TESTING OF PRESSURE RELIEF VALVE "RV1919"

Prepared For

OFFICE OF PIPELINE &
HAZARDOUS MATERIALS SAFETY
NATIONAL TRANSPORTATION SAFETY BOARD
Washington, DC

DECEMBER, 2000

STRESS ENGINEERING SERVICES, INC.
Houston, Texas

National Transportation Safety Board

Memorandum

Date February 13, 2001

To: Docket File - DCA-99-MEW08

From: Allan C. Beshore, Investigator-in-Charge

Subject: Report Entitled "Testing of Relief Valve 1919"

The graphical representations contained in the Appendices to this report are in a multi-color format. Information may be lost when these graphs are reproduced in black and white.

Excel data files that can be utilized to reproduce the attached *graphs* in the original multi-color format are available upon request.

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PN1006947CRA

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Washington, DC

Prepared By: ______________________
George R. Ross, Ph.D.
Associate

Reviewed By: ______________________
S. Allen Fox, P.E.
Principal

Stress Engineering Services, Inc.
13800 Westfair East Drive
Houston, Texas 77041-1101

[illegible] 2000

EXECUTIVE SUMMARY

This report describes the tests that were conducted at Stress Engineering Services (SES) on September 18 through 22, 2000. The test subject was an 8 inch ANSI 300# relief valve. The valve was subjected to nondestructive tests which included radiography and the use of an optical probe. The valve was also subjected to a series of pressure tests. The pressure tests were conducted on the valve in the as-received condition, with the pilot valve replaced with a new high pressure (HP) exemplar pilot valve, and with the pilot valve replaced with a new low pressure (LP) exemplar pilot valve. Before installation onto the relief valve, the set point of the HP exemplar pilot valve was *checkedwith a dead weight tester. The original (accident) pilot valve was also checked with the dead weight tester. The set-point of the LP exemplar was checked with the dead weight tester and was changed to match the set point of the accident valve prior to installation on the relief valve.

When the accident pilot valve was on the relief valve, pressures in excess of the maximum allowable working pressure of the relief valve could be held on the inlet side. This was also the case when the LP exemplar pilot valve, with the set point adjusted to match the accident pilot valve, was installed on the relief valve. When the HP exemplar pilot valve was installed on the relief valve, the pressure and AE data and the volumes of hydraulic oil exiting the valve indicated that the pilot and relief valves were opening. Table 1 contains of summary of the pressure tests performed.

Once the tests were complete, the pilot valves and the relief valve were disassembled. Neither the nondestructive examination nor the disassembly revealed any broken parts. The components in the accident pilot valve were visually the same as those in the LP exemplar valve. After inspection, the valves were reassembled.

This report provides a factual account of the test activities and conclusions which can be drawn from the test data. The testing activities are presented in chronological order. Conclusions/observations which can be drawn from the test program include;

1. The components in the relief valve and accident pilot valve were in good condition. There was no damage to any of the components that would prevent the valve fiom functioning.
2. There were no debris or blockages in the pilot valve, relief valve, pilot sensing lines, or small valves in the pilot sensing lines which would prevent the valve from operating.
3. When fitted with an exemplar HP pilot valve, the relief valve operated properly. In every case where the inlet pressure exceeded the set-point of the HP pilot valve, the pressure was relieved.
4. The accident pilot valve was configured as a low pressure (LP) pilot valve, but an attempt had been made to increase the set point to that of a high pressure (HP) pilot valve.
5. Increasing the set point of a LP pilot valve to that of a HP pilot valve requires the main spring in the pilot valve to be too compressed to provide reliable operation.
6. It is possible that the accident pilot valve could have failed to operate in service due to the attempt to increase a LP pilot valve set point to that of a HP pilot valve. In order for the relief valve to open, the pilot valve must operate. Given the condition of the accident pilot valve, when it was examined at SES, it is conceivable that the accident pilot valve would operate sometimes and not operate at other times. This means that the relief valve could operate in an unpredictable manner.

Table **1. Summary** of Pressure Tests on Relief Valve

Description	Pilot Valve Set point (psig)	Results
Relief Valve with Accident Pilot	440 expected (opened 550-600 psig in first dead weight test)	Pressures in excess of **697** psig held on valve inlet side. The valve did not open.
Relief Valve with HP Pilot	**617** (**650** fully open)	Maximum inlet pressures consistently in **624-668** psig range. AE data indicates opening of pilot and relief valve. Hydraulic fluid measured from relief valve and pilot valve outlets.
Relief Valve with **Adjusted LP Pilot Valve**	500 (**600-650** fully open)	Pressures in excess of set point held on valve inlet side The valve did not open.

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1.0 INTRODUCTION

Stress Engineering Services, Inc. (SES) was contracted by the National Transportation Safety Board (NTSB) to conduct a series of tests on an eight (8) inch ANSI 300# relief valve. The relief valve was designated as valve "RV1919". The tests were conducted as part of the NTSB investigation of the rupture of an Olympic Pipeline, Co. (Olympic) liquid pipeline. The pipeline was located in Bellingham, Washington and ruptured on June 10, 1999. Valve RV1919 was located at the inlet side of the Bayview station for the purpose of relieving pressure upstream of the valve. When opened, RV1919 would divert the flow of product from the liquid pipeline into surge tanks at the Bayview station.

During the testing process, there were some changes to the test protocol. This report details the tests as they were conducted as SES. The activities are listed in chronological order. The tests conducted at SES were intended to;

1. Determine the as-received condition of the valve through nondestructive testing
2. Determine if and/or at what inlet pressure the valve would operate in the as-received condition
3. Determine if and/or at what pressure the valve would operate with a new high pressure (HP) exemplar pilot valve installed
4. Determine if and/or at what pressure the valve would operate with a new low pressure (LP) exemplar pilot valve with the set point, as determined by testing on a dead weight tester, changed to match the accident pilot valve installed
5. Conduct dead weight tests of pilot valves to determine set points
6. Disassemble and compare the accident, LP exemplar, and HP exemplar pilot valves
7. Disassemble the main valve and note any abnormalities

2.8 DAY 1: NONDESTRUCTIVE EXAMINATION

Although the valve was received at SES on September 11,2000 at 2:15 pm, testing did not start until September 18, 2000. When received, the valve was placed in a locked forensic storage unit. The crate was not removed from the storage unit or opened until the test witnesses were present on September 18, 2000.

Day 1 of testing began on September 18, 2000. The first activity was an introductory meeting. During this meeting, Robert Trainor of the **NTSB** gave an overview of the expected test plan. Key points included in his presentation were;

1. all photographs would be taken by SES and all parties will be provided copies of the photographs on a **CD,**
2. one set of field notes would be taken and distributed to all parties,
3. the NTSB took possession of the valve approximately ten (10) **days** after the accident,
4. the valve was shipped to SES, but has not been opened,
5. after the tests were completed, all parts of the valve would be turned over to the Department of Justice,
6. **NTSB has** purchased **two** exemplar pilot valves and will retain custody of the exemplar pilot valves,
7. any video tape taken during the test program would be taken without sound, and
8. SES is to prepare a report for the NTSB and the report will be distributed to all parties.

George Ross of SES gave a short presentation of a tentative test schedule and presented the lab safety rules for visitors to the group. The handouts provided **by Dr.** Ross are included in Appendix A of this report.

2.1 Uncrating the Valve

The first activity following the kick-off meeting was the removal of the crate containing the valve from the forensic storage unit and unpacking the valve. Figure 2.1 shows the valve being removed from the forensic storage unit. The sealed crate is shown in Figures 2.2 through 2.4.

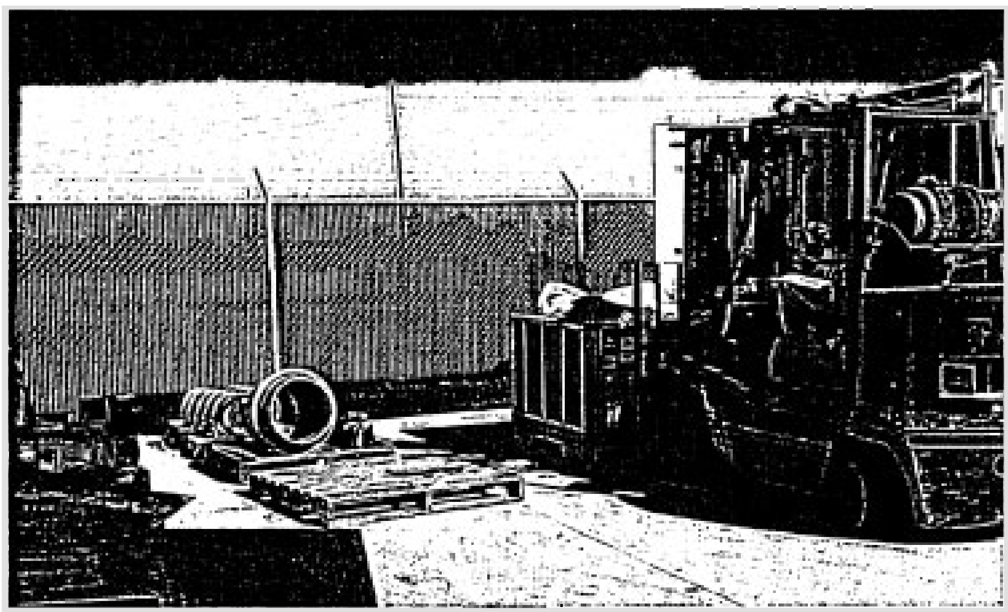


Figure 2.1 Removing Crate From Storage

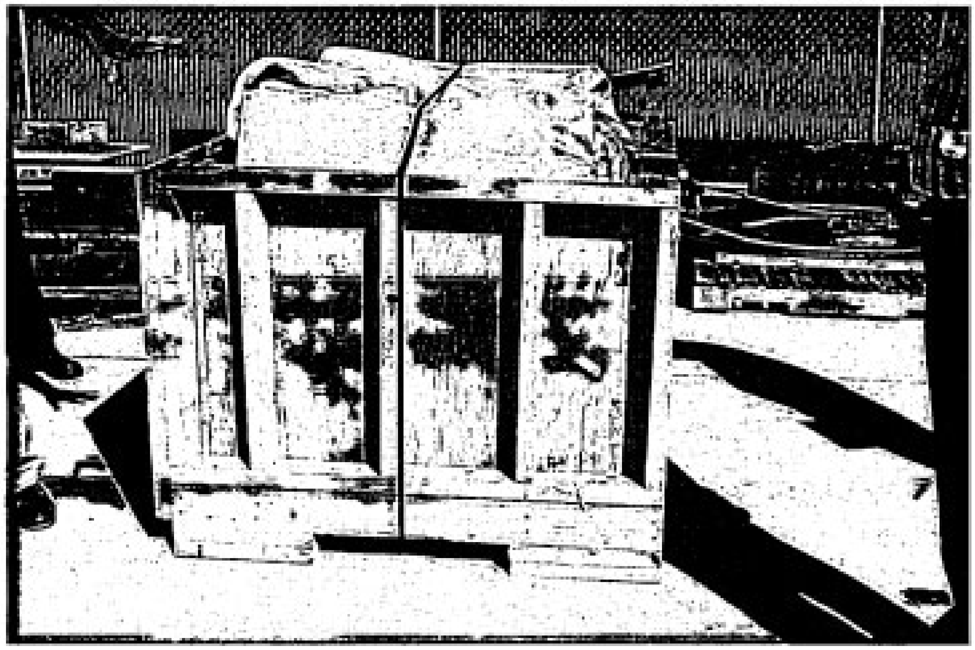


Figure 2.2 Sealed Crate

Figure 2.3 Signed Tags on Sealed Crate

Figure 2.4 Signed Tags on Sealed Crate

The steel bands on the crate were added by SES when the crate was received. Figures 2.3 and 2.4 show the tags that were signed by Allan Beshore, of the NTSB, when the valve was crated by the NTSB. The tags were secure and intact.

Representatives from Fischer-Rosemount noted that the crate was different from the one in which the valve was placed when in Bellingham, Washington. The NTSB representatives explained that the valve had to be repacked in order to comply with hazardous material shipping requirements and was repacked before shipment to NTSB in Washington, DC.

Once the crate was examined, it was opened and the valve removed. Figures 2.5 and 2.6 show the valve being unpacked and removed from the crate.

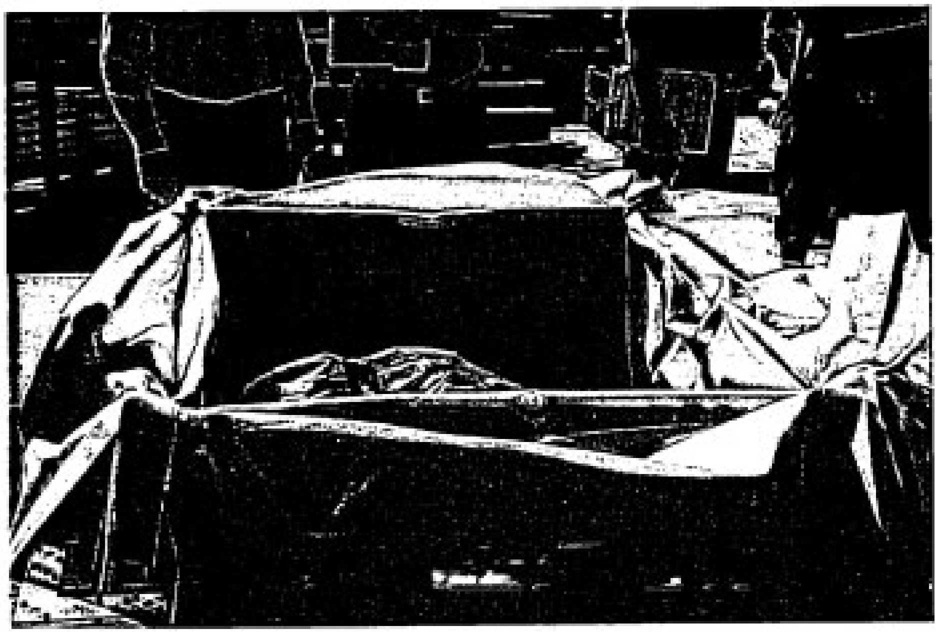


Figure 2.5 Unpacking Valve

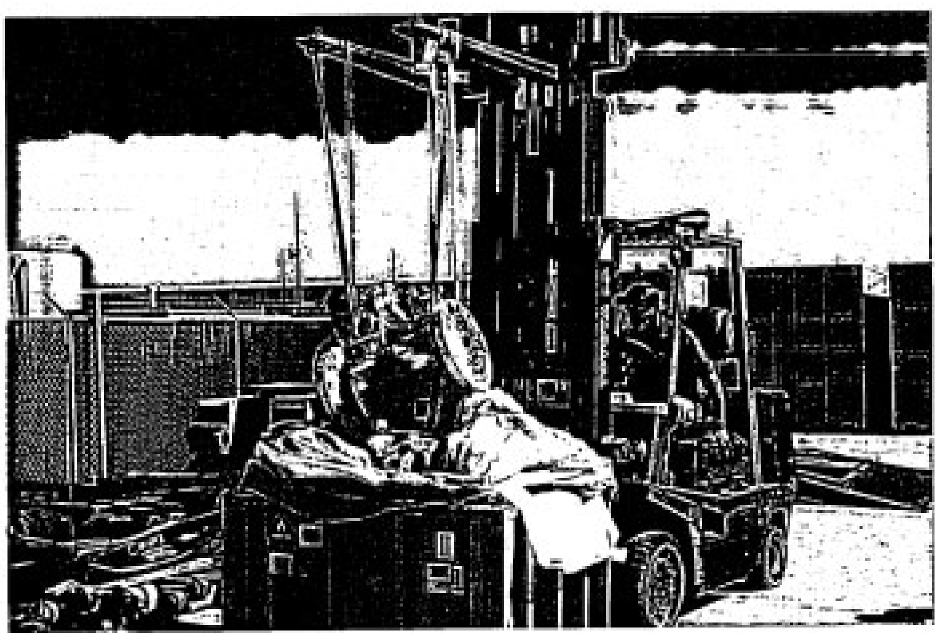


Figure 2.6 Removal of Valve From Crate

Once the valve was removed from the crate, a visual examination of the valve was conducted to determine the overall condition of the valve. There was some absorbent material inside the outlet flange of the valve which was removed during this examination. There was nothing of note in the outlet flange of the valve.

A tag reading "RV-1919" was attached to the relief valve. The following data appeared on the name plate for the relief valve and the pilot valve:

Relief Valve Name Plate:	Size: 8" [inches] Flange (ANSI): 300
	Serial No.: 9801-27803-1-1
	Figure No.: M 760 AP
Pilot Valve Name Plate:	Model No.: 1760
	Part No.: 453200
	Spring Range: 70-180

Five manual valves were installed in the pilot sensing lines. The Fisher-Rosemount representatives stated that these manual valves were not standard equipment. Four of the valves appeared to be ball valves with handles. The fifth valve was located on a tee in one of the lines and had a knob that could be turned to open or close the valve. The four ball valves were tagged and numbered 1 through 4. Valves 1, 2, and 3 were fully closed. Valve 4 was located in the sensing line between the inlet side of the relief valve and the housing containing the needle valve and strainer assembly. Valve 4 was not fully closed. Photographs of the manual valves which show the orientations and locations of the manual valves are shown in Figures 2.7 through 2.10.

