTICAL CONSTRAINT EQUATIONS WITHIN TOLERANCE OF 0.10000E-06

MERGE COINCIDENT KEYPOINTS WITHIN TOLERANCE OF  0.10000E-03
KEYPOINT      4 USED FOR KEYPOINT(S)      29
KEYPOINT     24 USED FOR KEYPOINT(S)      25
KEYPOINT     30 USED FOR KEYPOINT(S)      31
LINE      2 USED FOR LINE(S)      45
LINE      4 USED FOR LINE(S)      17
LINE     43 USED FOR LINE(S)      46

DELETE SELECTED AREAS FROM      8 TO     12 BY      4

    DELETED    2 AREAS

DELETE SELECTED LINES FROM     16 TO     16 BY    1

    DELETED     1 LINES

LINE CONNECTS KEYPOINTS     10    18
 LINE NO.=     10  KP1=     10  TAN1=    1.0000    0.0000    0.0000
                   KP2=     18  TAN2=   -1.0000    0.0000    0.0000

DEFINE AREA BY LIST OF KEYPOINTS
```

```
  KEYPOINT LIST =     9    13    17    18    10

    AREA NUMBER =     3

 MERGE COINCIDENT NODES WITHIN TOLERANCE OF  0.10000E-03

MERGE IDENTICAL MATERIALS WITHIN TOLERANCE OF  0.10000E-06

MERGE IDENTICAL ELEMENT TYPES

MERGE IDENTICAL REAL CONSTANT SETS WITHIN TOLERANCE OF  0.10000E-06
ZERO REAL CONSTANT SETS WERE MERGED

MERGE IDENTICAL ELEMENTS

MERGE IDENTICAL COUPLED DOF SETS

MERGE IDENTICAL CONSTRAINT EQUATIONS WITHIN TOLERANCE OF 0.10000E-06

MERGE COINCIDENT KEYPOINTS WITHIN TOLERANCE OF  0.10000E-03

ALL SELECT    FOR ITEM=AREA COMPONENT=
 IN RANGE        1 TO        17 STEP        1

   11  AREAS (OF    11  DEFINED) SELECTED BY ASEL COMMAND.

SET DIVISIONS ON LINE    30 (IF SELECTED AND UNMESHED)
     TO  NDIV =     8,  SPACING RATIO =    1.000

SET DIVISIONS ON LINE    47 (IF SELECTED AND UNMESHED)
     TO  NDIV =     8,  SPACING RATIO =    1.000

SET DIVISIONS ON LINE    33 (IF SELECTED AND UNMESHED)
     TO  NDIV =    18,  SPACING RATIO =    1.000

SET DIVISIONS ON LINE    25 (IF SELECTED AND UNMESHED)
     TO  NDIV =     6,  SPACING RATIO =    1.000

SET DIVISIONS ON LINE     3 (IF SELECTED AND UNMESHED)
     TO  NDIV =     6,  SPACING RATIO =    1.000

CONCATENATE LINES
     LINES =    38   43

COMPOSITE LINE NO.=    11  KP1=    100  KP2=      8

REAL CONSTANT NUMBER=        2

SELECT        FOR ITEM=AREA COMPONENT=
 IN RANGE        2 TO        10 STEP        8

    2  AREAS (OF    11  DEFINED) SELECTED BY  ASEL  COMMAND.

ALSO SELECT   FOR ITEM=AREA COMPONENT=
 IN RANGE       14 TO        17 STEP        3

    4  AREAS (OF    11  DEFINED) SELECTED BY ASEL  COMMAND.

PRINT GEOMETRY ITEMS ASSOCIATED WITH THE CURRENTLY SELECTED AREAS

*** NOTE ***                             CP=       3.000   TIME= 17:34:47
Density not associated with all selected areas.  Geometry items are
 based on a unit density.
```

```
 TOTAL NUMBER OF AREAS SELECTED =      4  (OUT OF     11 DEFINED)

 TOTAL SURFACE AREA OF ALL SELECTED AREAS =  0.27265

 TOTAL VOLUME OF ALL SELECTED AREAS =  0.27265

 CENTROID:  XC=-0.31755      YC= 0.53141      ZC= 0.00000E+00

                   *** MOMENTS OF INERTIA ***
         (BASED ON A UNIT DENSITY AND A UNIT THICKNESS)

          ABOUT ORIGIN      ABOUT CENTROID       PRINCIPAL
   IXX =   0.91400E-01       0.14406E-01       0.38531E-02
   IYY =   0.61609E-01       0.34115E-01       0.44668E-01
   IZZ =   0.15301           0.48521E-01       0.48521E-01
   IXY =   0.28138E-01      -0.17871E-01
   IYZ =   0.00000E+00       0.00000E+00
   IZX =   0.00000E+00       0.00000E+00

   PRINCIPAL ORIENTATION VECTORS (X,Y,Z):
     0.861  0.508  0.000   -0.508  0.861  0.000    0.000  0.000  1.000
     (THXY=   30.563  THYZ=    0.000  THZX=    0.000)

*GET  ainner    FROM  AREA  ITEM=AREA       VALUE= 0.272648197

GENERATE NODES AND ELEMENTS   IN  ALL  SELECTED AREAS
   ** AREA     2 MESHED WITH    48 QUADRILATERALS,      0 TRIANGLES **
   ** AREA    10 MESHED WITH    48 QUADRILATERALS,      0 TRIANGLES **
   ** AREA    14 MESHED WITH   144 QUADRILATERALS,      0 TRIANGLES **
   ** AREA    17 MESHED WITH    48 QUADRILATERALS,      0 TRIANGLES **

NUMBER OF AREAS MESHED      =         4
MAXIMUM NODE NUMBER         =       949
MAXIMUM ELEMENT NUMBER      =       288

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT    FOR ITEM=VOLU COMPONENT=
 IN RANGE        0 TO         0 STEP        1

     0  VOLUMES (OF      0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT    FOR ITEM=AREA COMPONENT=
 IN RANGE        1 TO        17 STEP        1

    11  AREAS (OF     11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT    FOR ITEM=LINE COMPONENT=
 IN RANGE        1 TO        49 STEP        1

    38  LINES (OF     38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT    FOR ITEM=KP   COMPONENT=
 IN RANGE        1 TO       102 STEP        1

     25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT    FOR ITEM=ELEM COMPONENT=
 IN RANGE        1 TO       288 STEP        1

     288  ELEMENTS (OF      288  DEFINED) SELECTED BY  ESEL  COMMAND.
```

```
ALL SELECT   FOR ITEM=NODE COMPONENT=
 IN RANGE       1 TO      949 STEP        1

     949  NODES (OF      949  DEFINED) SELECTED BY NSEL  COMMAND.

REAL CONSTANT NUMBER=         1

SELECT       FOR ITEM=AREA COMPONENT=
 IN RANGE       1 TO        3 STEP        2

    2  AREAS (OF    11  DEFINED) SELECTED BY  ASEL  COMMAND.

ALSO SELECT  FOR ITEM=AREA COMPONENT=
 IN RANGE       6 TO        7 STEP        1

    4  AREAS (OF    11  DEFINED) SELECTED BY ASEL  COMMAND.

ALSO SELECT  FOR ITEM=AREA COMPONENT=
 IN RANGE      11 TO       15 STEP        4

    6  AREAS (OF    11  DEFINED) SELECTED BY ASEL  COMMAND.

ALSO SELECT  FOR ITEM=AREA COMPONENT=
 IN RANGE      16 TO       16 STEP        1

    7  AREAS (OF    11  DEFINED) SELECTED BY ASEL  COMMAND.

GENERATE NODES AND ELEMENTS   IN  ALL  SELECTED AREAS
   ** AREA     1 MESHED WITH   102 QUADRILATERALS,       0 TRIANGLES **
   ** AREA     3 MESHED WITH    63 QUADRILATERALS,       0 TRIANGLES **
   ** AREA     6 MESHED WITH   170 QUADRILATERALS,       0 TRIANGLES **
   ** AREA     7 MESHED WITH    60 QUADRILATERALS,       0 TRIANGLES **
   ** AREA    11 MESHED WITH    60 QUADRILATERALS,       0 TRIANGLES **
   ** AREA    15 MESHED WITH   180 QUADRILATERALS,       0 TRIANGLES **
   ** AREA    16 MESHED WITH    90 QUADRILATERALS,       0 TRIANGLES **

NUMBER OF AREAS MESHED      =         7
MAXIMUM NODE NUMBER         =      3174
MAXIMUM ELEMENT NUMBER      =      1013

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT   FOR ITEM=VOLU COMPONENT=
 IN RANGE       0 TO        0 STEP        1

     0  VOLUMES (OF      0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT   FOR ITEM=AREA COMPONENT=
 IN RANGE       1 TO       17 STEP        1

   11  AREAS (OF    11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT   FOR ITEM=LINE COMPONENT=
 IN RANGE       1 TO       49 STEP        1

   38  LINES (OF    38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT   FOR ITEM=KP   COMPONENT=
 IN RANGE       1 TO      102 STEP        1

    25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT   FOR ITEM=ELEM COMPONENT=
```

```
 IN RANGE        1 TO      1013 STEP        1

    1013  ELEMENTS (OF     1013  DEFINED) SELECTED BY  ESEL  COMMAND.

ALL SELECT    FOR ITEM=NODE COMPONENT=
 IN RANGE        1 TO      3174 STEP        1

    3174  NODES (OF     3174  DEFINED) SELECTED BY NSEL  COMMAND.

SELECT        FOR ITEM=LINE COMPONENT=
 IN RANGE       30 TO        32 STEP        1

    3  LINES (OF    38  DEFINED) SELECTED BY LSEL  COMMAND.

SELECT       ALL NODES (INTERIOR TO LINE, AND AT KEYPOINTS)
       RELATED TO SELECTED LINE SET.

      47  NODES (OF     3174  DEFINED) SELECTED FROM
       3 SELECTED LINES BY NSLL COMMAND.

SYMMETRY CONSTRAINTS FOR COORDINATE SYSTEM  0 IN DIRECTION   Y
ON SURFACE DEFINED BY ALL SELECTED NODES

*** NOTE ***                               CP=      4.500   TIME= 17:34:48
Nodes on symmetry surfaces are rotated into coordinate system 0.

TOTAL SPECIFIED CONSTRAINTS=   141

SELECT        FOR ITEM=KP   COMPONENT=
 IN RANGE        9 TO        17 STEP        8

     2  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

SELECT       NODES ASSOCIATED WITH SELECTED KEYPOINTS

       2  NODES (OF     3174  DEFINED) SELECTED FROM
       2 SELECTED KEYPOINTS BY  NSLK  COMMAND.

SPECIFIED CONSTRAINT UX   FOR SELECTED NODES        1 TO    3174 BY        1
REAL= 0.000000000E+00   IMAG= 0.000000000E+00
ADDITIONAL DOFS=  UY    UZ     ROTX  ROTY  ROTZ

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT    FOR ITEM=VOLU COMPONENT=
 IN RANGE        0 TO         0 STEP        1

     0  VOLUMES (OF      0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT    FOR ITEM=AREA COMPONENT=
 IN RANGE        1 TO        17 STEP        1

   11  AREAS (OF    11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT    FOR ITEM=LINE COMPONENT=
 IN RANGE        1 TO        49 STEP        1

   38  LINES (OF    38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT    FOR ITEM=KP   COMPONENT=
 IN RANGE        1 TO       102 STEP        1

    25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.
```

```
ALL SELECT   FOR ITEM=ELEM COMPONENT=
 IN RANGE       1 TO     1013 STEP        1

    1013  ELEMENTS (OF     1013  DEFINED) SELECTED BY  ESEL  COMMAND.

ALL SELECT   FOR ITEM=NODE COMPONENT=
 IN RANGE       1 TO     3174 STEP        1

    3174  NODES (OF     3174  DEFINED) SELECTED BY NSEL  COMMAND.

***** ROUTINE COMPLETED *****  CP =         4.530


*****  ANSYS SOLUTION ROUTINE  *****


PERFORM A STATIC ANALYSIS
 THIS WILL BE A NEW ANALYSIS

WRITE ALL  ITEMS TO THE DATABASE WITH A FREQUENCY OF ALL
  FOR ALL APPLICABLE ENTITIES

SELECT       FOR ITEM=AREA COMPONENT=
 IN RANGE       2 TO       10 STEP        8

    2  AREAS (OF    11  DEFINED) SELECTED BY  ASEL  COMMAND.

ALSO SELECT  FOR ITEM=AREA COMPONENT=
 IN RANGE      14 TO       17 STEP        3

    4  AREAS (OF    11  DEFINED) SELECTED BY ASEL  COMMAND.

SURFACE LOAD ON ALL SELECTED AREAS
    LOAD KEY =1         LOAD LABEL = PRES
    VALUES =          1833.9           0.00000E+00

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT   FOR ITEM=VOLU COMPONENT=
 IN RANGE       0 TO        0 STEP        1

     0  VOLUMES (OF      0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT   FOR ITEM=AREA COMPONENT=
 IN RANGE       1 TO       17 STEP        1

   11  AREAS (OF    11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT   FOR ITEM=LINE COMPONENT=
 IN RANGE       1 TO       49 STEP        1

   38  LINES (OF    38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT   FOR ITEM=KP   COMPONENT=
 IN RANGE       1 TO      102 STEP        1

    25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT   FOR ITEM=ELEM COMPONENT=
 IN RANGE       1 TO     1013 STEP        1
```

```
    1013  ELEMENTS (OF     1013  DEFINED) SELECTED BY  ESEL  COMMAND.

 ALL SELECT   FOR ITEM=NODE COMPONENT=
  IN RANGE        1 TO      3174 STEP        1

    3174  NODES (OF     3174  DEFINED) SELECTED BY NSEL  COMMAND.

 *****  ANSYS SOLVE   COMMAND  *****

 TRANSFER SOLID MODEL BOUNDARY CONDITIONS TO FINITE ELEMENT MODEL
      SURFACE LOADS  TRANSFERRED FROM AREAS         =    288
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX   17:34:49  FEB 27, 2001 CP=      4.870

 APS Heater Sleeve MNSA Top Plate - Case 2c


                        S O L U T I O N   O P T I O N S

   PROBLEM DIMENSIONALITY. . . . . . . . . . . . .3-D
   DEGREES OF FREEDOM. . . . . . UX   UY   UZ   ROTX ROTY ROTZ
   ANALYSIS TYPE . . . . . . . . . . . . . . . . .STATIC (STEADY-STATE)

 *** NOTE ***                              CP=       4.920   TIME= 17:34:49
 Present time 0 is less than or equal to the previous time.
  Time will default to 1.

                       L O A D   S T E P   O P T I O N S

   LOAD STEP NUMBER. . . . . . . . . . . . . . . .     1
   TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
   NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
   STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .    NO
   PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
   DATABASE OUTPUT CONTROLS
      ITEM     FREQUENCY   COMPONENT
       ALL        ALL


 NONLINEAR MONITORING INFO IS WRITTEN TO FILE= c2c.mntr


 Range of element maximum matrix coefficients in global coordinates
 Maximum= 142740510 at element 470.
 Minimum= 35590692.7 at element 894.

   *** ELEMENT MATRIX FORMULATION TIMES
  TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

     1    1013  SHELL93       2.650    0.003
 Time at end of element matrix formulation CP= 8.33999979.

 Estimated number of active DOF= 18891.
 Maximum wavefront= 340.

