NEDO-32291
Supplement 1
DRF AXX-xxxxx
Class I
February 1997

# DRAFT

BWR Owners' Group
Licensing Topical Report

# System Analyses For The Simplification Of Selected Response Time Testing Requirements

Work Performed for the BWR Owners' Group
Response Time Testing Committee
NRC Project 691

## B.3 GE Type HFA 120 Vac Relay Failure Modes and Effects Analysis (FMEA)

### B.3.1 FMEA Results

#### *B.3.1.1 FMEA Applicability*

This FMEA addresses GE Type HFA 120 Vac Relay Model Numbers HFA51, HFA71, HFA151, and HFA171. Specifically, the results and conclusions apply to the following equipment:

a) Any GE Relay Model Number 12HFA51A49 or 12HFA71A49A

b) Any GE Relay Model Number 12HFA51A62

c) Any GE Relay Model Number 12HFA151A9 or 12HFA171A9A

#### *B.3.1.2 Bounding Response Times*

The maximum undetected response time of the relays is 40 ms provided Technical Specification Functional Tests (or equivalent) are performed and include the relay, and provided the following conditions are met:

a) The HFA manufacturer's instructions are followed for setup and adjustment of the relay prior to initial operation and after any repair or maintenance, and

b) Prior to installation or after any maintenance or repair of the relays, the normally open contacts of the relays are confirmed to open in 20 ms or less after power is removed from the coil.

Provided these conditions are met, all credible failure modes identified that increase response time to more than 40 ms also affect normal functioning of the trip unit, and thus are detectable by tests other than RTT. Even for the identified "undetected" failures, operating history indicates that they are not a probable failure. Even though some performance problems have been identified in the past, all were identified by tests or actions other than response time tests.

Based on this analysis, it is reasonable to conclude that any failure of a subject relay which has met the conditions of this section that could result in response times greater than 40 ms is not credible.

### B.3.2 Analysis

#### *B.3.2.1 Equipment Analyzed*

A GE 120 Vac Type HFA Relay, Model No. 12HFA51A49F was selected for detailed analysis.

#### *B.3.2.2 Similarity Analysis*

The relay analyzed is a Model No. 12HFA51A49F relay. The "F" suffix indicates a semi-flush mount case design. The basic model also comes with no suffix indicating surface mount with rear connections and an "H" suffix indicating a surface mount case with "front" connections (actually

on the side). The only difference between the "F" case and the "no suffix" case or the "H" case is the actual molding and shape of the exterior of the case. The "H" case also differs in the routing of the external contact connection points. The "H" case has the external connections for the contacts routed out to the side compared to the rear for the "F" case. All of these models have the same relay, coil, contacts and return spring mechanisms, so the differences do not result in any different failure modes than those analyzed, and the conclusions of the analysis may be applied to all equally.

A model 12HFA71A49A relay is the same as the analyzed model except that it is mounted in a "drawout" case. This difference, like for the suffix "H" model, affects only the external molding and shape of the case, and the connection details external to the basic relay case. This model also has the same relay, coil, contacts and return spring mechanisms as the analyzed relay, so the differences do not result in any different failure modes than those analyzed, and the conclusions of the analysis may be applied to this model as well.

Relay Models 12HFA51A62 are the same as relays with a "49" following the "12HFA51A" base number except that the coil rating is 125 Vac, 60 Hz (vs. 115 Vac, 60 Hz for the analyzed model). The differences between this model and the model analyzed are limited to the coil only. This could result in slightly different failure limits for some operating conditions, but none that affect the response time of the relay in the de-energized direction. Therefore, the conclusions of the analysis may be applied to these models as well.

Models 12HFA151A9 and 12HFA171A9A differ from Models 12HFA51A49 and 12HFA71A9A, respectively, only in the coil design. For the 12HFA151 and 171 relays, the coil has different materials for longer life and is rated nominally at 120 Vac, 60 Hz (vs. 115 Vac, 60 Hz for the analyzed model). These differences could result in slightly different failure limits for some operating conditions, but none that affect the response time of the relay in the de-energized direction. Therefore, the conclusions of the analysis may be applied to these models as well.

All relay models may have supplemental codes indicating the contact configuration of the relay as supplied from the factory. However, the contacts are designed to be field changeable, to the field configuration can be any combination of one or more normally open and up to five normally closed contacts (for the cases covered by this analysis, at least one contact is configured as a normally open contact). The analysis assumed the both limits, i.e., all normally open and all normally closed, so the conclusions of the analysis apply regardless of installed contact configuration.

Some of the above discussed relay models have been upgraded with improved coil assemblies since original delivery. These differences could result in slightly different failure limits for some operating conditions; but none that affect the response time of the relay in the de-energized direction. Therefore, the conclusions of the analysis may be applied to these upgraded models as well.

### *B.3.2.3 Review of Operating Experience*

The review of operating experience documented in Ref. 9.1 shows that there have been several types of problems with HFA relays, some of which had the potential to impact response time of the relay. However, most of those problems were detected by functional tests of the relays.

Appendix D includes a summary of identified HFA relay problems that were detected based on response time. Item 8 in Table D4.1 applies to the GE HFA set of relays and documents a total of 3 identified failures detected by response time degradation.

The problems were detected in the Turbine Valve Closure function in the RPS. The description does not say which specific function, but does state that the loop was "marginally outside acceptance criteria". The Turbine Valve Closure functions have response time requirements on the order of 80 ms or less. Therefore, it is reasonable to conclude that the actual times measured for the "failed" loops were on the order of 100 ms.

The experience data available lacks some specific details necessary to reach absolute conclusions regarding detectability of degraded response time conditions. However, due to the very small number of reported cases of relay failures detected by response time testing, the relatively large number detected by other surveillance testing, and the fact that all of the identified failures detected by response time testing were for a very short response time function, it appears reasonable to conclude that failures that result in increases in response time but that do not result in functional failures are very likely to result in only very small increases in response time.

### *B.3.2.4 Detailed Analysis*

#### B.3.2.4.1 Description

The GE Type HFA, a semi-flush mount multi-contact auxiliary relay Model No. 12HFA51A49F, includes a fixed coil/core assembly and the fixed half of six contacts mounted directly to a housing, and a moving armature/contact assembly held against pivot points on the housing by an adjustable spring/screw assembly and an armature stop mounted to the housing. Feedthroughs molded into the housing pass the electrical connections from the front side of the housing to the rear of the housing. "Pins" protrude out the rear side of the feedthroughs to form the connection terminals to the relay. A cover with a "window" covers the front of the assembly with a view of the armature/contact assembly through the window.

The whole assembly is approximately 6.5 inches wide by 7 inches high. The housing is approximately 4.5 inches deep with the contact pins protruding approximately 1.5 inches further to the rear. The cover protrudes approximately one inch to the front of the housing. The relay mounts through a panel with the window visible from the front.

The coil connects via short leads to their associated feedthroughs. The fixed half of the contacts which connect directly to their associated feedthroughs are reversible to form either a normally open (N.O.) or normally closed (N.C.) contact arrangement. Small "braids" connect the moving

half of the contacts, those mounted on the armature/contact assembly, to their associated feedthroughs in the housing.

The armature/contact assembly is a "sandwich" assembly of two molded plastic parts, six contacts with one end each attached to the small braid, a metal armature piece and twelve springs, two for each of the contacts. The molded plastic pieces are about 4.5 inches long and extend essentially for the width of the relay. The sandwich assembly is approximately 0.7 inches thick (depth) and 1.2 inches high with the armature piece attached to the back of the assembly. The contacts pass parallel to each other between the two plastic pieces which also support the two springs for each contact and extend approximately 1.6 inches beyond the molded plastic top of the sandwich, across the space occupied by the coil/armature assembly, to the fixed contacts. The springs provide the closing force for the contacts, which are relatively ridged, one spring for each direction of the contact (N.O. or N.C.). To the armature piece attached to the back of the armature/contact assembly is nominally a triangle with the corners cut off, and a rectangular "tail" in the direction away from the contacts. In the normal mounting configuration, the tail is down and the contacts point up. The bottom of the armature plate at the tail is a small "stop" bracket.

The two lower corners of the armature piece rest on two "chair-like" seats molded into the housing, each approximately 1/4 inch square. These seats are on either side of one end of the core piece, and form the pivot point for the armature. The back of the "chair" limits the downward travel of the armature/contact assembly while the small bracket on the bottom meets the pole piece to limit the upward travel. The housing limits the travel of the armature/contact assembly to the side. When the relay is energized, the armature/contact assembly is held firmly in place by the magnetic field.

The armature return spring has one end connected to the housing and one end connected via an adjustable attachment to the "tail" of the armature. This spring holds the armature open when the relay is not energized. A "stop" bracket mounted to the housing next to the fixed contacts extends over the end of the armature plate and with an adjustable stop limits the travel of the armature in the open direction. The core pieces limit the armature travel in the closed direction.

