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PIPING FLEXIBILITY ANALYSIS

FOR

TEST CELL "A" CRYOGENIC PROCESS LINES

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PIPING FLEXIBILITY ANALYSIS
FOR
TEST CELL "A" CRYOGENIC PROCESS LINES

I. INTRODUCTION

This report contains the results of piping flexibility analyses performed on the cryogenic process lines located in the Flow Control Room of Test Cell "A". These analyses were required as a result of piping modifications made in the Flow Control Room to accommodate NRX-A3 and NRX-A4/EST testing.

All required analyses were performed in accordance with the requirements of the American Standard Code for Pressure Piping, ASA B31.1 - 1955. The ASA Code requires that all piping systems be analyzed for the effects of the following significant loadings.

1. Pressure, internal or external.
2. Weight of pipe, fittings and valves containing fluid and insulation.
3. Thermal expansion or contraction of the line.

It is the intent of this report to show the assumptions, the limitations, and results of such an analysis.

II. SUMMARY AND CONCLUSIONS

The results of the thermal stress analysis indicate that all cryogenic

piping systems and their interconnecting lines within the Flow Control Room of Test Cell "A" have sufficient flexibility to safely absorb the change in length resulting from the expected temperature variations. The results show that the maximum expansion stress (S_e) for all systems analyzed is within the allowable stress range (S_a) specified by the ASA Code for Pressure Piping. All thermal stress problems were primarily analyzed by the Service Bureau Corporation. The detailed computation methods used in the SBC program for determining the forces, moments, stresses, deflections and rotations were considered as proprietary information; therefore, they were not obtainable. However, all SBC computations of stress intensification factors and expansion stress ranges used formulas specified in the ASA Code for Pressure Piping.

The results of the other piping stress analysis also indicated that the stresses sustained by the piping as a result of pressure, momentum and weight loading were not significant. These stresses were substantially less than the allowable stress value (S_H) specified by the ASA Code for Pressure Piping.

However, as a word of caution, the following statement from M. W. Kellogg Company's "Design of Piping System" should be quoted.

"Absolute assurance of safety would require perfect design, material, and fabrication; this is seldom, if ever, achieved."

It should be pointed out that with every erection and completion of a piping system, internal stresses may be introduced by cold pull, weld shrinkage, flange makeup, etc. This would establish an initial state of stress, which would be unknown and limited only by the yield point of the material.

On the other hand, there appears to be some margin of safety between the total sustained stresses and the ASA Code's overall allowable stress range which would allow some degree of initial stresses to exist in the piping.

III. BACKGROUND

Due to the complexity of the piping, i.e. multi-anchors, closed loops, multi-branch lines and piping support systems, the simplifying assumptions normally associated with manual pipe stress calculations were no longer valid. In the past, two anchor, three dimensional problems have been solved manually by using S. W. Spielvogel's "Piping Stress Calculations Simplified". The Spielvogel approach to this type of problem is to solve for the three unknown forces (x , y , z) with three simultaneous equations. However, the Spielvogel method does not provide a means for analyzing multi-anchors and multi-branch systems. The more complex problems could be performed manually by using the techniques described in M. W. Kellogg Company's "Design of Piping Systems," but the

amount of manual effort required to perform problems of this complexity is enormous. For example, one problem with 8 anchors, 4 closed loops, and 20 partial restraints, required approximately 86 simultaneous equations. The accuracy of solving and checking a complex piping problem by manual methods is also questionable. Therefore, from the standpoint of time and accuracy, it was considered more practical and economical to solve extremely complex pipe stress problems with the aid of a computer.

