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EXISTING REACTOR

REAR FACE PIPING REVIEW

by

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INTRODUCTION

The rear face or discharge area of a reactor contains all the appurtenances necessary to discharge irradiated fuel, to collect hot coolant from each process tube, to monitor tube and effluent temperatures, and to monitor the coolant for ruptured fuel elements. Generally, failure of a rear face piping component would not affect the safety of the reactor since the coolant has since fulfilled its purpose, that of cooling the fuel elements. The failure may, however, cause failure of one of the monitoring devices and if undetected could lead to a minor reactor incident.

The number of such piping failures which could be tolerated depends of course upon the location and size of the leak, and other component failures. Because the rear face is inaccessable during normal reactor operation, all such leaks must be repaired during shutdown periods. Past experience has shown that the length of a reactor outage is in a large part determined by the amount of work required on the rear face of the reactor. In order to prevent undue loss of production, it is desirable that equipment items and piping components located in the rear face of the reactor possess a high degree of reliability.

Preliminary engineering evaluations indicate that piping in the 105 B, D, F, DR, and H reactors has deteriorated to the extent that an increasing rate of component failure can be expected. In view of this, a budget submission[1] was made in the FY-1962 P. A. and C budget and has been included in the I.P.D. Plant Improvement Program.

The purpose of this report is to substantiate the need for this program and to review information generated during the past three years concerning the condition of rear face piping and hardware. This review includes the history of rear face piping and hardware problems, study activities undertaken to date to ascertain the condition of the components, action taken to correct actual component failures, programs recommended to correct deficiencies which operating experience and engineering judgement indicate are necessary, and programs to accumulate additional information to support design of new piping and hardware components.

SUMMARY AND CONCLUSIONS

The existing piping complex at the rear face of the older reactors, B, D, F, DR, and H are deteriorating under the effects of operation at temperatures and flows in excess of that for which they were designed. This is evidenced by cracking of risers due to overstress, stress corrosion caused by leaks and buildup of corrosive scale, cavitation of fittings due to high velocities and high temperatures, and by the low frequency vibrations caused by failure of crossheader supports and by boiling and high turbulence in the downcomer approaches.

While reactor safety is not directly affected by failure of many of these components, leaks must be minimized to preserve the integrity of the system. Eventually, a point will be reached where the outage time for repair will become prohibitive. Failure of a piping system is in general a function which increases exponentially. With the information presently available it is not possible to assess quanitatively at what rate actual failures of the reactor piping systems may be expected to occur. However, based upon the information which is available it is expected that additional failures can realistically be expected in the near future. In order to provide time for adequate replacement design and for normal budget procedures, action should be initiated now for replacement of the rear face piping at the B, D, F, DR, and H reactors.

The replacement of crossheaders will require the removal of all existing nozzles, gun barrel flanges, and associated hardware. Consideration should be given to utilizing this opportunity to provide for nozzle replacement since the material cost of the new nozzles would be offset by their improved hydraulic features. Provision for process tube expansion should likewise be considered to reduce Van Stone flange failures. This will require replacement of the process tubes and removal of the front face nozzles.

To provide for operating continuity at present power levels or moderate increases, interim measures should be initiated to reduce the incidence of failures prior to complete piping replacement. These measures include:

a. Careful examination and replacement of suspect connectors on a continuing basis.
b. Replacement of missing or damaged crossheader supports.
c. Periodic checking of reactor components for loose fittings, bolts, etc.

As part of a program of continuing investigation of this problem, it is recommended that a rear face crossheader be removed from a reactor for metallurgical examination and evaluation. The data can be used in the design and development of the replacement hardware and piping systems which should be adequate for present and proposed operating process flows and temperatures. The information thus gained should also provide a measure of the present rate of deterioration.

DISCUSSION

The following discussion presents a summary of available information regarding the major reactor rear face piping defects, problems and areas of concern. The sequence of presentation of this information is not in the order of relative importance. It is the aggregate of all these problem areas that dictate a major replacement effort should be considered rather than individual corrective measures.

1. Background

The B, D, and F Reactors were originally designed for process water flow rates of 30,000 gpm and a maximum tube outlet temperature of 65° C, with the bulk outlet temperature substantially lower. These figures represent 250 MW of heat generation. Today the coolant flow per reactor is typically 80,000 gpm with a bulk outlet temperature limit approaching 95° C representing approximately 1600 MW of heat generation. Thus the above reactors are now operating at six and one half times the original design power rating and are still utilizing the original rear face risers, crossheader piping and fittings.

The adequacy of the rear face piping was examined prior to initiation of the last major increase in flow, i. e., Project CG-558, "Reactor Plant Modifications for Increased Production". The design process water flow rate for this project was 71,000 gpm at a maximum tube outlet temperature of 105° C. Although it was recognized then that certain deficiencies would exist in the rear face piping systems, insufficient data was available to substantiate a recommendation for rear face piping additions or modifications other than replacement of downcomers.

Subsequent advances in technology as well as revised operating procedures have increased process water flows to approximately 80,000 gpm with seven pump operation and a bulk outlet temperature near 95° C. Calculations of thermal expansion induced stress at the terminal joint of rear crossheaders and risers have shown these joints to be overstressed at B, D, DR, and F reactors. Since failure of one or more of these joints does not involve personnel safety and also since calculation of these stresses is not exact due to the indeterminent degree of system restraint, a "wait and see" philosophy has been followed with respect to the seriousness of this overstress condition. Recent failures of three of these joints at DR as well as evidence of cavitation damage in crossheader fittings, stress corrosion of pigtails, and possible stress corrosion of crossheaders indicates that a serious problem of piping integrity exists.

2. <u>Budget Study Recommendations</u>

The rear face piping budget study[1] indicates the action recommended for the B, D, F, DR, H, and C reactors. A summary of these work items is included for convenient reference. ✓

B, D, F, DR, and H Areas

a. Replace rear face crossheaders, risers, crossunder lines and crossover lines.

b. Replace rear face nozzles, connectors, and seals.

c Install process tube expansion devices and retube reactor. This requires removal of front face nozzles. ✓

d. Install new rear face thermocouples and R.T.D. leads rather than attempt to salvage old wires.

e. Recalibrate panellit gages.

C Reactor

a. Modify riser support and crossover lines to provide for crossheader expansion.

3. Record of Past Failures on Rear Face Piping

The following list of piping failures is not a complete record. Numerous minor failures have occurred and have been corrected as a matter of course. These include connector replacements, crossheader fitting leaks, etc. The list is shown to point out that progressive damage is occurring, and that the failures can be expected to increase.

[redacted]

Area	Date	Exhibit No.	Description
105-B	2/57	---	Crack in crossover piping near downcomer
	3/57	---	Stress corrosion first noted in Du Pont type connectors
	6/59	---	Cracked weld on vent stack far riser
	5/60	---	Failed crossheader fitting
105-D,DR	1/59	---	Stress corrosion first noted in Du Pont type connectors at D and DR
105-DR	10/59	---	Cracked riser, near side at crossheader 23
	12/59	7 & 8	Cracked riser, near side, at crossheaders 21 and 25
105-F	10/58	---	Stress corrosion first noted in Du Pont type connectors
	1/60	---	Cracked near riser above 45 header at water sample line connection
105-H	6/58	25	Riser cracked near support between 21 and 23 crossheaders
	7/58	---	Stress corrosion first noted in Du Pont type connectors
	3/59	18	Thermocouple well failure from cavitation noted
	6/59	17	Cavitation noted on brass adapter - J Connector
	11/59	12	Gamma water monitor sample line failure due to stress corrosion

The above list does not, of course, include the thousands of failed connectors which were replaced before total fracture could occur. The list of riser failures is expected to grow as the number of stress cycles increase and the riser material reaches its fatigue strength limit.

4. Thermal Stress Study

Thermal stress levels in rear face crossheaders and risers have been calculated for the B, D, DR, F, and H reactor piping configurations. These calculations indicate a condition of overstress in two locations. At the B, D, DR, and F reactors the overstressed condition occurs in the 36" diameter rear riser, adjacent the riser-crossheader joint. At H reactor the 90° elbow stresses in the crossheader to riser expansion loop are calculated to be greater than the allowable stress specified by the A.S.A. code for pressure piping.

The following table shows both the allowable and the calculated stress under present operating conditions;

Reactor	Location of overstress	Calculated Stress (psi)	Allowable Stress (psi)
B, D, DR & F	36" Rear Riser	* 165,000	See Exhibit No. 5
H	4" Pipe Elbows in Expansion Loop	46,600 Maximum	27,500

* Calculated Stress Amplitude - $(S)_a$

It must be emphasized that the calculated stress in the riser is not the actual value of the stress in this location. The calculated stress is based on the elastic theory, which is not directly applicable to stress conditions produced by plastic yielding. The calculated stress is, however, utilized to obtain a strain range. This strain range is then compared to strain cycling test data. For the values used in design procedures, (Exhibit No. 5) the calculated stress amplitude of 165,000 psi is well above the design strength fatigue curve.

The significance of the large values of calculated stress is that under current operating conditions, the riser stress levels are such that fatigue type failures can be expected in increasing numbers. Three riser failures, in the form of cracks, have occurred to date at DR reactor. These cracks were at the location of calculated maximum stress.(Exhibits No. 7 and 8)

Commonly accepted methods[2] were utilized in calculating crossheader stresses and reaction forces for the B, D, DR, F, and H reactor piping configurations. Two assumptions were made with regard to crossheader restraint. Exhibits 1 and 2 show the moment diagrams and reaction forces for both original and present operating conditions with the assumption that the crossheader is restrained by a sliding anchor at the second crossheader support. The entire expansion of the crossheader therefore acts on the expansion loops at each end of the crossheader. This assumption was utilized in calculating the crossheader to riser expansion loop elbow stresses. Exhibits 3 and 4 show similar moment diagrams based on the assumption that the crossheader can expand as a free pipe, restrained only at the ends by a movable support.

Moments and reaction forces from Exhibits 3 and 4 were utilized in calculating stresses on the riser. The methods utilized in calculating riser stress levels are outlined in reference (3). Briefly, the limitations in method of calculation are as follows:

a. The procedure is developed for a nozzle (or crossheader) insert located at a sufficient distance from other crossheaders so that stress interaction effects may be neglected. That is, the ratio of effective cylinder length to radius is greater than one. The riser in question has an effective length to radius ratio of 0.46.

b. In calculating the Moment and Reaction Force at the crossheader riser joint, no consideration is given to the deflection of the riser from its cylindrical shape. Since the riser has a thin (3/16") wall, deflection actually occurs. This deflection reduces the reaction forces. The known movement of the riser from its vertical position has however, been considered.

c. The effects of pressure in the riser and stress concentration at the crossheader to riser joint are neglected. The membrane stresses due to pressure are negligible when compared with the stresses caused by external loads.

Exhibit No. 6 indicates the principal stresses as measured by a strain gage installed on the crossover pipe at DR reactor. These measured stresses are not the absolute value of stress in this location since the initial stress distribution at the point of gage installation is unknown.

In summary, the observed riser failures to date and the calculated riser stress amplitude at the location of failure indicates that the risers at B, D DR, and F Reactors can be expected to fail at an increasing rate until these components are replaced. The design of the crossheader to riser joint itself is unacceptable from the standpoint of present design practices. This fact, coupled with the doubtful integrity of the riser material provides an additional cause for concern. The rear crossheader to riser expansion loop elbows at H Reactor are stressed to levels greater than those permitted by commonly accepted piping codes. The measured stress levels in the crossover line elbow at DR Reactor relative to an unknown initial stress condition, are sufficiently high to provide a basis for question of the continued integrity of this and similar piping at other reactors.

5. Corrosion and Metallurgy

From the metallurgical and corrosion standpoint, stress is one of the two agents causing the large number of rear face component failures experienced at the five older reactors in the last three years; corrosion is the other. While all the older reactors have had numerous rear connector failures, and some of them have had fatigue cracks in risers and other piping, these should not be considered as individual problems and not necessarily connected. Considering the whole reactor rear face piping complex from the system aspect, it is possible to relate failure occurrences in terms of interacting stress, corrosion, thermal gradients, etc.

In the rear face piping systems, the components vary in their ability to absorb or distribute stress; nozzles are restricted and may not move laterally, crossheaders move laterally and exert thrust on restrained risers, connectors impose varying amounts of thrust on crossheaders, thermal expansion elongates, or contracts some components more than it does others. These stresses are dynamic and often are cyclic--thus components at times are in alternate compression and tension or varying tension, a necessary function leading to fatigue failure. Tensile and torsional stresses contribute substantially to the rate of corrosion of a material and lead to stress corrosion cracking--a mechanism that has failed thousands of connectors at the five older reactors.

Piping on a reactor rear face is almost wholly 18-8 austenitic stainless steel. Components which are not are process tubes and nozzles of aluminum, nozzle caps of carbon steel and connector fittings of plated brass. In this combination of materials of varying thermal expansion there are approximately 22,000 mechanical joints in the piping system and some percent of these leak. Due to stress and cyclic fatigue caused by stuck gun barrels, numerous Van Stone flanges shear or are cracked and resultant leakage wets the surrounding system. Hot ionized effluent of pH 7 (corrosive to carbon steel) flashes to steam on the hot piping around and below the leak and leaves a deposit of mineral salts. (Exhibits 9, 10, and 11) The analysis of a typical scale deposit is shown below.

ANALYSIS OF REAR FACE CORROSION SCALE

Ca, Mg	Large Amount Present
Al	Small Amount Present
Fe	Trace
HCO_3, CO_3	Large Amount Present
SO_4	1 1/2 percent
NH_3 or NH_4	None
PO_4	None
Cl	None
F	None

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A number of reducing ions in this scale are corrosive to the passive and protective film on the stainless piping components and vigorous pitting develops. It is this pitting combined with stress that characterizes stress corrosion cracking. Examples of component failures through stress corrosion are shown in Exhibits 12 through 16.

When a component such as a connector develops a crack and starts leaking, the surrounding parts of the system are wetted and the corrodant coating builds up, creating potential for more stress corrosion cracking and further leaking. The degradation becomes progressively worse under the dynamic stress conditions of the system. Once cracks, even of micro depth and length, have started on the surface, the integrity of the metal section is reduced, even if the cracks do not immediately penetrate the wall to become leaks.

Laboratory controlled stress cycle tests of in-service connectors that were not leakers and which did not show defects under non-destructive inspection tests failed 100-500 times faster than identical connectors that had not been in service. The in-service connectors removed for the tests were randomly selected and enough tests were made to demonstrate that stainless material on the rear face was considerably damaged by any repeated wetting and buildup of insoluble salt deposit.

This indication of the probable current quality of all rear face stainless piping is a real cause for concern.

Leaking connectors can and are replaced routinely, but in-place crossheaders, risers and other fixed piping which have deteriorated over the years cannot routinely be replaced, nor can they be repaired easily or with any degree of quality. Welding severely stresses restrained members even under controlled conditions. Reactor piping is restrained, and welding conditions are poor due to time limits, wet conditions, and radiological requirements for clothing and fresh air masks. Welding on the rear face is generally a patch attempt to bridge a wet crack until it stops leaking.

Stress corrosion cracked components on the rear face can be measured in the thousands and fatigue failures in the tens, but the rate of fatigue type failure is expected to increase as time goes on. Fatigue failure (cyclic stress below the yield point leading from micro fissuring to macro fracturing) is not necessarily the result of a large number of cycles of stress. It has been measured in some configurations in as few as 20 cycles.

In summary, the following factors indicate that consideration should be given now to planning for replacement of rear face piping.

1. Eight recorded fatigue failures of risers, tubes, and fittings have been found in three reactors.

2. Corrosion of the surface of all rear face piping is progressively lowering the resistance of the material to failure by cyclic stress.

3. Stress cycles leading to fatigue failure are accumulating toward some final figure at which components will fail.

[redacted]

4. Tests on connectors and examination of the piping system indicate that failure by stress corrosion will probably increase and the rate of fatigue failure will increase.

Consideration is being given to other materials of construction that are less susceptible to stress corrosion cracking than is the 18-8 type of stainless steel. Such a material should in addition have a lower coefficient of expansion than stainless steel and should be relatively insoluble in hot water. Carbon steel would be a logical, economical choice, except for corrosion from dripping or leaking water. The second choice, more costly than carbon steel but not subject to stress corrosion cracking and with expansion about the same as carbon steel, is the nickel alloy "Monel". Experimental connectors of this material have been ordered for installation on H. Their resistance to corrosion, fatigue cracking, and galvanic effects will be service tested this year.

6. Connector Failures

In March of 1957, the first evidence of stress corrosion failure of a 105-B rear face connector was found. Tests indicated a lowering of the fatigue life by a factor of 100 to 500 compared to a new connector. Additional samples taken at that time exhibited a lowering of fatigue life but concrete evidence of stress corrosion was lacking.

During mid 1958, 105-H experienced a series of failures of rear face connectors during reactor operation. Random samples of connectors showed that approximately 70 percent had been stress corroded. H Reactor Operation Management made the decision to replace all the Du Pont connectors with a "J" connector, utilizing O Rings for a seal inside a brass adapter attached to the rear crossheader. Complete replacement was made.

Samples taken during 1959 at B, D, DR, and F showed that 45 percent had stress corrosion and were potential failures. A decision was made to replace those suspected rear face connectors with a J-2 connector on an interim basis until a permanent replacement connector could be developed. By careful inspection, during all reactor outages, B, D, DR, and F areas have been able to replace most leaking and cracked connectors before an actual rupture occurs. Replacement of approximately fifty percent of the connectors has been completed at these reactors.

