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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR TDR NO 11992	APPROVALS <i>C. Connors</i>
TECHNICAL DATA RECORD		PAGE 1 OF 33	<i>J. J. Gimera</i>
AUTHOR C. V. DiPol <i>CVD</i>		DEPT & GROUP NO 731-133	DATE 6/10/66
		GO NO 7593	
TITLE SCTI - Bolted Flange Connections in High Temperature - High Pressure Steam Service		S/A NO 1323-4	TWR
		SECURITY CLASSIFICATION	
		(CHECK ONE BOX ONLY)	(CHECK ONE BOX ONLY)
PROGRAM SCTI		AEC ☒ DOD ☐	RESTRICTED DATA ☐
		UNCL. ☒	DEFENSE INFO. ☐
		CONF. ☐	
		SECRET ☐	
SUBACCOUNT TITLE SCTI Test and Evaluation		AUTHORIZED CLASSIFIER SIGNATURE _____ DATE _____	
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		ABSTRACT Bolted flange connections in high temperature - high pressure service at the SCTI are described. Review of various government and national society regulations and codes determined that the ASA "Code for Pressure Piping", ASA B31.1, is the applicable design code. The system was initially designed in accordance with this code. Current industry practices relative to bolted connections in extreme steam service were reviewed. The original design and installation conformed with code requirements and/or current industry practice, except in the areas of gasket material; bolt material; bolt preload; and in the use of bolted joints. Code requirements relative to gasket and bolting material are poorly defined, and current industry practice is to avoid bolted connections in extreme steam service insofar as possible. Thermal stress considerations in piping and in un-insulated flanges were evaluated, and the stress levels encountered in the system should not be a significant cause of leakage in properly bolted joints. The basic cause of the experienced steam leaks appeared to be inadequate bolting.	
		Engineering recommendation to assure sustained leak free operation is to eliminate bolted flange connections and go to an all welded system. Alternate modifications to the existing bolted connections were developed for program office evaluation and decision. These alternate modifications will significantly reduce the leakage potential but will not remove the possibility of future leaks at the joints. An outside consultant (C. F. Braun & Co.), was retained to assist in the evaluation of the problem, and its review and recommendations concur with this TDR.	

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I. INTRODUCTION & OBJECTIVES

A. Introduction:

During system checkout operations at the Sodium Components Test Installation on May 13, 1966, steam leaks occurred at various bolted flange connections in the high temperature - high pressure steam distribution system. These leaks occurred when steam generator outlet conditions had been at 1850 psi and 860°F for a period of 6 to 8 hours.

B. Objectives:

The objectives of this study were as follows: ⁽¹⁾

1. Review the basis of design of the steam piping and original material specifications to determine facts leading to the observed malfunctions of the bolted flange connections.
2. Develop possible temporary modifications that would permit placing the system back in service for continuation of checkout operations.
3. Develop permanent modifications for long term solution to the malfunctions.
4. Evaluation of future performance capability of the plant after permanent modifications are completed,

II. DISCUSSION

A. Background Information:

The SCTI is a 35-Mw design capacity fossil-fired test installation with capabilities to test intermediate heat exchangers and steam generators in a sodium system. The installation basically consists of primary and secondary sodium systems; a sodium heated steam generator; a steam pressure reducing and desuperheater system; a condenser; and a feedwater system. Original design of the steam system was completed in May, 1962. Initial construction was completed in April, 1964.

NOTE: Number in parenthesis refer to reference listed in Section VI of this report.

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At the present time, an ALCO steam generator is installed and the plant is undergoing operational checkout prior to starting the steam generator test program.

The high temperature - high pressure portion of the steam system from the steam generator through the desuperheater to the second stage pressure reducing station and high pressure feedwater heater contains a total of 17 bolted flange connections at instruments, valves and equipment. During checkout operations, when steam generator outlet conditions had achieved 1850 psi and 860°F for the first time and had been at these conditions for a period of 6 to 8 hours, steam leaks were observed at 8 of the 17 bolted flange connections. Figure 1 shows the relative location of the flanged connections, identifies those that leaked, and provides material and rating data at the time the leaks were observed.

B. Basis of Original Design:

1. Operating and Design Conditions: The nominal maximum operating conditions, and corresponding original design conditions for the portion of the steam system under study were as follows:

SYSTEM PORTION From To		Nominal Maximum Oper. Cond.		Design Cond.	
		Temp. °F	Press psig	Temp. °F	Press. psig
Steam Generator Outlet	Press.Reduc'g Station No. 1	1050	2200	1100	2500
Press.Reducing Station No. 1	Desuperheat'g Unit No. 1	1050	1825	1100	2000
Desuperheating Unit No. 1	Press.Reduc'g Station No. 2 & H.P. F.W. Heater	670	1800	1100	2000
HP F.W.Heater	PSV 203 & Restrict Orifice FE 201	650	1620	1100	2000

2. Applicable Design Codes: Review of various California State, AEC, National Society and AI regulations and design criteria (2) (3)(4) (5)(6), developed that the American Standard Code for Pressure Piping, ASA B31.1-1955 (7), is the applicable design code for the steam portion of the SCTI. Therefore, any reference to the "code" hereinafter in this report means the ASA B31.1. In particular, Sections 1, 6 and 7 of the code apply to the design of steam systems.

It is of interest to note that the state of California, Division of Industrial Safety, does not have legally specified design codes or requirements relative to steam piping systems. Although the code is unofficially accepted⁽⁸⁾.