Since the Los Alamos Scientific Laboratory was initially responsible for solving similar problems for Test Cell "A" and Test Cell "C", they were contacted to determine if LASL's program, MEC-21/7094, "A Piping Flexibility Analysis Program,"⁽¹⁾⁽²⁾ could be used for problems

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- (1) WANL has subsequently received a complete copy of LASL's program, MEC-21/7094. Copies of the application report LA-2929, MEC-21/7094, "A Piping Flexibility Analysis Program for the IBM 7090 and 7094", written by J. H. Griffin, were obtained from the Office of Technical Services. LASL hopes to issue a report eventually, describing the computational method employed in MEC-21/7094.
- (2) The LASL program is a modification of Mare Island Naval Shipyard Program MEC-21, which was written by John A. Olson and Robert V. Cramer of the Mare Island Naval Shipyard Engineering Computer Application Branch.

with closed loops and multiple branches. LASL advised that their program was capable of solving the most complex problems and that, as time permitted, LASL would be willing to analyze the particular Test Cell "A" problem if furnished with the necessary input data.

Isometric drawings were prepared for the NRX-A3 piping modifications and delivered to LASL. Subsequent analysis by LASL resulted in unexpected difficulties and they were able to furnish WANL with only incomplete computer results. Apparently, their program has some discrepancies inherent within itself which could not be corrected. When LASL was forced to suspend work on our program, they recommended the Service Bureau Corporation, a subsidiary of IBM, for obtaining quick and dependable piping flexibility analysis of our problem.

Before giving the problems to SBC, several Westinghouse divisions (APD, Bettis, and Lester Plant) were contacted to determine if they had a program capable of handling complex thermal stress problems. No suitable program could be made immediately available to WANL; therefore, in the interest of time, the problems were taken to the Service Bureau Corporation for analysis.

IV. ALLOWABLE STRESS RANGE

The allowable stress range established by the ASA Code for Pressure Piping, which includes all expansion, pressure and weight stress,

is expressed in the following formula:

$$S = 1.25 (S_c + S_h)$$

where S_c is the allowable stress in the cold condition and S_h is the allowable stress in the hot condition. Since the expansion stresses are calculated separately from the pressure and weight stresses, the ASA Code gives the following formula for the allowable expansion stress.

$$S_a = 1.25 (S_c + S_h) - S_h$$

or
$$S_a = 1.25 S_c + .25 S_h$$

As stated in the ASA Code, "The sum of the longitudinal stresses due to pressure, weight, and other sustained external loading shall not exceed S_h . Where the sum of these stresses is less than S_h , the difference between S_h and this sum may be added to the term $0.25 S_h$ in the formula for allowable expansion stresses."

In our problems S_c corresponds to cryogenic temperature and S_h corresponds to ambient temperature. The ASA Code gives an allowable stress (S) for 304 Stainless Steel of 18,750 psi between the temperature range of -20 to 100°F. Additional benefit is not permitted for temperatures below -20°F; therefore, S_c and S_h are equal and the formula becomes $S_a = 1.5 S_h$. By substituting in 18,750 psi for S_h , the maximum allowable expansion stress is found to be 28,125 psi.

V. THERMAL STRESS ANALYSIS

A total of seven different problems have been analyzed by SBC. Each of these problems is listed below under the SBC job number heading with a short description of each and a summary of the results. It should be pointed out again that the detailed computation methods used in the SBC program for determining the forces, moments, stresses, deflections and rotations were considered as proprietary information and, therefore, were not obtainable for our investigation.

The first four problems discussed below, (No. 1000, 1001, 1002, and 1003) were required as a result of the NRX-A3 piping modification to the Flow Control Room. The following isometric drawings, dated February 2, 1965, (attached) were used for data input.

1. Sheet 1 of 7

The 8 inch main propellant line from the facility pump, through ACV-3, to anchor A-2 at the 8 inch plug penetration.

2. Sheet 2 of 7

The GH_2 header from a simulated anchor A-3, on the Flow Control Room roof, through PCV-41 to the 8 x 8 x 6 reducing tee in the main propellant line.

3. Sheet 3 of 7

The LN_2 line from anchor A-5, near the Flow Control Room west wall, through JBV-19 to the 6 x 6 x 6 tee in the GN_2 header.

