“NORTH ANNA MAIN CONDENSER TUBE PLUGGING METHOD REDUCES CONTAMINANTS”

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Abstract

North Anna like other nuclear plants replaced their steam generators in 1993 and 1995. The plant needed to ensure that the new steam generators would last until the end of the life of the plant. The plant therefore started looking at ways to extend the life of the steam generators. The primary impact on steam generator life is the chemistry control of contaminants in the secondary plant water systems (condensate, heater drains, and feed water). The main ingress of contaminants at North Anna is leakage in the main condenser from circulating water (cooling lake-water) to secondary water (condensate). The main problems North Anna had with their main condensers were leaking tube to tubesheet joints and leaking plugs. The leaking tubesheet was corrected using a tubesheet coating. The leaking plugs presented more of a problem. North Anna had several hundred taper plugs installed in each main condenser that were leaking. This required that North Anna repair this during a refueling outage. The repair was to replace these plugs with a plug that would be more permanent and easy to install because of the time constraints for outage work. The Pop-A-Plug was selected because of its ease of installation and that it would work well with the tubesheet coating.

The taper plugs were replaced during a refueling outage with Expansion Seal Technologies’ Perma Plug, the condenser style plug in the Pop-A-Plug System. It required 8 shifts of work to remove the leaking taper plugs and 2 shifts to install the Perma Plugs. The benefit to the plant is difficult to quantify but a comparison of the contaminant levels before and after the work can show the significance of the repairs. The sodium levels of the condensate are the best indication of the

lake water leakage into the condensate. Prior to the installation of the Perma Plugs steam generator sodium levels were running 4 to 6 ppb. Today North Anna steam generator sodium levels run from 0.1 to 0.4 ppb.

Introduction

The North Anna Power Station is located about 40 mile west of Richmond Virginia. There are two Westinghouse PWR's located at this site. The plants are 3 loop PWWs rated at 2893 MWt and 950 MWe. The facility is owned and operated by Dominion Generation (name was changed from Virginia Power). The plants commercial operation dates are June 1978 for Unit 1 and December 1980 for Unit 2.

The plants main condenser description is as follows:

Manufacturer -	Ingersoll-Rand
Surface Area -	618,000 sq ft
Number of tubes -	53,856
GD of tubes -	1 inch
Tube Pitch -	1.25 inches
Wall thickness -	22 BWG
Tube Material -	304 Stainless Steel, Welded Seam
Tube Sheet Material -	304 Stainless Steel Tube Length - 44 ft

The tube to tubesheet joint on the main condensers of both units is an expanded rolled joint. During the original installation the tubes were under rolled. Therefore after several years of operation the tube to tubesheet joints began leaking. The tube to tubesheet joints were re-rolled in the mid 198O's which reduced the leakage to acceptable levels. During the early 1990's the leakage started increasing again at the tube to tubesheet joint. At this point it was not possible to roll the joint again without damaging the tube. The other problem noted at that time was the leaking tapered tube plugs. There were several hundred tube plugs leaking in each condenser. The repair investigation resulted in the installation of a tubesheet coating and replacing the tube plugs with Perma Plugs. The overall repairs resulted in the steam generator chemistry contaminants being reduced by a factor of 10.

Background

In 1993 and 1995 North Anna replaced the steam generators. At that time a major effort was made to reduce the contaminants that were leaking into the condensate. The condensers suffered from leaking tube plugs and leaking tube to tubesheet joints.

The tube-to-tubesheet leaks were a result of the initial tube installation. The main condenser tube to tubesheet joint is an expanded rolled joint. The proper expansion of the tube into the tubesheet must be accomplished to ensure the joint does not leak. The original installation of the condenser tubes on both North Anna 1 and 2 resulted in the tubes being under rolled (under expanded). After several years of operation the condensers developed tube to tubesheet leaks. During the mid 1980's the tubes were rolled again which reduced the leakage at that time to acceptable limits. Note the acceptable limits now are much lower. After the steam generators were replaced the effort to reduce contaminants in the secondary water chemistry identified that the tube to tubesheet joint were the major source of leakage.

The tube to tubesheet leakage was also occurring on tubes that were plugged. The investigation began to find a solution to this problem. The plant looked at the option to roll the tube again. Since the tube had be rolled twice there would be to great of a chance to damage the tubes to roll them again. The tubes were found to be anchored in the tubesheet but were leaking. The efforts were started to find a way of sealing the tube to tubesheet. One repair was to install a tubesheet coating to seal the tube to tubesheet joint. Plastocor Inc. installed a coating on the Unit 1 main condenser tubesheets in 1994 and on Unit 2 in 1995. At that time the tube plugging technique was also reviewed. Previously the plant had used a tapered plug, which was forcibly driven into the tube end. The coating would not allow the use of the taper plug easily because you would have to remove the coating prior to installing the plug to ensure that you would not chip the coating. At this time the Perma Plug was looked at for use with the coating.

The Perma plug used in this application is based on the patented high-pressure tube plugging system, P2 (reference proceedings from Fourth BOP Symposium "An Improved Plugging System for HX Tubing"), developed by EST. The plug itself is a three-piece assembly, consisting of the following: (See Figure 1)

- A tapered pin
- An internally tapered, externally serrated ring
- A breakaway

In near end applications, the plug is positioned in the rolled area of the subject tube, within the tube sheet region. Using an air over hydraulic tool, or manual tool, the annealed ring is held in place, while a center "Pull Rod", draws the pin through the annealed ring. As the pin is drawn through the annealed ring, the ring expands until it contacts the tube ID. The ring then slightly deforms along its serrations. At a predetermined force, the tensile strength of the breakaway is exceeded in the area which has been undercut to a specific diameter, (depending on the size and material construction of the plug), and the plug "pops" to complete the installation.

Hundreds of Perma Plugs have successfully undergone pressure, vibration and thermal cycling tests to simulate conditions far more severe than standard heat exchanger operating conditions. Plugs of this design were also tested with an Edwards helium leak detector capable of measuring leak rates as low as10^{-10} cc/sec. The plugs were installed in a test coupon and pressurized with helium at 35 psig. A mass spectrometer with a rigid connection to the opposite end of the test coupon monitored any leakage past the plug. This arrangement is capable of measuring the true leak rate past the plug. All thirty plugs tested in this fashion showed no detectable sign of leakage using the most sensitive leak detector scale.

The Perma Plug was determined to be the best plug for this application for two reasons. The plug could be inserted into the tubesheet below the tubesheet surface. Therefore the plug could be installed without having to remove any coating. The Perma Plug also helps reseal the tube into the tubesheet as the sealing ring expands and deforms on the tube ID. This is a secondary function of the plug's sealing method. North Anna has had Pop-A-Plugs installed in the main condensers for 5 years with no failures. The photographs attached show plugs that have been installed in North Anna main condensers since 1994.

The type of tube plug that North Anna used in the main condenser was a tapered plug that is driven into the tube to seal the leaking tube. During the investigation that was started in 1994 to reduce condenser leakage, there was found approximately 300 tube plugs leaking in both units. The taper plug used was made of stainless steel and a taper of as much a 10 mils per inch was used. There were several problems found with this plug. The taper that was used on these plugs was too large and over several heat up cycles it would allow the plug to become lose. The use of stainless steel also did not allow the plug to conform the tube. Therefore the plug would not actually contact the tube all the way around circumference due out of roundness of the tube in the tubesheet. The removal of these plugs showed that in most cases the plug contact with the tube was less than 150 degrees F. The removal of these plugs required a major effort because even though the plugs were loose the stainless steel plugs had galled against the stainless steel tube. The repair of these plugs required 8 shifts to remove the 300 plugs that were leaking and approximately 2 shifts to replace them with Pop a Plugs (See Figure 2).

References

1. EPRI BOP June 96, "An Improved Plugging System for HX Tubing"

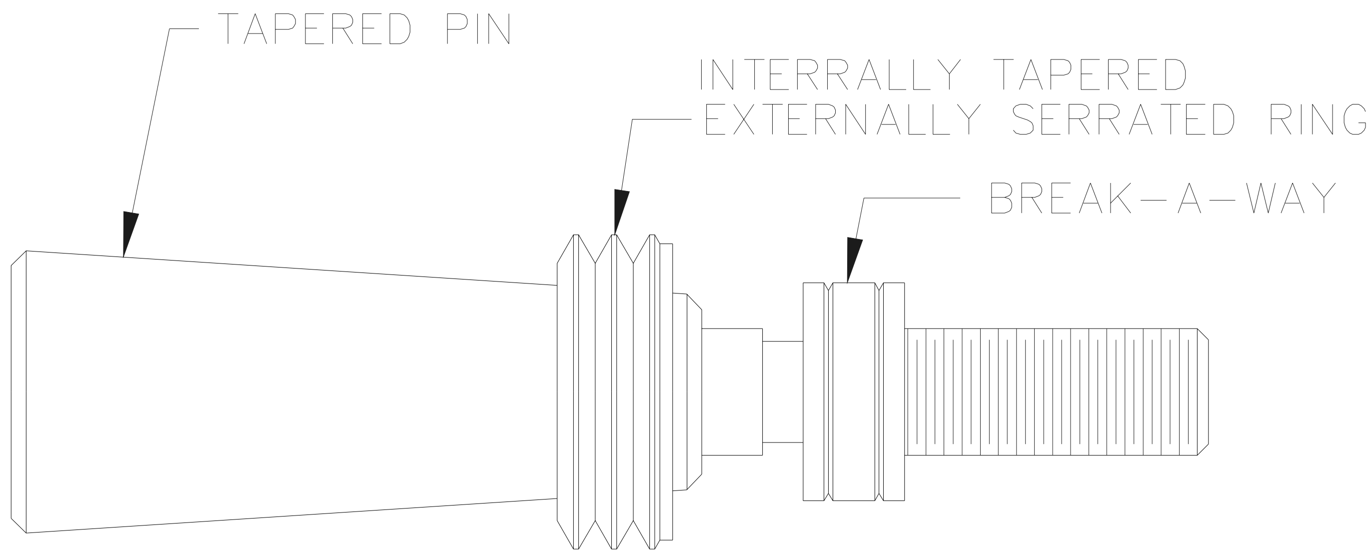

Figure 1. Perma Plug Assembly

Figure 2. Installed Perma Plug

AN IMPROVED PLUGGING SYSTEM FOR HX TUBING

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Abstract

Extensive technical analysis and a comprehensive testing program have identified the important parameters and changes needed for an improved tube plugging system. The new plugging system is specifically aimed to perform successfully in the severe operating conditions found in high pressure heat exchangers. There are two important components of the new system. The first is a new plug with improved gripping and sealing capability. The second is a simple procedure for preparing and sizing tubes to obtain successful plug installation.

The technical analysis and testing were facilitated by electronic measuring and computer recording means. The testing system utilized high temperature ovens, band heaters to create thermal cycling effects, vibration and shock generation, and high pressure systems capable of generating pressures in excess of 20,000 psi. Tests have been conducted on well over 1000 plugs.

Experience at the Davis-Besse Nuclear Power Station has shown that the new generation plugging system is substantially less costly than welded plugs. More than 72 of these new plugs could be installed in a single shift. In comparison, the welded plug required an experienced welder to spend the same time to install fifteen plugs. Savings, as compared to using explosively welded plugs, have also been recorded at other power stations.

Introduction

The Davis-Besse Nuclear Power Plant, powered by a single B&W PWR reactor with a capacity of 874 net Mwe, began commercial operation in July of 1978. This plant, owned and operated by Toledo Edison, is experiencing leaks in their feedwater heaters, typical of many nuclear and fossil plants. It was first determined that welded tube plugs provided the best permanent repair, particularly for high pressure heaters. However, welding is also expensive and time consuming. As few as fifteen plugs could be welded in a single shift. Successful welding requires time for careful preparation to enlarge and properly clean the tube in addition to the weld.

An alternative plugging solution was presented to Davis-Besse in 1994. A new mechanical tube plug design, the P2 Pop-A-Plug®, was developed to combine the permanence of a welded plug with speed and ease of installation. This plug is manufactured by Expansion Seal Technologies, a division of EST Group, Inc. One of the features of this new product is the simplified installation system. When the P2 plugs were first used by Davis-Besse maintenance personnel in October 1994, more than 72 plugs were installed in a single shift. The total savings for this one outage, in which 290 plugs were installed, were in excess of $5,000.

Background

There are many different ways of plugging leaking heat exchanger tubes. They range from expensive means such as explosive plugs or welded pins, through moderate cost plugs using elastomer or expanded metal seals, to the inexpensive tapered pin that is hammered into the tube.

Explosive plugs are used primarily in high pressure heat exchangers because of their high cost. They must be installed by a person certified to handle explosives, usually available only through a contractor. Permits may be required. The contractor must carefully prepare and clean the tube. The explosive plug is thimble shaped and packed with an explosive charge. Cleanliness is very important as contaminants will prevent the plug and tube from coming as close to each other as required during the explosion to effect a good bond. The weld is not a fusion weld as there is not enough heat generated to melt the metals. The joint is a result of the two materials being forced so hard against each other that they bond together. As long as contamination is not present, the joint strength exceeds the weakest material. The thimble shape is very important as it relieves the very large stresses that would otherwise occur because of substantial differential expansion due to the different materials involved. Adjacent tubes must be packed to prevent cracked ligaments and damage to adjacent tube-to-sheet joints unless the tube pitch to diameter ratio exceeds 1.7 or 1.8. This is among the most expensive methods, because of the high cost of both the plug and a certified technician to prepare the tube, protect the surrounding tubes, and install the plug safely. There is also a very high cost to the Utility in down time of the heat exchanger.

Welding of tapered pins or thimble plugs to tubes also requires extreme cleanliness and a skilled welder to make a leak tight weld. The stresses, from welding, may not be confined to a small area because heat flows easily to the surrounding metal. When the molten metal solidifies and contracts, stresses pull on the tube sheet ligament and adjacent tube to sheet joints. These stresses increase with the amount of heat and the molten metal volume and can cause damage to the ligament or adjacent tubes either immediately after the welding or at a later date. Cases have been recorded where welded pins, which appeared sealed after installation, later began to leak as a result of thermal cycling pulling apart the weld joint. Thimble shaped welded plugs are more reliable because they relieve stress at the weld joint. The installed cost of welded plugs and the economic losses from down time are very high. However, they are considered the most reliable method by many experts.

Lower cost elastomer seals, are not able to retain a tight seal because they lose their resilience with age and heat exchanger operating temperatures. The least expensive method, hammered in tapered pins, seal only at the end of the tube. The pin must be struck hard enough to distort the end of the tube because the tube never has a perfectly flat edge or round hole due to distortion from welding or erosion. The ligament or adjacent tube seals can be damaged, because of the necessary tube distortion, resulting in later expensive repair. There is no way of knowing how hard the pin must be struck to effect a seal and at the same time not damage the adjacent tubes. Furthermore, because the sealing surface approaches line contact, it may easily be loosened if struck sideways by a falling tool or an errant hammer blow. Loosened pins may be accidentally exploded outward against an unsuspecting maintenance person. Figure 1 shows the damage to a 1/2 inch thick Plexiglas plate caused by an exploding pin. This can occur during pressure test or be due to a pressure trapped in the tube. This unsafe situation has resulted in serious injury on more than one occasion. European industry is far ahead of the USA in protecting the lives of maintenance workers by moving away from the use of hammered in tapered pins.

Other moderate cost solutions expand a metal ring to seal against the tube ID. This is done by hammering a tapered pin through a ring to expand the ring. Another method uses threaded engagement to pull a tapered pin through the ring. Both are improvements over the hammered in tapered pin because they seal against the tube ID. However, the installer can still install the plug with too little force to seal or a large enough force to cause damage to the adjacent tubes.

There is one plug design that, independently of any operator action, limits the forces placed upon the tube sheet and adjacent tubes to protect them from damage. This is accomplished through the use of a tension limiting member, called a breakaway, that "pops" and limits the maximum force with which a metal ring can be forced against a tube ID. Figure 2 illustrates the original PRP series of the Pop-A-Plug®[1] design. A hydraulic ram, not shown, is shouldered against the plug positioner and draws the pull rod to the right, expanding the ring until it seals against the tube. The breakaway fractures at its reduced cross-section before the ligaments or adjacent tubes can be damaged.

However, the success of any plug installation depends upon more than avoiding damage to the ligament or adjacent tubes. The earlier Pop-A-Plug® design, called the PRP series, had several important drawbacks. It had a very narrow window of installation that was between 0.007 and 0.016 inches smaller than the tube. Therefore it was often undersized or oversized resulting in a leak or ejected plug. It had limited squeeze into the tube which limited it's ability to handle pressure. Heavy lubricants, which were required to control the friction between the pin and the ring, introduced undesirable variability. There was no good method for preparing or measuring the tube.

An extensive review, development, and testing program was undertaken to obtain reliable sealing by improving upon the basic idea of the Pop-A-Plug ®. This led to a new system of plugging which is both simple to execute and superior in sealing. The development goal was to obtain as reliable long term performance as welded or explosive plugs in high pressure heat exchangers at a fraction of their installed cost.

Goals for the New Plugging System

The design goals for an ideal plugging system are:

1. The plug must perform reliably over the life of the heat exchanger under the most severe conditions.
2. The plug installation system must be simple, quick, and reliable. The installer must not be required to have special skills. Plant maintenance personnel should be able to install the plug easily by following a few simple instructions. Correct sizing of the plug must be simple and foolproof. Preparation of the tube, sizing, and installation of the plug should require only a few minutes using simple tools.
3. The installation of the plug must not cause damage to adjacent tubes no matter what the operator does.
4. The plug must be safe for all maintenance workers.
5. The installed cost of the plug must be lower than explosive or welded plugs.

Installation Problems and Solutions

The first problem for any plugging system is PLUG SIZING. No known plugging system has a "one-size-fits-all" capability. If the plug is too small, it cannot be expanded enough to install the plug, or if it can be installed, it will leak or blow out at a low pressure. Basically, we must use the largest plug that will fit into the prepared tube hole. Each plug must work perfectly over a tube size range larger than the difference in available plug sizes.

Some heat exchangers employ different tube sizes or different wall thickness all within one tube bundle. Even if all tubes in a heat exchanger are one size, their actual ID's may vary considerably for a number of reasons. Foremost of these is erosion at the inlet end from fluid turbulence. The author has seen as much as 0.047 inches wall erosion in a thirty year old heater. Additional factors are variations in the tube sheet holes, the amount of wall reduction from rolling, and the tubes themselves. Selecting the plug size on the basis of the published tube dimensions, even if the effect of rolling is accounted for, will often lead to using undersized plugs and an improper installation.

Therefore, a first requirement is that the installation system must make it easy for the installer to accurately determine the correct size of plug to use in a prepared tube.

The number two problem is the ability of the plug to SEAL DEFECTS IN THE TUBE. Heat exchanger tubes are typically pitted and severely eroded by corrosion and fluid turbulence. The tube ID's may be out-of-round which increases the difficulty of sealing. Weld projection at the tube inlet will occur because the harder weld nugget erodes more slowly than the softer tube. This projection can prevent the installer from using the proper plug size.

<u>No</u> plug, designed to seal against the tube ID, can be installed without any tube preparation and be counted upon to provide a reliable seal. Tube defects must be corrected to get a good seal. However, no tube surface can be made perfect. We can imagine that the application of a greater sealing force will seal any surface imperfection by deforming it or the plug. Why can't we use a higher compressive force to accomplish sealing? Heat exchangers are made with thin ligaments to minimize size and cost. Therefore, if we are to prevent ligament and adjacent tube damage, we must limit the force used to seal a plug against a tube. In turn this requires that we properly prepare the tube to be able to make the plug seal with forces that will not damage the ligament or adjacent tubes.