3. Code Design Requirements: Code design requirements for bolted flange connections include applicable provisions of American Standards ASA B 16.5-1961, "Steel Pipe Flanges and Flanged Fittings"⁽⁹⁾ and ASA B16.20-1963, "Ring Joint Gaskets and Grooves for Steel Pipe Flanges"⁽¹⁰⁾. The various code design requirements are summarized in Table 1, together with corresponding details of the original design. It is evident from Table 1 that the original design complied with code requirements in all respects except for the selection of soft iron ring joint gaskets for 1050°F service. The code is very unspecific in this matter, merely stating that gasket material shall be "suitable for intended service conditions" and does not set an upper temperature limit for soft iron gaskets. However, current general practice is to not use soft iron rings in temperature service above 750°F⁽¹¹⁾ ⁽¹²⁾. In addition, although the 1500# flange at the inlet to the high pressure feedwater heater has a more than adequate pressure rating at operating temperature of 650°F (2511 psig allowable vs 1800 psig operating), this flange is in a piping category B line which has design conditions of 1100°F and 2000 psig⁽¹³⁾. Allowable pressure for a 1500# flange at 1100°F is 1555 psig.

TABLE I

COMPARISON OF ASA CODE REQUIREMENTS VS
ORIGINAL DESIGN FOR BOLTED FLANGE CONNECTIONS

ITEM	ASA Code Requirements (7) (9) (10)	Original Design (13)
Flanges	<p>Flanged or welding ends fittings required for steam service between 250 psig & 2500 psig and not exceeding 1100°F</p> <p>Comply with ASA B16.5 for dimensions, pressure ratings, and materials</p>	<p>Weld neck flanges.</p> <p>ASA B16.5- 2500# flanges, ASTM A182 Gr F347, per Table 8 of ASA B16.5 allowable service pressure at 670°F is 4186 psi and at 1050°F is 2785 psi. 1500# flange, ASTM A182 Gr F347. Allowable service pressure at 670°F is 2511 psi.</p>
Gaskets	<p>Dimensions and materials shall be suitable for intended service. Above 250°F, gaskets shall be metallic, asbestos or other non-combustible material. Ring gaskets shall conform with ASA B16.20.</p>	<p>Soft iron rings per ASA B16.20 or Flexitallic spiral wound stainless steel - asbestos filled gaslets.</p>
Bolts	<p>For steam systems between 250 psig & 2500 psig, and not exceeding 1100°F, bolts shall conform to ASTM A193. Stud bolts recommended above 750°F</p> <p>No specified requirement relative to initial bolt tension</p> <p>No specified requirement relative to field flange assembly</p>	<p>Stud Bolts, ASTM A193 Gr B8c (Type 347 Stainless Steel.)</p> <p>None specified</p> <p>Field flange assembly procedures specified.</p>

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- C. Current Industry Practices: Extensive review of published literature; contacts with steam plant design organizations; and consultation with C. F. Braun & Co., developed a number of current industry design practices with respect to bolted flange connections.

The most important conclusion reached from this review is that bolted flange connections in high temperature and high pressure steam lines are susceptible to leaks regardless of design and installation, and bolted joints are generally avoided. A type of construction not involving gasket sealing is generally preferred. With welded construction, joint leakage is no longer a factor (11)(12)(14)(15)(16)(17).

However, bolted connections have been successfully used in the past, and are sometimes unavoidable due to equipment requirements. Following is a summary of current design considerations and practices regarding bolted connections in high temperature - high pressure service, together with a discussion as to how these practices were applied to the SCTI.

1. Flange Material: Designs must comply with the provisions of ASA B16.5 relative to pressure - temperature ratings. Chrome-moly ferritic alloy flanges (ASTM A182 F22) have been used at temperatures up to 1000°F; above 1000°F, stabilized austenitic stainless steels (ASTM 182 F 321 or F 347) are required due to elevated temperature creep strength. Recent articles published by power companies have indicated less use of Type 347 Stainless Steel in high pressure steam service. Cracking in the heat affected zone next to welds has been the problem, with these cracks often showing up within a few weeks. The general solution has been to change to Type 321 Stainless Steel. The problem has not been universal, and is mentioned for future reference (12).
2. Gasket Type and Material: As previously noted, the code is not specific on this subject, other than that the material must be non-combustible for service temperatures above 250°F (7). Metallic ring joint gaskets are commonly used, particularly for the more extreme service conditions (11)(12)(18). In higher pressure systems a confined gasket such as a ring joint is recommended (12). Soft iron rings have proved unsuitable in temperature service above 750°F (11), and stabilized stainless steel rings are being used for these service conditions (11)(16)(17)(19). Differential thermal expansion occurs between the ring gasket and the flange ring joint groove when these items are of dissimilar material. When soft iron rings are used in stainless steel flanges, this differential expansion has a tendency to weaken the seal since the stainless steel tends to expand more than the soft iron. This potential problem can be eliminated by using stainless steel rings (12). Problems associated with any metallic ring joint gasket are high initial bolt loads required to obtain an adequate seal; and possible damage to a stainless flange ring facing by an equivalent hardness stainless steel ring. The bolt load problem will be more

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fully discussed subsequently in this report, and the possible flange facing damage is accepted as an unavoidable evil since stainless steel has proven to be the only feasible material capable of withstanding extreme temperature service.

Another type of gasket that is widely used and, in some instances preferred to metallic rings, is the spiral wound stainless steel - asbestos filled flat gasket, as manufactured by the Flexitallic Gasket Co. (11)(12)(16). This type of gasket requires a much lower initial bolt loading than metal rings due to greater resiliency, and can also accommodate greater external forces or moments on the joint without impairing the seal (11)(12). However, these gaskets are not recommended for temperature service above 900°F to 1000°F, and adequate backing ring support is required to assure the gasket will not blow out due to internal pressure (11).