4. Sheet 4 of 7

The LN₂ line from a tee upstream of JBV-19, through JBV-18, to a tee in the PCV-18 emergency cooling line and to anchor A-6 at the 6 inch plug penetration.

5. Sheet 5 of 7

The GH₂ emergency cooling line from a tee upstream of PCV-41 through PCV-18 and to the tee connection with the JBV-18 LN₂ line.

6. Sheet 6 of 7

The bypass and evacuation line from the 3 inch plug penetration.

This line splits with one branch going through valve 979 and connecting to an 8 x 8 x 3 tee in the main propellant line. The other branch going to a partial anchor A-8 on the Flow Control Room roof.

7. Sheet 7 of 7

A revised drawing of Sheet 6 was required to show 3 inch Schedule 10 S pipe and to replace anchor A-8 with a partial constraint.

SBC JOB NO. 1000

The following temperature configurations were stipulated for this particular problem.

1. LH₂ temperatures were assumed to exist from the facility pump to valve ACV-3.
2. LN₂ was assumed to be flowing through JBV-19, to the main propellant line and through the 8 inch plug penetration.
3. All other lines remained at ambient temperatures.

The location and value of several high stress points which were printed out in the computer results for this problem were:

1. Point 66	Downstream of anchor A-5 on the LN ₂ header (See Sheet 3)	21,040 psi
2. Point 20	Downstream of ACV-3 (See Sheet 1)	18,871 psi
3. Point 13	Upstream of ACV-3 (See Sheet 1)	19,222 psi
4. Point 2	Immediately downstream of facility pump (See Sheet 1)	19,718 psi
5. Point 19	On the 6 inch branch of the 8 x 8 x 6 tee connection downstream of ACV-3 (See Sheet 1)	12,152 psi
6. Point 19	Same point as above with stress intensification factor applied	22,200 psi

The SBC program calculates the expansion stress range for straight pipe, curved pipe and elbows using formulas as specified in the ASA Code for Pressure Piping. The appropriate stress intensification factors as stipulated in the ASA Code are calculated by the SBC Program and applied to the bending stresses for elbows but not for tees. Therefore, after the data was received from SBC, it was necessary to calculate the bending stresses from the bending moments printed out on the data sheets and then multiply by a calculated stress intensification factor for each tee. For example, the expansion stress (S_e) printed out for point 19 on the 6 inch branch of the 8 x 8 x 6 tee was only 12,152 psi

without the stress intensification factor. After applying this factor, the stress range at point 19 was found to be 22,200 psi. All the stresses for this run were below the maximum allowable expansion stress of 28,125 psi.

SBC JOB NO. 1001

The following temperature configurations were stipulated for this problem.

1. LH₂ was assumed to be flowing from the facility pump through ACV-3 to the 8 inch plug penetration.
2. LH₂ was also assumed to be returning from the test assembly through the 3 inch plug penetration and then through the bypass and evacuation line and out the flare stack. The interconnecting line containing valve 979⁽¹⁾ was also assumed at LH₂ temperature.
3. All other lines were assumed at ambient temperature.

(1) Valve was removed during NRX-A3 testing and the line was blanked off.

The following values of high stress were printed out for this run.

1. Point 44	At the anchor in the bypass and evacuation line (See Sheet 6)	25,088 psi
2. Point 2	Immediately downstream of the facility pump (See Sheet 1)	20,711 psi
3. Point 13	Upstream of ACV-3 (See Sheet 1)	19,758 psi
4. Point 36	In the 3 inch bypass and evacuation line (See Sheet 6)	20,877 psi
5. Point 26	On the 3 inch branch of the 8 x 8 x 3 tee connection to valve 979 (See Sheet 6)	17,602 psi
6. Point 26	Same point as above with stress intensification factor applied	29,800 psi

When the stress intensification factor was calculated and applied to the bending stresses at point 26, on the 3 inch branch of the 8 x 8 x 3 tee connection, the stress range at point 26 was found to be 29,800 psi.