 Time at end of matrix triangularization CP= 16.2799998.
 Equation solver maximum pivot= 99331096.4 at node 1806 UX.
 Equation solver minimum pivot= 6.147837842E-02 at node 850 ROTZ.
```

```
  *** ELEMENT RESULT CALCULATION TIMES
 TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

    1    1013  SHELL93       2.940    0.003

  *** NODAL LOAD CALCULATION TIMES
 TYPE  NUMBER   ENAME      TOTAL CP  AVE CP

    1    1013  SHELL93       0.180    0.000
*** LOAD STEP     1   SUBSTEP     1  COMPLETED.    CUM ITER =      1
*** TIME =   1.00000         TIME INC =   1.00000      NEW TRIANG MATRIX


  *** PROBLEM STATISTICS
 ACTUAL NO. OF ACTIVE DEGREES OF FREEDOM =  18891
 R.M.S. WAVEFRONT SIZE =   294.0


*** ANSYS BINARY FILE STATISTICS
 BUFFER SIZE USED=  4096
      19.375 MB WRITTEN ON ELEMENT MATRIX FILE: c2c.emat
       2.375 MB WRITTEN ON ELEMENT SAVED DATA FILE: c2c.esav
      42.797 MB WRITTEN ON TRIANGULARIZED MATRIX FILE: c2c.tri
       2.859 MB WRITTEN ON RESULTS FILE: c2c.rst

FINISH SOLUTION PROCESSING


***** ROUTINE COMPLETED *****  CP =        20.600


1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
ANSYS/Mechanical U
00044163           VERSION=HPPA 7/8XXX   17:35:05  FEB 27, 2001 CP=     20.600

APS Heater Sleeve MNSA Top Plate - Case 2c


          ***** ANSYS RESULTS INTERPRETATION (POST1) *****

*** NOTE ***                             CP=      20.610   TIME= 17:35:05
Reading results into the database (SET command) will update the current
 displacement and force boundary conditions in the database with the
 values from the results file for that load set.  Note that any
 subsequent solutions will use these values unless action is taken to
 either SAVE the current values or not overwrite them (/EXIT,NOSAVE).

INTERACTIVE LINES PER PAGE     =   300
INTERACTIVE CHARACTERS PER LINE=    80
FILE OUTPUT LINES PER PAGE     =   300
FILE OUTPUT CHARACTERS PER LINE=   132


USE LOAD STEP     1  SUBSTEP     0  FOR LOAD CASE 0

SET COMMAND GOT LOAD STEP=     1  SUBSTEP=     1  CUMULATIVE ITERATION=     1
  TIME/FREQUENCY=  1.0000
TITLE= APS Heater Sleeve MNSA Top Plate - Case 2c

SELECT       FOR ITEM=U    COMPONENT=Z     BETWEEN-0.10000E-02 AND -0.10000E-03
```

```
  KABS=  0.  TOLERANCE= 0.900000E-11

     2424  NODES (OF     3174  DEFINED) SELECTED BY  NSEL  COMMAND.

 PRINT U    NODAL SOLUTION PER NODE
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:05  FEB 27, 2001 CP=     21.350

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     1  SUBSTEP=     1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
       1 -0.45107E-03
       2 -0.39135E-03
       3 -0.44760E-03
       4 -0.44409E-03
       5 -0.44055E-03
       6 -0.43697E-03
       7 -0.43336E-03
       8 -0.42971E-03
       9 -0.42603E-03
      10 -0.42231E-03
      11 -0.41856E-03
      12 -0.41477E-03
      13 -0.41095E-03
      14 -0.40709E-03
      15 -0.40320E-03
      16 -0.39928E-03
      17 -0.39533E-03
      18 -0.39509E-03
      19 -0.39421E-03
      20 -0.39344E-03
      21 -0.39277E-03
      22 -0.39220E-03
      23 -0.39174E-03
      24 -0.39138E-03
      25 -0.39112E-03
      26 -0.39097E-03
      27 -0.39091E-03
      28 -0.39096E-03
      29 -0.39110E-03
      30 -0.44291E-03
      31 -0.44008E-03
      32 -0.43722E-03
      33 -0.43435E-03
      34 -0.43146E-03
      35 -0.42854E-03
      36 -0.42560E-03
      37 -0.42265E-03
      38 -0.41967E-03
      39 -0.41667E-03
      40 -0.41365E-03
      41 -0.41061E-03
```

42	-0.40755E-03
43	-0.40446E-03
44	-0.40136E-03
45	-0.39824E-03
46	-0.44398E-03
47	-0.44499E-03
48	-0.44592E-03
49	-0.44679E-03
50	-0.44759E-03
51	-0.44831E-03
52	-0.44896E-03
53	-0.44954E-03
54	-0.45004E-03
55	-0.45046E-03
56	-0.45080E-03
57	-0.44699E-03
58	-0.44612E-03
59	-0.44498E-03
60	-0.44358E-03
61	-0.44194E-03
62	-0.44382E-03
63	-0.44349E-03
64	-0.44311E-03
65	-0.44266E-03
66	-0.44217E-03
67	-0.44161E-03
68	-0.44101E-03
69	-0.44035E-03
70	-0.43964E-03
71	-0.43888E-03
72	-0.43807E-03
73	-0.43996E-03
74	-0.43918E-03
75	-0.43822E-03
76	-0.43709E-03
77	-0.43579E-03
78	-0.43670E-03
79	-0.43639E-03
80	-0.43604E-03
81	-0.43566E-03
82	-0.43525E-03
83	-0.43480E-03
84	-0.43431E-03
85	-0.43380E-03
86	-0.43325E-03
87	-0.43268E-03
88	-0.43208E-03
89	-0.43279E-03
90	-0.43211E-03
91	-0.43134E-03
92	-0.43048E-03
93	-0.42954E-03
94	-0.42944E-03
95	-0.42915E-03
96	-0.42885E-03
97	-0.42853E-03
98	-0.42820E-03
99	-0.42786E-03
100	-0.42750E-03
101	-0.42714E-03
102	-0.42676E-03
103	-0.42638E-03
104	-0.42599E-03

105	-0.42548E-03
106	-0.42492E-03
107	-0.42434E-03
108	-0.42377E-03
109	-0.42320E-03
110	-0.42204E-03
111	-0.42178E-03
112	-0.42152E-03
113	-0.42127E-03
114	-0.42103E-03
115	-0.42080E-03
116	-0.42058E-03
117	-0.42037E-03
118	-0.42017E-03
119	-0.41999E-03
120	-0.41982E-03
121	-0.41804E-03
122	-0.41760E-03
123	-0.41723E-03
124	-0.41694E-03
125	-0.41675E-03
126	-0.41451E-03
127	-0.41427E-03
128	-0.41406E-03
129	-0.41389E-03
130	-0.41374E-03
131	-0.41362E-03
132	-0.41354E-03
133	-0.41349E-03
134	-0.41347E-03
135	-0.41349E-03
136	-0.41355E-03
137	-0.41047E-03
138	-0.41014E-03
139	-0.40999E-03
140	-0.41001E-03
141	-0.41021E-03
142	-0.40684E-03
143	-0.40663E-03
144	-0.40647E-03
145	-0.40637E-03
146	-0.40632E-03
147	-0.40632E-03
148	-0.40638E-03
149	-0.40650E-03
150	-0.40667E-03
151	-0.40690E-03
152	-0.40719E-03
153	-0.40276E-03
154	-0.40256E-03
155	-0.40263E-03
156	-0.40296E-03
157	-0.40357E-03
158	-0.39903E-03
159	-0.39885E-03
160	-0.39875E-03
161	-0.39873E-03
162	-0.39878E-03
163	-0.39891E-03
164	-0.39911E-03
165	-0.39940E-03
166	-0.39977E-03
167	-0.40022E-03

168	-0.40075E-03
169	-0.39492E-03
170	-0.39486E-03
171	-0.39516E-03
172	-0.39581E-03
173	-0.39684E-03
174	-0.45805E-03
175	-0.45132E-03
176	-0.45164E-03
177	-0.45203E-03
178	-0.45247E-03
179	-0.45298E-03
180	-0.45354E-03
181	-0.45416E-03
182	-0.45484E-03
183	-0.45557E-03
184	-0.45635E-03
185	-0.45718E-03
186	-0.40132E-03
187	-0.45478E-03
188	-0.45147E-03
189	-0.44812E-03
190	-0.44474E-03
191	-0.44132E-03
192	-0.43786E-03
193	-0.43437E-03
194	-0.43083E-03
195	-0.42727E-03
196	-0.42366E-03
197	-0.42002E-03
198	-0.41635E-03
199	-0.41264E-03
200	-0.40890E-03
201	-0.40512E-03
202	-0.39169E-03
203	-0.39213E-03
204	-0.39266E-03
205	-0.39328E-03
206	-0.39399E-03
207	-0.39479E-03
208	-0.39568E-03
209	-0.39665E-03
210	-0.39770E-03
211	-0.39883E-03
212	-0.40004E-03
213	-0.44436E-03
214	-0.43726E-03
215	-0.43001E-03
216	-0.42262E-03
217	-0.41509E-03
218	-0.40742E-03
219	-0.39962E-03
220	-0.44819E-03
221	-0.44470E-03
222	-0.44117E-03
223	-0.43761E-03
224	-0.43401E-03
225	-0.43038E-03
226	-0.42671E-03
227	-0.42300E-03
228	-0.41926E-03
229	-0.41549E-03
230	-0.41167E-03

```
    231 -0.40783E-03
    232 -0.40395E-03
    233 -0.40004E-03
    234 -0.39610E-03
    235 -0.44510E-03
    236 -0.43803E-03
    237 -0.43082E-03
    238 -0.42346E-03
    239 -0.41597E-03
    240 -0.40833E-03
    241 -0.40056E-03
    242 -0.44904E-03
    243 -0.44557E-03
    244 -0.44207E-03
    245 -0.43853E-03
    246 -0.43495E-03
    247 -0.43134E-03
    248 -0.42769E-03
    249 -0.42400E-03
    250 -0.42028E-03
    251 -0.41653E-03
    252 -0.41273E-03
    253 -0.40891E-03
    254 -0.40505E-03
    255 -0.40116E-03
    256 -0.39723E-03
    257 -0.44611E-03
    258 -0.43909E-03
    259 -0.43193E-03
    260 -0.42462E-03
    261 -0.41717E-03
    262 -0.40957E-03
    263 -0.40185E-03
    264 -0.45014E-03
    265 -0.44670E-03
    266 -0.44323E-03
    267 -0.43972E-03
    268 -0.43617E-03
    269 -0.43258E-03
    270 -0.42896E-03
    271 -0.42530E-03
    272 -0.42161E-03
    273 -0.41788E-03
    274 -0.41412E-03
    275 -0.41032E-03
    276 -0.40648E-03
    277 -0.40262E-03
    278 -0.39872E-03
    279 -0.44736E-03
    280 -0.44041E-03
    281 -0.43331E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:05  FEB 27, 2001 CP=     21.380

 APS Heater Sleeve MNSA Top Plate - Case 2c

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=      1  SUBSTEP=      1
```

TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UZ
282	-0.42606E-03
283	-0.41867E-03
284	-0.41114E-03
285	-0.40347E-03
286	-0.45147E-03
287	-0.44807E-03
288	-0.44463E-03
289	-0.44116E-03
290	-0.43764E-03
291	-0.43410E-03
292	-0.43051E-03
293	-0.42689E-03
294	-0.42323E-03
295	-0.41953E-03
296	-0.41580E-03
297	-0.41204E-03
298	-0.40824E-03
299	-0.40441E-03
300	-0.40054E-03
301	-0.44884E-03
302	-0.44197E-03
303	-0.43495E-03
304	-0.42778E-03
305	-0.42047E-03
306	-0.41301E-03
307	-0.40542E-03
308	-0.45302E-03
309	-0.44967E-03
310	-0.44627E-03
311	-0.44284E-03
312	-0.43937E-03
313	-0.43586E-03
314	-0.43232E-03
315	-0.42874E-03
316	-0.42512E-03
317	-0.42147E-03
318	-0.41778E-03
319	-0.41406E-03
320	-0.41030E-03
321	-0.40651E-03
322	-0.40269E-03
323	-0.45054E-03
324	-0.44376E-03
325	-0.43683E-03
326	-0.42976E-03
327	-0.42253E-03
328	-0.41517E-03
329	-0.40767E-03
330	-0.50233E-03
331	-0.45929E-03
332	-0.46061E-03
333	-0.46199E-03
334	-0.46343E-03
335	-0.46493E-03
336	-0.46649E-03
337	-0.46808E-03
338	-0.46971E-03
339	-0.47137E-03

340	-0.47305E-03
341	-0.47474E-03
342	-0.47644E-03
343	-0.47815E-03
344	-0.47984E-03
345	-0.48152E-03
346	-0.48317E-03
347	-0.48480E-03
348	-0.48638E-03
349	-0.48793E-03
350	-0.48942E-03
351	-0.49086E-03
352	-0.49224E-03
353	-0.49355E-03
354	-0.49478E-03
355	-0.49594E-03
356	-0.49701E-03
357	-0.49799E-03
358	-0.49888E-03
359	-0.49968E-03
360	-0.50037E-03
361	-0.50096E-03
362	-0.50145E-03
363	-0.50184E-03
364	-0.50211E-03
365	-0.50227E-03
366	-0.46772E-03
367	-0.50042E-03
368	-0.49848E-03
369	-0.49650E-03
370	-0.49449E-03
371	-0.49244E-03
372	-0.49036E-03
373	-0.48824E-03
374	-0.48608E-03
375	-0.48390E-03
376	-0.48168E-03
377	-0.47943E-03
378	-0.47714E-03
379	-0.47483E-03
380	-0.47249E-03
381	-0.47012E-03
382	-0.40313E-03
383	-0.40506E-03
384	-0.40709E-03
385	-0.40923E-03
386	-0.41145E-03
387	-0.41375E-03
388	-0.41613E-03
389	-0.41856E-03
390	-0.42104E-03
391	-0.42355E-03
392	-0.42609E-03
393	-0.42864E-03
394	-0.43120E-03
395	-0.43374E-03
396	-0.43627E-03
397	-0.43876E-03
398	-0.44121E-03
399	-0.44361E-03
400	-0.44594E-03
401	-0.44820E-03
402	-0.45037E-03

403 -0.45245E-03
404 -0.45443E-03
405 -0.45630E-03
406 -0.45805E-03
407 -0.45967E-03
408 -0.46115E-03
409 -0.46250E-03
410 -0.46371E-03
411 -0.46476E-03
412 -0.46566E-03
413 -0.46640E-03
414 -0.46698E-03
415 -0.46739E-03
416 -0.46764E-03
417 -0.45278E-03
418 -0.44612E-03
419 -0.43932E-03
420 -0.43236E-03
421 -0.42526E-03
422 -0.41802E-03
423 -0.41064E-03
424 -0.45741E-03
425 -0.45417E-03
426 -0.45090E-03
427 -0.44759E-03
428 -0.44424E-03
429 -0.44086E-03
430 -0.43744E-03
431 -0.43398E-03
432 -0.43049E-03
433 -0.42696E-03
434 -0.42339E-03
435 -0.41979E-03
436 -0.41616E-03
437 -0.41249E-03
438 -0.40879E-03
439 -0.45564E-03
440 -0.44914E-03
441 -0.44249E-03
442 -0.43569E-03
443 -0.42875E-03
444 -0.42166E-03
445 -0.41444E-03
446 -0.46032E-03
447 -0.45717E-03
448 -0.45398E-03
449 -0.45075E-03
450 -0.44749E-03
451 -0.44419E-03
452 -0.44085E-03
453 -0.43748E-03
454 -0.43407E-03
455 -0.43062E-03
456 -0.42714E-03
457 -0.42362E-03
458 -0.42007E-03
459 -0.41649E-03
460 -0.41288E-03
461 -0.45876E-03
462 -0.45243E-03
463 -0.44596E-03
464 -0.43934E-03
465 -0.43257E-03

466	-0.42567E-03
467	-0.41862E-03
468	-0.46346E-03
469	-0.46040E-03
470	-0.45730E-03
471	-0.45417E-03
472	-0.45100E-03
473	-0.44779E-03
474	-0.44454E-03
475	-0.44126E-03
476	-0.43794E-03
477	-0.43459E-03
478	-0.43120E-03
479	-0.42778E-03
480	-0.42432E-03
481	-0.42083E-03
482	-0.41731E-03
483	-0.46209E-03
484	-0.45596E-03
485	-0.44967E-03
486	-0.44324E-03
487	-0.43667E-03
488	-0.42995E-03
489	-0.42310E-03
490	-0.46678E-03
491	-0.46382E-03
492	-0.46082E-03
493	-0.45778E-03
494	-0.45471E-03
495	-0.45160E-03
496	-0.44845E-03
497	-0.44527E-03
498	-0.44205E-03
499	-0.43879E-03
500	-0.43550E-03
501	-0.43218E-03
502	-0.42882E-03
503	-0.42543E-03
504	-0.42201E-03
505	-0.46558E-03
506	-0.45964E-03
507	-0.45356E-03
508	-0.44733E-03
509	-0.44096E-03
510	-0.43445E-03
511	-0.42781E-03
512	-0.47022E-03
513	-0.46736E-03
514	-0.46446E-03
515	-0.46153E-03
516	-0.45856E-03
517	-0.45555E-03
518	-0.45250E-03
519	-0.44942E-03
520	-0.44631E-03
521	-0.44316E-03
522	-0.43997E-03
523	-0.43675E-03
524	-0.43350E-03
525	-0.43021E-03
526	-0.42690E-03
527	-0.46916E-03
528	-0.46343E-03