Figure 2.7 Orientation of Valves 1 and 2

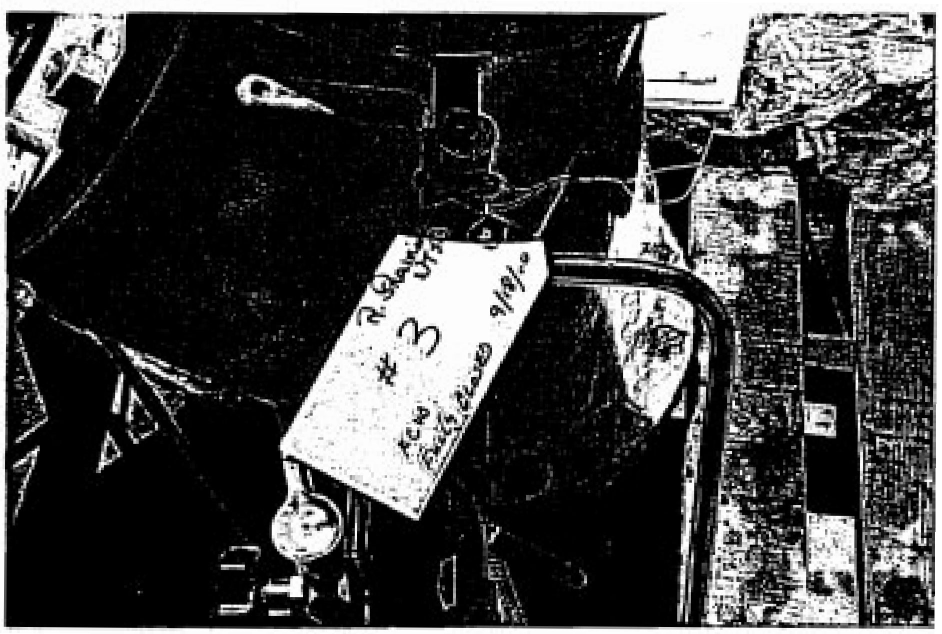


Figure 2.8 Orientation of Valve 3

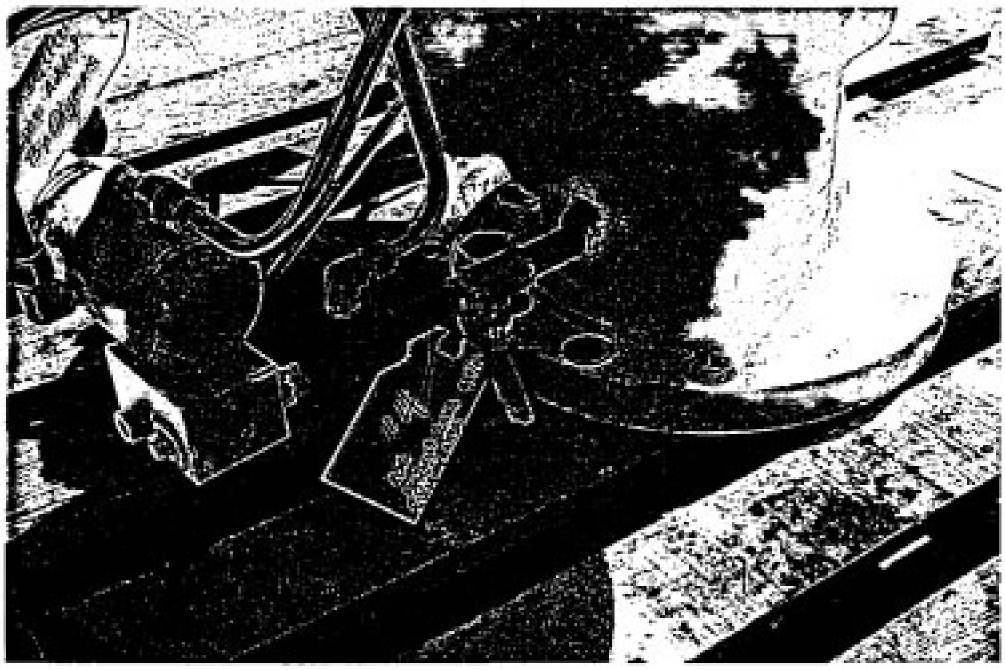


Figure 2.9 Orientation of Valve 4

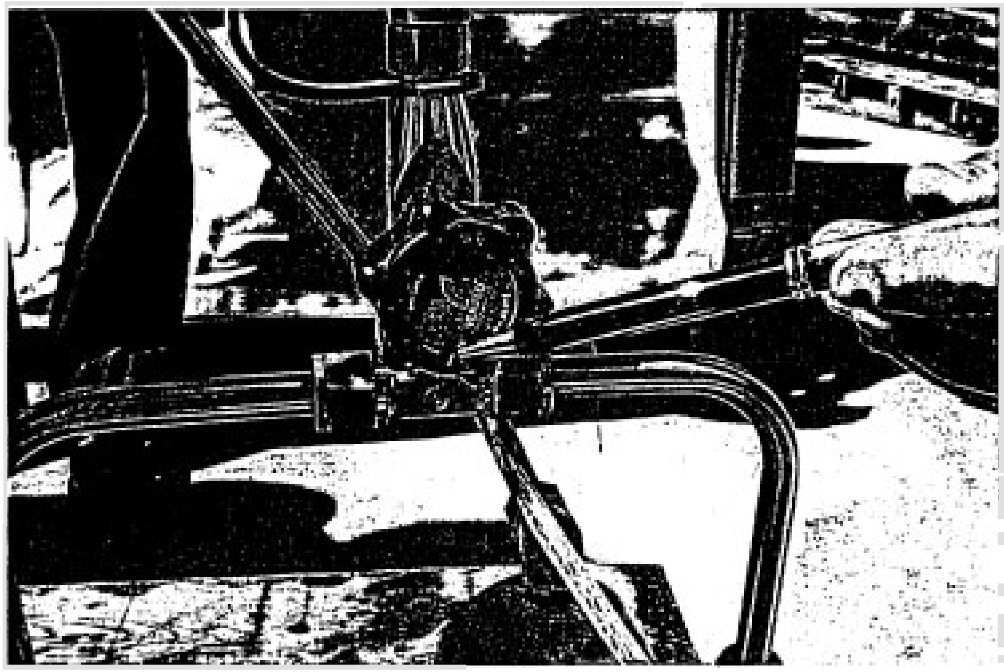


Figure 2.10 Orientation of Valve in Sensing Line

The final item of note in relation to the visual examination of the valve is that two nuts were missing from the cylinder head. SES understands that these nuts were in place before the valve was removed from the line. Figure 2.11 shows the studs where the nuts were missing. In addition to the nuts being missing, one of the studs had significant thread damage. The damaged stud is the one with the pen pointing to it in Figure 2.11.

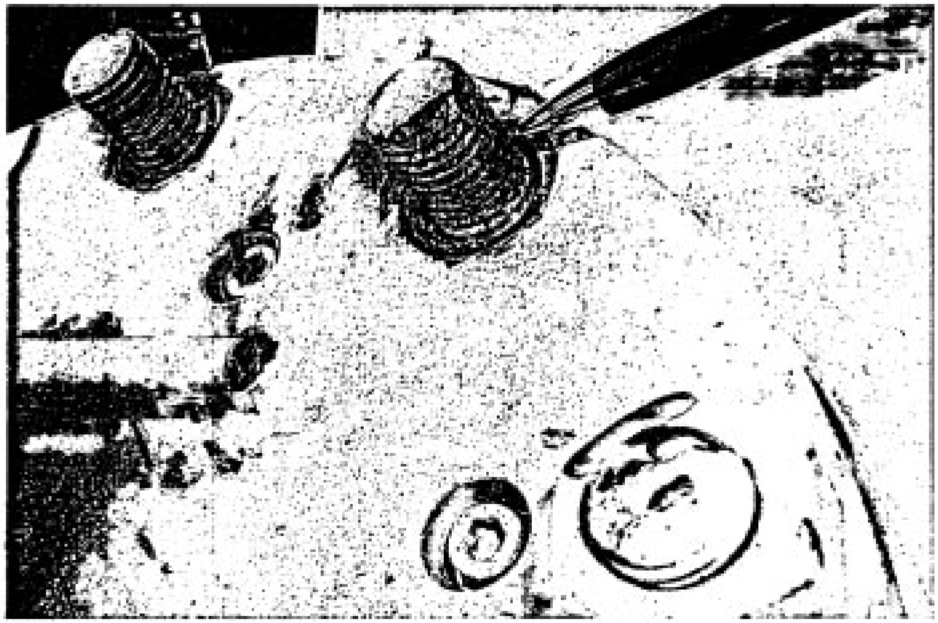


Figure 2.11 Missing Nuts and Damaged Stud

At this point, the valve was tumed over to Bart Crater of CONAM for radiographic inspection. The radiographs were taken on the back lot at SES. While the radiographs were being taken, a meeting was held to discuss the test setup.

2.2 Discussion of Test Set-up

A meeting was held *to* discuss the test set-up. Each witness was provided with a schematic of the test set-up as shown in Figure 2.12. The intent of the schematic was to show the general arrangement of the plumbing for the test and the locations of the pressure transducers. The schematic does not show the location of the control valves for the test or the acoustic emission (AE) sensors.

In the meeting, it was explained that two AE sensors would be used, one on the pilot valve and one of the main valve body. In addition, the test set-up would contain a valve between the accumulator and the inlet of the relief valve and bleed valves to bleed pressure from the inlet flange and the dump vessel. SES also explained that the intent was to replace the small valves in the sensing lines with tees and attach pressure transducers to the tees. If it was found that the small valves were not free of debris, the instrumentation would need to be reexamined.

As a result of the discussion, three changes were made to the test set-up. The first change was that one of the pressure transducers was relocated from the line to the inlet flange to the inlet flange itself. This involved sending the inlet flange back to the machine shop and having a one quarter inch (1/4 inch) NPT port added to the flange. This flange was sent to the machine shop and returned to SES on the afternoon of September 18, 2000. The second change was to add an additional pressure transducer to the pilot valve sensing line (i.e., the line from the pilot valve to the inlet side of the main relief valve). The thii change was that a strainer was added between the outlet flange of the relief valve and the dump vessel. The strainer was ordered on September 18 and arrived on September 19. The revised test set-up is shown in Figure 2.13.

Data acquisition was discussed and it was explained that the AE data and the pressure transducer data would be taken on separate systems. In order to correlate the data, the output from one pressure transducer would be read by both systems'.

One comment made during the discussion concerned the fluid which would be used to apply pressure to the valve. SES intended to use hydraulic oil. The hydraulic oil to be used was an ISO Grade 46 hydraulic oil. The concern was with the difference in viscosities of the hydraulic oil and the product which the pipeline carried. Since the hydraulic oil is thicker than gasoline, it was felt that the reaction times for the relief valve would be slower. SES pointed out that the valve was not being tested under full flow and that this would also affect the reaction time. It was proposed that the test be conducted with mineral spirits. However, after some consideration by SES, it was decided that an intemal review would be required before this could be done. The concern of SES was the danger due to the volatile nature of mineral spirits. It was felt that arrangements could be made to conduct the test with mineral spirits, but these arrangements would result in a delay in the test schedule. The group was presented with a sample of the hydraulic oil to be used in the test and it was agreed to proceed with the test using the hydraulic oil.

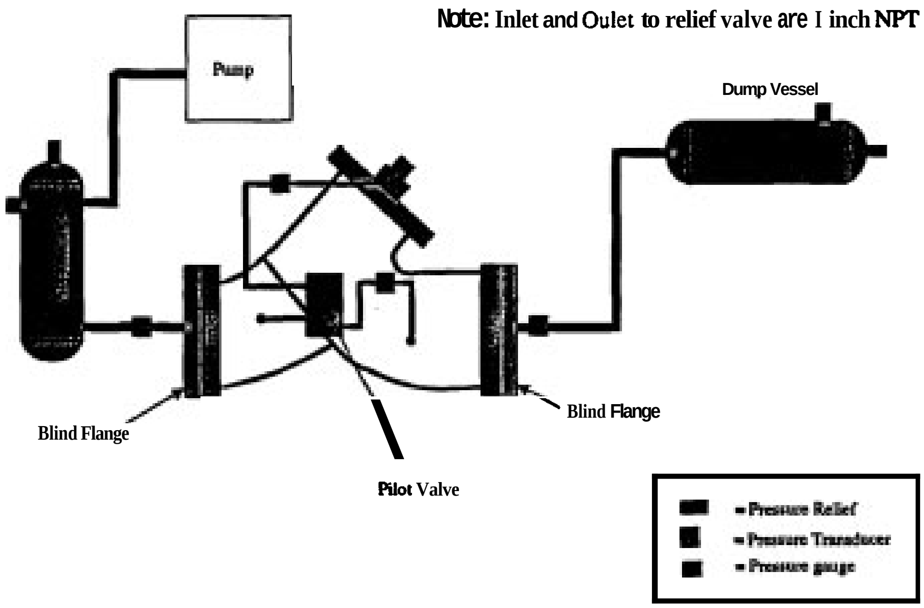


Figure 2.12 Original Schematic of Test Set-up

Schematic of Test Set-up

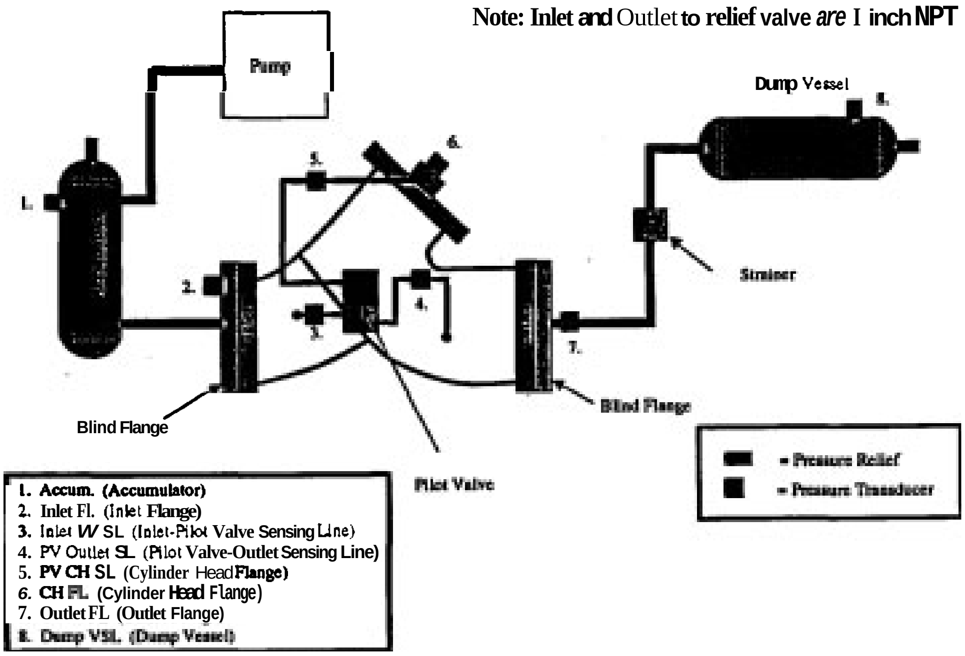


Figure 2.13 Revised Test Set-up

23 Radiographs

While the discussion of the test set-up was taking place, CONAM was taking radiographs of the relief valve. This included radiographs of the small valves which were tagged when the valve was unpacked (i.e., valves 1, 2, 3, 4, and the "knobbed" valve in the pressure sensing line), the pilot valve, and the main relief valve body. Two shots, approximately 90 degrees apart, were taken of valves 1, 2, 3, 4, and the "knobbed" valve in the pressure sensing line. One shot was taken of the pilot valve and one shot was taken of the main body of the relief valve. No broken parts, debris, or other abnormalities could be identified in the radiographs. The radiographer in charge was Bart Carter. The paperwork showing Bart Carter's certifications is presented in Appendix B.

2.4 Optical Probe and Visual Inspection

Once the radiographs were complete, the valve was moved from the back lot of the SES test facility into the main lab area. The valve was placed on a table and a visual and optical probe inspection conducted. The optical probe inspection was videotaped and photographs were taken during the inspection.

There was some light rust at the upstream side of the valve. The rust was cleaned out of the valve with a nylon bristle brush and placed in a labeled bag. The studs on the cylinder head which were missing nuts were labeled 1 and 2. Thread damage was observed on both of these studs. [Note: The NTSB later confirmed that the two nuts were removed on June 29,1999, to obtain the needed clearance for the removal of the relief valve from the pipeline system.]

The sensitivity screw was also examined. This sensitivity screw controls a needle valve. The position of the needle affects the closing speed of the relief valve. Measurements were taken to record the position of the sensitivity screw. The top of the screw was 0.345 inches below the top of the housing nut. The height of the housing nut was 9/16 inch. A sketch illustrating these dimensions is included in Figure 2.14. The housing which contains the sensitivity screw is rectangular in shape and contains a strainer in addition to the needle valve. The pilot valve mounts to a port in this housing. In Figure 2.9, the housing can be seen adjacent to the pilot valve.