This stress was only slightly above the allowable stress range of 28,125 psi, and would not ordinarily require additional stress analysis.

However, the input data had specified the entire bypass and evacuation line as 3 inch SCH 40 S and actually the majority of this line had been fabricated from 3 inch SCH 10 S pipe. Due to this difference in the pipe schedule and more accurate information on the routing of the line and anchor location, a re-run was requested. This re-run is discussed under SBC Job No. 1002.

SBC JOB NO. 1002

A revised isometric drawing was submitted for data input for this run. (See Sheet 7) In order to reduce the cost of this run, only the 3 inch section of line from points 26 through 44 was resubmitted with the displacements and rotations at point 26 from Job No. 1001 applied to point 26 for this run. The maximum stress found in this run was 10,996 psi at point 43.1. The reason for the reduction in the stresses throughout this line was primarily due to the changing of the anchor at point 44 to a partial constraint. This was more representative of the actual support located on the roof of the FCR.

SBC JOB NO. 1003

This problem also analyzed the NRX-A3 piping modification. LN_2 was assumed to be flowing through JBV-18 to the 6 inch emergency purge line and through the 6 inch plug penetration. (See Sheet 4) Only the section of line between point 58 and point 86 was analyzed with deflection applied to point 58 and force and moments applied to point 79. These deflections, force and moments were obtained from Job No. 1001 data. The maximum stress printed out in the data was 17,699 psi at point 70. After applying the stress intensification factor to the bending stress at the 6 x 6 x 6 SCH 10 tee at point 58, the maximum stress was found to be 28,000 psi at this point.

All the problems discussed thus far have been for the NRX-A3 piping modification. The next three problems discussed below (No. 1004, 1010, and 1011) were required for the NRX-A4/EST modification to the main propellant line. SBC Job No. 1004 was required as a result of rerouting the line downstream of ACV-3 from the 8 inch plug penetration to a 6 inch plug penetration. Sheet 1 of the isometric drawings dated February 2, 1965, was used for data input for this problem. SBC Job Nos. 1010 and 1011 required new isometric drawings, Sheets 1 through 6, dated August 12, 1965, to show the new NRX/EST propellant supply header from dewars A, B and C through JBV-3, FE-4 and F-56 to the 8 inch plug penetration.

SBC JOB NO. 1004

The following temperature configurations were stipulated for this problem.

1. LH_2 temperatures were assumed from the facility pump to ACV-3.
2. LN_2 was assumed to be flowing through JBV-19, to the main propellant line and up to the 6 inch plug penetration.
3. All other lines were assumed at ambient temperature.

The following values of high stress were printed out for this run.

1. Point 22	Downstream of filter F-39 (See Sheet 1, dated 2/2/65)	24,352 psi
2. Point 2	Immediately downstream of the facility pump (See Sheet 1, dated 2/2/65)	18,735 psi
3. Point 13	Upstream of ACV-3 (See Sheet 1, dated 2/2/65)	19,023 psi
4. Point 26.5	Upstream of ACFI spool piece (See Sheet 1, dated 2/2/65)	19,055 psi
5. Point 66	Downstream of anchor A-5 on the LN ₂ header (See Sheet 3, dated 2/2/65)	20,843 psi

All the stresses for this run were below the maximum allowable stress range of 28,125 psi.

SBC JOB NO. 1010

The following temperature configuration was stipulated for this problem.

1. LH₂ was assumed to be flowing from all three dewars through JBV-3, FE-4, and F-56 to the 8 inch plug penetration.

The following points were printed out with stresses greater than the allowable expansion stress range of 28,125 psi.