The pick-up voltage of the relay is set by adjusting the armature/contact return spring. The maximum armature opening distance is adjusted by adjusting the "stop". This determines both the maximum travel in the direction to close N.C. contacts, and the travel required to close the armature when the relay is energized. The contact position between open and close is adjusted by bending the moving contacts.

The pick-up voltage, the contact positioning, and the armature travel indirectly determine the operation time of the relay contacts. There is no direct adjustment of response time.

### B.3.2.4.2 Results of FMEA

GE Type HFA relay FMEA results are tabulated in Table B.3-1 and Table B.3-2. All credible failure modes identified that increase response time more than approximately a factor of 2 also affect normal functioning of the relay, and thus arre detectable by tests other than RTT. This

conclusion assumes that Technical Specification Functional Tests are performed and include the relay, and that the manufacturer's recommended setup and adjustment procedures are followed.

Even for the identified "undetected" failures, operating history indicates that they are not probable failures. Even though a number of performance problems have been identified in the past, all were identified by functional tests, not response time tests. This result is reasonable due to the simple basic design and the high degree of interaction between mechanisms that affect response time and those involved in normal functioning of the relay. Based on this analysis, it is reasonable to conclude that any failure or degradation of the relay that could result in an increase of more than a factor of 2 in the "de-energize" response time (drop out time) is not credible provided the utility has implemented the vendor recommended adjustment procedures following any replacement or repair of the relay.

#### B.3.2.4.3 Bounding Response Times

There is no vendor's specification for response time for the HFA 120 Vac Relay models covered by this analysis. However, GENE's acceptance criteria for the relay is 60 ms maximum for closure of a normally closed contact and 20 ms maximum for opening of a normally open contact, both measured from the time power is removed from an energized relay. For the RPS and Isolation circuits, all relays in the trip path are energized in the non-tripped state and utilize the normally open contacts (contacts open and relays de-energize to transmit the trip condition). GENE qualification testing of GE HFA AC relays showed operation times of 9 ms (vs. specification of 20 ms) and 17 ms (vs. specification of 60 ms) (Ref. 9.5). Based on this FMEA, the worst case expected delay for the HFA Relay is a factor of 2 increase over nominal.

The similarity analysis concludes that differences between relays covered by this analysis do not affect the detectability of response time degradation. Using the specified maximum of 20 ms for a normally open contact, which should be conservative, the worst case expected delay from the HFA Relay is 40 ms (normally open contact, relay changing from energized to de-energized). No additional margin is judged necessary for the HFA Relay, provided the relay to which the results of this analysis are applied has an initial acceptance criteria of 20 ms maximum opening time for normally open contacts (from energized state), and such criteria is applied for any replacement relays or after repair or maintenance of a relay.

### Table B.3-1 - GE Relay Type HFA Principle Design Components and Their Primary Function

| Item | Description | Function |
|---|---|---|
| 1. | Housing | • Provide the pivot "point" for the armature/contact assembly.<br>• Retain one end of the armature/contact return spring.<br>• Provide mechanical support for all of the components.<br>• Limit the lateral travel of the armature/contact assembly.<br>• Position the core assembly which in turn limits the armature/contact assembly travel.<br>• Position the fixed contacts. |
| 2. | Cover | • Provide a dust cover<br>• Prevent personnel contact with electrical contacts<br>• Prevent foreign object entry into the relay mechanism |
| 3. | Armature/Contact assembly molded plastic parts, overall assembly | • Position the contacts relative to the armature.<br>• Position the contacts.<br>• Hold the contact springs.<br>• Limit the travel of the contacts. |
| 4. | Moving contacts and "extension" braid | • Make (N.O. contacts) or interrupt (N.C. contacts) the circuit when relay is energized, and conversely when relay is de-energized.<br>• Connect to the feedthroughs in the housing (braid)<br>• Transfer contact "wiping" force from contact springs |
| 5. | Springs for moving contact | • Provide wiping and seating force for the contacts<br>• Provide margin for contact adjustment variation |
| 6. | Armature plate with attached "stop" bracket | • Provide closing force for the relay contacts when relay is energized via item 3.<br>• Transmit the opening force from the armature/contact return spring to the to the contacts when the relay is de-energized via item 3.<br>• Limit the travel of the armature/contact assembly when the relay is de-energized (limits travel of contacts) via item 8.<br>• Provides the pivot point for the armature/contact assembly<br>• Limits the travel in two directions of the armature/contact assembly<br>• Completes the magnetic circuit for the relay. |

## B.7 RPS Scram Contactor Relay Failure Modes and Effects Analysis (FMEA)

### B.7.1 Contactor FMEA Methodology

The RPS Scram Contactors are common to all RPS scram instrument loops. Therefore, a test of any RPS scram instrument loop tests the RPS Scram Contactors.

This FMEA does not directly address failures of the RPS Scram Contactor, but rather assumes that failures can occur that affect response time of the contactors. This FMEA focuses on identifying RPS scram instrument loop RTTs that are expected to be retained by the utility, and analyzes those RTTs to determine the bounding values of RPS Scram Contactor response time that can result without detection by those retained RTTs.

Specifically, this analysis identifies retained RPS scram instrument loop RTTs, identifies the acceptance criteria (maximum time allowed) for the RTT, and subtracts from that the response time for loop components other than the RPS Scram Contactor in order to establish the response time for the RPS Scram Contactor. In order to determine the bounding maximum credible RPS Scram Contactor (that still passes the RTT), the minimum credible response time for the instrument loop components other than the RPS Scram Contactor is established and used in this analysis.

This methodology assumes that the utility performs the retained RTT as a total loop without intermediate measurements. In some cases utilities perform the retained RTT in overlapping partial tests. In those cases, the utility may have a bases to show a smaller RPS Scram Contactor bounding response time due to a lower acceptance criteria (smaller time) for the partial loop and fewer "other component" response times to subtract from the acceptance criteria (and therefore, less uncertainty). However, other than to acknowledge that alternate method, this analysis does not address partial loop response time test approaches.

The conclusions of the analysis are in the form of bounding values of response times that may go undetected, and tests that are assumed to be performed in the determination of the identified bounding values.

### B.7.2 FMEA Results

#### *B.7.2.1 FMEA Applicability*

This FMEA addresses GE CR105, GE CR205, and GE CR305 Magnetic Contactors, and Potter & Brumfield MDR Rotary Relays when used as an interposing relay between two of the above Magnetic Contactors. Specifically, this analysis applies to:

a) Any GE CR105, GE CR205, and GE CR305 Magnetic Contactors, and

b) Any 120 Vac Small AC Non-Latching type Potter & Brumfield MDR series rotary relays,

provided the components are applied as an RPS Scram Contactor controlling a set of Scram Solenoid Pilot Valves (SSPVs) in one of the following two configurations:

1) One GE CR105, GE CR205, or GE CR305 Magnetic Contactor that directly operates a set of SSPVs, or
2) One interfacing Potter & Brumfield MDR relay which controls a GE CR105, GE CR205, or GE CR305 Magnetic Contactor which operates a set of SSPVs.

For this analysis, either configuration is referred to as the "RPS Scram Contactor".

#### *B.7.2.2 Conclusions of FMEA*

The maximum undetected response time of the RPS Scram Contactor is 65 ms provided the plant performs APRM upscale scram trip RTT with an acceptance criteria of 90 ms maximum, and the APRM RTT includes the APRM electronics and at least one interposing relay, not shared by other loops, between the APRM output and the RPS Scram Contactor.

Provided these conditions are met, all credible failure modes identified that increase response time of the RPS Scram Contactor to more than 65 ms also result in failure to meet the APRM upscale scram trip RTT acceptance criteria.

Based on this analysis, it is reasonable to conclude that any failure of the RPS Scram Contactor which has met the conditions of this section that could result in response times greater than 65 ms is not credible.

### B.7.3 Analysis:

#### *B.7.3.1 Loop Analyzed*

The APRM upscale scram trip (120%) instrument loop for a typical BWR4, BWR5 and BWR6 were evaluated.

#### *B.7.3.2 Method of Analysis*

The analysis is conducted in multiple parts including: 1) an analysis of the typical loop to determine the components in the loop, 2) a review and evaluation of available vendor and qualification data to determine the minimum likely response time for components in the loop other than the RPS Scram Contactor, 3) identification of the RTT acceptance criteria (response time), and, based on these 4) calculate the maximum credible RPS Scram Contactor response time that would still pass the RTT.

#### *B.7.3.3 Description*

The typical APRM upscale scram trip instrument loop includes the APRM electronics and output relay (the output relay is considered part of the APRM), an interfacing relay, and the RPS Scram Contactor.