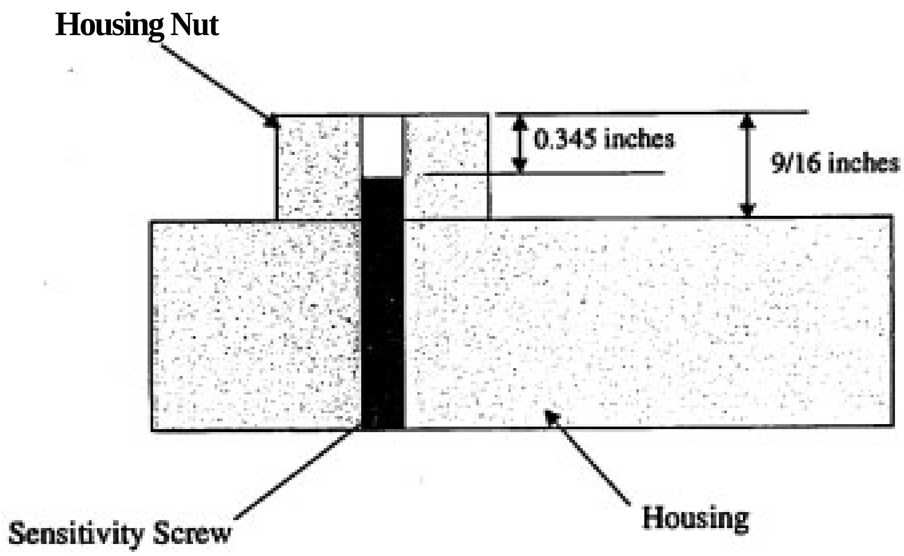


Figure 2.14 Measurements of Sensitivity Screw Location

An optical probe was then used to examine the valve. The probe was passed through all of the sensing lies. Due to the numerous turns in the lines, some of the connections in the sensing lines were opened to allow for insertion of the probe. Table 2.1 summarizes the optical probe examination.

Probe Number	Description	Observation
•	Through valve #4 into the strainer (straight ahead view)	No obstructions
2	Through valve #4 into the strainer (90 degree view)	No obstructions, strainer appears clean
3	Into needle valve/strainer housing	Probe view fuzzy due to gasoline in housing
4	Into needle valve/strainer housing after removing a few drops of gasoline with a cotton swab	Could see the shaft of needle valve, but could not see the end of the shaft
5	Through line from cylinder head to needle valvdstrainer housing.	No obstructions
6	Through loop from pilot valve back to the sensing line on the inlet side of the main valve.	There was a small amount of gasoline in the line, but no obstructions.
7	Through loop from pilot valve to the outlet side of the main valve.	There was a small amount of gasoline in the line, but no obstructions.
8	Into the outlet side of the main valve (from the outside)	No obstructions
9	Into the pilot valve	No obstructions
10	From the inside of main valve outlet side to tee in the line	No obstructions, could see closed small valve
11	From the inside of main valve outlet side to tee in the line with small valve opened	No obstructions
12	Cylinder head	No obstructions
13	Cylinderhead	No obstructions
14	Inlet side of main valve	No obstructions

All of the lines and components were examined with the optical probe. There were no debris or blockages found. All of the lines and the strainer were clean. During the examination, a significant amount of gasoline, approximately 5 quarts, was drained from the cylinder head. Figure 2.15 shows the gasoline being drained from the cylinder head. Figure 2.16 shows the gasoline that was drained. The gasoline was discolored, but appeared fiee of debris. Figures 2.17 through 2.19 show the optical probe inspection.

There was nothing found during the radiographic, visual, or optical probe inspection that would indicate that the valve would not operate.

Figure 2.15 Draining Gasoline from Cylinder Head

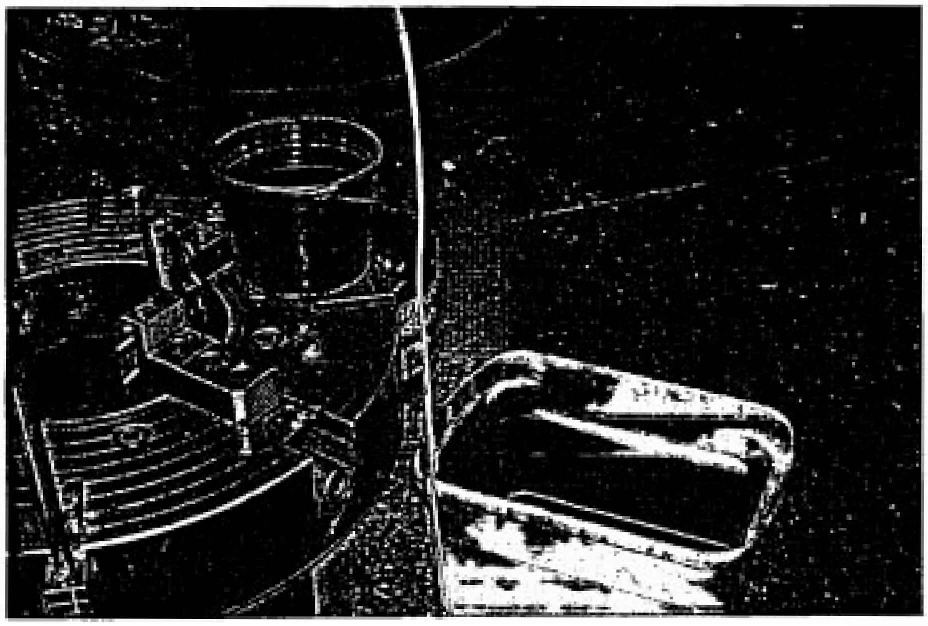


Figure 2.16 Gasoline Drained from Cylinder Head

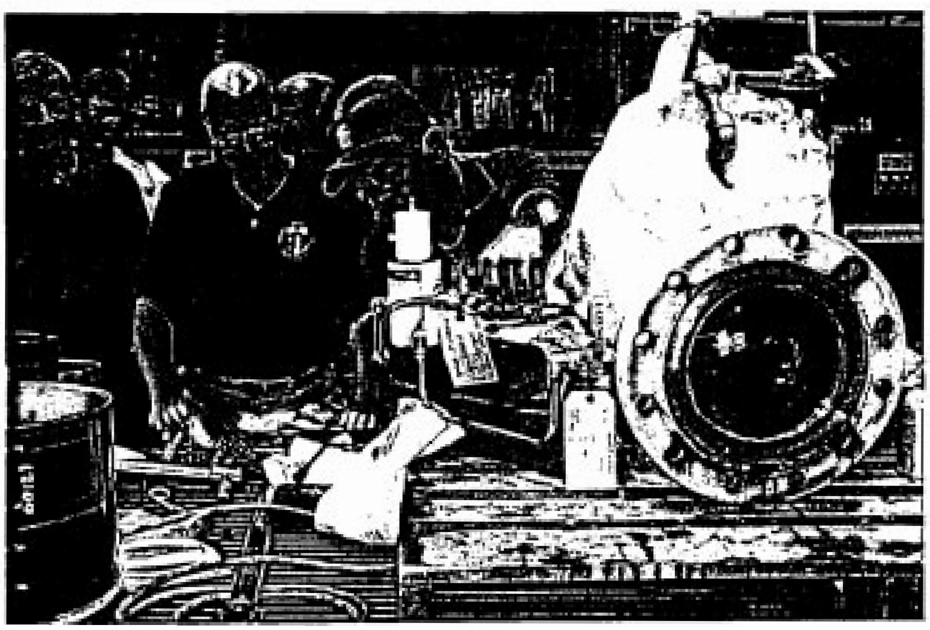


Figure 2.17 Optical Probe Inspection (View 1)

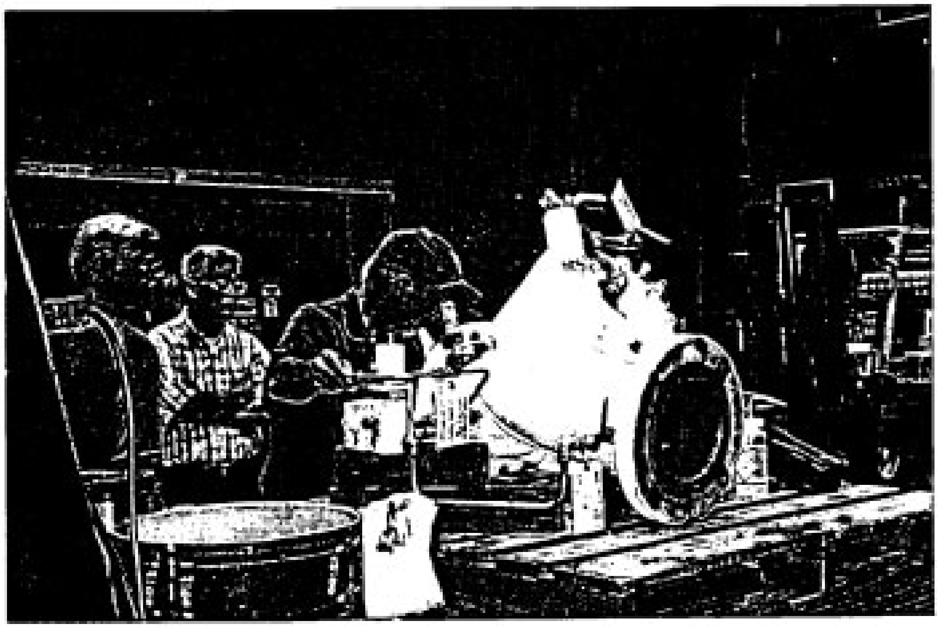


Figure 2.18 Optical Probe Inspection (View 2)

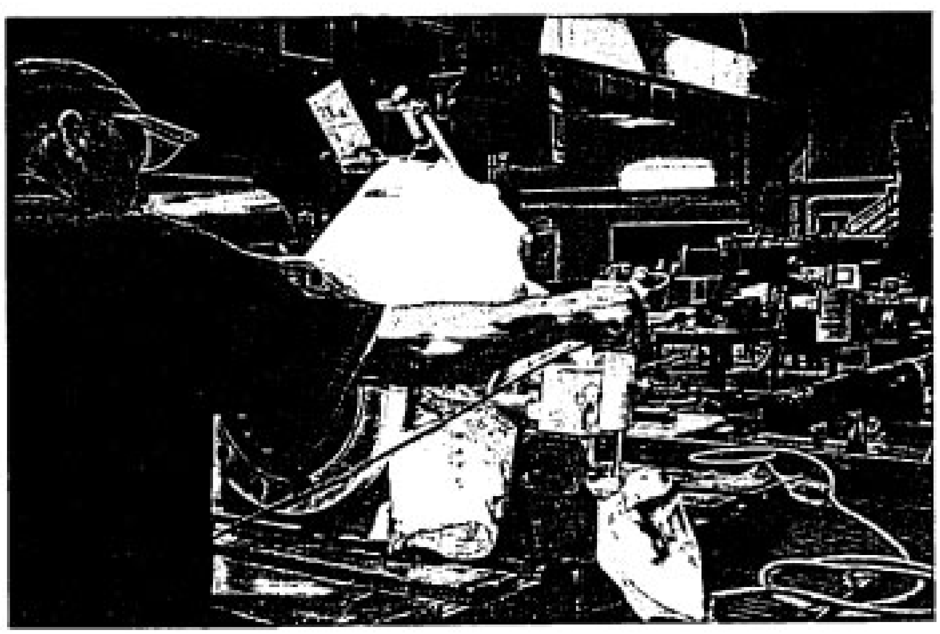


Figure 2.19 Optical Probe Inspection (View 3)

Once the inspection was complete, the valve was placed in the test pit. The test pit was sealed until representatives from NTSB arrived the following morning. The sealing of the test pit is shown in Figure 2.20.

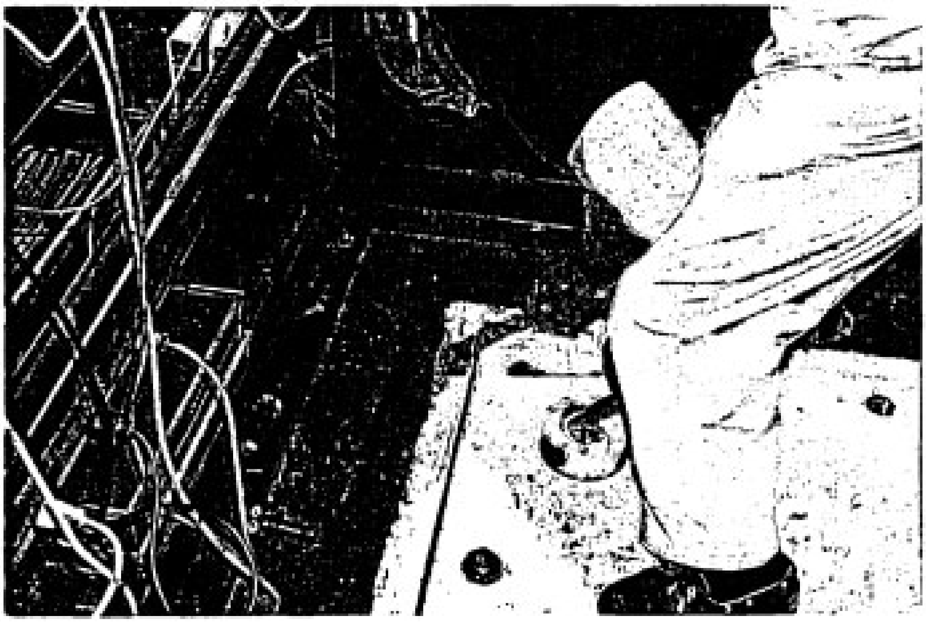


Figure 2.20 Sealing of Test Pit

3.0 DAY 2: PRESSURE TEST OF ACCIDENT VALVE

The majority of the day on September 19, 2000 was spent setting up the test equipment. This included installing flanges on the relief valve and torquing the bolts to 188 ft-lbs, replacing the small valves with tees, mounting the pressure transducers and AE sensors, and assembling the plumbing for the test set-up. While the test equipment was being set-up, a meeting was held to review the proposed test protocol and the activities of the previous day. The final activity for the day was the pressure test of the as-received valve.

3.1 Day 2 Meeting

The group met at 10 am. The first item of discussion was the set of field notes from the previous day. All of the parties were allowed to review the notes. The group was then asked to point out any areas in the notes that needed revision. Once the revisions were made, the participants signed the field notes.

During the meeting, the specifications for the hydraulic oil and the revised test set-up schematic as shown in figure 2.13 were handed out.

One area of discussion concerned the calibration of the pressure transducers. Jim Liou, representing the City of Bellingham, suggested that the pressure transducers be checked on a dead weight tester prior to the test. George Ross of SES pointed out that the pressure transducers were all in calibration and that it is standard SES practice to calibrate transducers once a year. In addition, any time that a transducer is overloaded it is red tagged and recalibrated. As a result of the discussion, it was decided that the pressure transducers would not be checked on the dead weight tester prior to the test. However, the City of Bellingham was welcome to contract with SES to check the transducers immediately after the test. SES's standard calibration practices and the calibration certificates for the pressure transducers and the dead weight tester used in the tests are included in Appendix C.

3.2 Test of As-received Relief Valve

The pressure test of the as-received relief valve began on the afternoon of September 19, 2000 at approximately 3:45 pm. Although the test is referred to as testing the valve in the as-received condition, the valve had been disturbed to some extent. During the optical probe inspection, the sensing lines had to be removed to provide entrance points for the probe. In addition, in the pressure test, the small valves in the sensing lines were replaced with tees. It was necessary to replace the valves with tees so that the pressure transducers could be placed in the system. Since the small valves were found to be free of debris (i.e., clean and clear), it is felt that replacing the small valves with tees did not affect the operation of the valve.

3.2.1 Test Set-up

The test set-up used for this test is illustrated in Figure 3.1. The original test protocol had called for pressurizing the inlet and outlet of the relief valve to 20 psig, Unfortunately, during the initial test set-up, a bleed valve was not installed between the inlet flange and the isolation valve. The inlet pressure could be bled off, but would have to bled through the pump. This would require bleeding the pressure from the accumulator. When this was discovered, the test protocol was changed so that the dump vessel would be vented to atmospheric pressure and the inlet pressure would be kept at the residual inlet pressure after each test run. This eliminated the need to bleed the inlet and accumulator pressure between runs and would result in less delay between test runs. The dump tank was then vented to atmosphere and the accumulator charged to 800 psig in preparation for the first test run. The bleed line on the dump tank was a small diameter (i.e., ¼ inch) line. As a result it took some time to bleed the 20 psig pressure from the tank.

The principle behind the test set-up is that the accumulator is initially isolated from the relief valve. The pump is used to charge the accumulator to a preset pressure. The isolation valve between the pump and the accumulator is then shut. The data acquisition system is started. While taking data, the isolation valve between the accumulator and the relief valve is opened. Opening the isolation valve allows the fluid in the accumulator to flow, under pressure, to the relief valve.

There are two indicators from which it can be determined if the pilot valve activated. First there is an AE sensor on the pilot valve to pick up mechanical noise. Secondly, a change in pressure on the outlet side of the pilot would indicate that the pilot has activated. Similarly, if the relief valve activates, there will be a change in the outlet pressure and there is an AE sensor on the main valve body to check for mechanical noise.

A photograph of the test set-up is shown in Figure 3.2.

