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TITLE

EXISTING REACTOR REAR FACE PIPING REVIEW

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EXISTING REACTOR REAR FACE PIPING REVIEW

by

J. M. Fox, et. al.

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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. Because the rear face is inaccessable during normal reactor operation, all such leaks must be repaired after charge-discharge. Experience has shown that the length of an outage is in a large part determined by the amount of work required on the rear face. It is desirable then that equipment items and piping components located in the rear face possess a high degree of reliability.

The purpose of this report is to review all 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 taken 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 beginning to show 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 build up of corrosive scale, cavitation of fittings due to high velocities and high temperatures, and by the low frequency vibrations cuased 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 any 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 generally exponential. To provide time for adequate replacement design and for normal budget procedures, action should be initiated now for replacement of the rear face piping.

The replacement of crossheaders will require the removal of all nozz[illegible] and hardware. Consideration should be given to utilizing this opportunity to provide for process tube expansion and nozzle replacement.

To provide operating continuity at present power levels interim measures should be taken to reduce the incidence of failures. This includes:

1. Careful examination and replacement of suspect pigtails on a continuing basis.
2. Replacement of missing or damaged crossheader supports.
3. Periodic checking for loose fittings, bolts, and nuts.
4. Instulation of braces to break up low frequency vibrations.

A program should likewise be initiated for removal of a crossheader for destructive analysis of stress corrosion and for development and design of replacement hardware and piping suitable for the new flows and temperatures.

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DISCUSSION

The following discussion presents the major rear face piping defects, problems and areas of concern. The sequence of presentation is not being made on the basis of importance. It is the aggregate of all these problem areas that dictate a major replacement effort should be considered.

1. Background and Past History

The B, D, and F Reactors were originally designed for process flows of 30,000 gpm and 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 near 95° C, representing approximately 1600 MW of heat generation. Thus the above reactors are now operating at six and one half time the original design rating and are still using the original rear face crossheader piping and fittings.

The adequacy of the rear face piping was examined prior to initiation of the last major increase in flow, that is, project CG-558, "Reactor Plant Modifications for Increased Production". The design flow rate for the project was 71,000 gpm at a bulk outlet temperature of 90° C. No rear face piping additions or modifications other than replacement of downcomers was felt to be required for the 558 conditions.

Subsequent advances in technology as well as revised operating procedures have increased flows to approximately 80,000 gpm with seven pump operation at a bulk outlet temperature near 95° C.

Calculations of thermal expansion induced stress at the terminal joint of rear crossheaders and risers have shown that these joints are 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. Thermal Stress Study

The results of several sets of pipe stress calculations indicates that under design conditions and the logical expansion path of the crossheader the stresses in the 36 inch O.D. riser are in excess of the ultimate strength of the 304 s●ainless steel used in this member. The fact remains that the riser is in use and has not completely failed, although some cracking has occurred in the ●ise● at points of high stress.

The calculations were accomplished using the elastic limit theory. It is readily apparent from the stress strain curve for stainless steels that the behavior of this material follows the elastic theory relationship for a relatively short interval. In order to interpret the calculations, it was assumed that the common factor relating the elastic theory calculations and actual conditions was the strain of the material. Then for any calculated stress, a strain is known which in turn indicates a stress on the stress strain curve which is a much better approximation of the actual conditions prevailing in the material.

The yield point is not clearly defined for stainless steel. Most sources of mechanical properties indicate a zone ranging from 60 to 105 KSI. International Nickel Company gives the yield strength of 304, cold rolled stainless in compression as 95 KSI. In the case of the riser, it is safe to assume that the material does yield and a plastic deformation occurs at the stress levels achieved in reactor operation. This is referred to as self-springing or self-inducted cold spring when it occurs in piping structures. In this case the mechanism in

[redacted]

effect relieves the stress by a factor of two. As shown in Figure __, the stress becomes a completely reversing stress cycle as soon as equilibrium conditions are attained.

