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REGION V

February 27, 1987
023-02098-JGH/DRL

U.S. Nuclear Regulatory Commission
Region V
1450 Maria Lane - Suite 210
Walnut Creek, California 94596-5368

Attention: Mr. D. F. Kirsch, Director
Division of Reactor Safety and Projects
Palo Verde Nuclear Generating Station (PVNGS)
Units 1, 2, 3
Docket Nos. 50/528, 529, 530

Subject: Final Report - DER 86-29
A 50.55(e) Condition Relating to Letdown Heat Exchanger Nozzle Crack
File: 87-006-216

Reference: (A) Telephone conversation between R. C. Sorenson and D. R. Larkin on November 14, 1986. (Initial Notification - DER 86-29)
(B) ANPP-39248, dated December 5, 1986. (Interim Report - DER 86-29)
(C) ANPP-39651, dated January 9, 1987. (Time Extension - DER 86-29)
(D) ANPP-40101, dated February 12, 1987. (Time Extension - DER 86-29)

Dear Sir:

The NRC was notified of a potentially reportable deficiency in Reference (A), an interim report by Reference (B), and a time extension by Reference (C) and (D).

Attached, is our final written report of the Deficiency under the requirements of 10CFR 50.55(e) and 10CFR21.

Very truly yours,

VG Haynes

J. G. Haynes
Vice President
Nuclear Production

~~8703120076~~

JGH/DRL:kp

21pp

Attachments

cc: See Page 2

February 27, 1987
023-02098-JGH/DRL

cc: J. M. Taylor
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Washington, D. C. 20555

A. C. Gehr (4141)
R. P. Zimmerman (6295)

Records Center
Institute of Nuclear Power Operations
1100 Circle 75 Parkway - Suite 1500
Atlanta, Georgia 30339

FINAL REPORT - DER 86-29
DEFICIENCY EVALUATION 50.55(e)
ARIZONA NUCLEAR POWER PROJECT (ANPP)
PVNGS UNITS 1, 2, 3

I. Description of Deficiency

On October 27, 1986, during Hot Functional Testing (HFT) in Unit 3, water was discovered leaking from the reactor coolant inlet nozzle of the Letdown Heat Exchanger (tag no. 3M-CHN-E02) located in the Auxiliary Building. The nozzle (identified as Nozzle A on vendor print N001-7.03-28-7) had a 120° circumferential, through-wall crack that was detectable by visual and dye penetrant examination. The Letdown Heat Exchanger is manufactured by Richmond Engineering Company (RECO) and supplied by Combustion Engineering under the NSSS contract.

II. Evaluation

This section of the report covers an evaluation of the physical evidence, probable causes, supportive analysis, and the root cause conclusion. Also discussed are Units 1 and 2 operability, transportability, and safety assessment.

A. Evaluation of Physical Evidence

Various physical inspections were performed after identification of the nozzle failure. The following summarizes the results of these inspections.

1. Nozzle/Piping Configuration

Nozzle A is a 2-1/2 inch diameter, Schedule 40, stainless steel (SA312-TP304) pipe stub, attached to the heat exchanger shell by a full penetration, double-ended bevel weld, which is reinforced with an external 1/2 inch fillet weld. (See Figure 1) This nozzle configuration conforms to ASME III, Class 2 Code requirements.

The 2 inch inlet piping connected to the nozzle rises vertically 3 feet 4 inches upstream of the nozzle, and then runs horizontally out of the heat exchanger room. The piping is supported on this horizontal run by a three-way restraint located approximately 3 feet from the riser.

2. Visual Inspection of Damaged Nozzle

A visual inspection performed by the an ANPP metallurgist of the cracked nozzle resulted in the following observations: The failure occurred on the top side of the nozzle adjacent to the toe of the reinforcing weld. As indicated in Figure 1, the toe of the

weld adjacent to the failure had been ground back leaving a groove approximately 1/32 inch deep by 1/8 inch wide and 2 inches long where the failure occurred. In addition, the geometry of the weld did not provide a smooth transition between the vessel and nozzle. As discussed later, this geometry and groove resulted in a stress concentration which significantly contributed to the nozzle failure.

The failure consisted of a main through-wall circumferential crack approximately 3 inches long on the nozzle exterior, and two other disconnected cracks parallel to the first, which did not penetrate the nozzle wall. The main crack was not perpendicular to the nozzle surface, but sloped back under the fillet weld at a slight angle. The length of this crack on the nozzle interior was about 1 inch shorter than on the nozzle exterior. This indicates that the crack started on the outside at the toe of the reinforcing fillet weld (where the groove was located) and propagated through the nozzle base metal. The main crack appears to be made up of two smaller hairline cracks that grew together as they propagated. This is a typical configuration for a high cycle/low stress fatigue failure.

Inspection of the nozzle indicated no evidence of plastic deformation, nor was there any indication of movement and/or distortion of the inlet piping. The Metallurgist's disposition of the failure mechanism was fatigue based on his visual examination.

3. Pipe Strain

Prior to repairing the nozzle, the inlet piping was cut loose from the nozzle and the free movement was measured as 1/8 inch, 1/8 inch, and 1/4 inch in the horizontal, vertical, and axial directions, respectively. Since the piping could be moved easily by hand into alignment with the nozzle, cold pipe strain is not considered to be a cause of failure. Hot pipe strain due to thermal growth of the piping system at operating temperatures has been determined by analysis to be within Code allowables.

4. Metallurgical Defects

Removal of a sample of the fractured material for metallurgical examination prior to the initial repair work was attempted. However, due to the nozzle configuration and the unknown slope of the crack a sample could not be obtained and still maintain the integrity of the nozzle for subsequent repair.