```
    529 -0.45756E-03
    530 -0.45154E-03
    531 -0.44537E-03
    532 -0.43907E-03
    533 -0.43264E-03
    534 -0.47372E-03
    535 -0.47097E-03
    536 -0.46817E-03
    537 -0.46534E-03
    538 -0.46248E-03
    539 -0.45957E-03
    540 -0.45663E-03
    541 -0.45366E-03
    542 -0.45065E-03
    543 -0.44760E-03
    544 -0.44452E-03
    545 -0.44141E-03
    546 -0.43827E-03
    547 -0.43509E-03
    548 -0.43188E-03
    549 -0.47277E-03
    550 -0.46725E-03
    551 -0.46159E-03
    552 -0.45578E-03
    553 -0.44983E-03
    554 -0.44375E-03
    555 -0.43753E-03
    556 -0.47722E-03
    557 -0.47457E-03
    558 -0.47188E-03
    559 -0.46916E-03
    560 -0.46640E-03
    561 -0.46360E-03
    562 -0.46076E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:05  FEB 27, 2001 CP=      21.410

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     1  SUBSTEP=     1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
    563 -0.45790E-03
    564 -0.45499E-03
    565 -0.45205E-03
    566 -0.44908E-03
    567 -0.44608E-03
    568 -0.44304E-03
    569 -0.43997E-03
    570 -0.43687E-03
    571 -0.47635E-03
    572 -0.47104E-03
    573 -0.46559E-03
    574 -0.45999E-03
```

575	-0.45426E-03
576	-0.44839E-03
577	-0.44239E-03
578	-0.48066E-03
579	-0.47811E-03
580	-0.47553E-03
581	-0.47290E-03
582	-0.47025E-03
583	-0.46755E-03
584	-0.46483E-03
585	-0.46206E-03
586	-0.45926E-03
587	-0.45643E-03
588	-0.45357E-03
589	-0.45067E-03
590	-0.44774E-03
591	-0.44478E-03
592	-0.44178E-03
593	-0.47984E-03
594	-0.47473E-03
595	-0.46949E-03
596	-0.46410E-03
597	-0.45857E-03
598	-0.45291E-03
599	-0.44712E-03
600	-0.48397E-03
601	-0.48153E-03
602	-0.47904E-03
603	-0.47652E-03
604	-0.47397E-03
605	-0.47137E-03
606	-0.46875E-03
607	-0.46608E-03
608	-0.46339E-03
609	-0.46066E-03
610	-0.45790E-03
611	-0.45510E-03
612	-0.45227E-03
613	-0.44941E-03
614	-0.44653E-03
615	-0.48317E-03
616	-0.47826E-03
617	-0.47321E-03
618	-0.46802E-03
619	-0.46269E-03
620	-0.45723E-03
621	-0.45165E-03
622	-0.48711E-03
623	-0.48476E-03
624	-0.48237E-03
625	-0.47994E-03
626	-0.47748E-03
627	-0.47499E-03
628	-0.47246E-03
629	-0.46989E-03
630	-0.46729E-03
631	-0.46466E-03
632	-0.46199E-03
633	-0.45930E-03
634	-0.45657E-03
635	-0.45381E-03
636	-0.45102E-03
637	-0.48629E-03

638	-0.48157E-03
639	-0.47670E-03
640	-0.47170E-03
641	-0.46655E-03
642	-0.46128E-03
643	-0.45589E-03
644	-0.49001E-03
645	-0.48775E-03
646	-0.48545E-03
647	-0.48312E-03
648	-0.48074E-03
649	-0.47834E-03
650	-0.47590E-03
651	-0.47342E-03
652	-0.47091E-03
653	-0.46837E-03
654	-0.46579E-03
655	-0.46319E-03
656	-0.46055E-03
657	-0.45788E-03
658	-0.45518E-03
659	-0.48914E-03
660	-0.48459E-03
661	-0.47989E-03
662	-0.47506E-03
663	-0.47009E-03
664	-0.46499E-03
665	-0.45977E-03
666	-0.49264E-03
667	-0.49045E-03
668	-0.48823E-03
669	-0.48598E-03
670	-0.48369E-03
671	-0.48136E-03
672	-0.47900E-03
673	-0.47661E-03
674	-0.47418E-03
675	-0.47172E-03
676	-0.46922E-03
677	-0.46670E-03
678	-0.46414E-03
679	-0.46156E-03
680	-0.45894E-03
681	-0.49168E-03
682	-0.48728E-03
683	-0.48274E-03
684	-0.47806E-03
685	-0.47324E-03
686	-0.46830E-03
687	-0.46323E-03
688	-0.49493E-03
689	-0.49282E-03
690	-0.49067E-03
691	-0.48849E-03
692	-0.48627E-03
693	-0.48401E-03
694	-0.48173E-03
695	-0.47940E-03
696	-0.47704E-03
697	-0.47465E-03
698	-0.47223E-03
699	-0.46978E-03
700	-0.46729E-03

701	-0.46478E-03
702	-0.46224E-03
703	-0.49387E-03
704	-0.48960E-03
705	-0.48519E-03
706	-0.48064E-03
707	-0.47595E-03
708	-0.47114E-03
709	-0.46620E-03
710	-0.49687E-03
711	-0.49481E-03
712	-0.49273E-03
713	-0.49060E-03
714	-0.48844E-03
715	-0.48625E-03
716	-0.48402E-03
717	-0.48175E-03
718	-0.47946E-03
719	-0.47713E-03
720	-0.47476E-03
721	-0.47237E-03
722	-0.46995E-03
723	-0.46749E-03
724	-0.46501E-03
725	-0.49566E-03
726	-0.49150E-03
727	-0.48719E-03
728	-0.48275E-03
729	-0.47817E-03
730	-0.47347E-03
731	-0.46864E-03
732	-0.49840E-03
733	-0.49640E-03
734	-0.49436E-03
735	-0.49228E-03
736	-0.49017E-03
737	-0.48802E-03
738	-0.48584E-03
739	-0.48362E-03
740	-0.48137E-03
741	-0.47909E-03
742	-0.47678E-03
743	-0.47443E-03
744	-0.47206E-03
745	-0.46965E-03
746	-0.46722E-03
747	-0.49703E-03
748	-0.49295E-03
749	-0.48873E-03
750	-0.48437E-03
751	-0.47988E-03
752	-0.47525E-03
753	-0.47051E-03
754	-0.49952E-03
755	-0.49755E-03
756	-0.49554E-03
757	-0.49350E-03
758	-0.49142E-03
759	-0.48931E-03
760	-0.48716E-03
761	-0.48498E-03
762	-0.48277E-03
763	-0.48052E-03

764	-0.47824E-03
765	-0.47593E-03
766	-0.47359E-03
767	-0.47122E-03
768	-0.46882E-03
769	-0.49796E-03
770	-0.49393E-03
771	-0.48977E-03
772	-0.48546E-03
773	-0.48103E-03
774	-0.47646E-03
775	-0.47177E-03
776	-0.50020E-03
777	-0.49825E-03
778	-0.49626E-03
779	-0.49424E-03
780	-0.49219E-03
781	-0.49009E-03
782	-0.48797E-03
783	-0.48581E-03
784	-0.48361E-03
785	-0.48139E-03
786	-0.47913E-03
787	-0.47684E-03
788	-0.47452E-03
789	-0.47217E-03
790	-0.46980E-03
791	-0.49842E-03
792	-0.49443E-03
793	-0.49029E-03
794	-0.48601E-03
795	-0.48160E-03
796	-0.47707E-03
797	-0.47241E-03
798	-0.41753E-03
799	-0.39592E-03
800	-0.39683E-03
801	-0.39781E-03
802	-0.39887E-03
803	-0.40000E-03
804	-0.40121E-03
805	-0.40249E-03
806	-0.40385E-03
807	-0.40528E-03
808	-0.40679E-03
809	-0.40837E-03
810	-0.41003E-03
811	-0.41176E-03
812	-0.41358E-03
813	-0.41550E-03
814	-0.44168E-03
815	-0.44039E-03
816	-0.43902E-03
817	-0.43759E-03
818	-0.43611E-03
819	-0.43457E-03
820	-0.43298E-03
821	-0.43134E-03
822	-0.42967E-03
823	-0.42796E-03
824	-0.42622E-03
825	-0.42446E-03
826	-0.42269E-03

```
     827 -0.42092E-03
     828 -0.41918E-03
     829 -0.41884E-03
     830 -0.41963E-03
     831 -0.41956E-03
     832 -0.41948E-03
     833 -0.41935E-03
     834 -0.41924E-03
     835 -0.41907E-03
     836 -0.41897E-03
     837 -0.40602E-03
     838 -0.40832E-03
     839 -0.41023E-03
     840 -0.41244E-03
     841 -0.41416E-03
     842 -0.41616E-03
     843 -0.41744E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:05  FEB 27, 2001 CP=      21.450

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=      1  SUBSTEP=      1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
     844 -0.42968E-03
     845 -0.42791E-03
     846 -0.42629E-03
     847 -0.42447E-03
     848 -0.42296E-03
     849 -0.42123E-03
     850 -0.42009E-03
     851 -0.42528E-03
     852 -0.43083E-03
     853 -0.43629E-03
     854 -0.42225E-03
     855 -0.42491E-03
     856 -0.42754E-03
     857 -0.43015E-03
     858 -0.43274E-03
     859 -0.43531E-03
     860 -0.43785E-03
     861 -0.42452E-03
     862 -0.42944E-03
     863 -0.43426E-03
     864 -0.42173E-03
     865 -0.42403E-03
     866 -0.42639E-03
     867 -0.42864E-03
     868 -0.43093E-03
     869 -0.43315E-03
     870 -0.43539E-03
     871 -0.42354E-03
     872 -0.42782E-03
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873	-0.43200E-03
874	-0.42103E-03
875	-0.42290E-03
876	-0.42495E-03
877	-0.42680E-03
878	-0.42885E-03
879	-0.43072E-03
880	-0.43268E-03
881	-0.42216E-03
882	-0.42576E-03
883	-0.42940E-03
884	-0.40362E-03
885	-0.40158E-03
886	-0.39982E-03
887	-0.40712E-03
888	-0.40612E-03
889	-0.40517E-03
890	-0.40434E-03
891	-0.40356E-03
892	-0.40281E-03
893	-0.40210E-03
894	-0.40829E-03
895	-0.40686E-03
896	-0.40565E-03
897	-0.41143E-03
898	-0.41073E-03
899	-0.41002E-03
900	-0.40951E-03
901	-0.40898E-03
902	-0.40852E-03
903	-0.40804E-03
904	-0.41279E-03
905	-0.41195E-03
906	-0.41130E-03
907	-0.41553E-03
908	-0.41508E-03
909	-0.41475E-03
910	-0.41452E-03
911	-0.41429E-03
912	-0.41410E-03
913	-0.41388E-03
914	-0.41705E-03
915	-0.41692E-03
916	-0.41683E-03
917	-0.42636E-03
918	-0.42284E-03
919	-0.41922E-03
920	-0.42638E-03
921	-0.42470E-03
922	-0.42296E-03
923	-0.42119E-03
924	-0.41932E-03
925	-0.41749E-03
926	-0.41552E-03
927	-0.42312E-03
928	-0.41954E-03
929	-0.41579E-03
930	-0.42304E-03
931	-0.42145E-03
932	-0.41969E-03
933	-0.41793E-03
934	-0.41598E-03
935	-0.41413E-03

936	-0.41206E-03
937	-0.41996E-03
938	-0.41635E-03
939	-0.41251E-03
940	-0.41988E-03
941	-0.41845E-03
942	-0.41661E-03
943	-0.41492E-03
944	-0.41285E-03
945	-0.41101E-03
946	-0.40885E-03
947	-0.41724E-03
948	-0.41354E-03
949	-0.40957E-03
951	-0.22851E-03
970	-0.10296E-03
971	-0.10993E-03
972	-0.11711E-03
973	-0.12450E-03
974	-0.13210E-03
975	-0.13990E-03
976	-0.14790E-03
977	-0.15610E-03
978	-0.16449E-03
979	-0.17308E-03
980	-0.18185E-03
981	-0.19082E-03
982	-0.19997E-03
983	-0.20930E-03
984	-0.21882E-03
1031	-0.21219E-03
1032	-0.19598E-03
1033	-0.17989E-03
1034	-0.16391E-03
1035	-0.14804E-03
1036	-0.13227E-03
1037	-0.11660E-03
1038	-0.10100E-03
1042	-0.18650E-03
1043	-0.15464E-03
1044	-0.12320E-03
1047	-0.19319E-03
1048	-0.17719E-03
1049	-0.16131E-03
1050	-0.14554E-03
1051	-0.12988E-03
1052	-0.11431E-03
1058	-0.16807E-03
1059	-0.13663E-03
1060	-0.10559E-03
1063	-0.17491E-03
1064	-0.15912E-03
1065	-0.14345E-03
1066	-0.12789E-03
1067	-0.11243E-03
1074	-0.15037E-03
1075	-0.11934E-03
1079	-0.15738E-03
1080	-0.14180E-03
1081	-0.12634E-03
1082	-0.11099E-03
1090	-0.13342E-03
1091	-0.10282E-03

1095	-0.14060E-03
1096	-0.12524E-03
1097	-0.10999E-03
1106	-0.11725E-03
1111	-0.12462E-03
1112	-0.10947E-03
1122	-0.10189E-03
1127	-0.10944E-03
1516	-0.33992E-03
1517	-0.41208E-03
1518	-0.40679E-03
1519	-0.40163E-03
1520	-0.39660E-03
1521	-0.39173E-03
1522	-0.38698E-03
1523	-0.38238E-03
1524	-0.37791E-03
1525	-0.37357E-03
1526	-0.36937E-03
1527	-0.36529E-03
1528	-0.36133E-03
1529	-0.35748E-03
1530	-0.35375E-03
1531	-0.35012E-03
1532	-0.34660E-03
1533	-0.34318E-03
1534	-0.37218E-03
1535	-0.34979E-03
1536	-0.32783E-03
1537	-0.30624E-03
1538	-0.28501E-03
1539	-0.26411E-03
1540	-0.24353E-03
1541	-0.22327E-03
1542	-0.20333E-03
1543	-0.18371E-03
1544	-0.16442E-03
1545	-0.14547E-03
1546	-0.12688E-03
1547	-0.10862E-03
1553	-0.23400E-03
1554	-0.23951E-03
1555	-0.24502E-03
1556	-0.25055E-03
1557	-0.25609E-03
1558	-0.26163E-03
1559	-0.26719E-03
1560	-0.27276E-03
1561	-0.27834E-03
1562	-0.28392E-03
1563	-0.28952E-03
1564	-0.29511E-03
1565	-0.30072E-03
1566	-0.30633E-03
1567	-0.31194E-03
1568	-0.31755E-03
1569	-0.32316E-03
1570	-0.32876E-03
1571	-0.33435E-03
1572	-0.33014E-03
1573	-0.31718E-03
1574	-0.30434E-03
1575	-0.29163E-03