The "J" type connector has not solved the stress corrosion problem of the rear face piping, i.e., keeping the piping surfaces dry. The "J" connectors achieve two aims: (1) assist maintenance forces in quick replacement of a connector, (2) serve as a temporary connector until a satisfactory replacement is developed. The "J" connectors utilize an "O" Ring for sealing and thermal expansion. This seal fails due to vibration of the crossheaders and deterioration of the O Ring under radiation. The "J" connectors themselves are failing through stress corrosion caused by wetting from other leaking connectors and caps, from tube replacement programs and normal discharge wetting. Once a corrosion pit develops in a connector, the stress from vibration and thermal cycling accelerates the condition until a pinhole becomes a crack and eventually a ruptured connector.

[redacted]

Since it would be impractical to completely dry up the rear face, the solution to the connector problem is to remove the stress caused by vibration and thermal effects; and to replace the connectors with a material not subject to stress corrosion under rear face conditions.

7. Fluid Flow Analysis

At existing process flow rates high fluid velocities, temperatures, and pressure drops in reactor rear face piping components cause cavitation and system vibration problems. Examination of the pressure profile from front crossheader to rear crossheader of a standard B, D, or F reactor process channel shows the following relative energy losses across the various segments of the channel. About 14 percent of the energy loss occurs in the inlet fittings; 59 percent of the energy loss occurs along the active fuel charge and 27 percent of the total loss occurs in the outlet fittings.[4] A pressure gradient graph showing the energy loss of existing B, D, F, DR, and H rear face fittings has been prepared. (Exhibit 19 - curves A and B) A diagrammatical comparison of an existing assembly and a "K" assembly is shown on Exhibit 20.

For purposes of comparison, the pressure gradient which would result from changing the existing rear nozzles, connectors and fittings to a K reactor assembly is also indicated. (Exhibit 19 - curve C) Curve "C" is based upon uniform distribution of flow to each crossheader, with a maximum number of crossheaders in use. To meet this criteria in the B, D, and F reactors, the tubes must be reunited to provide a separate header for each row of tubes. (Except for the top and bottom two rows.) To provide for these reduced friction losses in H and DR reactors, additional crossheaders must be added.

From the referenced graphs it is concluded that operation with the type "K" connector will provide sufficient back pressure in the effluent system to prevent critical flow, boiling or dual phase flow at any point, with adequate margin of safety for normal short period power level transients. The effect of temperature surges and probability of boiling in the riser and crossover line are covered in details in References (5)(6) and (7). The only point in the effluent system where nominal boiling may result in mechanical damage is at the top of risers and in the crossover line, where the pressure is atmospheric or less. Boiling at these points is dependent on the bulk effluent temperature reaching 98 to 100 C. Boiling at less than 100 C may be circumvented by adequate venting, but very large vents would be required for operation under boiling conditions.

Replacement is the only alternate considered feasible as a solution to problems of stress cracking in the nozzle to crossheader connectors. Larger diameter connectors will be required to reduce the fluid velocity in these components and minimize vibration. Installation of larger connectors will necessitate modification of the existing aluminum connector fitting on the nozzle, replacement of this fitting or replacement of the nozzle. Recent evidence indicates that the aluminum connector fittings on the nozzles at D reactor are eroding in a manner similar to the damage found on crossheader fittings at B, D, and F reactors. As closely as can be determined, this fitting erosion was first noticed on three or four fittings which were removed from D reactor in January, 1960.

[redacted]

As an alternate to replacing the rear face fittings with a "K" type assembly, reaming of existing B, D, and F reactor rear crossheader Parker fitting, rear nozzle Parker fitting and use of "J" type nozzle to crossheader connector has been proposed. It has been postulated that this increased flow may allow either reactor power level to be increased or be utilized to reduce process water bulk outlet temperature while maintaining present power level. The latter use would presumably reduce fuel element ruptures, tube corrosion and thermal stress levels in rear face piping. To fully evaluate this proposal, answers must be obtained to the following questions concerning rear face piping:

a. Will the increased flow cause system vibration, shock loading or other problems which would negate the desirable effects of reduced tube corrosion, fuel ruptures, and thermal stresses brought about by lower bulk outlet temperature at present power levels?

b. If the rear face piping components will be replaced in the not too distant future, will it be advantageous from a production standpoint to go ahead with power level increases realizing that increased component failure rates may result?

The existing rear nozzles do not have to be replaced because of cavitation or erosion damage. However, nozzle replacement is recommended for two reasons. First, nozzle to connector fitting replacement will be required to obtain an assembly compatible with the new connectors. Secondly, improved hydraulic performance can be attained with a new nozzle that utilizes a smooth curbed flow path rather than the 90° bends that the flow must traverse in the existing nozzle.

The largest part of the 27 percent loss in the outlet fittings undoubtedly occurs in the present restrictive crossheader fitting, connector, and nozzle to connector fitting, but significant pressure drop can be regained by eliminating the two 90° right angle bends in the existing nozzles and enlarging the flow path. Since the time required to remove and replace the nozzles will be the same whether or not the existing nozzles are used, and the material cost of the new nozzles appears to be offset by the improved hydraulic features of the new nozzles, replacement has been recommended.

The consideration of Panellit system trip span deserves mention in the reduction of flow velocities on the rear face. The lower flow velocity will provide the panellit trip system with a narrow drop span whereas in the present system, the trip span is relatively wide. The "K" and "C" reactors are operating on the narrow span and the system in the B, D F, DR, and H could operate equally as well on the narrower range. The change in system would require more adjustment of gages to maintain the desired trip functions and operating stability of the reactor.

In summary, the rear face piping was not designed for the present flows and temperatures. The near three fold increase in flows has resulted in high velocities, vibration, and cavitation. Aside from the structural reasons for piping and fitting replacement, the improved hydraulics and attendant possible production increase is a desirable adjunct.

8. <u>Parker Fitting Investigations</u>

Cavitational flow has been know to exist in rear crossheader "Parker" fittings at B, D, DR, F, and H Reactors for the last five or six years. Calculations indicating the initiation of cavitational flow as a result of high flow rates and temperatures in the present fittings were verified by experimental data in 1954[8]. To obtain an estimate of the effect of cavitation in rear crossheader fittings resulting from past and current operating conditions, 21 fittings at B, D, and F reactors were visually examined during the period October 6, 1959 to November 30, 1959.[9]

 [redacted]

Of the 21 fittings inspected, 15 showed evidence of cavitation deterioration. Eight of these fittings can be termed "slightly" damaged. A saw tooth type of erosion estimated to be approximately 1/16 inch deep and extending about 1/8 inch up the inner flared portion of the fitting was evident on two fittings and has been termed potentially severe. It has been estimated that about 8.0 percent of the fittings have damage exceeding .05 inch in depth of erosion and 1.0 percent have damage exceeding 0.10 inch. Statistical analysis of the data obtained from the inspection provided the basis for this estimate.

A small borescope was utilized to visually inspect the interior surface of the 21 rear crossheader fittings. Table 1 shows the location of the fittings which were inspected and summarizes the type of damage noted. Efforts to obtain photographs of damage were unsuccessful. To provide a basis for statistical analysis of data, the extent of damage was classified into three categories. (Exhibit 21) The cases of saw tooth erosion which appeared to be 1/16 inch deep and 1/8 inch long on the inner fitting edge were classified as heavy or potentially severe damage. Fittings which showed evidence of the start of saw tooth erosion were classified as light damage when the depth appeared to be about 1/32 inch or the inner fitting edge had been rounded off by pitting. Those fittings having small pits either in the flared portion or on the edge of the fitting were termed light pitting.

Crossheader fittings at B, D, and F reactors were specified to be nitrided prior to installation. This surface hardening which probably resisted cavitation attack for some time, has been removed in portions of the fittings which show the saw tooth type of erosion. Bubbles are apparently formed in the throat of the fitting and compressed as they proceed along the flared section. Upon reaching the inner edge of the fitting, the pressure has increased sufficiently to cause bubble collapse with resulting fitting damage.

Although a satisfactory estimate of damage rate is not known, at present, it is known that once cavitation attack begins, conditions are immediately created for an increased rate of attack.

Although "Parker" fittings were not inspected at DR and H reactors, there is no reason to assume that rear crossheader fittings at these reactors are exempt from cavitational damage. The crossheader fittings at DR and H are of a type similar to those used at B, D, and F reactors. However, at H reactor, due to the design of the crossheader fitting connection, the cavitation damage is evidently occurring in a 90° elbow attached to the "Parker" fitting. (Exhibit 22) Thermocouple wells which have been removed from the H reactor crossheader fitting connection, provide evidence that cavitation is, in fact, occurring at this location. (Exhibit 18) The cavitational attack in the H reactor crossheader fitting could be of greater concern than at the other reactors due to the location at which it occurs.

9. Piping Vibration - B, D, DR, F, and H

A program for the measurement of reactor rear face piping vibration was initiated in October, 1959, in support of development work for a replacement rear nozzle to crossheader connector. The information obtained is of significance to the general problem of rear face piping deterioration as well as the specific connector problem.

The measurements which have been made to date have been principally at 105-H and 105-F. Vibration information was obtained from rear nozzles, connectors, and crossheaders within the process tube outline. A similar pattern of vibration has been noted in both areas with variations in magnitude. Briefly, the pattern consists of the following at current operating conditions:

a. High frequency vibrations (approx. 1000 to 8000 cycles per second) which indicate internal impacts due to cavitation. Increasing numbers of leaks support this evidence, as well as erosion observed in fittings after removal. (Exhibit 17) Some comparison can be gained from the K reactor, which has larger fittings, much lower throat velocities, and correspondingly less turbulence. The high frequency vibrations on rear crossheaders at K indicate far lower accelerations than those of the older reactors.

b. Low frequency vibrations of excessively large amplitude are plainly visible where the rear face crossover manifold discharges into the downcomer. At this point, both measurement and calculation confirm a negative pressure in the 42-inch pipe; at 93° C this obviously causes boiling and high turbulence and represents a high energy source of vibrations. The observed vibration, confirmed by calculations, is at about four cycles/ second, and of at least 1/2 inch amplitude, peak to peak. This motion is so great that the top works of the 42-inch valve in this line moves at a frequency of 3-6 CPS and an amplitude of 1-1/2 inch. The forces causing this motion have cracked the concrete base under the support of this valve at H area. (Exhibit 23)

   A low frequency movement also occurs at the lower end of the H rear face riser. The riser was anchored to the building structure at mid point, but the movement has torn the riser wall. (Exhibit 25)

c. This same low frequency vibration, transmitted back through the risers, has been measured with large amplitude on some of the rear crossheaders. (In one location indications were as high as 0.9 inch peak to peak.) This large displacement of the crossheader results in high stresses in the connectors and fittings, and contributes to the observed failure of these components.

   The crossheaders, being stiff four inch pipes, can resonate at low (four cycle) frequency only if a length of approximately thirty feet is unsupported. Observation confirms that many crossheader supports are either bent or missing entirely and that unsupported pipe lengths up to 30 feet do exist. (Exhibits 24 and 26) However, upward bowing of the crossheaders under thermal expansion would have the same effect. The ideal solution would be the installation of snubber supports which would support the crossheaders and dampen vibration while providing for thermal expansion. Considerable development would be required to design a device which would fit into the crowded tube pattern area.

[redacted]

10. Stuck Gunbarrels

Water leaks resulting primarily from cracked or sheared rear face process tube Van Stone flanges have been experienced over the past several years, particularly at the older reactors. Such leaks contribute to the problem of stuck gunbarrels which were originally installed to accommodate the thermal expansion and contraction of the process tubes where they pass through the cast iron reactor shield. The stuck gunbarrels cause more Van Stone flange failures which in turn cause more stuck gunbarrels. Shown below is the number of reactor outage hours charged to leak testing for each reactor for the past four years:

Reactor	B	D	F	DR	H	C	KE	KW
1956	Not Detailed	272	534	26	272	None	None	None
1957	202	105	447	104	193	None	None	None
1958	157	107	260	226	55	8	11	95
1959	238	109	345	129	119	131	24	None

Not all water leaks are due to sheared or cracked Van Stone flanges; however, the above table does indicate that the water leaks have been more severe at 105-F and B where the stuck gunbarrel problem is more prominent.

Attempts to free stuck gunbarrels have been made by using a "knocker" or impact tool. The gunbarrels can be loosened but freeze or rust tight within a few weeks. Considerable manpower was utilized at 105-F to free the gunbarrels, but no permanent solution was achieved. Several solutions to the stuck gunbarrel problem have been proposed(10). One of the more promising is a sleeve which fits over and slides on the exiting gunbarrel. The nozzle is attached to the sleeve, and a rubber boot provides the gas seal between the sleeve and gunbarrel. Several of these sleeves have been installed at 105-F recently under Production Test IP-286-I, Testing of Gunbarrel Attachments at F Reactor.

The use of zirconium process tubes, along with proposed gunbarrel modifications to permit thermal expansion and contraction, should minimize water leaks, reduce rear face maintenance, and practically eliminate tube replacements, except for catastrophic fuel element failures.

11. Outage Economics

The primary justification for the proposed rear face piping replacement is continuity of reactor operation.

During the past 14 months, B, D, F, and H reactors have experienced nine rear nozzle to crossheader connector failures resulting in a total of 55 hours of lost production. Actually, thousands of connectors have failed, but a vigorous inspection and replacement program has caught most connectors before total failure could occur. This indication of increasing stress corrosion, coupled with the recent crossheader-riser joint failure at DR reactor and crossheader fitting erosion at B, D, and F reactors indicates a general deterioration of rear face piping systems and that failure of these components will become more frequent until corrective action is taken. On the basis of failures which have occurred to date, expenditure of funds in the magnitude required by this project cannot be amortized in a three year period.

Whether or not a particular component failure causes a significant loss in production depends not only on the component and frequency of occurrence but on the type of failure and the time it occurs. If an unscheduled outage, caused by a nozzle to crossheader connector failure or a crossheader fitting failure, occurs after several weeks of normal reactor operation, this outage can be substituted for a planned outage. In this case the only lost production attributed to the component failure would be the time required to replace or repair the damaged component plus the time required to cool the reactor and a portion of the time necessary to regain equilibrium operation. The magnitude of lost time chargeable to a connector failure in this case can be on the order of six hours in an outage totaling forty hours. The same failure occurring shortly after the reactor has recovered from an outage would result in a larger amount of lost production. Assuming only a small amount of maintenance work could be accomplished during the outage the lost production may be as high as 32 hours.

A spray type of connector or crossheader fitting failure would in all probability cause the reactor to be shut down. However, under certain circumstances the panellit gage on the tube with the ruptured connector could be adjusted to maintain tube protection and the reactor started up before sufficient time had elapsed to require the reactor to take a minimum outage. It is estimated that the minimum outage required by formation of xenon after the reactor is shut down will be about 35 hours in FY-1962.

Failure of a crossheader riser joint similar in type to that which occurred at DR would cause very little lost production at B, D, F, or DR reactors. The reactor could continue to operate and, due to the location of rear risers, schedule repair to coincide with normal rear face work. Failure of an expansion loop elbow at H or C, although either reactor could presumably continue to operate until the next scheduled outage, would result in lost production. Due to the riser location at these reactors, postponement of normal rear face work would be required until elbow repair completion. Again, the amount of lost production will depend on the severity of failure as well as when it occurred and the amount of other maintenance work that can profitably be accomplished during the outage. Since service conditions have been severe and the present condition of rear riser and crossheader material is unknown, complete failure of several joints or elbows during a temperature surge is not an unreasonable possibility to consider. The integrity of such repair or the current piping itself would remain questionable due to the unknown material condition.

12. Basis for Budgetary Submission

Replacement of rear face piping is proposed to prevent future equipment failures and provide more reliable piping systems at B, D, DR, F, H, and C reactors. If the Reactor Expansion Program currently being studied does not prove advisable, replacement of essentially all rear face piping components and installation of gunbarrel attachments are recommended at B, D, DR, F, and H reactors. Modifications to rear riser supports and crossover line are recommended at C reactor. Total costs of the proposed replacement and modifications are:

B, D, DR, F, H and C Reactors

Project Costs	$16,700,000
Outage Time	287 Days

Since the cost and outage time for the recommended work at C Reactor is significantly less than at any other reactor, these items are also shown on a project basis.

C Reactor

Project Costs	$300,000
Outage Time	7 Days

It should be noted that of the $16,700,000 budget cost outlined in the Budget Study[1] only $9,650,000 is actually required for the rear face piping with new rear face nozzles. Since the replacement of piping components will require removal of all rear face nozzles and piping, an opportune time is provided for installation of a hydraulically improved nozzle which would be more compatible with the new connectors, and likewise to provide a method which will permit thermal expansion of process tubes in the now sticking gunbarrels, thereby reducing process tube Van Stone flange failures. The expansion sleeve installation in turn will require new gas seals and replacement of process tubes. These costs are therefore included in the $16,700,000.

CURRENT STUDY PROGRAM

At the present time, an engineering effort in support of the program presented below is underway in the Facilities Engineering Operation. This effort will be expanded in the near future to further the accomplishment of the program objectives. This program consists of the following generalized activities.

1. Obtain additional information to establish the rate of piping system deterioration through stress corrosion, overstress and vibration and to determine what interim measures can be taken to reduce the failure occurrence while maintaining present operating levels or moderate increases until total project action can be initiated.

2. Obtain additional engineering information to support the design of replacement rear face piping systems and/or components.

The first objective of this program is necessary in order to establish what priority should be given to the various problems to assure continuity of reactor operation. Information in this category includes: Calculations, field tests, laboratory and model investigations and destructive analyses of existing components to determine the full extent of significant strain damage and the deterioration from cavitation, vibration, corrosion, etc. This program includes a proposal for the complete removal of one crossheader from a typical reactor for analysis.

The second objective of the program is necessary in order to provide a system that will be adequate for existing and forecasted operating conditions, which can be installed with a minimum of outage time and capital expenditure. Items in this category include:

1. Cavitational tests to determine suitable materials, proper passage shapes under severe velocity and temperature effects.

[redacted]

2. Dynamic boiling flow tests to evaluate shapes of passages, vapor locking, shock, etc.

3. Fabrication of test models of significant components and sections of the proposed systems to assure operational compliance of desired design features prior to field installation of the equipment.