The repaired nozzle was metallurgically examined in situ by a metallurgist. A Texas Nuclear Alloy Analyzer was used to determine the chemical makeup of the original weld metal (Nozzle A) not disturbed by the repair, Nozzle B (outlet nozzle), and the shell wall. The analyses indicated that all of these materials conformed

to specification requirements. A severn gauge was also used to determine the ferrite content of the Nozzle A weld material. Readings of 7.5 to 10 percent were obtained, which indicate a ferrite content sufficient to suppress formation of microfissures in the weld metal.

5. Vendor Fabrication and Inspection

Review of the vendor Code Data Package did not identify that Nozzle A had been repaired in the vendor's shop prior to shipment. The nozzle is certified as having met Code (ASME Section III, Class 2) requirements, including passing liquid penetrant examination and hydrostatic testing in the vendor's shop. In addition, the nozzle passed a system hydrostatic test in the field prior to flushing.

According to Article NC-4424 of the Code, grinding by the fabricator is permitted to obtain a weld surface sufficiently free of grooves, valleys, and abrupt ridges as long as the weld or base metal meets thickness requirements. All design thickness requirements were met. In this case, however, grinding left grooves in a valley along with an abrupt ridge rather than smoothing out such undesirable features. It is concluded that vendor grinding produced the grooves since there was no record of field repairs.

6. Damage During Shipment or Installation

There were no marks on the heat exchanger to suggest that damage occured after manufacture, and there is no record of field repairs being performed prior to the failure. Therefore, improper handling during shipment, installation, or start-up is not considered a cause of failure.

B. Evaluation of Probable Causes

The potential failure mechanisms resulting in a crack of this type are tensile (ductile) overload, liquid metal embrittlement, stress corrosion cracking, weld metal microfissures, and fatigue. Each of these mechanisms were evaluated as summarized in the following sections.

1. Tensile Overload

Tensile overload was determined not to be the cause for failure because there was no plastic deformation of the nozzle, nor were there signs of pipe support movement or distortion.

2. Liquid Metal Embrittlement

Cracks associated with liquid metal embrittlement occur at temperatures higher than the eutectic point of the metals involved. The crack pattern due to liquid metal embrittlement is craze type

rather than showing well defined directionality as seen in the observed failure. For a thin wall stainless steel pipe such as Nozzle A, liquid metal embrittlement is possible only due to contamination during the welding process during fabrication and is usually found either by a surface examination with a liquid penetrant or during the hydrostatic test. Since the heat exchanger did not leak on hydrotesting and was free of linear dye penetrant indications (as determined by a review of the Code data package), liquid metal embrittlement is not considered the cause of the failure.

3. Stress Corrosion Cracking (SCC)

Two mechanisms of stress corrosion cracking were evaluated. These were 1) Intergranular Stress Corrosion Cracking (IGSCC) and, 2) Transgranular Stress Corrosion Cracking (TGSCC).

The nozzle crack started in the heat affected zone (HAZ) of the weld at the bottom of the notch. However, the crack did not follow the HAZ, but instead propagated through the unaffected base metal. The HAZ is where the greatest degree of sensitization would occur, and an intergranular stress corrosion crack would classically be expected to propagate in the sensitized grain structure of the HAZ. Therefore IGSCC is not considered to be a possible failure mode.

To have TGSCC, a corrodent containing chlorides must be present typically at or above 140 degrees F (in the pH ranges around 7). While the microstructure is always susceptible to SCC, these conditions would normally occur on the nozzle ID during hot start up. The crack started on the OD of the nozzle which is a most unlikely place for TGSCC to initiate.

The ID of the nozzle would be the most likely place for the initiation of either IGSCC or TGSCC. Thus it was concluded that SCC was not the cause of the failure.

4. Microfissuring

Full austenetic weld metal is subject to microfissuring. However, when there is at least three percent ferrite present in the weld metal (more than seven percent ferrite in the weld metal was actually present), the risk of cracking is minimized. Also, microfissuring is a phenomenon confined to the weld metal and therefore is not a cause for cracks occuring in the base metal.

5. Fatigue

Based on the above, tensile overload, liquid metal embrittlement, stress corrosion cracking, and microfissuring were eliminated as causes of the failure. The physical appearance and location of the crack identifies fatigue as the mechanism of the nozzle failure. The cause of the fatigue failure is established in the following sections.

C. Supporting Analysis

In evaluating the possibility that random transients or unanticipated cyclical loads could have caused the nozzle to fail, several areas potentially affecting nozzle loads were identified and evaluated using static and dynamic analysis techniques in accordance with the methods and procedures of Section NB-3600 of the ASME Code. All potential load contributors, except for seismic loads, were considered in the evaluation of stresses.

The evaluation reconstructed the history of loads at the nozzle from the start of flushing operations up to its failure during HFT. The evaluation also considered hypothetical loads resulting from worst case misoperation of the letdown system control valves that would generate pressure transients and hydraulic loads.

The various factors that could contribute to nozzle overstressing were divided into two main categories for evaluation; high cycle/low stress loads and, low cycle/high stress loads.

The high cycle/low stress loads result from flow induced vibration that could occur during flushing and system operation. The design of the piping system was evaluated for natural frequency of vibration, vibration displacement, and the resulting forces and stresses. To assess the ability of high cycle fatigue as being the cause of the nozzle failure, a fracture mechanics evaluation was performed. The fracture mechanics evaluation establishes a threshold stress amplitude range that would result in propagating a crack and the number of cycles required for the nozzle to fail. In order to determine if this failure mechanism was possible, expected stresses due to flow induced vibration were compared to the minimum required threshold value for crack propagation.

