

ATTACHMENT 1

**Combustion Engineering, Inc.
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Revision 02-NP**

**Series 44 & 51 Design
Steam Generator Tube Repair
Using a Tube Re-Rolling Technique**

January 1997

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Revision 02-NP

COMBUSTION ENGINEERING, INC.

January, 1997

Series 44 & 51 Design

Steam Generator Tube Repair

Using A Tube Re-Rolling Technique

FINAL REPORT

Combustion Engineering, Inc.
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Windsor, Connecticut

ABB
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ABSTRACT

A technique is presented for repairing degraded steam generator tubes in Westinghouse pressurized water reactors with Series 44 and 51 design steam generators. The technique alleviates the need for plugging or sleeving those steam generator tubes with defects in the tubesheet region.

Instead of traditional repair techniques (plugging and sleeving), the degraded tubes will be re-rolled above the original tubesheet hard roll to form a new leaktight joint above the initial tubesheet roll transition zone. This technique will re-establish the pressure boundary between the primary and secondary side systems and provide the necessary structural capability for operational and upset conditions.

This report details analyses and testing performed to verify the adequacy of the roll transition zone re-roll process for returning nuclear steam generator tubes back to service. It demonstrates that re-rolling tubes, with defects in the tubesheet region, is an acceptable repair technique.

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
	ABSTRACT	iii
1.0	INTRODUCTION	1
1.1	<u>Purpose</u>	1
1.2	<u>Background</u>	1
2.0	QUALIFICATION CRITERIA	3
2.1	<u>Technical Specification</u>	3
2.2	<u>Acceptance Criteria</u>	3
3.0	SUMMARY	5
4.0	REFERENCES	7
5.0	DESIGN DESCRIPTION OF RE-ROLL AND INSTALLATION EQUIPMENT	9
5.1	<u>Re-Roll Joint Design</u>	9
5.2	<u>Repair Of A Defective Re-Rolled Tube</u>	10
5.3	<u>Re-Roll Joint Installation Equipment</u>	10
5.4	<u>ALARA Considerations</u>	12
6.0	TEST PROGRAM	18
6.1	<u>Test Matrix</u>	18
6.2	<u>Tests Required On Coupons</u>	19

TABLE OF CONTENTS

(Continued)

<u>Section</u>	<u>Title</u>	<u>Page</u>
7.0	TEST RESULTS	20
7.1	<u>Coupon Preparation</u>	20
7.2	<u>Torque Development</u>	21
7.3	<u>Test Procedure</u>	22
7.4	<u>Coupon Results</u>	24
7.5	<u>Tube Growth Tests</u>	25
7.6	<u>Roller Life</u>	26
7.7	<u>Discussion</u>	26
8.0	STRUCTURAL CONSIDERATIONS	33
8.1	<u>Re-Roll Joint Configuration</u>	33
8.2	<u>Plug And Sleeve Program Applicability</u>	49
8.3	<u>References</u>	51
9.0	EDDY CURRENT EXAMINATION	52
9.1	<u>Installation Verification</u>	52
9.2	<u>Rotating Probe Examination</u>	52
10.0	EFFECT OF RE-ROLLING ON OPERATION	53

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
3-1	Re-Roll Test Matrix	6
7-1	Torque Development	21
7-2	Test Results	28
8-1	Axial Member Physical Properties- Westinghouse Series "44" First Re-Roll Joint Location Case	38
8-2	Axial Member Physical Properties- Westinghouse Series "51" First Re-Roll Joint Location Case	39
8-3	Axial Loads in Locked Tube- Westinghouse Series "44" First Re-Roll Joint Location Case	40
8-4	Axial Loads in Locked Tube - Westinghouse Series "51" First Re-Roll Joint Location Case	41
8-5	Axial Member Physical Properties- Westinghouse Series "44" Second Re-Roll Joint Location Case	45
8-6	Axial Member Physical Properties- Westinghouse Series "51" Second Re-Roll Joint Location Case	46
8-7	Axial Loads in Locked Tube- Westinghouse Series "44" Second Re-Roll Joint Location Case	47
8-8	Axial Loads in Locked Tube - Westinghouse Series "51" Second Re-Roll Joint Location Case	48
8-9	Tubesheet Ligament Stresses for Westinghouse Series "44" and "51" Steam Generators at Design Conditions	50

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
5-1	Re-Roll Joint Configuration	14
5-2	Remote Control Manipulator	15
5-3	Rotation Station And Controls	16
5-4	[] Tool	16
5-5	[] Equipment	17
5-6	Rolling Tool	17
7-1	Typical [] Trace	29
7-2	Typical Torque Trace - Wet Sludge Sample	30
7-3	Typical Torque Trace - Dry Sludge Sample	31
7-4	Load Test Traces	32
8-1	Re-Rolled Tube Model And Environment	35
8-2	Tube Schematic - Series "44" Steam Generators for First Re-Roll Joint Location Case	36
8-2	Tube Schematic - Series "51" Steam Generators for First Re-Roll Joint Location Case	37
8-3	Tube Schematic - Series "44" Steam Generators for Second Re-Roll Joint Location Case	43
8-4	Tube Schematic - Series "51" Steam Generators for Second Re-Roll Joint Location Case	44

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to provide information sufficient to back licensed F*, EF* and L* analyses in support of a 10CFR50.59 safety evaluation allowing installation of re-roll joints in Westinghouse-designed Series 44 and 51 steam generators with degraded tubes in the tubesheet region. This report demonstrates that reactor operation with a tube re-roll joint in the steam generator tubes will not increase the probability or consequence of a postulated accident condition previously evaluated. Also it will not create the possibility of a new or different kind of accident and will not reduce the existing margin of safety.

Combustion Engineering (CE) provides two types of leaktight re-roll joints for Westinghouse Series 44 and 51 steam generator tube repair. The first joint type can be located anywhere in the []

[] This joint type was designed to be located anywhere in the []

The steam generator tube with the re-roll joints meets the [] of tubes which are not degraded.

Design criteria for the re-roll joints were prepared to ensure that all design and licensing requirements are considered. Analyses and testing have been performed on the tube re-roll joints to demonstrate that the design criteria are met.

The effect of re-roll joints on steam generator heat removal capability and system flow rate are discussed in Section 10 of this report.

After the re-roll joints are installed, an examination is performed using eddy current (ET) techniques. The ET examination serves as a method to verify that the re-roll joint was [] in the steam generator tube and to assure that F*, EF* and/or L* criteria are met by the re-roll process.

Plugs or sleeves will be installed if the re-roll procedure is not successful or if there is unacceptable degradation of steam generator tubes due to the process.

1.2 Background

The operation of Pressurized Water Reactor (PWR) steam generators has, in some instances, resulted in localized corrosive attack at the roll transition zone region and in the tubesheet crevice region of the steam generator tubing. This corrosive attack results in a localized

reduction in steam generator tube wall thickness. Steam generator tubing has been designed with considerable margin between the actual wall thickness and the wall thickness required to meet structural requirements. Thus it has not been necessary to take corrective action unless structural limits are being approached.

Historically, the corrective action taken where steam generator tube wall degradation has been severe has been to install plugs at the inlet and outlet of the steam generator tube when the reduction in wall thickness reached a calculated value referred to as a plugging criteria. An additional repair option has been to bridge the defect utilizing a sleeve. Eddy current (ET) examination has been used to measure steam generator tube degradation and the tube plugging criteria accounts for ET measurement uncertainty.

Installation of steam generator tube plugs removes the heat transfer surface of the plugged tube from service and leads to a reduction in the primary coolant flow rate available for core cooling. Installation of steam generator sleeves does not significantly affect the heat transfer removal capability of the tube being sleeved and a large number of sleeves can be installed without significantly affecting primary flow rate. However, there is a minor reduction in flow rate associated with large numbers of sleeves and potential accessibility concerns as well.

The use of a tube re-roll process will alleviate these concerns as well as leave the tube in a condition to perform repairs at a later time.

2.0 QUALIFICATION CRITERIA

2.1 Technical Specification

Westinghouse Series 44 and 51 Steam Generators

2.1.1 Design and Operating Ratings

Primary Operating/Design Temperature:	590-611/650 ⁰ F
Primary Operating/Design Pressure:	2235/2485 psig
Secondary Operating/Design Temperature:	506-521/550 ⁰ F
Secondary Operating/Design Pressure:	690/1085 psig

2.1.2 Steam Generator Tube Data

Tube Hole Drilling (min./max.):	.888/.893 in.
Tube Nominal O. D.:	.875 in.
Tube Nominal Wall:	.050 in.
Tube Wall Reduction Due to Rolling:	4-6%

2.2 Acceptance Criteria

The following acceptance criteria were used to assess the performance of re-rolled joint coupon specimens during testing.

- 2.2.1 The established torque values shall yield a [] percent tube wall reduction. These values were chosen as a means of []. This range of values reflects ABB's experience in plug and sleeve rolling in steam generator tubes. Also, the [] accommodates the uncertainties associated with remote field applications.
- 2.2.2 The re-rolled tube joint shall exhibit no movement relative to the tubesheet during simulation of cyclic loading conditions.
- 2.2.3 The re-rolled tube joint shall exhibit no movement relative to the tubesheet at push test forces which represent the maximum load experienced by the tube under operating or accident conditions with the tube restrained at the first support plate. These loads are []

].

- 2.2.4 The re-rolled tube joint shall exhibit [] when subjected to secondary side pressure levels equal to [] the operating or upset condition pressure differential. Section 7.0 defines the basis for the test pressure selection.
- 2.2.5 The roller expander shall produce consistent rolls of bright metal surface finish. There shall be no measurable signs of wear which could effect the rolled joint over [], which is the proposed life of the roller expander, assuming a planned lubrication interval.
- 2.2.6 Non-destructive examination techniques shall be utilized to verify that the [] were properly placed in the tube and that F*, Elevated F* (EF*) and L* criteria were met.
- 2.2.7 The tube re-roll joint shall not adversely affect system flow rate or heat transfer capability of the steam generator tube.

3.0 SUMMARY

A total of [] re-rolled joint coupons consisting of [] were subjected to a rigorous qualification program. The program was designed to [] that could be experienced during field operations. These variables included the []

[]. Such conditions include the []
[]. The 1 1/4" effective length roll expander (for re-roll joints below the tubesheet neutral axis) was conservatively used to prepare all test coupons. Table 3.1 shows the complete test matrix.

Torque values associated with a [] percent tube wall reduction were established using production equipment. The minimum torque value [] used in the test program yielded a [] percent tube wall reduction, and the maximum torque value [] used in the test program yielded a [seven to eight] percent tube wall reduction. The nominal value was established at []. The tooling and control systems used in the test programs represent the present technology for re-roll production equipment. As technological advances are made, the updated equipment may be utilized upon completion of laboratory verification.

Adhering to the test matrix, samples were prepared for testing. The samples were []

1.

All samples prepared for Cases 1 through 5 were [], then []

[]. These samples were used to determine the effect on the rolled joint due to conditions expected in the steam generators, such as; the []

All samples prepared for Case 9 were [], then []

[]. These samples were used to determine the effect on the rolled joint due to the maximum steam generator loading.

All samples were [] There was []
[]. Samples were also []

Samples which had been re-rolled were [] after completion of the rolling operation. There were no [] of the tube due to the re-roll process.