ACKNOWLEDGEMENTS

The contributions of the following to the preparation of this report are acknowledged with appreciation: D. W. McLenegan, J. F. Mondt, R. J. Meyers, V. R. Hill, E. C. Shockey, P. H. Hutton, W. W. Porter and J. W. Hoage.

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(9) HW-63873 - Rear Crossheader Fitting Inspection B, D, and F Reactors - F. J. Kempf - 2/10/60 (Secret)

(10) HW-61387 - Recommendation for an Attachment to Relieve Stuck Gunbarrels at 105-F Reactor - P. B. McCarthy - 8/10/59 (Unclassified)

[redacted]

[redacted]

APPENDIX

Table I Parker Fitting Inspection Summary

Exhibit 1 Moment Diagram 105-B, D, DR, and F Rear Riser
2 Moment Diagram 105-H Rear Riser
3 Moment Diagram 105-B, D, DR, and F Rear Riser
4 Moment Diagram 105-H Rear Riser
5 Design Fatigue Strength Curve
6 105-DR Crossover Pressure and Strain Gage Data
7 105-DR Cracked Rear Riser
8 105-DR Cracked Rear Riser
9 Rear Face Scale Deposits
10 Rear Face Scale Deposits
11 Rear Face Scale Deposits
12 Gamma Monitor Sample Line Failure
13 Fear Face Connector Failure Crack
14 Stress Corrosion Photomicrograph
15 Stress Corrosion Photomicrograph
16 Stress Corrosion Photomicrograph
17 Cavitation of Nozzle Adapter
18 105-H Thermocouple Well Failure
19 Rear Face Pressure Profile
20 Rear Face Connector Comparison, K Versus B, D, F, DR, and H
21 Rear Face Parker Fitting Cavitation Damage B, D, F, and DR
22 Cavitation Damage in H Crossheader Fittings
23 Vibration Cracked Base - 105-H
24 Displaced Crossheader Supports
25 Cracked Riser - 105-H
26 Missing Crossheader Supports

  [redacted]

TABLE I - INSPECTION SUMMARY

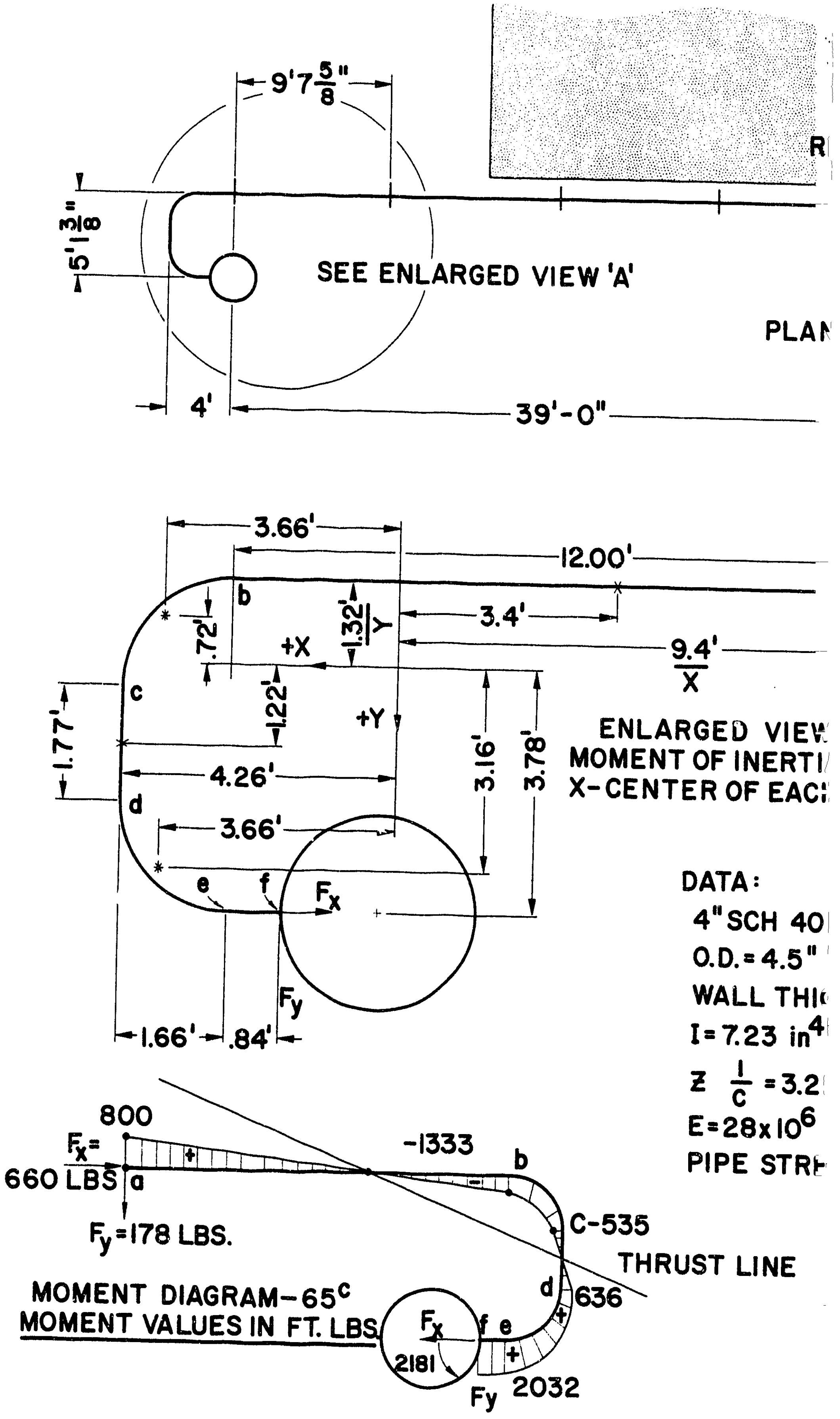
Reactor	Fitting Inspected (Tube No.)	Inspected	Inspected By	Type of Damage
B	1762	10/6/59	C. W. Harrison J. H. Hoage F. J. Kempf	*Saw tooth flow erosion on cross-header adjacent fitting ($\approx$ 1/32" deep; $\approx$ 1/16" wide)
	3389	"	"	Pitting on inner taper surface and slight erosion of inner edge of fitting
	3965	"	"	Shallow pitting (5 to 10 mils) on tapered surface. Slight edge erosion
	4077	"	"	None
	1563	11/30/59	P. D. Clare F. J. Kempf	Slight pitting and erosion on inner edge of fitting $\approx$ 1/32" deep extending $\approx$ 1/16" up tapered surface.
	1566	"	"	" " " " " "
	1570	"	"	" " " " " "
	1584	"	"	None
	1666	"	"	None
	1671	"	"	None
	1674	"	"	None
	1676	"	"	Slight pitting on tapered surface (5 to 10 mils)
	1682	"	"	Slight pitting on inner edge of fitting.
D	1862	11/4/59	V. R. Hill E. G. Shockey F. J. Kempf	Slight pits in rust colored inner surface of crossheader opposite fitting.
	3062	"	"	Saw tooth erosion on inner edge of fitting $\approx$ 1/16" deep and extending $\approx$ 1/8" up tapered surface.
	3885	"	"	No evidence of cavitation. Slight crud deposit on inner edge of fitting.

* Location of damage subject to question. Subsequent inspection of remaining fittings did not show damage in this area.

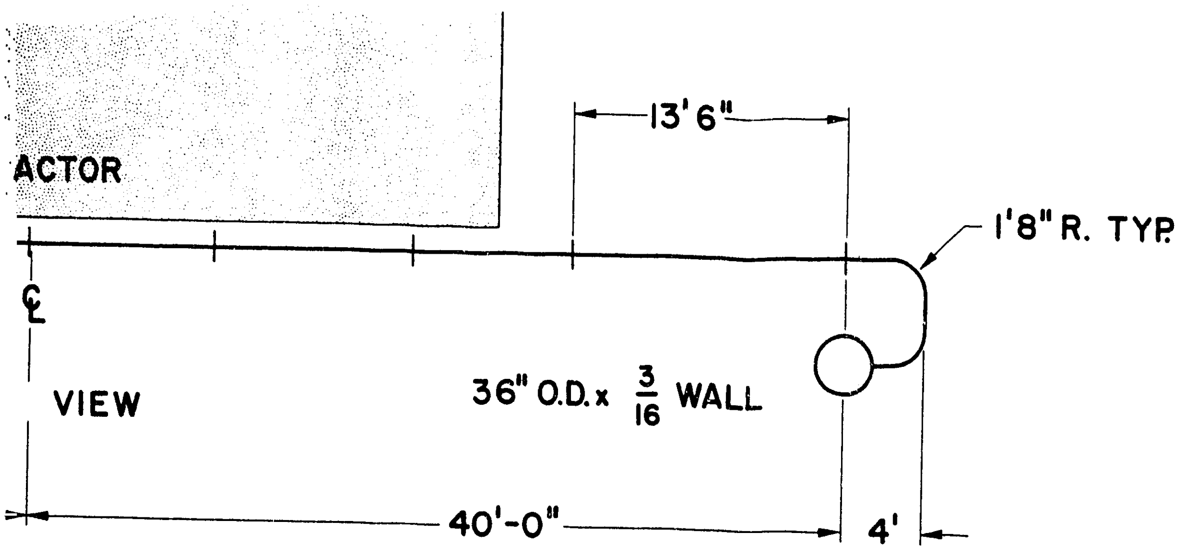
TABLE I (Continued)

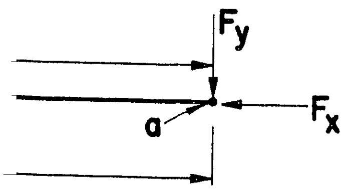
Reactor	Fitting Inspected (Tube No.)	Date Inspected	Inspected by	Type of Damage
F	3366	10/27/59	V.R. Hill F. J. Kempf	Saw tooth erosion on inner edge of fitting $\approx$1/16" deep and extending $\approx$1/8" up tapered portion of fitting.
	3457	"	"	Pin hole leak under weld (poor machining & incomplete weld penetration) Light pitting (5-10 mils) on inner edge of fitting.
	3481	"	"	Shallow crack in minimum cross-sectional area portion of fitting. Pits on tapered portion of fitting $\approx$1/32" deep at edge of fitting. Irregular built up deposit on crossheader wall.
	3681	10/25/59	C. W. Harrison J. H. Hoage F. J. Kempf	Shallow pitting on inner edge of fitting (5-10 mils)
	3683	"	"	Pitting and surface indications of cavitation on inner edge of fitting. Pock marks $\approx$1/32" deep in rust colored deposit on inside of crossheader opposite fitting.

[redacted]

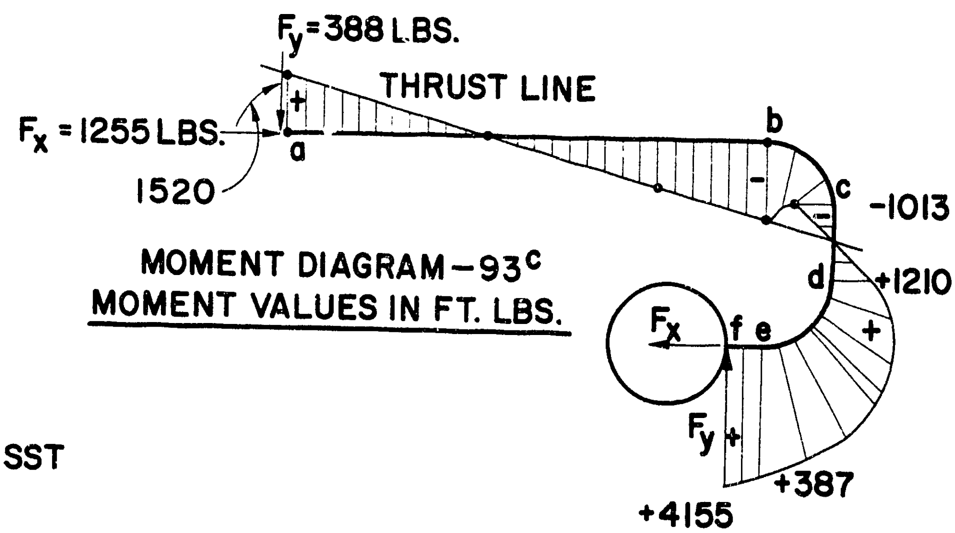


Rear Face Crossheader- Moment Diag





'A'
: DIAGRAM
SECTION



PIPE AISI TYPE 304 SST

KNESS = 0.237"

in^3

SI

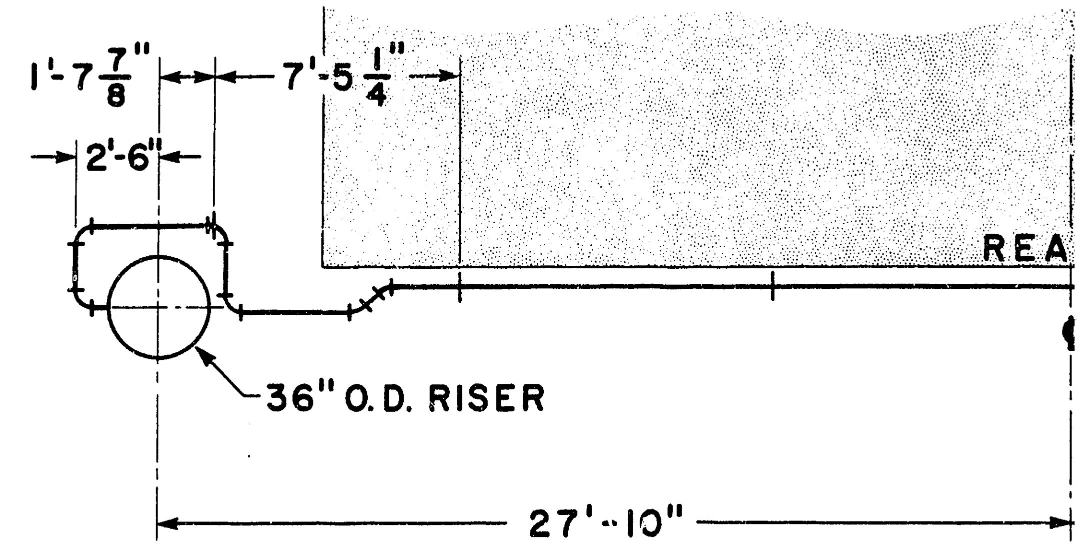
SS = $\frac{\text{MOMENT}}{\text{SECTION MODULUS}} = \frac{M}{Z}$

ASSUMPTION:

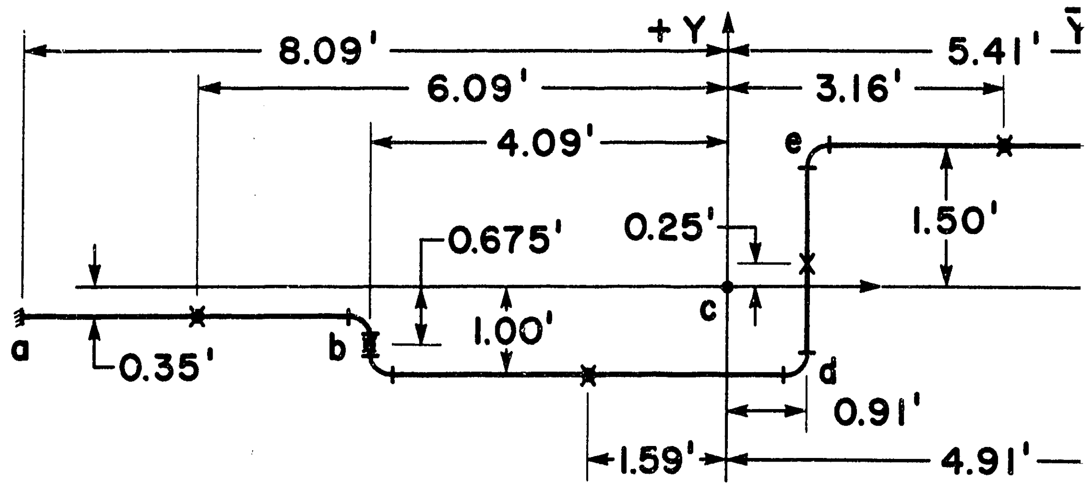
STRAIGHT PORTION OF 4" HEADER BETWEEN RISERS IS GUIDED BY THE SUPPORTS AND IS NOT FREE TO ASSUME THE ELASTIC CURVE.

xhibit No. 1

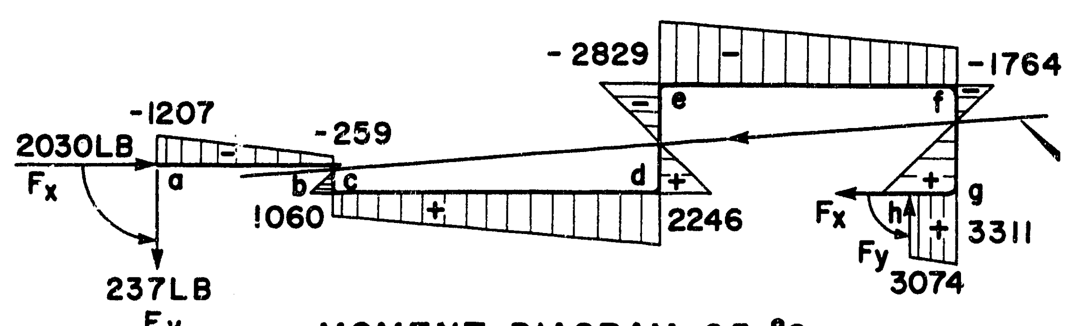
rams - Original and Present Operating Conditions