Summarizing what we have learned: **<u>In order to have a successful installation the tube must be prepared to eliminate defects and the correct size of plug must be determined by accurately measuring the tube.</u>**

It turns out that the sizing problem and tube preparation problem are interrelated. If we first remove any projection at the inlet we can use a very simple "go-no go" gage to determine the correct size of plug to use. <u>The correct size of plug is the largest plug that will fit into the prepared tube hole</u>. Figure 3 shows the "go-no go" gage with the "go" end inserted into the tube. The "go" end is the same size as the associated plug. The "no go" end is the size of the next largest plug. Therefore, if the “go” end fits and the “no go” end does not, the plug size marked on the gage is the largest plug that will fit in the tube hole. Alternately we could use the plug itself to determine the largest plug that would fit into the prepared hole. However, using the plug itself as a gage would possibly damage the outer serrations and interfere with good sealing.

The "go-no go" concept is much simpler to use than calipers, snap gages or ball micrometers as the latter require a skill usually associated with persons who are qualified to be machinists or inspectors. The "go-no go" gage concept takes care of the requirement for simply and reliably determining the correct plug size.

The previously mentioned erosion problem at the tube inlet is depicted in Figure 4. This projection must be removed if we are to accurately measure the tube ID and to permit the correct plug size to pass beyond the narrowed inlet. The projection may be easily removed using a tapered reamer. Because of the taper, this reamer will not scar the tube ID if aligned with the tube within a half angle of the reamer.

The ideal method of preparing the tube ID is to use a wire brush designed and manufactured to act like a fly cutter. The brush is operated by a power drill. It must be moved back and forth in the tube to prevent causing a tapered condition in the tube. Tests show that the brush accomplishes several important objectives. These are:

1. In approximately thirty seconds of brushing, enough metal is removed to enlarge the tube to a diameter that is within a few thousandths of the brush diameter.
2. the brush acts to reduce any out-of-round condition.
3. the brush removes pitting marks.
4. the brush creates a ridged surface condition which provides a better grip between the plug and tube.
5. The brushing operation is simple and can be done by anyone with a minimum of training

The effective use of the brush requires that any weld projection first be removed with a tapered reamer and the proper size brush be selected. The proper brush size is the smallest brush that interferes with the hole after the weld projection has been removed. If a smaller brush is used it will not readily remove imperfections. On the other hand if a brush larger is used, it will be hard to insert in the tube and the bristles will be bent excessively preventing them from acting as fly cutters. Because of this the larger brush will not cut as effectively as a properly sized brush. The first brush may not remove all the tube imperfections. This is especially true if a drill, which has been used to remove a tapered pin or inlet sleeve, has made a deep scar in the tube. In such a case, after brushing for about 30 seconds the next larger brush may be employed and so on until all the tube defects have been removed.

Figure 5 shows how the tube size increases with brushing time. At the start of this experiment, the brush was only 0.010 inches larger than the tube. Material removal occurs rapidly until the hole approaches the brush size after which the size increases only slowly. Therefore it is possible to size the hole accurately for the intended plug but only if the correct size of brush is first used. The brush works effectively because the bristles are harder than the tube material and only if the bristles are not bent excessively.

Figure 6 shows the result of brushing for short periods with successively larger brushes to rapidly enlarge the tube ID by several plug sizes.

This method is far superior to drilling or reaming with an adjustable reamer. Adjustable reamers, operated manually, require great care to remove material slowly. Because they cut along the entire length of the flutes and because the flutes are not all the same diameter, they very readily scar and gouge the tube causing a greater problem. Other brushes that have been used to prepare tubes acted only to polish the tube because they were not constructed to act as fly cutters.

The procedure using the "go-no go" gage and special wire brush makes it possible to prepare the tube easily and quickly with a minimum of training and skill. The graphs of Figures 5 and 6 show how quickly material is removed. Figure 5 also shows that the rate at which the tube is enlarged approaches a limit as the hole size approaches the brush OD. This is an important feature because the brush acts like a drill in sizing the hole.

Design of a New Improved Plug

We have seen from the previous discussion that, even after proper plug sizing and proper tube preparation, it is important to be able to reliably seal remaining defects in the tube with a force less than that which would damage adjacent tubes. In order to accomplish this we must be able to expand the ring so that it is squeezed into any remaining tube defects. We can measure the ability of a plug to squeeze into defects and reliably seal by using the test apparatus of Figure 7. This apparatus measures the stroke of the pin, using a LVDT, and the force acting on the pin, using a pressure transducer to monitor the hydraulic ram pressure. Typical data from actual testing is plotted in Figure 8.

There are four different regions in Figure 8a which shows a plug being installed in a tube whose ID is much larger than the initial plug OD. The first and second regions show the rapidly rising force accompanying the initial elastic deformation of the ring and the transition from elastic to total plastic deformation. Region 3 shows the more gradually increasing force required to expand the ring plastically until the ring OD first touches the tube ID. Region 4 is the most important as it shows the travel of the pin from the point where the ring first touches the tube until the breakaway "pops". The fourth region travel is very important because it tells how much the outer serrations of the ring are being squeezed against the tube. The squeeze of the ring into the tube increases with travel in the fourth region. It is obvious that the third region force level must be low in order to get the greatest fourth region travel and consequent squeeze.

Figure 8b shows what happens when the tube ID is close to the initial size of the plug OD. In this case the ring first contacts the tube after a very brief third region pin travel as compared to Figure 8a. Again if we are to obtain the same squeeze for both a closely sized tube and a larger tube, the third region force must be low in relation to the breakaway force.

It was found that internal serrations shown in the patented P2 plug[2] design of Figure 9 reduce the third region force. This design also shapes the ring so that it acts to sweep away any debris on the pin thus preventing it from being caught between the pin and the ring. This acts to prevent galling between the pin and ring.

The final measure of performance is the ability of the plug to seal and withstand high pressures. No leakage has been found on thousands of Plugs experimentally tested with shop air and water at pressures to 10,000 psi. Plugs of this design were also tested with an Edwards helium leak detector capable of measuring leak rates as low as 10^{-10} cc/sec using a test set up of Figure 10. This arrangement is capable of measuring the true leak rate past the plug. All thirty plugs tested in this fashion showed no detectable sign of leakage using the most sensitive leak detector scale.

Other tests are routinely run to increase the pressure across the plug until it is ejected from the tube. This is done using the test set-up shown in Figure 11 that is limited to slightly over 20,000 psi. Results of testing carbon steel plugs with the test coupons prepared by power brushing are shown in Figure 12. Figure 12 shows performance in several popular sizes for high pressure heat exchanger tubes as well as the effect of the initial clearance between the plug OD and tube ID. It is seen from this data that the plugs will perform well beyond the 0.020 size range permitted by the "go-no go" gage system. If the "no go" end of the gage will not enter the tube, the tube is less than 0.020 inches larger than the plug. If the user neglects to measure the tube and accidentally installs an undersize plug, the plug positioner will become jammed against the pin or the breakaway will fracture on the wrong side of the collar. Both of these mishaps are identified in Figure 13. Either of these two events should warn the user that he has installed an undersized plug. In such a case the undersized plug must be removed and a larger plug installed correctly.

Plugs were tested in coupons made with elliptical holes that were 0.012 to 0.016 inches out-of-round and the results compared with similar installations in round holes. There was no evidence of leakage. The blow-out test results are shown in Figure 14. This plot shows that blowout pressure was not affected by the out-of-round condition. Furthermore tests with the power brush on a hole, that was 0.0150 inches out-of-round before brushing, showed that the out-of-round condition was reduced to 0.002 inches after 10 seconds of brushing.

Tests were conducted on a mock-up of a tubesheet shown in Figure 15 to determine the stress placed upon adjacent tubes by the installation of a P2 plug. The tubesheet design was per TEMA class R with ligament thickness of 0.180 inches. Tubes were rolled into the six outer holes and the tube to sheet joints were vacuum leak tested using an Expansion Seal Technologies G-650 test gun. All the rolled joints were determined to be leak tight immediately after rolling. Dimensional measurements of the rolled tube ID's were taken with electronic calipers and recorded after the leak test. Strain gages were mounted to the tubesheet face at the narrowest section of the ligaments around the center hole to measure circumferential stress. A P2 plug was installed in the center tubesheet hole which did not have a tube installed. Measurements taken of the six outer tube ID's after the plug installation did not show evidence of any permanent deformation beyond the repeatability capability of the measurement system which was better than 0.0005 inches. The measured strain due to the plug installation was less than 30% of the strain when a tube was rolled into one of the outer holes of the tubesheet mock-up. Furthermore, a vacuum leak test performed on all the tube to tubesheet joints after the plug installation verified that all those joints remained leak tight.

One of the most important tests run on the new design of plug was thermal cycling. The test apparatus is shown in Figure 16. A 2-1/2 inch diameter coupon is surrounded by a band heater. The test plug is installed in the center of the coupon and one side of the plug is exposed to water under pressure. The water temperature and pressure are monitored by a thermocouple and pressure transducer. The band heater was cycled on and off as the water temperature behind the plug dropped to 400^{o}F and rose to 500^{o}F. At the same time water was trapped behind the plug at a pressure that cycled between approximately 5000 and 6000 psi. The rate of temperature rise and fall were respectively 750^{o}F/hr and 240^{o}F/hr. A portion of the temperature and pressure readings are shown in Figure 17. The thermal transients are more severe than would be expected in any base load heat exchanger as the OD of the small coupon experiences 1100^{o}F during the heating portion of the cycles. The plugs were visually monitored for signs of leakage and the test was run for over three hundred cycles. This is considered to be equivalent to about ten months of operation for a base load plant. No sign of leakage was observed during the entire test and the blowout pressures at the end of the test were in excess of 20,000 psi. It may also be significant to note that mechanical plugs of an earlier design showed leakage after less than 50 cycles.

A pressure cycling test was conducted by shocking the plugs with over 100 cycles of 0 to 7000 psi using the set-up in Figure 11. The pressure was cycled between atmospheric and 7000 psi by manually operating the shut-off and bleed valves. This was done rapidly to create a pressure change that is shown if Figure 18. The plugs were monitored for leakage and none was observed. Blowout tests at the conclusion showed no loss of gripping power as the blowouts were in excess of 19,120 psi..

The effect of prolonged service at 650^{o}F was tested in the set-up of Figure 16 where 24 plugs were tested for blowout at intervals of 1 hr, 10 hrs, and 100 hrs. Since creep is known to be a logarithmic function with time under these conditions of loading, the amount of creep for each decade of time would be the same. Therefore, the creep in the first hour would be the same as the creep between 1 hr and 10 hrs, or between 10 hrs and 100 hrs and so forth. If there was any measurable creep rate it would be possible to extrapolate it over longer periods of time in this manner. If the plug were to creep at these temperatures it would be expected to blow out at a lower pressure which was not the case as seen by the data in Figure 19. It appeared that prolonged service at this temperature actually increased the holding power of the plug.

Vibration tests were run using the test-set-up of Figure 20. The plugs were subjected to vibrations of 3g's at a frequency of 120hz while being subjected to a pressure difference of 7000 psi. There was no sign of leakage during the 13 hour test. Although this test was relatively short because of the noise generated and the large demand on our air supply, it was significant that there was no noticeable reduction in the blowout pressure of the plugs that had experienced this level of vibration.

Field Experience

The new design plug was first installed in April of 1994 in high pressure heat exchangers in a southern New Jersey fossil power plant. These plugs have continued to perform flawlessly to this date. From the time of this initial field test many thousands of plugs have been installed in heat exchangers in North America, Europe and Asia with excellent results. The new design plugs have also been installed in supercritical plants.

The Davis-Besse Nuclear Power Station heat exchangers, manufactured by Westinghouse Electric Corporation, have working temperatures of 500^{o}F and pressures of 1500 psi. Davis-Besse calculates they saved over $5,000 in the first installation of 290 P2 plugs as opposed to using welded plugs.

Substantial cost savings have been obtained by other users of Pop-A-Plugs®. Navajo Generating Station, Salt River Project, performed a study comparing the cost of installing Pop-A-Plugs® versus explosive plugs[3]. They achieved savings of $34,000 by installing 200 Pop-A-Plugs® instead of explosive plugs. Additionally they saved 6 1/2 days of downtime and avoided damage to the heat exchanger.

Levon Strickland, Engineer in charge of Feedwater heaters and Condensers at Santee Cooper, says their average cost of using explosive plugs is $6000 per incident[4]. He determined they saved between $4500 to 5000 per leakage incident by using Pop-A-Plugs. That is a saving of over 75%. Santee Cooper is the largest fossil plant in South Carolina.

Eddystone Generating Station of PECO Energy installed 14 Pop-A-Plugs® during an outage in March of 1995 instead of their normal practice of using explosive plugs[5]. John Hugues, PECO Maintenance Planner, calculated savings of $3,300 for just 7 tubes.

Acknowledgements

Many associates made important contributions to the development of the P2 Pop-A-Plug. Eugene Cunningham contributed the key idea of internal serrations that solved some difficult problems. Jim Berneski was responsible for many of the ideas and development of the tube preparation method. Henry Brandenburger also made valued contributions to the program. Glenn Craig and Jim Berneski did much of the testing.

References

1. US Patent number 4,425,943
2. US Patent number 5,437,310
3. Navajo Generating Station internal document
4. “Field Notes” in September 1993 edition of *Power Engineering*
5. Eddystone Generating Station internal memo dated 3/29/95