4.0 REFERENCES

- 4.1 Nuclear Power Business Nuclear Quality Assurance Manual, QAM-100, Third Edition, Revision 2.
- 4.2 Quality Assurance Procedures Manual, QAM-101, Revision 10.
- 4.3 Quality Plan No. 2004396-QP-94-014, Rev. 00, "Project Quality Plan for the Development and Qualification of a Tube Re-Roll Process for Westinghouse Steam Generator Tubes."
- 4.4 STD-400-153, Rev.00, "Test Plan for the Development and Qualification of a Steam Generator Tube Re-Roll Process for Westinghouse Series "44" and "51" Steam Generators."
- 4.5 00000-OSW-007, Rev. 00, "Test Procedure for the Development and Qualification of a Steam Generator Tube Re-Roll Process for Westinghouse Series "44" and "51" Steam Generators."
- 4.6 Telecopy to Dave Stepnick of ABB-CE from Richard Pearson of Northern States Power, dated December 21, 1994. Design Input on F-Star/L-Star Plugging Criteria.
- 4.7 TR-ESE-887, Rev. 00, "Test Report for the Qualification of the Roll Transition Zone Sleeve Rolled Joint for Westinghouse "D" Series Steam Generators."
- 4.8 CENC 1599, "Qualification Testing of Combustion Engineering Mechanical Tube Plug with Addendum A."
- 4.9 Test Report No. WO-94-205, "Test Report for the Additional Development and Verification of the Transition Zone Sleeve Rolled Joint for 3/4" Steam Generator Tubes."
- 4.10 Drawing No. C-SGN-217-458, Rev. 01, "Re-Roll Joint Configuration."
- 4.11 Qualification Report, GBRA 014 020, "Steam Generator Tube Repair by Tube Reexpansion." (ABB Reaktor)
- 4.12 "Doel 2 - Tube Reexpansion, ABB Conclusions about July Demonstration," 08/13/90. (ABB Reaktor)
- 4.13 "Repair of SG Tubes by Rerolled Expansion - Corrosion Test." (Laborelec Labs)
- 4.14 Memo No. PENG-95-015, "Testing of Steam Generator Tubesheet Reroll Samples," A. B. Goulet to E. P. Kurdziel, dated January 23, 1995.
- 4.15 Test Procedure For The Life Testing Of Roll Expanders, Procedure No. 00000-OSW-010, Rev 00.

- 4.16 Test Report For The Life Testing Of Roll Expanders With Decreased Lubrication Frequency, Test Report No. TR-400-002, Rev. 00.
- 4.17 Report No. A-ABBCE-9419-1119, Revision 00, "Evaluation of Tube Re-Rolling for Westinghouse Series 44 & 51 Steam Generators,".
- 4.18 Specification No. 00000-OSW-009, Rev. 00, "Design Specification for Re-Rolled Joints in Steam Generator Tubes."

5.0 DESIGN DESCRIPTION OF RE-ROLL JOINT AND INSTALLATION EQUIPMENT

5.1 Re-Roll Joint Design

Reference 4.17 contains requirements for the re-roll joint and its installation. The [] technology previously developed at ABB. Included in this category is the experience of ABB Reaktor in the areas of [], and the experience of ABB Combustion Engineering in the areas of []. ABB has installed over [] using rolling technology and over [] using similar technology.

The re-roll joint geometry is shown in the drawing presented in Figure 5-1. Multiple re-roll joints may be used in a tube. The critical parameters concerning the joint geometry were developed by the original equipment manufacturer using F*, EF* and L* analyses. Based on these analyses, it was determined that up to [] upon completion of the re-roll would meet F* criteria. In addition, , it was determined that up to [] upon completion of the re-roll would meet EF* criteria. Per the analyses, up to []

].

Based upon information provided by utility personnel who owned and operated Series 44 and 51 steam generators, ABB-CE determined that the original hard roll length in steam generator tubes ranged from a minimum of one and one half inches to a maximum of two and three quarter inches. Based upon this information, ABB-CE decided to [] from the steam generator tube end. This joint is put in place using a []. This geometry places the bottom edge of the re-roll joint a [] from the maximum height of the original roll transition.

As part of the re-roll joint, a [] may be performed prior to the hard roll process step. This [] utilizes current steam generator sleeving technology. The [] from the tube end and extending past the hard roll region. This process step serves a number of purposes; first, to []; second, to [] above the re-roll joint; and third, to [] upon process completion.

Through the use of [], the tube wall reduction from the hard roll will be limited from [] percent minimum to [] percent maximum. This range of wall reduction

ensures an acceptable re-roll joint under the variety of conditions tested under this program. This range of roll expansions is [], as well as industry experience demonstrating this range to provide optimum structural integrity for hard rolled joints.

5.2 Repair Of A Defective Re-Rolled Tube

If a tube is found to have an unacceptable re-rolled joint, the [] above the first re-roll. When [] are unacceptable or not possible, the tube can be sleeved in order to keep it in service or it can be taken out of service with standard mechanical tube plugs at both ends of the tube. In either case, approved methods to perform the processes are in place.

5.3 Re-Roll Joint Installation Equipment

The equipment used for the remote installation of re-rolled joints in a steam generator is made up of the following basic systems:

1. Remote Controlled Manipulator
2. Rotation Station
3. Tube [] Equipment
4. Tube [] Equipment
5. Tube Rolling Equipment
6. Tube Eddy Current Equipment

These systems, when used together, allow installation of the re-roll joints without entering the steam generator. In this way, personnel exposure to radiation is held to a minimum.

The tooling and methods described in the following sections represent the present technology for re-rolled joint installation. As technological advances are made in the installation process, the updated techniques may be utilized upon completion of laboratory verification by ABB-CE.

5.3.1 Remote Controlled Manipulator

The remote controlled manipulator (Figure 5-2) serves as a transport vehicle for repair and inspection inside a steam generator hot leg or cold leg plenum.

The manipulator consists of two major components; the manipulator leg and the manipulator arm. The manipulator leg is installed between the tubesheet and the bottom of the primary head and provides axial (vertical) movement of the arm.

The manipulator arm is divided into the head arm, probe arm and swivel arm. Each arm is moved independently with encoder position controlled electric motors. The swivel arm allows motion for tool alignment in various types of tube pitches. Computer control of the manipulator allows the operator to move tools from outside the manway and accurately position them under the proper tube against the tubesheet.

5.3.2 Rotation Station

The rotation station (Figure 5-3) mounts on the end of the manipulator arm through the use of a locking dovetail arrangement. The rotation station delivers the various tools required for the re-roll operation to the proper location. Cameras mounted on the rotation station are used to verify location as well as aid in the entry of tools into the tube. Proper elevations for the various tools are obtained through the use of hardstops. The rotation station also provides controlled rotation to some of the tools used in the re-roll operation. The station is controlled through the use of a torque monitoring system, which trips the station off when the preset torque value is reached.

5.3.3 Tube [] Equipment

The initial step in the re-roll process involves cleaning the tube [] (Figure 5-4). The purpose of this step is to [] during power plant operation. The []

[]. Additionally, the []
[]. An air motor rotates the [] as it is inserted into the end of the tube. At the appropriate elevation, the tool is []
[]. An interference fit between the tube and the []
[] upon completion of this process step.

5.3.4 Tube [] Equipment

When applicable, the [] equipment (Figure 5-5) is used to minimize the amount of corrosion products between the tube and tubesheet [] the steam generator tube. The []

[]. When the []

[]. A tool hardstop is provided for proper tool vertical positioning.

The []
[] prior to use. The unit is hooked up to a strip chart recorder in order to record the []

An expansion pressure is utilized to move the [] away from the area. This [] does not add to the structural integrity of the joint and no credit is taken during analysis of the joint.

The [] may be used with any of the re-roll joints (Figure 5-1). However, due to equipment reachability concerns, it is typically only used on the lower two re-rolls.

5.3.5 Tube Rolling Equipment

The tube rolling equipment (Figure 5-6) is used to expand the tube into intimate contact with the tubesheet, forming a strong leaktight joint. The rolling tool is positioned under the proper tube using the manipulator, which is then used to insert the tool into the tube. The rolling tool utilizes a hardstop to position it vertically in the proper location.

The rolling equipment consists of the air motor, tube expander, torque readout, strip chart recorder and torque calibration unit. The torque readout and settings of the rolling tool are verified on the torque calibration unit prior to rolling of the tube. The tube is expanded to a torque which has been demonstrated by testing to provide a leaktight joint. A strip chart record of the rolling tool torque is taken for evaluation of the rolling process on the individual tubes. The torque trace is used as the official record of the process. A second roll is performed to verify the torque level reached on the first re-roll. The evaluation of the torque trace is the basis for acceptance or rejection of the re-roll joint since the joint integrity is based on percent wall thinning. A rolled joint which fails to meet the acceptance criteria may be re-rolled. []

5.3.6 Tube Eddy Current Equipment

After the re-roll joints are installed, an examination is performed using eddy current (ET) techniques. The ET examination serves as a method to verify that the re-roll joint was [] in the steam generator tube and to assure that F*, EF* and/or L* criteria are met by the re-roll process.

5.4 ALARA Considerations

The steam generator repair operation is designed to minimize personnel exposure during re-roll operations. The manipulator is installed from the manway without entering the steam generator. It is operated remotely from a control station outside the containment building. The positioning accuracy of the manipulator is such that it can be remotely positioned without having to install templates in the steam generator.

The rotation station is designed so that the dovetail fitting quickly attaches to the manipulator. The rotation station is designed to quickly engage the individual re-rolling tools. The tools are simple in design and all operations are performed remotely using tools held by the manipulator. Each tool can be changed at the manway in 10-15 seconds. A tool operation is performed on several tubes rather than performing each tool operation on the same tube before proceeding to the next tube. This reduces the number of tool changes which are required. If tool repair is necessary, the tool is removed and re-roll operations continue using a spare tool. Tool repair is completed off the platform in a low radiation area.

Air, water and electrical supply lines for tooling are designed and maintained so that they do not become entangled during operation. This minimizes personnel exposure on the steam generator platform. All equipment is operated from outside the containment building.

In summary, the steam generator operation is designed to minimize personnel exposure to ionizing radiation and is in full compliance with ALARA standards.