PLAN

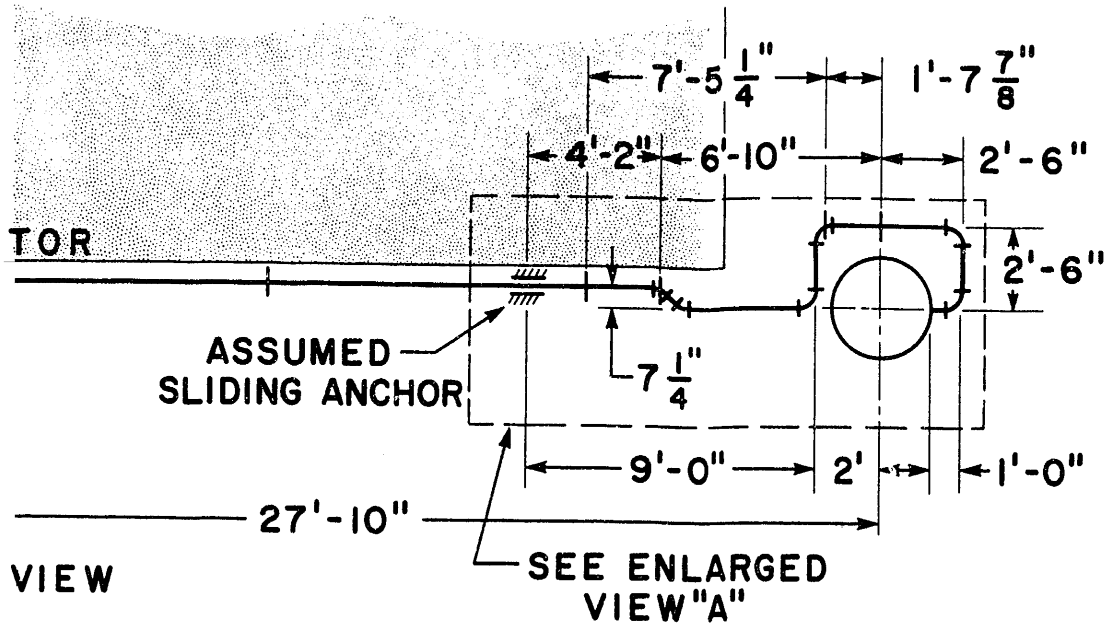


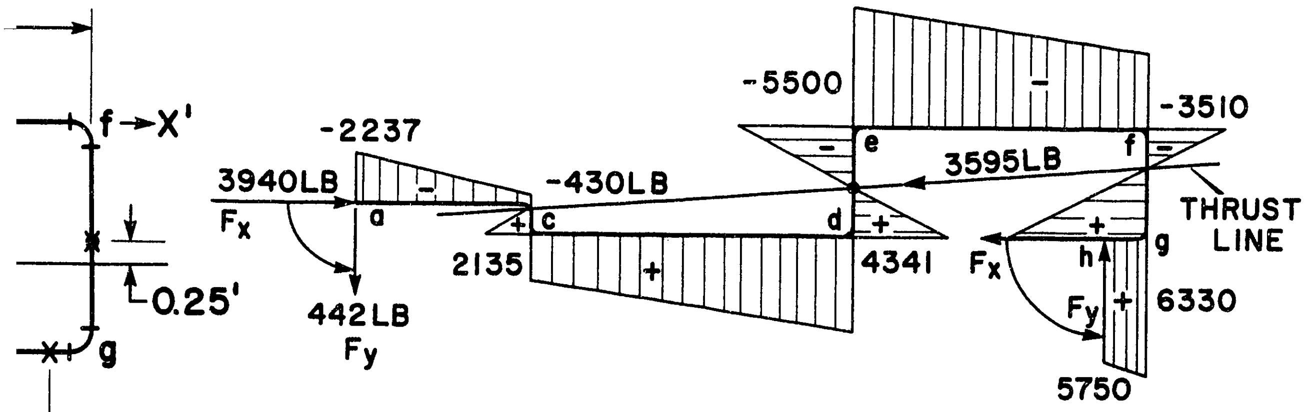
ENLARGED VIEW "A"
MOMENT OF INERTIA DIAGRAM
X-CENTER OF EACH SECTION



MOMENT DIAGRAM 65 °C
MOMENTS IN (FT-LBS)

Rear Face Crossheaders Moment Dia





MOMENT DIAGRAM 93 °C
MOMENTS IN (FT-LBS)

DATA:

PIPE - 4" SCH 40 TYPE 304 SST SEAMLESS

$I = 7.23\ in^4$ $E_c = 29.2 \times 10^6$

$Z = 3.22\ in^3$ $E_h\ 28.63 \times 10^6$

O.D. = 4.5"

ɪRUST LINE

$$\text{PIPE STRESS} = \frac{\text{MOMENT}}{\text{SECTION MODULUS}} \quad \frac{M}{Z}$$

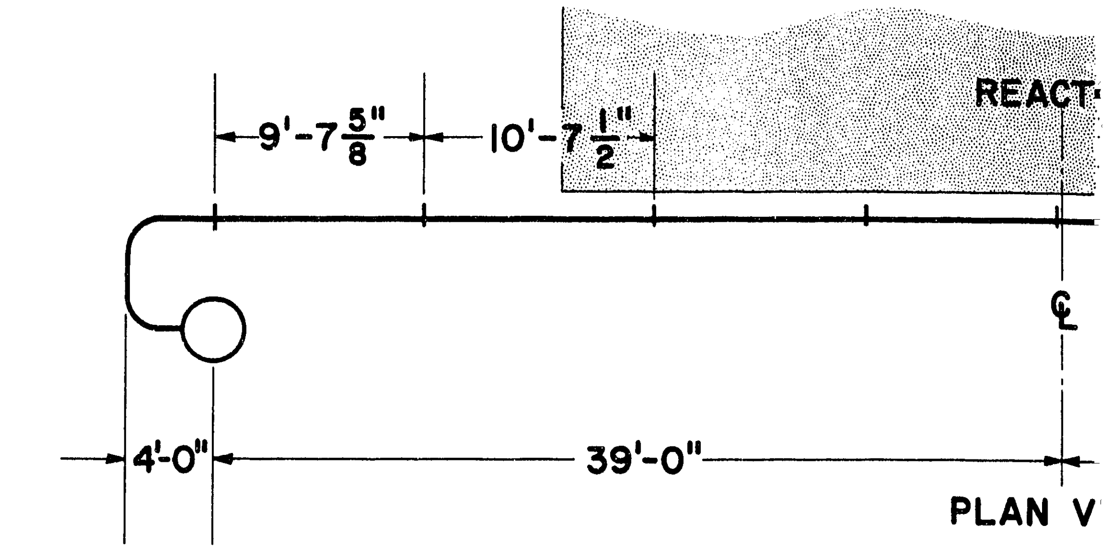
ASSUMPTION:

TOTAL EXPANSION, ABSORBED BY PIPE BETWEEN SLIDING ANCHOR AND RISER IS ΔX

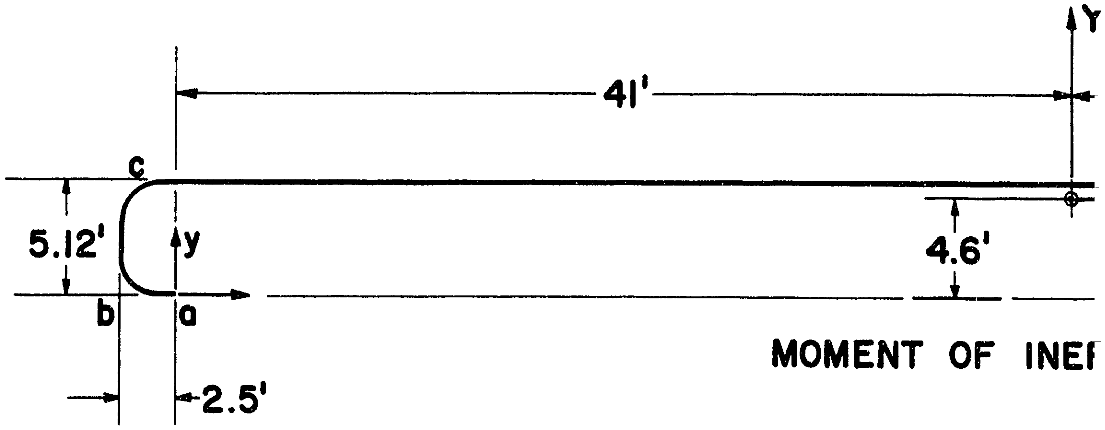
$$\Delta X = \frac{(1.74)(28)}{100} = 0.490 \text{ in}$$

Exhibit No. 2

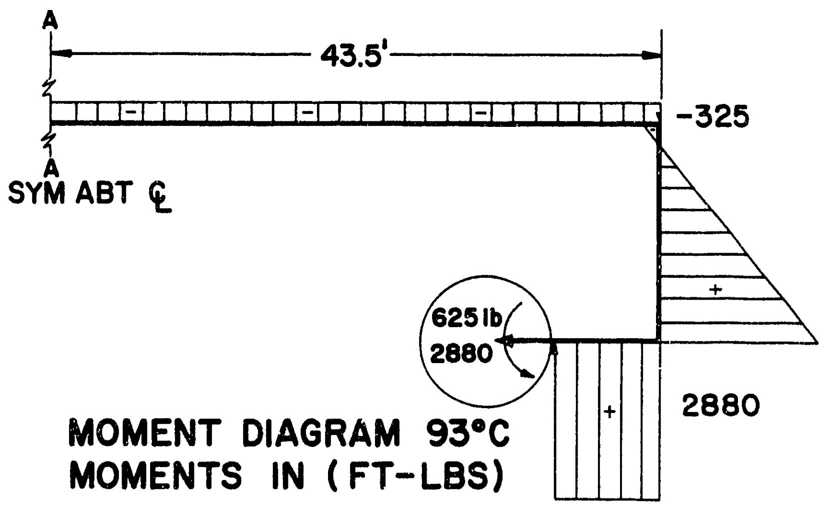
rams Original and Present Operating Conditions



PLAN V



MOMENT OF INEI



MOMENT DIAGRAM 93°C
MOMENTS IN (FT-LBS)

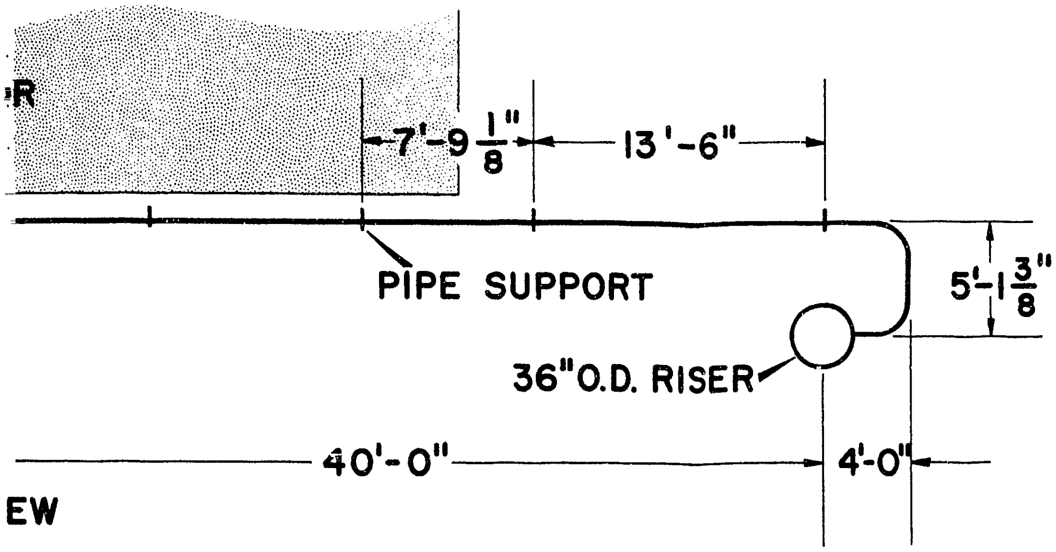
DATA:

4" SCH 40 F
O.D. = 4.5"
WALL THICK
$I = 7.23 \text{ in}^4$
$Z = \frac{I}{C} = 3.22$
PIPE STRES

ASSUMPTION:

1. STRAIGHT
HEADER BE
FREE TO AS
CURVE.

Rear Face Crossheader Moment Diag



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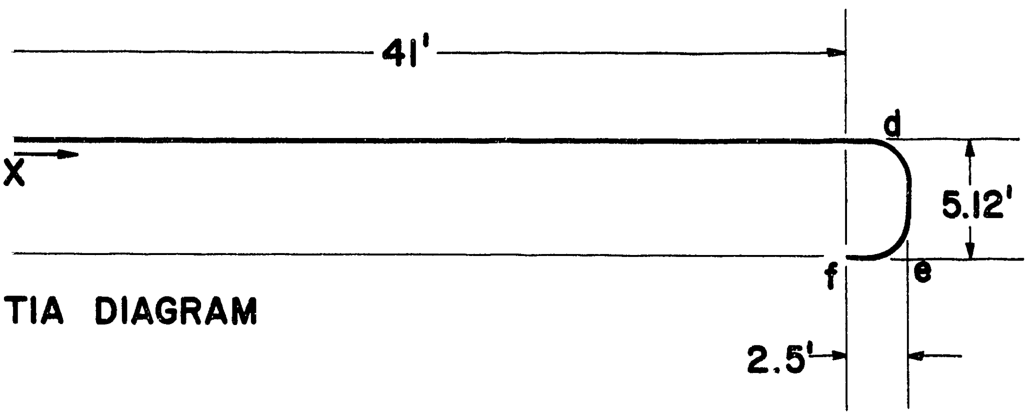


TIA DIAGRAM

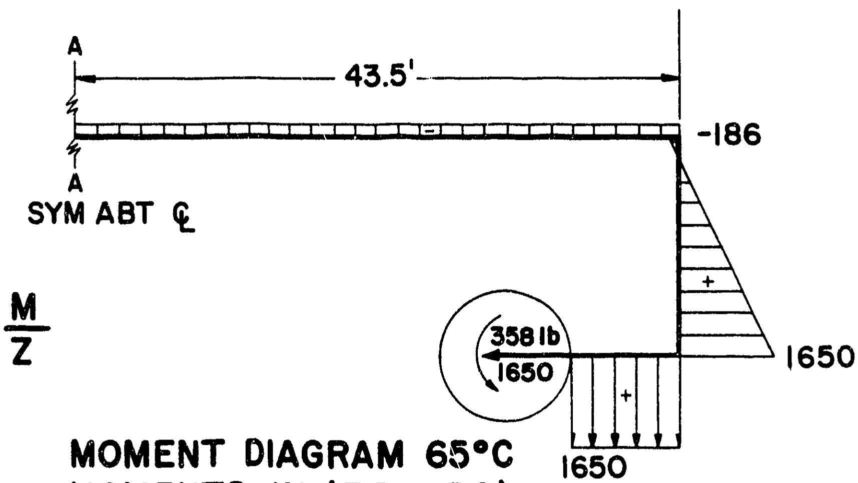
iPE AISI TYPE 304 SST

NESS = 0.237"

n^3

$$= \frac{\text{MOMENT}}{\text{SECTION MODULUS}} = \frac{M}{Z}$$

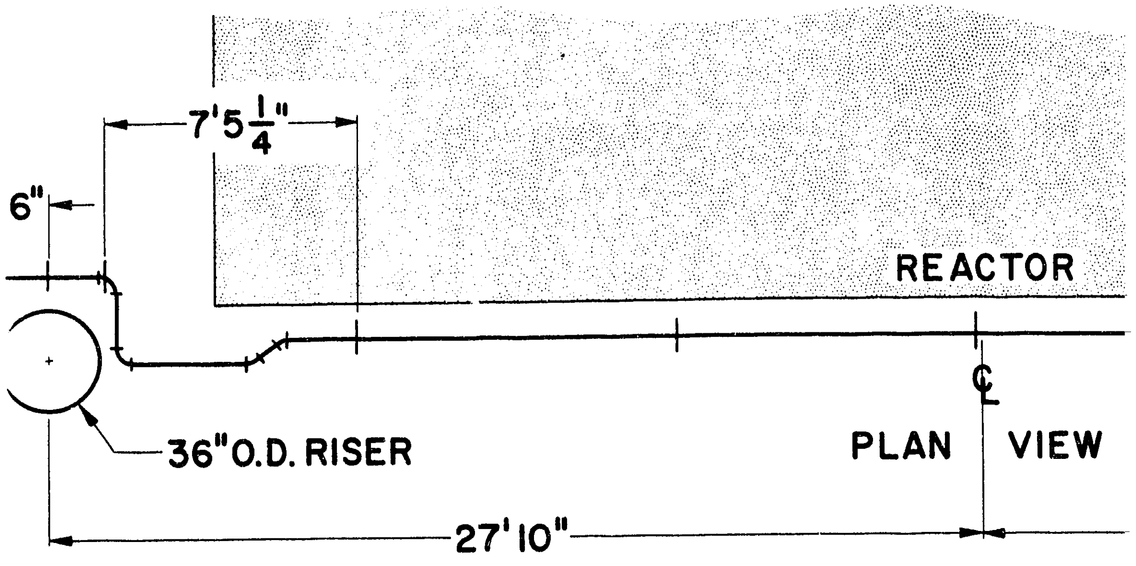
PORTION OF 4"
WEEN RISERS IS
UME THE ELASTIC