The low cycle/high stress loads result from operational thermal and hydraulic transients in the letdown system. These transients were evaluated to establish stresses induced in the nozzle and the integrated effect on nozzle integrity. A cumulative usage factor (UF) evaluation was performed in accordance with the ASME Code Section NB-3600. To account for the groove at the toe of the weld, stress indices for socket weld joints were used in an ASME III Code Class 1 fatigue evaluation in accordance with Section NB-3683.2 (Note, the letdown heat exchanger is an ASME Code Class 2 vessel).

In summary, the following sections will show that the most probable sequence of events resulting in nozzle failure was high cycle/low stress fatigue crack propagation to or near through-wall during flushing. This was followed by low cycle/high stress transient conditions occuring during hot functional testing.

Table 1 provides summary of the evaluation of transient and cyclical loads.

1. High Cycle/Low Stress Loads

Flow induced vibration will be amplified by the natural frequencies of the piping system and can provide a high number of stress cycles in a short time period (hours or days rather than months or years). The stress amplitude necessary for fatigue crack initiation and propagation is dependent on the vibration amplitude and frequency. As noted in Section II.A.2 & 5, the weld geometry and presence of the groove with grinding marks provided a site for stress concentration and crack initiation. Fracture mechanics data provides an estimate of the range of minimum stress amplitudes necessary for fatigue crack propagation.

1.1 Fracture Mechanics Evaluation

The fracture mechanics analysis demonstrates that a crack initiating at a sharp grinding mark or scratch would propagate under the applied cyclic loads. This was determined using the following equation:

$$\Delta K_{th} = C\,(\Delta\sigma_{th})\sqrt{\pi a} \qquad \text{(Ref. 1, 2, 3)}$$

where ΔK_{th} = threshold stress intensity factor range; ksi $\sqrt{\text{in}}$
C = shape factor
$\Delta\sigma_{th}$ = threshold stress range (=2 x threshold stress amplitude); ksi

a = flaw depth; in

Based on a simplified model approximating the groove and the flaw as a planer flaw perpendicular to the axis of the pipe, the minimum stress amplitude for fatigue crack propagation was determined to range from 7.0 to 3.5 ksi. Due to the conservatism in this model as compared to the actual condition, it is concluded that the threshold stress is at the lower end of this range. This conclusion is supported by review from an independent consultant (Reference 4). Vibration displacements of 0.48 mil at 3.5 inches from the toe of the fillet weld will provide 3.5 ksi stress at the top of the nozzle.

The rate of fatigue crack propagation was determined using the following equation:

$$da/dN = C\ E\ S\ (\Delta K)^n$$

Where da/dN = rate of crack advancement; inch per cycle
C = material constant = 1.59×10^{-9} (inch/cycle)/ $(\text{ksi}\sqrt{\text{in}})^n$
n = material constant = 3.3
S = R ratio correction factor = $(1.0 - 0.5R^2)^{-4}$
E = 1.0 for air
R - stress ratio ($\sigma\,min/\sigma\,max$) = 0.6 for ΔK=5;
= 0.79 for ΔK=3.5

Substituting ΔK = 5 or 3.5 ksi $\sqrt{\text{in}}$,

$$da/dN = 0.7 \text{ or } 0.4 \times 10^{-6} \text{ inch/cycle}$$

The above calculation shows that even with stresses at the lower threshold stress amplitude (e.g. 3.5 Ksi), a crack will propagate to 0.4 inch depth in one million cycles.

Both of the above calculations represent a reasonable basis for quantitative fatigue failure analysis.

1.2 Flow-Induced Vibration Sources

Two flow conditions existed that could give the requisite number of cycles, that of the normal steady state flow vibration and the flow induced vibration during system flushing operations.

1.2.1 Normal Steady State Flow

Measurements were made during normal flow conditions during HFT (between 50 and 90 gpm) and the displacement was found to be 0.035 mil at 3.5 inches from the toe of the weld. A calculation was performed with results provided in Table 1. Based on the fracture mechanics evaluation, normal steady state flow results in stress levels well below the crack propagation threshold that will not adversely affect the integrity of the heat exchanger nozzle.

1.2.2 Flushing Flow

The Unit 3 flush of the letdown system piping occurred in January, 1986, lasted approximately 44 hours at an estimated flow rate of 200 gpm based on pump characteristics and piping configurations. One of the applicable flush paths (per Flushing Procedure 91FL-3CH03) is shown on Figure 2.

The theory of turbulent boundary layers suggest that the fluctuating energy in the turbulent layer varies as the square of the mean flow velocity (Reference 5). It is reasonable to assume that the vibration of the pipe wall is proportional to the pressure fluctuations in the boundary layer. The piping vibration levels levels, measured at a distance of 3.5 inches from the toe of the weld for steady state flows of 50 gpm to 90 gpm were extrapolated to that for the estimated flushing flow rate of 200 gpm. At 200 gpm, the extrapolated range of vibration levels would be from 0.2 mil to 0.6 mil displacement. The lower threshold calculated for crack propagation is 0.48 mil displacement, which is well within the range of estimated flushing flow rate induced vibration displacements.

Increasing the flow rate to 200 gpm will result in a greater contribution from the higher frequency components, (Reference 8), which will further increase the piping response beyond the 0.2 mil to 0.6 mil displacement extrapolated above. Conservatively this was not considered.

If a conservative vibration range of 3 to 10 Hz is assumed, then 475,000 to 1.6 million cycles would result from the flushing operation. Therefore, there were a sufficient number of stress cycles (approximately 500,000 cycles for crack propagation of 0.2 inch) to propagate the crack to or near through-wall.

In summary, it is concluded that estimated flow induced vibration during the flushing process, when combined with the existing nozzle groove and grind mark conditions, is reasonably projected to cause crack propagation to or near through-wall.