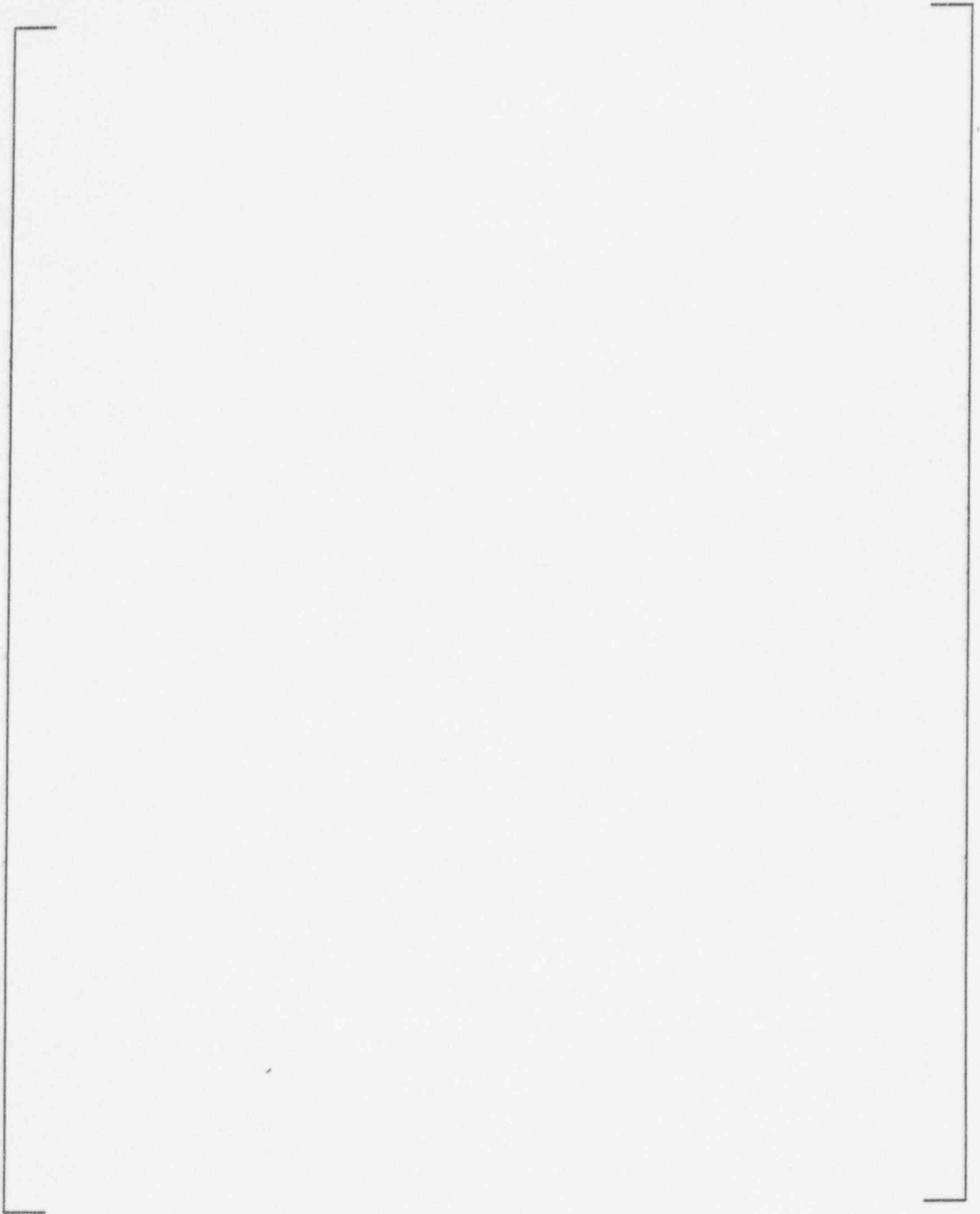


Figure 5-1

Re-Roll Joint Configuration

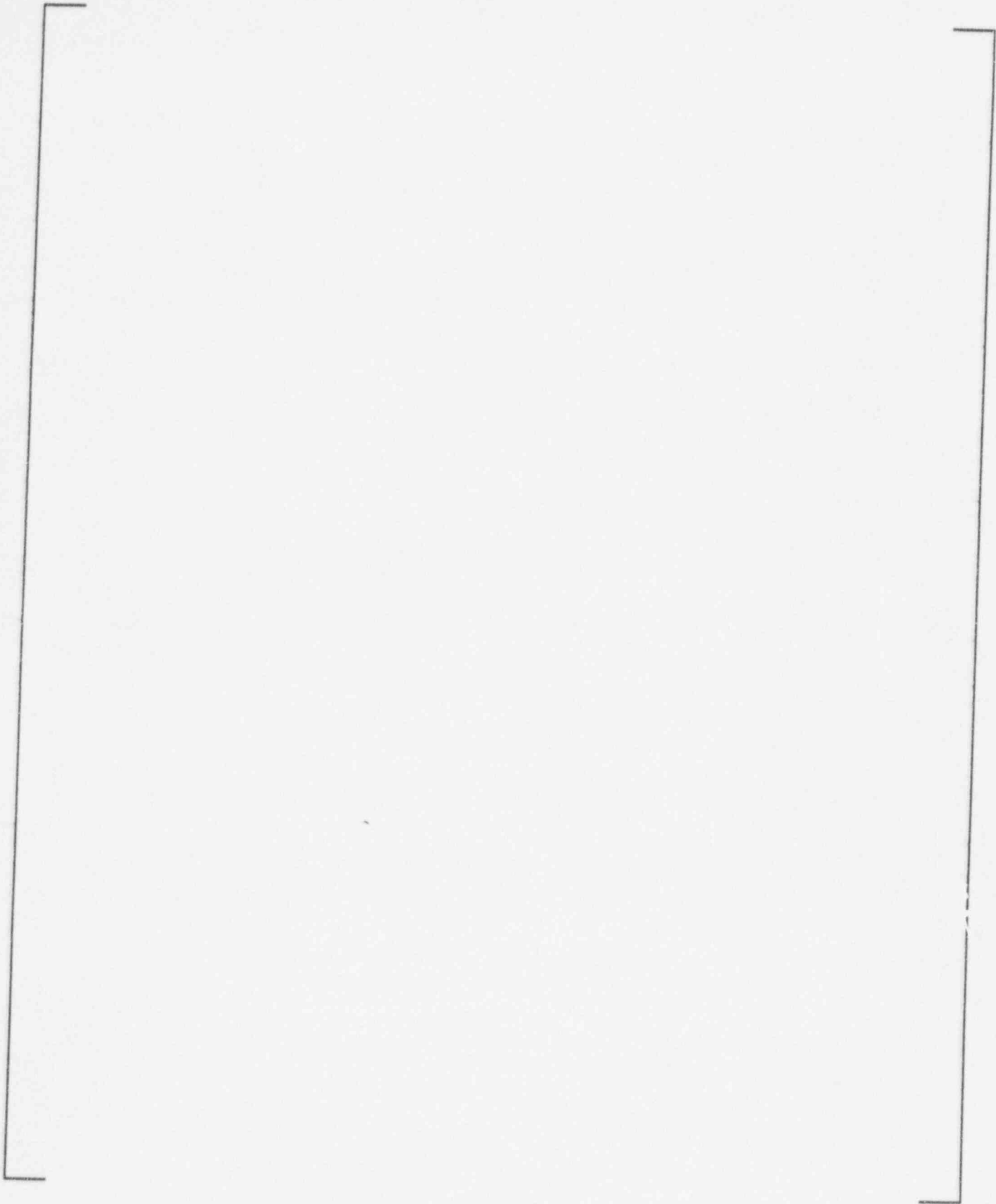


Figure 5-2

Remote Control Manipulator

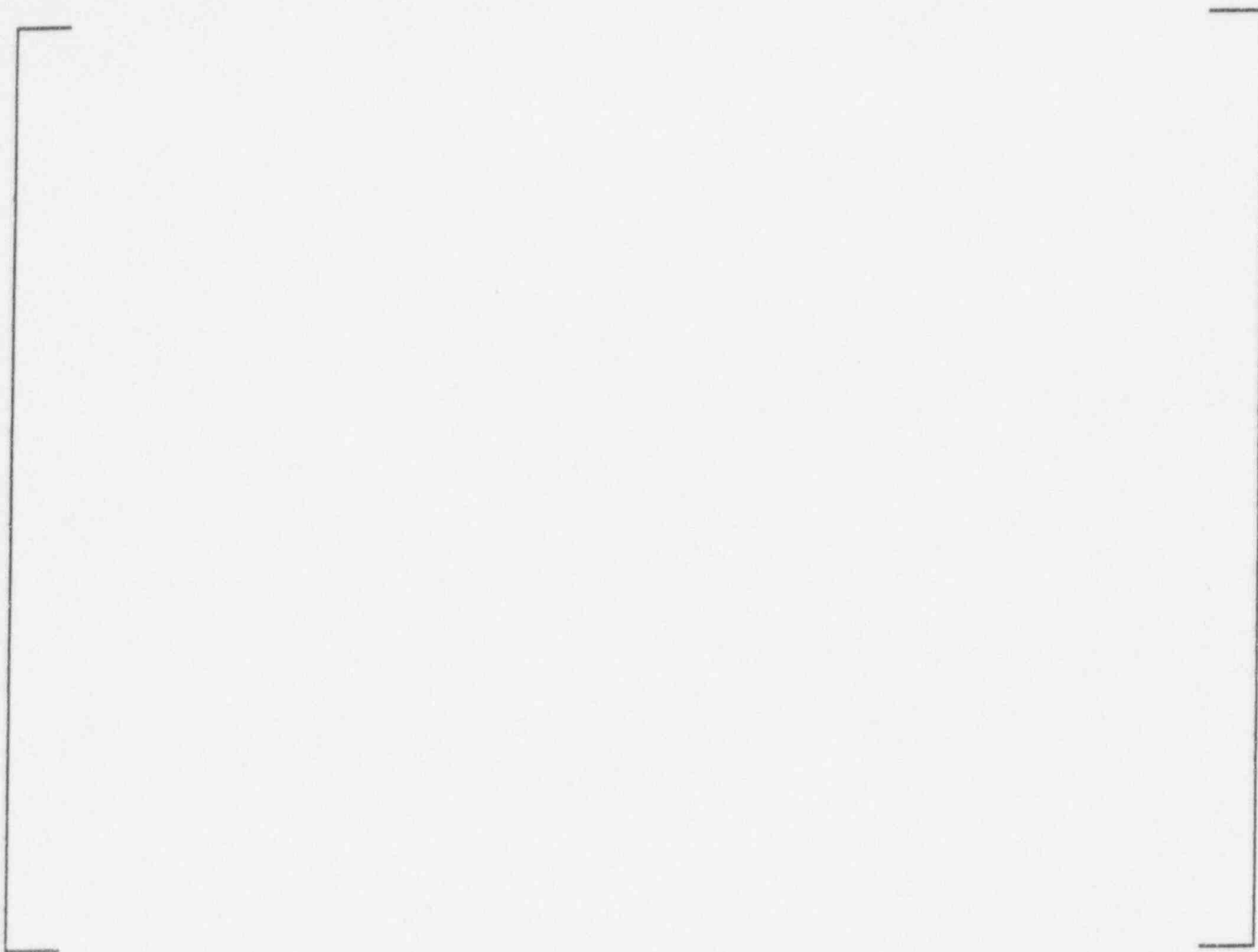


Figure 5-3

Rotation Station And Controls



Figure 5-4

Brushing Tool



Figure 5-5

Hydraulic Expansion Equipment



Figure 5-6

Tube Roll Expander

6.0 TEST PROGRAM

6.1 Test Matrix

A test matrix was developed to test the re-roll joint over a range of test conditions. This matrix is shown in Table 3-1. The matrix represents a range of conditions to which the re-rolled joint was tested. A total of [] coupons were tested for each test case. A description of each of the test conditions and type of tests is given below.

6.1.1 Tube Dimensions

One heat of Inconel 600 tubing was used in this program. The heat number is [], purchased from Sandvik Steel Co. The tubing was purchased to nominal dimension of .875" O.D. x .050" wall, however, the tube wall dimensions were not uniform, varying from a minimum of []. This was accounted for in the measurement step of sample preparation.

6.1.2 Tube [] Size

A [] sizes was tested in the re-roll program. This range of [] sizes represents actual tubesheet [] sizes per the original equipment manufacturer's specification. The [] sizes tested were the [].

Changes in [] affect the amount of wall thinning the tube will experience and require that the roller expander perform consistently over a [].

Test Case 1 performed the re-roll in a []. Test Cases 2 and 3 performed the re-roll in []. [] torque was defined as that torque required to produce approximately [] percent wall thinning and [] torque as that torque required to produce approximately [] percent wall thinning.

6.1.3 Surface Finish

The tube holes for this program were bored to produce a surface finish of [] RMS. The tubes were purchased to a [] RMS outside diameter surface finish and were received with a [] RMS finish. These variables were constant throughout the test program.

6.1.4 Torque Setting

A minimum and maximum torque setting was developed as part of this program. As described earlier, these settings are defined as the torque required to produce

approximately [] percent tube wall thinning. Test Cases 2 and 3 performed the re-roll using a [] percent wall thinning. These re-rolls were performed in [] in order to force the rollers [] .