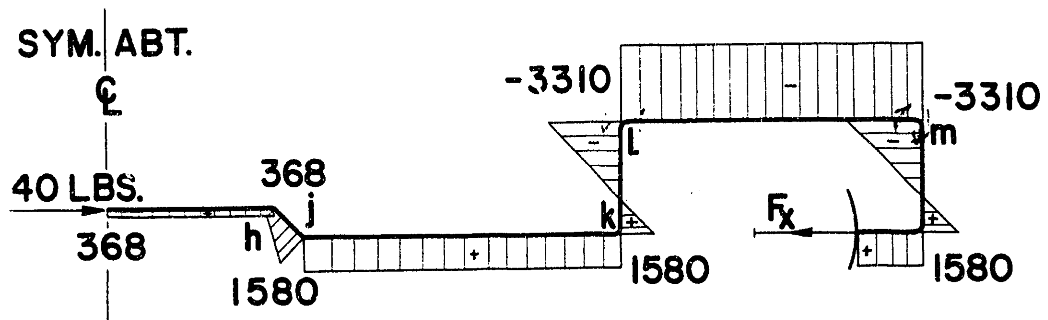


MOMENT DIAGRAM 65°C
MOMENTS IN (FT-LBS)

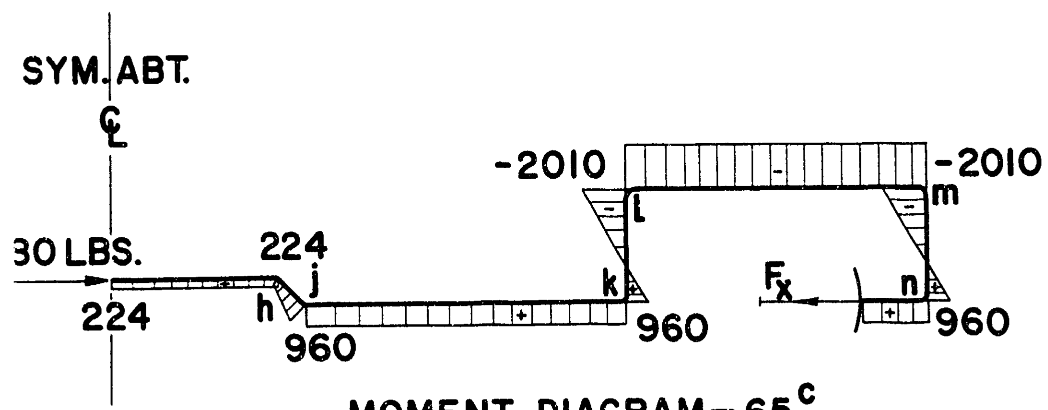
Exhibit No. 3

ams Original and Present Operating Conditions





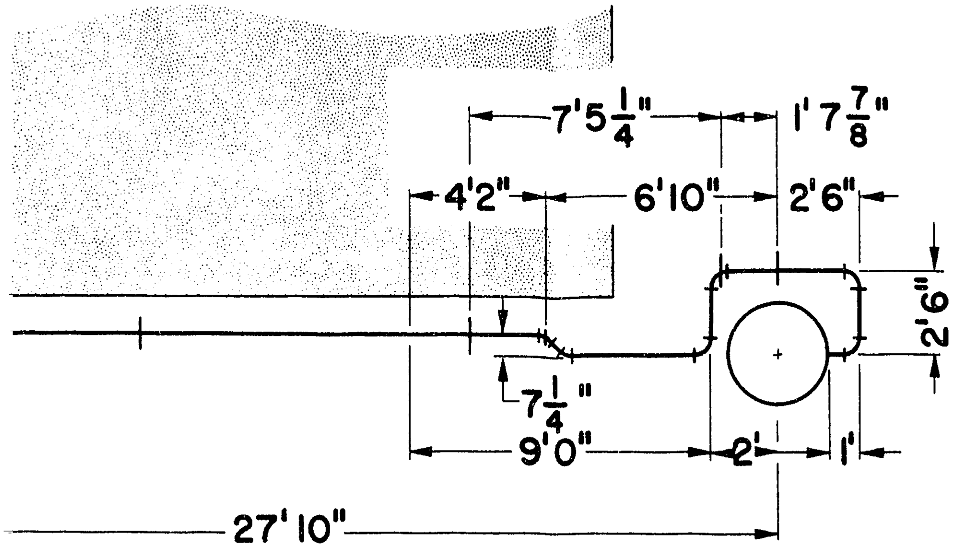
MOMENT DIAGRAM – 95^C
MOMENTS ARE IN FT. LBS.

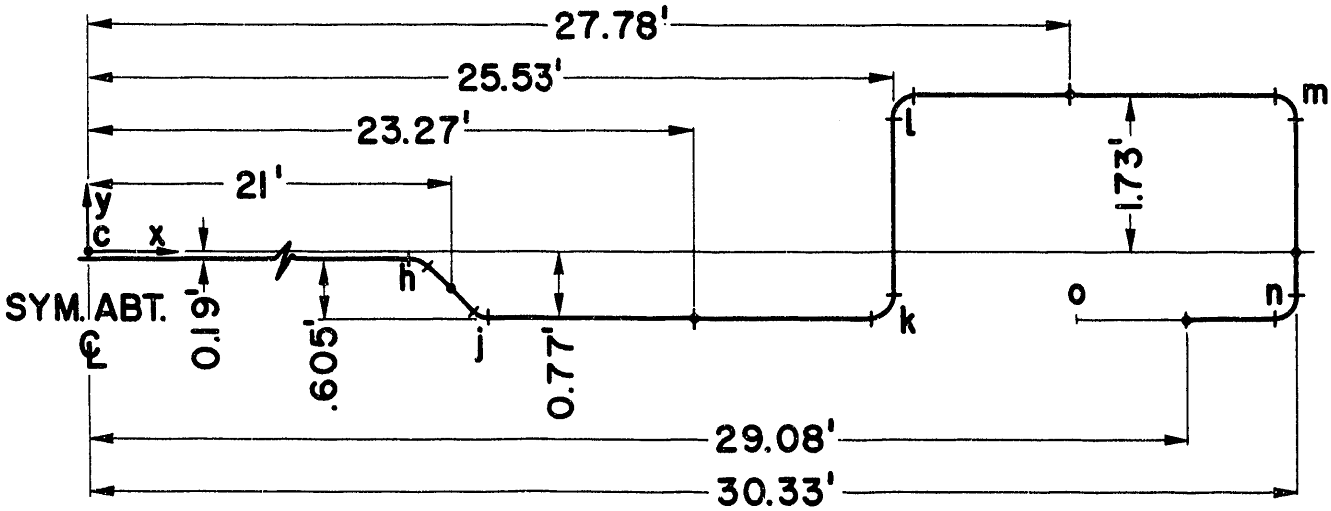


MOMENT DIAGRAM – 65^C
MOMENTS ARE IN FT. LBS.

Ex

Rear Face Crossheader Moment Diagrams Or





MOMENT OF INERTIA DIAGRAM

DATA:

PIPE - 4" SCH 40 TYPE 304 SST SEAMLESS

$I = 7.23 \text{ in}^4$ $E_c = 29.2 \times 10^6$

$Z = 3.22 \text{ in}^3$ $E_h = 28.63 \times 10^6$

O.D. = 4.5"

$$\text{PIPE STRESS} = \frac{\text{MOMENT}}{\text{SECTION MODULUS}} = \frac{M}{Z}$$

ASSUMPTION:

STRAIGHT PORTION OF 4" HEADER BETWEEN RISERS IS FREE TO ASSUME THE ELASTIC CURVE.

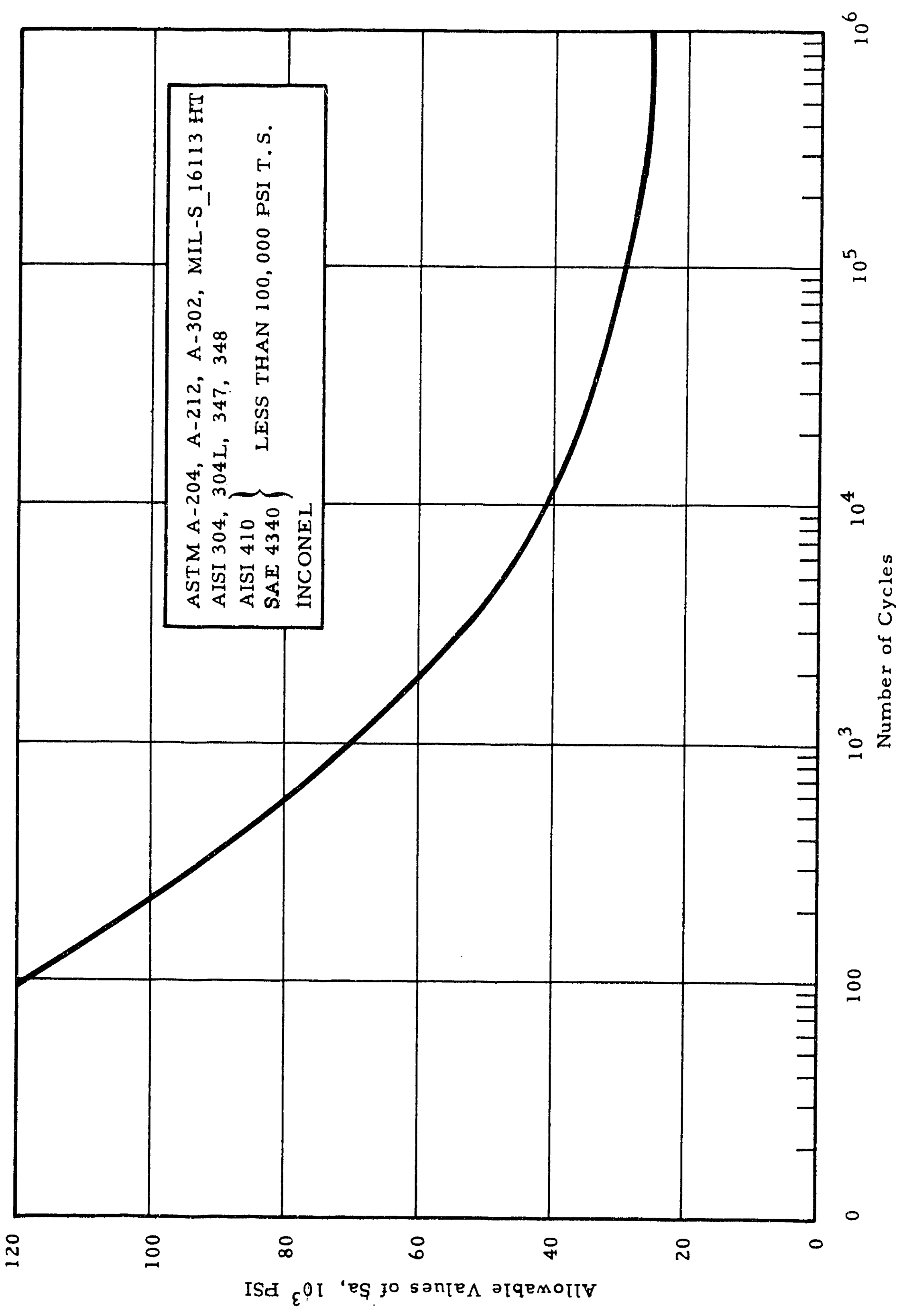
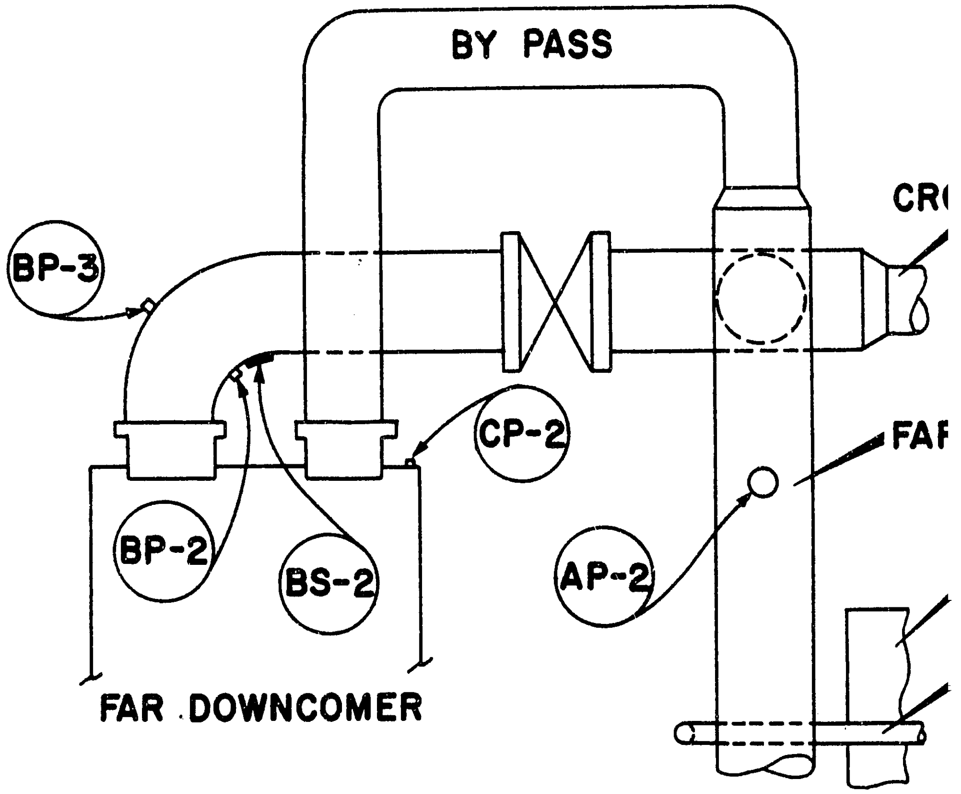


Exhibit No. 5
Design Fatigue Strength Curve



PRESSURE DATA

GAGE NO.	FLOW GPM %	EFF. TEMP. °C	LOCATION	PRESSURE HIGH PSIG	LO PSI
BP-2	100	92	INSIDE ELBOW INTO FAR DOWNCOMER	.5	-2.5
BP-3	100	92	OUTSIDE ELBOW INTO FAR DOWNCOMER	1.5	.5
CP-2	100	92	FAR DOWNCOMER LID	.3	-1.5
AP-2	100	92	NEAR TOP OF FAR RISER	6.2	4.8

Crossov

SS-OVER

RISER

R-REACTOR

OP CROSS
EADER

STRAIN GAGE DATA

ROSETTE NO.	POWER CONDITION %	FLOW %	PRINCIPAL STRESSES PSI		θ	ORENTATION FROM AXIS OF PIPE
			σ_1	σ_1		
BS-2	0	100	829	41	32°	CCW
BS-2	40	100	-11,780	-13,219	17°	CCW
BS-2	70	100	-13,488 ±125	-18,788 ±125	18°	CCW
BS-2	100	100	-13,845	-19,445	56°	CCW