3. Bolting Considerations: Flanged connections most likely to give trouble are those where adequate initial bolt stresses were not developed, either due to insufficient tightening during installation or due to the use of low yield strength material such as stainless steel (14)(18). For the problems experienced at the SCTI, bolting appears to be the basic weakness (11)(12). Recommended initial bolt stress level to properly seat and maintain a seal in a metallic ring joint flange assembly is in the range of 30,000 to 35,000 psi (11)(15), and differential thermal expansion considerations at elevated line temperatures could possibly increase bolt stresses above these levels. Austenitic stainless steel, with a low temperature yield strength in the range of 35,000 psi and elevated temperatures (1100°F) yield strength in the range of 28,000 psi, is incapable of establishing sufficient force to consistently seat metal ring joint gaskets (12)(14)(17)(18). Higher yield strength alloy bolts are readily available and are commonly used in ring joint flange assemblies. Where system temperatures are below 800°F, ASTM A193 Gr B7 is an adequate bolting material (12)(15). For temperatures between 800°F and 950°F, ASTM A193 Gr B14 is used (12)(15)(17). Both of these alloys have cold yield strengths in excess of 105,000 psi and continue to display high yield strength at their service temperature limits. For temperatures above 950°F, where high cold bolting strength is needed to seat the gasket and high elevated temperature strength is also needed, special alloys are available and have been approved for use in boilers and pressure vessels by ASME Code cases 1295 and 1296. One of these alloys is a 19 chrome 9 nickel alloy (19-9DL). Carpenter Steel Co. data for this alloy in the hot-cold worked condition specified by ASME Code case 1295 indicates a room temperature yield strength of 125,000 psi and a 1200°F yield strength of 88,000 psi (20). This type of bolting material was used by SCTI operations personnel to replace original austenitic stainless steel studs and eliminate leakage from the cover plate joint in the ALCO steam generator (11). In addition to the use

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of low cold strength stainless steel studs, the actual situation at SCTI was compounded by apparent inadequate initial tightening of the joints. Although records were not kept of initial stud tension during construction contractor work, joints that had been remade by SCTI operations crews were tightened to a stud stress level of approximately 10,000 psi (11).

An additional design feature which tends to improve bolting performance is to leave the bolted flanges uninsulated (11)(14)(17)(21). This would result in lower stud temperatures, with corresponding higher tensile strength, and would facilitate inspection of the joint and periodic retightening. Leaving the flanges uninsulated does raise the possibility of a temperature differential between the flange and the stud, which, when combined with differential thermal expansion between dissimilar metals, could result in high stud stresses. However, preliminary calculations of these stresses based upon ferritic or 19-9DL studs and stainless steel flanges, and an assumed temperature differential of 50°F between the flange and the stud, indicates that the total stresses in the studs would be substantially below yield strength. Furthermore, these calculations were based on the conservative assumption that all differential thermal expansion is converted to forces on the studs, and does not take credit for elastic deformation of the flange or additional compression of the gaskets. Copies of the calculations are provided in the appendix to this report. For personnel safety, some form of personnel protection should be provided around the exposed flanges. This could be an expanded metal cage around the joint with a solid portion immediately opposite the flange face.

4. External Forces on Bolted Joints: In piping applications of bolted flange connections there normally exists other loadings in addition to internal pressure. These are usually longitudinal forces and bending moments due to weight and thermal expansion of the pipe line. By far the majority of piping flange applications in the United States utilize ASA standard B16.5 flanges. This ASA standard gives allowable pressure temperature ratings, but offers no guidance as to permissible bending loadings. These flanges have been customarily used up to the allowable ratings without any check of their capacity to carry additional loadings. While occasional difficulties due to such loads have been encountered, their service record must be considered very good (14). Good design practice indicates the desirability of keeping flanged joints at a minimum, and, insofar as possible, locating needed flanges in the most advantageous locations with respect to applied moments (11)(12) and (14). Past experience has shown that when flanges are

located at points where thermal forces and moments are well within code allowables, they are largely ignored as a significant cause of joint leakage (11).

Review of the dead weight and thermal expansion forces and moments on the high temperature - high pressure portions of the steam system subsequent to recent relief valve modifications has been made. The thermal stress analysis indicates that maximum thermal stresses at flanged connections are in the order of 50 - 65% of code allowable, and in many locations these stresses are negligible. At some locations, particularly at Pressure Reducing Station No. 1, this represents a significant increase in the thermal stress level over that existing prior to the modifications of the relief valves, and could have been a significant factor in causing leakage in a poorly bolted connection. However, these stress levels are well within code allowable, and should not be a significant cause of leakage in a properly bolted connection (12).

Review of dead load and spring hanger moments and stresses, subsequent to the modifications of the relief valves, showed that extremely high values existed at some points in the system. This was primarily due to overload settings on the spring hangers. This problem is more thoroughly discussed and reported in a separate TDR (22), and modifications to remove the excess spring hanger loads have been initiated. Upon implementation of the modifications, dead weight moment and stress levels would be reduced to a low level so as to not be a significant cause of flange leakage.

5. Operation and Maintenance Practices: Past experience with bolted connections indicate that greatest leakage troubles arise due to rapid changes in system temperature - particularly temperature quenches - which can create sizeable temperature differences in flange components (i.e. - flange, gasket & studs) (14)(17)(18). The flange usually cools faster than the stud and in a differential way, generally causing a reduction in gasket pressures (18). If this reduction is sufficient to result in a loss of gasket - flange surface contact, a leak would occur, or, at best, it would be improbable that surface irregularities between the gasket and flange remain aligned such that the joint would properly remake itself when studs cool down and tightening forces are reestablished. In addition, virtually all alloy stud material is not perfectly elastic, and some permanent elongation will occur during prolonged exposure to elevated temperature and stress. This is

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another reason given for avoiding flanged connections (14). Common practice in flanged connections is to periodically check stud tightness, and in particular to do so approximately 24 hours after system has reached temperature and after each major temperature variation (11)(12)(15).