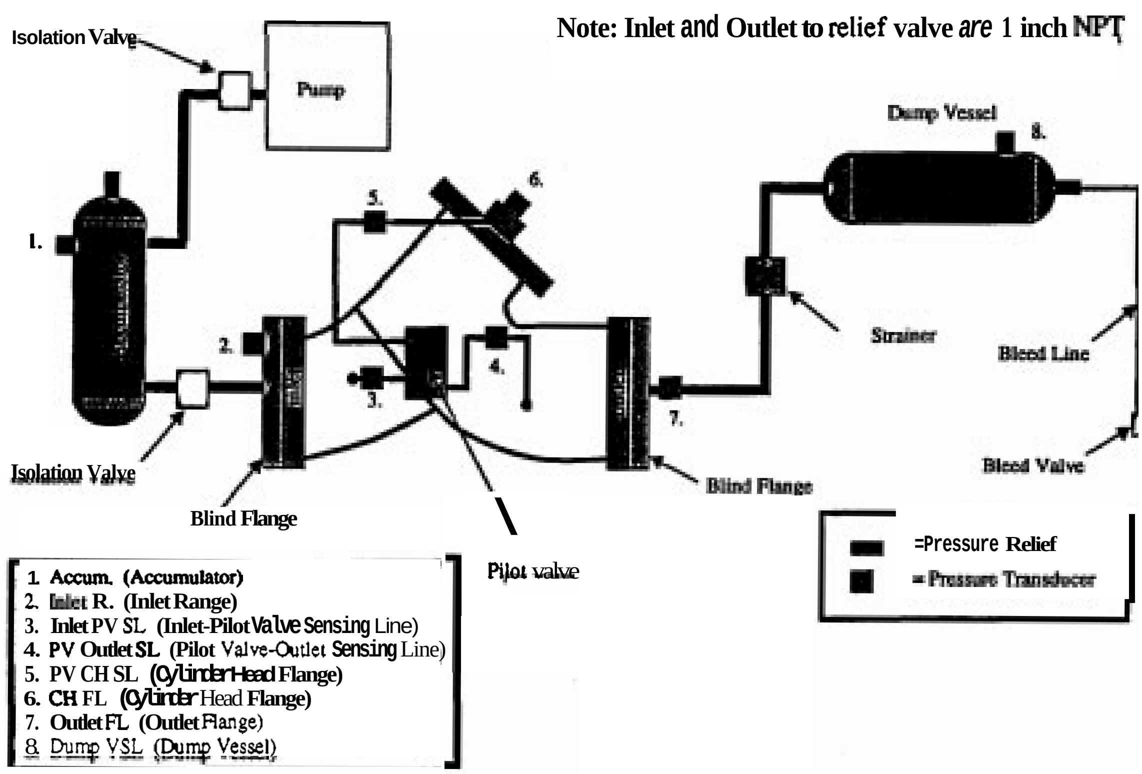


Figure 3.1 Test Set-up For As-received Valve

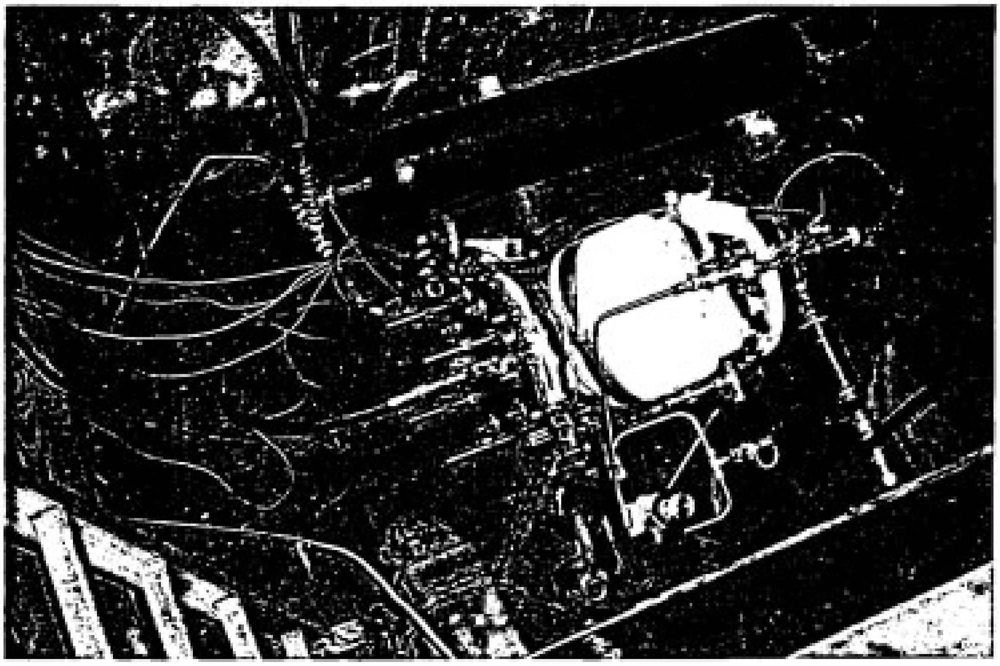


Figure 3.2 Photograph of Test Set-up

3.2.2 Test Results

The test was started with the accumulator charged to 800 psig. The isolation valve between the relief valve inlet flange and the accumulator was then opened. During this run, the inlet pressure reached a maximum of 52 psig. A second run was then made and the inlet pressure reached a maximum pressure of 99 psig. During the third run, the inlet pressure reached a maximum of 55 psig. On the fourth, fifth, and sixth runs, the inlet pressure reached 127 psig, 384 psig, and 762 psig. The inlet pressure was held for approximately 3 minutes and dropped to 706 psig during that time. The set point for the pilot valve was expected to be 440 psig. It was not until the sixth run, that a pressure on the inlet greater than this set point was achieved. There were no AE "hits" during the test that indicated that either the pilot or relief valve opened.

Table 3.1 summarizes the test results. Plots of the test data are included in Appendix D. The plots include traces of pressure as a function of time for all of the pressure transducers.

Table 3.1 Pressure Test of As-Received Valve

Run	Accumulator Pressure at Start of Run		Maximum Inlet Pressure Achieved		Maximum Outlet Pressure Achieved		Residual Inlet Pressure		Volume	Volume of Fluid	Comments
	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press.	Time (sec)	Press. (psig)	Time (sec)	Outlet Flange (cups)	valve Outlet	
1	801	7.7	52	184.3	26	30.7	45	291	NA	NA	No AE hits indicating opening of the valves were detected
2	825	5	99	20.4	37	10.8	91.9	103.9	NA	NA	No AE hits indicating opening of the valves were detected
3	818	4.4	55	45.6	40	11.6	55	45.6	NA	NA	No AE hits indicating opening of the valves were detected
4	804	4	127	71.6	31	8.5	114	376	NA	NA	No AE hits indicating opening of the valves were detected
5	800	377	384	394	6	379	370	518	NA	NA	No AE hits indicating opening of the valves were detected
6	800	518.2	762	518.6	1	518.8	706	1354	NA NA	NA NA	No AE hits indicating opening of the valves were detected

* "… Pressure at Start of Run" is the time when the valve isolating the accumulator from the inlet of RV1919 was opened and marks the starting time of each test run.

It can be concluded from these test runs that the valve was leaking. This is evident because the valve was initially filled with hydraulic oil and the accumulator volume is on the same order as that of the valve. If the valve were not leaking, much higher inlet pressures would have been achieved on the first three test runs. In addition for run 1, the peak outlet and inlet pressures were approximately equal. In runs 2 and 3, outlet pressures comparable to those at the inlet were also seen. In run 4, the valve began to seal better and the maximum inlet pressure was significantly higher than the outlet pressure. In runs 5 and 6, the outlet pressure is negligible in comparison to the inlet pressure. This indicates that as the pressure on the inlet side increased, the valve began to seal better.

It can also be concluded that the pilot and relief valves did not open during the test. This is evident because the maximum inlet pressure of 762 psig is much greater than the set point.

At the end of the day, some changes were made to the test set-up. These changes are discussed in Section 4 of the report, since they pertain to the day three tests. Once the set-up changes were made, the valve was left in the pit with the lids bolted down.

4.0 DAY 3: PRESSURE TESTS OF VALVE AND DEAD WEIGHT TESTS

Day 3 of testing began on September 20, 2000. The following activities took place;

1. Meeting to discuss the notes from the previous day
2. Retested relief valve with accident pilot (slight modifications to test set-up)
3. Dead weight tests
4. Disassembled accident pilot valve
5. Pressure test with high pressure (HP) exemplar valve

4.1 Day 3 Meeting

The day three meeting began at 8:30 am on September 20,2000. The first item of discussion was the set of field notes from the previous day. All of the parties were allowed to review the notes. The group was then asked to point out any areas in the notes that needed revision. Once the revisions were made, the participants signed the field notes.

SES explained the changes made to the test set-up to the group. These changes consisted of increasing the size of the bleed line from the dump vessel, increasing the line size from the pump to the accumulator, and adding a bleed valve between the accumulator to inlet flange isolation valve and the inlet flange.

4.2 Day 3 Test Set-up

The revised test set-up used for the Day 3 tests is presented in Figure 4.1. The changes which were made to the set-up were;

1. the line size of the dump vessel bleed line was increased,
2. the size of the line between the pump and the accumulator was increased, and
3. a bleed valve was added between the accumulator to inlet flange isolation valve and the inlet flange.

These changes were made to improve the efficiency of the testing process.

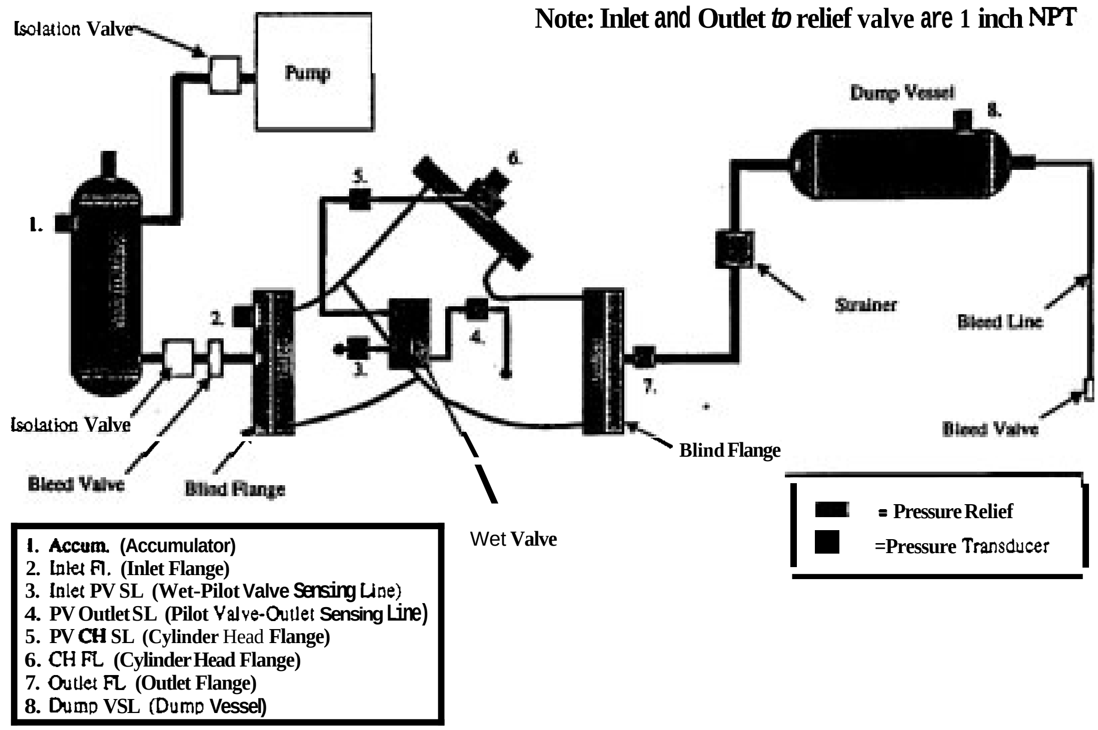


Figure 4.1 Test Set-up Used for September 20,2000 Tests

The testing procedure used was the same as adopted the previous day. The dump vessel was open to atmospheric pressure and the accumulator charged to 800 psig. The intent was to test the valve with the residual pressure at the inlet. However, the relief valve did not operate during the test. Therefore, the bleed valve was used to bleed the inlet pressure to 300 psig between runs.

4 3 Day 3 Test of As-Received Valve

On September 20, 2000, the as-received valve was run through three pressure cycles. During the first pressure cycle, only 84 psig was achieved on the inlet side of the valve. The was accompanied with a pressure at the outlet of 22 psig. This pressure at the outlet is indicative of the valve leaking. On the second and third runs, the valve held pressures in excess of 690 psig on the inlet side of the valve. The maximum outlet pressures during the second and third runs were 6 psig and 1 psig respectively. The expected set point for the pilot valve was 440 psig. The data was consistent with the previous data in that both the pressure and AE data indicated that the relief valve and pilot valve did not operate during the test. The test runs are summarized in Table 4.1. Plots of the test data, which include traces of pressure as a function of time for each data channel, are included in Appendix E.

Table 4.1 Pressure Test of As-Received Valve (Day 3)

Run	Accumulator Pressure at Start of Run		Maximum Inlet Pressure Achieved		Maximum Outlet Pressure Achieved		Residual Inlet Pressure		Volume of Fluid from Outlet Flange (cups)	Volume of Fluid from Pilot Valve Outlet (cups)	Comments
	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)			
1	800	8.2	84	60.1	21.9	57.3	65.3	98.6	NA	NA	No AE hits indicating opening of the valves were detected
2	800	672.2	697	720	6.4	680.8	650	1349	NA	NA	NO AE hits indicating opening of the valves were detected
3	800	153.5	792	155.9	0	NA	771	200	NA	NA	No AE hits indicating opening of the valves were detected

* Note: The time listed under "Accumulator Pressure at Start of Run" is the time when the valve isolating the accumulator from the inlet of RV1919 was opened and marks the starting time of each test run.

Once the test runs were complete, the accident pilot valve was removed from the relief valve for dead weight testing.

4.4 Dead Weight Tests

In order to establish the set-points of all of the pilot valves, the accident, HP exemplar, and LP exemplar pilot valves were tested on a dead weight tester. The set-up for the dead weight tests is shown in Figures 4.2 and 4.3.

The port from the dead weight tester was connected to the sensing port of the pilot valve. Shop air at 30 psig was connected to the inlet port of the pilot valve and a hose was connected from the outlet of the pilot valve to a graduated cylinder filled with water. When the dead weight tester supplies enough pressure to the sensing port, the pilot opens and the air is allowed to flow from the inlet to the outlet of the pilot valve. The air then travels from the outlet of the pilot valve through the tube and produces bubbles in the water filled graduated cylinder. Using this set-up, it was established that the HP exemplar pilot valve opened at 617 psig and the air flowed freely through the pilot valve at 650 psig. The LP exemplar pilot valve opened at 100 psig and allowed a free flow of air at 120 psig. The accident pilot valve first opened between 550 and 600 psig and reseated at 270 psig. In a subsequent run, the accident pilot valve first opened at 400 psig and reseated at 270 psig. In the final run, the accident pilot opened at 350 psig and exhibited full flow at 700 psig.

The results of the dead weight test on the accident pilot valve indicate that the accident pilot valve did not open consistently. The initial opening pressure ranged from 350 psig to 550 psig. This is an extremely large range. The HP and LP exemplar valves had much better defined opening pressures.