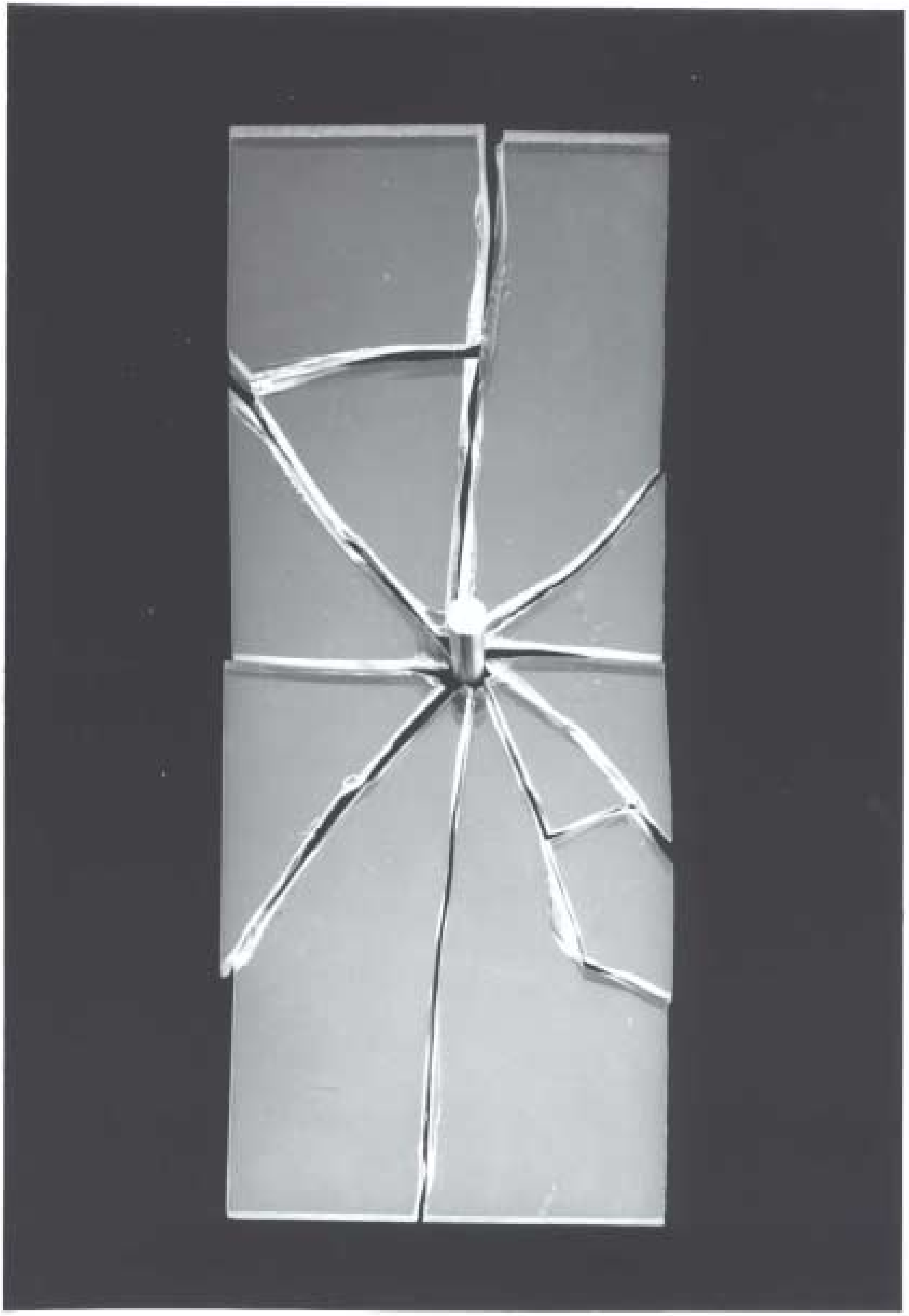

Figure 1

OLD STYLE PRP POP-A-PLUG

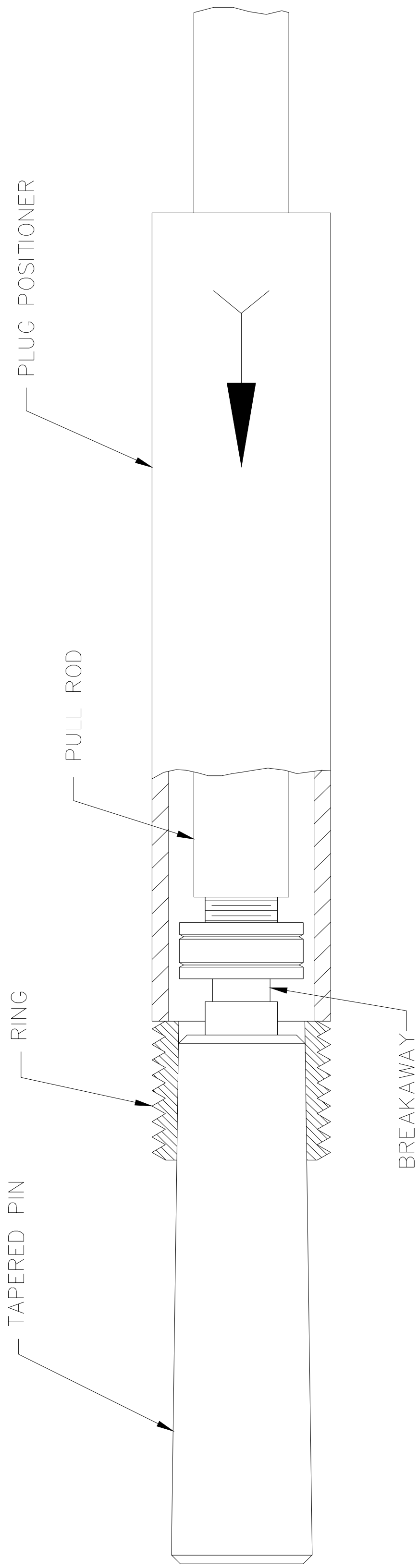

FIGURE 2

SIMPLE METHOD FOR DETERMINING TUBE SIZE

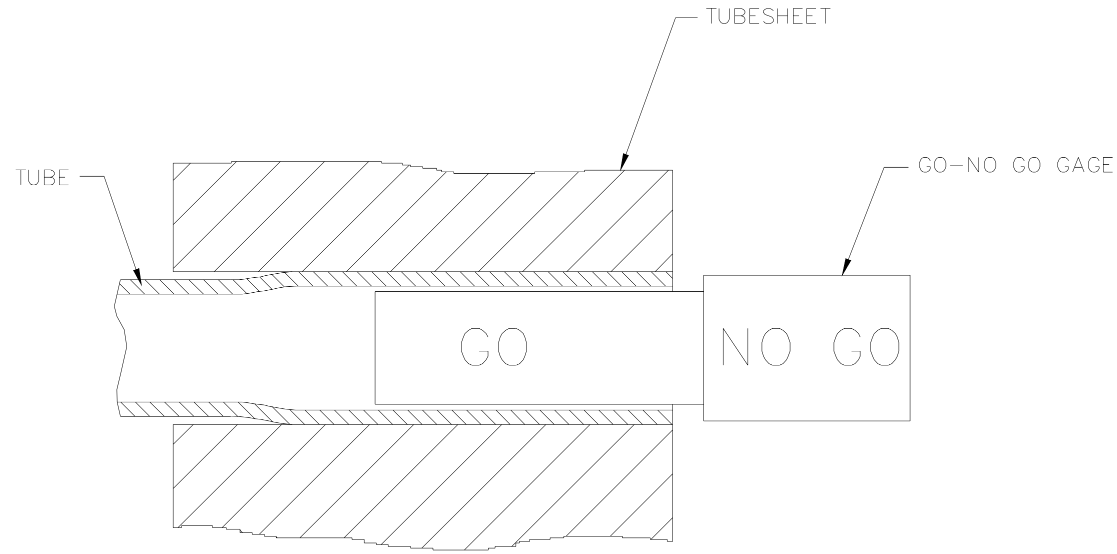

FIGURE 3

TUBE INLET EROSION

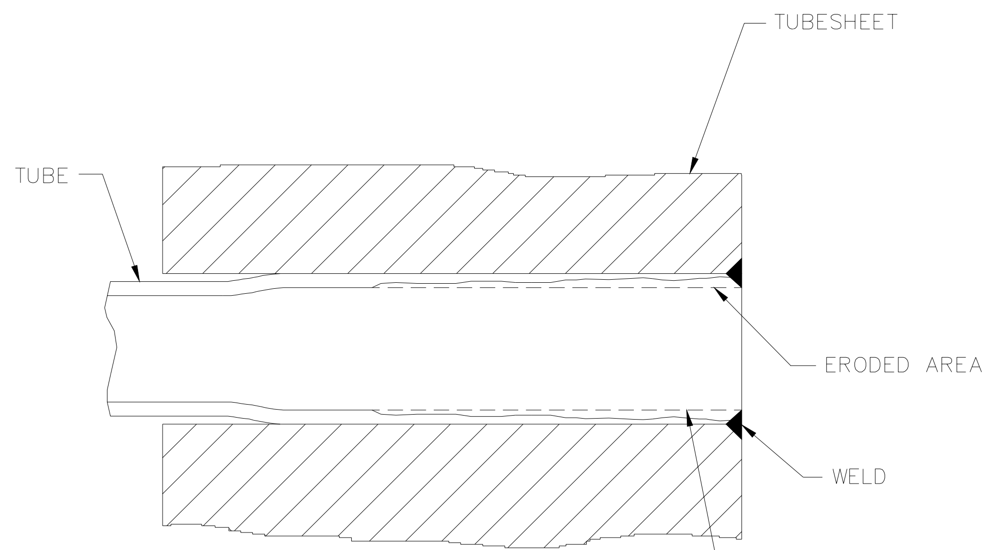

FIGURE 4

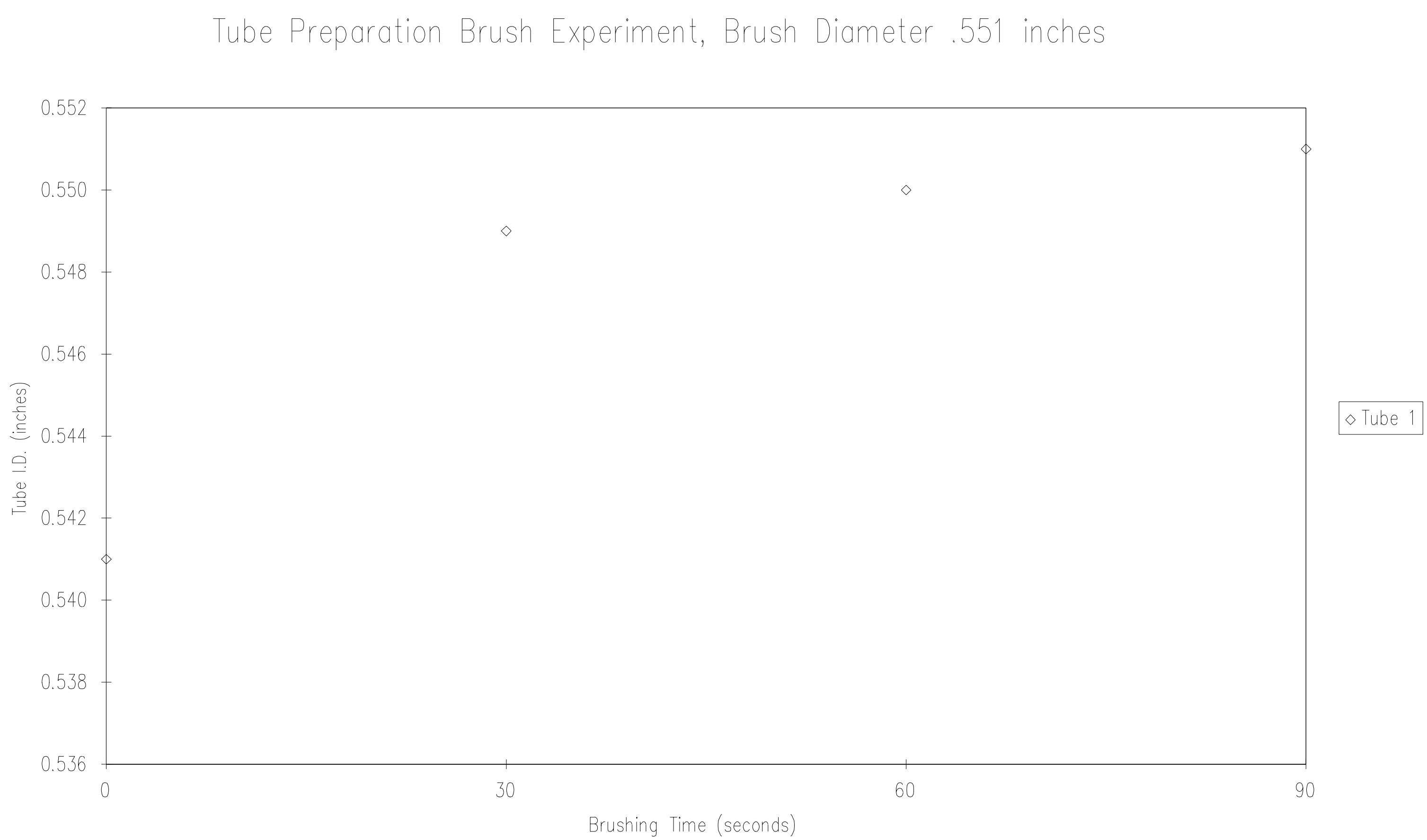
Tube Preparation Brush Experiment, Brush Diameter .551 inches
0.552
0.550
0.548
0.546
0.544
0.542
0.540
0.538
0.536
Tube I.D. (inches)
0
30
60
90
Brushing Time (seconds)
Tube 1

FIGURE 5

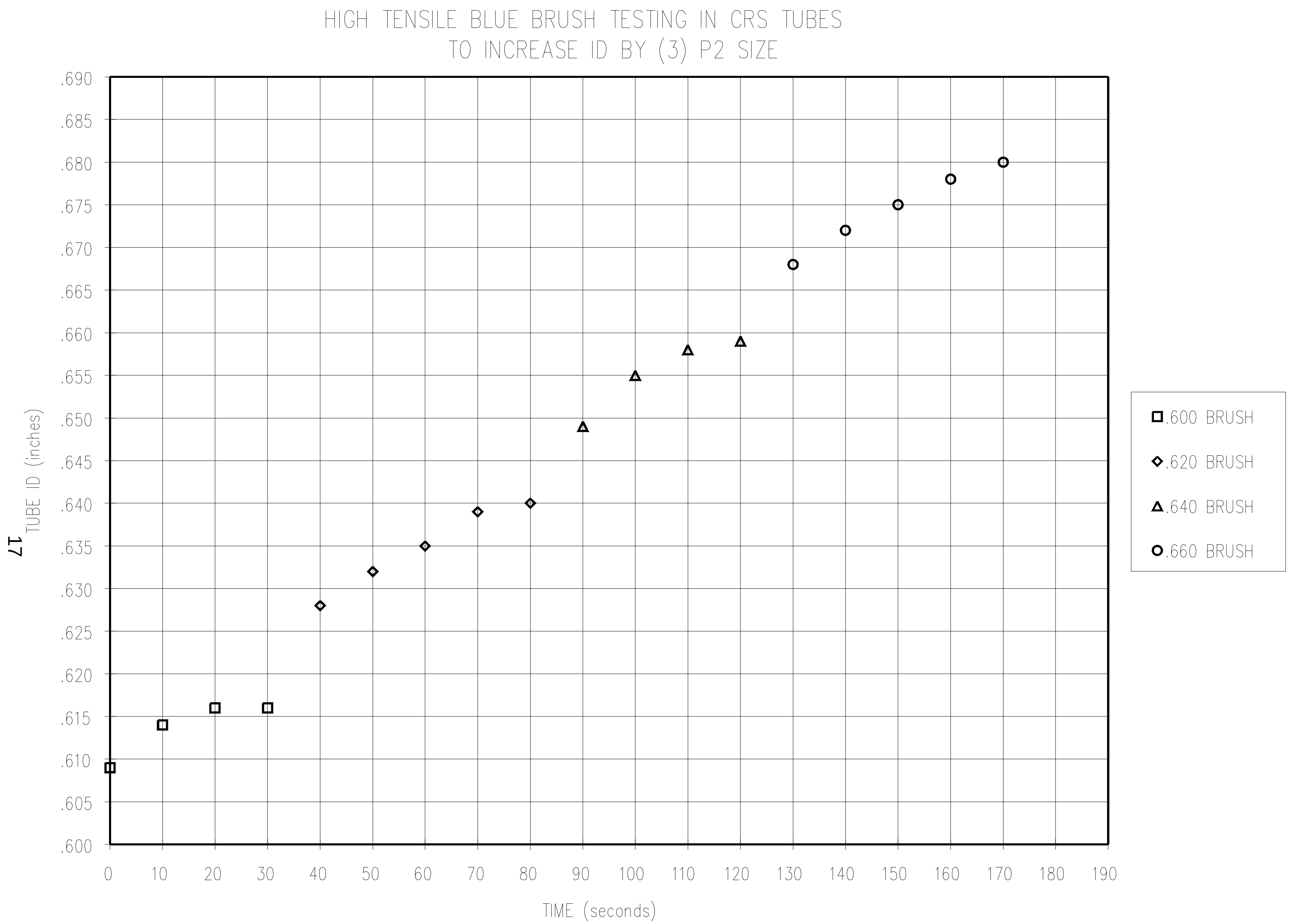
HIGH TENSILE BLUE BRUSH TESTING IN CRS TUBES
TO INCREASE ID BY (3) P2 SIZE
.690
.685
.680
.675
.670
.665
.660
.655
.650
.645
.640
.635
.630
.625
.620
.615
.610
.605
.600
TUBE ID (inches)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
TIME (seconds)
.600 BRUSH
.620 BRUSH
.640 BRUSH
.660 BRUSH

FIGURE 6

DEVELOPMENT TEST APPARATUS

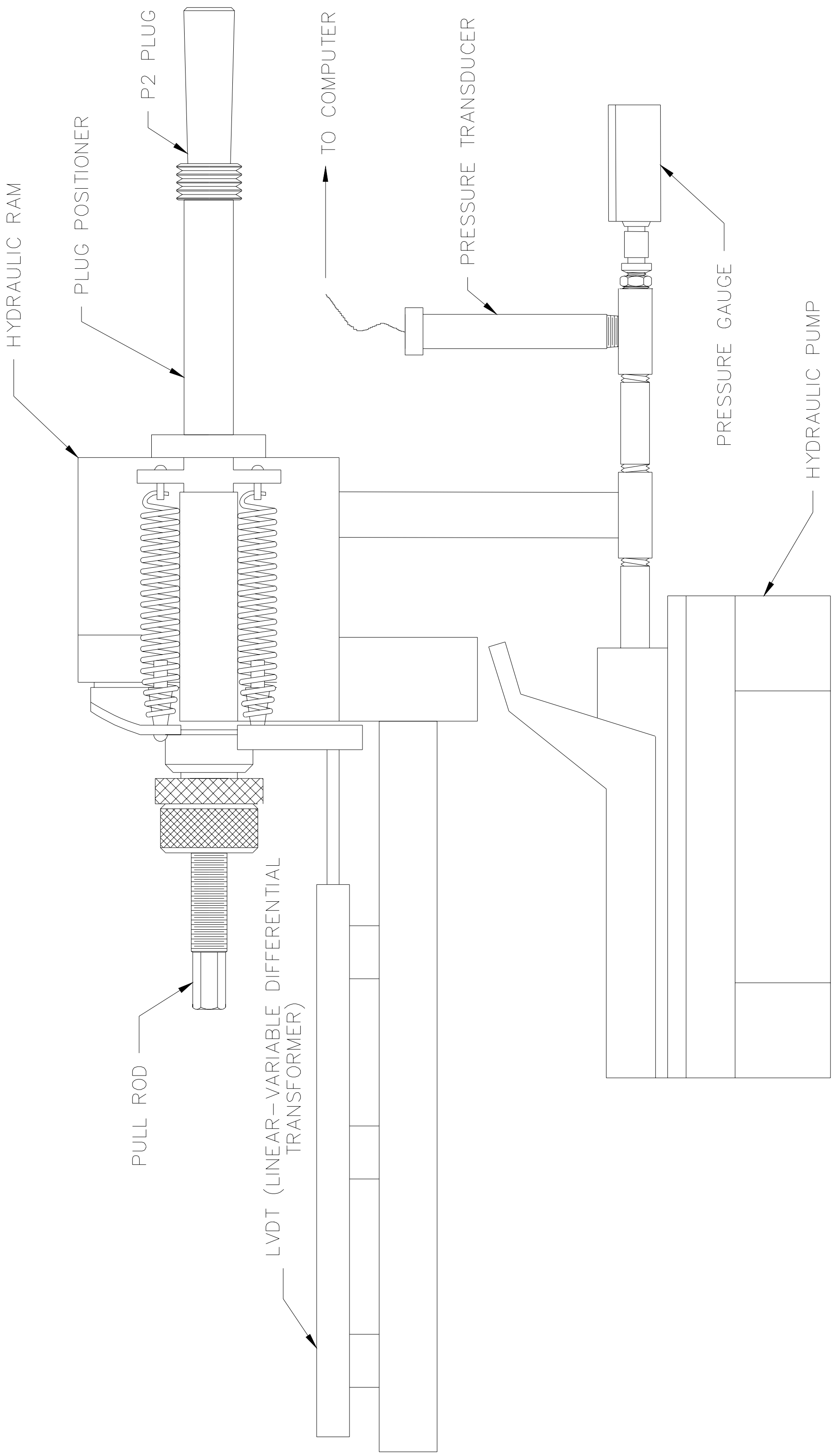

FIGURE 7

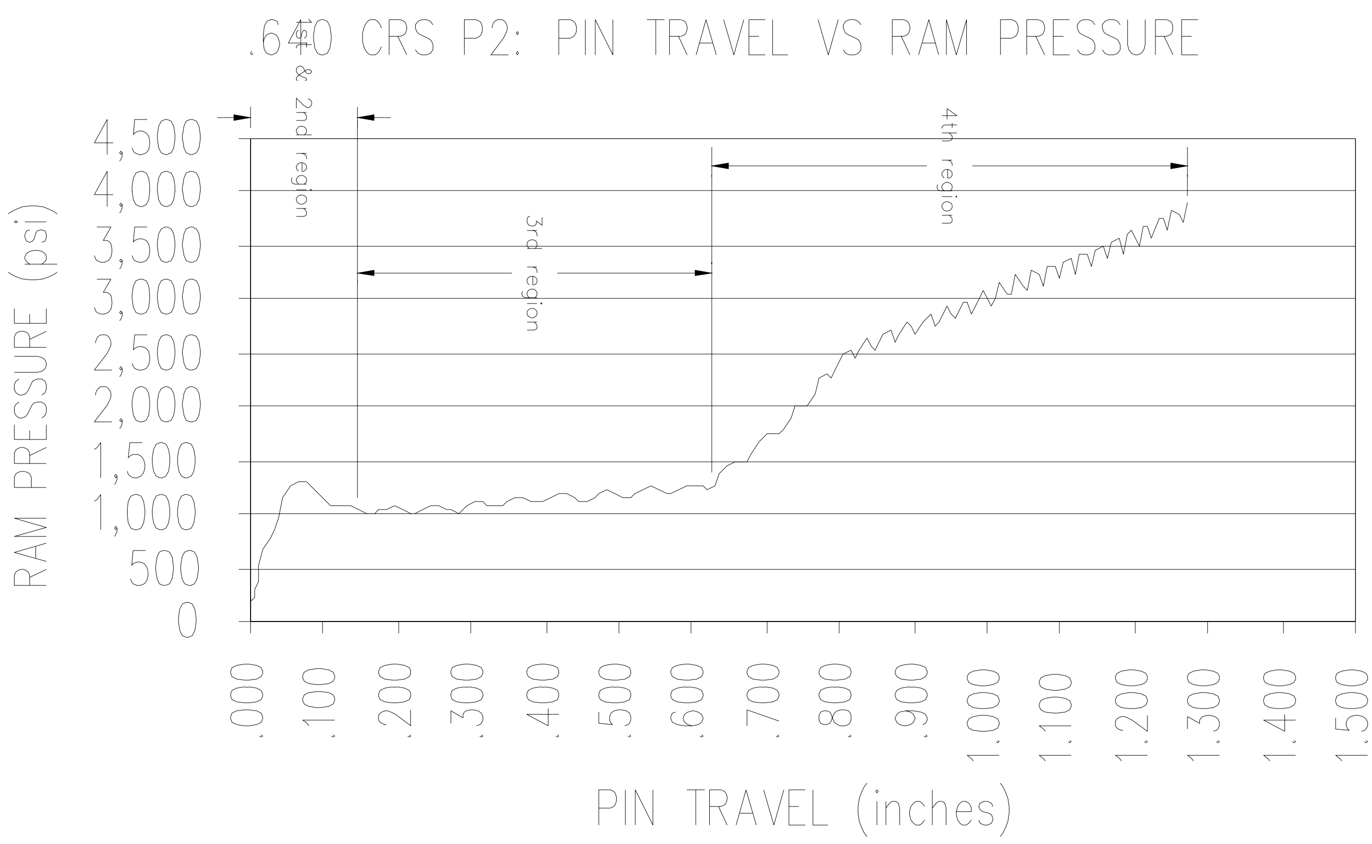
.640 CRS P2: PIN TRAVEL VS RAM PRESSURE
1st & 2nd region
3rd region
4th region
RAM PRESSURE (psi)
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
.000
.100
.200
.300
.400
.500
.600
.700
.800
.900
1.000
1.100
1.200
1.300
1.400
1.500
PIN TRAVEL (inches)