6.1.5 Sludge Conditions

The possibility exists that sludge will be present in the annulus between the tube and tubesheet during re-rolling operations. Sludge in both the [] prior to performing the re-roll. Test Cases 4, 5 and 8 simulated these conditions. A []

[] for Test Cases 4 and 8. This same []

[] was performed. This extra preparation step assured a [] condition in the annulus.

The sludge formulation was based upon [] .

6.1.6 Roller Expander

Roller expander geometry is a constant with the []

[] . This roller expander geometry is based upon experience gained in plug and sleeve installation programs. The 1 1/4" effective length roll expander was conservatively used to prepare all test coupons. Since the geometry for this roll expander is identical (with the exception of increased roll length) to that of the 2" expander, the results of the test program are conservative.

6.2 Tests Required On Coupons

The test procedure requires a hydrostatic leak test after re-rolling the tube into the block. Upon completion of the hydrostatic test, the coupons were subjected to cyclic loading tests, after which the coupons were hydrostatically tested a second time. The hydrostatic tests were performed from the secondary side in order to increase the conservatism of the test. Finally, the coupons were subjected to a push test to determine the load at which joint movement occurs.

7.0 TEST RESULTS

7.1 Coupon Preparation

Mock tubesheets were machined with [] as defined in the test matrix. Additionally, a split block with a nominal hole size was machined. This block was used to develop the torque range required to meet the acceptance criteria.

7.1.1 Tube Installation

Steam generator tubes were cut to six inch lengths and rolled into the tubesheet blocks at the lower end of the blocks. This was done to anchor the tube in the block and to simulate the original hard roll. If the particular coupons required sludge conditions, the sludge was brushed onto both the tube outside surface and the tube hole inside surface prior to locking the tube in place. Measurements required for tube wall reduction calculations were taken prior to installing the tube into the block.

7.1.2 Tube []

The tube inside surfaces were []. The coupons were placed in a test stand and the rotation station was used to perform the []. The []

7.1.3 Tube []

Where applicable, the tubes were [] described earlier. The [] for testing will not detrimentally affect the use of a [] during the field effort. An [] was used to [expand the tube] into the block. A typical [] trace, as recorded on the strip chart, is shown in Figure 7-1.

7.1.4 Tube Re-Rolling

The re-rolling operation was performed by fixturing the coupon into a rolling stand. The 1 1/4" roll expander was conservatively used for all re-rolling tests. The test matrix defined the torque levels that were required for coupon preparation. A typical torque trace, as recorded on the strip chart (torque is along the Y-axis, while time is along the X-axis), is shown in Figure 7-2 for a coupon prepared with wet sludge. The wet sludge is easily pushed from behind the tube and there is a smooth, steady increase in torque.

A typical torque trace, as recorded on the strip chart, is shown in Figure 7-3 for a coupon prepared with dry, hard sludge. The dry, hard sludge is fragmented and moved about during the rolling operation. The torque setpoint is reached over a much longer period of time.

7.1.5 Coupon Numbering

The following numbering system was used to identify the coupons.

B1, B2, B3	Case 1	[]
A1, A2, A3	Case 2	[]
A4, A5, A6	Case 3	[]
C1, C2, C3	Case 4	[]
C4, C5, C6	Case 5	[]
D1, D2, D3	Case 7	[]
E1, E2, E3	Case 8	[]
F1, F2, F3	Case 9	[]

7.2 Torque Development

The first step in the program was to develop torque levels associated with tube wall thinning of [] percent. This was done by using the split block arrangement. Tubes were placed in the split block, rolled, then measured to determine wall thinning. Table 7-1, shown below, gives the values for the various torques using the 1 1/4 inch effective length roll. Similar values are expected with the 2 inch effective length roll and these values will be verified prior to actual steam generator work.

Table 7-1

<u>Torque (in-lbs)</u>	<u>Wall Thinning (%)</u>	<u>Torque (in-lbs)</u>	<u>Wall Thinning (%)</u>
------------------------	--------------------------	------------------------	--------------------------

--	--	--	--

Based upon the above information, maximum and minimum torque values were chosen for the 1 1/4" effective length roll. These values were [] for the minimum torque setpoint, [] for the nominal torque setpoint and [170 in-lbs] for the maximum torque setpoint. These were the torque settings that were utilized during the testing process.

A test coupon was rolled to the system limited (based on supply air) torque value of [] This sample, with a wall thinning of [], successfully passed cyclic, push and hydro testing.

7.3 Test Procedure

Reference 4.5 is the detailed procedure describing all step-by-step activity for the test program. This section summarizes the procedure used to conduct the various tests on the coupons. Table 7-2, at the end of this section, summarizes all the test results.

7.3.1 Cyclic Loading Tests

Normal operating and postulated accident conditions result in cyclical axial and flexure loading conditions on the steam generator tube and tubesheet. The maximum tubesheet loadings result from a flexure pattern where tubesheet ligament stress across the majority of the tubesheet is tensile above the neutral axis and compressive below the neutral axis. For re-roll joints below the neutral axis, the compressive stress would tend to close the tubesheet hole during operating conditions, thus increasing the tube to tubesheet joint contact pressure. For re-roll joints above the neutral axis, the tensile stress could open the tubesheet hole during operating conditions, thus potentially reducing the tube to tubesheet joint contact pressure. An extensive test and qualification program on the Roll Transition Zone Sleeve rolled joint (Reference 4.7), has shown that the tubesheet flexure has no effect on the joint structural integrity or leak tightness. Therefore, only axial loads were applied to test coupons during the re-roll joint cyclic test program.

The re-rolled joints were subjected to a cyclic axial load test to demonstrate structural capability of the joint. The loads used for the cyclic tests were based upon the operating loads experienced by a tube [], as this was the worst case loading condition on the tubes. These loads are []

[]. Section 8 provides an analysis of this condition. The re-rolled joints for Test Case 9 were conservatively loaded between [] for a total of [] cycles. The loading was applied to these re-rolled joint at [] using an MTS Testing Machine. []

All coupons prepared for Cases 1 through 5 were [] []

] These samples were used to determine the effect on the rolled joint due to conditions expected in the steam generators, such as; the [

].

7.3.2 Push Tests

As described in the previous section, steam generator tubes are subjected to loading conditions while in operation. The maximum loads to which the tube is subjected are [

] The re-rolled coupons were push tested to a load of [] using an MTS Testing Machine. Coupons from test cases 1 through 5 exhibited [] at this load and the test was terminated. Typical load traces are shown in Figure 7-4. Test Cases 7 and 9 coupons were pushed to failure. The failure occurred due to tube buckling at a load of []; the re-rolled joint did not [].

7.3.3 Hydrostatic Leak Tests

Hydrostatic tests were performed on the coupons before and after cyclic testing. The tests were performed from the secondary side in order to increase the conservatism of the test. The test was performed at [

] The first pressure level represents a secondary side test.

The ASME Code hydrostatic test pressure of:

$$1.25 \times \text{Primary Design Pressure} = 1.25 \times 2485 \text{ psi} = 3106 \text{ psi}$$

is the basis for the first primary side pressure level. Re-rolled joints passing the test at this pressure are considered acceptable. For added conservatism, ABB-CE increased the pressure [] above the acceptance criteria. This represents a factor of safety of over [] for the test.

All samples except the samples [] exhibited leaktightness. Samples C1, C2 and C3 had an [

].

In order to comply with the guidelines of Regulatory Guide 1.121, which call for a test pressure of three times the operating differential, Test Case 7 coupons were pressurized to [] from the primary side. [

].

7.3.4 Collapse Tests

The possibility exists that sludge will be present in the annulus between the tube and tubesheet during re-rolling operations. The moisture in wet sludge, trapped between two re-rolled joints, has the potential of flashing to steam under operating temperatures. The pressure build up during this event will be released either through the rolled joints or by a collapse of the tube. Test coupons containing wet sludge were heated, for up to eight hours, at 650°F.

7.4 Coupon Results

Test Case 1 - []

Coupons B1, B2 and B3 of this test case successfully passed all phases of testing.

[]

Test Case 2 - []

Coupons A1, A2 and A3 of this test case successfully passed all phases of testing.

[]

Test Case 3 - []

Coupons A4, A5 and A6 of this test case successfully passed all phases of testing.

[]

Test Case 4 - []

Coupons C1, C2 and C3 of this test case successfully passed all phase of testing.

[]

Test Case 5 - []

Coupons C4, C5 and C6 of this test case successfully passed all phases of testing.

[]

Test Case 6 - []

See Section 7.6 for the results of the roller life test.

Test Case 7 - []

Coupons D1, D2 and D3 of this test case successfully passed the primary side hydrostatic leak test. []

Test Case 8 - []

[]

[]

Test Case 9 - []

Coupons F1, F2 and F3 of this test case successfully passed all phases of testing.

[]

7.5 Tube Growth Tests

An additional area of concern was the area of steam generator tube growth or contraction during the re-rolling operation. Three coupons were prepared and measured prior to the re-rolling operation. The samples were then [], a length which represents the amount of unrolled tube that will be

[] in the steam generators. The coupons were then subject to a torque that resulted in [three] percent wall thinning. The results are shown below.

Tube No.	Initial Length	[]	[]	Change
1	6.060"	[]	[]	[]
2	6.068"	[]	[]	[]
3	6.069"	[]	[]	[]

The change in length due to the [] and the length change due to the [], for an overall length change of, on average, [].

7.6 Roller Life

ABB-CE has a large volume of experience with rolling operations. References 4.15 and 4.16 document life testing performed on roller expanders during sleeve roll qualification testing. This data is applicable to the current program, since similar roller designs are employed and similar materials are involved. In both of the referenced programs, there was no evidence of detrimental wear beyond burnishing marks and a slight change in color on the mandrel and rolls. []

[]

7.7 Discussion

Torque values associated with tube wall thinning of [] were established using production rolling equipment. These values were established by rolling tube samples in a split block and recording the torque trace. The tubes were then removed from the block, sectioned and measured to determine wall thinning. Based upon the acceptance criteria established, which bracketed original equipment manufacturing criteria and reflected ABB-CE rolling experience, torque values for the 1 1/4" effective length roller in the range of [] were established. Similar values for the 2" effective length roller will be established prior to actual steam generator work.

Using the torque values established, the tests called out in the test matrix were performed. All samples were prepared using a production control system and tooling. All [] coupons, representing various steam generator conditions, were tested and met the acceptance criteria. The low torque coupon (A1-A3) preparation resulted in torques above the minimum value of []. This occurred due to an overshoot of the intended value by the system. However, it still resulted in a low wall thinning value of approximately [] percent.

A cyclic load range of [] was used to test all of the coupons for a total of []. The load value was based on the worst case loading the tube would

experience and cycling the tube through the total amount of load cycles the tube experiences during operation, regardless of loading conditions. This approach assures a high degree of conservatism. Under these loading conditions, [].

A push test load of [] was applied to all of the re-roll joint coupons. This value represents a load greater than the maximum tube loading conditions described earlier. The tests were stopped before joint failure was observed. [] As an additional test, six coupons were pushed to failure. Failure occurred by tube buckling at [].

Hydrostatic leak tests were performed on all coupons before and after cyclic loading. The test pressures represented a secondary side hydrostatic test and a primary side hydrostatic test. All tests were performed from the secondary side of the coupons, which represents a high degree of conservatism. The ASME Code hydrostatic test pressure of [] An additional [] was then applied to increase the factor of safety further. [] coupons were tested from the primary side at a pressure of []. This represents a pressure greater than the three times operating differential pressure set forth in Regulatory Guide 1.121.