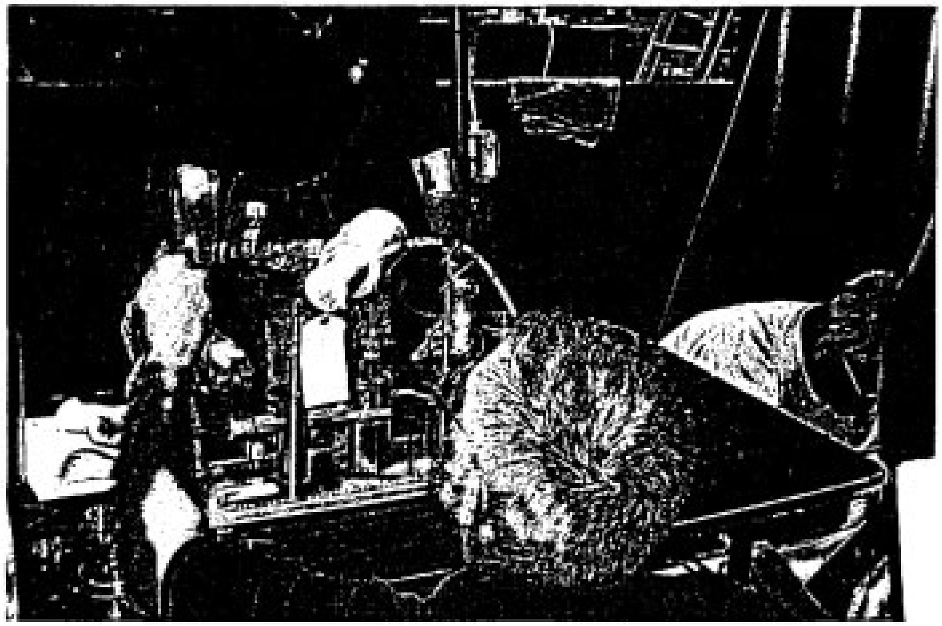


Figure 4.2 Dead Weight Test Set-up

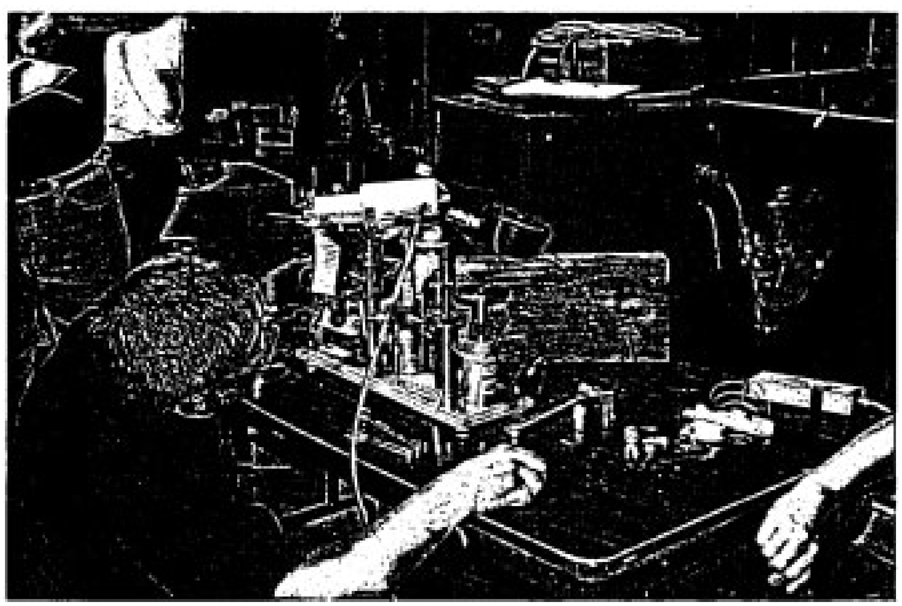
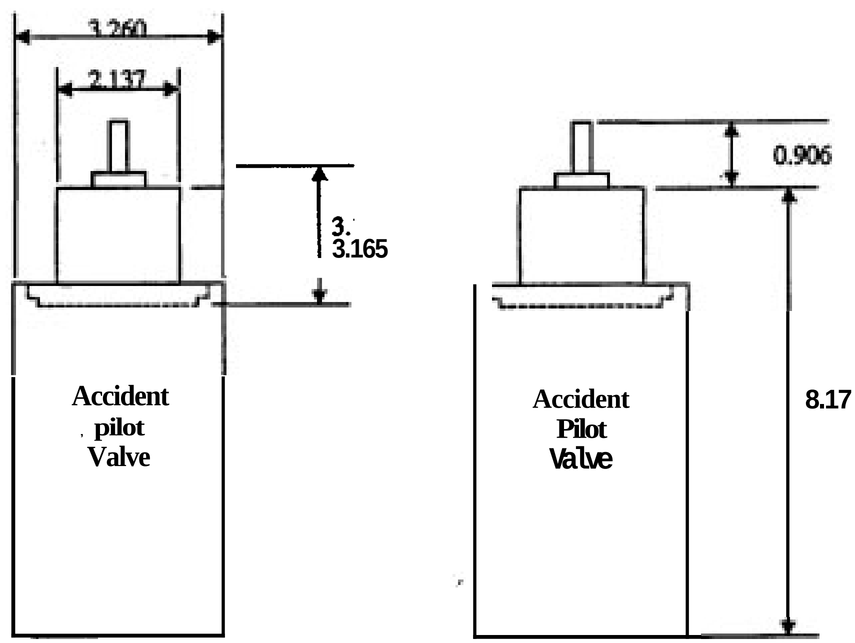


Figure 4.3 Dead Weight Test Set-up (view 2)

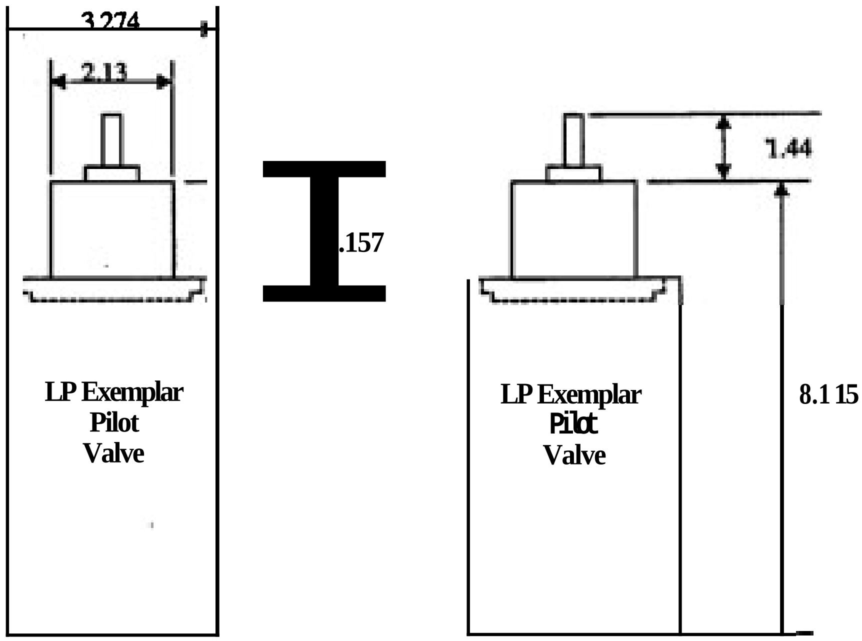
4.5 Dimensions of Pilot Valves

Dimensions of the pilot valves were also taken. These dimensions were taken from the actual pilot valves and also fiom the radiograph taken on Monday, September 18, 2000. The dimensions taken from the actual valves are presented in Figures 4.4 through 4.6. The dimensions resulting from the examination of the radiograph are presented in Table 4.2.



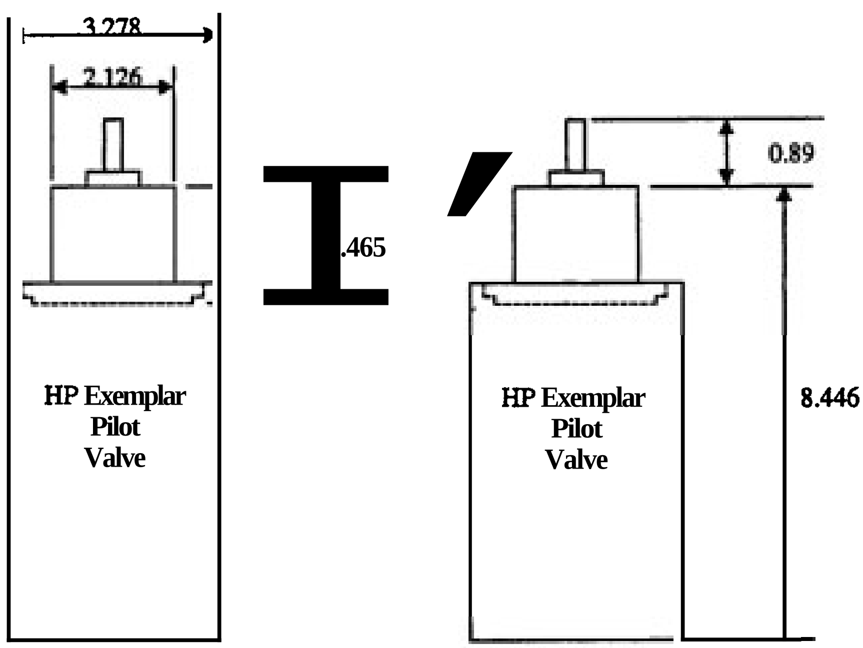
Note: All dimensions are in inches

Figure 4.4 Outside Dimensions of Accident Pilot Valve



Note: All dimensions are in inches

Figure 4.5 Outside Dimensions of LP Exemplar Pilot Valve



Note: *All* dimensions are in inches

Figure 4.6 Outside Dimensions of HP Exemplar Pilot Valve

Description	Approximate Dimension (inches)
Diameter of Upper Cylinder	2 1/8
Diameter of Lower Cylinder (near bottom)	3 5/16 +
Diameter of Lower Cylinder (near top)	3 5/16 +
Apparent overall length of lower cylinder from bottom to top of lip	5 7/16
Apparent distance between the centerlines of 6 coils of the main spring	1 1/2

After the dimensions were taken, the accident pilot valve was disassembled, the HP exemplar pilot valve was installed on the relief valve, and the LP exemplar pilot valve set aside for subsequent tests.

The height of the adjustment screw on the top of the accident pilot valve was 0.906 inches. On the LP exemplar pilot valve, the adjustment screw height was 1.44 inches. Since the accident pilot was originally configured as a LP pilot valve, it can be concluded that the adjustment screw had been tightened down approximately ½ inch.

4.6 Disassembly of the Accident Pilot Valve

The accident pilot valve was disassembled to determine if there were any broken parts and to compare with the exemplar valves which were disassembled later in the test program.

The first item checked during the disassembly was the adjustment screw on top of the pilot valve. This adjustment screw is used to adjust the force of the main spring in the pilot valve. As the screw is tightened, the force required to activate the pilot valve increases. The screw was tightened as far as possible. It was found that the screw could be tightened less than one quarter (114) of a turn. This indicates that the spring in the pilot valve was compressed almost as far as possible when it was in service. The adjustment screw was then loosened twenty-five (25) turns so that the pilot valve could be disassembled.

The next step in the disassembly process was to remove and inspect the spring cover. There was no apparent damage to the O-ring in the spring cover. The O-ring was brown in color and had no cuts or tears. The O-ring groove was clean. There was no visible damage to the inside of .the cover. However, there was a sticky residue on the piston seating surface of the inside cover.

Once the cover was inspected, the spring was removed. The spring had a bronze colored stripe. According to the Hsher-Rosemount representatives, this bronze stripe is used by the relief valve manufacturer to indicate the pressure range of the spring. A measurement was taken between the centerlines of six (6) coils of the spring to compare to the compressed spring measurement taken from the radiograph. The measurement was 1.73 inches for the uncompressed spring. The apparent length of the compressed spring as determined from the radiograph and presented in Table 4.2 was 1.5 inches. The spring was not damaged nor was any corrosion present.

The piston, inside the cylinder, was then examined. There was some black residue on the inner mating surface of the cover and the cylinder and some slight corrosion on the same surface. This region was wiped with a cotton swab and the swab retained in a plastic bag labeled "A". There was also some slight residue on the top of the piston (i.e., the spring side).

The piston was then removed from the cylinder. The bottom side of the piston was clean and had a light coating of oil. The O-ring on the piston was in good condition and brown in color. At this point in the disassembly procedure, some measurements were taken. The measurements are summarized in Table 4.3.

Table 4.3 Measurements of Components in Accident Pilot Valve

Description	Measurement (inches)
Width of o-ring groove	0.1545
Diameter of o-ring groove	1.8775
Diameter of piston	2.1165
Diameter of piston without o-ring	2.1368 (average of 3 measurements)
Internal diameter of pilot cover	2.1245 (average of 2 measurements)

The damper spring was then removed. This was followed by the removal of the cage retainer ring, the cage assembly, and the poppet. In the opinion of the Fischer-Rosemount representatives, the poppet moved normally inside the cage assembly.

Finally, the poppet retaining ring and the poppet were removed. The inside of the cage was clean and the poppet o-ring in place. Figures 4.7 through 4.10 show some selected photographs taken during the disassembly of the accident pilot valve.

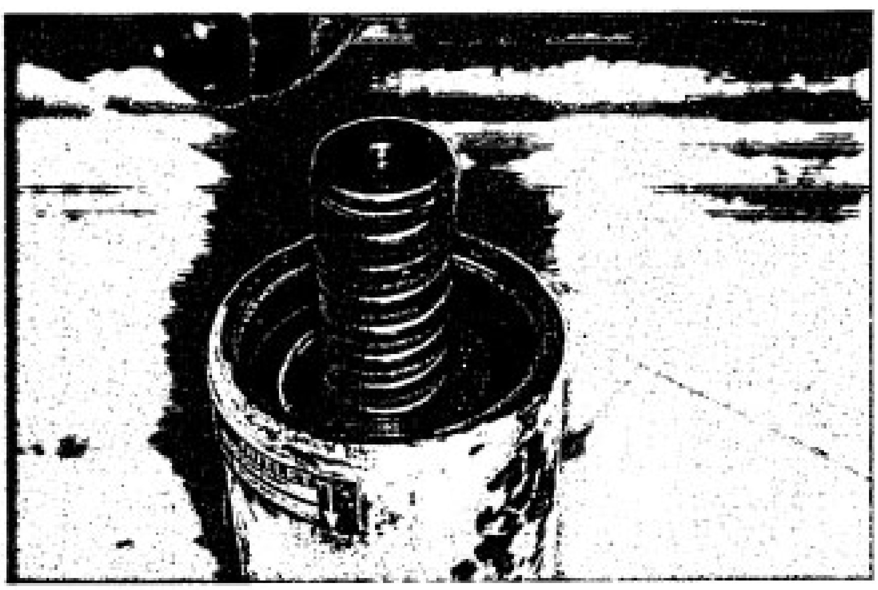


Figure 4.7 Accident Pilot Valve with Cover Removed

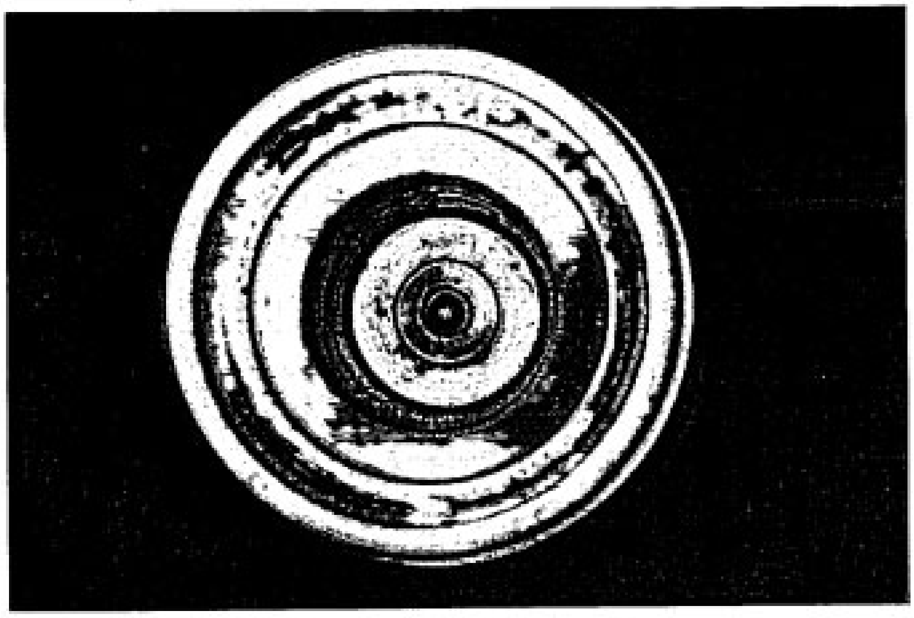


Figure 4.8 Inside Cover of Pilot Valve

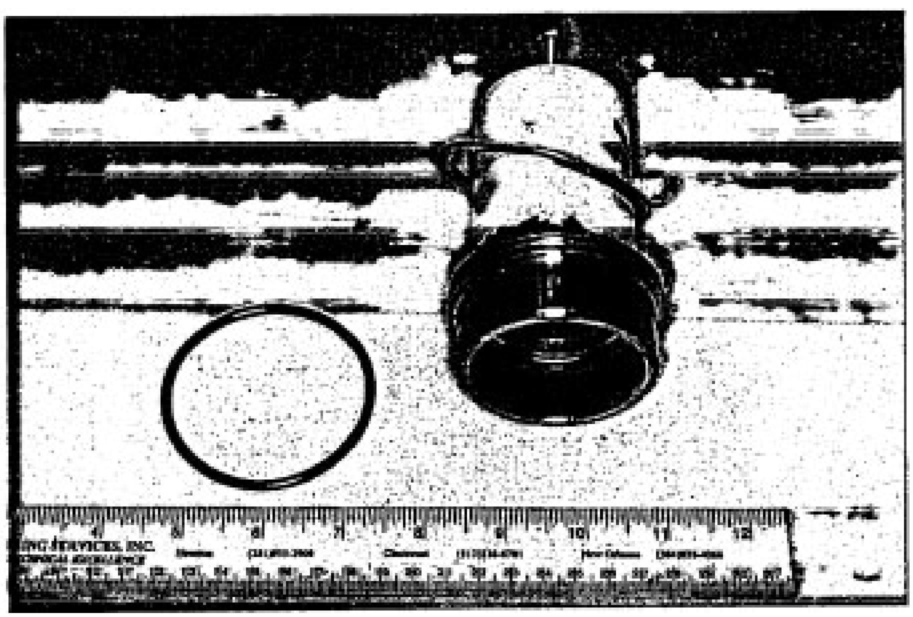


Figure 4.9 Cover of Pilot Valve

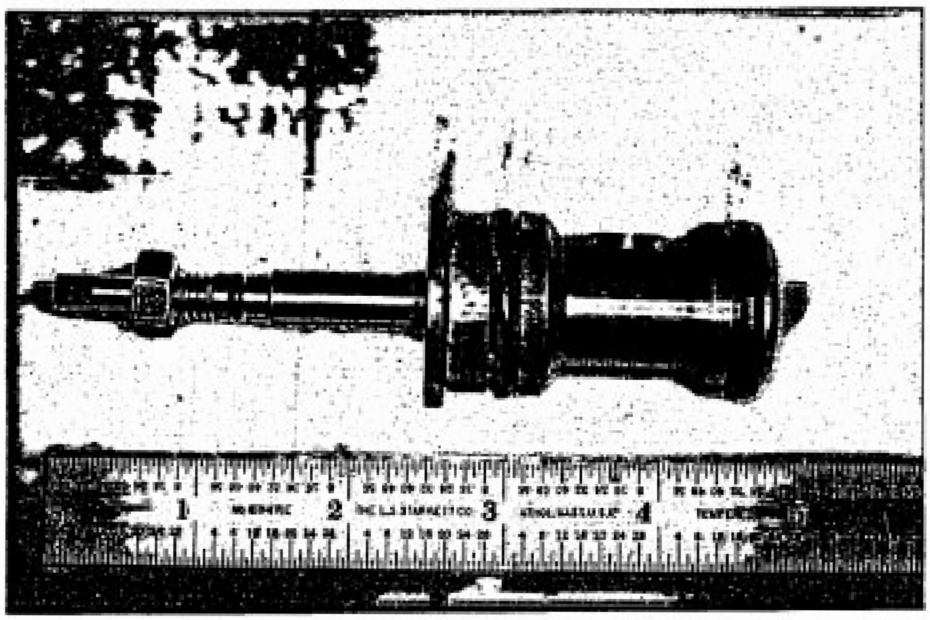


Figure 4.10 Pilot Valve Poppet Assembly

4.7 Day 3 Test of Relief Valve with HP Exemplar Pilot Valve Installed

The relief valve was pressure tested with the HP exemplar pilot valve installed. The set point as determined by the dead weight tests was 617 psig. The first run resulted in an increase in the inlet pressure to approximately 43 psig. The second run resulted in an inlet pressure of 110 psig. This was accompanied by a slight momentary increase in the outlet pressure and it was noted at this point that there was a small steady stream of oil flowing from the overflow/bleed line coming from the dump tank. At this point the valve was removed from the end of the overflowhleed line and the end of the line placed in a 55 gallon drum. On the third run, there was a large spike in the pressure at the outlet flange and oil could be heard flowing into the 55 gallon drum. On the subsequent runs, a noticeable spike in the outlet flange occurred each time pressure was applied to the valve. The residual inlet pressures were on the order of 400 psig, depending on the delay between successive pressure cycles. Between runs, the inlet pressures decreased. This decrease in inlet pressure is an indication the valve was leaking. The AE data for these runs was examined and indications were found that both the pilot and relief valves were opening and that the maximum time lapse between the opening of the pilot valve and the opening of the relief valve was 0.02 seconds. Appendix F contains a brief discussion of the AE data. The AE data taken during this series of test runs is in file 6947T32.DTA.