The construction specification (13) for the initial installation provided some requirements relative to field assembly of flanged joints. However, no requirements were given relative to initial stud tension, or measurement techniques for determining the initial tension.

Industry practice is to specify initial bolt tension and method of measurement. Torque wrenches are commonly used, but more accurate micrometer measurement of actual stud elongation is recommended for critical joints. Included as Appendix 1 to this report is a recommended procedure for assembling bolted flange connections. This procedure is written for stainless steel studs and includes specific stud elongation for that material. However, the procedure is applicable to any stud material when appropriate unit elongations for desired initial stress levels are substituted.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions:

1. The only positive way to assure long term leak free performance of joints is to utilize a design and construction concept (welded construction), that does not rely upon gasket sealing. Due to the inherent nature of gasketed bolted flange connections, there are numerous factors such as flange deformation; gasket material; bolt materials and stresses; external loads; installation and operational procedures; etc., that could possibly contribute to flange leakage, regardless of design.

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2. There are alternate remedial measures which could improve the original design and installation, thereby reducing the probability of future leaks. However, the possibility of future leaks occurring after these remedial measures are completed would exist, and there appears to be no basis for establishing an accurate qualitative value which could be used to predict the future leak free performance of the plant.

B. Recommendations

1. Primary Recommendation: In order to positively assure sustained leak free performance of the joints, all portions of the steam piping system that can see service conditions of 600°F and 1500 psig, or greater, should be modified to a welded construction, eliminating all bolted flange connections.
2. Alternate Recommendations: The following alternate recommendations would improve existing conditions and materially reduce the probability of future leaks. However, these modifications would not preclude the possibility of future leaks developing, and are offered as an alternative to the primary recommendation of a welded system, should schedule or budgetary considerations dictate such a choice. Temporary and long term modifications are described, with the temporary modifications being such that maximum utilization of existing available material is made. The intent being that the plant can be quickly placed back in service for continued checkout operations. Because the temporary modifications utilize the existing stainless steel studs, and permanent elongation and attendant retightening of the joint is anticipated with each temperature cycle of the system, it is recommended that steam generator tests, where the system will be subjected to full loads and transient conditions, not be started until the long term modifications are completed.
 - a. Derating of Portions of the System: Portions of the system downstream of the Desuperheating Unit No. 1, which are now rated as category B (1100°F; 2000 psig design conditions), should be derated to reflect actual maximum service conditions of 650°F to 670°F and 1800 psig.

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Recommended new piping category and specification is as follows; (Specification 7593-4485-1 and P&ID, AI Dwg. No. 7593-448511 should be revised accordingly.)

New Pipe Category

Design Conditions

Category **B-1**: 1800 psig Main Steam & H.P.
F. W. Heater Supply & Vent.

700°F 2000 psig

Material - Category B-1

Pipe: Seamless stainless steel ASTM A312 Grade 347
 2 inch and smaller - schedule 80S, plain ends.
 2-1/2 inch and larger - schedule 160, butt weld ends.

Fittings: 2 inch and smaller - 6000 lb socket weld stainless steel ASTM A182 Grade F347. Dimensions ASA B16.11

Flange: 2500 lb, or 1500 lb as indicated on drawings, welding neck type stainless steel ASTM A182 Grade F347. Dimensions ASA B16.5 ring joint or raised face according to the joining equipment or valve.

Gaskets: Stainless steel oval rings per ASA B16.20 or Flexitallic Type "CG" with Type 347 stainless steel as required.

Bolts: Stud bolts ASTM A193 Grade B7 or B14, threaded full length after heat treatment.

Nuts: Semi-finished heavy series hexagonal ASTM A194 Grade 2H.

Joints: 2 inch and smaller - socket weld.

 2-1/2 inch and larger - socket weld.

Valves: 2500 lb standard forged stainless steel body ASTM A182 Grade F347 or Grade F316, welded or integral bonnet, socket weld ends, OS & Y, stainless steel trim, solid wedge and plug disc, stellite facing. (All 2 inch or smaller).

Instrument Connection:

Temperature: 1 inch half coupling-6000 lb socket weld, ASTM A182, Grade F347.

Pressure: 3/4 inch half coupling - 6000 lb socket weld, ASTM A182, Grade F347.

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b. Temporary Modifications:

(1) Flanges in service above 700°F and 1800 psig.

- a) Replace any ferritic ring joint gaskets with stainless steel gaskets. Stainless steel gaskets can be either oval or octagonal; and can be either TP 304, 316 or 347, whichever is more readily available.
- b) Reassemble joints with existing stainless steel studs and nuts. Tighten to approximately 90% of yield stress at temperature (approximately 25000 psi in the cold condition). Stagger nut tightening to get even distribution of forces on gasket and achieve equal bolt loads. Determine initial stresses in studs by appropriate measurement of elongation. Follow procedure described in Appendix 1 for assembling the joint.
- c) Leave flanges uninsulated. Install appropriate personnel protection.
- d) Check and tighten nuts as required after system has reached temperature and after any major temperature variation. Standard torque wrenches are sufficiently accurate for this purpose.
- e) If joint continues to leak, replace stainless steel studs and nuts with ASTM A193-B14 ferritic alloy or 19-9DL alloy studs and nuts. Pre-tighten these studs to 30,000 to 35,000 psi stress level and recheck tightness during operation.

(2) Flanges 600-700°F & 1500 psig to 1800 psig service.