1. Point 72		31,046 psi
2. Point 74	All three of these points were near the pipe support PS-20 (See Sheet 5, dated 8/12/65)	40,555 psi
3. Point 75		34,868 psi

These high stresses were not realistic because in the input data SBC had assumed that the pipe support, PS-20, acted as a partial restraint along both the X and Y axis. The instructions to SBC (See Sheet 6) stated that all pipe supports (PS-1 through PS-20) were to be considered as partial constraints, preventing any movement in the (-) Y (downward) direction only. Thus, the restraints along the X axis at points 73 and 74 produced the above high stresses. The hanger support at PS-20 should not restrain the line along the X axis. Even though this particular hanger support is bolted to lugs welded on the unjacketed 8 inch line, there appears to be enough flexibility in the 4 foot vertical support rod and turnbuckle to permit the line to move freely along its X axis. However, NTO is presently modifying this support to a clevis type hanger support as a result of Test Systems Design's preliminary evaluation of this data.

In order to have data which would verify the necessary flexibility in this EST propellant feed line, a rerun was requested with the partial restraints, PS-1 through PS-20, removed from the input data. The results of this rerun are discussed under SBC Job No. 1011.

SBC JOB NO. 1011

The temperature configuration stipulated for this run was the same as for SBC Job No. 1010. The results from this run are listed below.

1. Point 20	Upstream of JBV-2 at location of pipe support PS-10 (See Sheet 3 dated 8/12/65)	10,949 psi
2. Point 23	Upstream of JBV-2 at 90° elbow (See Sheet 3 dated 8/12/65)	10,618 psi
3. Point 31	Upstream of JBV-1 at location of pipe support PS-6 (See Sheet 3 dated 8/12/65)	10,420 psi
4. Point 34	Upstream of JBV-1 at 90° elbow (See Sheet 3 dated 8/12/65)	10,045 psi

The results from this rerun were more representative of the stresses which would be obtained in the actual line. The SBC Code could not accurately simulate single-acting restraints such as clevis hangers and resting supports. Their program could not simulate a restraint acting only in a negative Y direction. SBC assumes that all partial restraints are double acting, which means that the line is restricted from moving in both the positive and negative Y direction. This additional restriction would obviously cause unrealistic forces and deflections to occur throughout the system. The results of this rerun indicated that the deflections along the Y axis, at the points where the line was initially restrained, were all positive. This indicates that the results obtained from this analysis would be identical to the results that would have been obtained if the SBC Code could have simulated single acting supports. The reason for this conclusion is that the rerun showed that the line tends to move up due to thermal contraction; therefore, since the existing supports are only preventing the line from moving down, they would not have any affect on the results of this analysis.

VI. OTHER SUSTAINED STRESS

The results presented thus far have been the stresses sustained in the pipe caused by thermal contraction of the piping system as a result of the cryogenic fluid passing through the system. The stresses due to thermal contraction are normally the more significant ones. However, all piping systems are subject to pressure, momentum and weight loading which produces additional longitudinal stresses within the pipe. As stated previously, the ASA Piping Code requires that these additional longitudinal stresses be less than (18750 psi) S_h .

A. Pressure Stresses

The longitudinal pressure stresses can be calculated with the following formula:

$$S_p = P \frac{A_f}{A}$$

where:

S_p = Longitudinal pressure stress (psi)

P = Internal pressure (psig)

A_f = Flow area (in²)

A = Metal cross-sectional area (in²)

The "reactor only" pump discharge line is fabricated from 8 inch Schedule 40 pipe and normally operates at approximately 1000 psig. The longitudinal pressure stress in this line would then be:

$$S_p = \frac{(1000 \text{ psig}) (50.027 \text{ in}^2)}{8.40 \text{ in}^2} = 5960 \text{ psi}$$

The EST propellant feed line from the dewars to the 8 inch plug penetration is fabricated from 8 inch Schedule 5S pipe and normally operates at approximately 85 psig. The longitudinal pressure stress in this line would be equal to:

$$S_p = \frac{(85 \text{ psig}) (55.5 \text{ in}^2)}{(2.92 \text{ in}^2)} = 1610 \text{ psi}$$