The test runs are summarized in Table 4.4. Plots of the test data are included in Appendix G. The plots include pressure as a function of time curves for each pressure transducer.

Run	Accumulator Pressure at Start of Run		Maximum Inlet Pressure Achieved		Maximum Outlet Pressure Achieved		Residual Inlet Pressure		Volume of Fluid from Outlet Flange (cups)	Volume of Fluid from Pilot Valve Outlet (cups)	Comments
	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)			
1	805	8	43	38.4	41	38.4	13	100	NA	NA	
2	800	644	110	672.3	37	668.8	34	2000	NA	NA	
3	801	175	498	203	471	192	418	628	NA	NA	
4	803	628	668	632	70	647	430	841	NA	NA	
5	802	841	662	841	135	849	298	1280	NA	NA	
6	802	1280	652	1281	51	1290	417	1490	NA	NA	
7	802	1490	645	1490	145	1500	445	1690	NA	NA	
8	800	1690	643	1700	229	1710	456	1950	NA	NA	
9	803	1950	645	1950	123	1960	556	2010	NA	NA	

From these test runs, it can be concluded that the relief valve itself operates properly and that any failure to operate is due to the pilot valve not functioning.

There was some discussion about measuring volumes output by the pilot and main valve at this point. As a result, some modifications were made to the test set-up to allow for taking some order of magnitude measurements on the following day.

5.0 DAY 4: PRESSURE TESTS OF RELIEF VALVE WITH HP EXEMPLAR VALVE INSTALLED AND ADJUSTED LP EXEMPLAR VALVE INSTALLED

Day 4 of testing began on September 21, 2000. The day's activities included;

1. Meeting to discuss the notes from the previous day and AE results
2. Retested relief valve with HP pilot (slight modifications to test set-up)
3. Dead weight test to adjust set-point of LP exemplar valve
4. Disassembled HP exemplar pilot valve
5. Pressure test of relief valve with adjusted LP exemplar valve installed
6. Disassembled LP exemplar valve

5.1 Day 4 Meeting

The meeting on day 4 was begun at 8:30am. As before, the field notes from the previous day were discussed, edited, and signed by the parties. Claudio Allevato, ASNT III of SES gave a brief *summary* of the AE results obtained during the test with the HP exemplar pilot valve installed. Mr. Allevato found evidence of mechanical noise from both the pilot and relief valves. The mechanical noise was of the type that would indicate that both valves opened.

Modifications which were made to the test set-up were also discussed.

5.2 Test Set-up for Day 4

Following the September 19, 2000 test of the relief valve, with the HP exemplar pilot valve installed, there was some discussion about measuring volumes output by the pilot and main valve. As a result, some modifications were made to the test set-up to allow for taking some order of magnitude measurements. The dump vessel was removed from the test set-up and a hose from the outlet flange of the relief valve was run to a bucket. In addition, the connection between the outlet port of the pilot valve and the relief valve was disconnected. Pressure transducer #4 was left on the relief valve and gave a reading of the pressure on the outlet side of the relief valve. The line was capped off just past the pressure transducer. A hose was attached to the outlet port of the pilot valve and routed to a bucket. These modifications made it possible to take order of magnitude measurements of the volumes passing through the pilot and relief valves during the test. A schematic of this revised test set-up is shown in figure 5.1.

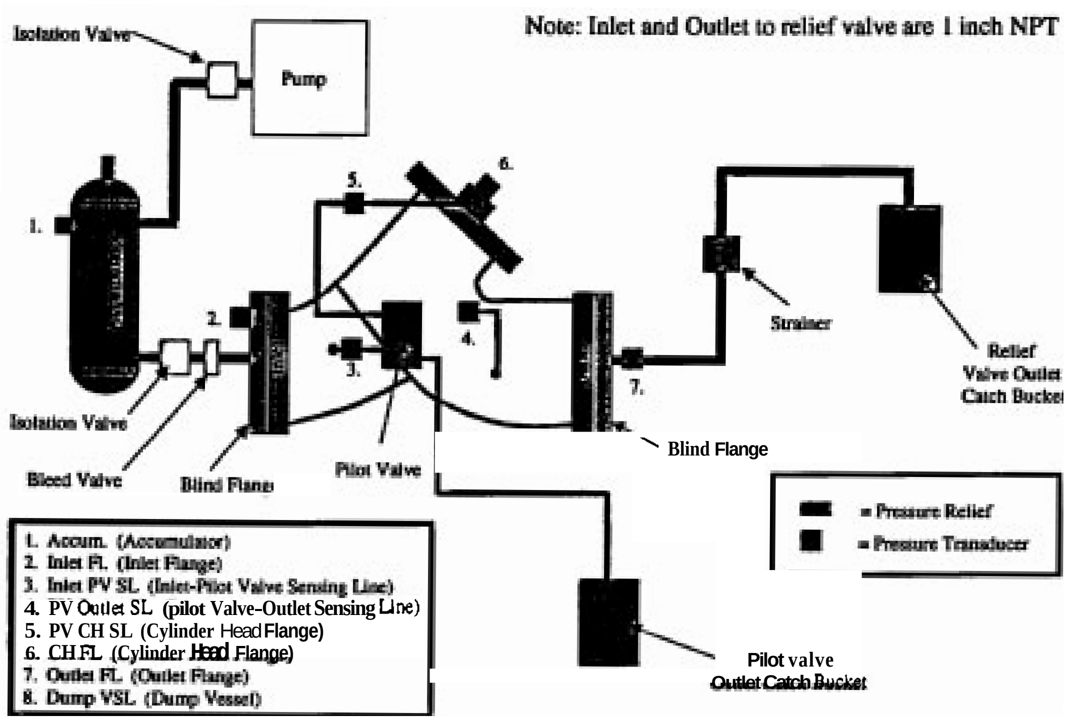


Figure 5.1 Test Set-up for September 21, 2000

Volumes of hydraulic fluid from each test run were measured from the catch buckets using a measuring cup. This resulted in order of magnitude measurements of the flow through the pilot and relief valves.

5.3 Test of Relief Valve with HP Pilot Valve Installed

The relief valve was tested with the modified set-up by charging the accumulator to 800 psig, isolating the pump from the accumulator, and then opening the isolation valve between the accumulator and the inlet flange. Pressure data and AE data were recorded during the test runs.

Between each run, the catch buckets for the relief valve outlet and pilot valve outlet were emptied and the volumes measured.

It should be noted there was a small steady stream of hydraulic fluid flowing from the line connected to the outlet flange of the relief valve throughout this test. This is indicative of a small leak in the relief valve. The slow reduction in the inlet pressure between the test runs is also an indication of the valve leaking. Another item of note is that for the first six (6) runs, no volumes were recorded from the pilot valve outlet catch bucket. This does not mean that there was not any fluid exiting the pilot valve. The hose connected to 'the pilot valve outlet was initially empty. Therefore, during the first six (6) runs, the fluid exiting the pilot valve was filling the hose.

As with the test conducted the day before, when the isolation valve between the accumulator and the inlet of the relief valve was opened, there was a spike in the outlet pressure. Residual inlet pressures on the order of 500 psig were seen. In addition, the AE sensors picked up mechanical noise from both the pilot and relief valves. The AE data is discussed in Appendix F. Finally, the hydraulic fluid entering the catch buckets indicated that the pilot and relief valves were opening.

A total of eleven runs were made. Run 8 was interrupted/stopped due to interference from one of the witnesses. The data plots for runs 4 through 7 and 9 through 11, included in Appendix I of this report, show that the reaction of the valve is repeatable.

These runs show that the relief valve operated properly when the HP exemplar pilot valve was installed. The maximum inlet pressures achieved are on the order of the pilot valve set point. In addition, significant volumes of hydraulic fluid were allowed to flow from the relief valve outlet and in the latter runs flow was measured from the pilot valve outlet. Finally, the AE data also indicate that both the pilot and relief valves were opening.

Table 5.1 Pressure Test of Relief Valve with HP Pilot Valve Installed (Day 4)

Run	Accumulator Pressure at Start of Run		Maximum Inlet Pressure Achieved		Maximum Outlet Pressure Achieved		Residual Inlet Pressure		Volume of Fluid from Outlet Flange (cups)	Volume of Fluid from Pilot Valve Outlet (cups)	Comments
	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)			
1	800	5.2	477	20	481	20	20	503	24	0	
2	799	503	541	509	544	509	48	872	32	0	
3	800	872	576	877	576	877	83	1235	30	0	
4	797	1235	632	1236	68	1237	351	1428	14	0	
5	804	1428	635	1429	181	1436	471	1619	13	0	
6	800	1619	648	1619	197	1626	558	1828	15	0	
7	794	1828	650	1828	146	1836	541	2033	12 ½	½	
8	798	2033	665	2033	13	2040	400	2162	8 1/2	1/3	Interrupted
9	804	2162	644	2164	131	2170	519	2358	15	½	
10	801	2358	655	2358	125	2365	503	2664	14	2/3	
11	800	2664	643	2665	76	2672	495	3000	17 1/3	1 1/3	

* Set point of HP pilot valve = 617 psig.

** Note: The time listed **under** "Accumulator Pressure at **Start** of Run" is the time when the valve isolating the accumulator **fiom** the inlet of RV1919 was opened **and marks** the **starting** time of each test run.

5.4 Dead Weight Test to Adjust Set-point of LP Exemplar Valve

The set point of the LP Exemplar pilot valve was changed using the dead weight tester. The same set-up was used for conducting the previous dead weight tests. The air pressure used **was** **15** psig **air. The** goal was to match the set point of the accident valve as closely as possible. **This** activity took several iterations which are summarized in Table **5.2.** Once the set point **was** adjusted to the satisfaction of all parties, the HP exemplar pilot valve was removed from the relief valve and LP exemplar pilot valve **was** installed.

Height of Adjustment Screw (inches)	Pressure (psig)		
	Start of Release	Fully Open	
1.078	150	240	
1.048	145	244	Screw tightened ½ turn.
0.919	210	270-280	Screw adjusted to approx. height of accident pilot valve
0.853	-	-	Screw tightened 1 ¼ turns, nearly completely tightened. Valve did not open.
0.8595	700	-	Screw loosened 1/8 turn. Valve did not open fully
0.864	500	-	Screw loosened 1/8 turn. Valve did not open fully
0.8795	500	-	Screw loosened 1/8 turn. Valve did not open fully
0.870	500	600	Screw tightened 1/16 turn.
0.871	500	600-650	Screw tightened 1/16 turn. Valve left at this adjustment and installed on relief valve

The LP exemplar pilot valve was left at the last setting (i.e., fully open between 600-650 psig) and installed on the relief valve for pressure testing. Although the intent of this activity was to adjust to set point of the LP exemplar pilot valve, some conclusions can be made from this information. First the set point of the valve on the data plate is a maximum of 180 psig. In order to increase the set point to 600 psig, the adjustment screw had to be tightened down over ½ inch. This puts the spring in the valve in a nearly completely compressed state and the pilot valve becomes very sensitive to small changes in the adjustment screw setting. Even a change in the adjustment screw of 1/8 of a turn can mean the difference between the pilot valve opening or failing to open.

5.5 Disassembly of HP Exemplar Pilot Valve

While the LP exemplar pilot valve was being installed on the relief valve, the HP exemplar pilot valve was disassembled. Dimensions taken during the disassembly are presented in Table 5.3.

Table 5.3 Dimensions Taken During Disassembly of HP Exemplar Pilot Valve

Description	Dimension '(inches)
Adjustment Screw Height	**0.886**
Valve Cover External Diameter	**2.126**
Valve Base External Diameter	**3.272**
Height of Cover (to bottom of groove on base of cover)	**3.468**

In addition to the dimensions presented in Table **5.3,** dimensions of the piston were also taken. **The** piston dimensions **are** presented in **Figure 5.2.**

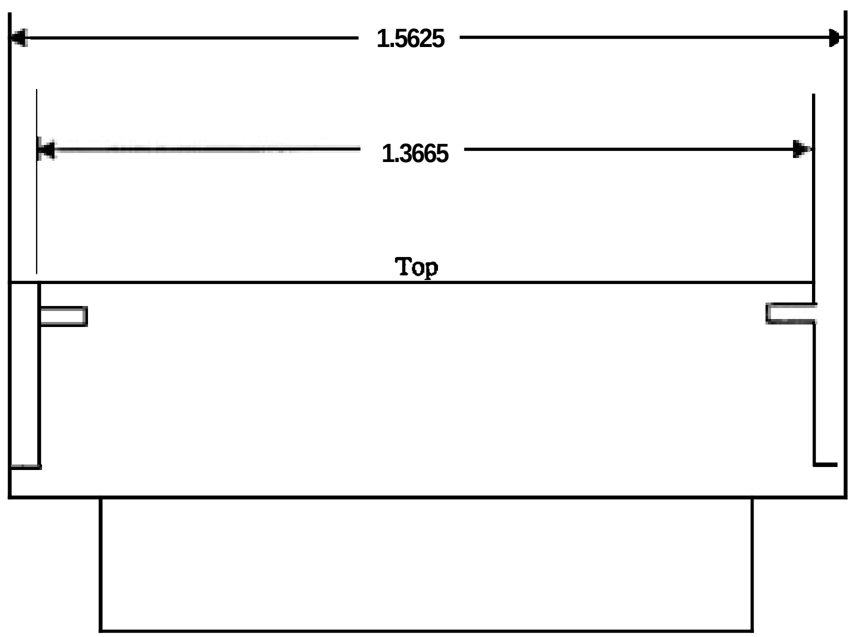


Figure 5.2 Dimensions of Piston from HP Exemplar Pilot Valve

It **was** noted **that** the dimension **taken at** the top of the piston, **1.3665** inches, does not match the **1 13/64** inch dimension in the available literature (i.e., the pilot spring selection table).

In comparing the internal components of the HP exemplar pilot valve to the internal components from the accident pilot valve, the only difference of note was the piston. The two pistons are shown in Figure 5.3.

Figure 5.3 Pistons from HP Exemplar and Accident Pilot Valves

5.6 Pressure Test of Relief Valve with Adjusted LP Exemplar Valve Installed

The pressure test was run with the LP exemplar pilot valve installed on the relief valve. This test was done after the set point had been adjusted as discussed in Section 5.4. A total of fourteen (14) runs were made. On the first six (6) runs, the pressure on the outlet flange increased immediately when the pressure was applied to the relief valve. This was accompanied by a large flow into the outlet flange catch bucket. The AE indicated that the pilot valve was not activating. On each run, the pressure decreased rapidly to 50 psig on the inlet side. Therefore, it appeared that the fluid was leaking through the relief valve. This behavior is similar to what was experienced with the accident pilot valve installed and strengthens the conclusion that the valve was leaking.

For run 7, the pressure in the accumulator was increased to 1000 psig. This time, the inlet side of the valve retained approximately 25 psig. The accumulator was then pumped to a pressure of 1200 psig for run 8. At the end of run 8, the residual inlet pressure was approximately 367 psig. For all the subsequent runs, runs 9 through 14, the accumulator was charged to 800 psig and the inlet pressure held at approximately 800 psig. Between each run, the inlet pressure was bled to 350 to 400 psig before the next run. For run 9 there was still a small flow of hydraulic oil from the outlet flange, but the flow was only a very small stream. For runs 10, 11, and 12, this stream was reduced to a drip. This drip stopped (i.e., was not present) for runs 13 and 14.

The behavior of the relief valve with the adjusted LP exemplar pilot valve installed was essentially the same as that experienced when the relief valve was tested with the accident pilot valve installed. This leads one to the conclusion that the accident pilot valve was not modified adequately to perform reliably as a HP pilot valve. Information provided to SES indicated that some of the intemal components in the accident pilot valve were changed before the set point was changed. However, it does not appear that these changes accomplished the intended objective.