- a) Establish appropriate system controls to limit temperature to a maximum of 700°F.
- b) Use soft iron joint gaskets or Flexitallic spiral wound stainless steel with asbestos packing gaskets with integral backing ring. If Flexitallic gaskets are used, insure that style is suitable for the ASA rated ring joint groove.
- c) Reassemble joints with existing stainless steel studs and nuts. Tighten to approximately 90% of yield stress at temperature (approximately 27,000 psi in the cold condition). Stagger nut tightening to achieve even distribution of forces and equal stud loading. Determine initial stresses in studs by appropriate measurement techniques. Follow procedure described in Appendix 1.

- d) Leave flanges uninsulated. Install appropriate personnel protection
- e) Check and tighten nuts, using torque wrenches, as required after system has reached temperature and after any major temperature variation.

(3) Installation Procedures

Appendix 2 provides suggested axial loadings and unit elongations of various size stainless steel studs to achieve stress levels of 25,000 psi and 27,000 psi in the cold condition.

c. Long Term Modifications

(1) Flanges in service above 700°F and 1800 psig.

- a) Retain Type 321 or 347 stainless steel ring joint gaskets. Replace any type 304 gaskets installed under temporary modifications with type 321 or 347.
- b) Replace stainless steel studs with 19-9 DL alloy studs conforming to ASTM-A193, and replace stainless steel nuts with 19-9 alloy nuts conforming to ASTM-A194. Tighten studs to 30,000 to 35,000 psi tension when assembling joints. Stagger nut tightening to achieve even distribution of forces and equal stud loading. Determine initial stresses in studs by appropriate measurement techniques. Follow the procedure described in Appendix 1, except unit elongation of stud shall be between 0.00103 in/in (30,000 psi stress level) and 0.00121 in/in (35,000 psi stress level).
- c) Leave flanges uninsulated. Install appropriate personnel protection.
- d) Check and tighten nuts as required after system has reached temperature and after any major temperature variation. Standard torque wrenches are sufficiently accurate for this purpose.

(2) Flanges in 600°F to 700°F and 1500 psig to 1800 psig service:

- a) Retain controls to limit line temperature to a maximum of 700°F.
- b) If Flexitallic spiral wound gaskets installed under temporary modifications gave adequate service, replace soft iron rings with the spiral wound gaskets. If ring joint gaskets are to be used, replace any carbon steel rings with stainless steel rings.

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- c) Replace stainless steel studs and nuts with ASTM-A193 B7 or B14 studs and ASTM-A194 Grade 2H nuts. Tighten studs to 30,000 to 35,000 psi tension when assembling joint. Stagger nut tightening to achieve even distribution of forces and equal stud loading. Determine initial stresses by appropriate measurement techniques. Follow the procedure described in Appendix 1, except unit elongation shall be between 0.00100 in/in (30,000 psi stress level), and 0.00117 in/in (35,000 psi stress level).
- d) Leave flanges uninsulated. Install appropriate personnel protection.
- e) Check and tighten nuts after operation as previously described.

IV. REVIEW BY CONSULTANT

- A. The C. F. Braun Co. was retained as a consultant to assist in determining the causes of the experienced leaks and to further assist in developing temporary and long term remedial action. The findings, conclusions, and recommendations of the consultant is contained in C. F. Braun Report: "SCTI Steam Piping Study" dated 6/3/66. This report confirms and indicates concurrence with the findings, conclusions and recommendations of this TDR.

V. FUTURE PERFORMANCE CAPABILITY

A. ALCO Steam Generator Test Program:

- 1. If the primary recommendation of system modification to an all-welded construction is adopted, the possibility of future steam leaks from flanged connections in the piping system is eliminated.
- 2. If the alternate temporary and long term recommendations are adopted, continued checkout and test operations is feasible. However, the possibility of future steam leaks from the bolted flange connections exists, and increased operational maintenance effort can be expected, especially since transient conditions will be imposed on the system by the proposed test program.

B. Future Test Programs

- 1. If the primary recommendation of an all welded system is adopted, it is considered reasonable to expect continued leak-free performance of the joints. However, the system should be reviewed with respect to the specified service conditions imposed by the particular test program.

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2. If the alternate temporary and long term recommendations are adopted, no statement can be made relative to future leakage of the joints until a review based on specific service conditions imposed is made. However, it is reasonable to assume that the possibility of future steam leaks would still exist.

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VI. REFERENCES

- 1) Work Release 7593-1323-4-112 002
- 2) California Administrative Code - Title 8, Industrial Relations, Chapter 4- Division of Industrial Safety.
- 3) ASME Boiler & Pressure Vessel Code - Section I, Power Boilers.
- 4) ASME Boiler & Pressure Vessel Code - Section VIII, Unfired Pressure Vessels.
- 5) AI EDM - Section 6-2-2
- 6) AEC Manual, Appendix 6301 - " General Design Criteria"
- 7) American Standard: "Code for Pressure Piping ", ASA B31.1 - 1955
- 8) Personal Communication - C. V. DiPol, (AI)/J. Wachter, (California Division of Industrial Safety - Boiler and Pressure Valve Section), dated 5/19/66
- 9) American Standard: " Steel Pipe Flanges and Flanged Fittings", ASA B16.5- 1961.
- 10) American Standard: "Ring Joint Gaskets and Grooves for Steel Pipe Flanges", ASA B16.20-1963.
- 11) IL, C.V. DiPol to C. C. Connors dated 5/23/66, Subject "SCTI - Minutes of Meetings on Bolted Flange Connections in High Temperature - High Pressure Steam Lines".
- 12) C. F. Braun Report, Dated 6/3/66: "SCTI Steam Piping Study"
- 13) AI Specification No. 7593-4485-1 dated 5/11/62; "SCTI - Steam Power System & Auxiliaries"
- 14) "Design of Piping Systems", M. W. Kellogg Co., Second Edition, 1956.
- 15) "Piping Design & Engineering"; Grinnell Co. Inc., Second Edition, 1965.
- 16) Personal Communication, C. V. DiPol/ Mr. Parminter (So. California Edison Co.) dated 5/20/1966.