All coupons held pressure for a [] minimum at each pressure level with no observable leakage except for the coupons with []. These coupons exhibited an [] []

[]

[]

[]

Table 7-2

Test Results

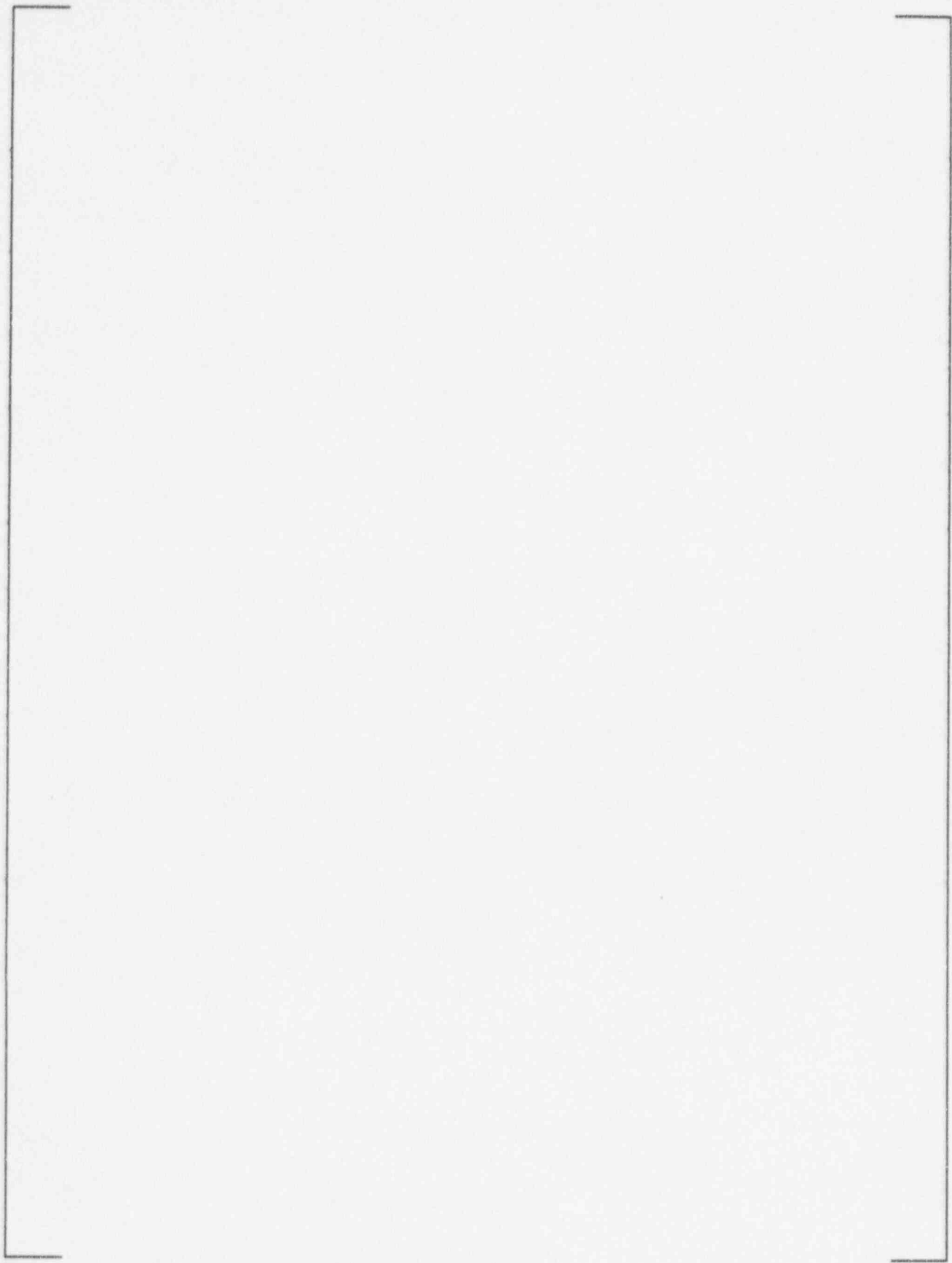


Figure 7-1

Typical Expansion Trace

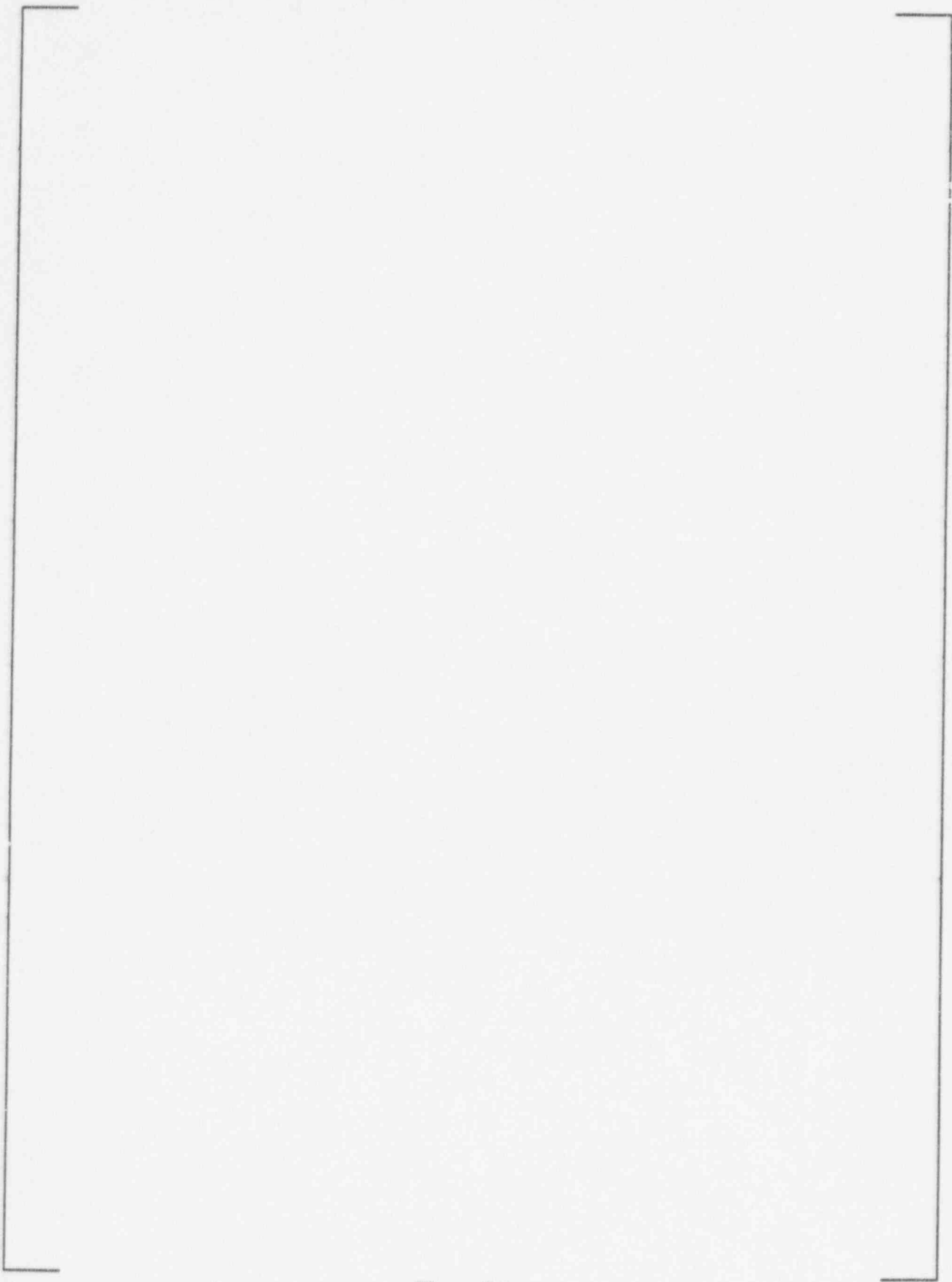


Figure 7-2

Typical Torque Trace - Wet Sludge Sample

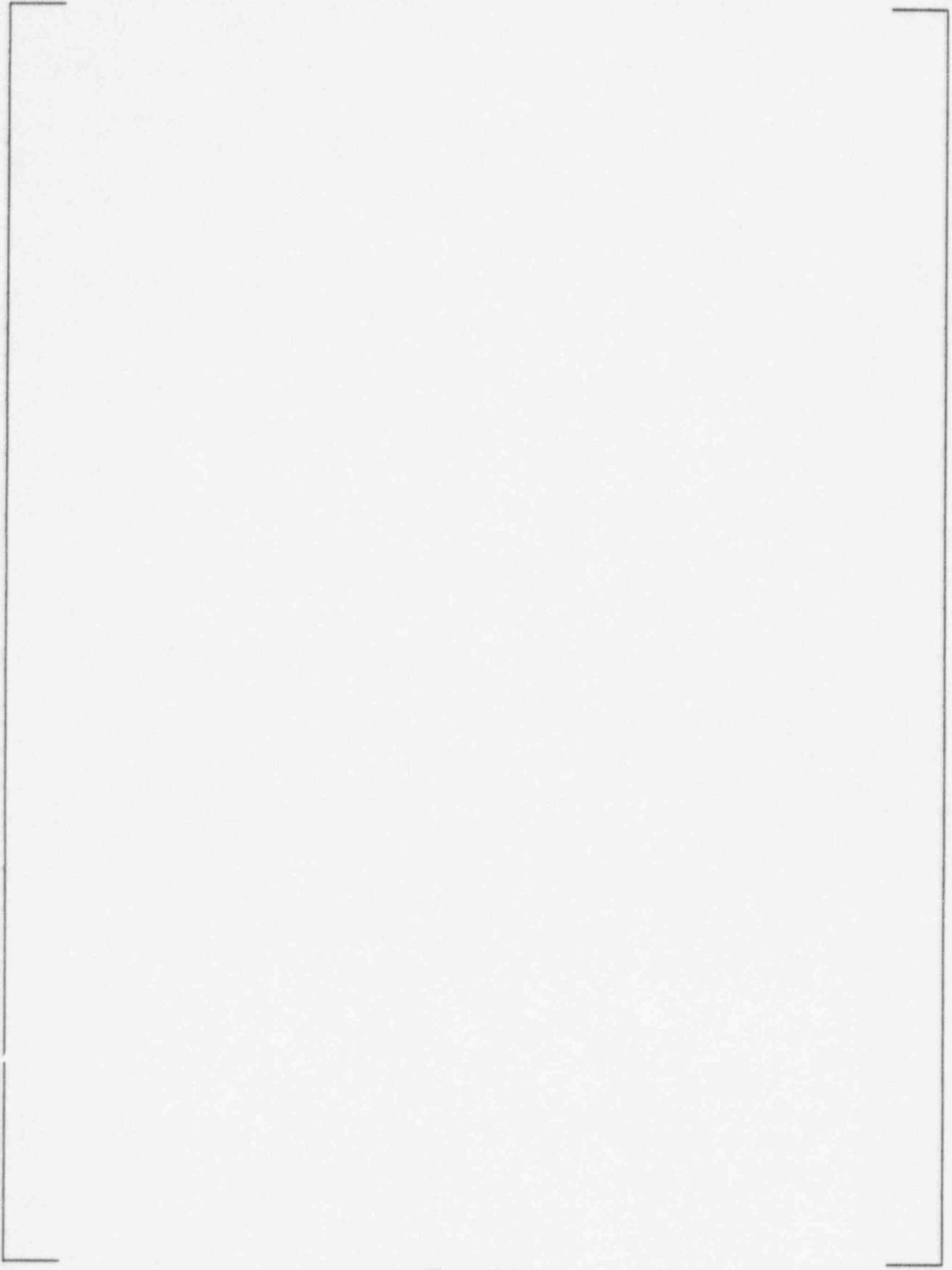


Figure 7-3

Typical Torque Trace - Dry Sludge Sample