FIGURE 8A

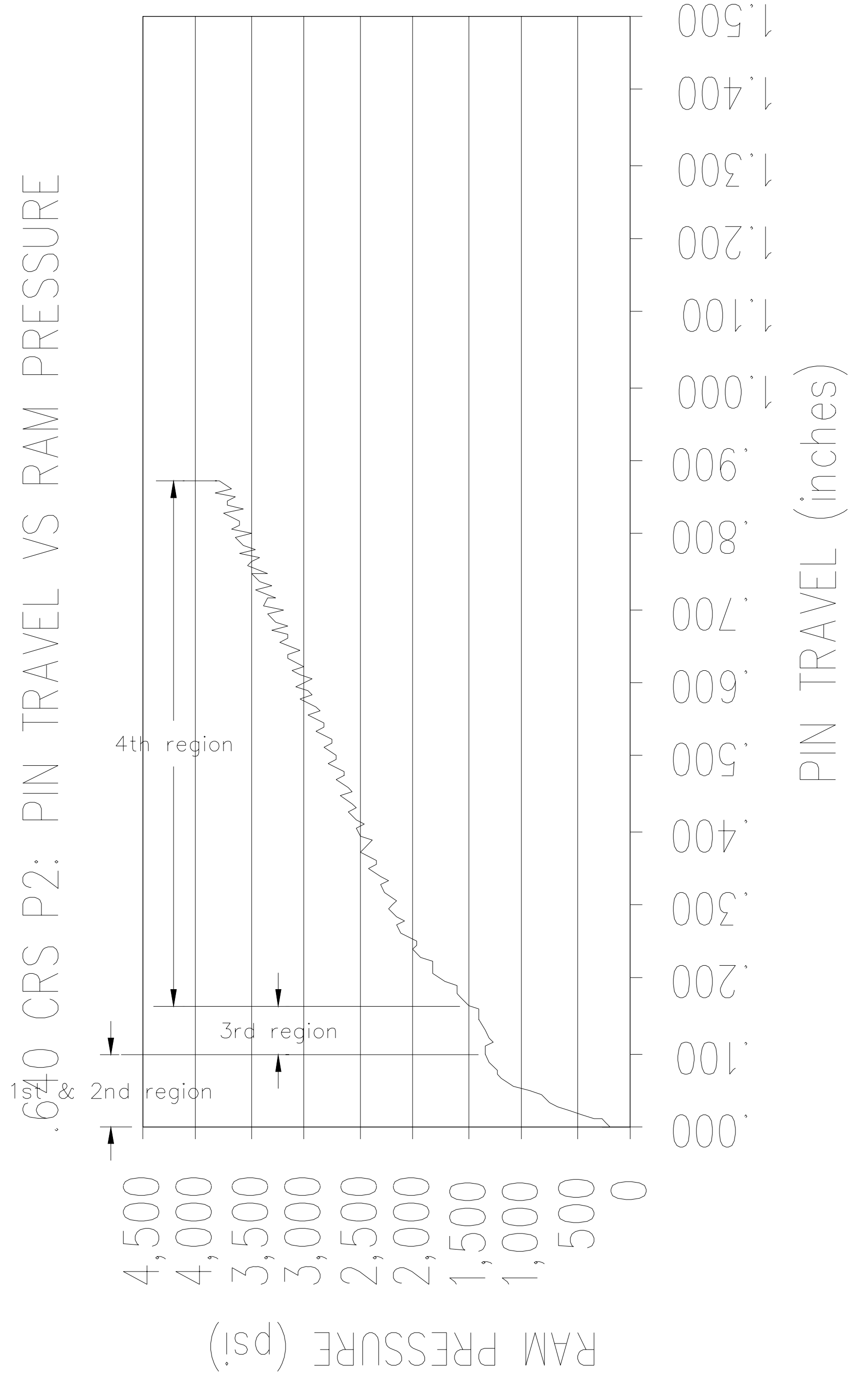
.640 CRS P2: PIN TRAVEL VS RAM PRESSURE
4th region
3rd region
1st & 2nd region
PIN TRAVEL (inches)
.000
.100
.200
.300
.400
.500
.600
.700
.800
.900
1.000
1.100
1.200
1.300
1.400
1.500
RAM PRESSURE (psi)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500

FIGURE 8B

NEW P2 POP-A-PLUG DESIGN

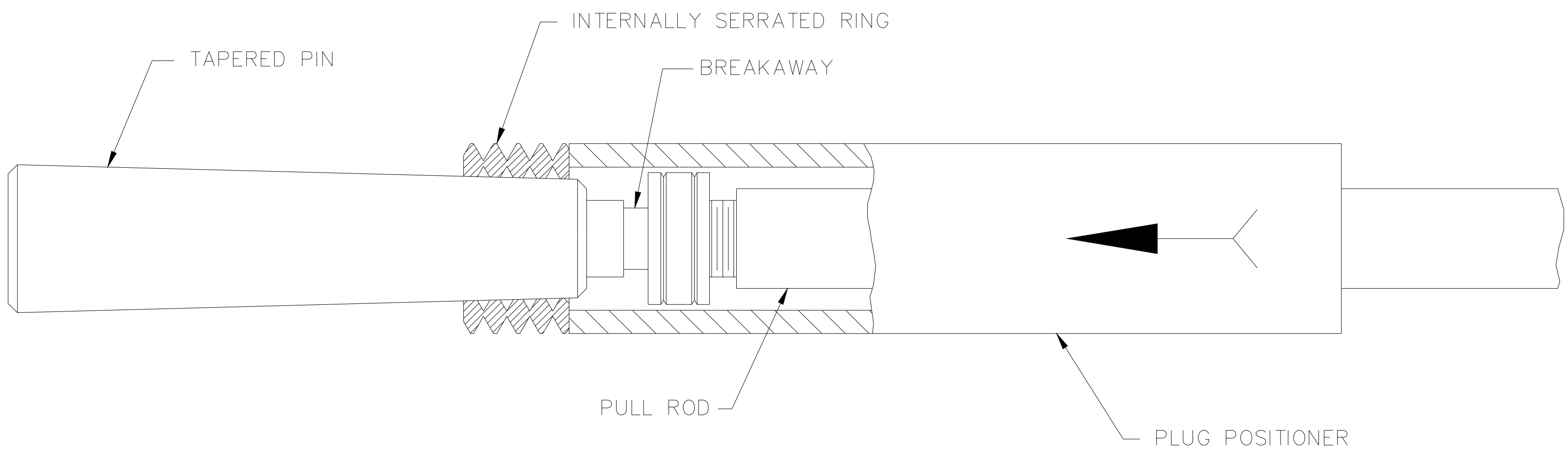

FIGURE 9

HELIUM LEAK TEST SET-UP

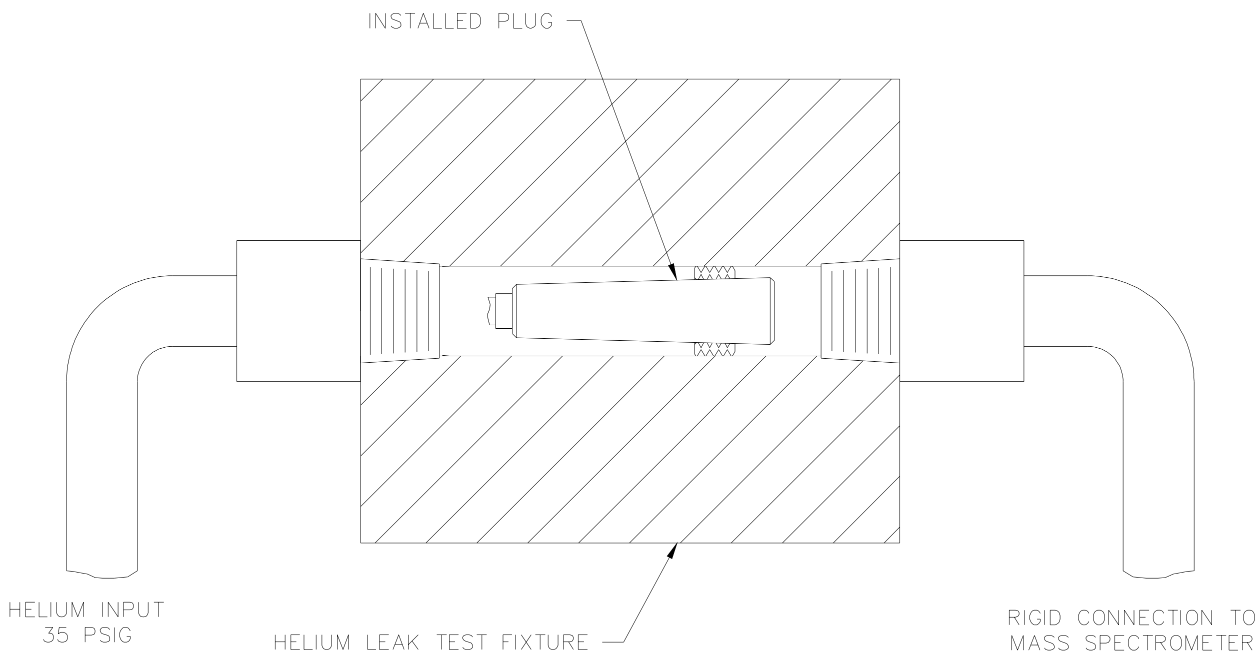

FIGURE 10

BLOW-OUT TEST SET-UP

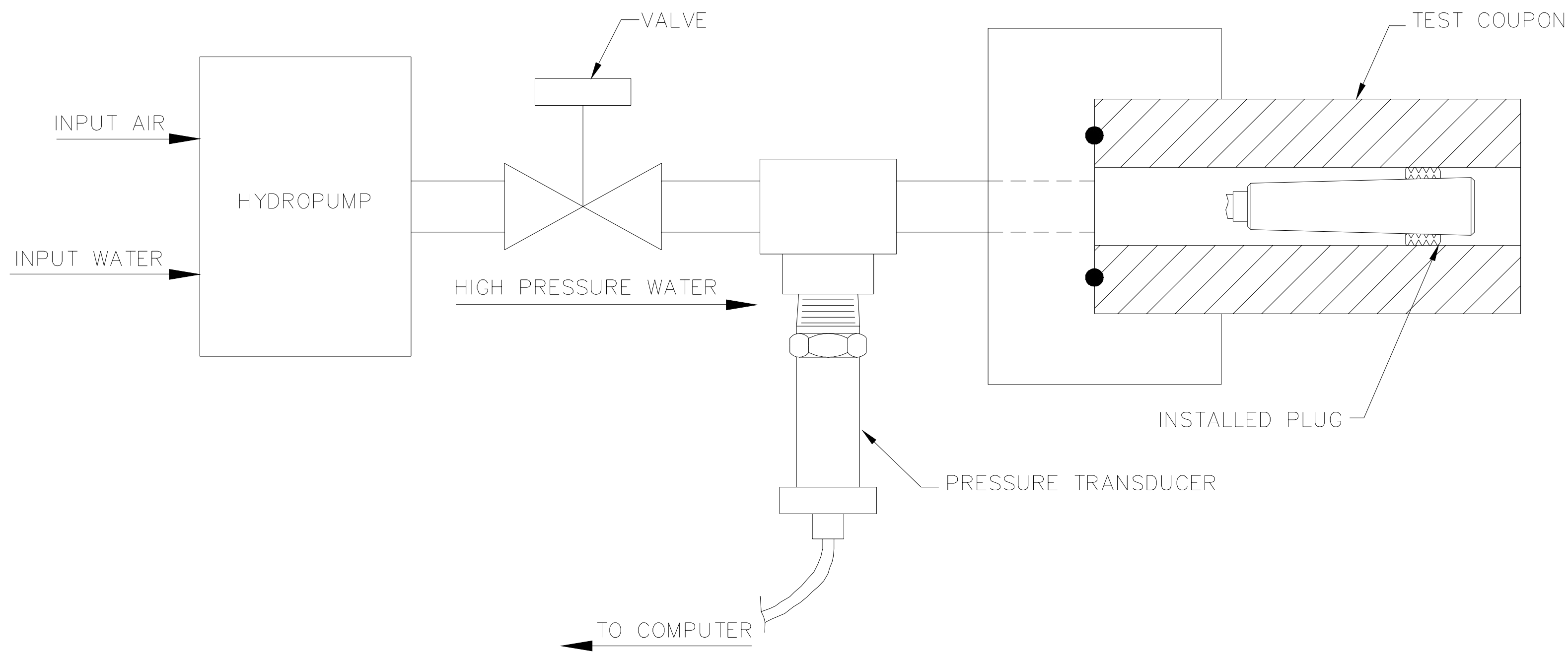

FIGURE 11

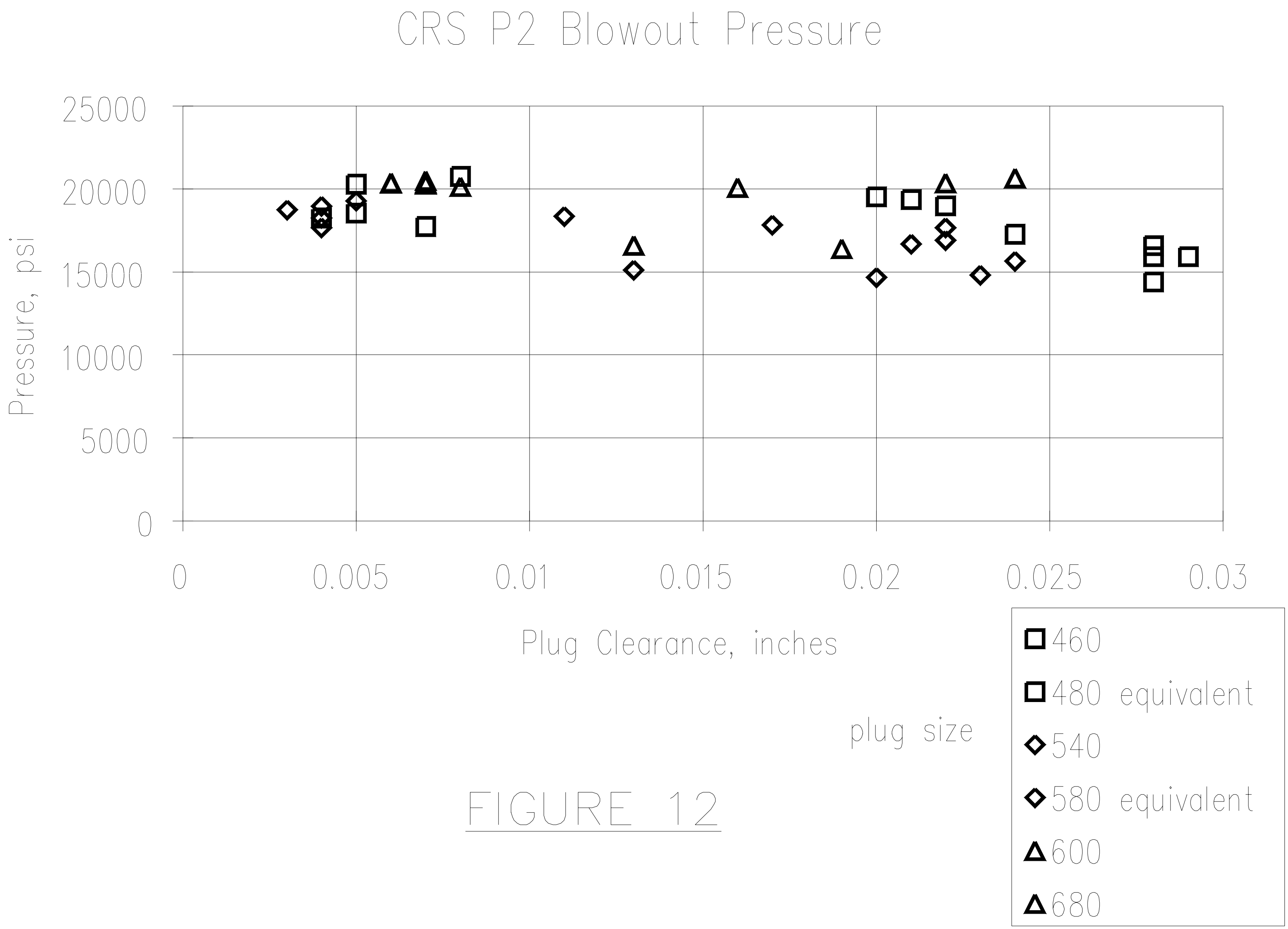
CRS P2 Blowout Pressure
Pressure, psi
25000
20000
15000
10000
5000
0
0
0.005
0.01
0.015
0.02
0.025
0.03
Plug Clearance, inches
plug size
460
480 equivalent
540
580 equivalent
600
680