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- 17) Personal Communication, T. A. Stempel (AI) / F. Cannizzo (R. M. Parsons Co.) dated 5/20/1966.
- 18) "Pressure Vessel and Piping Design"; Collected Papers of the ASME, 1959.
- 19) "Chemical and Heat Resistance of Gasket Materials" Johns-Manville Co.
- 20) "Carpenter Alloys for Elevated Temperature Service" Carpenter Steel Co., 1958.
- 21) Personal Communications, C. V. DiPol/W. J. Anderson (AI-D782)
- 22) TDR No. NAA-SR-11961 (to be released)

VII. APPENDIXES

1. Recommended Procedure for Assembling Stainless Steel Bolted Flange Connections in High Temperature High Pressure Steam Lines.
2. Flange Stud Preload Stresses and Loads for Approximately 90% Yield Stress at Temperature - Stainless Steel Type 347 Studs.
3. Calculations.

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APPENDIX 1

Recommended Procedure for Assembling Stainless Steel Bolted Flange Connections in High Temperature - High Pressure Steam Lines

1. Flanged connections shall be made up with faces parallel and bores concentric.
2. Gaskets shall be properly located and aligned.
3. Thread lubricant suitable for the intended temperature service shall be used on threads of studs and nuts.
4. All studs shall be tightened with suitable wrenches. Studs shall be tightened in a staggered sequence of alternate, diametrically opposite studs.
5. Each stud bolt shall be ground on both ends for obtaining micrometer measurements of its overall length, and shall also be numbered on one end for identification purposes.
6. Each stud shall be set cold to the total elongation necessary to establish the required stress level. This total elongation shall be determined by multiplying the appropriate unit elongation (.00085 in/in for 25,000 psi stress and .00092 in /in for 27,000 psi stress) by the active length of the stud. The active length of each stud is the distance between bearing faces of each nut plus one nut thickness. Total elongation shall be determined by micrometer measurement of each stud before and after tightening. Tolerance on total elongation shall be plus 0.0000 inches; minus 0.0005 inches.

(Note: for a 7 inch active stud length this corresponds to a stress level tolerance of plus 0 psi; minus 2,000 psi).
7. A complete record shall be made of all initial and final cold measurements of the elongation of each stud in each joint. These measurements shall be identified by the numbers on the bolts, together with a complete description and location of the joint.

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NO. NAA-SR-TDR 11992DATE 6/10/66PAGE 23 OF 33**APPENDIX 2****Flange Stud Preload Stresses & Loads for ~ 90% Yield
Stress at Temperature - Stainless Steel Type 347 Studs**

Stud Dia. (in)	Thread Rt. Area (in ²)	1050°F FLANGES		700°F FLANGES	
		Stress (psi)	Load (Lbs)	Stress (psi)	Load (Lbs)
3/4	.302	24,835	7,500	26,500	8,000
7/8	.419	25,060	10,500	27,440	11,500
1	.551	25,400	14,000	27,225	15,000
1-1/8	.693	25,250	17,500	27,420	19,000
1-1/4	.890	24,720	22,000	26,970	24,000
1-1/2	1.294	25,115	32,500	27,050	35,000
1-3/4	1.744	24,940	43,500	26,950	47,000
2	2.300	25,000	57,500	26,960	62,000
2-1/4	3.021	24,990	75,500	26,980	81,500
2-1/2	3.716	25,025	93,000	27,010	100,000

NOTES:

1. Unit elongation of studs for 25,000 psi stress level shall be .00085 in/in of active length.
2. Unit elongation of studs for 27,000 psi stress level shall be 0.00092 in/in of active length.
3. Active length of each stud is the distance between bearing faces of each nut plus one nut thickness.

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APPENDIX 3 - CALCULATIONS

SCTI STEAM FLANGES

TASK Check flange stud stresses due to: (1) Differential thermal expansion between stainless steel flange and other alloy bolts; and (2) Temperature differential between bolt & flange due to leaving flanges uninsulated.

Assumptions and Basis of Analysis

1. Investigate stresses for a 4" - 2500# flange assembly.
2. Assume 10% temperature differential from line temperature to flange temperature at stud circle due to leaving flanges uninsulated. (Ref: Discussions with C. F. Braun Co. Consultant on 5/20/66).
3. Assume 50°F temperature differential between average temperature of flange at stud circle and average temperature of stud.
4. Consider following cases:
 - a. Flange in 1050°F service
 - (1) Temporary modifications - S.S. flange & S.S. studs
 - (2) Long term modifications - S.S. flange & 19-9DL studs
 - b. Flanges in 700°F service
 - (1) Temporary modifications - S.S. flanges & S.S. studs
 - (2) Long term modifications - S. S. flanges & ASTM A-193-B7 studs.
5. Assume gasket is rigid under thermal stress conditions (conservative assumption).