1576	-0.27907E-03
1577	-0.26667E-03
1578	-0.25444E-03
1579	-0.24239E-03
1580	-0.23051E-03
1581	-0.33908E-03
1582	-0.33163E-03
1583	-0.32424E-03
1584	-0.31692E-03
1585	-0.30965E-03
1586	-0.30245E-03
1587	-0.29532E-03
1588	-0.28826E-03
1589	-0.28126E-03
1590	-0.27434E-03
1591	-0.26750E-03
1592	-0.26072E-03
1593	-0.25403E-03
1594	-0.24741E-03
1595	-0.24086E-03
1596	-0.23440E-03
1597	-0.22801E-03
1598	-0.22170E-03
1599	-0.21546E-03
1600	-0.33325E-03
1601	-0.31677E-03
1602	-0.30069E-03
1603	-0.28500E-03
1604	-0.26974E-03
1605	-0.25492E-03
1606	-0.24052E-03
1607	-0.22657E-03
1608	-0.21305E-03
1609	-0.34430E-03
1610	-0.33498E-03
1611	-0.32580E-03
1612	-0.31675E-03
1613	-0.30783E-03
1614	-0.29904E-03
1615	-0.29040E-03
1616	-0.28188E-03
1617	-0.27351E-03
1618	-0.26528E-03
1619	-0.25719E-03
1620	-0.24925E-03
1621	-0.24145E-03
1622	-0.23379E-03
1623	-0.22628E-03
1624	-0.21891E-03
1625	-0.21167E-03
1626	-0.20458E-03
1627	-0.19763E-03
1628	-0.33683E-03
1629	-0.31683E-03
1630	-0.29752E-03
1631	-0.27889E-03
1632	-0.26096E-03
1633	-0.24373E-03
1634	-0.22721E-03
1635	-0.21141E-03
1636	-0.19629E-03
1637	-0.34995E-03
1638	-0.33878E-03

1

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 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX   17:35:05  FEB 27, 2001 CP=     21.480

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     1  SUBSTEP=     1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
    1639 -0.32781E-03
    1640 -0.31704E-03
    1641 -0.30647E-03
    1642 -0.29611E-03
    1643 -0.28596E-03
    1644 -0.27602E-03
    1645 -0.26629E-03
    1646 -0.25677E-03
    1647 -0.24747E-03
    1648 -0.23836E-03
    1649 -0.22947E-03
    1650 -0.22079E-03
    1651 -0.21233E-03
    1652 -0.20408E-03
    1653 -0.19603E-03
    1654 -0.18818E-03
    1655 -0.18053E-03
    1656 -0.34085E-03
    1657 -0.31736E-03
    1658 -0.29484E-03
    1659 -0.27328E-03
    1660 -0.25272E-03
    1661 -0.23315E-03
    1662 -0.21454E-03
    1663 -0.19692E-03
    1664 -0.18025E-03
    1665 -0.35607E-03
    1666 -0.34305E-03
    1667 -0.33029E-03
    1668 -0.31781E-03
    1669 -0.30560E-03
    1670 -0.29368E-03
    1671 -0.28204E-03
    1672 -0.27068E-03
    1673 -0.25960E-03
    1674 -0.24880E-03
    1675 -0.23829E-03
    1676 -0.22807E-03
    1677 -0.21812E-03
    1678 -0.20845E-03
    1679 -0.19904E-03
    1680 -0.18993E-03
    1681 -0.18109E-03
    1682 -0.17250E-03
    1683 -0.16418E-03
    1684 -0.34537E-03
```

1685	-0.31838E-03
1686	-0.29265E-03
1687	-0.26820E-03
1688	-0.24503E-03
1689	-0.22313E-03
1690	-0.20252E-03
1691	-0.18311E-03
1692	-0.16494E-03
1693	-0.36269E-03
1694	-0.34782E-03
1695	-0.33328E-03
1696	-0.31908E-03
1697	-0.30524E-03
1698	-0.29176E-03
1699	-0.27863E-03
1700	-0.26585E-03
1701	-0.25344E-03
1702	-0.24140E-03
1703	-0.22970E-03
1704	-0.21835E-03
1705	-0.20737E-03
1706	-0.19674E-03
1707	-0.18644E-03
1708	-0.17647E-03
1709	-0.16685E-03
1710	-0.15756E-03
1711	-0.14858E-03
1712	-0.35040E-03
1713	-0.31992E-03
1714	-0.29099E-03
1715	-0.26365E-03
1716	-0.23790E-03
1717	-0.21373E-03
1718	-0.19112E-03
1719	-0.17001E-03
1720	-0.15037E-03
1721	-0.36985E-03
1722	-0.35312E-03
1723	-0.33680E-03
1724	-0.32089E-03
1725	-0.30541E-03
1726	-0.29037E-03
1727	-0.27575E-03
1728	-0.26158E-03
1729	-0.24785E-03
1730	-0.23454E-03
1731	-0.22168E-03
1732	-0.20926E-03
1733	-0.19725E-03
1734	-0.18566E-03
1735	-0.17450E-03
1736	-0.16373E-03
1737	-0.15334E-03
1738	-0.14337E-03
1739	-0.13377E-03
1740	-0.35597E-03
1741	-0.32200E-03
1742	-0.28988E-03
1743	-0.25965E-03
1744	-0.23134E-03
1745	-0.20493E-03
1746	-0.18036E-03
1747	-0.15761E-03

1748	-0.13657E-03
1749	-0.37755E-03
1750	-0.35897E-03
1751	-0.34086E-03
1752	-0.32325E-03
1753	-0.30614E-03
1754	-0.28953E-03
1755	-0.27345E-03
1756	-0.25787E-03
1757	-0.24281E-03
1758	-0.22828E-03
1759	-0.21426E-03
1760	-0.20074E-03
1761	-0.18775E-03
1762	-0.17523E-03
1763	-0.16321E-03
1764	-0.15168E-03
1765	-0.14058E-03
1766	-0.12995E-03
1767	-0.11974E-03
1768	-0.36210E-03
1769	-0.32464E-03
1770	-0.28934E-03
1771	-0.25624E-03
1772	-0.22536E-03
1773	-0.19672E-03
1774	-0.17027E-03
1775	-0.14591E-03
1776	-0.12352E-03
1777	-0.38581E-03
1778	-0.36537E-03
1779	-0.34549E-03
1780	-0.32617E-03
1781	-0.30744E-03
1782	-0.28928E-03
1783	-0.27172E-03
1784	-0.25474E-03
1785	-0.23838E-03
1786	-0.22260E-03
1787	-0.20743E-03
1788	-0.19286E-03
1789	-0.17886E-03
1790	-0.16546E-03
1791	-0.15260E-03
1792	-0.14032E-03
1793	-0.12855E-03
1794	-0.11729E-03
1795	-0.10653E-03
1796	-0.36878E-03
1797	-0.32784E-03
1798	-0.28937E-03
1799	-0.25342E-03
1800	-0.22001E-03
1801	-0.18915E-03
1802	-0.16081E-03
1803	-0.13490E-03
1804	-0.11124E-03
1805	-0.39465E-03
1806	-0.37232E-03
1807	-0.35065E-03
1808	-0.32964E-03
1809	-0.30929E-03
1810	-0.28961E-03

1811	-0.27059E-03
1812	-0.25224E-03
1813	-0.23456E-03
1814	-0.21757E-03
1815	-0.20124E-03
1816	-0.18560E-03
1817	-0.17063E-03
1818	-0.15632E-03
1819	-0.14268E-03
1820	-0.12965E-03
1821	-0.11725E-03
1822	-0.10539E-03
1824	-0.37349E-03
1825	-0.33034E-03
1826	-0.28975E-03
1827	-0.25172E-03
1828	-0.21628E-03
1829	-0.18345E-03
1830	-0.15324E-03
1831	-0.12559E-03
1832	-0.10032E-03
1833	-0.39399E-03
1834	-0.37467E-03
1835	-0.35255E-03
1836	-0.33107E-03
1837	-0.31018E-03
1838	-0.28992E-03
1839	-0.27028E-03
1840	-0.25123E-03
1841	-0.23283E-03
1842	-0.21503E-03
1843	-0.19788E-03
1844	-0.18136E-03
1845	-0.16547E-03
1846	-0.15024E-03
1847	-0.13562E-03
1848	-0.12164E-03
1849	-0.10824E-03
1852	-0.37221E-03
1853	-0.33179E-03
1854	-0.29012E-03
1855	-0.25080E-03
1856	-0.21385E-03
1857	-0.17933E-03
1858	-0.14732E-03
1859	-0.11780E-03
1861	-0.38975E-03
1862	-0.36985E-03
1863	-0.35025E-03
1864	-0.33096E-03
1865	-0.31116E-03
1866	-0.29033E-03
1867	-0.27008E-03
1868	-0.25039E-03
1869	-0.23127E-03
1870	-0.21273E-03
1871	-0.19476E-03
1872	-0.17740E-03
1873	-0.16064E-03
1874	-0.14449E-03
1875	-0.12897E-03
1876	-0.11406E-03
1880	-0.36759E-03

```
    1881 -0.32817E-03
    1882 -0.28991E-03
    1883 -0.25002E-03
    1884 -0.21166E-03
    1885 -0.17554E-03
    1886 -0.14175E-03
    1887 -0.11043E-03
    1889 -0.38590E-03
    1890 -0.36544E-03
    1891 -0.34531E-03
    1892 -0.32550E-03
    1893 -0.30601E-03
    1894 -0.28677E-03
    1895 -0.26781E-03
    1896 -0.24915E-03
    1897 -0.22991E-03
    1898 -0.21064E-03
    1899 -0.19193E-03
    1900 -0.17376E-03
    1901 -0.15613E-03
    1902 -0.13913E-03
    1903 -0.12271E-03
    1904 -0.10691E-03
    1908 -0.36339E-03
    1909 -0.32298E-03
    1910 -0.28380E-03
    1911 -0.24573E-03
    1912 -0.20879E-03
    1913 -0.17204E-03
    1914 -0.13659E-03
    1915 -0.10350E-03
    1917 -0.38243E-03
    1918 -0.36144E-03
    1919 -0.34085E-03
    1920 -0.32059E-03
    1921 -0.30063E-03
    1922 -0.28098E-03
    1923 -0.26158E-03
    1924 -0.24250E-03
    1925 -0.22369E-03
    1926 -0.20517E-03
    1927 -0.18693E-03
    1928 -0.16901E-03
    1929 -0.15142E-03
    1930 -0.13417E-03
    1931 -0.11689E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:06  FEB 27, 2001 CP=      21.510

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=      1  SUBSTEP=      1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
```

1932	-0.10021E-03
1936	-0.35961E-03
1937	-0.31832E-03
1938	-0.27829E-03
1939	-0.23945E-03
1940	-0.20173E-03
1941	-0.16525E-03
1942	-0.13008E-03
1945	-0.37932E-03
1946	-0.35789E-03
1947	-0.33686E-03
1948	-0.31619E-03
1949	-0.29584E-03
1950	-0.27580E-03
1951	-0.25604E-03
1952	-0.23658E-03
1953	-0.21740E-03
1954	-0.19853E-03
1955	-0.17996E-03
1956	-0.16170E-03
1957	-0.14377E-03
1958	-0.12619E-03
1959	-0.10902E-03
1964	-0.35628E-03
1965	-0.31420E-03
1966	-0.27343E-03
1967	-0.23389E-03
1968	-0.19553E-03
1969	-0.15838E-03
1970	-0.12256E-03
1973	-0.37657E-03
1974	-0.35477E-03
1975	-0.33336E-03
1976	-0.31233E-03
1977	-0.29164E-03
1978	-0.27126E-03
1979	-0.25117E-03
1980	-0.23139E-03
1981	-0.21191E-03
1982	-0.19272E-03
1983	-0.17385E-03
1984	-0.15530E-03
1985	-0.13708E-03
1986	-0.11921E-03
1987	-0.10171E-03
1992	-0.35337E-03
1993	-0.31061E-03
1994	-0.26923E-03
1995	-0.22907E-03
1996	-0.19014E-03
1997	-0.15248E-03
1998	-0.11612E-03
2001	-0.37420E-03
2002	-0.35207E-03
2003	-0.33036E-03
2004	-0.30902E-03
2005	-0.28803E-03
2006	-0.26736E-03
2007	-0.24700E-03
2008	-0.22695E-03
2009	-0.20722E-03
2010	-0.18780E-03
2011	-0.16869E-03

2012	-0.14990E-03
2013	-0.13144E-03
2014	-0.11332E-03
2020	-0.35088E-03
2021	-0.30758E-03
2022	-0.26567E-03
2023	-0.22503E-03
2024	-0.18565E-03
2025	-0.14757E-03
2026	-0.11079E-03
2029	-0.36777E-03
2030	-0.34470E-03
2031	-0.32208E-03
2032	-0.29986E-03
2033	-0.27802E-03
2034	-0.25655E-03
2035	-0.23545E-03
2036	-0.21474E-03
2037	-0.19443E-03
2038	-0.17456E-03
2039	-0.15514E-03
2040	-0.13623E-03
2041	-0.11784E-03
2042	-0.10002E-03
2048	-0.34864E-03
2049	-0.30484E-03
2050	-0.26246E-03
2051	-0.22141E-03
2052	-0.18168E-03
2053	-0.14332E-03
2054	-0.10637E-03
2057	-0.37027E-03
2058	-0.34763E-03
2059	-0.32542E-03
2060	-0.30359E-03
2061	-0.28213E-03
2062	-0.26101E-03
2063	-0.24023E-03
2064	-0.21978E-03
2065	-0.19967E-03
2066	-0.17990E-03
2067	-0.16050E-03
2068	-0.14145E-03
2069	-0.12280E-03
2070	-0.10455E-03
2076	-0.34675E-03
2077	-0.30251E-03
2078	-0.25975E-03
2079	-0.21836E-03
2080	-0.17837E-03
2081	-0.13988E-03
2082	-0.10302E-03
2085	-0.36884E-03
2086	-0.34600E-03
2087	-0.32360E-03
2088	-0.30159E-03
2089	-0.27995E-03
2090	-0.25867E-03
2091	-0.23773E-03
2092	-0.21715E-03
2093	-0.19693E-03
2094	-0.17708E-03
2095	-0.15762E-03

2096	-0.13858E-03
2097	-0.11996E-03
2098	-0.10181E-03
2104	-0.34538E-03
2105	-0.30083E-03
2106	-0.25778E-03
2107	-0.21616E-03
2108	-0.17602E-03
2109	-0.13753E-03
2110	-0.10087E-03
2113	-0.36788E-03
2114	-0.34490E-03
2115	-0.32236E-03
2116	-0.30023E-03
2117	-0.27847E-03
2118	-0.25707E-03
2119	-0.23603E-03
2120	-0.21536E-03
2121	-0.19508E-03
2122	-0.17519E-03
2123	-0.15573E-03
2124	-0.13672E-03
2125	-0.11818E-03
2126	-0.10017E-03
2132	-0.34455E-03
2133	-0.29978E-03
2134	-0.25654E-03
2135	-0.21478E-03
2136	-0.17458E-03
2137	-0.13613E-03
2141	-0.36739E-03
2142	-0.34432E-03
2143	-0.32171E-03
2144	-0.29949E-03
2145	-0.27766E-03
2146	-0.25619E-03
2147	-0.23510E-03
2148	-0.21438E-03
2149	-0.19407E-03
2150	-0.17417E-03
2151	-0.15473E-03
2152	-0.13576E-03
2153	-0.11731E-03
2160	-0.34423E-03
2161	-0.29936E-03
2162	-0.25602E-03
2163	-0.21419E-03
2164	-0.17397E-03
2165	-0.13559E-03
2169	-0.36735E-03
2170	-0.34426E-03
2171	-0.32161E-03
2172	-0.29937E-03
2173	-0.27751E-03
2174	-0.25602E-03
2175	-0.23491E-03
2176	-0.21418E-03
2177	-0.19386E-03
2178	-0.17397E-03
2179	-0.15455E-03
2180	-0.13562E-03
2181	-0.11722E-03
2188	-0.34442E-03

2189	-0.29954E-03
2190	-0.25620E-03
2191	-0.21437E-03
2192	-0.17417E-03
2193	-0.13583E-03
2197	-0.37894E-03
2198	-0.35707E-03
2199	-0.33565E-03
2200	-0.31461E-03
2201	-0.29391E-03
2202	-0.27354E-03
2203	-0.25347E-03
2204	-0.23369E-03
2205	-0.21419E-03
2206	-0.19497E-03
2207	-0.17601E-03
2208	-0.15730E-03
2209	-0.13890E-03
2210	-0.12073E-03
2211	-0.10261E-03
2216	-0.34511E-03
2217	-0.30032E-03
2218	-0.25706E-03
2219	-0.21529E-03
2220	-0.17513E-03
2221	-0.13681E-03
2222	-0.10059E-03
2225	-0.36862E-03
2226	-0.34563E-03
2227	-0.32308E-03
2228	-0.30093E-03
2229	-0.27916E-03
2230	-0.25775E-03
2231	-0.23670E-03
2232	-0.21603E-03
2233	-0.19576E-03
2234	-0.17590E-03
2235	-0.15650E-03
2236	-0.13757E-03
2237	-0.11917E-03
2238	-0.10132E-03
2244	-0.34628E-03
2245	-0.30169E-03
2246	-0.25860E-03
2247	-0.21696E-03
2248	-0.17687E-03
2249	-0.13853E-03
2250	-0.10221E-03
2253	-0.36991E-03
2254	-0.34704E-03
2255	-0.32462E-03
2256	-0.30259E-03
2257	-0.28092E-03
2258	-0.25962E-03
2259	-0.23866E-03
2260	-0.21807E-03
2261	-0.19785E-03
2262	-0.17803E-03
2263	-0.15862E-03
2264	-0.13967E-03
2265	-0.12121E-03
2266	-0.10328E-03
2272	-0.34792E-03