Figure 7-4

Typical Load Traces

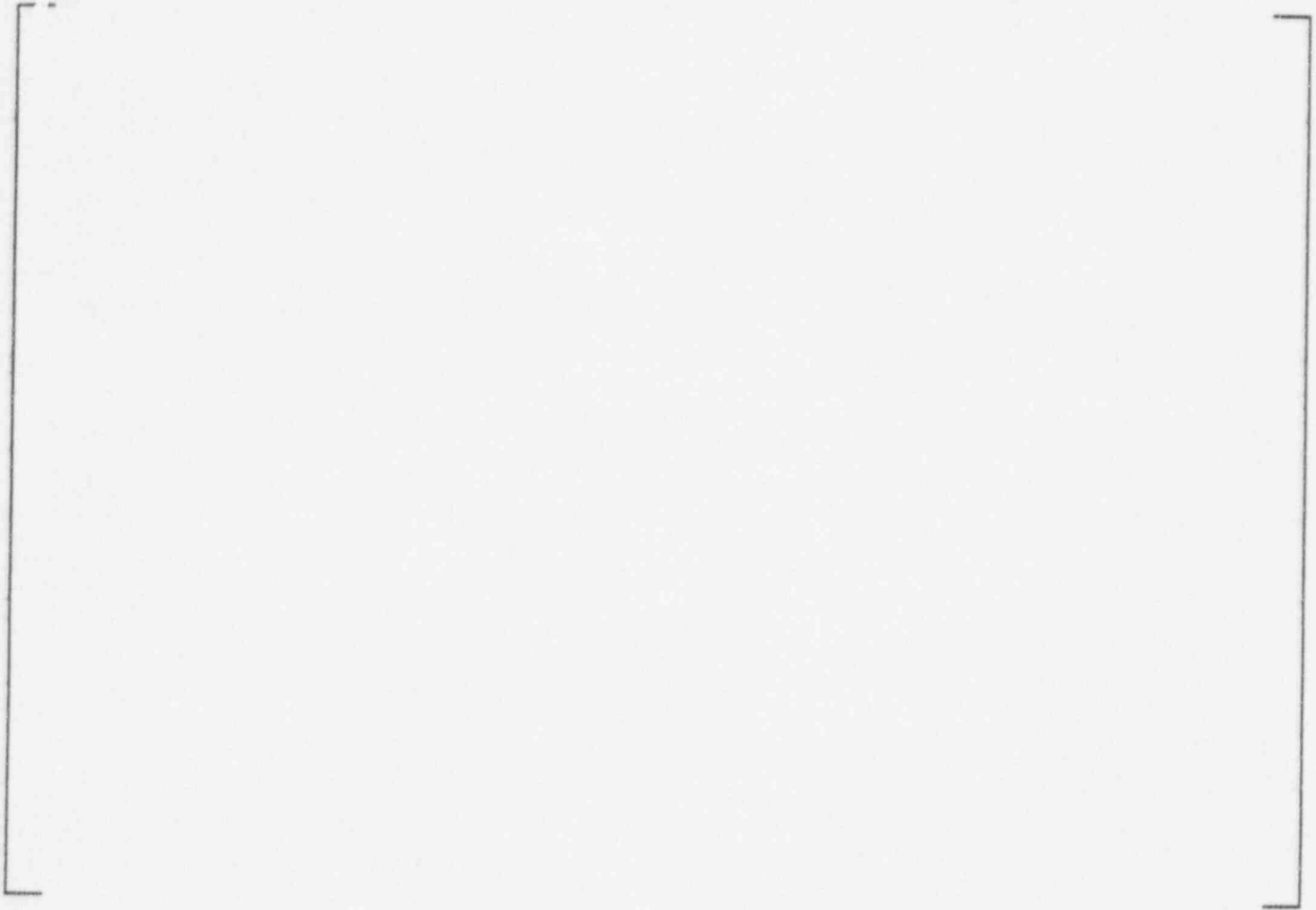
8.0 STRUCTURAL CONSIDERATIONS



8.1 Re-Roll Joint Configuration

8.1.1 Axial Loading for the First Re-Rolled Joint Location Case





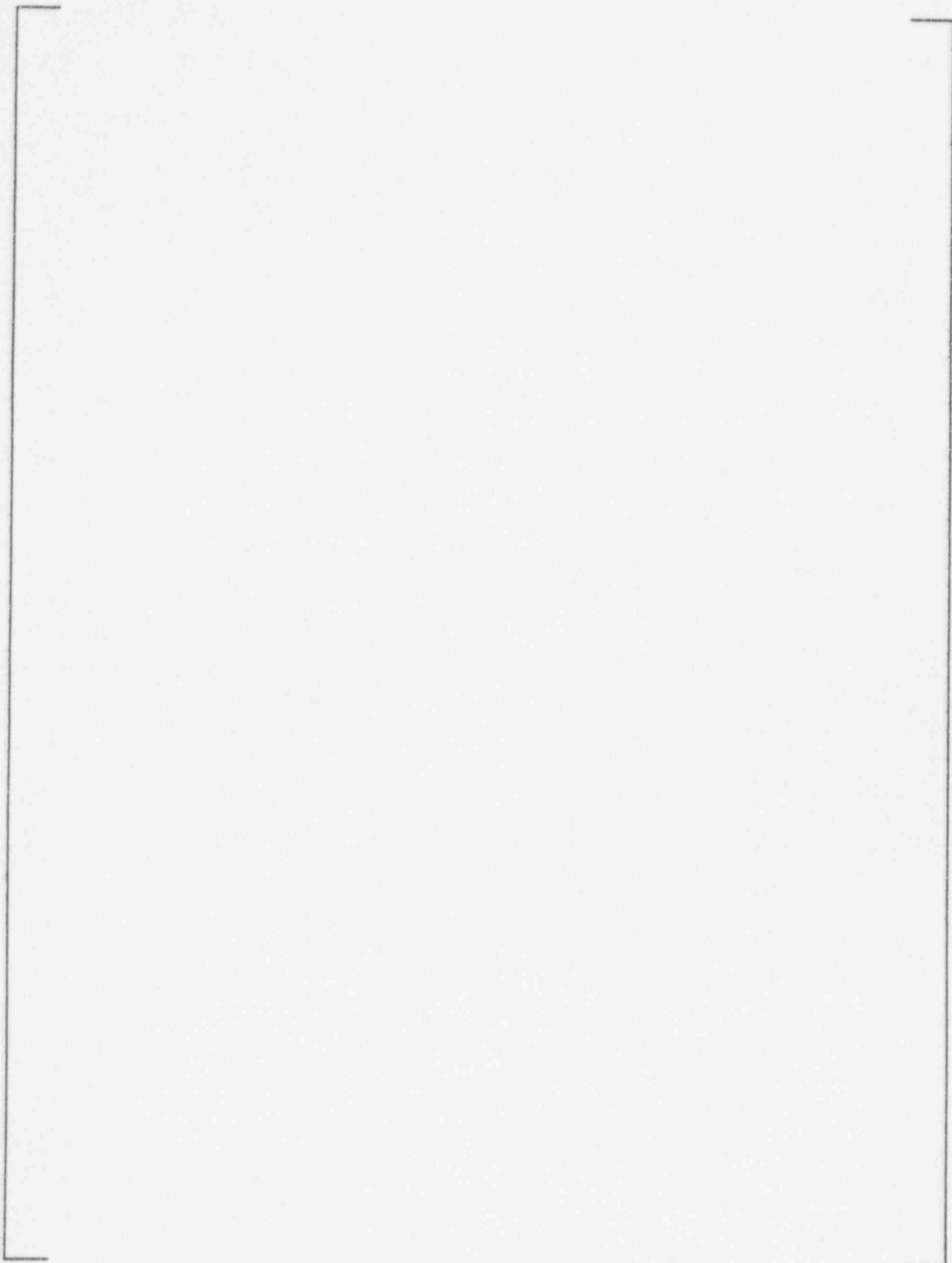


Figure 8-1
Re-Rolled Tube Model and Environment

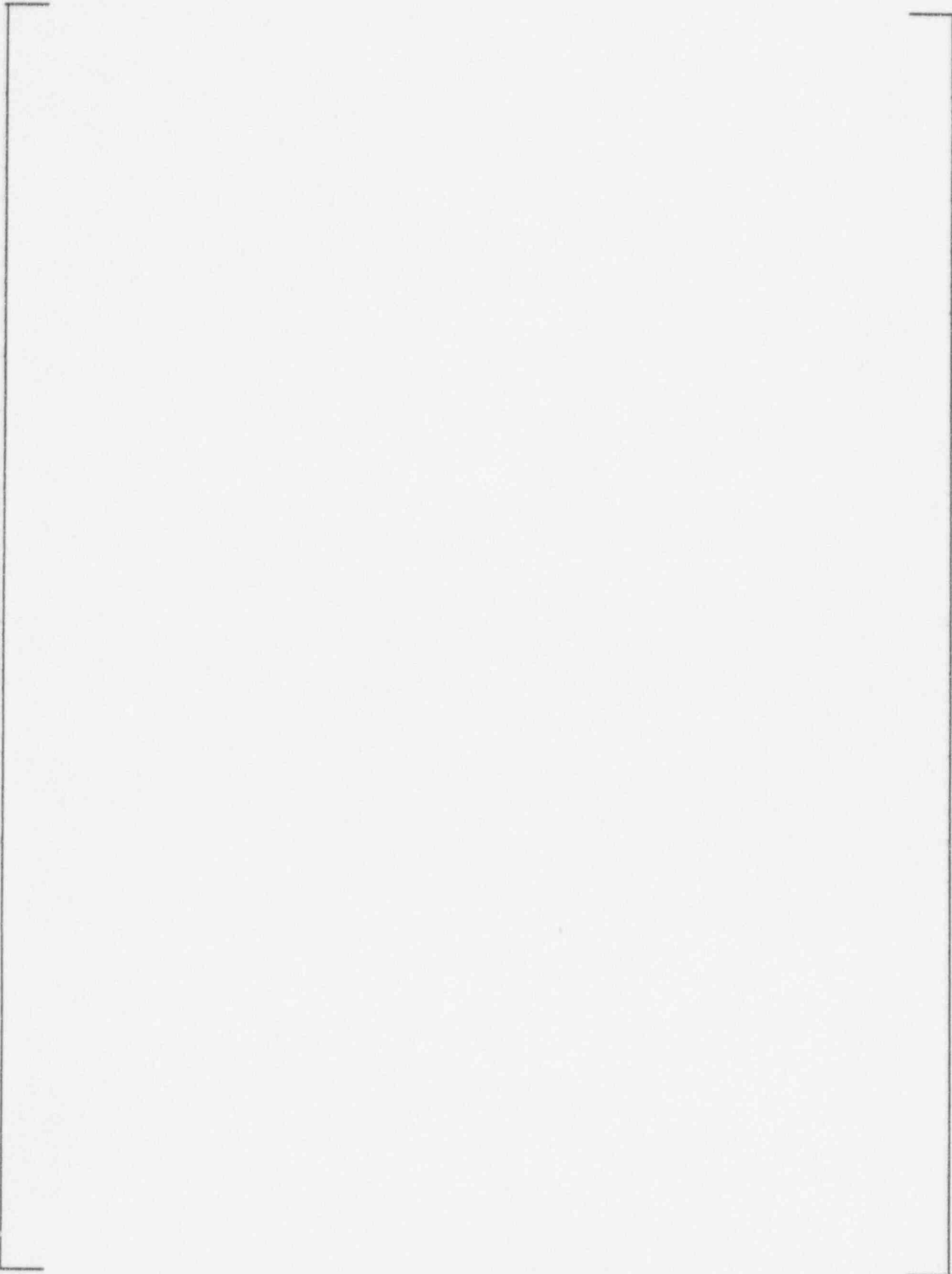


Figure 8-2
Tube Schematic - Series "44" Steam Generators for the
First Re-Rolled Joint Location Case