The design of the APRM is similar for all plants. The response time delays in the APRM portion of the loop can be considered in three parts: 1) filter delays at the LPRM input amplifier (between the LPRM detectors and the APRM processing electronics), 2) electronic processing delays between the LPRM amplifiers and the input to the APRM output relay, and 3) delays due to the response time of the APRM output relay.

The interfacing relay in the BWR4 generation plant is typically a 120 Vac GE HFA relay. The BWR5, BWR6 (and some later BWR4) plants generally use a Potter & Brumfield MDR relay, also 120 Vac.

For BWR4 plants, each instrument loop typically operates two RPS Scram Contactors in parallel, each of which is typically single CR105, CR205 or CR305 that is operated directly from the interfacing relay. For BWR5 and BWR6, each instrument loop typically operates either two or four RPS Scram Contactors where one is typically a single CR105, CR205 or CR305 that is operated directly from the interfacing relay while the remainder comprise a Potter & Brumfield MDR relay operated directly from the interfacing relay and a single CR105, CR205 or CR305 which operates from the MDR relay.

In all cases, the RPS Scram Contactor is common to all RPS scram instrument loops while the interfacing relay is dedicated to the specific loop.

Response time testing of the APRM upscale scram trip instrument loop includes the APRM electronics, the interfacing relay, and the RPS Scram Contactors (all contactors operated from the loop). The normal acceptance value for the APRM upscale scram trip response time is 90 ms. The design generally assumes 40 ms for the APRM response and 50 ms for the interfacing relay and RPS Scram Contactors.

*B.7.3.4 Analysis*

The APRM response time is the sum of the filter response delay, the electronics and the APRM output relay. The filter is nominally a 15 ms time constant filter. The specific delay that results from this filter depends on the characteristics of the input signal, but is typically between about 10 and 20 ms. The electronics delays are short, on the order of a few milliseconds. The APRM output relay is a small, fairly fast relay, which typically responds in less than 10 ms. The response times are likely to remain relatively constant, but in particular are not likely to become substantially faster than nominal. Based on a 40 ms designed response time, it is assumed, based on engineering judgment, that the fastest response of the APRM part of the channel is 20 ms, one half of the design allocation.

The Potter & Brumfield MDR relay (small AC non-latching) is specified to release in 5 to 18 ms. It isassumed for this calculation that the release time is 5 ms. The HFA 120 Vac relay is specified to have a release time of 14 ms or less. GE qualification tests measured times on the order of 9 ms. To bound these values, the minimum release time for the interfacing relay is assumed to be 5 ms. This also covers any case that uses an Agastat GP or EGP relay as the interfacing relay.

K.6.1 Transmitters/Switches Included in EPRI Analyses

The EPRI analysis scope included the majority of pressure sensor instrumentation currently installed or expected to be installed in U.S. plants. The pressure sensors which are applicable to the BWR plants participating in this BWROG study are the Barton, Rosemount, and SOR transmitters/switches. Sensor failure modes associated with all Barton transmitters, models 763 and 764, switches model 288/289, and SOR switches were not found to affect sensor response time without significantly affecting calibration. The BWROG reviewed and provided comments on the draft EPRI analysis report prior to issuance. All comments were addressed in the final report.

Only two failure modes and two manufacturing/handling defects were identified in Reference 1 as affecting response time without concurrently affecting sensor output. These failure modes and defects apply only to sensors utilizing a fill fluid to transfer the process pressure to the sensing element. Rosemount supplies the only sensors of this type identified for plants participating in this BWROG study. The two failure modes are the slow loss of fill fluid during pressurized operations and variable damping potentiometer misadjustment during maintenance. The two manufacturing and handling defects are low sensor fill fluid from the manufacturing process and crimped capillaries from the manufacturing process, improper handling by the manufacturer, or damage during field installation/maintenance.

A discussion of these failure modes and effects are included in Appendix F. The effect of these failure modes and effects on RTT elimination can be summarized as follows:

(1) Slow loss of fill fluid - A slow loss of fill fluid causes a gradual degradation of the measurement process by reducing the ability of the working fluid to rapidly transmit pressure changes to the sensing diaphragm. Current response time tests are ineffective in detecting the initial stages of slow fluid loss. For sensors that are susceptible to the slow loss of fill-oil, Drift Analysis is the preferred method to detect the change in instrument performance. Other diagnostic techniques such as sluggish response and process noise analysis may be used to supplement Drift Analysis. When enough fluid (Reference 10-13) is lost to cause a significant response time degradation, the sluggish response of the leaking sensor will be detected during transmitter calibration.

(2) Variable damping potentiometer misadjustment - Damping devices have been utilized in fast acting trip circuits to minimize the potential for inadvertent actuations. The use of a variable damping potentiometer in the transmitter design provides a means of applying the same type of transmitter to several circuits that require additional electronic filtering capability. Variable damping potentiometer misadjustment can affect the response time in circuits having capacitors and resistors that control electronic response time. Measures must be taken to ensure that the potentiometer is at the required setting at time of installation and after major maintenance.

Therefore, no additional response time tests are required. A more detailed discussion on damping filters is also found in Appendix F.

(3) Manufacturing and handling defects - Low sensor fill fluid during manufacturing and crimped fill capillaries due to manufacturing or mishandling during installation/maintenance were identified in Reference 1 as affecting transmitter response time. Response time is the only sensor characteristic affected by these manufacturing and handling defects. Since November 1989, vendor testing has been implemented to ensure acceptable fill and capillaries. In addition, when low fill fluid or crimped capillaries affect response time, the degradation can be identified by pre-installation calibration.

### K.6.2 Transmitters/Switches Not Included in EPRI Analysis

The following two switch models are not part of the EPRI report (Reference 1 of main report) but were supplemented by BWROG.

#### K.6.2.1 Barksdale Pressure Switches

The only potential failure mode for model TC9622-3 (piston with O-ring) occurs if the switch is misapplied in process or range. The O-ring seal can swell due to pressure above its rating, and this swelling causes the plunger pin to react sluggishly. This will increase the instrument response time. Since safety-related switches are carefully specified and verified, this failure mode is considered extremely unlikely. The only electrical failure mode occurs in the microswitch. This will not produce a delay, but will cause failure to operate, which can be readily detected during surveillance testing.

The Barksdale B1T and B2T series are Bourdon tube instruments and do not have components that can cause response time related failures. Therefore, response time testing is not required.

#### K.6.2.2 Barton 760 Transmitters

Barton 760 is a differential pressure transmitter which contains a mechanical bellows and electronic circuit similar to Model 764. As concluded in Reference 1 of main report, response time testing is not required for the Barton 764 Model. This conclusion also applies to Model 760.

## K.7 Loop Devices

### K.7.1 Rosemount/GE Trip Unit Noise Suppression Filter Capacitor

The WBR 2000-50 capacitor, used as a process noise filter in an analog transmitter loop, is manufactured by Cornell Dubilier-Sangamo Components. It is a 2000 ufd aluminum electrolytic capacitor with a 50V rating. Failure modes of the capacitor are (1) open, (2) short, (3) increased leakage, and (4) change in capacitance. When installed in parallel with the trip unit input, short circuit and increased leakage current failures can affect analog loop accuracy. Loop calibration procedures (end to end) performed on a periodic basis can demonstrate loop operability within the required performance requirements as long as the capacitor is in the circuit during the procedure. Open circuit failures are in the conservative direction and are not a concern with respect to response time. Capacitance change failures can include (a) decreased capacitance, which is in the conservative direction with respect to response time, and (b) an increase of capacitance. The vendor states that capacitance may increase by 10% with time. These parts are already specified with a -10%/+75% tolerance. The time delay added by the capacitor should have sufficient margin to the maximum allowable to account for this possible increase. With surveillance tests demonstrating loop operability, there are no failures with the capacitor which will adversely affect system response time.

### K.7.2 745 Alarm Unit

These alarm units are used only in trip functions such as reactor water cleanup isolation. A review of the schematic diagram revealed that only the input 4.99K resistor and 10 microfarad capacitor contribute to a delay time on the order of 50 milliseconds. If the input resistor failed to a higher

differences between response times for transmitters with a 41.4" - 173.2" span and transmitters with a 107.5" - 447.3" span (instrument range values not given).

## FMEAs

FMEAs were performed on the sensor-types listed in table 2-1 below. Based on the data collected from the industry for this investigation, these sensor-types represent the majority of pressure sensor instrumentation currently installed or expected to be installed in safety-related systems in U.S. plants. These sensor-types also are representative of the various sensor designs (e.g., bourdon tube, force-balance, capacitance, and strain gage).