2. Low Cycle/High Stress Loads

Fluid temperature, pressure and flow rate data were recorded during hot functional testing in October 1986 just prior to the nozzle failure. Forcing functions due to various system transients were also determined. A fatigue evaluation of the combined effects was performed utilizing the criteria of ASME Section III Article NB-3600 as delineated below. It was concluded that the transients experienced during Hot Functional Testing were not sufficient to significantly contribute to a fatigue crack propagation of the nozzle, but may have been the mechanism during HFT to result in final breach of the pressure boundary.

2.1 Evaluation of HFT Thermal Transients

The HFT thermal and flow transient data was reduced to histograms and used in Bechtel computer program ME-643 to calculate the ΔT_1, ΔT_2, T_a and T_b terms due to the thermal transients (rapid temperature changes). These terms were then used along with loads due to dead weight, pressure, and thermal expansion in Bechtel computer program ME-913 to determine peak thermal gradient and discontinuity stresses. The program also determines the load set pairs and calculates corresponding usage factor. The methodology utilizes the techniques of Article NB-3600. To account for the existing groove, stress indices for girth fillet weld to socket weld fittings were assumed per Table NB-3683.2-1. The results of this evaluation are shown in Table 1. The temperature and flow transients that were recorded during HFT prior to the nozzle failure were compared to the transients given in the design specification and found to be less severe.

2.2 HFT Pressure Transients

The effects of pressure transients are discussed in the paragraphs below. The enveloping effect of these transients and the temperature transients evaluated above were analyzed and resulted in a total cumulative usage factor of less than 0.1. This result is well below a usage factor of 1.0 allowed by the Code.

2.2.1 Evaluation of Backpressure Control Valve Closure

The peak dynamic loads on letdown piping resulting from the transients reported during HFT were calculated using the system response data to the transients. During cycling of the pressure valves PV-201P and PV201Q, the letdown flow was completely interrupted when switching from one PV to the other due to a closed blockvalve upstream of the other PV. Using the maximum letdown flow, letdown heat exchanger outlet pressure, and valve characteristic data, the transient loads were calculated for pipe segments between the letdown heat exchanger and the level control valve. The loads are caused by the pressure wave propagating from the closed pressure valve toward the reactor coolant loop and are a function of the rate of change of pressure and velocity.

The static forcing function from the above analysis was modeled into Bechtel computer program ME-101 to determine the loading at the letdown heat exchanger nozzle. These loads were included in conjunction with thermal and pressure transients in the enveloping calculation discussed above.

2.2.2 Evaluation of Valve Cycling

In order to evaluate the forces generated near the inlet nozzle of the letdown heat exchanger due to the cycling of one of the level control valves, a computer model of the letdown piping from the RCS connection to the purification ion exchanger unit was developed.

This model, run on Bechtel's inhouse computer Code NE 820, included the regenerative and letdown heat exchangers. The back pressure valve was modeled as a control valve which opened or closed attempting to maintain constant backpressure as its upstream pressure increased or decreased, respectively. The level control valve was cycled from its initially throttled position to fully closed, then to fully open and then fully closed and so on.

The opening and closing times of the level control valve were based on actual field test data and were 0.78 seconds and 1.84 seconds, respectively. The back pressure valve was opened/closed in 0.56 seconds. Forcing functions were generated due to the level control valve cycling and the back pressure valve reacting to the pressure change.

The time history forcing function from the above analysis was compared with the loads of 2.2.1 and found to be enveloped.

2.3 Evaluation of Nozzle Post Repair Valve Cycling Vibration Data

Following repair of the failed nozzle, displacement measurements were recorded by a transducer mounted on the nozzle while the letdown and back pressure control valves were cycled. This was performed to determine the transient loading to the repaired nozzle. A calculation was performed to determine the stress levels at the nozzle induced due to the measured displacements. The resulting cyclic stresses are significantly below that required for fatigue crack propagation.

2.4 Hypothesized Water Hammer Due to Level Control Valve Misoperation

The worst case dynamic load hypothesized for the letdown piping system would be a water hammer event as a result of valve misoperation. A hypothetical situation was postulated under which, as a consequence of misoperation of the level control and pressure control valves, a partial voiding of the system piping occurs. Under this scenario, it was assumed that the level control valves are closed while the pressure control valves are open. This would result in the depressurization and flashing of the stagnant fluid downstream of the level control valves.

With the cooling water continuing to flow on the shell side of the heat exchanger, the steam will be condensed creating a void in the piping between the level control valve and the heat exchanger. The opening of the level control valve at a later time will cause the void to be collapsed and cause water hammer loads in the piping. These water hammer loads were developed utilizing the configuration of the letdown system piping, valve characteristic data, and process conditions upstream and downstream of the system boundary. Based on these data steam/liquid impact velocities and corresponding water hammer loads on the piping are calculated.

This condition could occur during manual shifting of the letdown control valves. However, steps 17.4.6 and 17.4.7 of PVNGS operating procedure 41OP-1CH01 require warmup of the line between the control valves and the letdown heat exchanger via the letdown control valve bypass line (valve CHNHV526). The procedures also require slow operating of the letdown control valve in order to reduce the potential for severe water hammer loading. This allows the back pressure valve to modulate smoothly.

A calculation was performed using the postulated loads from the above evaluation. The resulting stress at the nozzle was conservatively calculated to be 22,000 psi. Utilizing the stress indices discussed in II.C.1.1 to account for the groove on the nozzle, this conservative loading by itself would require approximately 1500 occurrences to reach a usage factor of 1.0. Using the stress indices for a tapered

transition joint to approximate the ungrooved nozzle, the loading would require approximately 18,000 occurrences to reach a usage factor of 1.0.

Based on the number of cyles required, this hypothetical scenario is not considered to be a factor in the fatigue failure in the Unit 3 nozzle.

These results demonstrate that the transients experienced during HFT and those hypothesized were not sufficient to significantly contribute to a fatigue crack propagation of the nozzle. However, they may have been the mechanism during HFT to result in final breach of the pressure boundary.