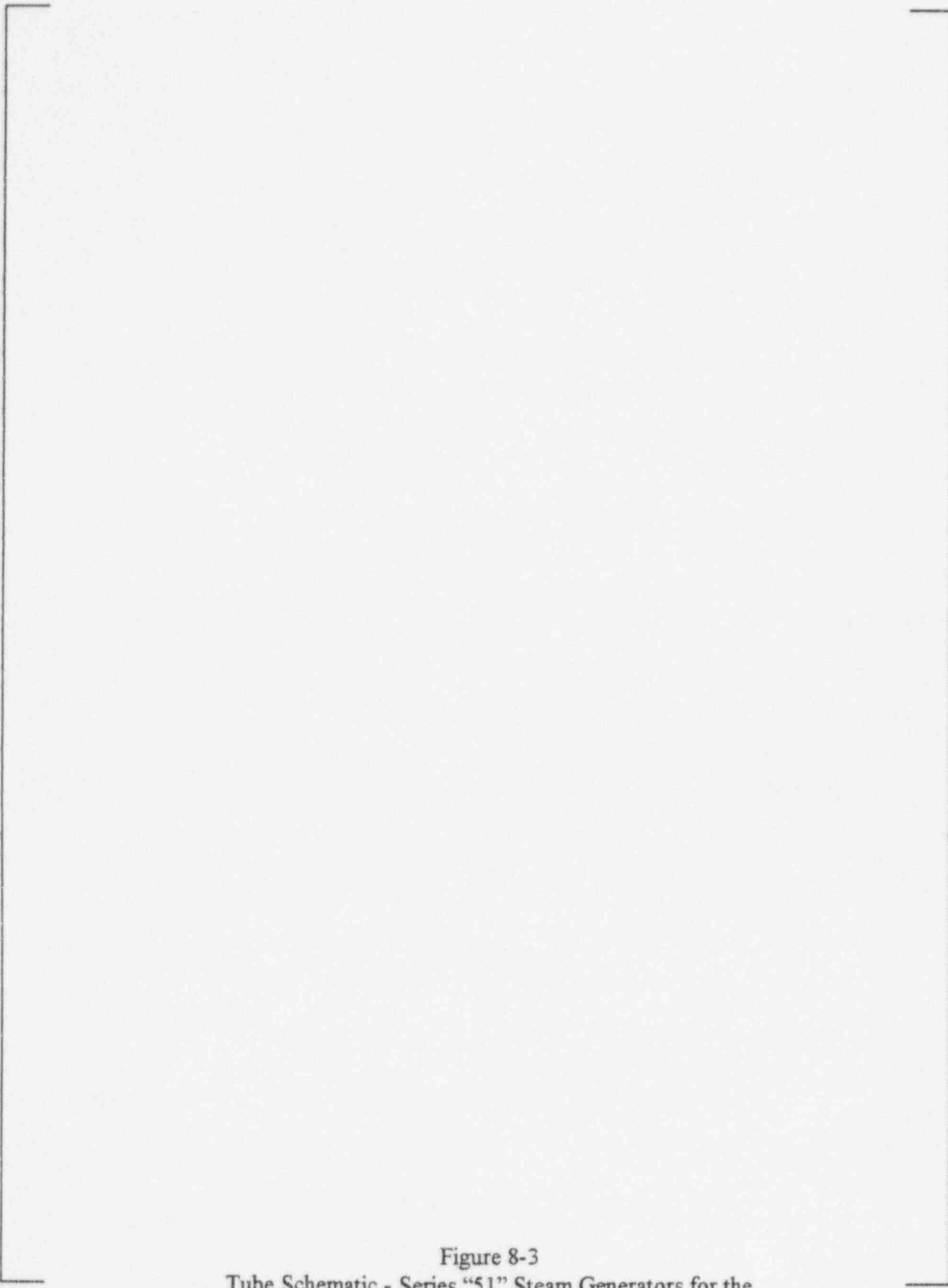


Figure 8-3
Tube Schematic - Series "51" Steam Generators for the
First Re-Rolled Joint Location Case

Table 8-1
Axial Member Physical Properties - Westinghouse Series "44" Steam Generators
for
the First Re-Rolled Joint Location Case

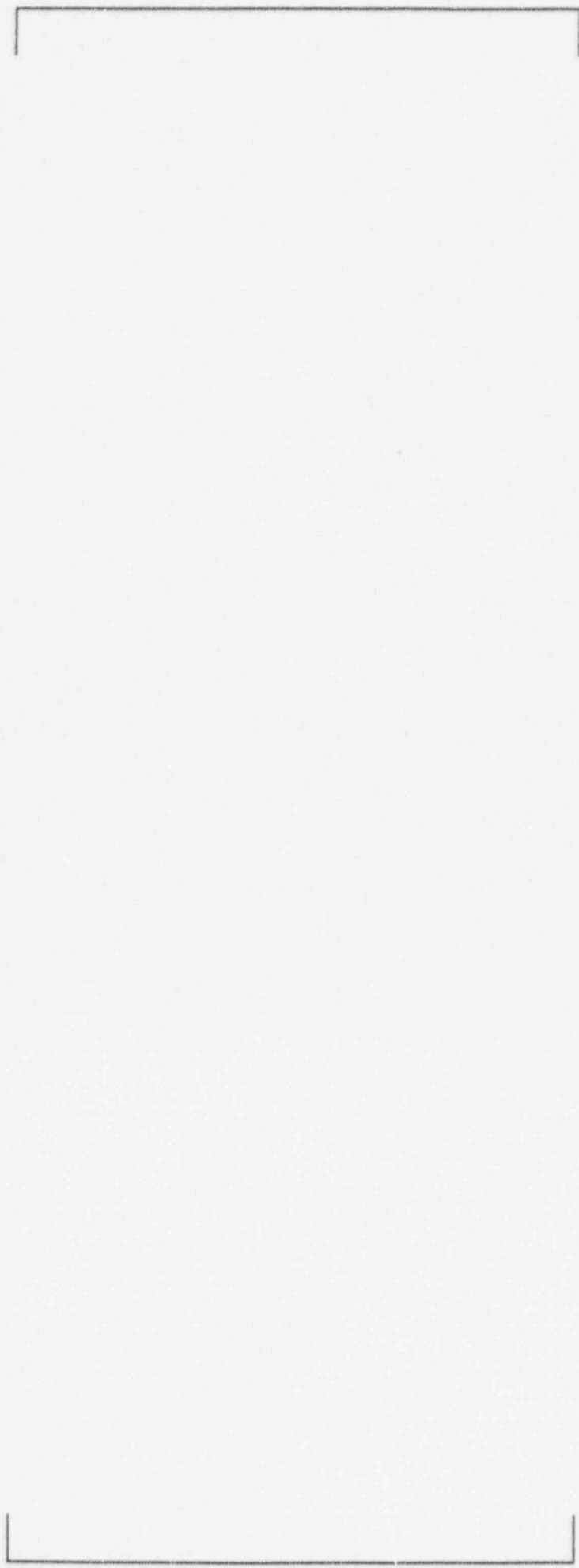


Table 8-2

Axial Member Physical Properties - Westinghouse Series "51" Steam Generators
for
the First ReRolled Joint Location Case

Table 8-3

Axial Loads in Locked Tube - Westinghouse Series "44" Steam Generators
for
the First ReRolled Joint Location Case

Table 8-4

Axial Loads in Locked Tube - Westinghouse Series "51" Steam Generators
for
the First ReRolled Joint Location Case

8.1.2 Axial Loading for the Second Re-Rolled Joint Location Case



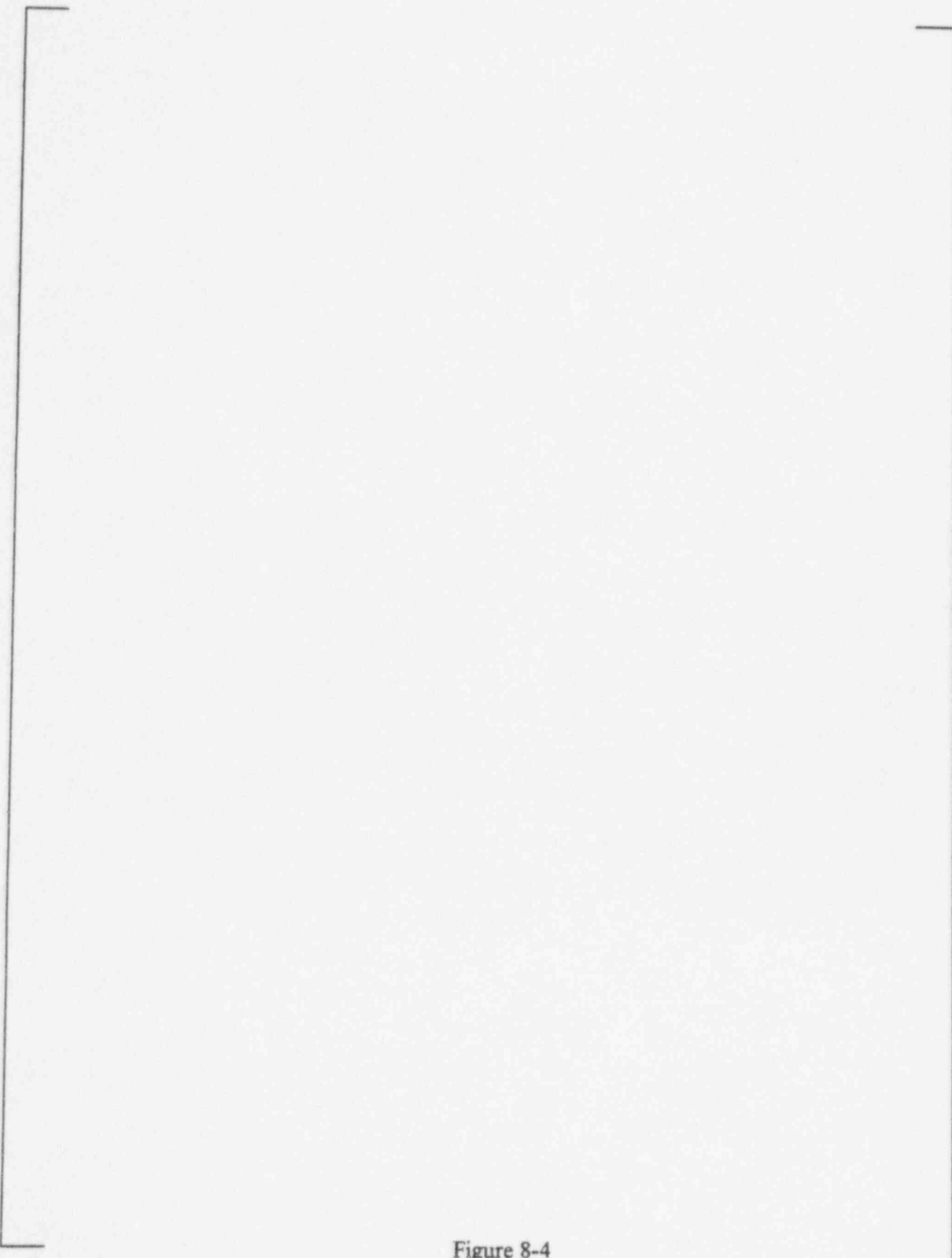


Figure 8-4
Tube Schematic - Series "44" Steam Generators for the
Second Re-Rolled Joint Location Case