PERIOD OF OSCILLATION SECONDS
.2
.2
.3
.8

Exhibit No. 6
DR Reactor
r Line Pressure and Strain Gage Data

UNCLASSIFIED

EXHIBIT NO. 7
105-DR CRACK IN NEAR RISER AT 25 CROSSHEADER DEC. 1954

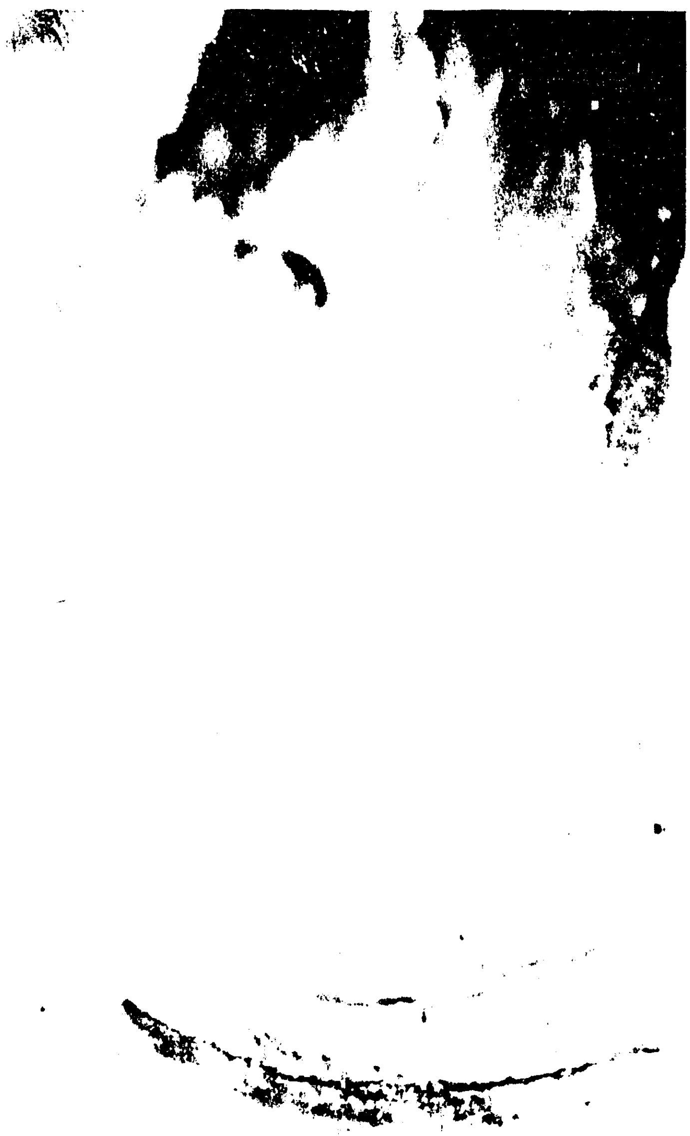


EXHIBIT NO. 8
105-DR - CRACK IN NEAR RISER AT 21 CROSSHEADER
DEC. 1959

EXHIBIT NO. 9
105-F REAR FACE - VIEW SHOWING SCALE BUILDUP

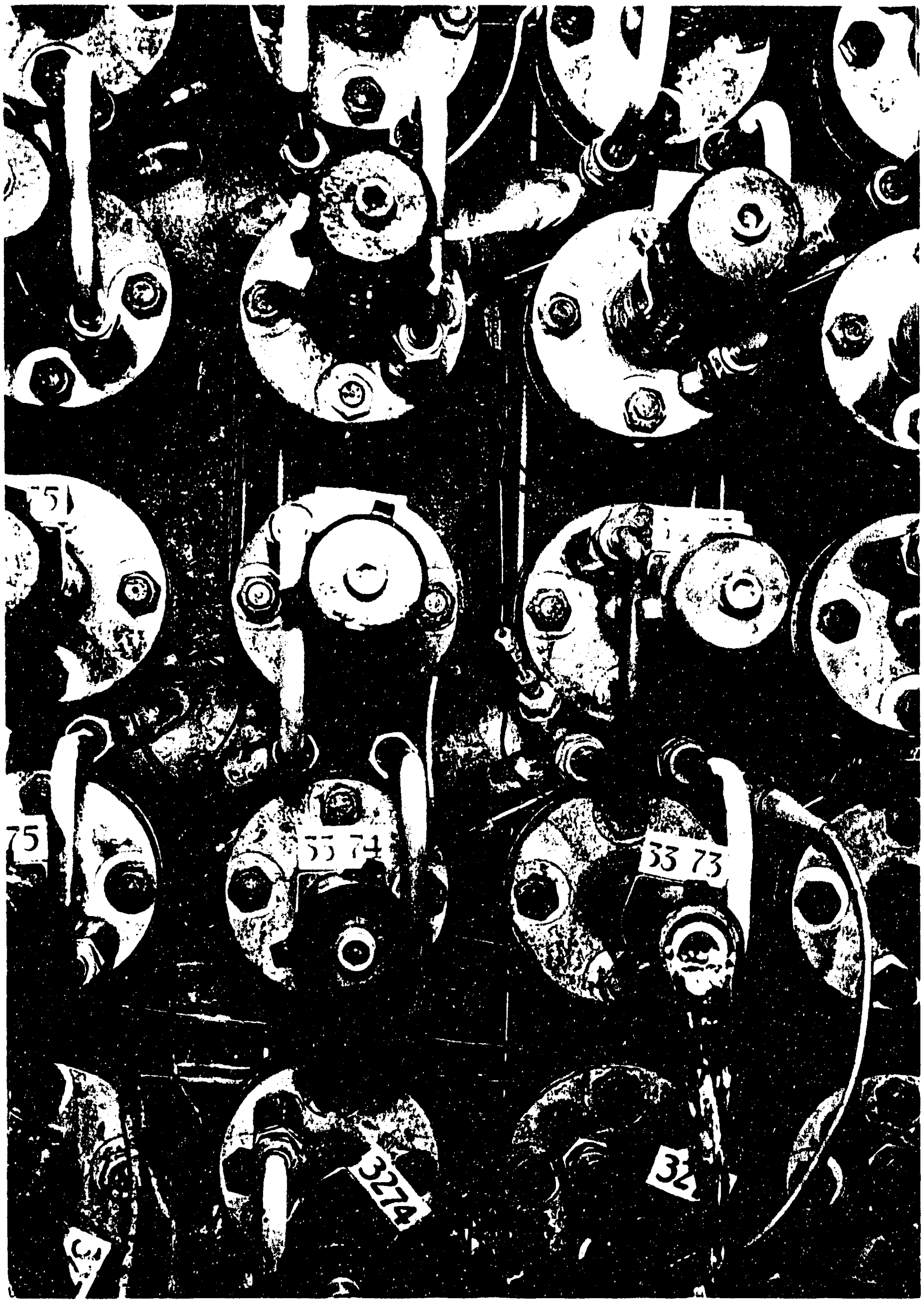


EXHIBIT NO. 10
105-H REAR FACE - VIEW SHOWING SCALE BUILDUP
ON CROSSHEADERS AND LOOSE THERMOCOUPLE FITTINGS

EXHIBIT NO. 11
105-H REAR FACE - VIEW SHOWING WET CONDITIONS, SCALE BUILDUP, THERMOCOUPLE CONNECTIONS LOOSE FROM VIBRATION

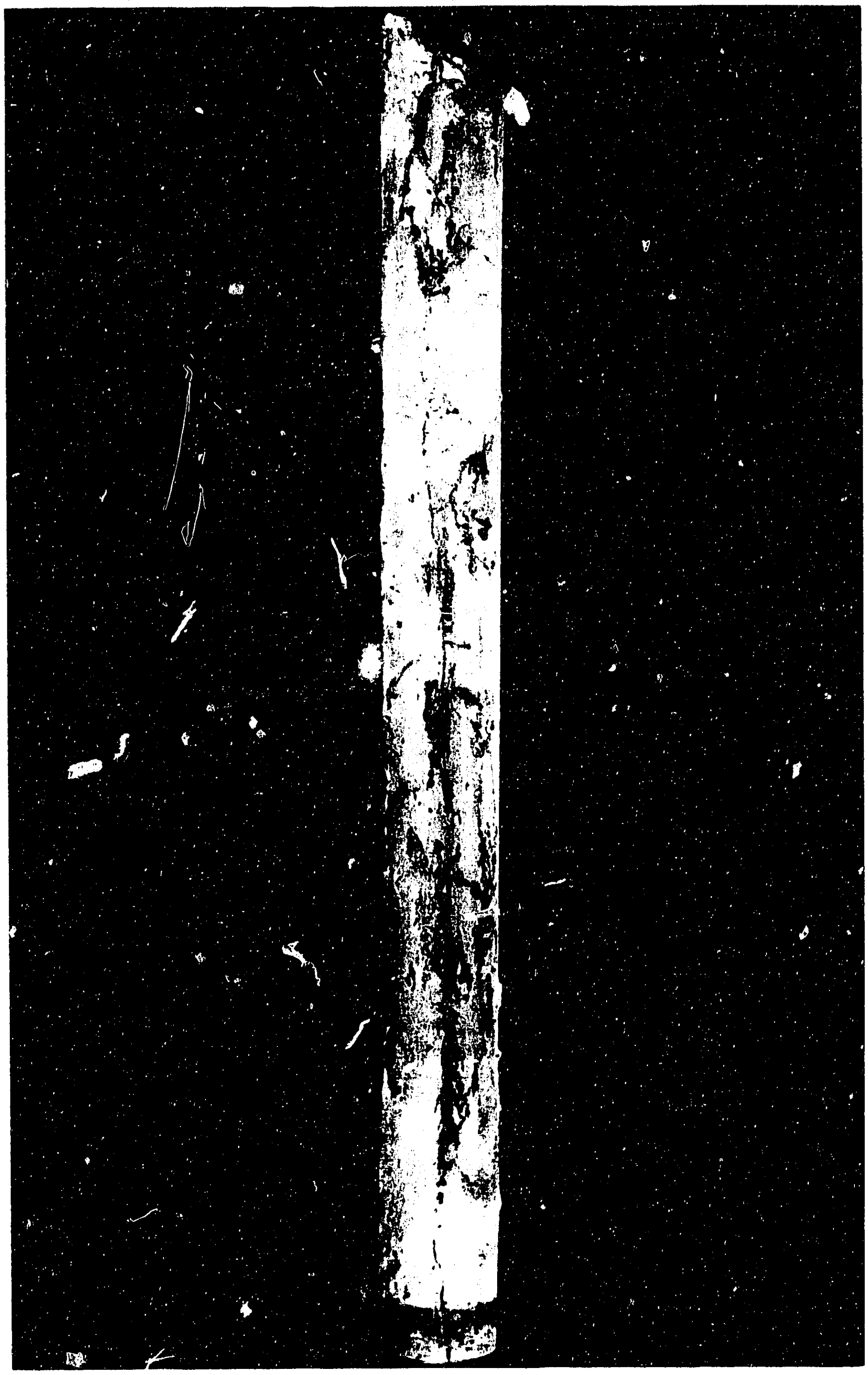


EXHIBIT NO. 12
105-H REAR FACE - GAMMA MONITOR WATER SAMPLE LINE
STRESS CORROSION FAILURE

EXHIBIT NO. 13
105-H REAR FACE - ENLARGEMENT OF STRESS CORROSION
CRACK IN CONNECTOR

EXHIBIT NO. 14
105-H REAR FACE - PHOTOMICROGRAPH OF STRESS CORROSION CRACK IN CONNECTOR

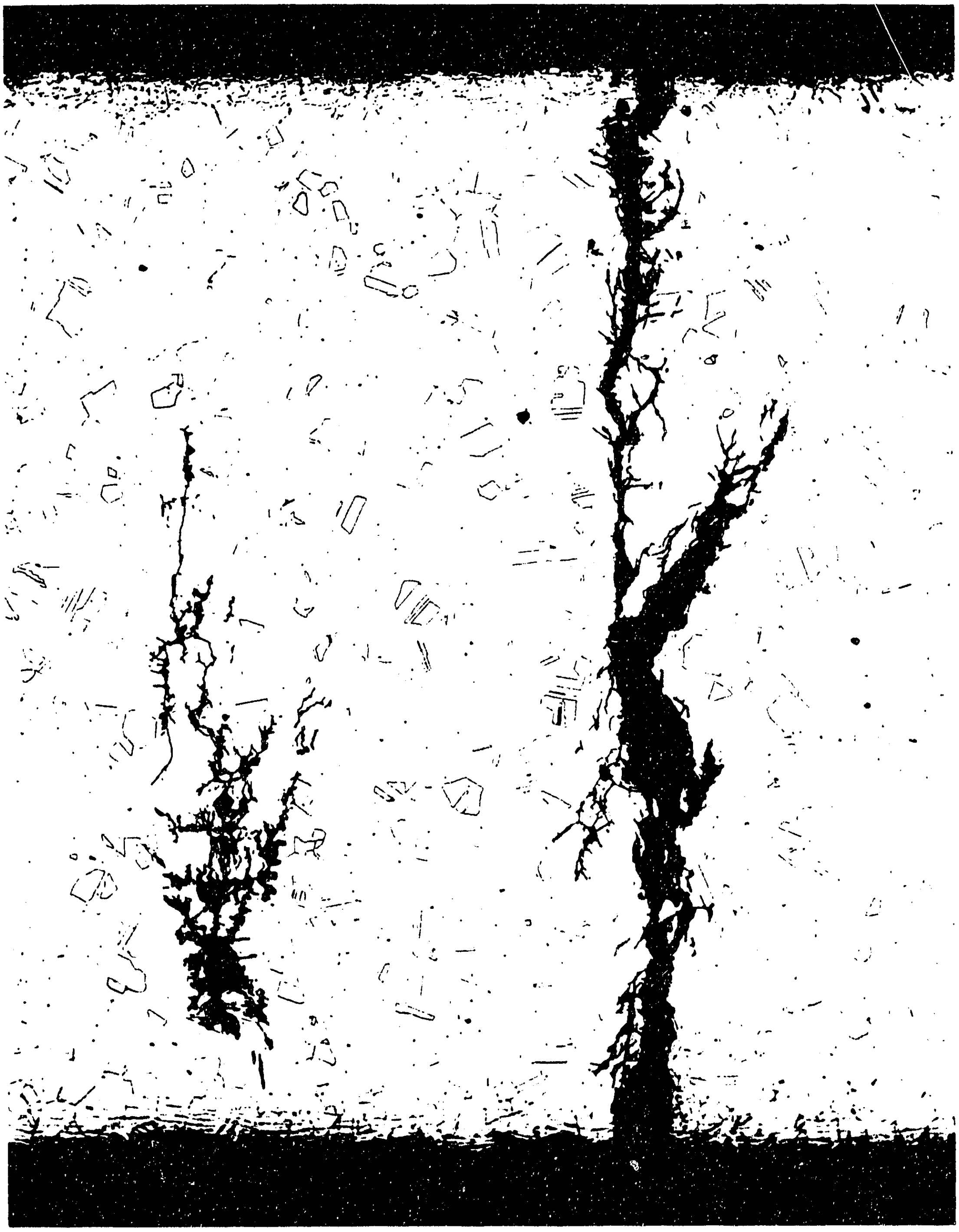


EXHIBIT NO. 15
105-H REAR FACE - PHOTOMICROGRAPH OF STRESS CORROSION CRACKS IN CONNECTOR

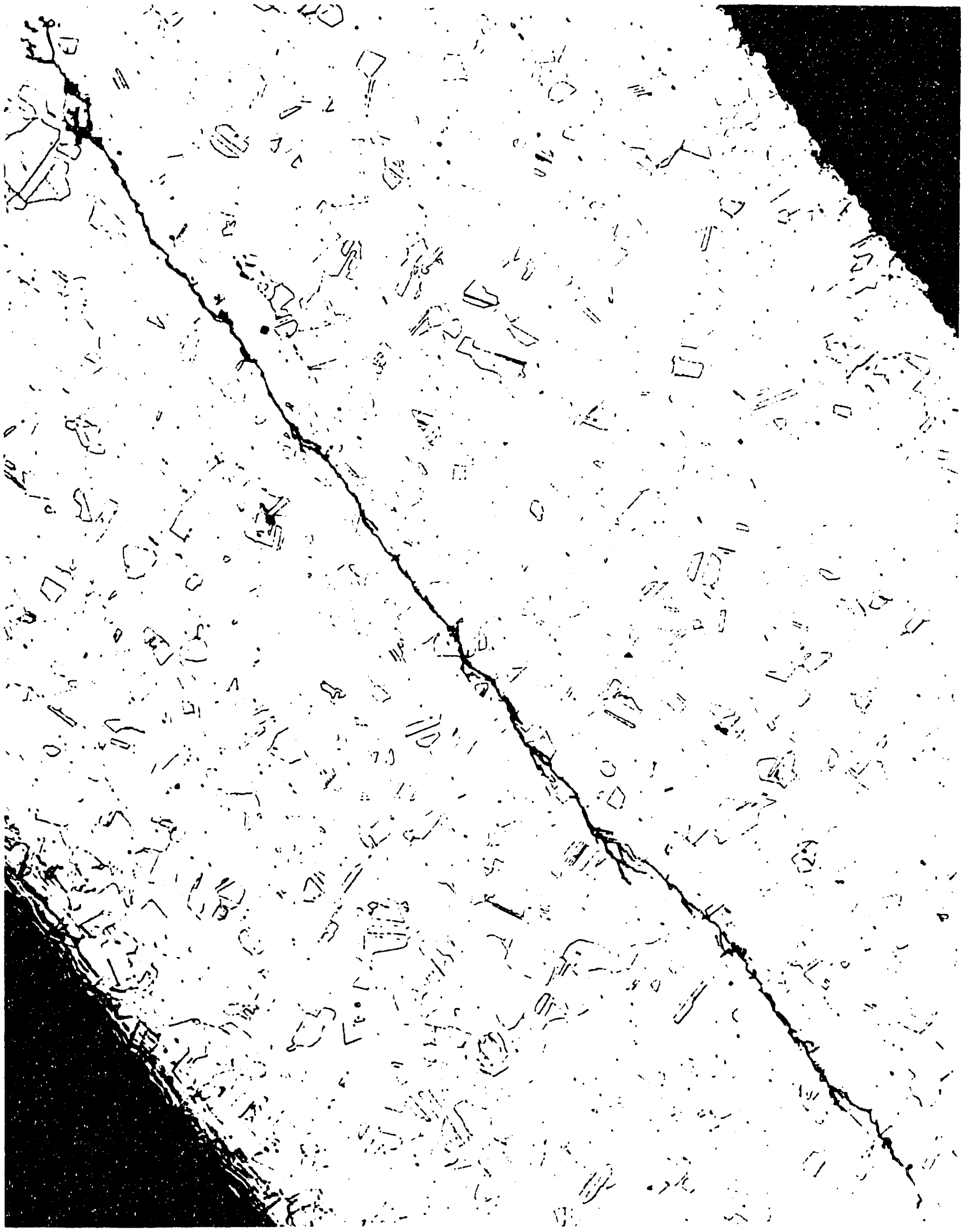


EXHIBIT NO. 16
105-H REAR FACE - PHOTOMICROGRAPH OF STRESS CORROSION IN CONNECTOR ALONG CENTRAL AXIS-UNDETECTIBLE FROM THE SURFACE