FIGURE 12

INSTALLATION OF UNDERSIZED PLUG

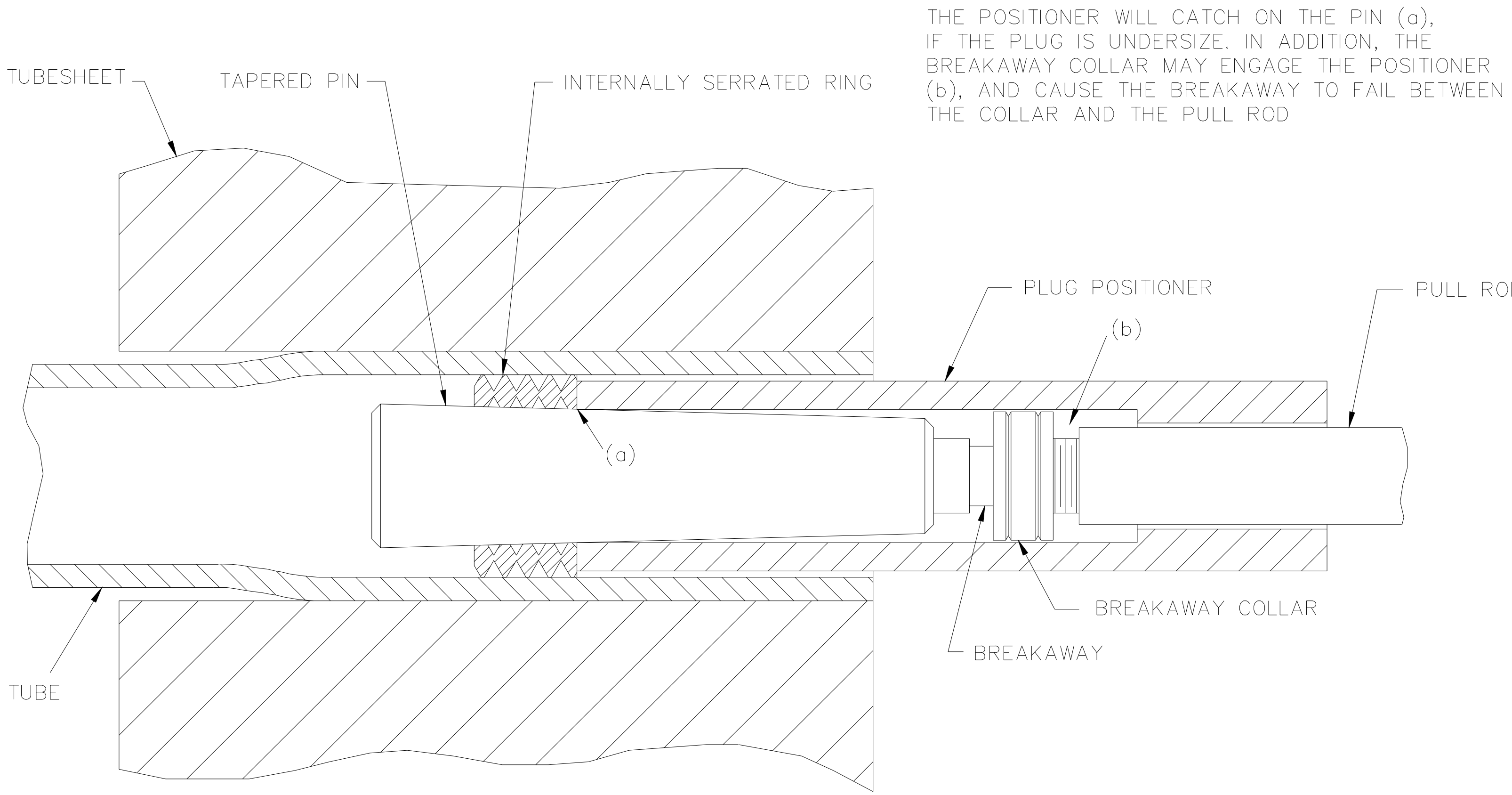

FIGURE 13

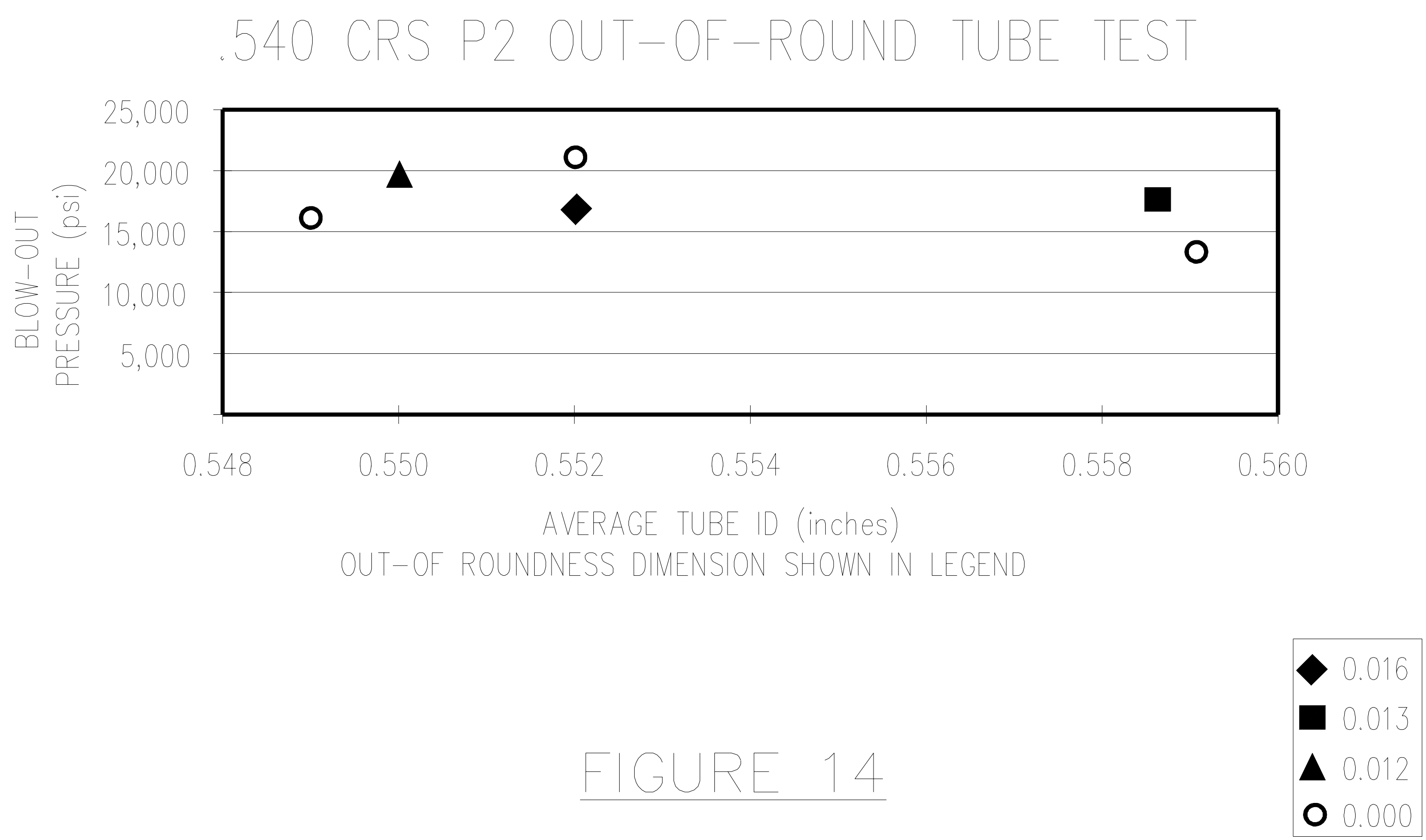
.540 CRS P2 OUT-OF-ROUND TUBE TEST
BLOW-OUT PRESSURE (psi)
25,000
20,000
15,000
10,000
5,000
0.548
0.550
0.552
0.554
0.556
0.558
0.560
AVERAGE TUBE ID (inches)
OUT-OF ROUNDNESS DIMENSION SHOWN IN LEGEND
0.016
0.013
0.012
0.000

FIGURE 14

TUBESHEET MOCK-UP PER TEMA CLASS R

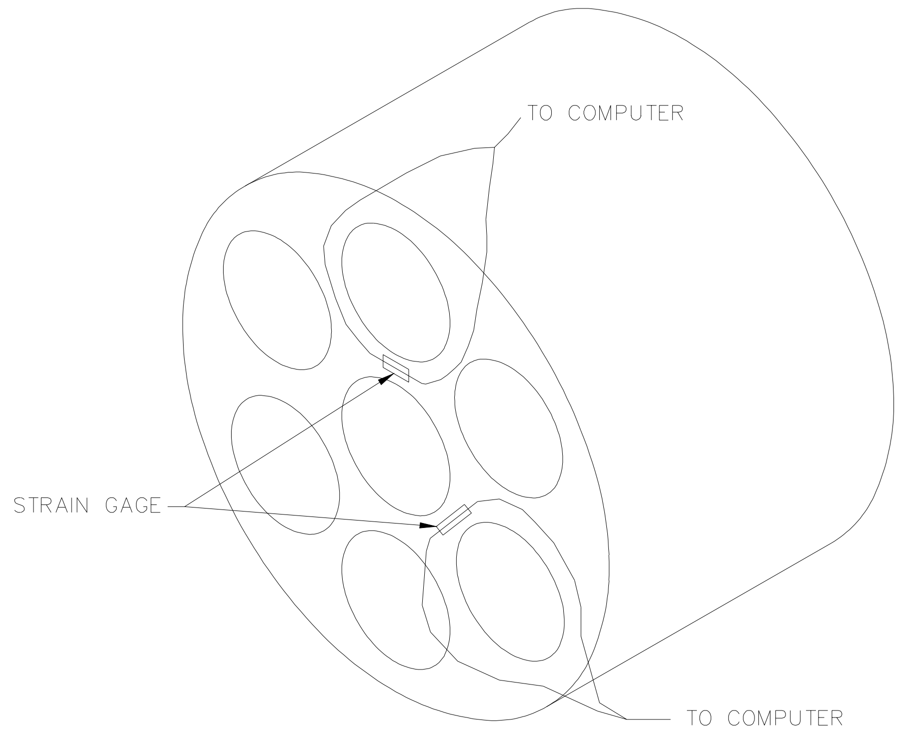

FIGURE 15

THERMAL CYCLE TEST SET-UP

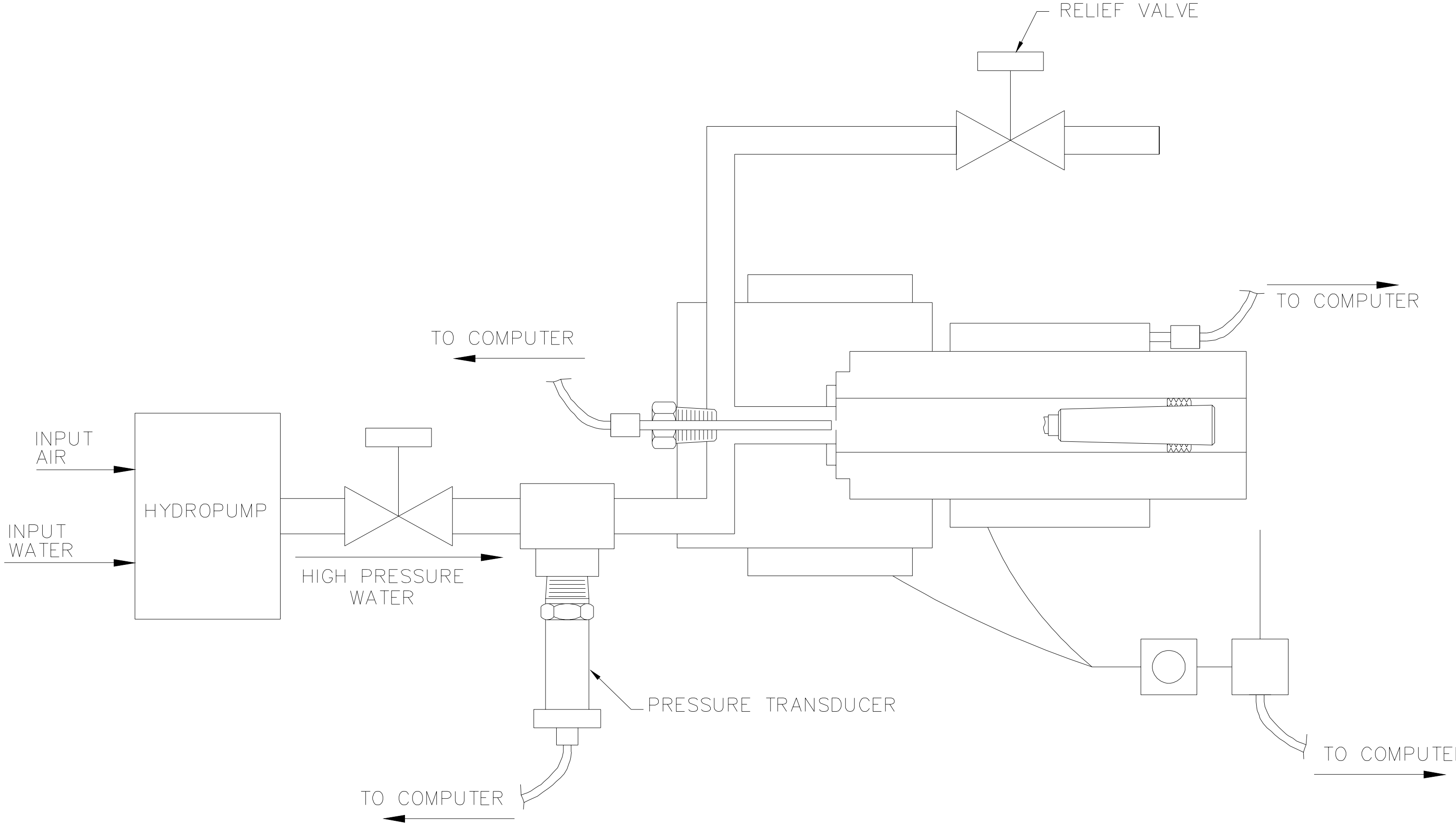

FIGURE 16

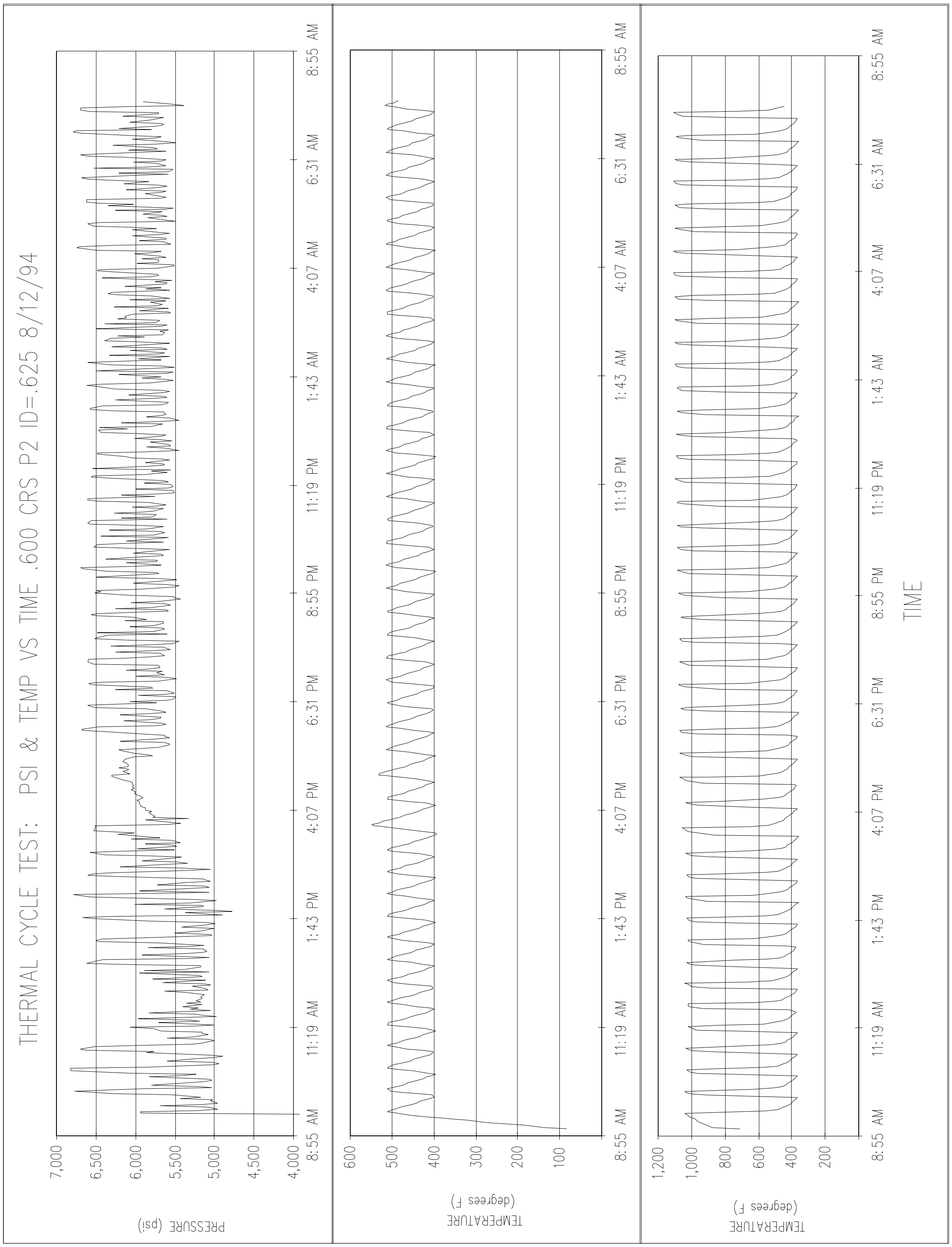
THERMAL CYCLE TEST: PSI & TEMP VS TIME .600 CRS P2 ID=.625 8/12/94
PRESSURE (psi)
7,000
6,500
6,000
5,500
5,000
4,500
4,000
TEMPERATURE (degrees F)
600
500
400
300
200
100
TEMPERATURE (degrees F)
1,200
1,000
800
600
400
200
8:55 AM
11:19 AM
1:43 PM
4:07 PM
6:31 PM
8:55 PM
11:19 PM
1:43 AM
4:07 AM
6:31 AM
8:55 AM
TIME

FIGURE 17

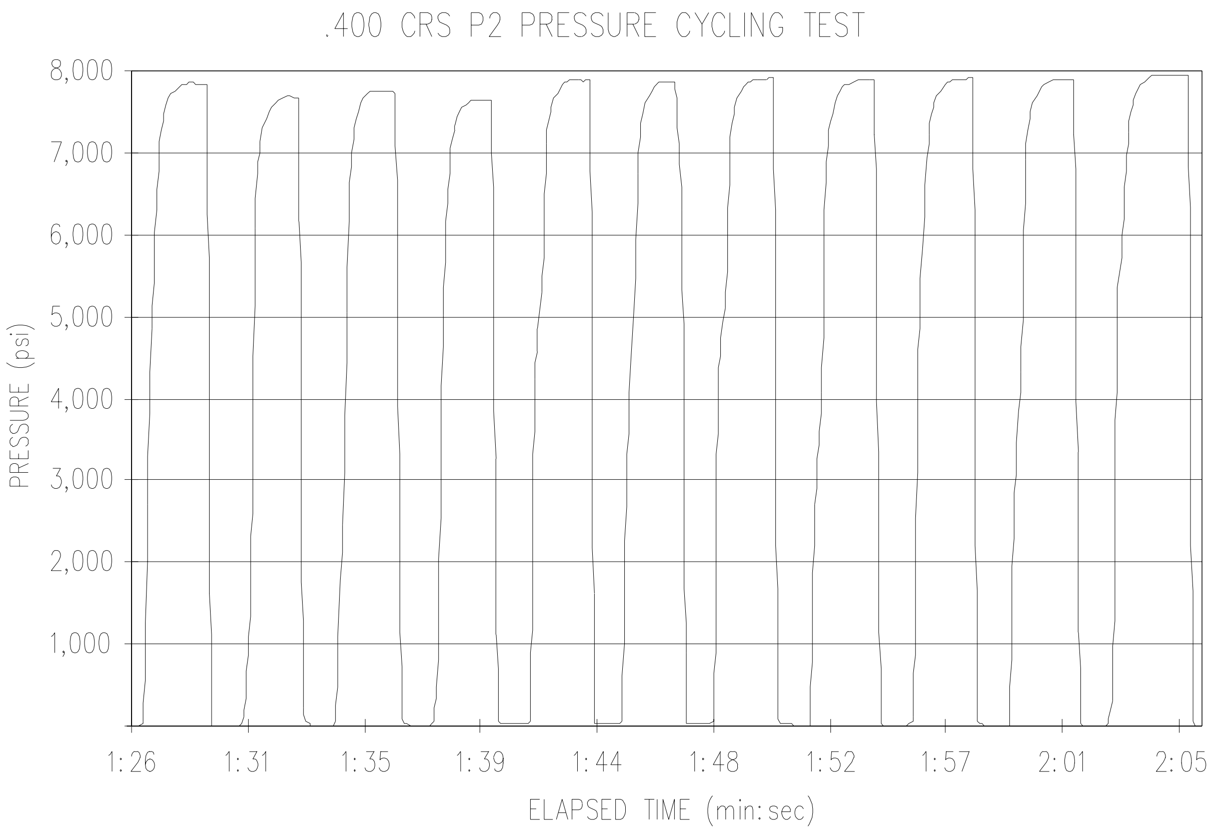
.400 CRS P2 PRESSURE CYCLING TEST
PRESSURE (psi)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
1:26
1:31
1:35
1:39
1:44
1:48
1:52
1:57
2:01
2:05
ELAPSED TIME (min:sec)

FIGURE 18

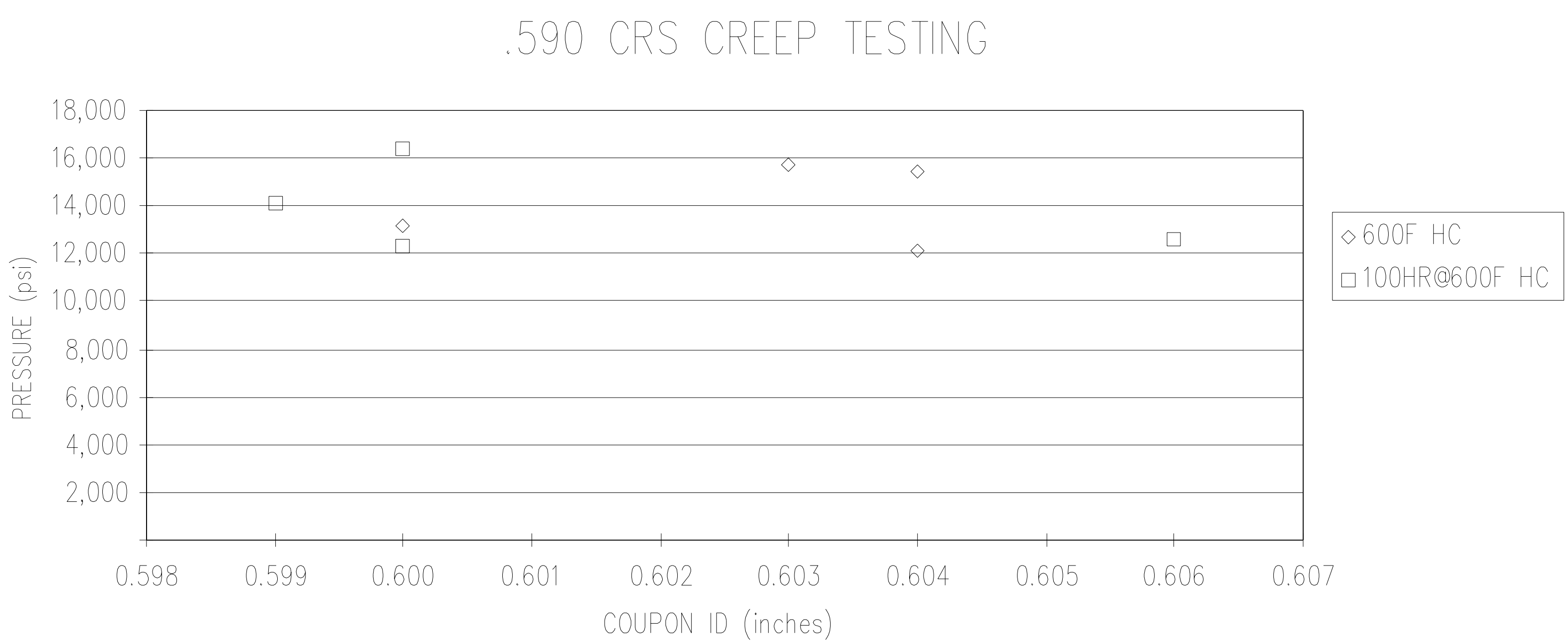
.590 CRS CREEP TESTING
PRESSURE (psi)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0.598
0.599
0.600
0.601
0.602
0.603
0.604
0.605
0.606
0.607
COUPON ID (inches)
600F HC
100HR@600F HC