D. Root Cause

The root cause of the failure is high cycle/low stress fatigue based on physical evidence, test data, and analyses. The conclusions reached are as follows:

1. The primary root cause is believed to be the geometry of the weld area including the presence of the circumferential groove with grinding marks into the base metal where the crack occurred.

2. The origin and visual characteristics of the cracks are typical of high cycle fatigue failures in a ductile material such as stainless steel. The nozzle was subjected to flushing performed in January, 1986 at sufficient velocities during the 44 hour flush period to result in a large number of low stress cycles at stress levels that have been projected to be of sufficient magnitudes to have reached the range for crack propagation. Four days after the start of hot functional testing in October 1986, the nozzle failure was observed. This followed a series of transients during HFT which may have caused the final breach in the pressure boundary. Independent consultants (References 6 and 7) have confirmed the conclusions reached with regards to the potential flow induced stresses and susceptibility to failure.

3. All mechanisms other than high cycle/low stress fatigue have been eliminated.

Based on the visual evidence, analytical results, and the elimination of the other failure mechanisms, it is concluded that the nozzle weld condition in combination with the flow induced vibration during the flushing of this line condition is the most probable mechanism to result in a high cycle - low stress fatigue failure.

E. Units 1 and 2 Operation

The condition identified in Unit 3 was evaluated for applicability to Units 1 and 2 with the following results:

1. Visual examinations, for evidence of leakage, were performed on both units letdown heat exchangers initially. This was done at the first opportunity for each unit (i.e., unit shut down). The results confirmed no evidence of leakage.

2 Subsequently, NDE (liquid penetrant) inspections were performed on the inlet and outlet nozzles of the Unit 1 and 2 letdown heat exchangers. The inspection confirmed that no fatigue cracks were present.

   Unit 2's welds did not have grooves around the toe of the weld, however, the general profile of the weld did not provide a smooth transition from vessel to nozzle. The liquid penetrant exam did not reveal any indications.

   Unit 1's welds had similar profiles as Unit 3 and had the same type groove around the toe of the weld. Liquid penetrant exams did reveal indications that were determined to be superficial.

   As a prudent action, the Unit 1 and 2 letdown heat exchanger inlet and outlet nozzle welds have been reworked in the field to remove the grooves and improve the weld profile to eliminate any areas of stress concentration. This provides futher assurance that these nozzles will be satisfactory for the intended service.

3. Cyclic stresses during normal plant operation have been shown to be acceptacle by testing and/or analyses.

Based on the above, and on the FSAR/CESSAR analysis and the safety assessment in Section II.G of the consequences of postulated breaks in the letdown lines outside containment, continued use of the letdown heat exchanger did not and does not pose a hazard to the safe operation of Units 1 and 2.

F. Transportability

The letdown nozzle crack problem has been determined to be not transportable to other areas of Palo Verde due to the following reasons:

1. The Unit 1 and 2 letdown heat exchangers inlet and outlet nozzles, which have similar weld configurations, experienced hydraulic and thermal transients, and was put through a similar flush operation, did not have any indications of any fatigue crack initiations after several thousand hours of operation. This would indicate that the Unit 3 nozzle fatigue failure was the result of a unique conbination of physical and operational factors limited to that nozzle.

2. The letdown heat exchangers are the only equipment manufactured by RECO for Palo Verde. Since the root cause of the failure is believed to be unique to this nozzle weld geometry and workmanship, it is not expected that this condition exists in any other location at Palo Verde. To provide additional assurance of this, a review applicable to other vendor supplied components in safety related systems, will be conducted. See corrective action section.

3. This type nozzle configuration (i.e. small bore pipe stub-ins) is a standard practice allowed for by the ASME Code. There have been no generic industry notifications that problems exist with these type nozzles.

4. The Unit 3 flushing operations of the letdown system could not have damaged other piping system components. The piping system between the flushing connection and the nozzle is relatively flexible. The nozzle is the only point of rigid fixity where pipe loads are concentrated. In-line components, such as valves which are remote from the failure location are an integral part of the piping system and any pipe motion would easily be transmitted through them without resulting in any significant stress inducement.

G. Safety Assessment

A break in the letdown system during normal operation would cause a release of primary coolant and represent a failure of an ASME Code component. This could adversely affect the safety of operations because it would disrupt the normal operation of the primary system, limit the continued operation of the plant, potentially expose offsite and onsite personnel to a radiation hazard, and could result in injury to plant personnel in the area.

Per PVNGS FSAR/CESSAR Section 15.6.2, a double-ended break of a letdown line outside containment "results in a two-hour thyroid inhalation dose which is a small fraction of 10CFR100 guidelines." An analysis was performed to evaluate smaller breaks than those analyzed in CESSAR Section 15.6.2. The spectrum of breaks analyzed ranged from a single-ended break down to the largest break that would remain undetected by the Auxiliary Building Lower Level Ventilation Exhaust Monitor (RU-9). None of the breaks analyzed resulted in doses higher than the letdown line break previously analyzed in the CESSAR, and all of the letdown breaks analyzed resulted in doses which are small fractions of 10CFR100 guidelines.

III. Reportability Assessment

Based upon the above, this condition is being reported under 10CFR Part 50.55(e) and 10CFR Part 21. All requirements for reporting under the regulations have been addressed except 21.21(b)(3) subpart (vi) with regard to the names and locations of other facilities.

IV. Corrective Action

The nozzle crack was initially weld repaired under NCR NA-1942 in order to support HFT. After HFT was completed, additional welding was performed to increase the size of the reinforcing weld from the original 1/2 inch size to 3/4 inch. The final weld provides four benefits:

1. The highest stress point is moved into a region further down the nozzle which was relatively unaffected by fatigue.

2. The fatigued area is now bridged with new weld material which compensates for any fatigue-induced weakness in the nozzle.