I. Configuration of 4" - 2500# flange at stud circle:

Active length of stud = distance between nut bearing faces
plus thickness of 1 nut.

$$L_A = 7-1/32" + 1-5/16" = 8.34"$$

II. MATERIAL DATA

A. Flanges: ASTM A-182 Gr F347

B. Stainless Steel Studs - ASTM A-193 Gr B8c (TP347)

1. Modulus of elasticity (Ref.(1))

- a. at 600°F E $\approx 25.5 \times 10^6$ psi
- b. at 700°F E $\approx 25 \times 10^6$ psi
- c. at 900°F E $\approx 23.2 \times 10^6$ psi
- d. at 1000°F E $\approx 23 \times 10^6$ psi

2. Yield stress (Ref(1))

- a. at 500°F - 700°F: Fy $\approx 32,000$ psi
- b. at 900°F : Fy $\approx 31,500$ psi
- c. at 1000°F : Fy $\approx 29,500$ psi

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3. Average coefficient of thermal expansion Ref.(1)

a. 70 - 700°F $\alpha = 9.90 \times 10^{-6}$ in/in °F

b. 70-1000°F $\alpha = 10.3 \times 10^{-6}$ in/in °F

C. Ferritic Alloy Studs ASTM A-193 B7

1. Mod. of elasticity Ref. (2)

a. at 600°F: $E \approx 28 \times 10^6$ psi

b. at 700°F: $E \approx 27 \times 10^6$ psi

2. Yield stress Ref. (2)

a. at 600°F: $F_y \approx 93000$ psi

b. at 700°F: $F_y \approx 89000$ psi

3. Coeff. of Thermal Exp. Ref. (2)

a. 70-700°F: $\alpha = 7.05 \times 10^{-6}$ in/in

D. 19-9DL Alloy Studs (ASTM A-193 & Code Case 1295)

Hot - Cold Worked

1. Modulus of Elasticity Ref. (3)

a. at room temperature: $E = 29 \times 10^6$ psi

b. at 1000°F - No Hot Data

Assume $E \approx 23 \times 10^6$ psi

2. Yield Stress Ref. (3)

a. at room temperature : $F_y = 125,000$ psi

b. at 1200°F : $F_y = 88,000$ psi

3. Coeff. of Thermal Exp.

a. at 1000°F $\alpha = 9.78 \times 10^{-6}$ in/in °F

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III. Flanges at 1050°F

A. Stainless Steel Studs

1. Flange temp. at studs = .9 x 1050°F = 950°F

2. Stud temp. 950°F - 50°F = 900°F

3. Differential unit elongation due to 50°F Δt

$$\Delta \epsilon = \Delta t \alpha = 50^\circ\text{F} \times 10.3 \times 10^{-6} \text{ in/in}^\circ\text{F} = 515 \times 10^{-6} \text{ in/in}$$

4. Thermal Stress Due to Diff. Elong.

Assume all reflected in bolts (i.e. - no flange bending and no gasket compression)

$$f_t = \Delta \epsilon \cdot E = 515 \times 10^{-6} \times 23 \times 10^6 \approx 12,000 \text{ psi}$$

5. Total Stress in Bolts if cold tension is 25,000 psi

$$f_{\text{Tot}} = 25,000 + 12,000 = 37,000 \text{ psi}$$

6. Yield Stress at 900°F = F_y = 31,500 psi

7. Amount of stress over yield

$$f_{\text{Tot}} - F_y = 37,000 - 31,500 \approx 5,500 \text{ psi}$$

8. This corresponds to permanent set of approximately

$$\frac{5500}{23 \times 10^6} = 239 \times 10^{-6} \text{ in/in} = 0.00024 \text{ in/in}$$

9. When compared to initial cold stress of 25,000 psi = .00085 in/in the stud stress would be reduced to

$$\frac{.00085 - .00024}{.00085} \times 25000 \approx 18,000 \text{ psi}$$

when the joint returns to cold condition

10. Retighten stud to 25,000 psi before starting up again

B. 19-9DL Studs and 19-9DL Nuts

1. Flange temp. studs = 950°F = nut temp.

2. Stud temp. = 900°F

3. Flange elongation & Nut elongation

$$\Delta \epsilon_{\text{FL}} (7.03) \text{ in} (950-70)^\circ\text{F} (10.3 \times 10^{-6}) \text{ in/in} = 63,720 \times 10^{-6} \text{ in}$$

$$\Delta \epsilon_{\text{NUT}} = (1.3) \text{ in} (950-70)^\circ\text{F} (9.78 \times 10^{-6}) \text{ in/in} = 11,188 \times 10^{-6} \text{ in}$$

$$\text{TOTAL } \Delta \epsilon_{\text{FL \& NUT}} = 74,908 \times 10^{-6} \text{ in.}$$

4. Stud Elongation

$$\Delta L_{ST} = (8.34)_{IN} (900-70)^{\circ}F (9.78 \times 10^{-6})_{IN/IN^{\circ}F} = 67.697 \times 10^{-6} IN$$

5. Differential Elongation

$$\Delta L = \Delta L_{F-N} - \Delta L_{ST} = 7.211 \times 10^{-6} IN$$

6. Assume this is all taken as tension in stud

$$a) \Delta E_{ST} = \frac{7.211 \times 10^{-6}}{8.34} = 865 \times 10^{-6} IN/IN$$

$$b) f_t = \Delta E_{ST} \cdot E_{ST} = 865 \times 10^{-6} \times 23 \times 10^6 \approx 19,900 \text{ psi}$$

7. Combined Stress in Stud with 30,000 psi preload

$$f_{TOT} = 30,000 + 19,900 \approx 50,000 \text{ psi}$$

8. Yield Stress of 19-9DL @ 1200°F

$$F_y \geq 88,000 \text{ psi} \quad \& \quad \frac{f_{TOT}}{F_y} \leq \frac{50,000}{88,000} = 0.57$$

Design O.K.