FIGURE 19

VIBRATION TEST SET-UP

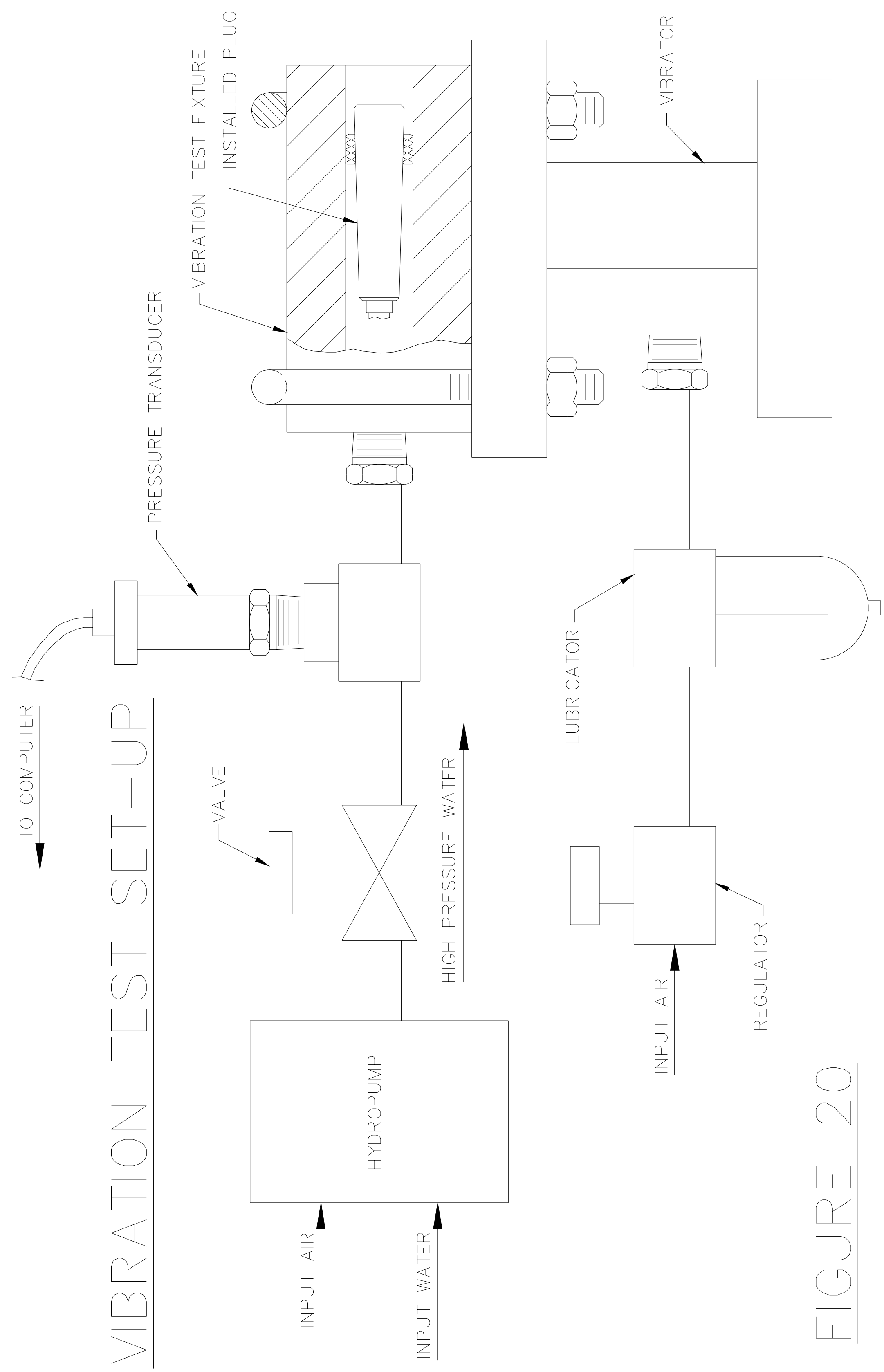

FIGURE 20

“THROUGH-THE-TUBE PLUGGING APPLICATION FOR ONCE THROUGH HEAT EXCHANGERS”

Presented AT EPRI BOP Heat Exchanger NDE Symposium, June 1998

Lin Turner
Browns Ferry Nuclear Power Station
Tennessee Valley Authority
Huntsville, Alabama

Henry Brandenberger
Expansion Seal Technologies
334 Godshall Drive
Harleysville, Pennsylvania 19438

ABSTRACT

The majority of shell and tube heat exchangers in a typical power plant are either a U-tube or floating head design. When tube leaks occur in these heat exchangers, the two types are substantially different in the time required to repair them and return these units to service. In order to repair any exchanger, both ends of a leaking tube must be sealed.

U-tube heat exchangers allow reasonably easy access to both ends of a problem tube. Floating head design heat exchangers are considerably more difficult to repair, as the design does not incorporate a manway in the shell of the unit, in order to access the far end of a problem tube.

A traditional method of sealing tube ends in floating head heat exchangers, involves “dropping the floating head”, making the repair, and reassembling the unit.

A technique developed by Expansion Seal Technologies was used in lieu of the traditional methods during the Browns Ferry U2C9 Outage.

The subject floating head style RHR exchanger was plugged, by accessing one head, and positioning a hydraulically installed plug through the designated tubes to the far tubesheet. This resulted in considerable timesaving, along with a substantial reduction in man-rem.

INTRODUCTION

The Browns Ferry Nuclear Power Plant, located near Athens, AL is a three-unit plant powered by GE/BWR reactors. Currently one unit is in extended shutdown and the other two units are producing approximately 2200 Mwe. This facility is owned and operated by the Tennessee Valley Authority, and began commercial operation in the Mid 1970's.

An RHR heat exchanger, designated RHR Heat Exchanger 2B, was scheduled for Eddy current testing during the U2C9 outage. The RHR unit is a vertical, floating head design, with SA-249 Type 304 Stainless Steel Tubes, 3/4" x 18 BWG.

The Eddy current results showed four tubes should be plugged, three of which had greater than 90% wall loss and fourth tube was at 73% wall loss. The task of plugging tubes in this unit was extremely difficult using the traditional repair method. This involved the removal of the lower head, requiring maintenance staff use of several layers of c-zone clothing, possible facemasks, tents, and HEPA ventilation, due to the very high levels of contamination. These extensive contamination control requirements added to the difficulty of removing the heat exchangers bottom head in order to seal the tube ends. Using the traditional method, radiation exposure normally exceeds 5000 millirem to complete the repair. Due to the extended length of time this particular exchanger had been in operation, the estimated dose was projected at over 10,000 millirem.

An alternate technology was offered to the Browns Ferry facility by Expansion Seal Technologies of Harleysville, PA. This method eliminated the need to remove the floating head, and allowed the designated tubes to be permanently sealed from the accessible end. By removing only the upper head of the exchanger, there are fewer radiological restrictions, and a significant reduction in radiation exposure.

By using the EST technology, Maintenance personnel were able to complete the repair using only 71 millirem. The savings in man-rem alone were in excess of $75,000.00.

BACKGROUND

Due to the difficulties associated with the repair, a study was performed by BFN plant personnel comparing the possible repair strategies and their procedures.

PLUGGING OPTIONS:

1. Do Not Plug
   Advantages:
   - No immediate cost or resource expenditure.

   Disadvantages:
   - Tubes will leak (with possible radioactive contamination released to Tennessee River)

2. Perform Plugging as in Past History (drop bottom head)
   Advantages:
   - Performed in past
   - Procedure in place and TVA personnel can implement
   - Vendor manual specifies this method

   Disadvantages:
   - Poor working conditions (awkward welding)
   - Potential for damaging other components (bellows)
   - Rigging evaluation required
   - High personnel radiation dose (14 man-rem)
   - Time to implement plugging (~72 continuous hours)
   - Welding (QC – Inspection of each weld)

3. Through Tube Plugging—Pop-A-Plug
   Advantages:
   - Cost includes vendor person to install plug while demonstrating method to BFN personnel
   - Cost includes purchase of equipment
   - Has been successfully performed in nuclear applications
   - Demonstration at BFN was impressive per Maintenance
   - Good reputation among industry contacts
   - RHR temperature, pressure, and expansion is within sealing/holding pressure of plug
   - Estimated installation time <8 hours
   - Will provide assistance to complete QA and code paperwork

   Disadvantages
   - Estimated cost $5K
   - Never performed on a RHR HEX (has been installed on RBCCW HEX)
   - Could not verify integrity of plug by visual inspection
   - Owner of OEM name will not approve this method (will not change vendor manual)

4. Explosive Plugging
   Advantage:
   - Owner of the OEM name
   - Installed in other nuclear plant's RHR systems (never from opposite end)
   - Actually welds to tube ID
   - Estimated installation time ~12 hours

   Disadvantages:
   - Estimated cost $15K
   - Difficulty in supplying required safety-related paperwork
   - No QA program for this application
   - Always dropped bottom head when using explosive plugging (could possibly rig a wire)
   - Could not verify integrity of plug by visual inspection

5. Re-sleeving
   Advantages:
   - Maintains some functionality of the tube (flow and heat transfer)
   - Provides all paperwork (SA/SE, Code, QA)
   - Provides, in writing, equivalent amount of tube plugging for the re-sleeving work performed
   - Mechanical seals, no welding
   - Have done work for TVA (fossil plants)
   - Industry contact is complementary of work (none found installed in RHR HEX)

   Disadvantages
   - Estimated cost $70K
   - Do not usually install full length sleeves (at least 3 of the RHR HEX tubes need full length)
   - Estimated installation time 24 hours

After an evaluation the EST method was chosen. Although EST is an ISO-9001 company, and has supplied safety-related product to the nuclear industry for over 15 years, the following needed to be completed in order to use this technology in the Browns Ferry RHR heat exchangers.

Major Requirements:

- Safety evaluation (10CFR50.59)
- Work Order Document (step text)
- Audit of EST QA program
- ASME documentation and approval
- Addition of EST to BFN Approved Suppliers List
- Procurement Engineering Evaluation and Documentation
- QA review of work order document and supporting information

- Design Review to insure this HEX could continue to meet its design basis (FSAR, Vendor information, calculations, etc.
- Contingencies (If it did not work)

Minor Requirements:

- Site Training of EST personnel
- Escort for EST while on site
- Materials: Tools and Vendor Equipment

HOW THE PLUG WORKS

The CPI/Perma plug used, in this application, is based on the patented high-pressure tube plugging system, P2 (reference proceedings from Fourth BOP Symposium "An Improved Plugging System for HX Tubing"), developed by EST. The plug itself is a three-piece assembly, consisting of the following: (Figure 1)

- A tapered pin
- An internally tapered, externally serrated ring
- A breakaway

In near end applications, the plug is positioned in the rolled area of the subject tube, within the tube sheet region. Using an air over hydraulic tool, or manual tool, the annealed ring is held in place, while a center "Pull Rod", draws the pin through the annealed ring. As the pin is drawn through the annealed ring, the ring expands until it contacts the tube ID. The ring then slightly deforms along its serrations. At a predetermined force, the tensile strength of the breakaway is exceeded in the area which has been undercut to a specific diameter, (depending on the size and material construction of the plug), and the plug "pops". (Figure 2)

The CPI/Perma plug differs from the high pressure P2 plugs in two areas, the expansion capability and the pressure rating.
In order to have a successful "Through the Tube" installation, the plug OD must be small enough to pass through the unrolled middle of the subject tube, yet have enough expansion capability to seal the tube in its rolled area, within the tubesheet.

The pressure rating of the CPI/Perma plug is to 700 psi, compared to the 7,500 psi of the P2.

EQUIPMENT REQUIRED

1. Pop-A-Plug, Hydraulic installation Tool, with Air Regulator, and pulling studs. (Figure 3)
2. 20 feet of rod and tube extensions, to allow the plug to be positioned at the far end of the heat exchanger. (Figure 4)

3. A 3-foot Channel Head Pull Rod Assembly, to allow the hydraulic ram to be outside the Channel Head while installing plugs. (Figure 5)
4. A 30 foot Tape Measure, and 2 small locking pliers.
5. 20 pieces of V-627-E-QA plugs, 0.627” OD, Installation range 0.628” thru 0.690”, 304 Stainless Steel Construction.

TUBE CLEANING

After the tubes that need to be plugged are identified, the dirt and scale needs to be removed that may interfere with the plug passing through the tube. This may be accomplished by Hydroblasting, a tube cleaning machine, or High Tensile Brushes supplied by EST (Figure 6). The brushes are threaded onto the installation rods, and passed through the tube.

CALCULATION OF INSTALLATION DEPTH

The CPI/Perma Plug must be installed in the rolled area of the tube, within the tubesheet. It is recommended that the plug be positioned in the middle of the rolled area (Figure 7). To determine the proper installation depth, subtract one half of the far end roll length from the tubesheet to tubesheet dimension.

Tubesheet face to tubesheet face – 20 ft. = 240”.
Far end roll length – 4”
Installation depth = 240 – (1/2 x 4”) = 238”
(Figure 8)

PULL ROD ASSEMBLY

The Pull Rod Extensions are assembled to achieve the desired length, along with the Channel Head Pull Rod Assembly, and a “stand off ring” is positioned at the required installation depth. (Figure 9)

For “Through the Tube” applications, a pulling stud is used in lieu of the breakaway on the plug. In applications over 10 feet, the pull rod extensions are subject to elastic deformation, by the hydraulic ram used to install the plug.
If the breakaway was used, when the breakaway sheared, there is a possibility that as the rods return to their original length, the assembly could contact the ring of the plug, and affect the seal.

Once the assembly was complete, the plug was passed through the subject tube, and the Hydraulic Ram was installed. The ram was activated to a specific pressure as read on the pump’s gage. This pressure is based on the size and material of construction of the plug.

After the required pressure was reached, the hydraulic pressure was released, the ram was removed, and the assembly was unthreaded from the plug.
Once all the “Through the Tube” plugs were set, the near end of the tubes were plugged, using the Channel Head Pull Rod Assembly, and the CPI/PERMA plug, with the breakaway.

The exchanger was reassembled and made available for service
The total time to seal the four tubes was approximately 2 hours.
This compares to a minimum of 72 continuous hours if the repair was completed using the traditional repair method.

COST SAVINGS

The estimated savings using the EST method was over $100,000.00 (not including management costs) which included man-rem savings of $75,000.00.

ADDITIONAL EXCHANGER APPLICATIONS

In addition to the Browns Ferry RHR Heat Exchanger, the EST technology has been used successfully in the following “Through the Tube” applications.

Turbine oil coolers
Hydrogen coolers
Lube oil coolers
Chillers

REFERENCES

1. US Patent number 4,425,943
2. US Patent number 5,435,310
3. BFN Work Order 97-003912-001
4. TVA Bulletin Vol. XIII, No 6, January 1998
5. EST Energy News, Vol. 3 Issue 2, December 1997
6. EPRI BOP June 96, “An Improved Plugging System for HX Tubing”