The amount of plastic flow determines the stress pattern after yielding. In Figure __, the point of zero stress was taken to be at 1/2 the indicated stress on the stress strain curve. A new set of axes was drawn about this point, and the stress pattern indicated by a hysteresis loop showing a completely reversed stress cycle. The maximum stress is reduced and actually occurs in both tension and compression.

The American Iron and Steel Institute gives the following values for endurance limits of 304 cold worked stainless steels.

1/4 hard - 48,000 psi

1/2 hard - 70,000 psi

3/4 hard - 92,500 psi

This indicates that in the original design condition, the stress levels are low enough that fatigue should not be a problem in a soundly fabricated structure.

The rigid riser supports cause the crossheader expansion to be restrained and thus the expansion results in stress rather than in movement of the system.

The risers in question were fabricated about 1943, using materials and methods of that period. The quality of the 304 stainless has improved in recent years, and there is reason to believe the materials in use may not have mechanical properties as good as present day materials. The welding done in connection with the fabrication of the risers was shielded electrode arc welding, not the inert gas welding used at present. No stress relief or special precautions were used when these fabrications were accomplished. The quality of welding would not be acceptable by present standards. The failure of the weld on the near riser of

 [redacted]

DR Reactor (See Exhibit___) tends to bear this out. The failure lies adjacent to the weld bead of the crossheader to riser connection which is the high stress area of the rear face piping assembly.

To correct the high stress conditions and to provide a sound piping system in the rear face, the following action should be taken:

1. The riser should be suspended on temperature compensating roller supports that would permit the entire riser assembly to move horizontally and vertically as the rear face piping temperatures increase. This support system will relieve the stress in the crossheaders and riser connections.
2. The crossheaders should be supported to allow for free thermal expansion and at the same time compensate for the vertical deflection due to riser expansion. There should not be any rigid anchors in this piping system. The stresses in the crossheader would be due to a small vertical deflection about 0.30 inch at each end of the 87 foot pipe, which is very minor.
3. The riser should be replaced with new risers. The old risers have been subjected to severe thermal stresses and vibrations. The quality of welding does not meet present standards. There are residual stresses that will contribute to corrosion and fatigue problems. The present integrity of the metal cannot be guaranteed. The new riser should be 1/2 inch thick for more rigidity to withstand the high forces and the possibility of future rear face pressurization. The crossheader connection should be reinforced five inch nozzles for connection to five inch pipe and five inch gate valves to reduce the high water velocities.
4. New crossheaders should be installed with larger pigtail connectors. The metal cannot be guaranteed for the same reasons as given in paragraph 3 above for the riser. The larger connectors are needed to reduce the high water velocities and eliminate cavitation. Due to the fact that one pigtail connec-

tor completely broke at "B" area May 13, 1960 and from observations it had started cracking a long time ago and finally failed, it is evident that rear face maintenance is going to increase rapidly as failure of old piping continues to grow.

5. The risers above the support should be uniformly increased in diameter from the support to the crossover pipe connection to decrease the water velocities slowly and prevent cavitation. The diameter of the pipe from the valve to the downcomer should be increased uniformly to reduce the high velocities at the downcomer inlet. It has been shown that the high velocity heads in this piping are causing negative pressures and steam formation, which collapses under a positive pressure releasing large amounts of energy. The fluctuation of positive to negative pressure is occurring at the same period as the vibration of the entire piping system. Therefore, if this high velocity head can be reduced slowly the low frequency vibration can be eliminated.

3. <u>Piping Vibration - B, D, DR, F, and H</u>

A study of reactor rear face piping vibration was initiated in October, 1959 in support of development work on a replacement for failing reactor rear connectors. The information obtained is of significance to rear face piping in general as well as the rear connector problem.

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

1. In the rear-face pigtails and fittings, strong vibrations at high frequencies (1000-8000 cycles per second) indicate internal impacts due to cavitation. Increasing numbers of leaks support this evidence, as well as wear observed in fittings after removal. Erosion in crossheaders also has been observed,

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directly opposite points where water enters at high velocity.