B. Stresses Due to Change in Momentum

A fluid flowing steadily through a pipe bend produces forces on the piping system due to the change in momentum of the fluid. These forces can be calculated from the following expression given as Equation 6.6 in Hunsaker and Rightmire's "Engineering Application of Fluid Mechanics":

$$F_x = \frac{\rho_1 Q_1}{g} (V_{x2} - V_{x1})$$

where:

F_x = Force along X axis (lb)

Q_1 = Rate of flow entering the elbow (ft³/sec)

ρ_1 = Density of fluid lb/ft³

V_{x1} = V_1 or the X component of velocity entering the elbow

V_{x2} = $V_2 \cos \theta$ or the X component of velocity leaving the elbow. Since the elbow is 90°, $\cos \theta = 0$ and $V_{x2} = 0$

g = Acceleration of gravity $32.2 \frac{\text{lbm/ft}}{\text{lbf/sec}^2}$

therefore:

$$F_x = \frac{Q}{g} V_1$$

by substituting in $Q = \frac{V_1 A_f}{144}$

and $V_1 = \frac{W_1}{\rho_1 A_f} (144)$

where:

W = Mass flowrate lb/sec

A_f = Flow area (in²)

this expression for the force becomes

$$F_x = \frac{W^2}{\rho A_f g} 144$$

By dividing F_x by the metal cross-sectional area (A), the longitudinal stress due to change in momentum can be shown as:

$$S = \frac{144 W^2}{\rho A_f g A}$$

The mass flowrate through the EST propellant feed line is 77 lb/sec; therefore, the longitudinal stress due to the change in momentum can be shown to be:

$$S = \frac{(144) (77)^2}{32.2 (55.5) (2.92) (4.41)} = 37.2 \text{ psi}$$

where:

$$\begin{array}{rcl} \rho & = & 4.41 \text{ lb/ft}^3 \\ \text{at } P & = & 100 \text{ psia} \\ T & = & 38^\circ\text{R} \end{array}$$

C. Weight Loading

All piping systems must be analyzed for their adequacy in carrying all gravitational loading such as weight of pipe, insulation, contents, fittings, valves, etc. The support system must also provide the necessary support throughout the thermal cycle. There are no rigorous methods for performing an accurate analysis of weight loading on the existing piping system located in the Flow Control Room of Test Cell "A". Test Cell "A" piping supports are made primarily of rigid clevis hangers and sliding supports. The fabrication and installation of these types of supports have an important influence on the load carrying characteristics of each support. For example, several extra turns on one turnbuckle could increase the initial load carried by that rod hanger and reduce the load carried by another. The same would be true of sliding supports, whose height was not accurately established.

Actually, the support system for Test Cell "A" does not meet the ASA Code requirements. The Code required that either spring or

compensated type hangers be used for piping systems undergoing thermal variations, with the hangers designed for a maximum variation in supporting effect of 25% for the total vertical travel between the ambient and cold position. The Code also requires the use of constant support hangers for piping systems subjected to appreciable vertical movements due to thermal contraction. These types of hangers are required to prevent any excessive transfer of loads from support to support, or from support to piping.

The SBC program could simulate concentrated loads but could not simulate a uniformly distributed load such as weight per length of pipe. Test Systems Design was advised by SBC that two methods could be used to solve the weight loading problem in conjunction with their program. One method was to analyze the problem for thermal stress analysis with the partial restraints included. The computer results would show the forces of the pipe on the restraints. If the upward forces at the restraint points were less than weight of the pipe at that point, then the supports were adequate throughout the thermal cycle. If the upward forces were larger than the pipe weight, then the hanger or support should be relocated and a computer rerun would be required. The other method was to submit the problem for thermal stress analysis with the partial restraints excluded. The computer results would then show the vertical deflections of the pipe at the

restraint points. If the vertical deflections were small, less than 1/8 inch upward, a rigid clevis hanger would be adequate at that point. If the upward vertical deflections were larger than 1/8 inch at a restraint point, the hanger would have to be relocated to a point where the deflection was smaller or replaced with a spring or compensated type hanger.