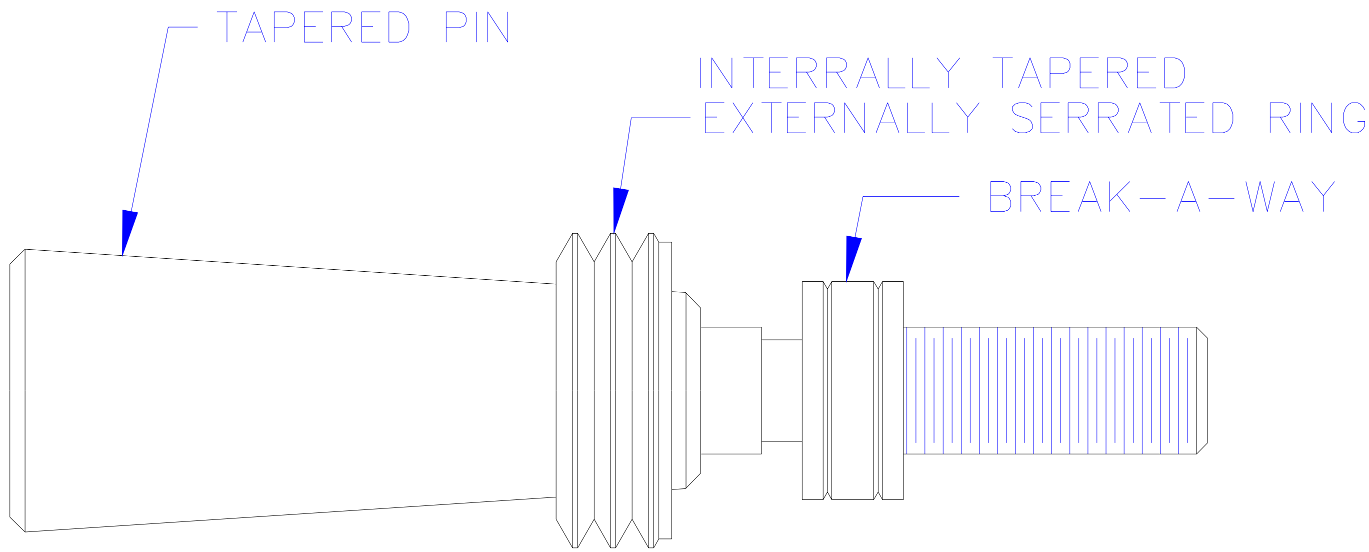
TAPERED PIN
INTERRALLY TAPERED
EXTERNALLY SERRATED RING
BREAK-A-WAY

Figure 1

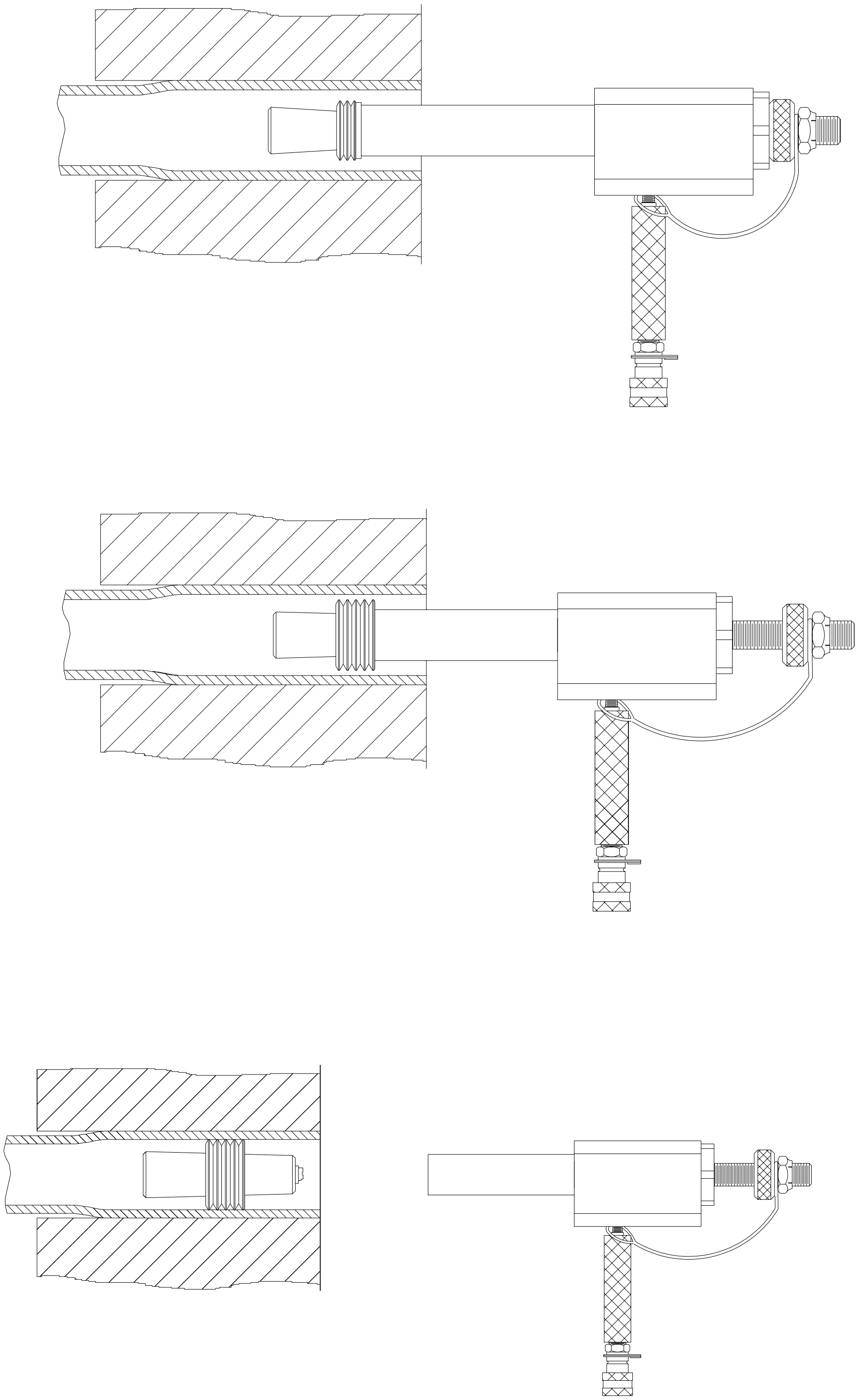

Figure 2

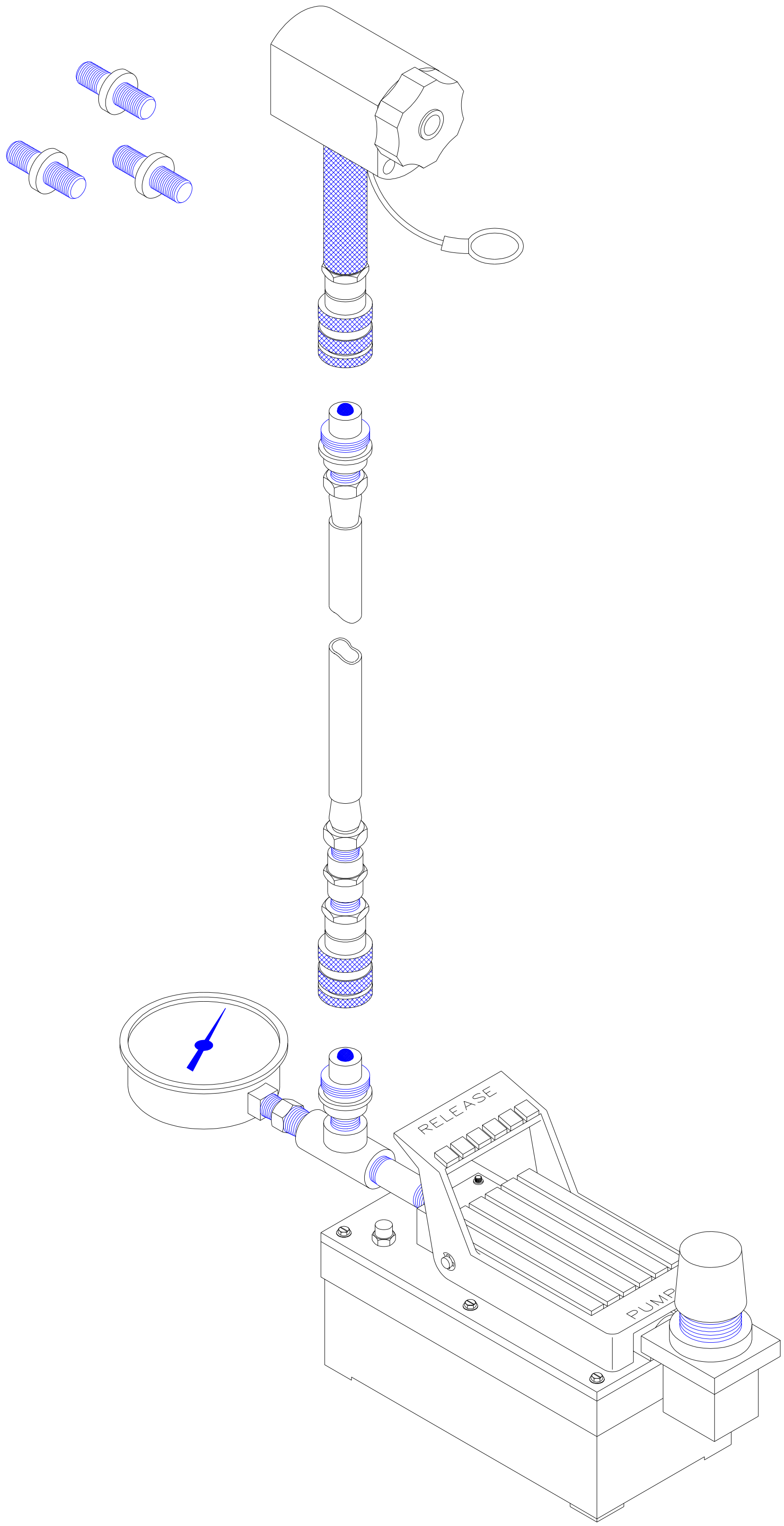

Figure 3

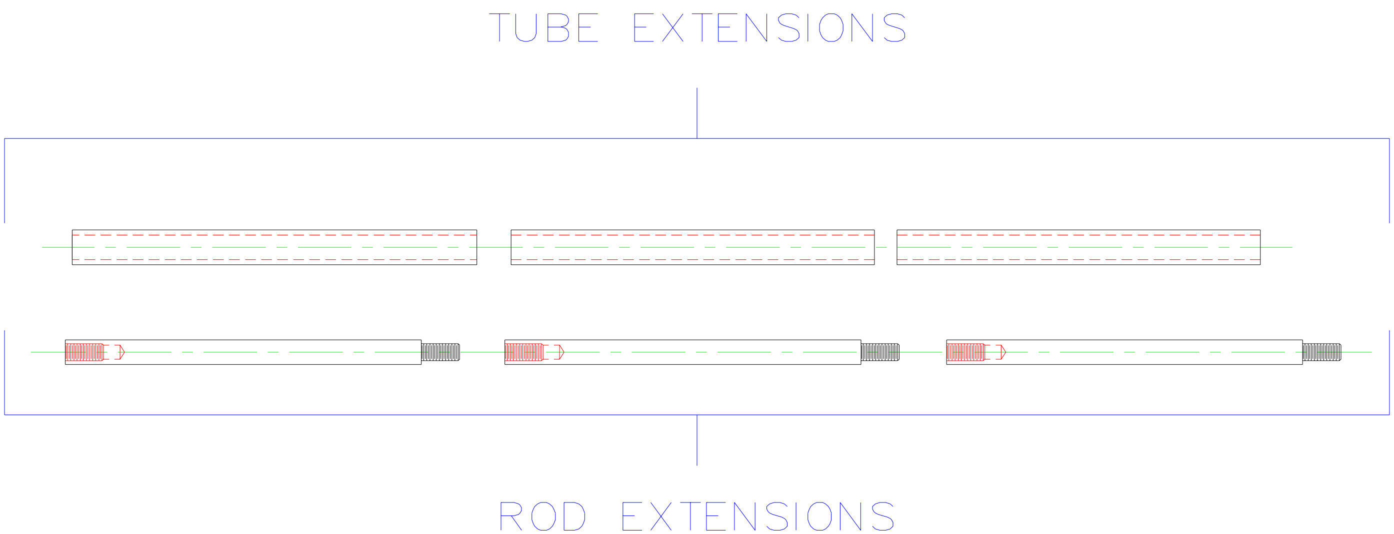

Figure 4

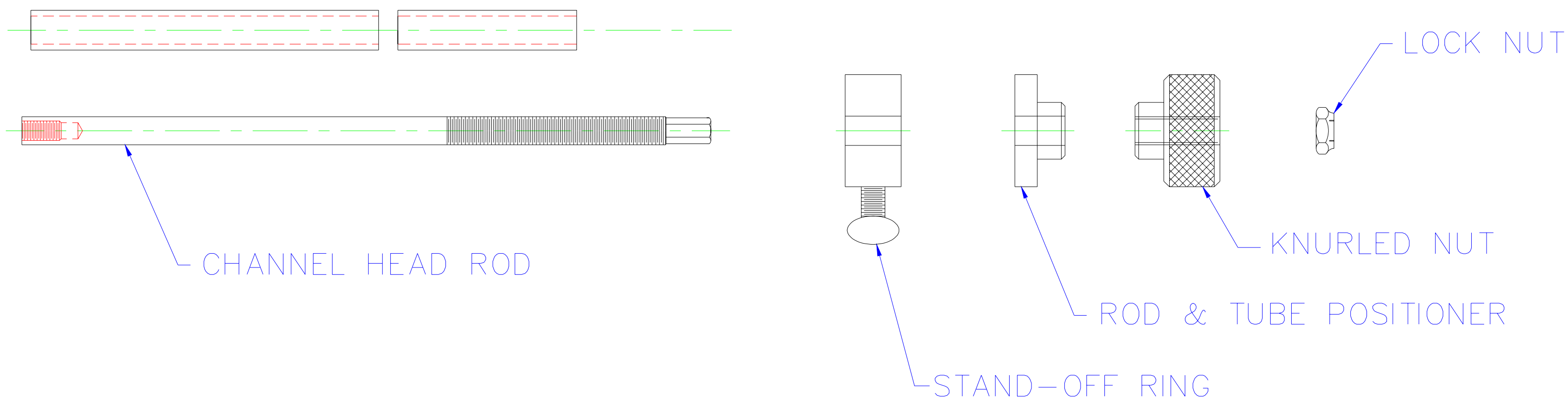
LOCK NUT
CHANNEL HEAD ROD
KNURLED NUT
ROD & TUBE POSITIONER
STAND-OFF RING

Figure 5

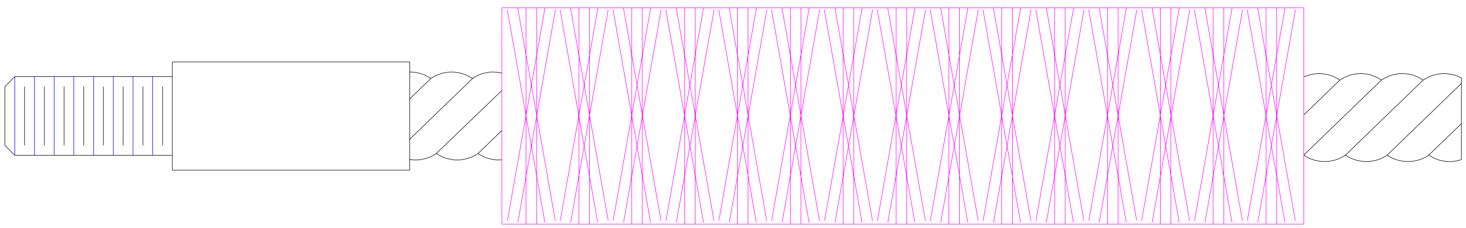

Figure 6

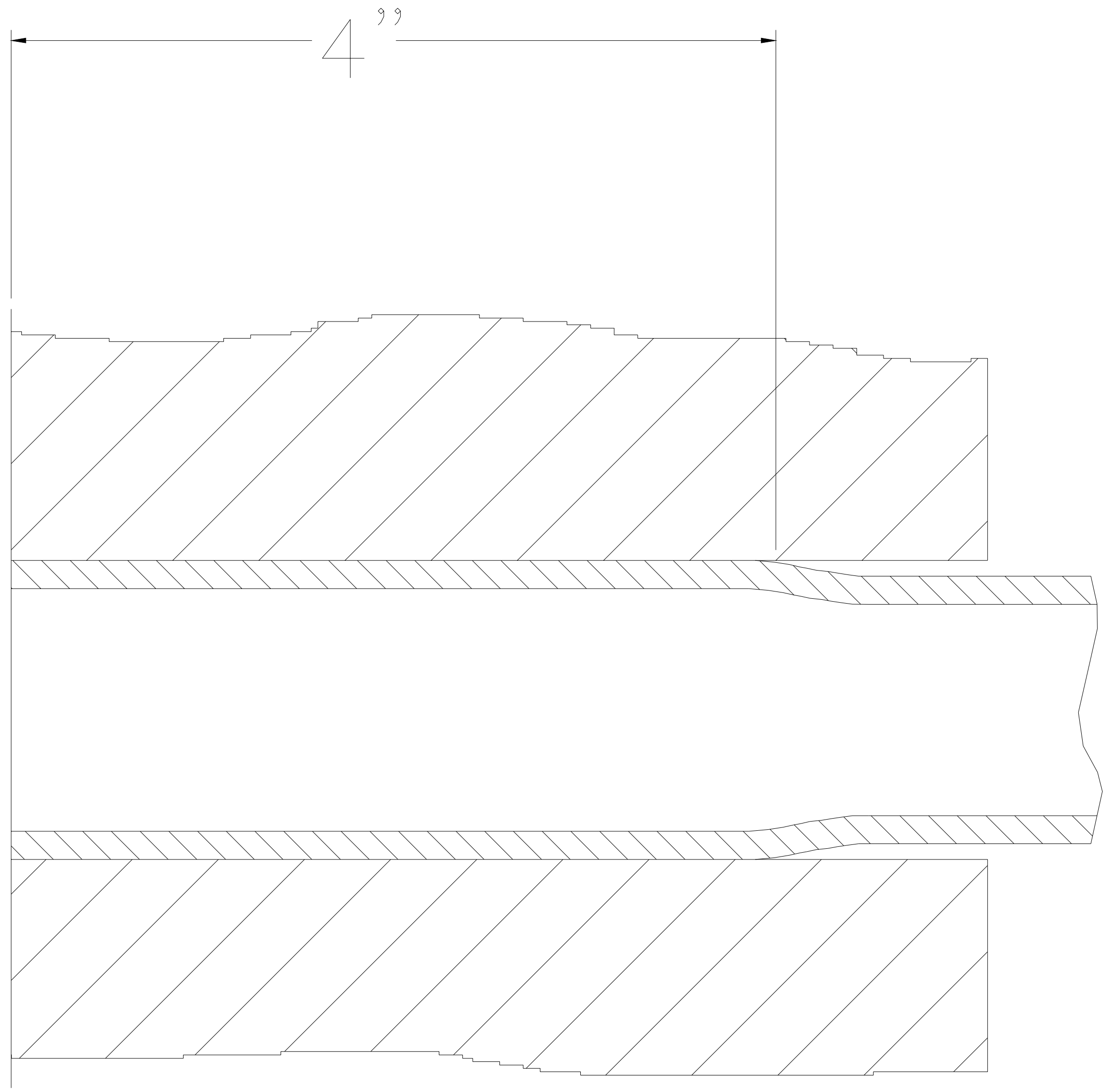

Figure 7

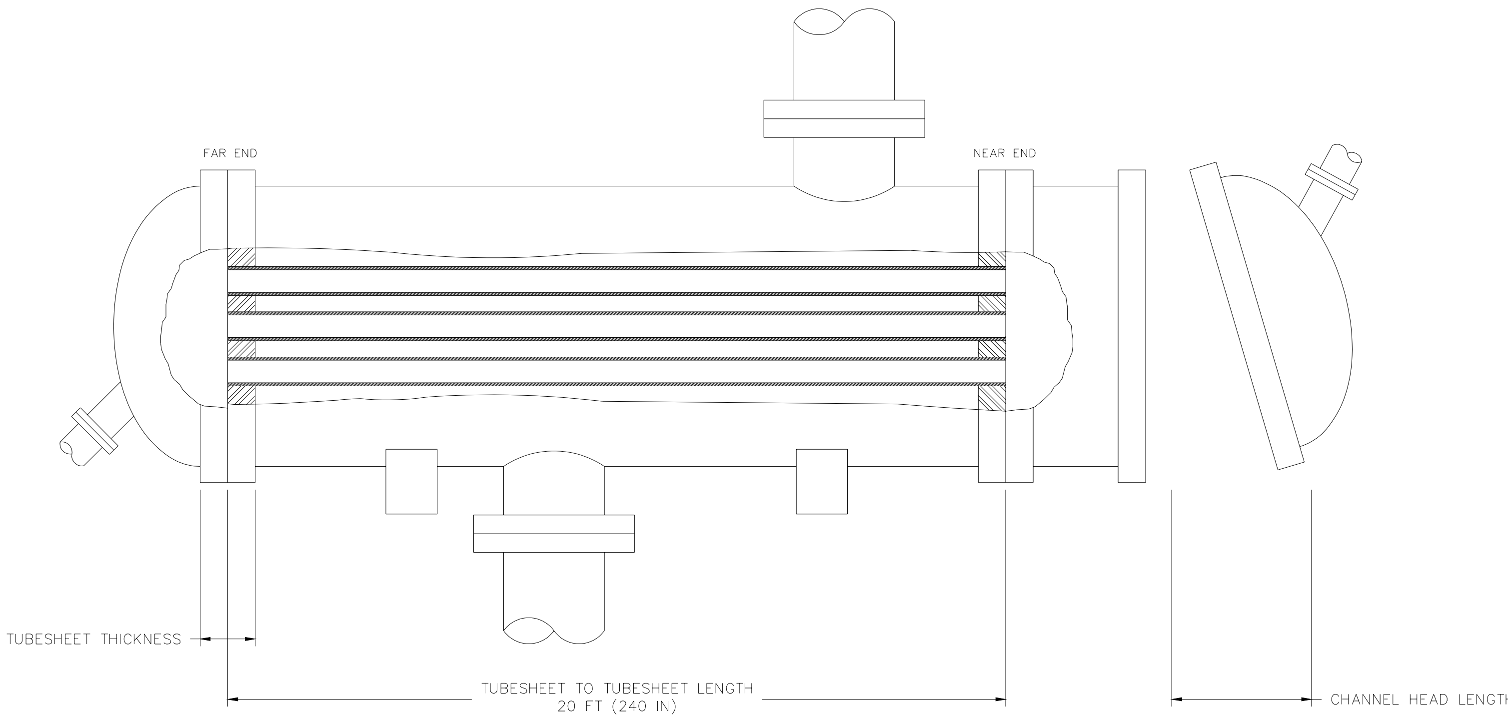
FAR END
NEAR END
TUBESHEET THICKNESS
TUBESHEET TO TUBESHEET LENGTH
20 FT (240 IN)
CHANNEL HEAD LENGTH

Figure 8

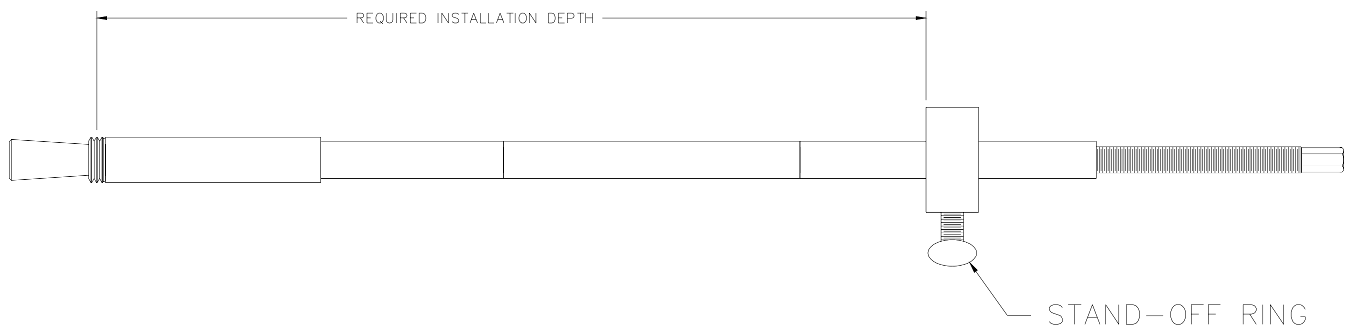

Figure 9

MECHANICAL TUBE PLUGS AND WELL-ANCHORED TUBE STABILIZERS AS A MEANS FOR HEAT EXCHANGER LIFE EXTENSION

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Abstract

The Pop-A-Plug II, or P2, mechanical tube plug was introduced to the utility industry at the EPRI BOP Conference in June 1996. The design objective was to produce a mechanical tube plug with the long term installed stability of a welded or explosively installed plug. This paper will update the performance history of the Pop-A-Plug® as well as update new developments and applications. We will also provide case histories documenting how the combination of Pop-A-Plugs and well-anchored cable, or solid rod type tube stabilizers significantly extends the life of plant heat exchangers.