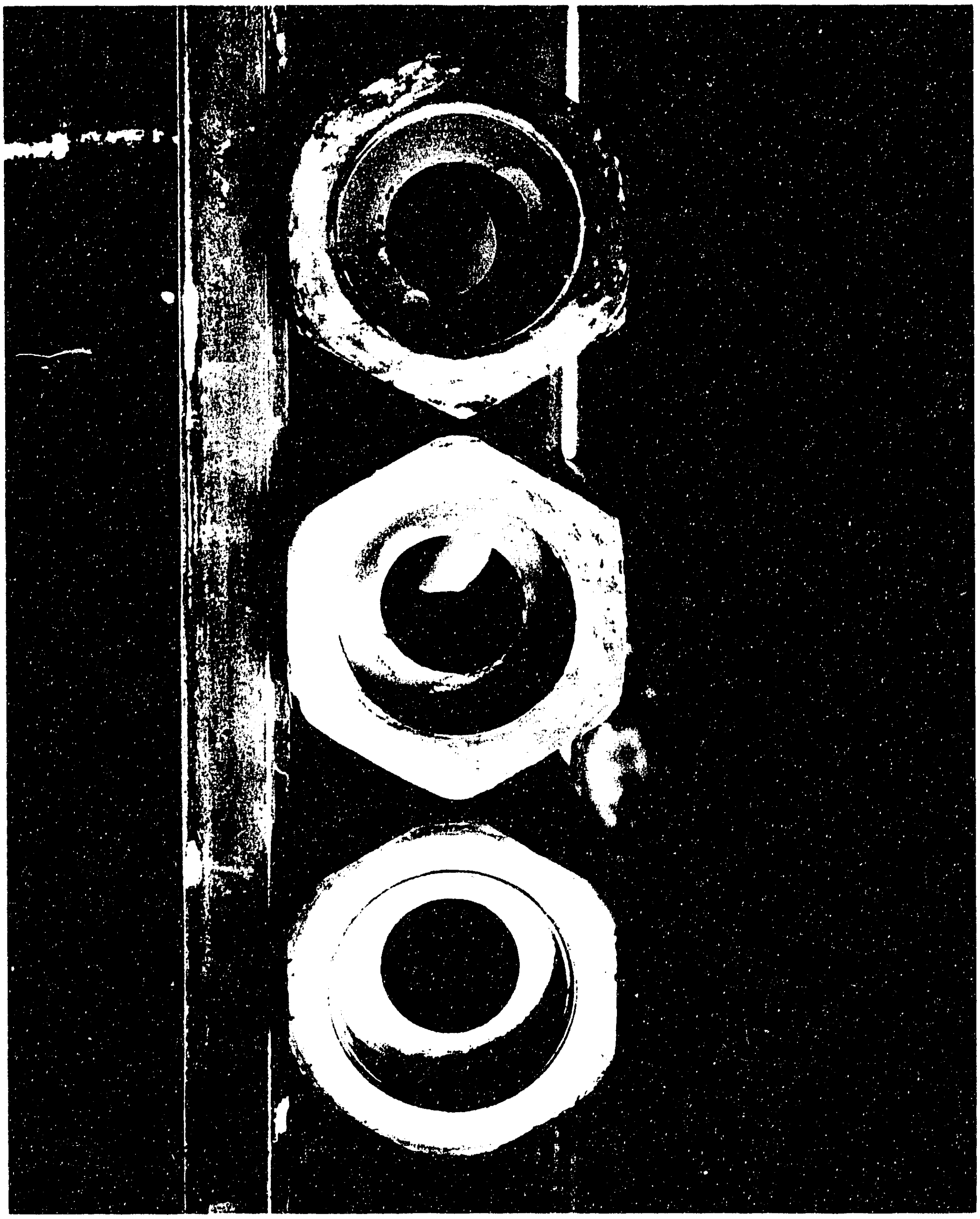


EXHIBIT NO. 17
105-H REAR FACE - CAVITATION OF BRASS ADAPTERS

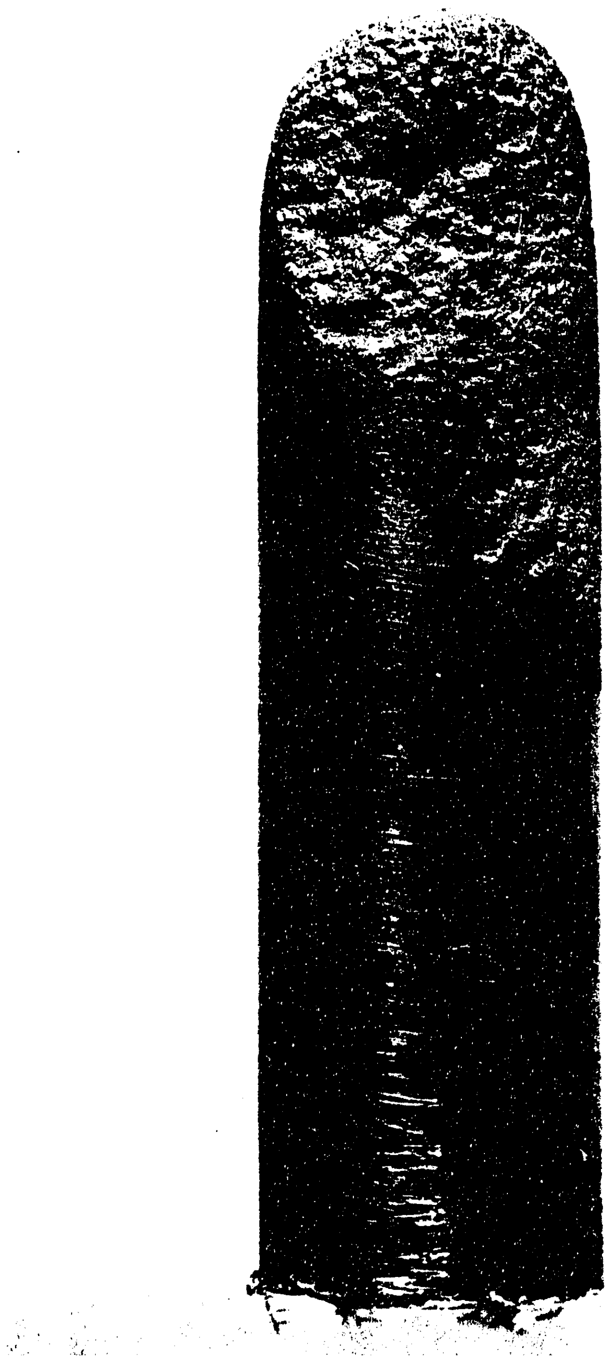


EXHIBIT NO. 18
105-H REAR FACE - CROSSHEADER CONNECTOR THERMOCOUPLE WELL FAILURE THROUGH CAVITATION

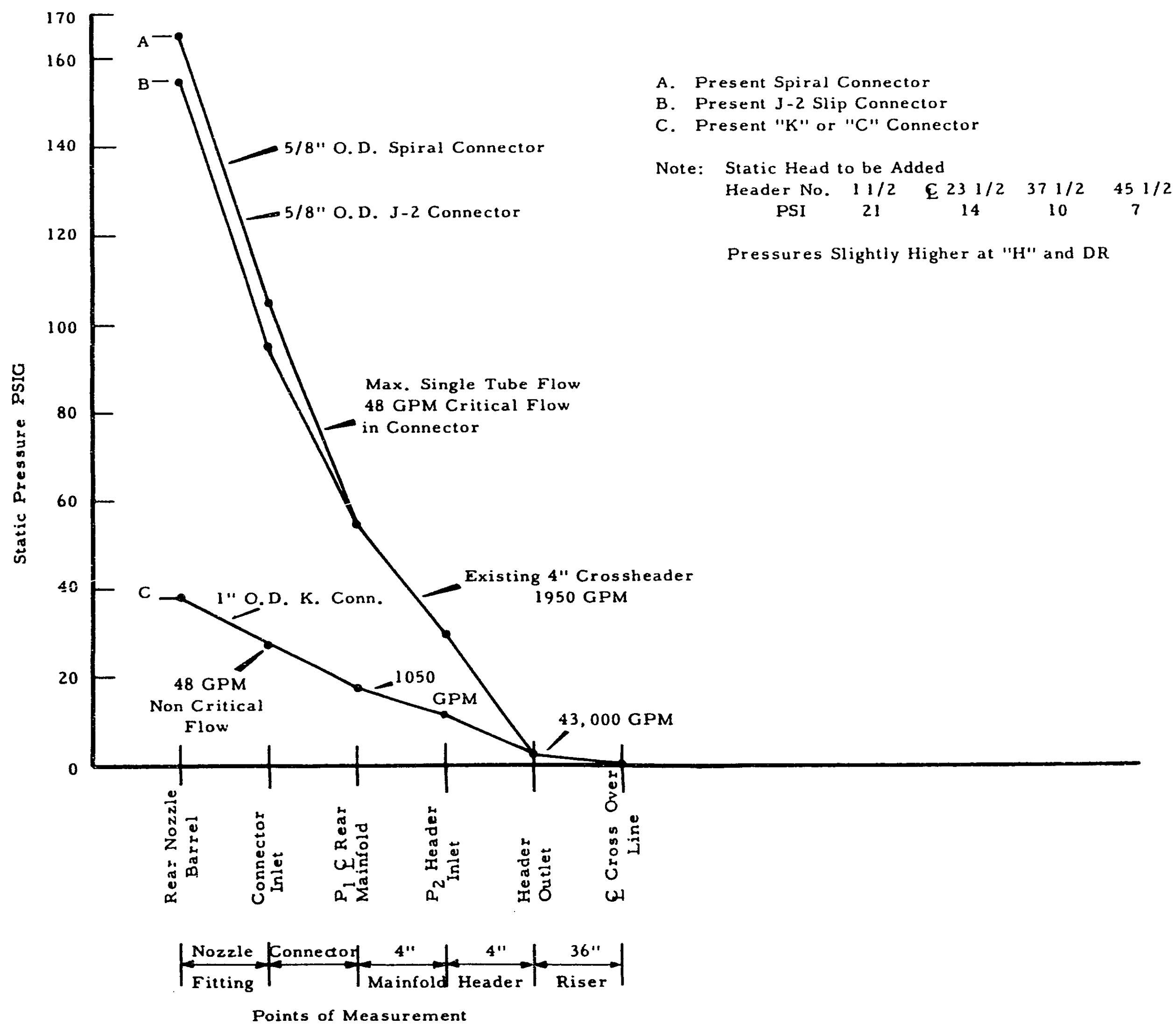
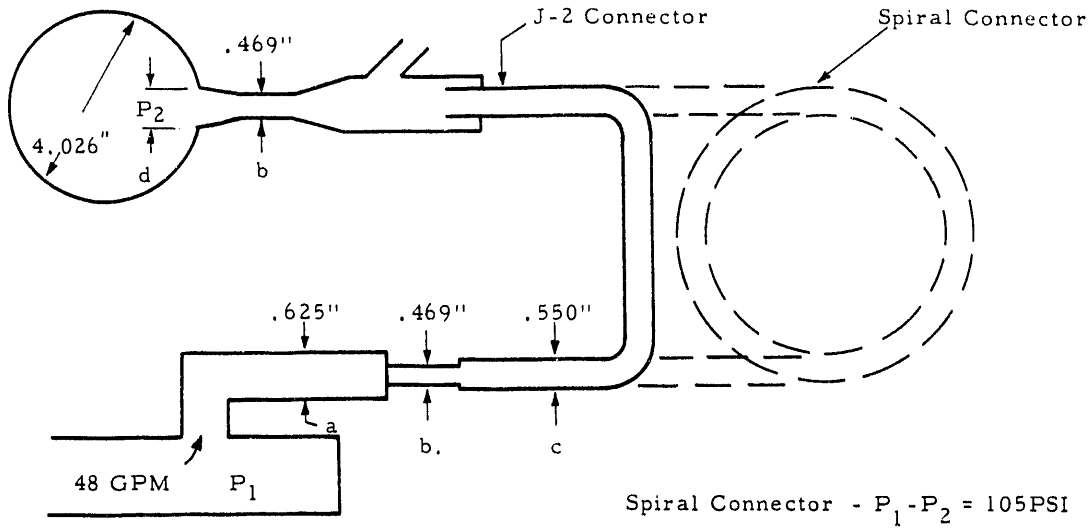


Exhibit No. 19

Pressure Profile - Tube Outlet to Top of Riser for Present Operating Conditions
B, D, DR, F, H Reactors

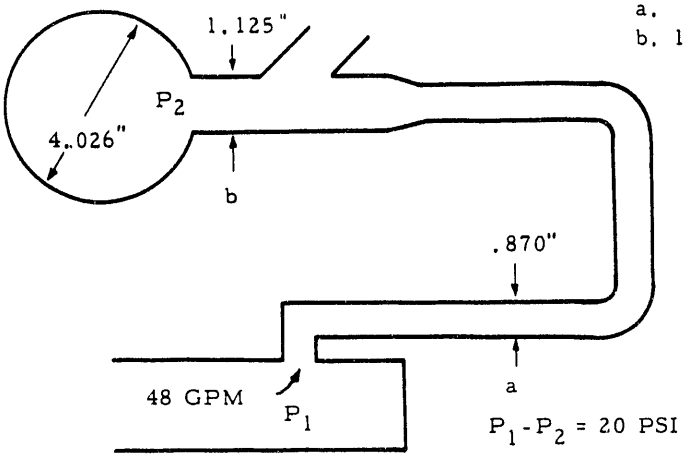


Spiral Connector - P_1-P_2 = 105PSI
J-2 Connector - P_1-P_2 = 95PSI

Present Spiral and J-2 Connector

	A in.^{2}	V ft./sec.	hVft.	PV PSI
b	.172	89.25	124	51.5
c.	.237	65.0	65	27.0
a.	.306	50.0	39	16.2

	A in^2	V $\frac{ft.}{sec.}$	hVft.	PV PSI
a.	.592	21	6.85	2.85
b.	1.0	15.35	3.65	1.52