```
   2273 -0.30362E-03
   2274 -0.26080E-03
   2275 -0.21936E-03
   2276 -0.17938E-03
   2277 -0.14102E-03
   2278 -0.10453E-03
   2281 -0.37160E-03
   2282 -0.34891E-03
   2283 -0.32666E-03
   2284 -0.30480E-03
   2285 -0.28330E-03
   2286 -0.26214E-03
   2287 -0.24132E-03
   2288 -0.22085E-03
   2289 -0.20072E-03
   2290 -0.18095E-03
   2291 -0.16156E-03
   2292 -0.14259E-03
   2293 -0.12405E-03
   2294 -0.10599E-03
   2300 -0.35001E-03
   2301 -0.30611E-03
   2302 -0.26365E-03
   2303 -0.22252E-03
   2304 -0.18272E-03
   2305 -0.14438E-03
   2306 -0.10767E-03
   2309 -0.37368E-03
   2310 -0.35122E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:06  FEB 27, 2001 CP=      21.540

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=      1  SUBSTEP=      1
   TIME=    1.0000       LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UZ
   2311 -0.32919E-03
   2312 -0.30755E-03
   2313 -0.28627E-03
   2314 -0.26532E-03
   2315 -0.24469E-03
   2316 -0.22437E-03
   2317 -0.20438E-03
   2318 -0.18472E-03
   2319 -0.16539E-03
   2320 -0.14641E-03
   2321 -0.12781E-03
   2322 -0.10960E-03
   2328 -0.35253E-03
   2329 -0.30913E-03
   2330 -0.26714E-03
   2331 -0.22642E-03
   2332 -0.18693E-03
```

2333	-0.14871E-03
2334	-0.11183E-03
2337	-0.37614E-03
2338	-0.35395E-03
2339	-0.33220E-03
2340	-0.31083E-03
2341	-0.28981E-03
2342	-0.26912E-03
2343	-0.24874E-03
2344	-0.22866E-03
2345	-0.20887E-03
2346	-0.18938E-03
2347	-0.17018E-03
2348	-0.15128E-03
2349	-0.13269E-03
2350	-0.11441E-03
2356	-0.35547E-03
2357	-0.31266E-03
2358	-0.27125E-03
2359	-0.23108E-03
2360	-0.19205E-03
2361	-0.15416E-03
2362	-0.11730E-03
2365	-0.30921E-03
2366	-0.45451E-03
2367	-0.44208E-03
2368	-0.43036E-03
2369	-0.41931E-03
2370	-0.40889E-03
2371	-0.39905E-03
2372	-0.38977E-03
2373	-0.38102E-03
2374	-0.37277E-03
2375	-0.36499E-03
2376	-0.35767E-03
2377	-0.35078E-03
2378	-0.34431E-03
2379	-0.33823E-03
2380	-0.33254E-03
2381	-0.32720E-03
2382	-0.32222E-03
2383	-0.31757E-03
2384	-0.31323E-03
2393	-0.10999E-03
2394	-0.12088E-03
2395	-0.13183E-03
2396	-0.14279E-03
2397	-0.15373E-03
2398	-0.16461E-03
2399	-0.17539E-03
2400	-0.18601E-03
2401	-0.19645E-03
2402	-0.20665E-03
2403	-0.21657E-03
2404	-0.22618E-03
2405	-0.23542E-03
2406	-0.24427E-03
2407	-0.25267E-03
2408	-0.26061E-03
2409	-0.26804E-03
2410	-0.27493E-03
2411	-0.28126E-03
2412	-0.28699E-03

2413	-0.29211E-03
2414	-0.29659E-03
2415	-0.30041E-03
2416	-0.30356E-03
2417	-0.30602E-03
2418	-0.30779E-03
2419	-0.30885E-03
2420	-0.35936E-03
2421	-0.31738E-03
2422	-0.27681E-03
2423	-0.23745E-03
2424	-0.19920E-03
2425	-0.16202E-03
2426	-0.12579E-03
2429	-0.38317E-03
2430	-0.36180E-03
2431	-0.34088E-03
2432	-0.32035E-03
2433	-0.30017E-03
2434	-0.28032E-03
2435	-0.26077E-03
2436	-0.24151E-03
2437	-0.22254E-03
2438	-0.20383E-03
2439	-0.18540E-03
2440	-0.16722E-03
2441	-0.14934E-03
2442	-0.13173E-03
2443	-0.11429E-03
2448	-0.36438E-03
2449	-0.32350E-03
2450	-0.28406E-03
2451	-0.24587E-03
2452	-0.20884E-03
2453	-0.17294E-03
2454	-0.13822E-03
2455	-0.10493E-03
2457	-0.38789E-03
2458	-0.36709E-03
2459	-0.34675E-03
2460	-0.32682E-03
2461	-0.30725E-03
2462	-0.28802E-03
2463	-0.26911E-03
2464	-0.25051E-03
2465	-0.23220E-03
2466	-0.21419E-03
2467	-0.19648E-03
2468	-0.17908E-03
2469	-0.16202E-03
2470	-0.14531E-03
2471	-0.12900E-03
2472	-0.11320E-03
2476	-0.36992E-03
2477	-0.33029E-03
2478	-0.29217E-03
2479	-0.25538E-03
2480	-0.21985E-03
2481	-0.18561E-03
2482	-0.15282E-03
2483	-0.12183E-03
2485	-0.39303E-03
2486	-0.37286E-03

2487	-0.35317E-03
2488	-0.33390E-03
2489	-0.31502E-03
2490	-0.29650E-03
2491	-0.27832E-03
2492	-0.26048E-03
2493	-0.24296E-03
2494	-0.22578E-03
2495	-0.20894E-03
2496	-0.19245E-03
2497	-0.17635E-03
2498	-0.16067E-03
2499	-0.14546E-03
2500	-0.13076E-03
2501	-0.11663E-03
2502	-0.10316E-03
2504	-0.37589E-03
2505	-0.33763E-03
2506	-0.30098E-03
2507	-0.26576E-03
2508	-0.23193E-03
2509	-0.19955E-03
2510	-0.16878E-03
2511	-0.13988E-03
2512	-0.11313E-03
2513	-0.39849E-03
2514	-0.37899E-03
2515	-0.36000E-03
2516	-0.34146E-03
2517	-0.32333E-03
2518	-0.30558E-03
2519	-0.28821E-03
2520	-0.27120E-03
2521	-0.25455E-03
2522	-0.23827E-03
2523	-0.22236E-03
2524	-0.20685E-03
2525	-0.19174E-03
2526	-0.17708E-03
2527	-0.16287E-03
2528	-0.14915E-03
2529	-0.13593E-03
2530	-0.12320E-03
2531	-0.11099E-03
2532	-0.38216E-03
2533	-0.34537E-03
2534	-0.31029E-03
2535	-0.27677E-03
2536	-0.24475E-03
2537	-0.21429E-03
2538	-0.18550E-03
2539	-0.15851E-03
2540	-0.13338E-03
2541	-0.40417E-03
2542	-0.38538E-03
2543	-0.36713E-03
2544	-0.34935E-03
2545	-0.33201E-03
2546	-0.31508E-03
2547	-0.29856E-03
2548	-0.28243E-03
2549	-0.26668E-03
2550	-0.25133E-03

2551	-0.23638E-03
2552	-0.22183E-03
2553	-0.20771E-03
2554	-0.19401E-03
2555	-0.18075E-03
2556	-0.16794E-03
2557	-0.15556E-03
2558	-0.14361E-03
2559	-0.13206E-03
2560	-0.38864E-03
2561	-0.35337E-03
2562	-0.31993E-03
2563	-0.28815E-03
2564	-0.25798E-03
2565	-0.22943E-03
2566	-0.20256E-03
2567	-0.17739E-03
2568	-0.15386E-03
2569	-0.40997E-03
2570	-0.39191E-03
2571	-0.37441E-03
2572	-0.35741E-03
2573	-0.34089E-03
2574	-0.32480E-03
2575	-0.30914E-03
2576	-0.29390E-03
2577	-0.27907E-03
2578	-0.26465E-03
2579	-0.25065E-03
2580	-0.23705E-03
2581	-0.22387E-03
2582	-0.21111E-03
2583	-0.19876E-03
2584	-0.18682E-03
2585	-0.17528E-03
2586	-0.16410E-03
2587	-0.15328E-03
2588	-0.39519E-03
2589	-0.36147E-03
2590	-0.32968E-03
2591	-0.29966E-03
2592	-0.27132E-03
2593	-0.24465E-03
2594	-0.21963E-03
2595	-0.19621E-03
2596	-0.17430E-03
2597	-0.41578E-03
2598	-0.39846E-03
2599	-0.38172E-03
2600	-0.36551E-03
2601	-0.34979E-03
2602	-0.33454E-03
2603	-0.31975E-03
2604	-0.30539E-03
2605	-0.29146E-03
2606	-0.27795E-03
2607	-0.26487E-03
2608	-0.25219E-03
2609	-0.23993E-03
2610	-0.22807E-03
2611	-0.21660E-03
2612	-0.20552E-03
2613	-0.19480E-03

```
    2614 -0.18442E-03
    2615 -0.17437E-03
    2616 -0.40170E-03
    2617 -0.36951E-03
    2618 -0.33937E-03
    2619 -0.31107E-03
    2620 -0.28452E-03
    2621 -0.25965E-03
    2622 -0.23641E-03
    2623 -0.21471E-03
    2624 -0.19442E-03
    2625 -0.42150E-03
1

 ***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
 ANSYS/Mechanical U
 00044163          VERSION=HPPA 7/8XXX    17:35:06  FEB 27, 2001 CP=     21.580

 APS Heater Sleeve MNSA Top Plate - Case 2c


  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=      1  SUBSTEP=     1
   TIME=    1.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE       UZ
    2626 -0.40490E-03
    2627 -0.38891E-03
    2628 -0.37347E-03
    2629 -0.35855E-03
    2630 -0.34412E-03
    2631 -0.33017E-03
    2632 -0.31666E-03
    2633 -0.30361E-03
    2634 -0.29098E-03
    2635 -0.27878E-03
    2636 -0.26699E-03
    2637 -0.25560E-03
    2638 -0.24461E-03
    2639 -0.23399E-03
    2640 -0.22375E-03
    2641 -0.21384E-03
    2642 -0.20427E-03
    2643 -0.19500E-03
    2644 -0.40805E-03
    2645 -0.37736E-03
    2646 -0.34880E-03
    2647 -0.32216E-03
    2648 -0.29732E-03
    2649 -0.27417E-03
    2650 -0.25264E-03
    2651 -0.23260E-03
    2652 -0.21392E-03
    2653 -0.42702E-03
    2654 -0.41113E-03
    2655 -0.39585E-03
    2656 -0.38116E-03
    2657 -0.36701E-03
    2658 -0.35336E-03
    2659 -0.34021E-03
```

2660	-0.32752E-03
2661	-0.31529E-03
2662	-0.30350E-03
2663	-0.29213E-03
2664	-0.28118E-03
2665	-0.27063E-03
2666	-0.26046E-03
2667	-0.25067E-03
2668	-0.24123E-03
2669	-0.23213E-03
2670	-0.22334E-03
2671	-0.21486E-03
2672	-0.41412E-03
2673	-0.38486E-03
2674	-0.35780E-03
2675	-0.33273E-03
2676	-0.30950E-03
2677	-0.28798E-03
2678	-0.26806E-03
2679	-0.24961E-03
2680	-0.23250E-03
2681	-0.43226E-03
2682	-0.41702E-03
2683	-0.40243E-03
2684	-0.38844E-03
2685	-0.37500E-03
2686	-0.36210E-03
2687	-0.34969E-03
2688	-0.33777E-03
2689	-0.32631E-03
2690	-0.31530E-03
2691	-0.30472E-03
2692	-0.29455E-03
2693	-0.28478E-03
2694	-0.27539E-03
2695	-0.26638E-03
2696	-0.25771E-03
2697	-0.24937E-03
2698	-0.24135E-03
2699	-0.23362E-03
2700	-0.41981E-03
2701	-0.39188E-03
2702	-0.36623E-03
2703	-0.34261E-03
2704	-0.32087E-03
2705	-0.30086E-03
2706	-0.28244E-03
2707	-0.26549E-03
2708	-0.24986E-03
2709	-0.43711E-03
2710	-0.42248E-03
2711	-0.40852E-03
2712	-0.39518E-03
2713	-0.38240E-03
2714	-0.37018E-03
2715	-0.35846E-03
2716	-0.34724E-03
2717	-0.33649E-03
2718	-0.32619E-03
2719	-0.31633E-03
2720	-0.30688E-03
2721	-0.29783E-03
2722	-0.28917E-03

2723	-0.28087E-03
2724	-0.27292E-03
2725	-0.26530E-03
2726	-0.25799E-03
2727	-0.25099E-03
2728	-0.42502E-03
2729	-0.39831E-03
2730	-0.37393E-03
2731	-0.35163E-03
2732	-0.33124E-03
2733	-0.31259E-03
2734	-0.29555E-03
2735	-0.27997E-03
2736	-0.26572E-03
2737	-0.44149E-03
2738	-0.42742E-03
2739	-0.41402E-03
2740	-0.40126E-03
2741	-0.38908E-03
2742	-0.37746E-03
2743	-0.36637E-03
2744	-0.35577E-03
2745	-0.34566E-03
2746	-0.33600E-03
2747	-0.32678E-03
2748	-0.31798E-03
2749	-0.30958E-03
2750	-0.30157E-03
2751	-0.29392E-03
2752	-0.28662E-03
2753	-0.27966E-03
2754	-0.27301E-03
2755	-0.26667E-03
2756	-0.42966E-03
2757	-0.40402E-03
2758	-0.38077E-03
2759	-0.35965E-03
2760	-0.34045E-03
2761	-0.32301E-03
2762	-0.30719E-03
2763	-0.29284E-03
2764	-0.27983E-03
2765	-0.44533E-03
2766	-0.43174E-03
2767	-0.41884E-03
2768	-0.40659E-03
2769	-0.39493E-03
2770	-0.38384E-03
2771	-0.37328E-03
2772	-0.36323E-03
2773	-0.35367E-03
2774	-0.34457E-03
2775	-0.33591E-03
2776	-0.32768E-03
2777	-0.31985E-03
2778	-0.31240E-03
2779	-0.30533E-03
2780	-0.29861E-03
2781	-0.29222E-03
2782	-0.28616E-03
2783	-0.28040E-03
2784	-0.43365E-03
2785	-0.40894E-03

2786	-0.38665E-03
2787	-0.36652E-03
2788	-0.34835E-03
2789	-0.33195E-03
2790	-0.31718E-03
2791	-0.30389E-03
2792	-0.29196E-03
2793	-0.44856E-03
2794	-0.43538E-03
2795	-0.42290E-03
2796	-0.41107E-03
2797	-0.39985E-03
2798	-0.38920E-03
2799	-0.37909E-03
2800	-0.36950E-03
2801	-0.36040E-03
2802	-0.35177E-03
2803	-0.34358E-03
2804	-0.33582E-03
2805	-0.32847E-03
2806	-0.32151E-03
2807	-0.31492E-03
2808	-0.30868E-03
2809	-0.30279E-03
2810	-0.29722E-03
2811	-0.29196E-03
2812	-0.43692E-03
2813	-0.41297E-03
2814	-0.39147E-03
2815	-0.37216E-03
2816	-0.35482E-03
2817	-0.33927E-03
2818	-0.32536E-03
2819	-0.31295E-03
2820	-0.30191E-03
2821	-0.45113E-03
2822	-0.43827E-03
2823	-0.42612E-03
2824	-0.41463E-03
2825	-0.40375E-03
2826	-0.39346E-03
2827	-0.38371E-03
2828	-0.37448E-03
2829	-0.36575E-03
2830	-0.35749E-03
2831	-0.34968E-03
2832	-0.34229E-03
2833	-0.33532E-03
2834	-0.32874E-03
2835	-0.32253E-03
2836	-0.31669E-03
2837	-0.31118E-03
2838	-0.30601E-03
2839	-0.30115E-03
2840	-0.43942E-03
2841	-0.41605E-03
2842	-0.39515E-03
2843	-0.37646E-03
2844	-0.35976E-03
2845	-0.34487E-03
2846	-0.33162E-03
2847	-0.31987E-03
2848	-0.30951E-03