Table 2-1

SENSOR TYPES INCLUDED IN FMEAs

Barton 288/289 Differential Pressure Indicating Switches
Barton 763 Gage Electronic Pressure Transmitter
Barton 764 Differential Pressure Electronic Transmitter
Foxboro N-E11DM Differential Pressure Transmitter
Foxboro N-E13DM Differential Pressure Transmitter
Foxboro N-E13DH Differential Pressure Transmitter
Foxboro N-E11GH Gage Pressure Transmitter
Foxboro N-E11GM Gage Pressure Transmitter
Tobar 32PA1 Absolute Pressure Transmitter
Tobar 32PG1 Gage Pressure Transmitter
Tobar 32DP1 Differential Pressure Transmitter
Rosemount Differential Pressure Transmitter Models 1151, 1152, 1153, 1154
Rosemount Pressure Transmitter Models 1151, 1152, 1153, 1154
Statham PD-3200 Differential Pressure Transmitter
Statham PG-3000 Pressure Transmitter
SOR Differential Pressure Switch
SOR Pressure Switch

The FMEA method of systems analysis was selected for the response time investigation because it provides a valid, systematic approach for identifying failure modes. FMEAs are a semi-quantitative technique to the extent that they are not supported by explicit calculations or testing for particular failure modes. Fill fluid viscosity effects, frictional linkage forces, and capillary effects are addressed on a generic basis. The failure modes included each physical boundary and force transmitting element, regardless of the probability for a failure mechanism.

Table 3-33

SOR DIFFERENTIAL PRESSURE SWITCH
FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 1 | High pressure chamber | Leak | Moisture/boron on switch body<br><br>Potential increased temperature<br><br>Potential errors due to sample line pressure drop | Visual/signal comparison | None | None |
| 2 | Low pressure chamber | Leak | Moisture/boron on switch body<br><br>Potential increased temperature<br><br>Potential errors due to sample line pressure drop for large leak | Visual/signal comparison | None | None |
| 3 | Diaphragm | Leak | Increases setpoint error as leak increases<br><br>Potential increased temperature | Setpoint test | None | None |

Table 3-33 (Cont'd)

SOR DIFFERENTIAL PRESSURE SWITCH
FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 4 | Piston shaft | Attachment problem/defect | Setpoint change or failure to operate | Setpoint test | None | None |
| 5 | Rotary shaft | Failure/defect | Setpoint change or failure to operate | Setpoint test | None | None |
| 6 | Rotary shaft bearings | Excess freedom | Erratic setpoint | Setpoint test | None | None |
| | | Excess friction | Setpoint change or failure to operate | Setpoint test | None | None |
| 7 | Rotary shaft O-ring seals | Leak to actuator spring chamber | Moisture/boron in spring chamber<br>Potential setpoint change due to seal problem/flow | Inspection and setpoint test | None | None |
| | | Leak to microswitch chamber | Moisture/boron in switch chamber Potential increase in temperature, increased conductivity when switch in "open" position | Inspection and setpoint test | None | None |

Table 3-33 (Cont'd)

SOR DIFFERENTIAL PRESSURE SWITCH
FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 8 | Microswitch actuator linkage | Attachment problem/defect | Setpoint change or failure to operate | Setpoint test | None | None |
| 9 | Microswitch | Change in actuation force | Setpoint change | Setpoint test | None | None |
| | | Electrical failure | Spurious output or failure to operate | Setpoint test | None | None |
| 10 | Setpoint spring | Change in compression | Setpoint error | Setpoint test | None | None |
| | | Change in force constant | Setpoint error | Setpoint test | None | None |

Table 3-35

SOR PRESSURE SWITCH
FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 1 | Inlet pressure chamber | Leak | Moisture/boron on switch body | Visual | None | None |
| | | | Increased temperature as process fluid leak increases | | | |
| 2 | Inlet diaphragm | Leak | Moisture/boron on switch body | Setpoint test | None | Switch failure likely |
| | | | Increased temperature as process fluid leak increases | | | |
| | | | Increased conductivity in switch "open" state, setpoint change as leak increases across diaphragm | | | |
| 3 | Actuator shaft | Friction | Setpoint change or failure to operate | Setpoint test | None | None |

Table 3-35 (Cont'd)

SOR PRESSURE SWITCH
FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 4 | Actuator spring | Change in compression | Setpoint error | Setpoint test | None | None |
| | | Change in force constant | Setpoint error | Setpoint test | None | None |
| 5 | Microswitch | Change in actuation force | Setpoint error | Setpoint test | None | None |
| | | Electrical failure | Spurious output or failure to actuate | Setpoint test | None | None |

Table 3-5

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 1 | High pressure housing and seals to transmitter housing | Process fluid leak | Signal drift due to increased heating of transmitter by process fluid and/or surface conductivity due to process fluid<br><br>Errors due to sample line pressure drop for large leaks<br><br>Electronic failure | Signal drift with respect to comparable signals | None | None |
| 2 | High pressure bellows | Leak to high pressure housing | Process fluid enters high pressure bellows due to action of bellows spring force | Signal drift due to action of bellows spring | None | Can affect low range limit due to high pressure overrange valve |
| 3 | High pressure bellows spring | Incorrect spring | Calibrated out or detected during initial calibration | Initial calibration | None | None |
| | | Change in spring constant | Signal drift due to change in valve stem shaft spring constant | Signal drift with respect to comparable signals | None | None |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 4 | High pressure bellows to high pressure housing seals | Leak to high pressure housing | Process fluid enters high pressure bellows due to action of bellows spring force | Signal drift due to actions of bellows spring | None | None |
| 5 | Fill plug seal | Small fill fluid leak to transmitter housing | Slow collapse of bellows folds | Fill fluid in transmitter housing | None | None expected due to flexibility and volume of bellows |
| | | Substantial fill fluid leak to transmitter housing | Damage to bellows | Fill fluid in transmitter housing<br><br>Signal drift due to restoring action of bellows spring | None | Transmitter will not calibrate and may have low range limit due to action of high pressure overrange valve |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 6 | Valve stem shaft | Incorrect position | Calibration offset with respect to transmitter design | Detect in initial calibration | None | None |
| | | Position changes | Signal offset | Signal drift with respect to comparable signals | None | Shaft has thread lock to bellows and no significant net rotary force |
| 7 | High pressure bellows overrange valve | Does not stop valve shaft or isolate bellows on overpressure | Potential bellows damage | Signal offset with respect to comparable signals | None | Offset and range may be changed by significant overpressure |
| 8 | Low pressure bellows overrange valve | Does not stop valve stem or isolate bellows on reverse overpressure | Potential bellows damage | Signal offset with respect to comparable signal | None | Offset and range may be changed by significant overpressure |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 9 | Silicone fill fluid | Increased viscosity | Increased response time | Response time test | Yes | No identified mechanism for gross viscosity increase; temperature effects must be acceptable for application<br><br>Small magnitude of bellows/shaft motion and shaft clearness provide low sensitivity to viscosity |
| 10 | Torque tube drive arm | Loosening | Offset and/or non-linear response | Signal offset or calibration linearity error or erratic response | None | None |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 11 | Torque tube | Small fill fluid leak to transmitter housing | Slow collapse of bellows folds | Fill fluid in transmitter housing | None | None expected due to flexibility and volume of bellows |
| | | Substantial fill fluid leak to transmitter housing | Damage to bellows | Fill fluid in transmitter housing<br><br>Signal drift due to restoring action of bellows spring | None | Transmitter will not calibrate and may have low range limit due to action of high pressure overrange valve |
| 12 | Low pressure housing and seals to transmitter housing | Process fluid leak | Signal drift due to increased heating of transmitter by process fluid and/or surface conductivity due to process fluid<br><br>Errors due to sample air pressure drop for large leaks<br><br>Electronic failure | Signal drift with respect to comparable signals | None | None |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 13 | Low pressure bellows | Leak to low pressure housing | Fill fluid enters low pressure housing due to action of bellows spring force | Signal drift due to actions of low pressure bellows spring | None | Can affect low range limit due to low pressure overrange valve |
| 14 | Low pressure bellows spring | Incorrect spring | Calibrated out or detected during initial calibration | Initial calibration | None | None |
| | | Change in spring constant | Signal drift due to change in valve stem shaft spring constant | Signal drift with respect to comparable signals | None | None |
| 15 | Low pressure bellows to low pressure housing seals | Leak to low pressure housing | Fill fluid enters low pressure housing due to action of bellows spring force | Signal drift due to actions of low pressure bellows spring | None | None |
| 16 | Actuating cam | Loosening on torque tube | Setpoint error | Setpoint test | None | None |
| | | Wear | Setpoint error | Setpoint test | None | None |

Table 3-5 (Cont'd)

BARTON MODEL 288/289 DIFFERENTIAL PRESSURE INDICATING SWITCH FAILURE MODES AND EFFECTS ANALYSIS TABLE

| NO. | NAME | FAILURE MODES | SYMPTOMS AND LOCAL EFFECTS INCLUDING DEPENDENT FAILURES | METHOD OF DETECTION | EFFECTS ON SENSOR RESPONSE TIME | REMARKS AND OTHER EFFECTS |
|---|---|---|---|---|---|---|
| 17 | Plunger screw | Change in position | Setpoint error | Setpoint test | None | None |
| 18 | Switch link | Loosening/ friction/wear | Erratic setpoint adjustment | Setpoint adjust | None | None |
| 19 | Switch adjust lever | Loosening/ friction/wear | Erratic setpoint adjustment | Setpoint adjust | None | None |
| 20 | Microswitch | Change in actuation force | Setpoint change | Setpoint test | None | None |
| 21 | Points drive linkage | Friction | Setpoint error | Setpoint test | None | None |

NOTE: Applications with capillary tubes need to be tested to verify that a tube crimp has not degraded response time.