3. The additional reinforcing fillet annealed the nozzle base metal that was affected by fatigue.

4. The groove marks have been removed and there is now a smooth transition between vessel and nozzle.

These improvements, together with the absence of any significant source of fatigue in the operating system, provide assurance that the nozzle will be satisfactory for its intended service.

Units 1 and 2 letdown heat exchanger nozzles have been reworked as a prudent action. ASME Section XI Inservice Inspection requires the letdown heat exchanger to be leak-tested every 3-1/3 years and hydrotested every 10 years.

Although we believe the root cause of this failure to be unique to the weld geometry, and limited to the letdown heat exchanger, we are in the process of reviewing other vendor supplied components in safety related systems for similar parameters (i.e., nozzle design and weld configuration, etc.). This review will be complete prior to July 1, 1987.

A copy of this report is being sent to Combustion Engineering and RECO for their evaluation and action.

V. References

1. R. A. Smith, "Fatigue Thresholds," Vol. 1, 1982, pp 33-44

2. L. P. Pook, "Fatigue Crack Growth Data for Various Materials Deduced from Fatigue Lives of Precracked Plates," Stress Analysis and Growth of Cracks, ASTM STP 513, pp 106-124, 1972

3. Evaluation of the Flaws in Austenitic Steel Piping, Transactions of the ASME, Journal of Pressure Vessel Technology, Vol. 108, August 1986, pp 352-366

4. Dr. Mircea D. Ratiu, DENG. Impell Corporation Walnut Creek, California

5. A. A. Townsend, "The Structure of Turbulent Shear Flow," Cambridge University, 1976, Second Edition

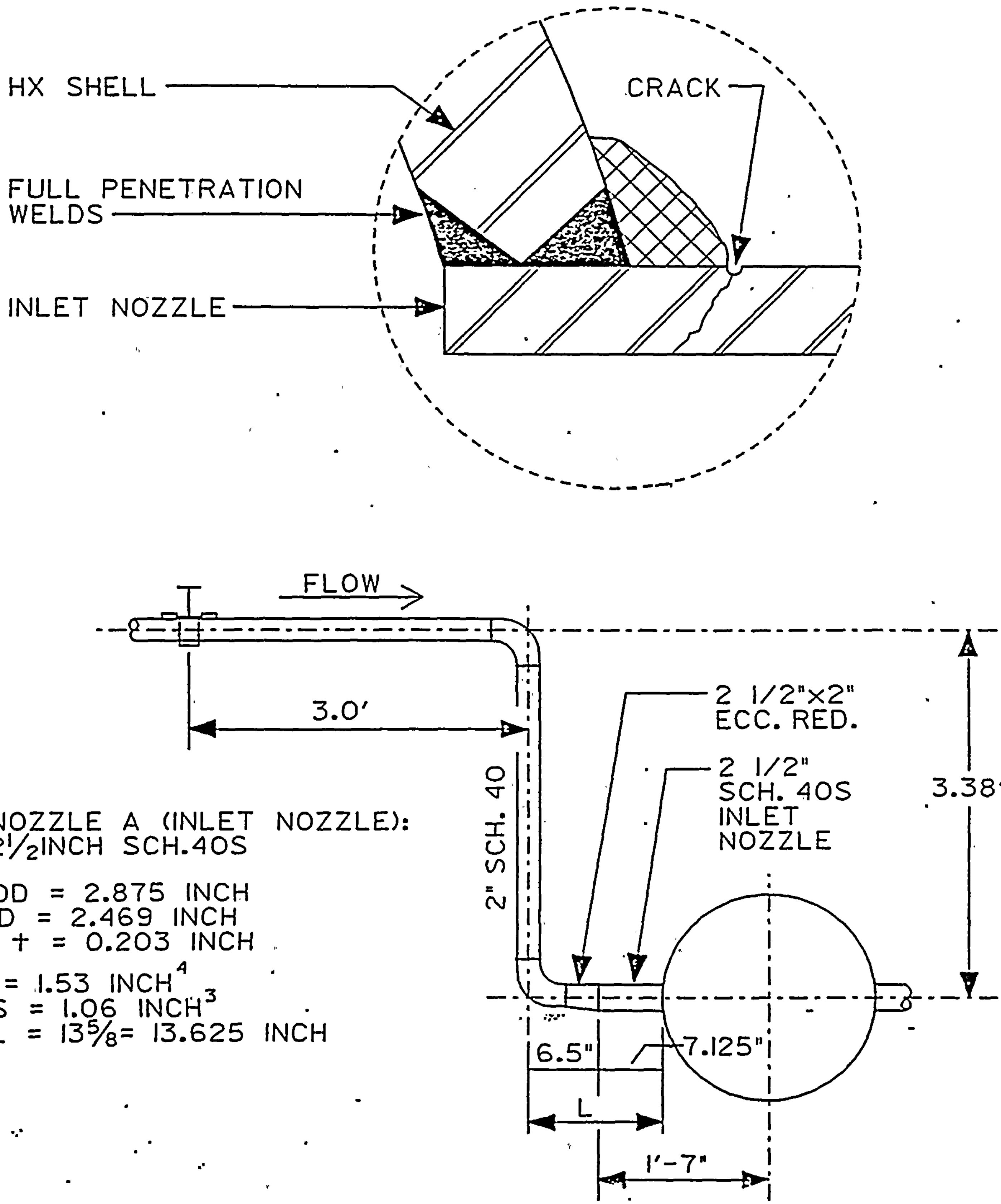
6. Larry E. McKnight, President, McKnight & Associates, Registered Professional Metallurgical Engineer, Brea, California

7. Dr. Mircea D. Ratiu, Gordon Hau, Robert Emerson, Impell Corporation Review of Unit 3 Letdown Heat Exchanger Nozzle Crack February 19-20, 1987