Present "K" Connector

Exhibit No. 20
Present Connector Velocity Comparison K vs. B, D, DR, F and H

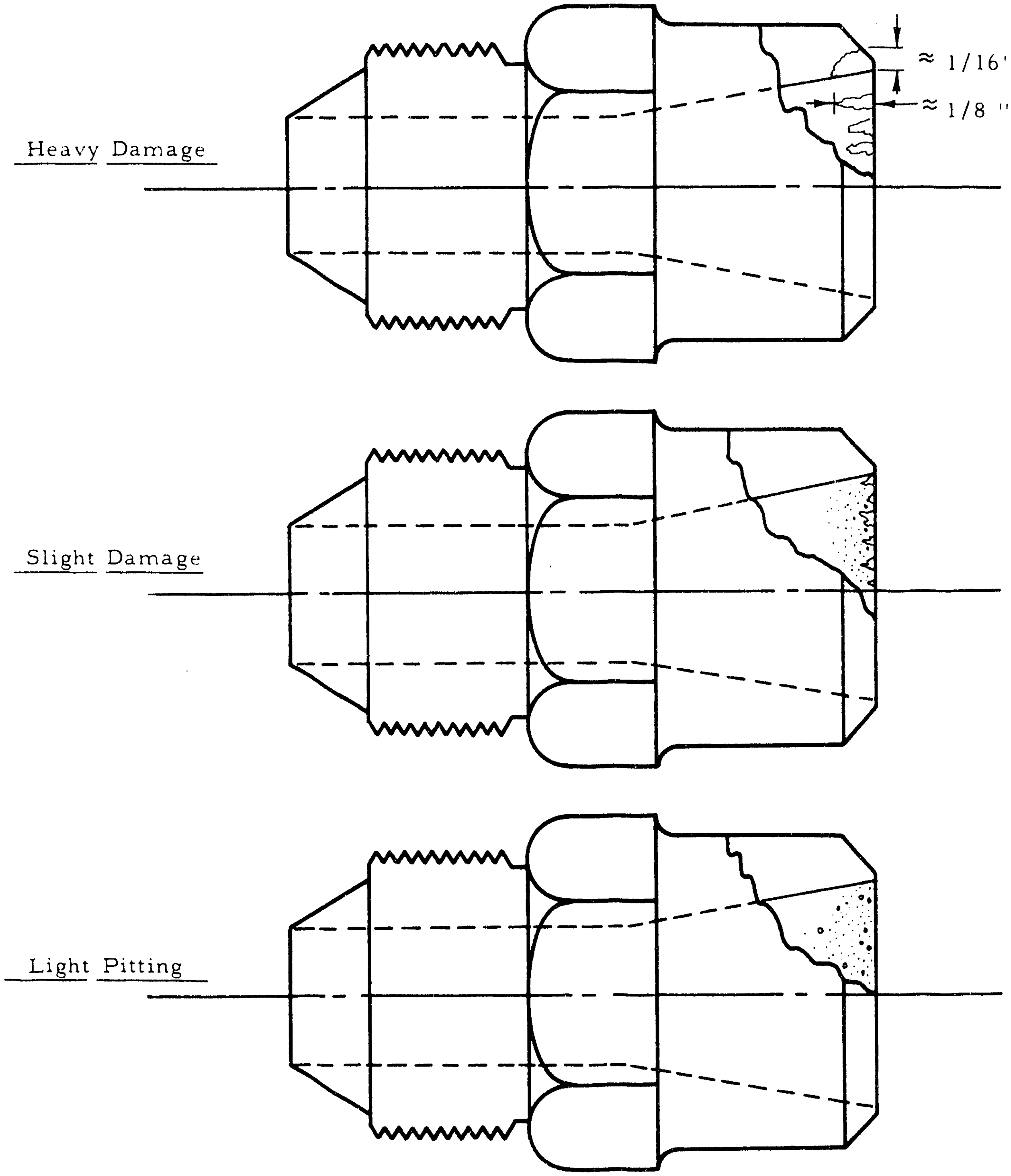


Exhibit No. 21
Parker Fitting Cavitation Damage B, D, F, DR

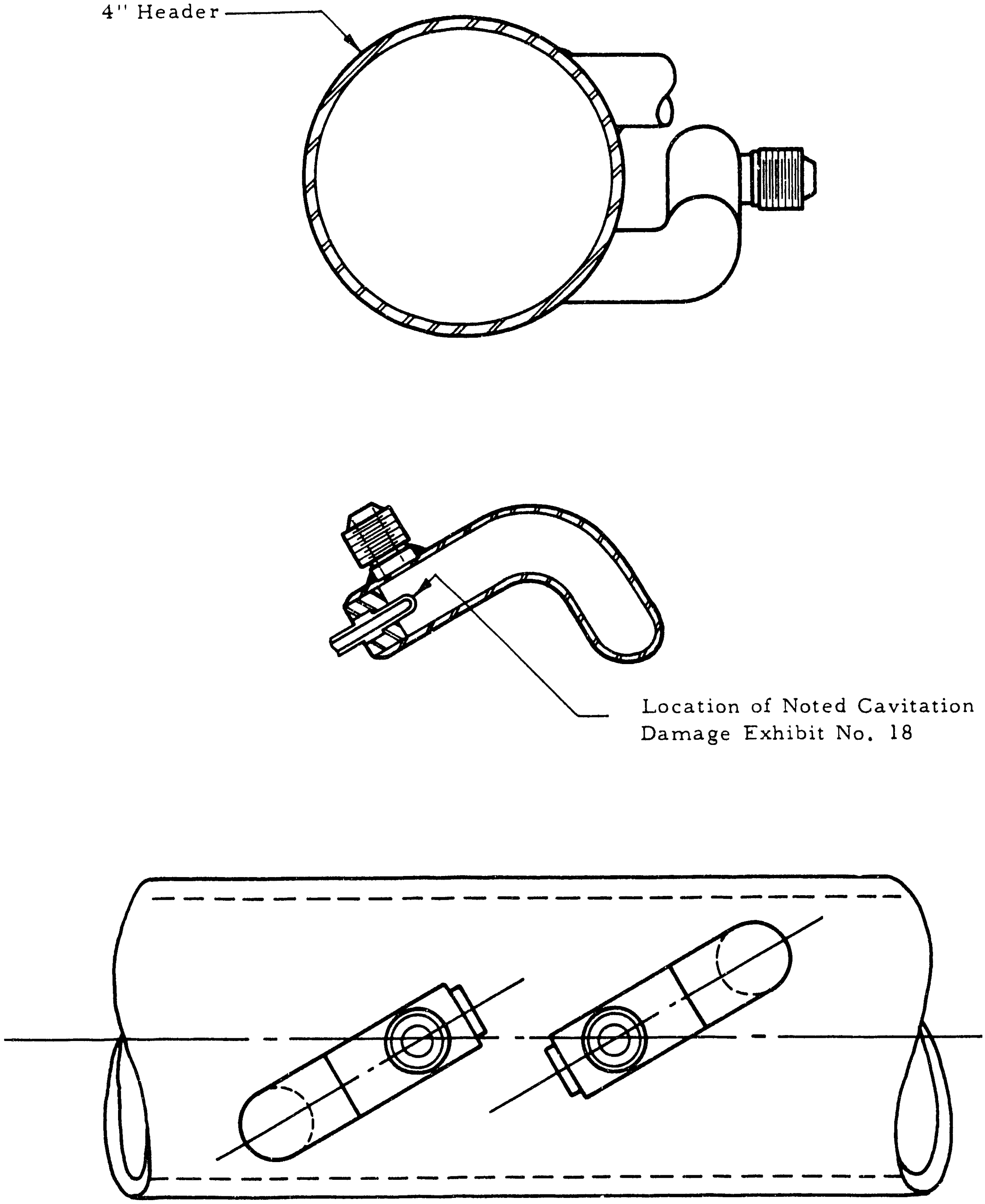


Exhibit No. 22
Cavitation Damage in H Reactor Crossheader Fittings

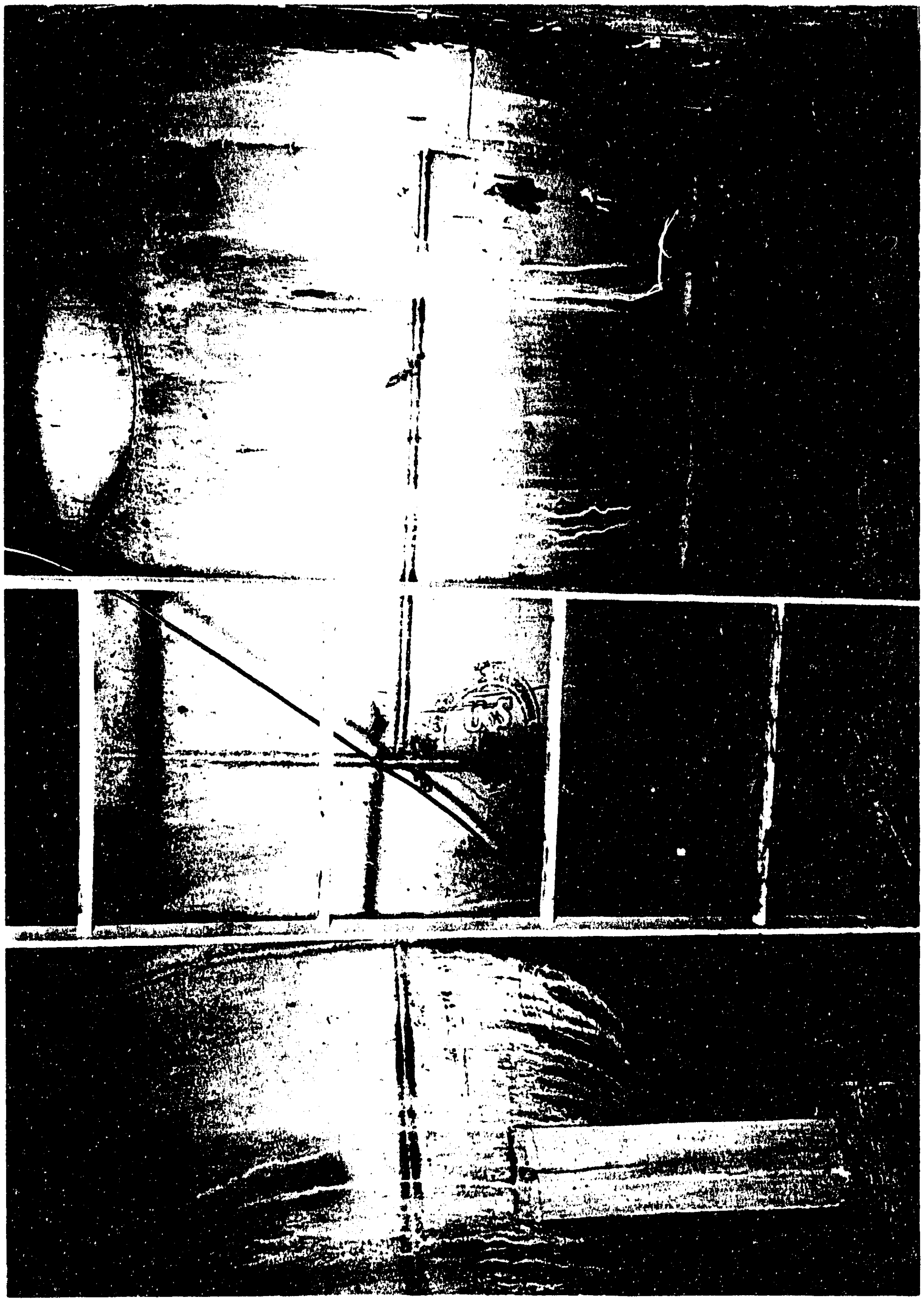


EXHIBIT NO. 23
105-H DOWNCOMER APPROACH - CRACKED FOOTING DUE TO VIBRATION

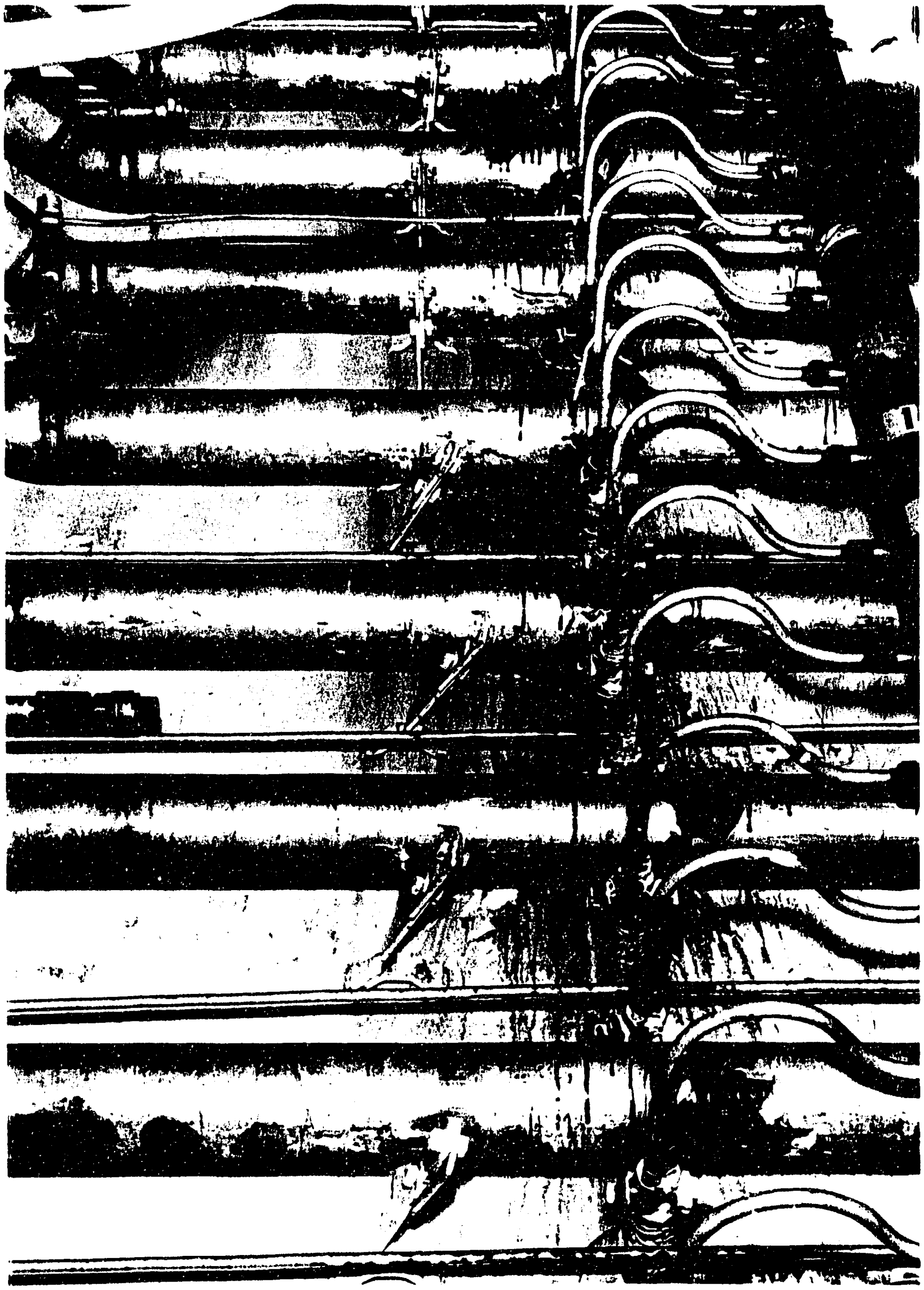


EXHIBIT NO. 24
105-H REAR FACE DISPLACED CROSSHEADER SUPPORTS

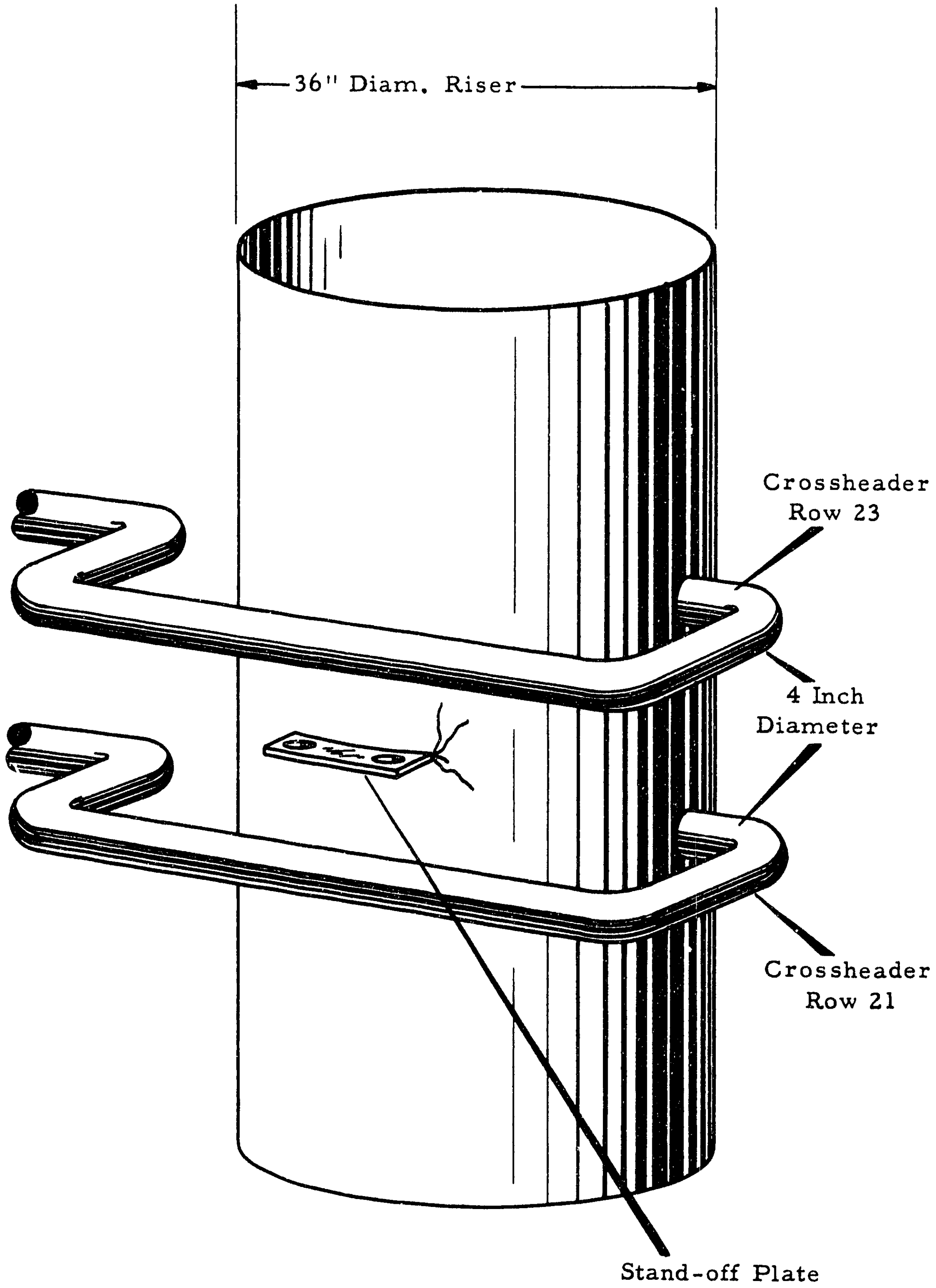


Exhibit No. 25
Example of Crack in Far Side Rear Face Riser 105-H Between Crossheaders 21 and 23

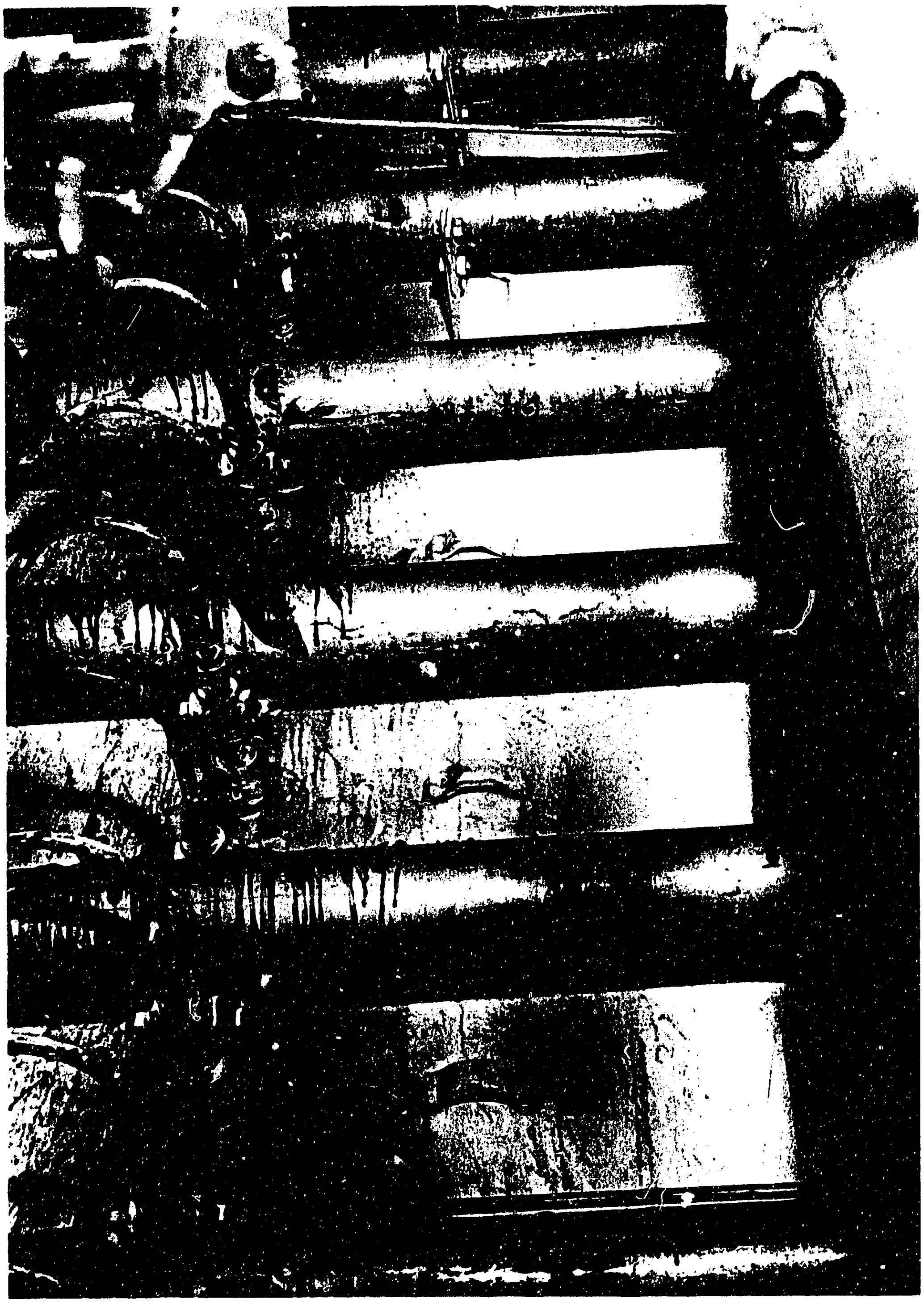


EXHIBIT NO. 26
105-H REAR FACE - MISSING CROSSHEADER SUPPORT BRACKETS

END

DATE FILMED

6 / 1 / 93