```
2849 -0.45300E-03
2850 -0.44037E-03
2851 -0.42846E-03
2852 -0.41722E-03
2853 -0.40659E-03
2854 -0.39655E-03
2855 -0.38706E-03
2856 -0.37810E-03
2857 -0.36963E-03
2858 -0.36164E-03
2859 -0.35410E-03
2860 -0.34699E-03
2861 -0.34029E-03
2862 -0.33399E-03
2863 -0.32806E-03
2864 -0.32250E-03
2865 -0.31728E-03
2866 -0.31239E-03
2867 -0.30783E-03
2868 -0.44112E-03
2869 -0.41813E-03
2870 -0.39764E-03
2871 -0.37937E-03
2872 -0.36310E-03
2873 -0.34864E-03
2874 -0.33584E-03
2875 -0.32455E-03
2876 -0.31465E-03
2877 -0.45413E-03
2878 -0.44165E-03
2879 -0.42988E-03
2880 -0.41878E-03
2881 -0.40831E-03
2882 -0.39842E-03
2883 -0.38909E-03
2884 -0.38029E-03
2885 -0.37198E-03
2886 -0.36415E-03
2887 -0.35677E-03
2888 -0.34983E-03
2889 -0.34330E-03
2890 -0.33717E-03
2891 -0.33141E-03
2892 -0.32602E-03
2893 -0.32098E-03
2894 -0.31627E-03
2895 -0.31188E-03
2896 -0.44197E-03
2897 -0.41918E-03
2898 -0.39890E-03
2899 -0.38084E-03
2900 -0.36478E-03
2901 -0.35055E-03
2902 -0.33797E-03
2903 -0.32691E-03
2904 -0.31724E-03
2905 -0.28252E-03
2906 -0.30527E-03
1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
ANSYS/Mechanical U
00044163.        VERSION=HPPA 7/8XXX   17:35:06  FEB 27, 2001 CP=      21.610
```

APS Heater Sleeve MNSA Top Plate - Case 2c

***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0

THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

NODE	UZ
2907	-0.30165E-03
2908	-0.29834E-03
2909	-0.29530E-03
2910	-0.29255E-03
2911	-0.29006E-03
2912	-0.28782E-03
2913	-0.28582E-03
2914	-0.28406E-03
2930	-0.10283E-03
2931	-0.11762E-03
2932	-0.13219E-03
2933	-0.14646E-03
2934	-0.16034E-03
2935	-0.17377E-03
2936	-0.18667E-03
2937	-0.19897E-03
2938	-0.21062E-03
2939	-0.22155E-03
2940	-0.23172E-03
2941	-0.24106E-03
2942	-0.24955E-03
2943	-0.25713E-03
2944	-0.26377E-03
2945	-0.26944E-03
2946	-0.27412E-03
2947	-0.27778E-03
2948	-0.28041E-03
2949	-0.28199E-03
3006	-0.10942E-03
3015	-0.10987E-03
3019	-0.13201E-03
3020	-0.12152E-03
3021	-0.11127E-03
3022	-0.10123E-03
3028	-0.13320E-03
3029	-0.11363E-03
3032	-0.15460E-03
3033	-0.14485E-03
3034	-0.13535E-03
3035	-0.12604E-03
3036	-0.11691E-03
3037	-0.10793E-03
3041	-0.15642E-03
3042	-0.13841E-03
3043	-0.12111E-03
3044	-0.10433E-03
3045	-0.17681E-03
3046	-0.16786E-03
3047	-0.15916E-03
3048	-0.15066E-03
3049	-0.14235E-03

3050	-0.13421E-03
3051	-0.12620E-03
3052	-0.11831E-03
3053	-0.11053E-03
3054	-0.17912E-03
3055	-0.16275E-03
3056	-0.14715E-03
3057	-0.13215E-03
3058	-0.19826E-03
3059	-0.19014E-03
3060	-0.18226E-03
3061	-0.17460E-03
3062	-0.16714E-03
3063	-0.15986E-03
3064	-0.15274E-03
3065	-0.14577E-03
3066	-0.13892E-03
3067	-0.20088E-03
3068	-0.18617E-03
3069	-0.17229E-03
3070	-0.15909E-03
3071	-0.21860E-03
3072	-0.21128E-03
3073	-0.20422E-03
3074	-0.19740E-03
3075	-0.19078E-03
3076	-0.18436E-03
3077	-0.17812E-03
3078	-0.17205E-03
3079	-0.16613E-03
3080	-0.22131E-03
3081	-0.20822E-03
3082	-0.19602E-03
3083	-0.18457E-03
3084	-0.23745E-03
3085	-0.23092E-03
3086	-0.22464E-03
3087	-0.21861E-03
3088	-0.21280E-03
3089	-0.20721E-03
3090	-0.20181E-03
3091	-0.19659E-03
3092	-0.19155E-03
3093	-0.24005E-03
3094	-0.22849E-03
3095	-0.21787E-03
3096	-0.20806E-03
3097	-0.25450E-03
3098	-0.24869E-03
3099	-0.24314E-03
3100	-0.23784E-03
3101	-0.23278E-03
3102	-0.22795E-03
3103	-0.22333E-03
3104	-0.21891E-03
3105	-0.21468E-03
3106	-0.25677E-03
3107	-0.24660E-03
3108	-0.23741E-03
3109	-0.22909E-03
3110	-0.26946E-03
3111	-0.26428E-03
3112	-0.25938E-03

3113	-0.25474E-03
3114	-0.25035E-03
3115	-0.24620E-03
3116	-0.24227E-03
3117	-0.23855E-03
3118	-0.23504E-03
3119	-0.27117E-03
3120	-0.26221E-03
3121	-0.25427E-03
3122	-0.24725E-03
3123	-0.28206E-03
3124	-0.27742E-03
3125	-0.27307E-03
3126	-0.26899E-03
3127	-0.26517E-03
3128	-0.26160E-03
3129	-0.25826E-03
3130	-0.25515E-03
3131	-0.25225E-03
3132	-0.28300E-03
3133	-0.27505E-03
3134	-0.26815E-03
3135	-0.26220E-03
3136	-0.29208E-03
3137	-0.28789E-03
3138	-0.28398E-03
3139	-0.28035E-03
3140	-0.27699E-03
3141	-0.27388E-03
3142	-0.27102E-03
3143	-0.26838E-03
3144	-0.26597E-03
3145	-0.29205E-03
3146	-0.28488E-03
3147	-0.27878E-03
3148	-0.27366E-03
3149	-0.29937E-03
3150	-0.29549E-03
3151	-0.29191E-03
3152	-0.28861E-03
3153	-0.28558E-03
3154	-0.28281E-03
3155	-0.28030E-03
3156	-0.27801E-03
3157	-0.27596E-03
3158	-0.29818E-03
3159	-0.29153E-03
3160	-0.28597E-03
3161	-0.28142E-03
3162	-0.30379E-03
3163	-0.30011E-03
3164	-0.29672E-03
3165	-0.29362E-03
3166	-0.29080E-03
3167	-0.28824E-03
3168	-0.28593E-03
3169	-0.28386E-03
3170	-0.28202E-03
3171	-0.30127E-03
3172	-0.29488E-03
3173	-0.28960E-03
3174	-0.28533E-03

```
MAXIMUM ABSOLUTE VALUES
NODE        330
VALUE  -0.50233E-03

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT    FOR ITEM=VOLU COMPONENT=
 IN RANGE         0 TO         0 STEP          1

     0  VOLUMES (OF      0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT    FOR ITEM=AREA COMPONENT=
 IN RANGE         1 TO        17 STEP          1

   11  AREAS (OF    11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT    FOR ITEM=LINE COMPONENT=
 IN RANGE         1 TO        49 STEP          1

   38  LINES (OF    38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT    FOR ITEM=KP   COMPONENT=
 IN RANGE         1 TO       102 STEP          1

    25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT    FOR ITEM=ELEM COMPONENT=
 IN RANGE         1 TO      1013 STEP          1

    1013  ELEMENTS (OF     1013  DEFINED) SELECTED BY  ESEL  COMMAND.

ALL SELECT    FOR ITEM=NODE COMPONENT=
 IN RANGE         1 TO      3174 STEP          1

    3174  NODES (OF     3174  DEFINED) SELECTED BY NSEL  COMMAND.

SELECT        FOR ITEM=LINE COMPONENT=
 IN RANGE        30 TO        32 STEP          1

    3  LINES (OF    38  DEFINED) SELECTED BY LSEL  COMMAND.

SELECT      ALL NODES (INTERIOR TO LINE, AND AT KEYPOINTS)
       RELATED TO SELECTED LINE SET.

      47  NODES (OF     3174  DEFINED) SELECTED FROM
       3 SELECTED LINES BY NSLL COMMAND.

PRINT S     NODAL SOLUTION PER NODE
1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2    *****
ANSYS/Mechanical U
00044163          VERSION=HPPA 7/8XXX   17:35:06  FEB 27, 2001 CP=     22.260

APS Heater Sleeve MNSA Top Plate - Case 2c


 ***** POST1 NODAL STRESS LISTING *****

 LOAD STEP=      1  SUBSTEP=      1
  TIME=    1.0000      LOAD CASE=   0
 SHELL NODAL RESULTS ARE AT TOP
```

NODE	S1	S2	S3	SINT	SEQV
330	3578.8	0.73797	-0.93903E-01	3578.9	3578.4
366	3288.4	484.85	-523.11	3811.5	3420.8
368	3429.1	153.45	-50.103	3479.2	3382.0
370	3295.4	273.23	-106.25	3401.6	3228.6
372	3173.0	366.09	-169.65	3342.7	3109.6
374	3058.7	436.94	-241.47	3300.1	3018.7
376	2949.6	489.91	-322.90	3272.5	2951.3
378	2843.8	528.53	-415.10	3258.9	2904.5
380	2739.7	555.79	-519.14	3258.9	2876.2
2365	1342.6	17.917	-141.05	1483.6	1410.9
2367	3230.9	355.59	-311.81	3542.8	3260.7
2369	2780.6	272.86	-265.59	3046.2	2815.8
2371	2451.5	197.80	-238.09	2689.6	2500.3
2373	2194.6	139.65	-219.92	2414.5	2256.3
2375	1986.0	97.604	-206.36	2192.4	2057.3
2377	1812.7	68.256	-194.60	2007.3	1889.7
2379	1666.5	48.078	-182.92	1849.5	1745.5
2381	1542.0	34.231	-170.36	1712.4	1619.8
2383	1435.1	24.653	-156.48	1591.6	1509.2
2905	976.92	0.11651	-2.1040	979.02	977.91
2907	1257.4	12.834	-122.78	1380.1	1317.6
2909	1182.1	9.0750	-101.85	1284.0	1232.2
2911	1113.4	6.0526	-76.955	1190.4	1151.1
2913	1047.2	3.2646	-45.501	1092.7	1069.1

MINIMUM VALUES

NODE	2905	2905	366	2905	2905
VALUE	976.92	0.11651	-523.11	979.02	977.91

MAXIMUM VALUES

NODE	330	380	330	366	330
VALUE	3578.8	555.79	-0.93903E-01	3811.5	3578.4

***** ESTIMATED BOUNDS CONSIDERING THE EFFECT OF DISCRETIZATION ERROR *****

MINIMUM VALUES

NODE	2905	366	366	2905	2905
VALUE	976.55	-432.08	-1440.0	978.66	977.55

MAXIMUM VALUES

NODE	366	366	366	366	366
VALUE	4205.3	1401.8	393.82	4728.4	4337.7

****

NODAL RESULTS ARE SHELL BOTTOM

PRINT S NODAL SOLUTION PER NODE

1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM RELEASE 5.5.2 *****
ANSYS/Mechanical U
00044163 VERSION=HPPA 7/8XXX 17:35:07 FEB 27, 2001 CP= 22.880

APS Heater Sleeve MNSA Top Plate - Case 2c

***** POST1 NODAL STRESS LISTING *****

LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0
SHELL NODAL RESULTS ARE AT BOTTOM

NODE	S1	S2	S3	SINT	SEQV

330	-0.64403	-1833.9	-3578.8	3578.1	3099.1
366	254.73	-1133.4	-3288.4	3543.1	3092.3
368	-98.919	-1838.3	-3429.1	3330.2	2885.0
370	-149.74	-1851.1	-3295.4	3145.6	2727.2
372	-159.35	-1871.0	-3173.0	3013.7	2617.9
374	-133.42	-1895.9	-3058.7	2925.2	2551.0
376	-76.965	-1923.9	-2949.6	2872.7	2521.5
378	5.8232	-1953.1	-2843.8	2849.7	2525.0
380	111.66	-1982.2	-2739.7	2851.4	2558.2
2365	141.05	-17.917	-1342.6	1483.6	1410.9
2367	311.81	-355.59	-3230.9	3542.8	3260.7
2369	265.59	-272.86	-2780.6	3046.2	2815.8
2371	238.09	-197.80	-2451.5	2689.6	2500.3
2373	219.92	-139.65	-2194.6	2414.5	2256.3
2375	206.36	-97.604	-1986.0	2192.4	2057.3
2377	194.60	-68.256	-1812.7	2007.3	1889.7
2379	182.92	-48.078	-1666.5	1849.5	1745.5
2381	170.36	-34.231	-1542.0	1712.4	1619.8
2383	156.48	-24.653	-1435.1	1591.6	1509.2
2905	2.1040	-0.11651	-976.92	979.02	977.91
2907	122.78	-12.834	-1257.4	1380.1	1317.6
2909	101.85	-9.0750	-1182.1	1284.0	1232.2
2911	76.955	-6.0526	-1113.4	1190.4	1151.1
2913	45.501	-3.2646	-1047.2	1092.7	1069.1

MINIMUM VALUES

NODE	372	380	330	2905	2905
VALUE	-159.35	-1982.2	-3578.8	979.02	977.91

MAXIMUM VALUES

NODE	2367	2905	2905	330	2367
VALUE	311.81	-0.11651	-976.92	3578.1	3260.7

***** ESTIMATED BOUNDS CONSIDERING THE EFFECT OF DISCRETIZATION ERROR *****

MINIMUM VALUES

NODE	366	380	366	2905	2905
VALUE	-662.20	-2630.5	-4205.3	978.66	977.55

MAXIMUM VALUES

NODE	366	2367	2905	366	366
VALUE	1171.7	292.80	-976.55	4460.0	4009.2

```
***************************************************************************

SELECT ALL ENTITIES OF TYPE= ALL  AND BELOW

ALL SELECT    FOR ITEM=VOLU COMPONENT=
 IN RANGE         0 TO          0 STEP          1

     0  VOLUMES (OF       0  DEFINED) SELECTED BY  VSEL  COMMAND.

ALL SELECT    FOR ITEM=AREA COMPONENT=
 IN RANGE         1 TO         17 STEP          1

   11  AREAS (OF     11  DEFINED) SELECTED BY ASEL COMMAND.

ALL SELECT    FOR ITEM=LINE COMPONENT=
 IN RANGE         1 TO         49 STEP          1

   38  LINES (OF     38  DEFINED) SELECTED BY LSEL COMMAND.

ALL SELECT    FOR ITEM=KP   COMPONENT=
 IN RANGE         1 TO        102 STEP          1
```

```
   25  KEYPOINTS (OF     25  DEFINED) SELECTED BY  KSEL  COMMAND.