IV. Flanges @ 700°F

A. Stainless Steel Studs & Flange

1. Again, Δt between flange & studs assumed at 50°F

2. Differential Unit Elongation

$$\Delta E = \Delta t \alpha = 50 \times 9.9 \times 10^{-6} = 495 \times 10^{-6} IN/IN$$

3. Assume all is taken in bolts

$$f_t = \Delta E \cdot E = 495 \times 10^{-6} \times 25.5 \times 10^6 = 12,600 \text{ psi}$$

4. Combined stress in stud with 27,000 psi preload

$$f_{TOT} = 27,000 + 12,600 = 39,600 \text{ psi}$$

5. Yield stress @ 600°F = 32,000 psi

6. Stress over yield = 39,600 - 32,000 = 7,600 psi

7. Permanent Set $\approx \frac{7600}{25.5 \times 10^6} \approx .0003 IN/IN$

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$$8. \text{ Residual stress} = \frac{.00092 - .0003}{.00092} \times 27000 = 18,200 \text{ psi}$$

when joint returns to cold condition.

9. Retighten joint to 27,000 psi before starting up again.

B. ASTM A-193-B7 Studs & Nuts

1. Flange & nut temperature = 630°F

2. Stud temperature = 580°F

3. Flange & nut elongation

$$\Delta l_{FL} = (7.03)(630-70)(9.9 \times 10^{-6}) = 38,976 \times 10^{-6} \text{ IN}$$

$$\Delta l_{NUT} = (4.3)(630-70)(7.05 \times 10^{-6}) = 5,132 \times 10^{-6} \text{ IN}$$

$$\Delta l_{FL \& NUT} = 44,108 \times 10^{-6} \text{ IN}$$

4. Stud elongation

$$\Delta l_{ST} = (8.34)(580-70)(7.05 \times 10^{-6}) = 29,983 \times 10^{-6} \text{ IN}$$

5. Differential Elongation

$$\Delta l = \Delta l_{F-N} - \Delta l_{ST} = 44,108 \times 10^{-6} - 29,983 \times 10^{-6}$$

$$\Delta l = 14,125 \times 10^{-6} \text{ IN}; \quad \text{flange elongation over stud}$$

6. Assume diff. elong. all goes to increase stress in stud

$$a) \quad \Delta \epsilon_{ST} = \frac{14,125 \times 10^{-6}}{8.34} = 1693 \times 10^{-6} \text{ IN/IN}$$

$$b) \quad f_{t_{ST}} = \Delta \epsilon \cdot E = 1693 \times 10^{-6} \times 28 \times 10^6 = 47,400 \text{ psi}$$

c) with 30,000 psi preload in stud, combined stress in stud

$$f_{TOT} = 30,000 + 47,400 = 77,400 \text{ psi}$$

7. Yield stress of stud at 600°F

$$F_y = 93,000 \text{ psi} > 77,400 \text{ psi}$$

$$\frac{f_{TOT}}{F_y} = \frac{77,400}{93,000} = 0.83$$

Design O.K.

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LONG TERM FIX

Calculate unit elongation of 19-9DL studs & ASTM A193 B7 or B14 studs for initial stress levels of 30,000 to 35,000 psi.

1. 19-9DL Studs

- a. Modulus of elasticity at ambient temp.

$$E = 29,000,000 \text{ psi (Carp. Steel: "Alloys for Elev. Temp. Service, Ref(3))}$$

- b. For 30,000 psi stress level

$$\epsilon = \frac{30,000}{29,000,000} = .00103 \text{ in/in}$$

- c. For 35,000 psi stress level

$$\epsilon = \frac{35,000}{29,000,000} = 0.00121 \text{ in/in}$$

2. ASTM A193 B7 or B14 Studs

- a. $E = 30,000 \text{ psi (U.S. Steel: "Steels for Elev. Temp. Service Ref (2))}$

- b. For 30,000 psi

$$\epsilon = \frac{30,000}{30 \times 10^6} = 0.00100 \text{ in/in}$$

- c. For 35,000 psi

$$\epsilon = \frac{35,000}{30 \times 10^6} = 0.00117 \text{ in/in}$$

TEMPORARY FIX

Calculate Preload on Stainless Steel - Type 347 Bolts

I. Background:

1. At a meeting on 5/19/66 attended by Eng'r, Operations and outside consultant (C. F. Braun), it was determined that lack of adequate bolting force was a major contributor to the steam flange leaks.
2. It was further determined that for interim repairs to get plant back on line, the existing stainless steel bolts should be tightened to approximately 90% of yield at operating temperature.

II. Determine Bolt Stresses & Axial Loads

A. Tensile yield strength (ref: "Steels for Elevated Temp. Service", published by United States Steel Co. Ref (1) for TP 347 S.S.)

1. At 700°F
 $F_y = 32,000 \text{ psi}$
.9 $F_y = 28,800 \text{ psi}$
2. At 1100°F
 $F_y = 28,500 \text{ psi}$
.9 $F_y = 25,600 \text{ psi}$

B. Conclusions:

1. For 700°F - 1825 psi line flanges
Stress bolts to 27,000 psi
2. For 1100°F - 2200 psi line flanges
Stress bolts to 25,000 psi

Calculate unit elongation of stainless steel studs to achieve desired cold stress level

1. Modulus of elasticity - TP 347 S.S. at ambient temp. (70°F)

$$E = 29.4 \times 10^6 \text{ \#/in}^2 \text{ (ref: U.S. Steel Co; "Steels for Elevated Temp. Service" Ref (1))}$$

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2. For 25,000 psi stress level

$$\epsilon = \frac{25,000}{29.4 \times 10^6} = .00085 \text{ in/in active length}$$

3. For 27,000 psi stress level

$$\epsilon = \frac{27,000}{29.4 \times 10^6} = .00092 \text{ in/in active length}$$

4. Active Length = Stud length between nut faces plus one nut thickness.
(Ref: "Piping Design & Engr" - Grinnell Co. Ref (4))

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- (2) "Steels for Elevated Temperature Service"
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- (3) "Carpenter Alloys for Elevated Temperature Service"
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- (4) "Piping Design & Engineering", Grinnell Co., 1965.