By: WLL Date: 4/14/97
PAS 4/15/97

**MSIV Low Pressure**
**One sided upper tolerance bounds**
**( - Barksdale B1T)**

$$D1 := \begin{bmatrix} 4 \\ 4 \\ 35 \\ 4 \\ 4 \\ 7 \\ 7 \\ 10 \\ 25 \\ 25 \\ 6 \\ 4 \\ 21 \\ 21 \\ 6 \end{bmatrix} \qquad D2 := \begin{bmatrix} 25 \\ 25 \\ 16 \\ 16 \\ 42 \\ 42 \\ 3 \\ 3 \\ 3 \\ 7 \\ 7 \\ 6 \\ 5 \\ 1 \\ 1 \\ 9 \end{bmatrix} \qquad Data := stack(D1, D2)$$

By: WLL Date: 4/14/97
PH 4/15/97

Establish mean and standard deviation using standard Mathcad functions:

Notation as follows:

n = number of data points
Mean = mean of the data
s = standard deviation

$n := \text{rows}(\text{Data})$ $\quad n = 31$

$\text{Mean} := \text{mean}(\text{Data})$ $\quad \text{Mean} = 12.7097$ $\quad s := \text{stdev}(\text{Data}) \cdot \sqrt{\frac{n}{n-1}}$ $\quad s = 11.9141$

The following analysis establishes the 95%/ 95% one sided upper tolerance interval. The tolerance interval is obtained from the matrix $Tol_{95}$ using MathCad's linterp function.

$$Tol_{95} := \begin{bmatrix} 4 & 5.14 \\ 5 & 4.2 \\ 6 & 3.71 \\ 7 & 3.4 \\ 8 & 3.19 \\ 9 & 3.03 \\ 10 & 2.91 \\ 12 & 2.74 \\ 15 & 2.57 \\ 20 & 2.4 \\ 25 & 2.29 \\ 30 & 2.22 \\ 40 & 2.13 \\ 60 & 2.02 \end{bmatrix} \qquad TF := \text{linterp}\left(Tol_{95}^{\langle 1 \rangle}, Tol_{95}^{\langle 2 \rangle}, n\right) \qquad TF = 2.211$$

One-sided upper tolerance bound

$T_{upper} := \text{Mean} + s \cdot TF$ $\quad T_{upper} = 39.0518$

By: WLL Date: 4/14/97
PAS 4/15/97

## Establish normality plot:

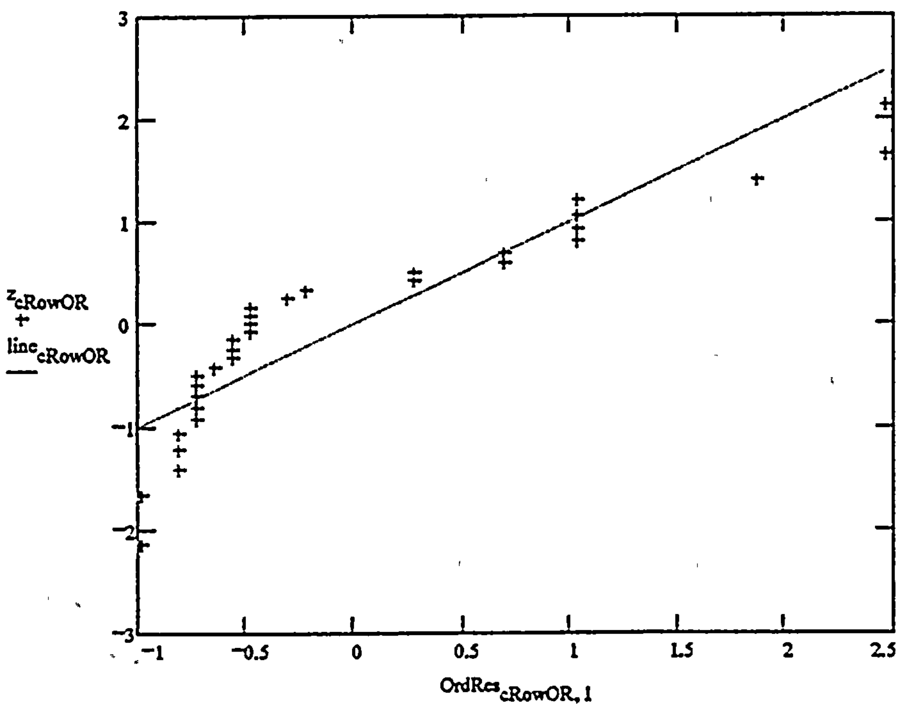
$Residuals := Data - Mean \qquad Standard_{Residuals} := \frac{Residuals}{s}$

$OrdRes := csort(Standard_{Residuals}, 1) \qquad cRowOR := 1 .. rows(OrdRes)$

$Prob_{cRowOR} := \frac{cRowOR - \frac{1}{2}}{rows(OrdRes)} \qquad OrdRes := augment(OrdRes, Prob)$

$x := 0 \qquad z_{cRowOR} := root(normal(0, 1, x) - Prob_{cRowOR}, x)$

$m := 1 \quad intercept := 0 \quad line_{cRowOR} := m \cdot OrdRes_{cRowOR, 1} + intercept$



By: WLL Date: 4/14/97
CHECKED FAS 4/15/97

**MSIV Low Pressure**
**One sided upper tolerance bounds**
**( - Barksdale B1T)**
(Note: All data in msec)

$$D1 := \begin{bmatrix} 4 \\ 4 \\ 35 \\ 4 \\ 4 \\ 7 \\ 7 \\ 10 \\ 101 \\ 25 \\ 25 \\ 6 \\ 4 \\ 21 \\ 21 \\ 6 \end{bmatrix} \qquad D2 := \begin{bmatrix} 25 \\ 25 \\ 16 \\ 16 \\ 42 \\ 42 \\ 3 \\ 3 \\ 3 \\ 7 \\ 7 \\ 6 \\ 5 \\ 1 \\ 1 \\ 9 \end{bmatrix} \qquad Data := stack(D1, D2)$$

Evaluate 101 as outlier

$\bar{x} = 15.4$

$n = 32$

$S = 19.51$

$$T = \frac{101 - 15.4}{19.51} = 4.39$$

Outlier at 0.1% significance level. Re-run analysis without this point

By: WLL Date: 4/14/97
PRS 4/15/97

Establish mean and standard deviation using standard Mathcad functions:

Notation as follows:

n = number of data points
Mean = mean of the data
s = standard deviation

$n := \mathrm{rows(Data)}$ $\quad n = 32$

$\mathrm{Mean} := \mathrm{mean(Data)}$ $\quad \mathrm{Mean} = 15.4688$ $\quad s := \mathrm{stdev(Data)} \cdot \sqrt{\frac{n}{n-1}}$ $\quad s = 19.5184$

The following analysis establishes the 95%/ 95% one sided upper tolerance interval. The tolerance interval is obtained from the matrix $\mathrm{Tol}_{95}$ using MathCad's linterp function.

$$\mathrm{Tol}_{95} := \begin{bmatrix} 4 & 5.14 \\ 5 & 4.2 \\ 6 & 3.71 \\ 7 & 3.4 \\ 8 & 3.19 \\ 9 & 3.03 \\ 10 & 2.91 \\ 12 & 2.74 \\ 15 & 2.57 \\ 20 & 2.4 \\ 25 & 2.29 \\ 30 & 2.22 \\ 40 & 2.13 \\ 60 & 2.02 \end{bmatrix} \qquad TF := \mathrm{linterp}\left(\mathrm{Tol}_{95}^{\langle 1 \rangle}, \mathrm{Tol}_{95}^{\langle 2 \rangle}, n\right) \qquad TF = 2.202$$