2. In the outlet fittings, velocities as high as 95 ft./sec. occur through a .469 inch throat. The corresponding velocity head drops the static pressure enough to clearly permit boiling and subsequent cavitation.

3. 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, see picture, Exhibit .

4. This vibration occurs at the lower end of the riser. At this point, (H Reactor) an attempt to anchor the thin-walled riser (to the reactor rear face) has evidently torn the riser wall and necessitated repairs. There is evidence of about 1/2 inch vibration at this point (See Exhibit No.)

5. This same low frequency vibration, transmitted back through the risers, has been measured with large amplitude (in one location, as high as 0.9 inch, peak to peak) on some of the rear crossheaders. This large movement overstresses the pigtails and fittings, and undoubtedly contributes to the increasing leakage incidence and relative high cost maintenance during shutdown.

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. The

[redacted]

original cause of this breakage of supporting brackets is the excessive thermal expansion, resulting from the higher water temperature; the large vibrations which have resulted are now causing further damage to pigtails and fittings.

6. To show the effect of high velocity through the pigtails and fittings of the older reactors, some comparison can be gained from the K Reactor, which has larger fittings, much lower throat velocities, and correspondingly less flashing, turbulence, and cavitation. Although the data presently available do not enable point-for-point comparisons, the high frequency (6000 cycle, cavitational) vibrations on rear crossheaders at K indicate far lower accelerations than those of the older reactors.

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

Cavitational flow has been known to exist in rear crossheader "Parker" fittings for the last five or six years. Calculations showing initiation of cavitational flow as a result of high flow rates in the present fittings were verified by experimental data in 1954(1). To obtain an estimate of the effect of cavitation in rear crossheader fittings resulting from past and current operating conditions, twenty one fittings at B, D, and F Reactors were visually examined during the period October 6, 1959 to November 30, 1959.

Of the 21 fittings inspected, 15 showed evidence of cavitation. 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 (Figure). It has been estimated that 8.2 percent of the fittings have damage exceeding .05 inch in depth of erosion and 0.9 percent have damage exceeding 0.10 inch. (Statistical analysis of the data obtained from the inspection provided the basis for this estimate).

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A small borescope was utilized to visually inspect the interior surface of the 21 rear crossheader fittings. Table 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. (Figure). 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 presumably 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 evident that once cavitation attack beings, 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

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of the "Pigtail" to crossheader fitting connection, the cavitation damage is probably occuring in a 90° elbow attached to the "Parker" fitting rather than in the "Parker" fitting itself.

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 in the last three years; corrosion is the other. While all the older reactors have had numerous "pigtail" failures, and some of them have had fatigue cracks in risers and other piping, opinion has been that these occurences are individual problems and not necessarily connected. Considering the whole piping complex on the rear face from the system aspect, it is possible to relate failure occurences in terms of interacting stress, corrosion, thermal gradients and the like.

In the system on a rear face 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, "pigtails" 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, a necessary function leading to fatigue failure. Tensile stresses contribute substantially to the rate of corrosion of a material and lead to stress corrosion cracking - a mechanism that has failed thousands of pigtails.

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 "pigtails" 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, 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 the leak and leaves a deposit of mineral salts. (Exhibit) The analysis of a typical scale deposit is shown in Table 1. 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. (Exhibits and)

When a component such as a pigtail 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 and it is not self healing 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 leakers. Laboratory controlled stress cycle tests of in-service pigtails that were not leakers and which did not show defects under non-destructive inspection tests failed 100-500 times faster than identical pigtails that had not been in service. The in-service pigtails 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 <u>any</u> repeated wetting and build up of insoluble salt deposit.

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

Out and out pigtail leakers can and are replaced routinely, but in-place cross-headers, 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 severly stresses restrained members even under controlled conditions and reactor piping is restrained. Welding on the rear face is generally a patch attempt to bridge a wet crack until it stops leaking - it is next to impossible to cut off water and dry out a section of piping so that a quality weld can be made.