8: J. C. Wachez, C.L. Bates, "Techniques for Controlling Piping Vibration and Failures," ASME Publication 76-Pet-18

FIGURE 1

UNIT 3 LDHX INLET NOZZLE A

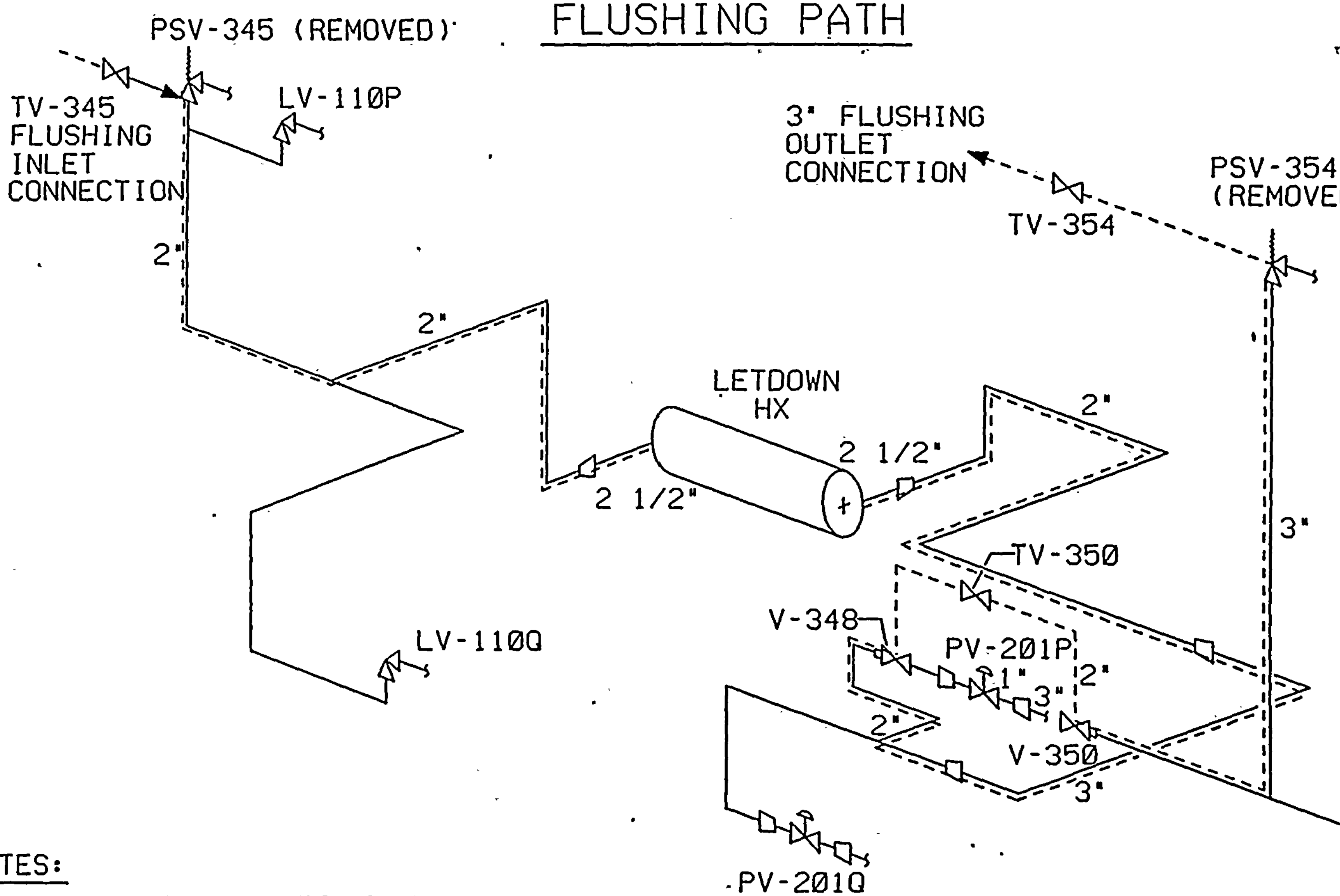


NOZZLE A (INLET NOZZLE):
$2\frac{1}{2}$ INCH SCH.40S

OD = 2.875 INCH
ID = 2.469 INCH
t = 0.203 INCH

$I = 1.53$ $INCH^4$
$S = 1.06$ $INCH^3$
$L = 13\frac{5}{8} = 13.625$ INCH

FIGURE - 2
FLUSHING PATH



NOTES:

1. DASH LINE INDICATES THE FLUSHING PATH
2. THE ABOVE FLUSHING PATH IS PER FLUSHING PROCEDURE 91 FL-3CH03, SECTION 8.1
3. INTERNALS OF VALVES V-348 & V-350 WERE REMOVED DURING FLUSHING.
4. SOURCE OF WATER IS REACTOR MAKEUP WATER PUMP VIA [illegible]MPER HOSE

TABLE 1 - SUMMARY OF STRESS EVALUATIONS OF THE FAILURE OF THE UNIT 3 LETDOWN HEAT EXCHANGER NOZZLE (DER 86-29)