The pressure test runs are summarized in Table 5.4. Plots of the test data, including pressure as a function of time plots for each data channel, are included in Appendix I.

Table 5.4 Pressure Test of Relief Valve with Adjusted LP Pilot Valve Installed (Day 4)

Run	Accumulator Pressure at Start of Run		Maximum Inlet Pressure Achieved		Maximum Outlet pressure Achieved		Residual Inlet Pressure		Volume of Fluid from Outlet Flange (cups)	Volume of Fluid from Pilot Valve Outlet (cups)	Comments
	Press. (psig)	Time (sec)	Press. (psig)	Time (sec)	Press. (psig)	Time	Press. (psig)	Time (sec)			
1	793	14	509	23.5	509	23.5	25	388	24 ½	0	
2	796	388	534	397.5	533	397.5	34	724	26	0	
3	799	724	553	731.9	552	731.9	46	1080	28	0	
4	798	1080	557	1087	555	1187	44	1503	30	0	
5	798	1503	574	1509	572	1509	56	1862	30	0	
6	800	1862	594	1865	594	1865	17	3000	28	0	
7	1000	3000	698	504.6	700	505	25	1390	68	0	
8	1210	1390	721	1391	723	1391	367	1879	68	0	
9	804	1879	857	1879	0	NA	782	2182	very small stream	0	
10	803	2182	798	2245	0	NA	788	2281	drip	0	Inlet pressure bled to 384 psig for start of this run
11	798	2281	793	2322	0	NA	786	2367	drip	0	Inlet pressure bled to 413 psig for start of this run
12	800	2367	795	2425	0	NA	782	2464	drip	0	Inlet pressure bled to 408 psig for start of this run
13	802	2464	798	2514	0	NA	780	2561	0	0	Inlet pressure bled to 347 psig for start of this run
14	798	2561	794	2601	0	NA	684	3263	0	0	Inlet pressure bled to 349 psig for start of this run. Inlet pressure dropped to 684 psig after a 10 minute hold

* Note: The time listed under "Accumulator Pressure at Start of Run" is the time when the valve isolating the accumulator from the inlet of RV1919 was opened and marks the starting time of each test run.

5.7 Comparison of the LP Exemplar Valve, HP Exemplar, and Accident Pilot Valves

The last activities to take place on September 21, 2000 were the disassembly of the LP exemplar pilot valve and the visual examination and comparison of the components from the LP, HP, and accident pilot valves.

The following observations were made during the visual examination and comparison of the components from the three pilot valves;

1. The piston and main spring cover from the LP exemplar pilot valve were different than the corresponding components from the HP exemplar pilot valve.
2. The components from the HP and LP pilot valves, excluding the piston and main spring cover, were the same. This includes the main spring and the lower cylindrical pilot valve body.
3. The piston and main spring cover from the accident pilot valve were the same as those from the LP exemplar pilot valve.
4. The components from the accident pilot valve (excluding the piston, main spring cover, and damping spring) were the same as those from the HP and LP pilot valves. The damping spring does not affect the set point of the pilot valve. Both the HP exemplar and LP exemplar pilot valves had damping springs 1 ¾ inches long. The damping spring in the accident pilot valve was 1 9/16 inches long.

The components from all three of the pilot valves were examined or damage and wear. The only notable observations were:

1. There was some possible scoring observed on the poppet valve stem of the LP exemplar pilot valve
2. There was some possible wear observed on the poppet valve stem of the accident pilot valve.
3. The poppet valves from all three pilot valves opened and closed freely.

Neither possible scoring on the poppet valve stem of the LP exemplar pilot valve nor the possible wear observed on the poppet valve stem of the accident pilot valve appeared to be severe enough to affect the operation of the pilot valve. The pilot valves were boxed-up for the night so that photographs of the poppet valve stems could be taken the next morning.

In summary, other than the difference in damping spring lengths, the components fiom the LP exemplar pilot valve appeared to be the same as those from the accident pilot valve. In addition, no wear or damage which would affect the operation of the pilot valves was observed.

Figure 5.4 shows the three pilot valves before disassembly. Figures 5.5 through 5.8 show side-by-side views of the disassembled pilot valves and selected components.

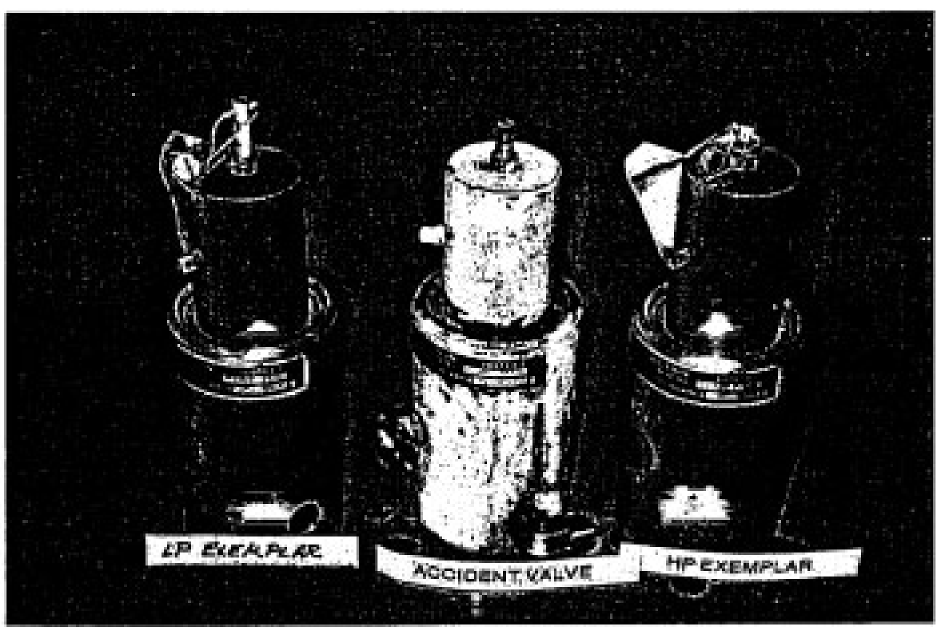


Figure 5.4 Pilot Valves Prior to Disassembly

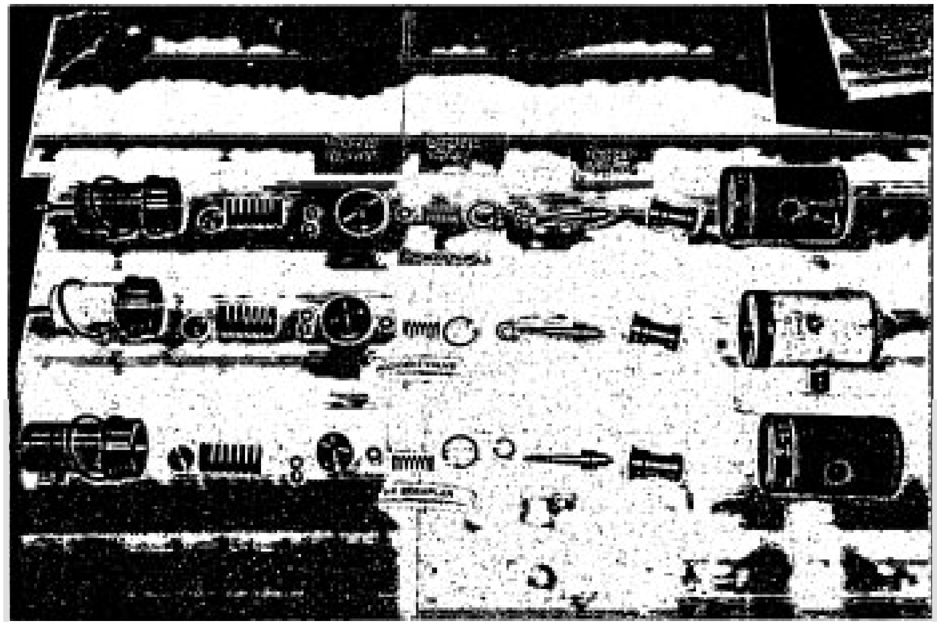


Figure 5.5 Disassembled Pilot Valves

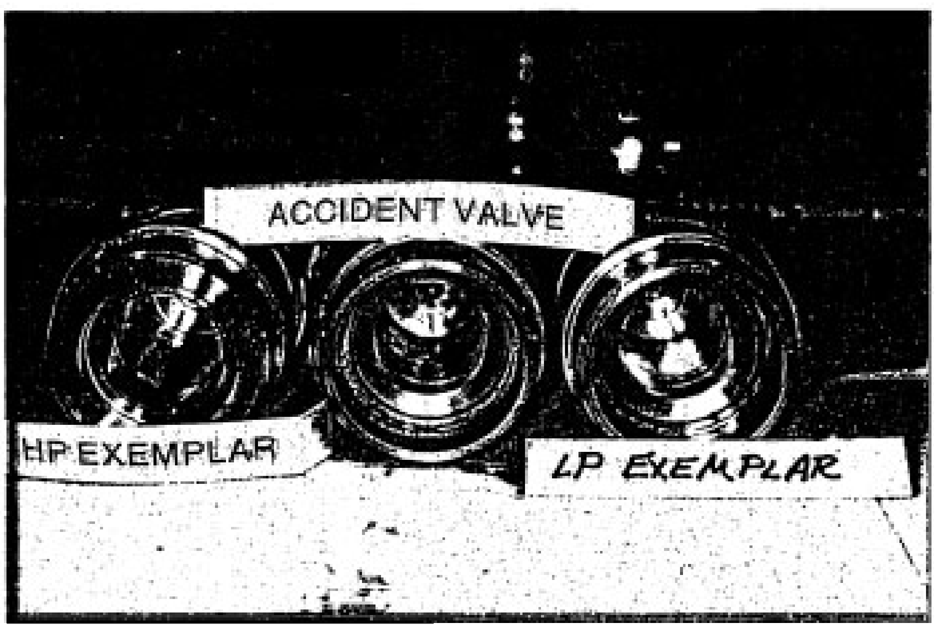


Figure 5.6 Inside of Top Covers from Pilot Valves

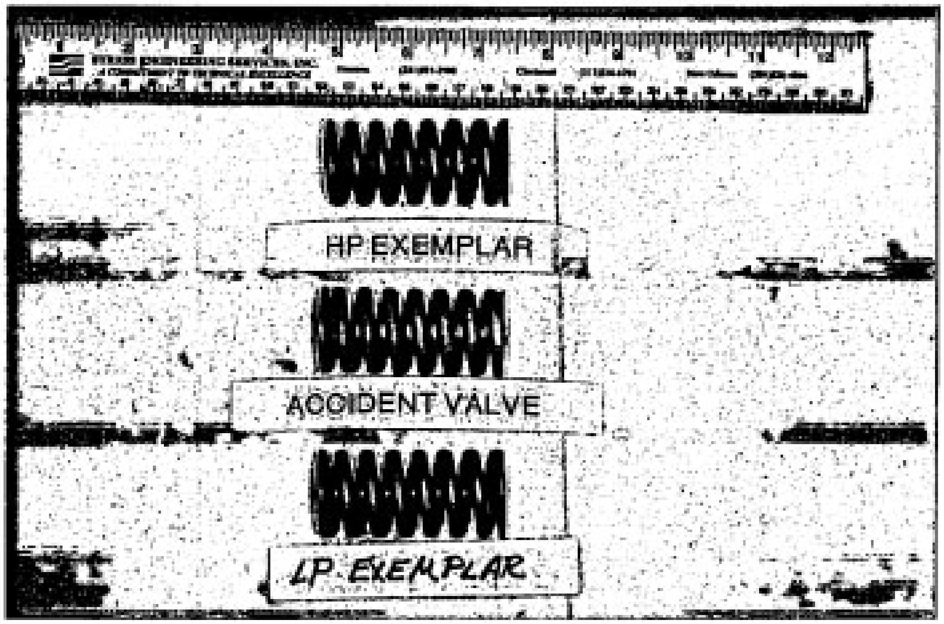


Figure 5.7 Main Springs from Pilot Valves

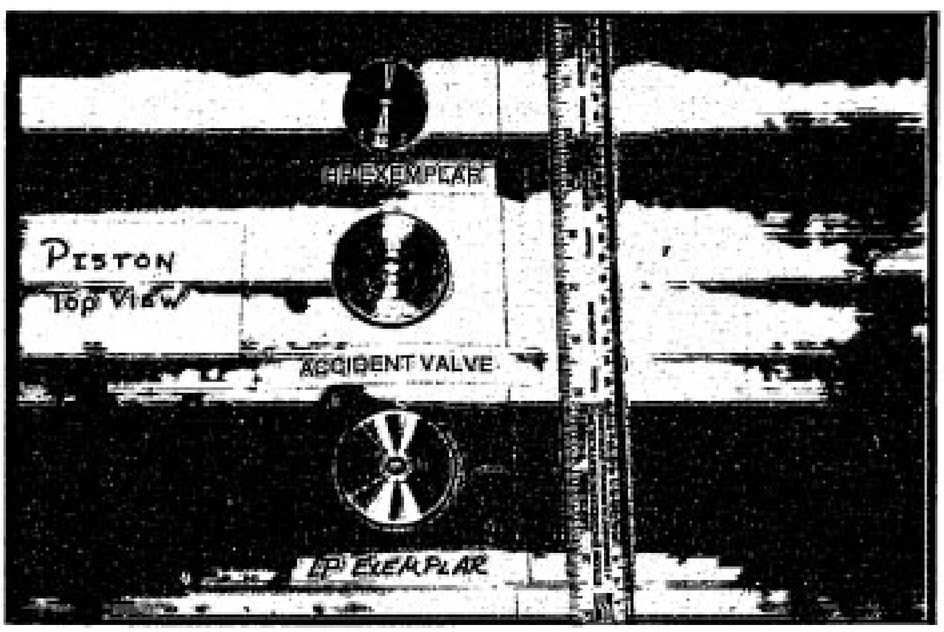


Figure 5.8 Pistons from Pilot Valves

Figure 5.8 is a key photograph in that it shows that the pistons in the LP and accident pilot valves were the same. However, the piston from the HP pilot valve is significantly different. Therefore, one can conclude that the accident pilot valve is essentially the same as the LP pilot valve and can be expected to behave in the same manner.

4.0 DAY 5: DISASSEMBLY OF MAIN VALVE

Day 5 of testing began on September 22, 2000. The activities for the day included;

1. Meeting to discuss the field notes from the previous day
2. Took photographs of pilot valve poppet assemblies under a stereo microscope
3. Reassembled pilot valves
4. Disassembled relief valve
5. Reassembled relief valve
6. Reviewed the notes from September 22,2000
7. Transferred custody of relief valve and samples taken from the relief valve to DOJ

6.1 Day 5 Meeting

The meeting on day 5 was begun at 8am. As on the previous days, the field notes from the prior day were discussed, edited, and signed by the parties.

6.2 Stereo Microscope Photographs

Photographs were taken of the LP exemplar pilot valve, HP exemplar pilot valve, and accident pilot valve poppet shafts under a stereo microscope. Figures 6.1 through 6.5 show examples of the possible wear or scoring on the poppet valve stems from the LP exemplar and accident pilot valves. This possible wear or scoring was mentioned previously in Section 5.7 of this report.