While stress corrosion cracked components can be measured in the thousands and fatigue failures in the tens, 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 is as few as 20 cycles.

For purposes of planning and in order to anticipate failure of hard to remove in-place piping it is restated that:

1. Eight recorded fatigue failures 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 accummulating toward some final figure at which components will fail.
4. Tests on pigtails and examination of the piping system indicate that failure by stress corrosion will probably increase and the rate of fatigue failure will increase.

Replacement criteria for rear face piping to accommodate the present hydraulic and thermal loading and to assure reduced maintenance expectancy, should consider 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, chromium iron 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.

TABLE I

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	

6. Fluid Flow Analysis

The present rear face piping, nozzle and connector assembly exhibit high pressure drops in components such as crossheaders and its fittings, the connectors, and nozzle.

The pumping cost for these rear face pressure drops which can be eliminated is calculated to be in the neighborhood of 72,000 horsepower per reactor or an annual saving of $140,000 in electrical energy alone. Further effect of the high velocities present in the flow system is the cavitation prevailing in the crossheader fittings. This condition excites vibrational frequencies from 20 to 6,200 cycles per second. Other low frequency vibrations are excited by flow conditions in the elbow discharging to the riser the the "T" connection to the riser. The major deteriorating effect of the low frequency vibration is the loosening of the fittings. The stress increase in the vibrations is not of significance in the crossheader, however it is quite extensive in crossover and effluent system discharge to the downcomer.

Pressure gradient and velocity graphs have been prepared for comparison purposes and are included in Exhibits ___ through ___. These graphs are condensations of flow data from Document HW-63581 and HW-63756-1.

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.

To provide lower friction losses in the rear face and relieve vibration and cavitation problems, the following action is recommended:

<u>B, D, F, Reactors</u> - Replace existing crossheaders and reconnect tubes tubes to provide a separate header for each row of tubes, except for the two top and bottom rows. Install new one inch O.D. connectors with flow characteristics similar to present "K" connectors. Four inch crossheaders and headers with 36 inch risers are considered suitable for present operating levels, or with an increased level equal to "C" at 95,000 gpm.

<u>DR, and H Reactors</u>

Replace existing crossheaders and install additional four inch crossheaders and valves to provide a separate manifold and header for each row of tubes. Install new one inch O.D. connectors with flow characteristics similar to present "K"

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connectors. The present 36 inch size risers and a full pattern of four inch schedule 40 crossheaders will present adequate flow area.

Flow charts have been prepared for the above described modifications and are included in Exhibits ___ through ___.

Comparison of modified B, D, DR, F, and H Piping with present "C" piping is shown on Exhibit ___. The proposed modifications to rear face piping for B, D, DR, F, and H is equivalent to present "C" piping, so that the six reactors would then have the same rear face piping flow characteristics with capability of eventually operating at "C" reactor capacity.

From the graphs above it is concluded that operation at 80,000 gpm 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 periods power level transients. The effect of temperature surges and probability of boiling in the riser and crossover line are covered in details in Documents HW-51327, HW-52793, and HW-55486. 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 zero or less. Boiling at these points is dependent on the bulk effluent temperature reaching 98 to 100 C. This condition may be circumvented by adequate venting.

Proposed modifications to the rear face piping results in the following general benefits:

1. Continuity of operation by increasing the mechanical reliability of the system by: reduction of high velocities, cavitation, excessive vibration, reduction of thermal and external stresses.
2. Increased hydraulic efficiencies and reduction of power input.
3. Possibility of increasing operating levels without increase in bulk temperature

4. Decrease in maintenance and reactor down time.

The modified rear face piping as recommended indicates a possible reduction in supply pressure of 117 to 127 psi at 80,000 gpm. Taking a conservative figure of 110 psi and using this saving to increase the flow, maintaining the present supply pressure of about 575 psig, the indicated increase in flow is ten percent. With minor changes to the front face piping and fuel element and/or tube changes, flow rates up to 95,000 gpm are possible at nominal cost. If flow is maintained at the present 80,000 gpm rate, the reduction in supply pressure represents a considerable saving in horsepower. At this rate it is estimated that 65 electrical input horsepower are required for each pound of pressure, or a saving of 65 x 110 = 7,200 EHP per reactor.