ALL SELECT   FOR ITEM=ELEM COMPONENT=
 IN RANGE        1 TO     1013 STEP        1

   1013  ELEMENTS (OF     1013  DEFINED) SELECTED BY  ESEL  COMMAND.

ALL SELECT   FOR ITEM=NODE COMPONENT=
 IN RANGE        1 TO     3174 STEP        1

   3174  NODES (OF     3174  DEFINED) SELECTED BY NSEL  COMMAND.

PRINT FZ   REACTION SOLUTIONS PER NODE
1

***** ANSYS - ENGINEERING ANALYSIS SYSTEM  RELEASE 5.5.2   *****
ANSYS/Mechanical U
00044163          VERSION=HPPA 7/8XXX   17:35:07  FEB 27, 2001 CP=     22.910

APS Heater Sleeve MNSA Top Plate - Case 2c


 ***** POST1 TOTAL REACTION SOLUTION LISTING *****

 LOAD STEP=     1  SUBSTEP=     1
  TIME=    1.0000      LOAD CASE=   0

 THE FOLLOWING X,Y,Z SOLUTIONS ARE IN GLOBAL COORDINATES

   NODE       FZ
    950   158.66
   1315   341.34

TOTAL VALUES
VALUE    500.00

EXIT THE ANSYS POST1 DATABASE PROCESSOR


***** ROUTINE COMPLETED *****  CP =        22.930



***** END OF INPUT ENCOUNTERED *****

PURGE ALL SOLUTION AND POST DATA
SAVE ALL MODEL DATA

ALL CURRENT ANSYS DATA WRITTEN TO FILE NAME= c2c.db
 FOR POSSIBLE RESUME FROM THIS POINT


NUMBER OF WARNING MESSAGES ENCOUNTERED=          0
NUMBER OF ERROR   MESSAGES ENCOUNTERED=          0


*---------------------------------------------------------------------------*
|                                                                           |
|                           ANSYS RUN COMPLETED                             |
|                                                                           |
|---------------------------------------------------------------------------|
|                                                                           |
|          RELEASE 5.5.2         UP19990107       HPPA 7/8XXX               |
```

```
|                                                                          |
|       CP TIME       (sec) =          23.450       TIME  =  17:35:08      |
|       ELAPSED TIME  (sec) =          26.000       DATE  =  02/27/2001    |
|                                                                          |
*--------------------------------------------------------------------------*
1

 Start of Job Log:     Tue Feb 27 17:34:40 EST 2001

     1  ansys55 -m 48

 End of Job Log:       Tue Feb 27 17:35:08 EST 2001
1

  Date/Time: Tue Feb 27 17:35:08 EST 2001

  Job Statistics:

     CPU Time (User)     = 21.0 Secs.
     CPU Time (System)   = 3.2 Secs.
     CPU Time (Total)    = 24.2 Secs.