One-sided upper tolerance bound

$T_{upper} := \mathrm{Mean} + s \cdot TF$ $\quad T_{upper} = 58.4482$

By: WLL Date: 4/14/97
PHS 4/15/97

## Establish normality plot:

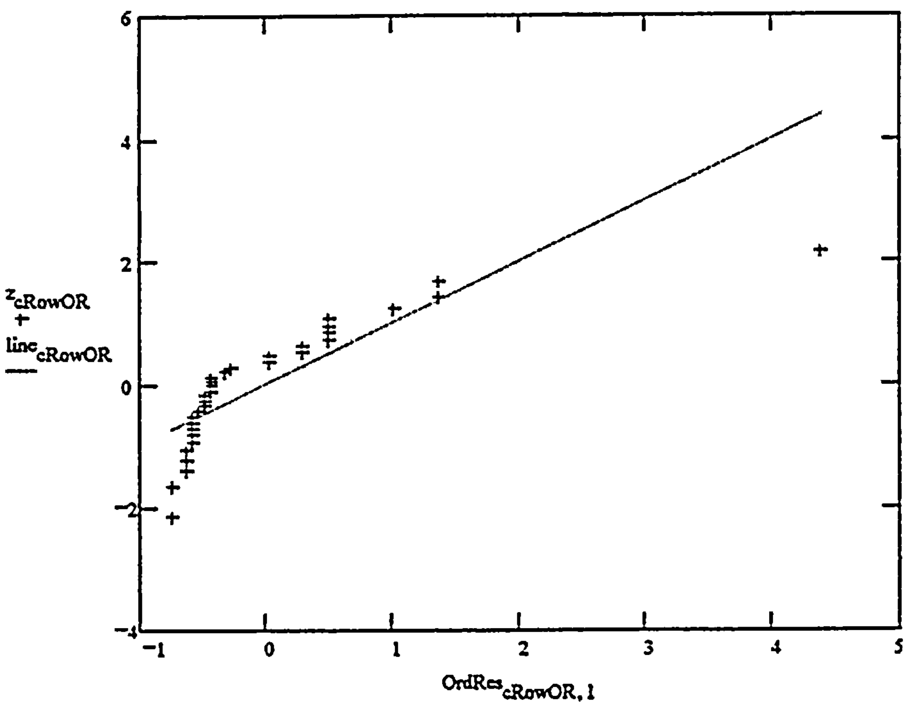
$\text{Residuals} := \text{Data} - \text{Mean} \qquad \text{Standard}_{\text{Residuals}} := \dfrac{\text{Residuals}}{s}$

$\text{OrdRes} := \text{csort}\left(\text{Standard}_{\text{Residuals}}, 1\right) \qquad \text{cRowOR} := 1 .. \text{rows}(\text{OrdRes})$

$\text{Prob}_{\text{cRowOR}} := \dfrac{\text{cRowOR} - \frac{1}{2}}{\text{rows}(\text{OrdRes})} \qquad \text{OrdRes} := \text{augment}(\text{OrdRes}, \text{Prob})$

$x := 0 \qquad z_{\text{cRowOR}} := \text{root}\left(\text{normal}(0, 1, x) - \text{Prob}_{\text{cRowOR}}, x\right)$

$m := 1 \qquad \text{intercept} := 0 \qquad \text{line}_{\text{cRowOR}} := m \cdot \text{OrdRes}_{\text{cRowOR}, 1} + \text{intercept}$



By: WLL Date: 4/14/97
CHECKED PAS 4/15/97

## Main Steam Line High Flow
## One sided upper tolerance bounds
## (Barton 288A - Data)

(Note: All data are in msec)

$$D1 := \begin{bmatrix} 200 \\ 19 \\ 20 \\ 60 \\ 72 \\ 31 \\ 26 \\ 66 \\ 70 \\ 74 \\ 12 \\ 12 \\ 63 \\ 70 \\ 63 \\ 112 \\ 70 \\ 97 \\ 47.5 \end{bmatrix} \qquad D2 := \begin{bmatrix} 64 \\ 65 \\ 9 \\ 60 \\ 31 \\ 90 \\ 27 \\ 30 \\ 73 \\ 45 \\ 72 \\ 92 \\ 158 \\ 40 \\ 6 \\ 100 \end{bmatrix}$$

Evaluate 200 and 158 as outlier

Use Table 5 of ASTM E 178-94

$S^2 = 56,801$

$S^2_{1,2} = 26,548$

$n = 35$

$\frac{S^2_{1,2}}{S^2} = \frac{26,548}{56,801} = 0.467$

Data := stack(D1,D2)

These points are outliers at the 0.1% level of significance

Establish mean and standard deviation using standard Mathcad functions:

Notation as follows:

n = number of data points
Mean = mean of the data
s = standard deviation

$n := \text{rows}(Data) \qquad n = 35$

$Mean := \text{mean}(Data) \qquad Mean = 61.3286 \qquad s := \text{stdev}(Data)\cdot\sqrt{\frac{n}{n-1}} \qquad s = 40.8734$

$S_{sq} := \sum_{i=1}^{n} (Data_i - Mean)^2 \qquad S_{sq} = 56801.4714$

By: WLL Date: 4/14/97
PAS 4/15/97

The following analysis establishes the 95%/ 95% one sided upper tolerance interval. The tolerance interval is obtained from the matrix $Tol_{95}$ using MathCad's linterp function.

$$Tol_{95} := \begin{bmatrix} 4 & 5.14 \\ 5 & 4.2 \\ 6 & 3.71 \\ 7 & 3.4 \\ 8 & 3.19 \\ 9 & 3.03 \\ 10 & 2.91 \\ 12 & 2.74 \\ 15 & 2.57 \\ 20 & 2.4 \\ 25 & 2.29 \\ 30 & 2.22 \\ 40 & 2.13 \\ 60 & 2.02 \end{bmatrix} \qquad TF := \mathrm{linterp}\left(Tol_{95}^{\langle 1\rangle}, Tol_{95}^{\langle 2\rangle}, n\right) \qquad TF = 2.175$$

One-sided upper tolerance bound

$T_{upper} := Mean + s \cdot TF$ $\qquad$ $T_{upper} = 150.2281$

By: WLL Date: 4/14/97
PAS 4/15/97

## Establish normality plot:

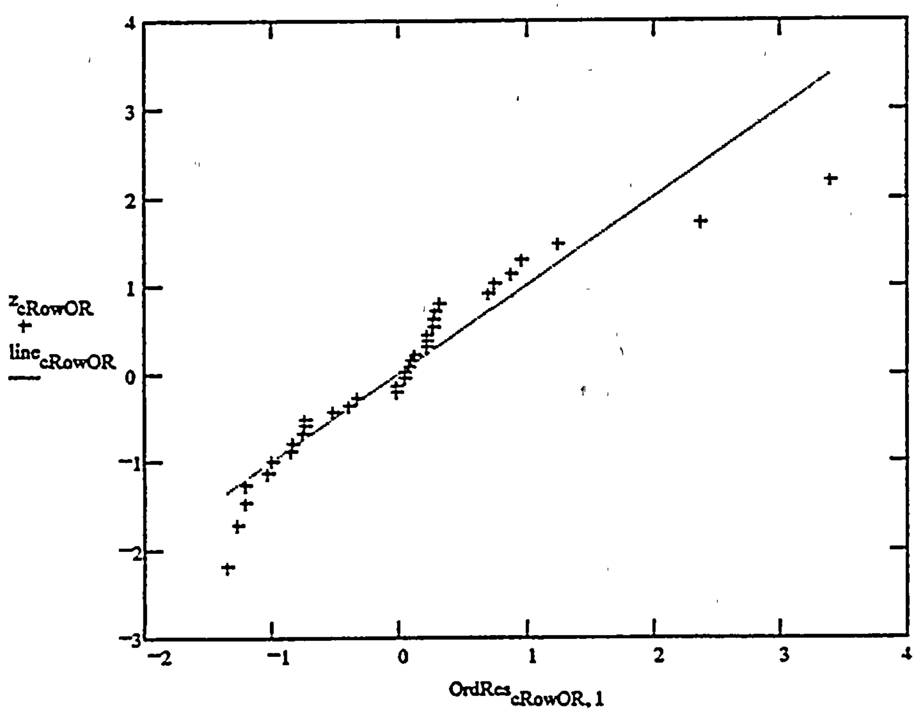
$Residuals := Data - Mean \qquad Standard_{Residuals} := \frac{Residuals}{s}$

$OrdRes := csort\left(Standard_{Residuals}, 1\right) \qquad cRowOR := 1 .. rows(OrdRes)$

$Prob_{cRowOR} := \frac{cRowOR - \frac{1}{2}}{rows(OrdRes)} \qquad OrdRes := augment(OrdRes, Prob)$