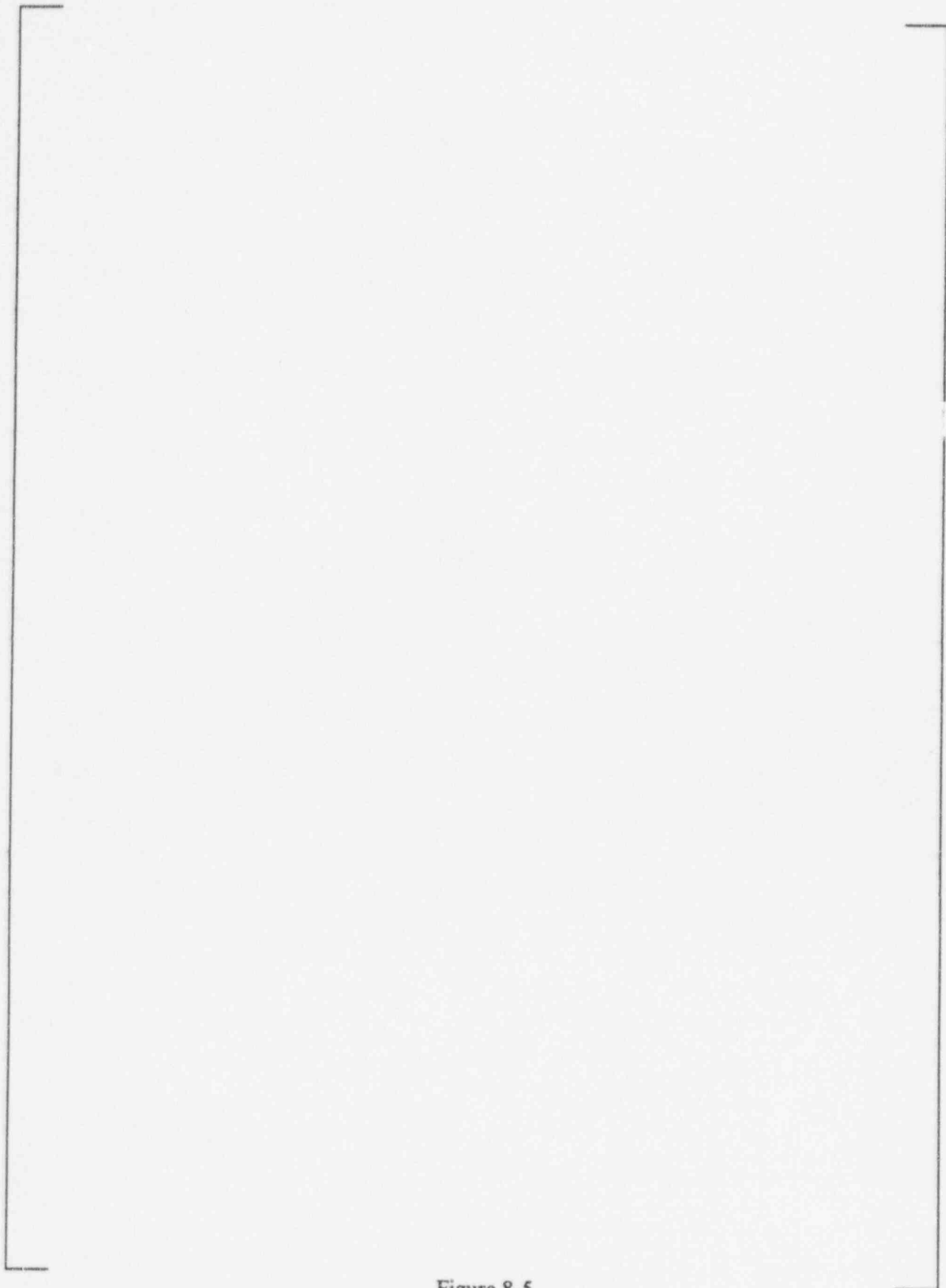


Figure 8-5
Tube Schematic - Series "51" Steam Generators for the
Second Re-Rolled Joint Location Case

Table 8-5

Axial Member Physical Properties - Westinghouse Series "44" Steam Generators
for
the Second Re-Rolled Joint Location Case

Table 8-6

Axial Member Physical Properties - Westinghouse Series "51" Steam Generators
for
the Second Re-Rolled Joint Location Case



Table 8-7

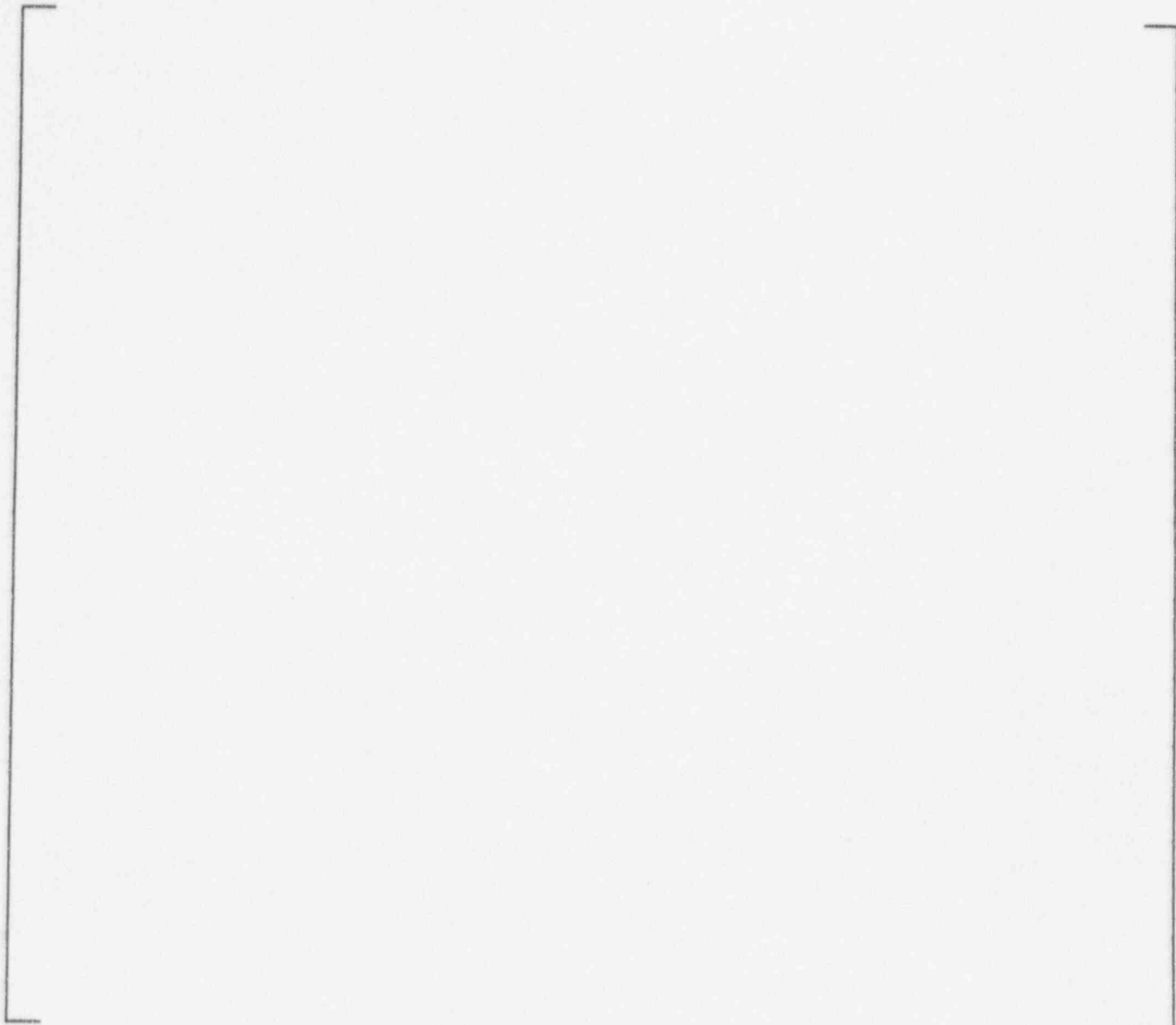
Axial Loads in Locked Tube - Westinghouse Series "44" Steam Generators
for
the Second Re-Rolled Joint Location Case



Table 8-8

Axial Loads in Locked Tube - Westinghouse Series "51" Steam Generators
for
the Second Re-Rolled Joint Location Case

8.1.3 Tubesheet Ligament Stresses



8.2 Plug and Sleeve Program Applicability

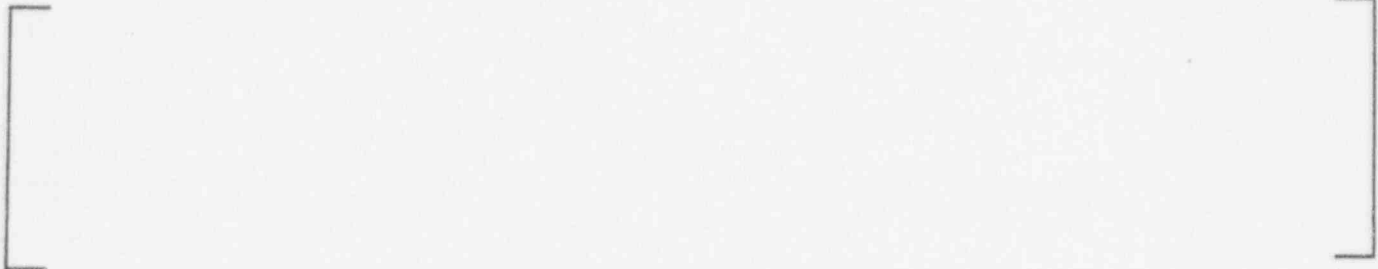


Table 8-9

Tubesheet Ligament Stresses
for
Westinghouse Series "44" and "51" Steam Generators
at
Design Condition



8.3 References

- 8.3.1 Westinghouse Steam Generator Standard Information Package, January 04, 1982 (REF-96-002).
- 8.3.2 Northern States Power Co. (Richard P. Pearson) Fax to ABB/CE (Dave Stepnick), dated 9/09/96.
- 8.3.3 "Primary/Secondary Boundary Components Steady State Stress Evaluation", prepared by P. Wedler, Westinghouse Electric Corp., April 1965 (REF-96-001).
- 8.3.4 Mark's "Standard Handbook for Mechanical Engineering", 8th Edition, 1979.
- 8.3.5 "Mechanical Engineering Reference Manual", by Michael R. Lindeberg, P.E., 9th Edition, 1994.
- 8.3.6 ASME Boiler and Pressure Vessel Code, Section III for Nuclear Power Plant Components, 1986 edition, no addenda.
- 8.3.7 ABB/CE Report No. CEN-620-P, Revision 01-P, "Series 44 & 51 Design Steam Generator Tube Repair Using a Tube Re-Rolling technique", April 1995.

9.0 EDDY CURRENT EXAMINATION

9.1 Installation Verification

Upon completion of the re-roll process, an eddy current technique, using a [], is employed to verify that the [] have been placed in the proper location in the tube.

9.2 Rotating Probe Examination

Upon completion of the installation, an [], or equivalent, is pulled through the re-rolled tube to detect tube indications. Since the parent tube, with known ECT indications, has been worked with [both a hydraulic expansion and a hard roll], an inspection is necessary to determine if the original indications have changed. The [] results will be compared with previous test results in order to determine whether or not the original indications have propagated. This test will be used to verify that the F* and L* criteria of undegraded hard roll tube length above previous indications are met.

10.0 EFFECT OF RE-ROLLING ON OPERATION

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I.