7. Reaming of Existing Rear Parker Fittings

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 as a method of increasing process tube flow rate by approximately eighty percent. 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.

Prior to a recommendation to enlarge rear Parker fittings, answers must be obtained to the following questions concerning rear face piping:

1. 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.
2. 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

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with power level increases realizing that increased component failure rates may result?

Prior to answering these questions, a better correlation between process flow rates, bulk outlet temperature, and rate of component failure must be obtained. Reliable estimates of failure rate is especially necessary before the economics of question two can be evaluated. This information is not currently available.

(Optional Inclusion)

Increasing power level and resulting stress level is not recommended per se., since the integrity of the existing rear face piping is questionable. Based on the number of failures in rear face components to date, even a small percentage increase in power level may significantly increase the rate of component failure.

Hydraulic demand curves have been determined by laboratory tests for various combinations of reamed Parker fittings with both enlarged and present "pigtails". These tests were performed on a geometrically simulated B, D, or F reactor process tube assembly.

Preliminary laboratory tests have also been conducted to determine some of the effects of reaming the Parker fittings to 0.610 inch I.D. These tests indicate that the strength of a materially sound fitting would not be significantly reduced and that high frequency vibration would not be increased.

Reaming of a limited number of fittings at one of the reactors on a production test basis and further analysis of test results will be required to evaluate the strength limitations of the existing fittings.

8. Rear Nozzle Assembly Flow Consideration

The rear nozzle assembly does 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 pigtails. Secondly, improved hydraulic performance can be attained with a new nozzle that utilizes a smooth curved flow path rather than the 90° bends that the flow must traverse in the existing nozzle.

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.(Ref) While 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, significant pressure drop can be regained by eliminating the two 90° right angle bends in the existing nozzles and enlarging the flow path.

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.

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.

(Ref) HW-63756-1 - Laboratory Determination of Normal Operating F[redacted] with Enlarged Outlet Fittings-B, D, F, Reactors - E. D. Waters - [redacted]

9. <u>Stuck Gunbarrels</u>

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 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.

Several solutions to the stuck gunbarrel problem have been proposed and are discussed in Document HW-61387, "Recommendations for an Attachment to Relieve Stuck Gunbarrels at 105-F Reactor". 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.

The attached drawing, SK-1-3754, indicates one of the solutions. It 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

[redacted]

Production Test IP-286-I, Testing of Gunbarrel Attachments at F Reactor. This is presented as a possible solution, however, any new developments would also be considered.

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.

10. Rear Face Pigtails

In March of 1957, the first evidence of stress corrosion failure of a 105-B rear face connector was found by Materials Development. 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 leaking and cracked connectors before an actual rupture

 [redacted]

occurs. Replacement of approximately fifty percent of the connectors has been completed.

The "J" type connector has not solved the basic 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.

Failure of the Du Pont connectors would have occurred eventually, if CG-558 had not increased water flows and temperatures. Occasional wetting and the vibration from flowing water and thermal cycling will cause failure.

This failure was accelerated by excessive wetting of rear face piping surfaces by leaks caused by the process tube replacement program the zone temperature monitor installation and cap leaks from increased charge-discharge operation.

Once a corrosion pit develops in a connector, the stress from vibration and thermal cycling accelerated the condition until a pinhole became a crack and eventually a ruptured connector. Replacement of a few connectors with leaky "J" connectors caused more wetting, stress corrosion and failure. For various reasons, the "J" connectors themselves have failed from stress corrosion.

The solution can be achieved by several methods: (1) Dry up the rear face, remove the water scale depositedby leaks; (2) Remove the stress caused by vibration and thermal effects; and (3) Replace the connectors with a material not subject to stress corrosion under rear face conditions, or a combination of these.