Introduction

The second generation Pop-A-Plug® was introduced at the EPRI BOP conference in June of 1996. Introduced as "*An Improved Plugging System for HX Tubing*", the P2 was designed to meet or exceed the long term installed stability previously only available with welded or explosively installed tube plugs.

Early experiences at Davis-Bessie demonstrated that this new generation plugging system is substantially less costly than welded plugs. Savings, as compared to using explosively welded plugs, have also been documented at other power stations. However, the benefits of cost reductions are quickly forgotten if the performance objectives are not sustained.

By way of review, the P2 Pop-A-Plug is a three-piece mechanical plug, consisting of:

- A tapered Pin
- An annealed, Ring with external serration and internal serrations
- A Breakaway

The plug installs by threading the breakaway into a pull rod. The pull rod mounts into a hand-held hydraulic jack or Ram. The leaking tube is plugged by positioning the plug in the leaking tube, at the tube sheet, and activating the Ram. The ram pulls the tapered pin through the ring. The internal taper of the ring matches the taper of the ring.
The taper of the pin causes the ring to expand radially outward is a smooth uniform manner. Patented internal serrations on the ring control coefficient of friction and ensure that installation force goes to set the plug and is not consumed by friction. As the pin continues to travel through the ring, the serrations make contact with the tube ID. Continued travel causes the ring's external serrations to compress and mushroom against the tube wall like an expanding bullet. The serrations do not dig or bite into the tube. When sufficient force is generated to set the plug, an undercut on the Breakaway fails or "pops". The Breakaway controls the plugs installation force. The undercut on the

Breakaway is controlled so that every plug of the same size and material installs within 5% of the design installation force. Extensive testing by EST and Utilities alike, has shown that installation force is not sufficient to cause damage to tubes, tube sheet or surrounding ligaments.

The P2 Pop-A-Plug® entered the market as the most thoroughly engineered and tested tube plug ever developed. Testing included:

1. Metal creep tests.
2. Zero (0) to 8,000 psi (551 Bar) pressure cycle testing.
3. Thermal cycle testing.
4. Surrounding ligament stress tests.
5. Blow out testing in out-of-round tubes.
6. Blow out tests documenting blow out pressures of up to 20,000 psi (1379 Bar).
7. Helium Leak Tests showing leak tight integrity at greater than 1×10^{-11} cc/sec at a 35 psi (2.4 Bar) differential pressure.

However, the key to a successful installation is not only a function of the plug design itself but is also impacted by the delivery system. Be it painting a wall or plugging tubes, a successful outcome is a function of preparation. The P2 "kit" comes complete with, 10 plugs in individually sealed tubes, a tube prep brush and a Go/No-Go Gage. The prep brush acts as a fly cutter and will remove five to seven thousandths of an inch (0.005" to 0.007" / 0.13 to 0.18mm) of material. A 30 second brushing interval is usually sufficient to remove any tube defects and deliver a suitable plugging surface. Brushes are provided in two tensile materials. The low tensile brush is supplied with Brass and 90/10 CuNi plugs. High tensile brushes are supplied with Carbon Steel, Stainless Steel, Monel, 70/30 CuNi and harder plug materials. To differentiate the two the tip of a high tensile brush is painted blue. A low tensile brush is unpainted. The provided Go/No-Go Gage also ensures that the proper size plug is selected to match the tube ID. A short form installation instruction is included with this document, however the installation steps can be summarized to include:

1. Determine theoretical tube ID from HE data sheet, past plugging history or actual measurement.
2. Verify tube material from same source.
3. Verify heat exchanger tube and shell side operating temperatures and pressures. The P2 is generally rated to 7000 psi (480 Bar) at 700 degrees F (371 deg C). This actual rating is material dependent and may be higher or lower depending upon actual plug size and material. Higher ratings are available on a consult factory basis.
4. Use the collected data to select a plug size and material to match the tube. Each plug has a 0.020 inch (0.5mm) expansion range. One of the unwavering "ten commandments" of plug installation is that the plug material must match the tube material. Now would also be a good time to determine tube sheet thickness and determine the plug installation depth, and to plan for the contingency of having to remove a severely deteriorated tube and plugging directly into the tube sheet hole. If it becomes necessary to remove the tube

and plug into the tube sheet be wary of a material change. Tube and tube sheet material are not always the same.

5. Gather plugs and installation equipment. If the tubes are welded, a tapered reamer should be available to remove any weld material that may obstruct the tube ID and fool the Go/No-Go Gage. Many utilities store installation ram, pullrods, reamers and plugs in a rolling cart that keeps everything together and can be moved to any heat exchanger needing service. Such a cart may also include tube test guns.
6. Once at the heat exchanger in question inspect the work area. Ensure that all safety precautions are in place, i.e, proper tagging and lock out. Other considerations include: is there a channel head present? Is there a division plate to contend with? Are the leaking tubes properly identified and marked? Are the leaking tubes accessible or are they up against a partition plate or in the outer most ring of tubes adjacent to a channel or hemi-head.
7. Inspect the tubes to be plugged. If the tubes are welded, remove any weld bead or eyebrow. Failure to remove weld droop will lead to an inaccurate gagging by causing the use of a gauge small enough to clear the weld bead. This will most likely lead to selection of an undersized plug. Installation of an undersized plug will almost always leads to a plug that will leak initially or after thermal or pressure cycles.
8. Measure the tube ID with the Go/No-Go Gage supplied with each kit of plugs. The small "Go" end of the gage should fit in the tube through the planned installation depth and the large No-Go end should not. Each gage is stamped with the corresponding brush and plug size.
9. Once use of the Go/No-Go Gage has confirmed the required, plug size, remove the tube prep brush also supplied with the plugs and brush the tube. Approximately 30 seconds of brushing will size the tube end; remove tube defects; reduce the ovality of an out-of-round tube; and provide an improved sealing surface for the plug.
10. After brushing the tube inspect it to ensure all defects, cracks pitting, etc. have been removed. It is occasionally necessary to use successively larger brushes to completely remove all defects.
11. Gage the tube a second time after brushing. Brushing is intended to remove 0.005 to 0.007 inch (0.13 to 0.18mm) of material. Brushing may remove enough material to require moving up to the next larger plug size.
12. Once the tube is adequately prepared, thread the selected plug into the matching pull rod assembly. The pull rod should already be mounted in the hydraulic installation ram. Attach safety cable to the back of the pull rod.
13. Check that the ram is properly assembled and that it is connected to a source of shop air.
14. Position the plug in the tube to be plugged at the desired installation depth.
15. Step on the foot pedal of the hydraulic pump. The ram will stroke and pull the pin through the ring, expanding the ring and sealing the tube. As the ram strokes watch the pressure gage on the pump. The Breakaway on each plug is undercut to break at a specific pressure. The Breakaway should pop when the gage reaches the appropriate pressure. If the needle on the gage passes the

breakaway pressure and then quickly exceed 6000 psi (413 Bar) on the first stroke of the ram you will need to make a second stroke.

16. Step on the foot pump release. The ram will relax its stroke. Tighten the knurled nut on the pull rod to take up any slack in the pull rod. Stroke the ram again. The Breakaway should pop on the second pull. If the breakaway does not pop on the second pull there is a good chance the plug is undersized. Disconnect the pull rod. Even though the plug seems tight is will not hold pressure. Follow the plug removal procedure and repeat the process using a larger brush and plug.
17. After the Pop-A-Plug® has been installed, the fractured section of the breakaway remaining in the nose of the plug should be removed. Although experience indicates that the breakaway stub will not unthread during normal heat exchanger operating conditions, the best practice is to remove the breakaway stub after installing the plug.

In tracking 12 years of installations the P2 Pop-A-Plug® has repeatedly demonstrated that it has exceeded all performance expectations. We must quickly add that the Pop-A-Plug has also demonstrated repeatedly that **In order to ensure a successful installation, the tube must be adequately prepared to eliminate defects, and the correct plug size must be determined by accurately measuring the tube. Failure to follow these guidelines may result in plug leaks.**

While the P2 Pop-A-Plug® was making its way in heat exchangers throughout the utility and other industries, product development continued. The range of installation tools expanded to include a robust Manual Installation Tool, a Close Quarters ram and an Outer Perimeter Tool. The Manual Installation Tool provided for quick and easy installation of a few plugs using just a manual crescent wrench or the ever-present impact wrench. The Close Quarters ram facilitated the installation of a Pop-A-Plug along the outer perimeter of hemi-head heat exchangers. The Outer Perimeter Tool enabled working in even tighter quarters including up under angled division plates.

In addition to tooling variations of the P2 Pop-A-Plug® also expanded the reach of the design into other critical heat exchangers. A medium pressure plug, named CPI Plug™, was developed. The CPI™ Plug differs from the P2 in that it has a shortened pin with a higher taper angle. This delivers a high expansion range of 0.060 inch (1.5mm) and working pressures to 1000 psi (69 Bar). It also has fewer but wider and deeper serrations to provide better sealing in less than perfectly clean tubes. The high expansion range also enables a technique known as Through-the-Tube Plugging™. This technique enables plugging of the back end of a straight through, floating head, exchanger without having to remove the back head. This technique has found a wide acceptance in the plugging of turbine oil coolers and hydrogen coolers. The CPI Plug design further evolved into the Perma Plug™, a lifetime warranted, all metal tube plug for condensers, balance of plant and service water heat exchangers. . The shortened pin of the Perma Plug does not protrude past the face of the tube sheet enough to interfere with any type of mechanical leak test. There is not sufficient interference to allow build up or foreign object damage. Removing hundreds and even thousands of deteriorating elastomer and both metallic and non-metallic hammer-in taper plugs and replacing them with Perma Plugs has been the salvation of numerous condensate and service water systems.

Tube Stabilizers

The reliability of the Pop-A-Plug system has also found its way into a unique and unexpected application. When mated to one end of a solid rod or cable the Pop-A-Plug becomes the means to firmly hold a length of rod or cable in place within a damaged or fractured heat exchanger tube.

This type of repair is typically indicated in situations where tube OD damage has been caused by improperly designed or installed impingement plates, or where the tubes are subjected to abnormal flow induced vibrations leading to fracture or tube fretting at tube support plates. If these conditions are allowed to continue broken or fractured tubes will vibrate and oscillate striking and damaging adjacent tubes, causing them to fail. Literally the heat exchanger will begin consuming itself from the inside out. Historically the operator was limited to a number of costly alternatives – change the flow characteristics; redesign and replace the impingement plate; prematurely plug several rows of tubes allowing the tubes to act as sacrificial elements or attempt to strengthen or stabilize the affected tube from within. The latter is often judged the least expensive alternative and the tube stabilizer concept was born.

A tube stabilizer is a length of segmented rod or cable that is inserted into a damaged or fractured tube in order to strengthen the tube and reduce the collateral effects of further damage and wear. Tube stabilizers are basically either of two design types, a rod type or cable type. Rod type stabilizers are an assembly of a series of solid stainless steel rod segments that are threaded together successively increasing the overall length until the rod is long enough to reach through the tube support plate beyond the damaged section of the affected tube. Cable stabilizers are simply a length of stainless steel cable long enough to reach from the tube end to beyond the damaged section. Rod type stabilizers provide greater tube fill capability (they can be manufactured closer to the actual tube ID) where cable types offer a greater degree of flexibility and therefore can be more easily inserted in the tight confines of a limited access channel head or hemi head heat exchangers.

In recent years the limitations of simply inserting solid rod or cable into a damaged tube have been noted. A blunt rod will not be able to "pick-up" the disjoint end of a severed tube and the unrestrained tube ends may continue to freely whip around, damaging adjacent tubes. The cut ends of the cable easily unravel and often lead to the cable becoming jammed during installation. The lack of a simple means to fix or anchor the stabilizer in position has lead to stabilizer movement or migration within the tube. This movement is the result of ongoing vibrations or stresses incurred during thermal cycling. In some cases loose stabilizers have forcibly pushed out tube plugs leading to unexpected tube leaks. In one reported case a cable stabilizer actually exited the tube in which it had been installed and made its way out of the heat exchanger before lodging in a piece of equipment downstream.

A stabilizer anchor provides the means to firmly fix one end of the tube stabilizer assembly in position thereby limiting movement of the stabilizer within the tube. EST has adapted Pop-A-Plug technology to create an effective anchor, see Figure 1. EST's Stabilizer Anchor consists of an appropriately sized Pop-A-Plug inside a thimble. The thimble is drilled and tapped on the end opposite the plug so that it can be threaded onto the end of the stabilizer rod or cable assembly. Pop-A-Plug Anchors are sized very much like P2 Pop-A-Plugs - they are available in 0.020" (0.5mm) increments to fit tube ID's ranging from 0.501 inches to 0.980 inches (12.7 to 24.8mm). The Anchor is set using a Pull Rod assembly and the same hydraulic ram that is used to install Pop-A-Plugs. As the plug is pulled the ring expands within the thimble and the thimble within the tube effectively locking the stabilizer assembly in place. Since the anchor body is smooth and the anchor installation may occur beyond the tube sheet the anchor should not be relied upon to seal the tube. Once the anchor has been set, Pop-A-Plugs are typically installed at either tube end to seal the tube.

Figure 1. Pop-A-Plug Tube Stabilizer Anchor Assembly

In addition to either the rod or cable type stabilizer EST offers two tip configurations, a wedge type and a bullet type, see Figure 2. The wedge type is used to help capture and realign broken tubes. The bullet type is more commonly used. Stabilizer tips like stabilizer rods are available in any length in order to accommodate tube end clearance limitations – typical tip / segment lengths range from 1 foot to 6 feet (304 to 1829mm).

Figure 2. Tube Stabilizer Tips, Wedge Type (top) and Bullet Type (bottom)

The cable ends are swaged to prevent them from unraveling and provide attachment points for the stabilizer anchor and tip. Cable stabilizers can be provided fully assembled or in individual components that can be assembled on the job. This provides the utility extra flexibility in that bulk cable can be cut and swaged on the jobsite. This can be a critical time saver during an outage when the extent of required stabilization may not be known until the exchanger is opened and inspected.

Preparing for and performing a typical Pop-A-Plug Tube Stabilizer installation is outlined as follows.

Preparation (refer to Figure 3)

1. Determine the location of tube weakness or fracture.
2. Determine the distance from the inner tube sheet face to the tube support plate beyond the damaged or fracture point. Subtract from this length 2.75 inches (69.9mm) to establish the overall stabilizer length. If the point of velocity impingement is not well defined it is suggested that the stabilizer be sized to run the full length of the tube. In this case an additional allowance must be made for the change in length of the rod or cable during thermal cycles.
3. Select the stabilizer type: rod or cable. If the rod style is chosen pay particular attention to the distance, measured along the tube axis, between the outer tube face and the head. This measurement provides guidance in determining the overall rod segment length.
4. Determine the stabilizer tip type; wedge or bullet. Wedge type tips are used to capture and realign severed tube ends. Bullet tips are used in most other installations.
5. Based upon tube OD and wall thickness data from the data sheet or from actual measurements determine the correct Stabilizer Anchor size and rod or cable diameters.
6. Order stabilizers and installation equipment.

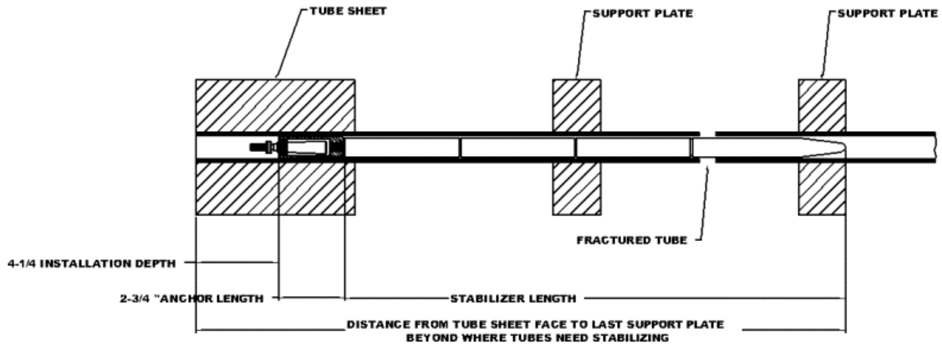

Figure 3. Tube Stabilizer Layout

Installation (refer to Figure 3)

1. Clean the tubes to facilitate installing the stabilizer components.
2. Insert the stabilizer tip. On a cable installation gently feed the cable into the tube. On rod type installations, thread together successive length, make certain there is a star lock washer between segments, use thread locking agent if permissible, tighten using locking pliers and move on to the next segment.
3. Attach the stabilizer anchor, use lock washer, thread locking agent if permissible and tighten using locking pliers. Feed the stabilizer assembly to the desired installation depth. A minimum installation depth of 4.5 inches (114.4mm) is necessary to ensure being able to install a tube plug after stabilizing.
4. Once the cable or rod and anchor are positioned in the tube, thread the pull rod into the breakaway of the anchor, mount the pull rod in the small ram and stroke the ram as if you were installing a Pop-A-Plug. Remove the breakaway stub.
5. Install Pop-A-Plug tube plugs.

Refer to the most recent copy of EST Document DC1050 for further instruction or contact EST directly.

Once tubes are stabilized and plugged they provide a substantial barrier to further impingement and vibration induced and virtually eliminates the possibility that fractured tubes will damage surrounding tubes.

References:
"*An Improved Plugging System For HX Tubing*", presented at EPRI BOP Conference, June 1996, Gerald M. Wolf-Davis Bessie NGS and Robert B. Adams-EST Group, authors.

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