     Total Elapsed Time = 00:00:25 hr:min:sec
     CPU Utilization     = 95%
     Page Faults         = 806
     I/O Blocks          = 10351
```

ATTACHMENT D

CALCULATION OF THE TOP PLATE TEMPERATURE

Calculation of Top Plate temperature for Heater Sleeve MNSA (based on Tie Rods axial conduction)

Infinite Fin ("Heat Transfer - a Basic Approach", M.N. Ozisik, McGraw-Hill Inc., 1985)

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-mx} \qquad m^2 = \frac{hP}{kA}$$

Ambient Temperature	T,inifinite	120	°F
Base Temperature	T,o	653	°F
Nominal dimension	tie rod OD	0.375	in
Nominal dimension	tie rod OD	0.03125	ft
Tie Rod area	A	0.000767	ft2
Tie Rod perimeter	P	0.098175	ft
Tie Rod therm cond (Ref 5.9, 300°F)	k	8.8	btu/hr-ft-F
generic outside film coefficient	h	1.7	btu/hr-ft2-F
calulcated coefficient	m	4.972652	

Length	x	T
0	0	653
0.6	0.0500	536
1.2	0.1000	444
1.8	0.1500	373
2.4	0.2000	317
3.0	0.2500	274
3.6	0.3000	240
4.2	0.3500	214

ATTACHMENT E

QUALITY ASSURANCE FORMS

DESIGN REPORT REVIEW CHECKLIST

Instructions: The Independent Reviewer is to complete this checklist for each Design Report. This checklist may be incorporated into the Design Report or maintained separate.

Title: Addendum to CENC-1336, CENC-1395 and CENC-1490 Analytical Reports for Arizona Units 1, 2 and 3 Pressurizers

Document Number: PV-PS-DR-0006 **Revision Number:** 001

	Yes	N/A
1. Have all drawings been prepared and independently reviewed in accordance with QP 3.7?	☐	☒
2. Are Checklists for the Design Analysis (QP 3.4) and Drawing (QP 3.7) review attached to the Design Report or on file with the CEO as quality records?	☒	☐
3. Have the analyses been separately prepared and independently reviewed in accordance with QP 3.4? ; or	☒	☐
4. Is the analyses to be independently reviewed in conjunction with the compilation and verification of the design report?	☒	☐
5. Have all applicable TCRs, DCRs, NCRs, etc. been listed and reconciled in the Design Report?	☒	☐
6. Are all applicable drawings and analyses used for design and construction in agreement with, and identified and described in the Design Report?	☒	☐
7. Are the correct revision levels of all design output documents listed?	☒	☐
8. Have provisions been made for a copy of the Owner's Review of the Design Report to be attached to the Design Report?	☐	☒
9. Does the Design Report contain sufficient details and references to permit certification by a Registered Professional Engineer (RPE)?	☒	☐
10. Is the Design Report in accordance with the format requirements of the procedure?	☒	☐

Comments (if any)

Checklist completed by:

	Printed Name	Signature	Date
Independent Reviewer	C. R. Schmidt	C R Schmidt	3-16-01

Design Analysis Verification Checklist

Instructions: If a major topic area (generally unnumbered, bold face type such as **Use of Computer Software**) is not applicable, then N/A (not applicable) next to the topic may be checked and the check boxes for all items under it may be left blank. Where there is no check box under N/A for a numbered item, such a response is generally inappropriate. If N/A is checked in such a situation, document the basis at the end of this checklist in the Comments section.

	Author Yes	Author N/A	IR Concur.
Overall Assessment			
1. Are the results/conclusions correct and appropriate for their intended use?	☒		☐
2. Are all limitations and contingencies on the results/conclusions documented?	☒		☐
Assignment of Cognizant Engineers, Independent Reviewers and Mentors			
1. If there are multiple Cognizant Engineers, has their scope been documented?	☐	☒	☐
2. If there are multiple Independent Reviewers, has their scope been documented?	☐	☒	☐
3. If there will be multiple Management Approvers, has their scope been documented?	☐	☒	☐
4. If an Independent Reviewer is the supervisor or Project Manager, has authorization as an Independent Reviewer been documented?	☐	☒	☐
5. If there is a Mentor, has their scope and responsibilities been adequately documented?	☐	☒	☐
Use of Computer Software			
For software which has been validated under QP 3.13:		☐	☐
1. Is the software listed on an Approved QC-1 Software List?	☒	☐	☐
2. Is the software applicable for this analysis?	☒		☐
For Code-Like Constructs validated under QP 3.14.		☒	☐
1. Is the Code-Like Construct listed on an Approved QC-1 Software List?	☐		☐
2. Is the Code-Like Construct applicable for this analysis?	☐		☐
3. Was the Code-Like Construct used directly in the controlled location?	☐	No ☒	☐
- If No above, is the copy identical to the version in the controlled location? (Leave blank if not applicable.)	☐		☐
- If changes were made to the Code-Like Construct to meet specific analysis needs, were such changes documented as non-validated software following paragraph 3.3.3? (Leave blank if not applicable. Complete the next section of this Checklist if "Yes".)	☐		☐
For software which has not been validated under QP 3.13 or QP 3.14:		☒	☐
1. Is the computer type, program name and revision identification documented?	☐		☐
2. Is a copy of the software included in the Design Analysis?	☐		☐
3. Have tests been documented which are adequate to demonstrate correct operation for the software's intended use?	☐		☐
4. Is the output from the tests included in the Design Analysis?	☐		☐
5. Has the Cognizant Engineer documented the results of the tests and the basis for concluding the software is operating correctly for its intended use?	☐		☐
6. Did the software, as used in this analysis, give correct results?	☐		☐

Design Analysis Verification Checklist

Use of Computer Software (continued)	Author Yes	Author N/A	IR Concur.
1. Were spreadsheets used in this Design Analysis in any way - data display, plotting, computations, etc.?	☐	No ☒	☐
- If data display only (no computations or plotting), check "Yes" and skip remaining questions.	☐	☐	☐
- If used for computations:	☐	☐	☐
• Are the computations adequately documented?	☐		☐
• Are the results correct?	☐		☐
- If used for ploting:	☐	☐	☐
• Is the data to be plotted correct?	☐		☐
• Are the plots correct in other respects? (titles, scales, labels, etc.)	☐		☐
8. Is a copy of the spreadsheet included in the Design Analysis? (A copy of the file may be included or sufficient detail included in the analysis documentation to permit recreating the spreadsheet.)	☐		☐
Objective of the Design Analysis			
1. Has information necessary to define the task been included or referenced?	☒		☐
2. Have the objectives been enumerated?	☒		☐
3. Has the applicability and intended use of the results been documented?	☒		☐
Assessment of Significant Design Changes			
1. Have significant design-related changes that might impact this analysis been considered?	☒		☐
2. If any such changes have been identified, have they been adequately addressed?	☒	☐	☐
Analytical Techniques (Methods)			
1. Are the analytical techniques (methods) described in sufficient detail to judge their appropriateness?	☒		☐
2. Are the analytical techniques used or their application governed by an NRC issued SER?	☐	No ☒	☐
If yes, have the applicable SERs been documented?	☐		☐
If yes, has the basis for concluding the analysis is in conformance been documented?	☐		☐
3. Have analytical techniques incorporated by reference to generic analyses, lead plant analyses or previous cycle analyses been previously verified?	☐	☒	☐
4. Are any modifications or departures from previously approved analytical techniques or Conventional or Automated Procedures documented and justified?	☐	☒	☐
5. If superseded approved analytical techniques or engineering procedures are used, is their use justified and approved?	☐	☒	☐
6. Does the issue date of referenced approved Conventional or Automated Procedures predate their use in this analysis?	☐	☒	☐
Selection of Design Inputs			
1. Are the design inputs documented?	☒		☐
2. Are the design inputs correctly selected and traceable to their source?	☒		☐
3. Are the bases for selection of all design inputs documented?	☒		☐
4. Is previously unverified design input uised in this analysis?	☐	No ☒	☐
If Yes, is-it treated in accordance with QP 3.2, paragraph 3.4 for use of unverified desing information?	☐		☐

Design Analysis Verification Checklist

Selection of Design Inputs (continued)	Author Yes	Author N/A	IR Concur.
5. Is the verification status of design inputs transmitted from customers or CENP Nuclear Systems appropriate and documented?	☒	☐	☐
6. Is the use of customer-controlled sources such as Tech Specs, UFSARs, etc. authorized, and does the authorization specify amendment level, revision number, etc.?	☐	☒	☐
Assumptions			
1. If there are no assumptions, is this documented?	☐	☒	☐
2. Are local assumptions documented, fully justified and verified?	☒	☐	☐
3. Are Internal and External Assumptions which must be cleared by CENP or the customer listed on a Contingencies and Assumptions form?	☒	☐	☐
4. Is the Project Manager responsible for clearing the Assumptions identified on the form?	☒	☐	☐
Results/Conclusions			
1. Are all results contained in or referenced in the Results/Conclusion section? (Where feasible, in the enumerated order of the objectives.)	☒		☐
2. Are all limitations on the results/conclusions and their applicability documented in this section?	☒		☐
3. Are all contingencies on the results that must be cleared listed in the Results/Conclusion section or the Contingencies and Assumptions form referenced?	☐	☒	☐
4. Is the Project Manager responsible for clearing the Assumptions or Contingencies identified on the form?	☐	☒	☐
Other Elements			
1. Has a comparison of the results with those of a previous cycle or similar analysis been documented and significant differences explained?	☐	☒	☐
2. Have applicable Codes (e.g., ASME Code) and standards been appropriately referenced and applied?	☒	☐	☐
3. Is the information from relevant literature searches/background data adequately documented and referenced?	☒	☐	☐
4. Are hand calculations correct and appropriately documented?	☒	☐	☐
5. Is all applicable computer output and input included?	☒	☐	☐
6. Is all computer software used identified by name and revision identification?	☒	☐	☐
References			
1. Are all references used to perform the analysis listed?	☒	☐	☐
2. Are the references as direct as possible and appropriate to the source?	☒		☐
3. Is the reference notation specific to the information utilized, including revision level or date of issue, and where appropriate, identification of the location of the information in the reference, such as page, table or paragraph number?	☒		☐

Independent Reviewer's Statement of Verification Activities:

Independent Reviewer to describe details of verification activities beyond the obvious on this checklist including, but not limited to the review of new methods, use of software under paragraph 3.3.3, spreadsheet use, assessment of design and methodology changes, engineering judgments, the use of previously unverified inputs, etc.

Design Analysis Verification Checklist

The Form and Format section of the Checklist below may be completed by a Checker under the direction of the Independent Reviewer.

Form/Format	Author Yes	Author N/A	IR Concur.
1. Is the document legible, reproducible and in a form suitable for filing and retrieving as a Quality Record?	☒		☐
2. Except as permitted by 3.1.3.a, are all pages identified with the document number, including revision number?	☒		☐
3. Except as permitted by 3.1.3.a, do all pages have a unique page number?	☒		☐
4. Have all changes been authenticated by the initials and date of the Quality Records Controller?	☐	X	☐
5. Are all files on CD-ROM identified by the path name?	☐	☒	☐
6. Are all computer disks identified with the analysis number?	☐	☒	☐
7. Are any unverified sections of an otherwise verified analysis clearly indicated?	☐	☒	☐
For a "Memorandum Revision" to a completed Design Analysis:		☒	☐
1. Have the title and document number been preserved without change?	☐		☐
2. Does this revision meet the criteria for a "simple revision"?	☐		☐
3. Are the Author, Independent Reviewer and Management Approver and their roles identified?	☐		☐
For a revision to a completed analysis in the "Complete Revision" and "Page Change Package" formats:		☒	☐
1. Where practical, have changes and additions been identified by mechanisms such as vertical lines, etc.?	☐		☐
2. Where practical, have deletions been identified by mechanisms such as strike outs, etc.?	☐		☐
3. Have indications of change in previous revisions been removed?	☐		☐
4. Does the distribution of the revision include those on the distribution of the previous revision?	☐		☐
For a "Complete Revision":		☐	☐
1. Have the title and document number been preserved without change?	☒		☐
2. Has the revision number been incremented by one?	☒		☐
For a "Page Change Package":		☐	☐
1. Are pages numbered in accordance with the original analysis?	☐		☐
2. Are instructions provided for the insertion and deletion of revisied pages?	☐		☐
3. Has a new Title Page been prepared?	☐		☐
4. Does the Package Contents Page reflect the change package contents?	☐		☐

☐ Form/Format section completed by the Independent Reviewer.

☐ Form/Format section completed by the Checker identified below:

Checker Name: ____________________ Signature: ____________________

Reviewer's Comment Form

Title: Addendum to CENC-1336, CENC-1395 and CENC-1490 Analytical Reports for Arizona Units 1, 2 and 3 Pressurizers

Document Number: PV-PS-DR-0006 Revision Number: 001

Comment Number	Reviewer's Comment	Response Required?	Author's Response	Response Accepted?
1	Make editorial changes as noted	N		

APPENDIX B

Westinghouse Electric Company

ASME Construction Code Reconciliation Report

NOME – 01 – V1 - 0092

For

Pressurizer Heater Sleeve

Mechanical Nozzle Seal Assemblies

At Palo Verde Nuclear Generating Station

Units 1, 2 and 3

Westinghouse Electric Company
Nuclear Services

2000 Day Hill Road
Windsor, CT 06095

March 22, 2001
NOME-01-V1-0092

Arizona Public Service Company
Palo Verde Nuclear Generating Station
5801 S. Wintersburg Road
Tonopah, AZ 85354-7529
Attn: Rex Meeden

SUBJECT: Mechanical Nozzle Seal Assemblies (MNSA)
CEOG Task 2014 – Large Heater Sleeve MNSAs
Code Reconciliation

Dear Mr. Meeden:

Enclosed for your use and information is the following document:

Construction Code Reconciliation for Palo Verde Pressurizer Heater Sleeve Mechanical Nozzle Seal Assembly (MNSA)

If there are any questions or comments please call me at (860)285-2030.

Sincerely,

John T. McGarry
Project Manager

xc: F. Kiraly

Construction Code Reconciliation for Palo Verde Pressurizer Heater Sleeve Mechanical Nozzle Seal Assembly (MNSA)

The purpose of this reconciliation is to demonstrate fulfillment of the requirements for use of a later edition of the Construction Code for a Mechanical Nozzle Seal Assembly to be used at Arizona Public Service's Palo Verde Units 1, 2 and 3. This is intended to allow the use of the CE Nuclear Power LLC MNSA, which is built to an Edition of the ASME Code which is later than the Edition of the Code of Construction to which the Pressurizer Assembly was designed and analyzed.

In accordance with Arizona Public Service Project Specification No. 14273-PE-130, the Construction Code for the Palo Verde Units 1, 2, and 3 Pressurizer Assembly is the ASME 1971 Edition through Winter 1973 Addenda (hereinafter referred to as the **Construction Code**). The Construction Code associated with the Installation is the 1974 Edition through the Winter 1975 Edition (hereinafter referred to as the **Installation Code**). The ASME Section XI program at Palo Verde 1, 2, and 3 is in accordance with the 1992 Edition, with the 1992 Addenda (hereinafter referred to as the **Section XI Code**). The Construction Code used for the MNSA project is the 1989 Edition, No Addenda, of the ASME Code, Section III (hereinafter referred to as the **Replacement Code**).

The Palo Verde MNSA Project involves both Repair and Replacement activities in accordance with the Section XI Code. Subparagraph IWA-4170(b) states that "Repairs and installation of replacement items shall be performed in accordance with the Owner's requirements and the original Construction Code of the component or system. Later Editions and Addenda of the Construction Code or of Section III, either in their entirety or portions thereof, and Code Cases may be used." The Replacement Code is therefore acceptable for the Repair activities, which includes Installation.

In addressing Code Applicability, the Section XI Code (Subparagraph IWA-4170 (c)) specifies that "Items to be used for replacement shall meet the following requirements, unless the alternative of IWA-4170 (d) is adopted:" Subparagraph IWA-4170(d) specifies:

> "An item to be used for replacement may meet revised Owner's Requirements, or all or portions of the requirements of later Editions and Addenda of the Construction Code or Section III when the Construction Code was not Section III, provided that the following requirements are met.
>
> (1) The requirements affecting the design, fabrication, and examination of the item to be used for replacement are reconciled with the original Construction Code and Owner's Requirements to ensure that the item is satisfactory for the specified design and operating conditions.
>
> (2) Mechanical interfaces, fits and tolerances that provide satisfactory performance are compatible with the system and component requirements.
>
> (3) Materials are compatible with the installation and system requirements."

These three requirements are addressed individually in below:

Requirement 1

> "The requirements affecting the design, fabrication, and examination of the item to be used for replacement are reconciled with the original Construction Code and Owner's Requirements to ensure that the item is satisfactory for the specified design and operating conditions."

Discussion

CE Nuclear Power LLC has prepared design specification V1-NOME-SP-0082, Rev. 00 for the Mechanical Nozzle Seal Assembly, specifying the Construction Code (i.e., the Replacement Code) for the MNSA to be the 1989 Edition of the ASME B&PV Code with no Addenda.

The Design requirements in the Pressurizer Assembly Specification (14273-PE-130) for ASME Code Class 1 components, are per Article NB-3000 of the Construction Code. The fabrication and Installation requirements are per Article NB-4000 of the respective Construction and Installation Codes. The Examination requirements are per Article NB-5000 of the Construction Code. Similar Articles specify the Design, Fabrication and Installation, and Examination requirements of the Replacement Code. The corresponding Articles for Design, Fabrication and Installation, and Examination requirements of the Replacement Code are Articles NB-3000, NB-4000, and NB-5000, respectively. It is noted that Testing requirements are defined in a similar fashion per Article NB-6000 of both Codes. Although the APS MNSA's have been evaluated for leaktightness, they are not N-stamped and hydrotesting of each MNSA is not required. Therefore no reconciliation of Testing requirements is deemed necessary.

A comparison of each of the requirements of Design, Fabrication, and Examination for the Construction and Installation Codes and the Replacement Code is provided below:

Design

The MNSA uses the General Design Criteria (NB-3100) and Design by Analysis (NB-3200) for its design rules. Thus, reconciliation of Sub-Articles 3300, 3400 and 3500 is unnecessary.

There have been two primary changes in NB-3110 between the Construction Code and the Replacement Code. In the Construction Code, Design Conditions (NB-3112) included a definition of Pressure, Temperature, and Mechanical Loads and Operating Conditions (NB-3113) included a definition of Normal, Upset, Emergency, Faulted and Test Conditions. In the Replacement Code, Paragraph NB-3112 has been renamed "Design Loadings" and still includes Pressure, Temperature, and Mechanical Loads but directs the user to NCA-2142 for

how to establish those loads. NCA-2142 in the Replacement Code remains consistent with the rules in NB-3112 of the Construction Code. Also, in the Replacement Code, Paragraph NB-3113 has been renamed "Service Conditions" and directs the user to NCA-2142 for classification of Service Conditions. Because the NRC has final authority over what an event is classified after discussions with the Owner/Licensee, it was determined that ASME was at best duplicating and at worst conflicting with the Regulatory Authority and the Code was revised to simply include the analytical limits for each condition (which were also renamed A, B, C, D, and Test). The classification of events within each category is now left to be agreed to by the NRC and the Owner/Licensee. The MNSA Design Specification classifies the events in the same fashion as the Pressurizer Assembly Specification which was agreed to by the NRC and APS and is considered reconciled. NB-3300 has added nomenclature and acronyms over the years and has become more refined and prescriptive. However, this Sub-article is concerned with components under external pressure, spherical and cylindrical shells, etc. which do not effect the design of the MNSA.

Stresses in the various parts of the MNSA are determined using common strength of materials elastic methods. These resultant stresses are then categorized and combined as required in NB-3200 and compared to specified allowables. This method is consistent between the Construction Code and the Replacement Code. The bolting items are designed and analyzed to NB-3230. Except for nomenclature differences, the Construction Code and the Replacement Code are identical in this area. As such, they require no reconciliation.

Finally, a Design Report has been prepared and demonstrates that the modified design is satisfactory for use for the design and operating conditions specified in V1-NOME-SP-0082, Rev. 00.

Fabrication and Installation

The preponderance of rules in NB-4000 for Fabrication and Installation are concerned with welding, weld preparation, repair by welding, etc. There is no welding involved in the fabrication or installation of the MNSA; therefore, the welding requirements need no reconciliation.

The Subarticles related to the MNSA are limited to NB-4100 and NB-4700. Within these, only Sub-subarticles NB-4110, 4120, 4130 and 4710 and Paragraph NB-4211 actually apply.

NB-4110 is simply the Introduction to the Article and is essentially identical between Code Editions. NB-4130, "Elimination and Repair of Defects" was renamed "Repair of Material" in the Replacement Code, but other than that is essentially the same as the Construction and Installation Codes. NB-4211 "Cutting" is identical in the Codes. NB-4710 is specific to the installation of bolts and studs and is identical between Code Editions. Thus, none of these Sub-subarticles or paragraphs requires reconciliation.

The applicable portions of NB-4120 are slightly different between Code Editions. The 1989 Code has been editorially changed to refer to "Certificate Holder(s)" versus "Manufacturer(s)" in the Construction and Installation Codes. Also, references to NA-8000

have been changed to NCA-8000. These changes were made to comply with other Code changes and are considered editorial in nature requiring no reconciliation. The technical requirement in the Replacement Code which does not appear in the Construction and Installation Codes is found in the addition of Subparagraph NB-4121.3 which requires that a new surface exam of the material be performed if the material is machined in the course of fabrication or installation. This is an improvement over the Construction and Installation Codes as it requires an additional examination intended to detect subsurface indications that are brought to the surface when the previously examined surface is removed. This requirement is not found in the Construction and Installation Codes and is more conservative. CE Nuclear Power LLC does perform this examination after machining and the results are forwarded in the data package for the MNSA. With this, the Replacement Code is considered reconciled with the Construction and Installation Codes.

Examination

It should be noted that the Examination requirements in NB-5000 of the Construction Code are for welds and welded fabrication. This does not apply to the MNSA. There are no welds or welded parts used in the assembly. Thus, no specific reconciliation between NB-5000 of the Construction Code and NB-5000 of the Replacement Code is necessary. However, the machined surfaces of the parts undergo a surface (liquid penetrant) examination after machining as required by the Replacement Code (NB-4121.3). This requirement is also found in NB-2547(c) of the Construction Code and NB-2547(c) and (d) of the Replacement Code.

The Section XI Code has separate examination and testing requirements for the installed replacement (IWA-4820, IWA-5000, IWB-2200 and IWA-2000) to assure proper installation and operation of the replacement item.

REQUIREMENT 2

> "Mechanical interfaces, fits, and tolerances that provide satisfactory performance are compatible with the system and component requirements."

Discussion

The MNSA serves to replace the pressure boundary provided by the heater sleeve to vessel J-weld. As such, the system and component requirements to be performed are the same as the J-weld: (1) maintain pressure boundary integrity (no leakage), and (2) prevent heater sleeve/heater ejection.

The relevant interfaces, fits, and tolerances to maintain pressure boundary integrity (no leakage) are associated with the seal between the Split Packing (Grafoil) of the Assembly and the Mechanical Nozzle. The leaktight integrity of the seal is demonstrated in the Leak Test Report provided with the Assembly.

The relevant interfaces, fits, and tolerances to prevent heater sleeve ejection are associated with the structural integrity of the Assembly under all design conditions assuming the internal J-weld has failed or the heater sleeve has failed outboard of the J-weld. The structural integrity of the Assembly under the specified loading conditions is proven in the MNSA Design Report and in the Leak Tests noted above. The tests and Design Report provide assurance that the mechanical interfaces, fit, and tolerances that provide satisfactory performance are compatible with the system and component requirements.

Requirement 3

"Materials are compatible with the installation and system requirements."

Discussion

The materials used to fabricate the Replacement item appear in an ASME published and NRC endorsed Edition of the Code and, therefore, may be considered acceptable for use in the Owner's Specification.

The Palo Verde MNSA is fabricated from SA-479 Type 304 austenitic stainless steel, and SA-453 Grade 660 high alloy, high temperature bolting material. Both of these materials are similar in general corrosion resistance to the Heater Sleeve material of SB-166 (Inconel) and are compatible with the Pressurizer Vessel base material SA-533 Grade B. Differences in coefficient of thermal expansion have been considered and Belleville Washers have been integrated into the design to maintain Assembly integrity from cold to hot conditions. The material specifications for SA-479 Type 304 austenitic stainless steel and SA-453 Grade 660 high alloy, high temperature bolting material, in the Construction Code are essentially the same as those of the Replacement Code. The MNSA materials are exempted from the fracture toughness requirements initiated in the Summer 1972 Addenda.

Material properties such as coefficient of thermal expansion, Yield Stress, and allowable design stresses for the MNSA material have been shown to be compatible with the installation and system requirements by acceptable results in the MNSA stress analysis and Design Report. Analysis had determined that the stress and fatigue usage factor in all of the parts of the MNSA are below ASME Code allowables, thus being compatible with system requirements.

Relative to examination of original bar stock, the rules of NB-2000 apply. In the Construction Code, NB-2540 stipulated the requirements for "Examinations and Repairs of Forgings and Bar". The same requirements are found in NB-2540 of the Replacement Code including the Acceptance Standards in NB-2545.3 and NB-2546.3. A slight difference between the two Codes is the addition of Subparagraph NB-2541(c) which specifically directs the user to NB-2580 for the requirements for bar material to be used for bolting. Although Paragraph NB-2580 appeared in the Construction Code, it was assumed that the user understood its use. Later Editions of the Code replaced that assumption with clear direction as to where to go for these requirements. For the MNSA, the requirements of

Paragraph NB-2580 are essentially the same in both Codes and were required in the Construction Code and are, therefore, considered reconciled.

It is therefore concluded that, with respect to Material, the Replacement Code is reconciled to the Construction Code and the Owner's Specification.

CONCLUSION

Based on the arguments in the preceding paragraphs, it is concluded that:

(1) The requirements affecting the design, fabrication, and examination of the item to be used for replacement are reconciled with the original Construction Code and Owner's Requirements to ensure that the item is satisfactory for the specified design and operating conditions, and

(2) Mechanical interfaces, fits, and tolerances that provide satisfactory performance are compatible with the system and component requirements, and

(3) Materials are compatible with the installation and system requirements.

Therefore, it is concluded that the requirements of the Construction and Installation Codes have been satisfactorily reconciled with the requirement of the Replacement Code for installation of the CE Nuclear Power LLC MNSA at Palo Verde 1, 2, and 3.