11. Record of Past Failures on Rear Face Piping

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 pigtails
	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 pigtails at D and DR
105-DR	10/59	______	Cracked riser, near side at crossheader 23
	12/59	______	Cracked riser, near side, at crossheaders 21 and 25
105-F	10/58		Stress corrosion first noted in Du Pont type pigtails
	1/60		Cracked near riser above 45 header at water sample line connection
105-H	6/58	______	Riser cracked near support between 21 and 23 crossheaders.
	7/58		Stress corrosion first noted in Du Pont type pigtails
	3/59	______	Thermocouple weld failure from cavitation noted
	6/59	______	Cavitation noted on base adapter - J Connector
	11/59	______	Gamma water monitor sample line failure due to stress corrosion

12. Outage Economics

The primary justification for the proposed project 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 reulsting in a total of 55 hours of lost production. In addition to the above failures of sufficient severity to cause the reactors to be shut down, inspections of these connectors at other reactors show increasing numbers of potentially severe stress cracks. This occurance coupled with the recent crossheader-riser joint failure at DR Reactor

 [redacted]

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 can not 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 occurance 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 would remain questionable due to the unknown material condition.

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 adviseable, 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:

<u>B, D, DR, F, H, and C Reactors</u>

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.

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C Reactor

Project Costs	$300,000
Outage Time	7 Days

For purposes of comparison, the project costs and outage time requirements at B, D, DR, F, and H are also indicated excluding installation of gunbarrel attachments and the associated gas seal and process tube replacement at B, D, DR, and H Reactors.

B, D, DR, F, and H Reactors

Project Costs	$13,100,000
Outage Time	280 Days

It should be noted that of the $16,700,000 budget cost outlined in the Budget Study only $ is actually required for the rear face piping. However since the replacement of piping components will require removal of all rear face nozzles and piping and 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.

Full pile discharge of metal will be required prior to removal of existing rear face piping. Additional containers will be provided for metal handling in the storage basins. Proper scheduling prior to full pile discharge is expected to minimize the production loss resulting from discharge of metal with low exposure.

Scheduling actual rear face piping replacement to coincide with major tube replacement which will be required at each reactor will reduce the outage time chargeable to replacing rear face hardware. For this study six days of tube replacement time and seven days for charge-discharge have been included as outage time chargeable to rear face hardware replacement at each of the B, D, DR, F, and H Reactors.

Performance of dry pile sub-critical tests, although not essential to project completion, are desirable prior to resuming reactor operation. These tests are recommended to provide information on reactor safety that can be obtained at no other time. Tests will require a total of thirty days at B, D, DR, F, and H Reactors, and are not considered as part of the proposed project outage time.

Outage time chargeable to the proposed replacement of rear face hardware has been estimated as follows:

B, D, DR, F, and H Reactors		Each Reactor
Decontaminate Rear Face		2 days
Rear Face Hardware Replacement		41 days
Charge-Discharge		7 days
Tube Removal and Replacement		28 days
Dry Pile Sub Critical Tests		6 days
Outage Time Per Reactor		84 days
Time not charged to Proposed Project:		
Tube Removal and Replacement	22 days	
Dry Pile Sub Critical Tests	6 days	
		28 days
Time Charged to Proposed Project		56 days/reactor
B, D, DR, F, and H Reactors		280 days
C Reactor		7 days
		287 days

[redacted]

[redacted]

13. Program Proposal

A program should be initiated immediately to :

1. Secure additional information to establish the rate of deterioration and to determine what interim measures can be taken to reduce the failure occurance while maintaining present operating levels until total project action can be initiated.
2. Supply additional engineering information to support the design of replacement rear face piping systems and/or components.

The first objective is necessary to establish what priority should be given to the various problems to assure continuity of 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 would include the complete removal of one crossheader from a typical reactor for analysis.

The second objective is necessary 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.
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.

[redacted]

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