$x := 0 \qquad z_{cRowOR} := root\left(normal(0, 1, x) - Prob_{cRowOR}, x\right)$

$m := 1 \quad intercept := 0 \quad line_{cRowOR} := m \cdot OrdRes_{cRowOR, 1} + intercept$



By: WLL Date: 4/14/97
PAS 4/15/97

## Main Steam Line High Flow
## One sided upper tolerance bounds
## (Barton 288A -  Data)

$$D1 := \begin{bmatrix} 19 \\ 20 \\ 60 \\ 72 \\ 31 \\ 26 \\ 66 \\ 70 \\ 74 \\ 12 \\ 12 \\ 63 \\ 70 \\ 63 \\ 112 \\ 70 \\ 97 \\ 47.5 \end{bmatrix} \qquad D2 := \begin{bmatrix} 64 \\ 65 \\ 9 \\ 60 \\ 31 \\ 90 \\ 27 \\ 30 \\ 73 \\ 45 \\ 72 \\ 92 \\ 40 \\ 6 \\ 100 \end{bmatrix} \qquad Data := stack(D1, D2)$$

Establish mean and standard deviation using standard Mathcad functions:

Notation as follows:

n = number of data points
Mean = mean of the data
s = standard deviation

$n := rows(Data) \qquad n = 33$

$Mean := mean(Data) \qquad Mean = 54.197 \qquad s := stdev(Data) \cdot \sqrt{\frac{n}{n-1}} \qquad s = 28.8032$

$$S_{sq} := \sum_{i=1}^{n} \left(Data_i - Mean\right)^2 \qquad S_{sq} = 26547.9697$$

By: WLL Date: 4/14/97
PAS 4/15/97

The following analysis establishes the 95%/ 95% one sided upper tolerance interval. The tolerance interval is obtained from the matrix $Tol_{95}$ using MathCad's linterp function.

$$Tol_{95} := \begin{bmatrix} 4 & 5.14 \\ 5 & 4.2 \\ 6 & 3.71 \\ 7 & 3.4 \\ 8 & 3.19 \\ 9 & 3.03 \\ 10 & 2.91 \\ 12 & 2.74 \\ 15 & 2.57 \\ 20 & 2.4 \\ 25 & 2.29 \\ 30 & 2.22 \\ 40 & 2.13 \\ 60 & 2.02 \end{bmatrix} \quad TF := \mathrm{linterp}\left(Tol_{95}^{\langle 1 \rangle}, Tol_{95}^{\langle 2 \rangle}, n\right) \qquad TF = 2.193$$

One-sided upper tolerance bound

$T_{upper} := Mean + s \cdot TF \qquad T_{upper} = 117.3624$

By: WLL Date: 4/14/97
TAS 4/15/97

## Establish normality plot:

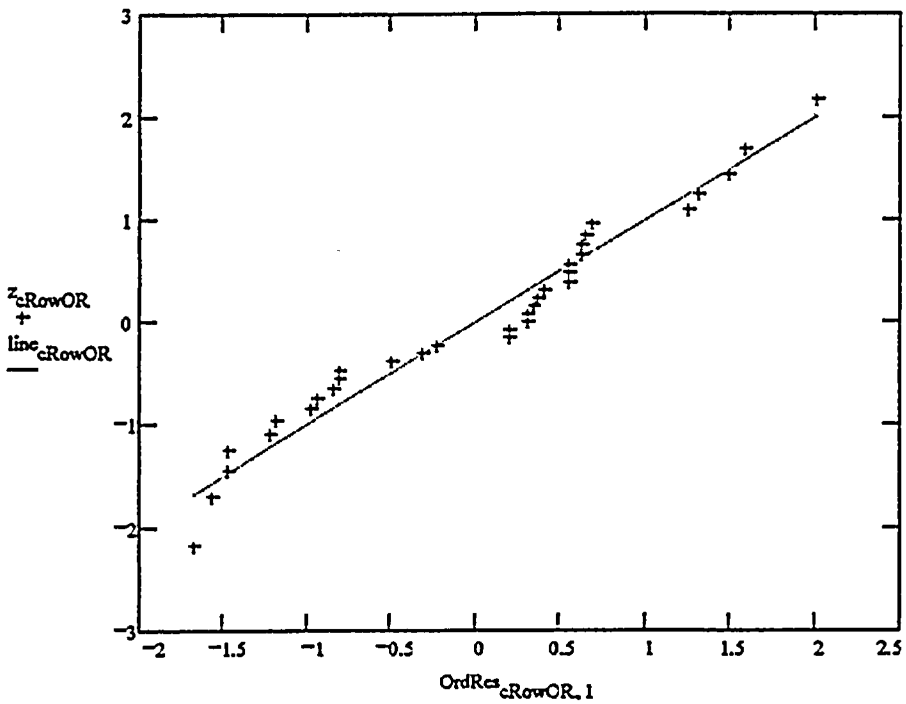
$\text{Residuals} := \text{Data} - \text{Mean} \qquad \text{Standard}_{\text{Residuals}} := \frac{\text{Residuals}}{s}$

$\text{OrdRes} := \text{csort}(\text{Standard}_{\text{Residuals}}, 1) \qquad \text{cRowOR} := 1 .. \text{rows}(\text{OrdRes})$

$\text{Prob}_{\text{cRowOR}} := \frac{\text{cRowOR} - \frac{1}{2}}{\text{rows}(\text{OrdRes})} \qquad \text{OrdRes} := \text{augment}(\text{OrdRes}, \text{Prob})$

$x := 0 \qquad z_{\text{cRowOR}} := \text{root}(\text{normal}(0, 1, x) - \text{Prob}_{\text{cRowOR}}, x)$

$m := 1 \quad \text{intercept} := 0 \quad \text{line}_{\text{cRowOR}} := m \cdot \text{OrdRes}_{\text{cRowOR}, 1} + \text{intercept}$