C.1 HIGH CYCLE / LOW STRESS

SECTION	ANALYSIS PERFORMED	INPUT DESCRIPTION	RESULTS (NOTE 1)	CONCLUSIONS
1.2.1 OPERATION	EVALUATION OF POST REPAIR NOZZLE VIBRATION DATA (NORMAL OPERATING FLOW RATES)	STRIP CHART DATA DURING NORMAL OPERATING FLOWRATES FOLLOWING REPAIR	STRESS: 0.4 Ksi FORCE: 20 LBSf CYCLES: MORE THAN 1.0E6 DISPLACEMENT: .035 MIL	STRESSES REMAIN WELL BELOW CRACK PROPAGATION THRESHOLD - NOZZLE INTEGRITY IS NOT AFFECTED.
1.2.2 FLUSHING	EVALUATION OF FLOW INDUCED VIBRATION DUE TO SYSTEM FLUSHING	DURATION: 44 CUMULATIVE HOURS TEMPERATURE: 60 - 80 DEG F ESTIMATED PRESSURE: 140 PSI ESTIMATED (ACTUAL PLANT DATA NOT AVAILABLE) ESTIMATED FLOW RATE 200 GPM	HIGHER FLOWRATES USED DURING FLUSHING COULD INDUCE STRESSES IN THE RANGE OF 3.5 TO 4.0 Ksi FOR APPROXIMATELY 1.0E6 CYCLES • ESTIMATED DISPLACEMENT RANGE 0.2 - 0.6 MIL	STRESSES EXCEED LOWER RANGE OF CRACK PROPAGATION THRESHOLD - PRESENCE OF PRE-EXISTING FLAW COULD RESULT IN NOZZLE FAILURE. 7-3.5 Ksi

C.2 LOW CYCLE / HIGH STRESS

SECTION	ANALYSIS PERFORMED	INPUT DESCRIPTION	RESULTS (NOTE 1)	CONCLUSIONS
2.1 THERMAL TRANSIENTS	FATIGUE EVALUATION OF THERMAL TRANSIENTS DURING HFT PRIOR TO FAILURE	• PLANT DATA: FLOW AND TEMP VS. TIME @ 3 MINUTE INTERVALS FROM 10/23 TO 10/27 • NOZZLE CONFIGURATION (FIGURE 1) • STRESS INDICES (NB-3683)	USAGE FACTOR: LESS THAN 0.07	THE TOTAL USAGE FACTOR(UF) FROM ALL LOW CYCLE / HIGH STRESS POTENTIAL
2.2 PRESSURE TRANSIENTS	FATIGUE EVALUATION OF PRESSURE TRANSIENTS DURING HFT PRIOR TO FAILURE	• PLANT DATA: FLOW AND PRESS VS. TIME @ 3 MINUTE INTERVALS FROM 10/23 TO 10/27 • NOZZLE CONFIGURATION (FIGURE 1)	NEGLIGIBLE CONTRIBUTION TO USAGE FACTOR	CONTRIBUTING FACTORS WAS CALCULATED TO BE LESS THAN 0.1 USING CONSERVATIVE STRESS INDICES TO ACCOUNT FOR THE PRESENCE OF THE GROOVE.
2.2.1 CONTROL VALVE CLOSURE	EVALUATION OF BACKPRESSURE CONTROL VALVE RAPID CLOSURES (PV201P, PV201Q)	• 300 MILLISECOND CLOSURE TIME FULL OPEN TO FULL CLOSED • Cv VS. VALVE POSITION FROM VENDOR CATALOG • MAX HFT FLOW RATE	FORCE: 36 LBSf CYCLES: APPROXIMATELY 100 STRESS: LESS THAN 1.0 Ksi DISPLACEMENT: 0.1 MIL NEGLIGIBLE CONTRIBUTION TO USAGE FACTOR	THE MAJOR CONTRIBUTOR IS THERMAL TRANSIENTS DUE TO TEMPERATURE VARIATIONS. THE FLOW TRANSIENTS ONLY HAD MINIMAL CONTRIBUTION TO THE USAGE FACTOR.
2.2.2 CONTROL VALVE CYCLING	EVALUATION OF LEVEL AND BACKPRESSURE CONTROL VALVE CYCLING	• VALVE CHARACTERISTICS FROM VENDOR CATALOG • PIPING NETWORK CONFIGURATION • SYSTEM RESPONSE IN AUTOMATIC MODE	TIME-HISTORY FORCING FUNCTIONS RESULTS SIMILAR TO 2.2.1 LOADS EFFECTS ARE BOUNDED BY ITEM 2.2.1 ABOVE	
2.3 POST REPAIR VIBRATION	EVAUATION OF POST REPAIR NOZZLE DISPLACEMENT DATA (LEVEL CONTROL VALVE CYCLING WITH BACKPRESSURE CONTROL VALVE OPEN)	STRIP CHART DATA AS A FUNCTION OF VALVE OPERATION	STRESS: 6.5 Ksi FORCE: 500 LBSf CYCLES: LESS THAN 100 DISPLACEMENT: 0.9 MIL LV110O OPENING YEILDS 1.2 mil (PK/PK) LV110P OPENING YIELDS 1.8 mil (PK/PK)	WILL NOT AFFECT USAGE FACTOR
2.4 WATER HAMMER	HYPOTHESIZED WATER HAMMER DUE TO LEVEL CONTROL VALVE MISOPERATION	UPSTREAM PRESSURE 2415 PSI / 300 DEG F 0.78 SECOND VALVE CLOSURE TIME DOWN STREAM PRESSURE = ATMOSPHERIC	FORCE: 1721 LBSf LV110O OPENING FORCE: 142 LBSf LV110P OPENING STRESS: 22 Ksi DISPLACEMENT: 3.0 mills	WOULD REQUIRE APPROXIMATELY 1500 WATER HAMMER EVENTS FOR A GROOVED NOZZLE TO REACH USAGE FACTOR OF 1.0 AND APPROXIMATELY 18000 FOR AN UNGROOVED NOZZLE.

NOTE 1: ALL FORCES AT VERTICAL PIPE RUN (13 5/8" FROM TOE OF WELD)
ALL DISPLACEMENTS AT 3.5" FROM TOE OF WELD
ALL SPECIFIED STRESSES AT TOE OF THE WELD (HALF RANGE - NO SIFs INCLUDED)