These methods were not entirely acceptable since they would require a complete redesign of the support system of Test Cell "A". However, it is still necessary to determine the stresses due to weight loading in the piping system utilizing the existing support system.

Normally, these stresses are only a small percentage of the allowable stress. For example, the maximum span between supports at Test Cell "A" is approximately 20 feet. The weight per foot for 8 inch SCH 5 pipe is nominally 10 lb/ft. From nomograph C-16 in M. W. Kellogg's "Design of Piping Systems," it can be shown that a 20 foot span of 8 inch SCH 5 pipe would produce a maximum bending stress of only 750 psi. However, to be conservative, a case could be postulated where one support is entirely unloaded as a result of a large vertical displacement due to thermal contraction. This case could be simulated by doubling the maximum span to 40 feet. The weight of

the pipe could also be doubled to 20 lb/ft to include additional weights such as the weight of the fluid, fittings, flanges, etc. The nomograph C-16 shows that the maximum bending stress would increase to only 6000 psi for this case, which would be well within the maximum allowable stress of 18,750 psi.

Therefore, based on past operation experience, and the spacing of the existing hangers and supports, it is Test Systems Design's contention that the additional stresses sustained in the piping due to weight loading while undergoing thermal contraction are within the allowable range. It should be re-emphasized, that although the supporting system now being utilized in Test Cell "A" appears to be acceptable, it does not represent the optimum design.

TEST CELL "A"
 PIPING MODIFICATIONS
 DATE 2/2/65 F.T.J.
 SHEET 1 of 7
 REVISED 6/20/65

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BRANCH 2 ROUTING
 FOR EST MODIFICATION

BRANCH 1
 8" SCH 40S 304 SS

DESIGNATES
 S/R 90° EL

BRANCH 3
 6" SCH 40S-304 SS

TEST CELL "A"
PIPING MODIFICATIONS
DTD. 2/2/65 ETS
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SEE SHEET 7
 REVISED 2/17/65 FOR
 SBC JOB NO. 1002

POINTS 29 THRU 44
 3" SCH 40S 304 SS

DATE 2/17/65
Sheet 7 of 7

POINTS	PIPE SIZE
(1) THRU (50)	8" SCH 5S
(50) THRU (52)	8" SCH 160
(52) THRU (55J)	8" SCH 5S
(55J) THRU (62)	8" SCH 40S
(62) THRU (63)	8" SCH 40S
(63) THRU (75)	8" SCH 40S

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NOTES: SEE SHEET 6

COMPOSITE ISOMETRIC -
 LH₂ PROPELLANT SUPPLY LINE
 TEST CELL "A" - NRDS
 EST MODIFICATION
 DATE 8/12/65 FTJ
 SHEET 1 of 6

TEST CELL "A" - NRDS
EST MODIFICATION
DATE 8/12/65 F.T.J
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TEST CELL "A" NRDS
EST MODIFICATION
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WESTINGHOUSE ELECTRIC CORPORATION

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NOTES:

1. Valves JBV-1, JBV-2, JBV-3, JBV-4 are considered as rigid members, 8 inches in length.
2. Pipe supports (PS-1 through PS-20) are considered as partial constraints, preventing any movement in the (-)y direction.
3. Anchors (A-1 through A-4) are rigid constraints, preventing displacement and rotation in all directions.
4. Temperature of entire system is (-)423°F.
5. Modules of Elasticity ($E(G)$) is 29×10^6 psi.
6. Coefficient of thermal contraction is (-) 307×10^{-5} in/in or (-) 3.685 in/100ft.
7. Poisson's ratio is 0.3.
8. All material is 304 SS. Pipe size and schedule are listed ^{on SHEET 1.} below.
9. The effect of the vacuum jacket is neglected.
10. All 90° elbows are long radius.