RAW DATA FROM
SUPPLY SYSTEM SURV. TESTS



| | Quant | Sensor | Response | | |
|---|---|---|---|---|---|
| | RTT | Ts(sec) | | | |
| | | | | | |
| Primary Containment | | Date | | Date | |
| Isolation On Rx Lvl low, low 2: | | | | | |
| MS-LS-61A | 7.4.3.2.3.2 | 6/11/94 | 0.685 | 4/25/92 | 0.675 |
| MS-LS-61B | 7.4.3.2.3.35 | 5/29/93 | 0.78 | 6/4/91 | 0.605 |
| MS-LS-61C | 7.4.3.2.3.36 | 5/11/93 | 0.5 | 6/5/91 | 0.53 |
| MS-LS-61D | 7.4.3.2.3.37 | 7/23/94 | 0.432 | 6/9/92 | 0.554 |
| *SOR 103AS-BB203-NX-JJTTX6.* | | | | | |
| | | | | | |
| | | | | | |
| Prim Cont Isol | | | | | |
| On MSL Press Low | | | | | |
| MS-PS-15A | 7.4.3.2.3.5 | (Sufficient Data Not Available.) | | | |
| MS-PS-15B | 7.4.3.2.3.5 | ( . sensor data substituted.) | | | |
| MS-PS-15C | 7.4.3.2.3.21 | (Sufficient Data Not Available.) | | | |
| MS-PS-15D | 7.4.3.2.3.21 | ( sensor data substituted.) | | | |
| *Barksdale B1T-M12SS-GE.* | | | | | |
| | | | | | |
| Prim Cont Isol On | | | | | |
| MSL Flow Hi | | | | | |
| MS-DPIS-8A, 9A, 810A, 11A | 7.4.3.2.3.6 | (Sufficient Data Not Available.) | | | |
| MS-DPIS-8B, etc | 7.4.3.2.3.18 | ( sensor data substituted.) | | | |
| MS-DPIS-8C, etc | 7.4.3.2.3.19 | " | " | " | " |
| MS-DPIS-8D, etc | 7.4.3.2.3.20 | " | " | " | " |
| *Barton 288A.* | | | | | |
| | | | | | |
| RPS Trip On | | | | | |
| Stm Dme Pres Hi | | | | | |
| MS-PS-23A | 7.4.3.1.3.9 | 5/4/93 | 0.072 | 4/28/91 | 0.063 |
| MS-PS-23B | 7.4.3.1.3.10 | 5/17/93 | Note A: | 5/16/91 | 0.04 |
| MS-PS-23C | 7.4.3.1.3.11 | 5/7/94 | 0.22 | 5/27/92 | 0.181 |
| MS-PS-23D | 7.4.3.1.3.12 | 5/7/94 | 0.040* | 5/26/92 | 0.050* |
| *SOR 29N6-B45-NX-C1A-JJTTX12.* | | | * Ts + TL | Note A: Test done by | |
| | | | | Not a valid t | |
| RPS Trip On | | | | | |
| Rx Low Lvl 3 | | | | | |
| MS-LIS-24A | 7.4.3.1.3.13 | 5/5/93 | PER 1.11 | 6/8/93 | 0.015 |
| MS-LIS-24B | 7.4.3.1.3.14 | 5/18/93 | PER2.053 | 6/7/93 | 0.083 |
| MS-LIS-24C | 7.4.3.1.3.15 | 5/9/94 | 0.48 | 4/29/92 | 0.02 |
| MS-LIS-24D | 7.4.3.1.3.16 | 5/9/94 | 0.64 | 4/30/92 | 0.19 |
| Barton 288A. | | | | | |
| | | | | | |
| Other observations onthis particular set of procedures cc Trtt criteria: | | | | | |
| | 7.4.3.2.3.6 | 6/2/92 | 0.5sec | 6/7/94 | 1.0 sec |
| | 7.4.3.2.3.18 | | | 5/15/93 | 0.5sec |
| | 7.4.3.2.3.19 | 6/7/89 | 1.0sec | 5/15/93 | 0.5 sec |
| | 7.4.3.2.3.20 | 6/1/92 | 0.5 sec | 6/4/94 | 1.0sec |
| Per SOR RTT For A 29N6-B45=<100msec. | | | | | |
| Note: "XXX" means not able to find. | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **Supplemental SOR Pressure Switch Rtt data:** | | | | | | | | |
| | | | | | Ts | | | |
| MS-LS-61B | | 7.4.3.2.3.25 | | 5/30/93 | 0.415 | | | |
| MS-LS-61C | | 7.4.3.2.3.26 | | 5/31/93 | 0.14 | | | |
| | | | | | | | | |
| **Supplemental ITT Barton Pressure Switch Rtt data:** | | | | | | | | |
| | | | | | Ts | | | |
| MS-LIS-24A | | 7.4.3.2.3.16 | | 5/26/94 | 0.52 | | | |
| MS-LIS-24C | | 7.4.3.2.3.46 | | 6/6/93 | 0.308 | | | |
| MS-LIS-24B | | 7.4.3.2.3.45 | | 6/8/93 | 0.2 | | | |
| | | | | | | | | |
| **More Directly Applicable Data For The Barksdale Pressure Switches:** | | | | | | | | |
| | | | | | | | | |
| | | | Quant | Sensor Plus Logic | | | Ts | TL |
| | | | RTT | Train Response: | | | Criteria | Criteria |
| Prim Cont Isol | | | | Ts(msec): | | | (sec) | (msec) |
| On MSL Press Low | | | | | | | | |
| MS-PS-15A | | | 7.4.3.2.3.5 | 5/21/91 | 13 | TS="0" | 0.95 | 50 |
| MS-PS-15B | | | | 6/3/92 | 13 | TS="0" | | |
| | | | | 6/12/89 | 26 | (Ts=24) | | |
| | | | | | | | | |
| MS-PS-15C | | | 7.4.3.2.3.2 | 5/22/90 | 20 | TS="0" | | |
| MS-PS-15D | | | | 6/4/92 | 37 | TS="0" | | |
| *Barksdale B1T-M12SS-GE.* | | | | 5/21/91 | 5 | TS="0" | | |

| Ts | Logic Train | | | | TL |
|---|---|---|---|---|---|
| Criteria | TL (ms). | | | | Criteria |
| | | | | | |
| | Date | | Date | | |
| | | | | | |
| 0.95 | 4/25/92 | 30 | 6/11/94 | 25 | 50 |
| " | 6/4/91 | 20 | 5/29/93 | 10 | " |
| " | 6/5/91 | 30 | 5/11/93 | 20 | " |
| " | 7/23/94 | 25 | 6/9/92 | 20 | " |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| 0.95 | ( Sensor Data Utilized.) | | | | 50 |
| " | ( Sensor Data Utilized.) | | | | " |
| " | ( Sensor Data Utilized.) | | | | " |
| " | ( Sensor Data Utilized.) | | | | " |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| 0.45 | 6/2/92 | 17 | 6/7/94 | 26 | 50 |
| " | 5/15/93 | 14 | XXX | XXX | " |
| " | 6/7/89 | 30 | 5/15/93 | 24 | " |
| " | 6/4/94 | 20 | 6/1/92 | 12 | " |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| 0.5 | 4/28/91 | 33 | 5/4/93 | 30 | 50 |
| " | 5/16/91 | 30 | 5/17/93 | 21 | " |
| " | 5/7/94 | 35 | 5/27/92 | 32 | " |
| " | 5/7/94 | XXX | 5/26/92 | XXX | " |
| the slow ramp only. | | | | | |
| st, data ignored. | | | | | |
| | | | | | |
| | | | | | |
| 1 | 5/5/93 | 30 | 6/8/93 | 15 | 50 |
| " | 6/7/93 | 25 | 5/18/93 | 25 | " |
| " | 4/19/92 | 30 | 5/9/94 | 30 | " |
| " | 5/9/94 | 40 | 4/30/92 | 30 | " |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

# RTT Statistical Analysis

## Results Summary -- Sensor Data

| EPN/ Function | Statistical Data Source | n | mean (sec) | s (sec) | $T_{upper}$ (sec) | $T_s$ (sec) | Assumed Sensor RTT Data Source | Comments |
|---|---|---|---|---|---|---|---|---|
| MS-LS-61A,B,C,D Rx Low Level | SS Surv, 2 bench tests | 10 | .5666 | .117 | 0.907 | 0.95 | LCS 1.0 sec (sensor) minus 0.05 secs (logic from RPS) | Acceptable fit to normal curve. |
| MS-PS-15A,B,C,D MSLine Low Pressure | Barksdale B1T | 32 | 0.015 | 0.02 | .0584 | 0.95 | LCS 1.0 sec (sensor) minus 0.05 secs (logic from RPS) | One outlier removed. Normality plot indicates that the distribution is skewed. However, there is a large margin between $T_{upper}$ and $T_s$ indicating acceptability of the results. |
| MS-DPIS MS High Flow | Barton 288A | 35 | 0.061 | 0.041 | 0.150 | 0.45 | LCS 0.5 secs (sensor) minus 0.05 secs (logic from RPS) | Two Outliers removed. Normality plot indicates that the distribution is slightly skewed. However, there is a large margin between $T_{upper}$ and $T_s$ indicating acceptability of the results. |
| MS-PS-23A,B,C,D RPS Trip on High Pressure | SS Surv, 4 bench tests | 11 | 0.083 | 0.06 | 0.2533 | 0.50 | GE Design Spec. 23A1877AA | Two outliers removed. Normality plot indicates that the distribution is skewed. However, there is a large margin between $T_{upper}$ and $T_s$ indicating acceptability of the results |
| MS-LIS-24A,B,C,D RPS Trip on Low Level | Barton 288A | 25 | 0.456 | 0.066 | 0.607 | 1.0 | GE Design Spec. 23A1877AA | Good fit to normal curve |

## Results Summary --Logic Data

| EPN/ Function | Statistical Data Source | n | mean (sec) | s (sec) | $T_{upper}$ (sec) | $T_{x(logic)}$ (sec) | Assumed Logic RTT Data Source | Comments |
|---|---|---|---|---|---|---|---|---|
| MS-LS-61A,B,C,D Rx Low Level and MS-DPIS-8A,B,C,D MS High Flow | SS Surv tests | 15 | 0.022 | 0.006 | 0.038 | 0.05 (Includes Solenoid) | Use Data from RPS FSAR Table 7.2-5 | Normality plot indicates that the distribution has a high peakedness indicating the normality assumption is conservative. In addition, there is a large margin between $T_{upper}$ and $T_{x(logic)}$ indicating acceptability of the results. |
| MS-PS-15A,B,C,D MSLine Low Pressure | NA | NA | NA | NA | NA | 0.05 (Includes Solenoid) | Use Data from RPS FSAR Table 7.2-5 | Valid data not available |
| MS-PS-23A,B,C,D RPS Trip on High Pressure and MS-LIS-24A,B,C,D RPS Trip on Rx Low Level | SS Surv tests | 14 | 0.029 | 0.006 | 0.045 | 0.05 (Includes Solenoid) | FSAR Table 7.2-5 | Large central peak. Normal distribution conservative. |

**Notes:** [illegible]ext Page

**Notes:**

n = number of data points
s = standard deviation
$T_{upper}$ = Upper one sided 95/95 tolerance bound
$T_s$ = response time assumed for instrument sensor
$T_{x(logic)}$ = response time assumed for logic strings (relays). The time assumed for RPS and MSIV Isolation logic includes the actuated solenoid valve.

The results in this table conservatively do not take credit for outlier removal. Outliers are identified only to assess if the distribution is normally distributed.