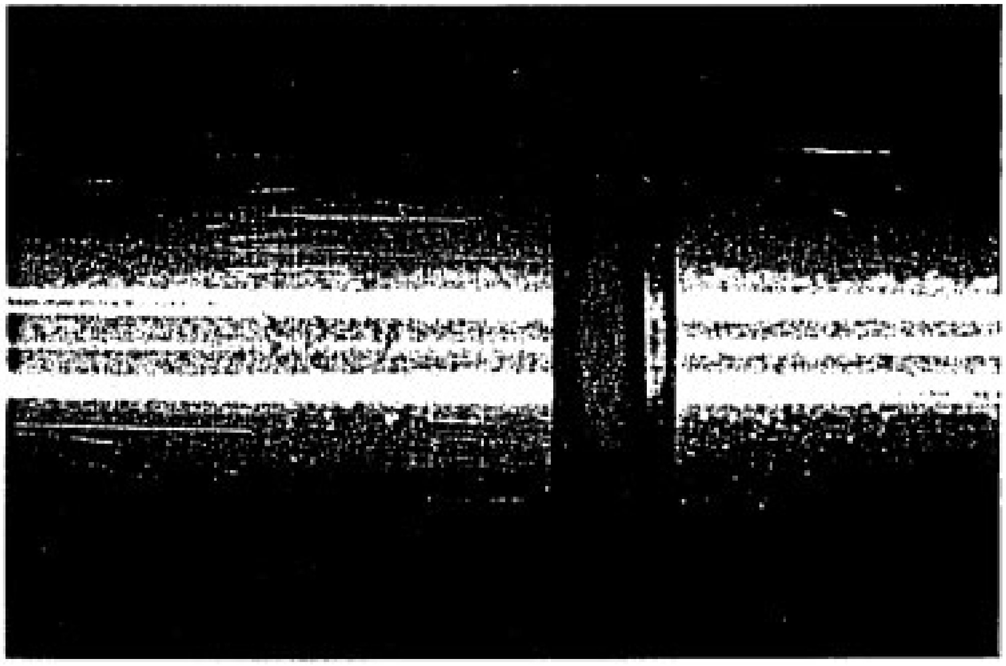


Figure **6.1 LP Exemplar Pilot Valve Poppet Shaft**

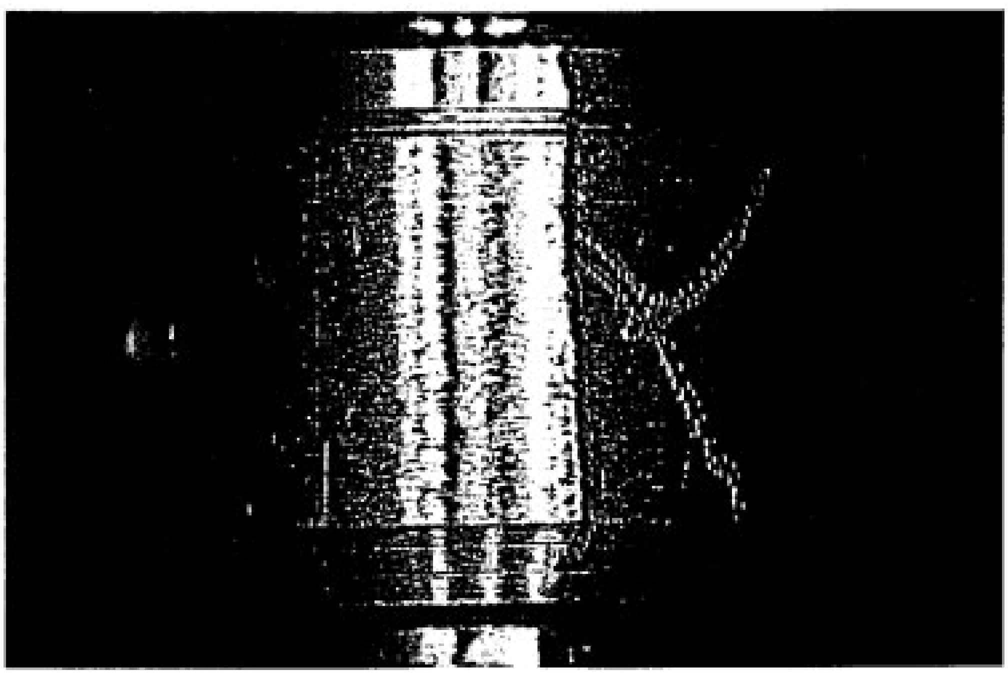


Figure **6.2 LP Exemplar Pilot Valve Poppet Shaft (view 2)**

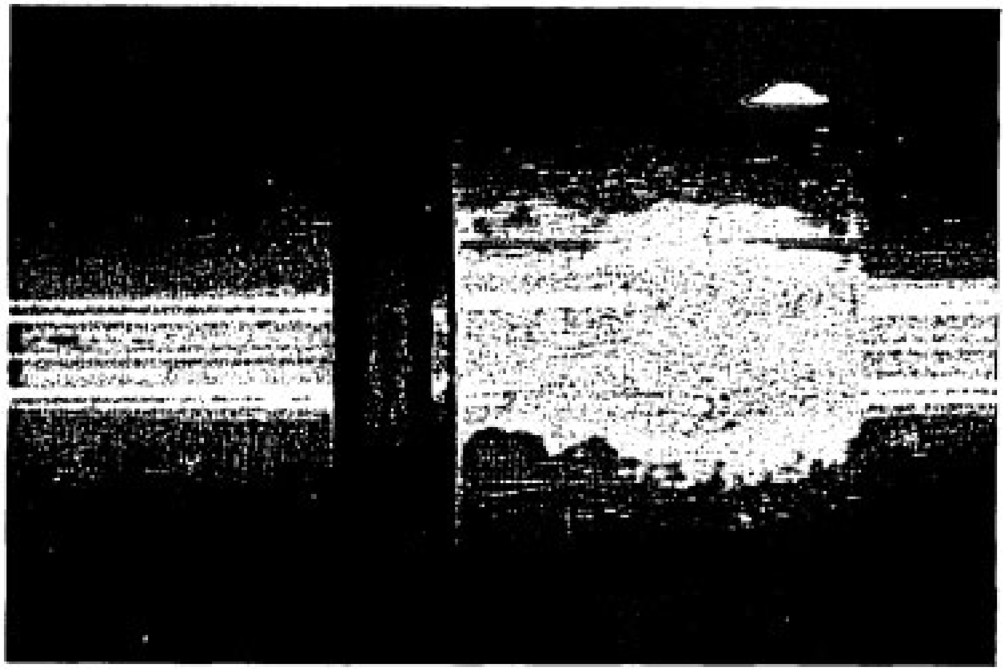


Figure **6.3 Accident Pilot Valve Poppet Shaft**

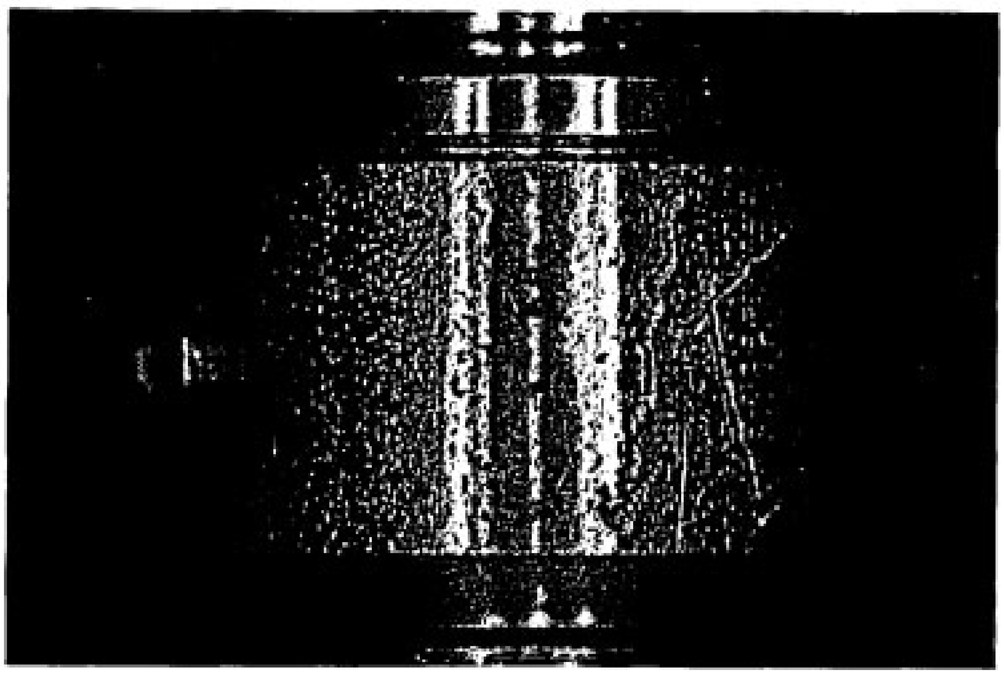


Figure **6.4 Accident Pilot Valve Poppet Shaft (view 2)**

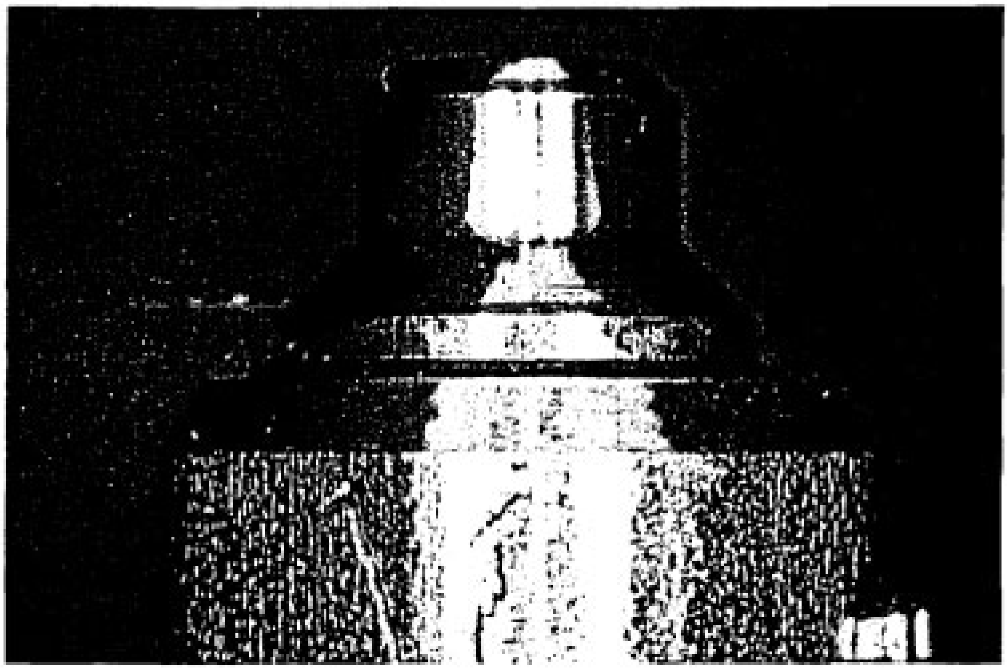


Figure *6.5* Accident Pilot Valve Poppet Shaft Profile

6.3 Reassembly of Pilot Valves

Once the photographs were taken, the pilot valves were reassembled. The accident pilot valve was reassembled as closely as possible to the way it was received. It should be noted that the retaining ring for the cage and poppet did not reseat fully. The exemplar pilot valves were assembled hand tight, so that they could be used for demonstration purposes in the future.

6.4 Disassembly of Relief Valve

The final major activity that was part of this test program was the disassembly of the main relief valve. The first component which was examined as part of this activity was the needle valvdstrainer assembly. When viewed through the fitting port, the shaft of the needle was smooth. The O-ring on the strainer was black in color and no particles were visible on the strainer. There was a small amount of residue on the base of the housing, but all the flow ports were open. At this point the strainer was removed and examined. The dimension from the top of the adjustment screw to the top of the retaining nut was 0.346 inches. This agrees well with the dimension of 0.345 inches taken during the optical probe examination and presented in Figure 2.14. The needle was tightened and could be turned approximately 1 7/8 of a turn. The needle was then removed and examined.

The first step in disassembling the cylinder of the main valve was to number the studs on the cylinder head. The nuts removed from the cylinder head were placed in numbered bags so that the nuts could be placed in the same locations when the valve was reassembled. After removing the nuts from the cylinder head, the cylinder assembly was removed. The cylinder assembly was placed in SES's Baldwin test frame and the crosshead was lowered until it was just touching the top of the assembly. This was necessary to safely let the pressure off of the main valve spring.

The hex head set screws were removed from the cylinder head and then the crosshead of the Baldwin was slowly raised. The cylinder head was then removed. This was followed by the removal of the main valve spring and piston. Dimensions taken during this examination are summarized in Table 6.1. Observations include:

1. The cylinder head gasket is a Garlock 3000
2. The O-ring on the cylinder head is black
3. Some small amounts of Teflon tape were found in the valve
4. A deposit and some small nicks were found on the sealing surface of the valve
5. Some signs of wear were noted on the piston
6. A black rubberlike material was found across the O-ring at the sealing surface. This material was wedged between the O-ring and the o-ring groove. The material was left in place.
7. The cylinder bore was found to be clean with no apparent damage.

Table 6.1 Dimensions Taken During Disassembly of Relief Valve

Description	Dimension (inches)
Diameter of Cylinder Head	7 13/16
Length of Main Relief Valve Spring	12 ½
Diameter of Main Relief Valve Spring	4 13/16
Diameter of Spring Coil	7/16
Cylinder Length	11 ¼
Cylinder Outside Diameter	9 ½
Cylinder Inside Diameter	8 ¾

Figures *6.6* **through 6.14 show the disassembly process.**

Figure 6.6 Strainer and Cap

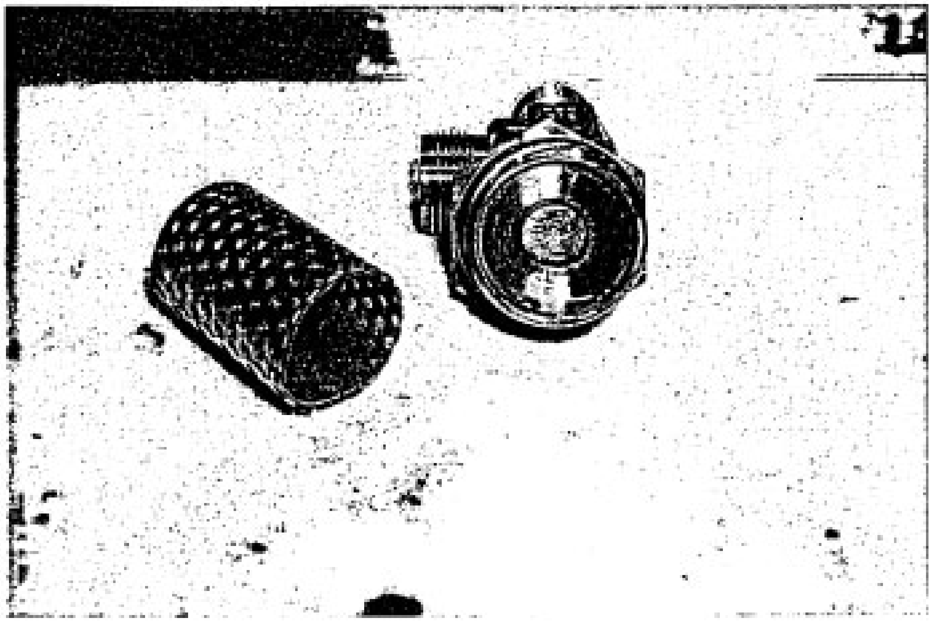


Figure 6.7 Cap Removed From Strainer

Figure 6.8 Needle

Figure 6.9 Removing Cylinder Head Nuts

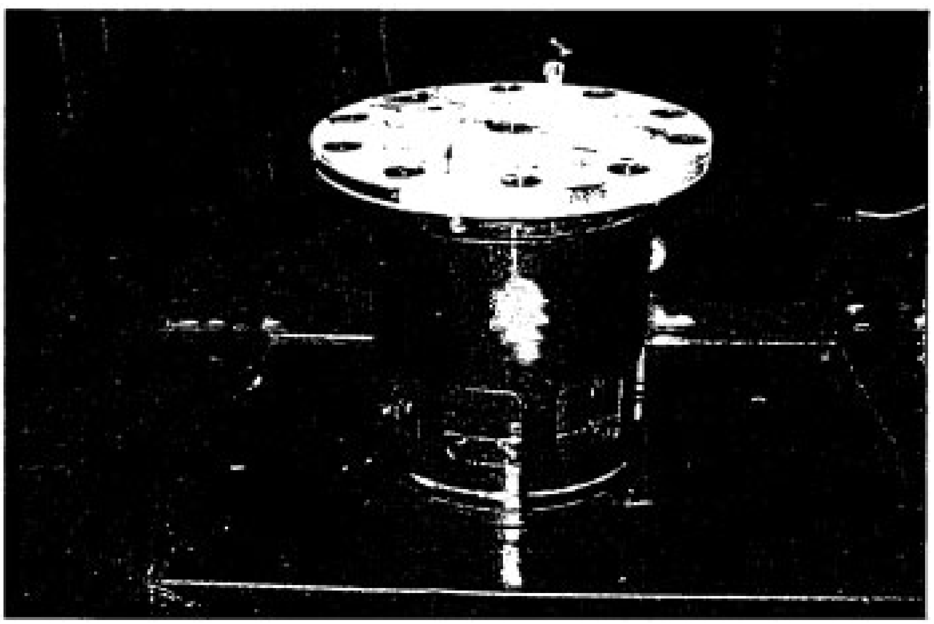


Figure 6.10 Cylinder Removed From Main Valve Body

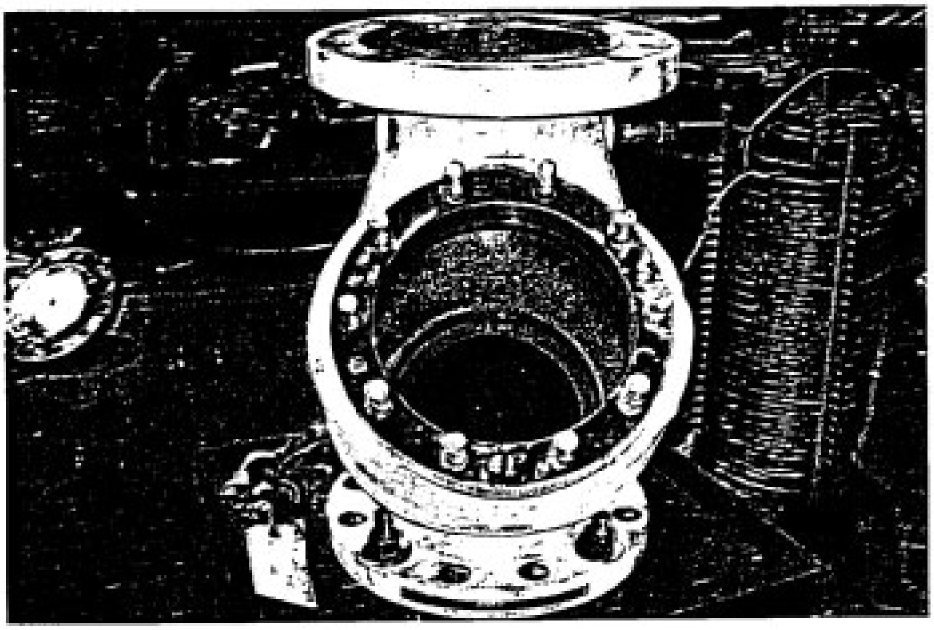


Figure 6.11 Main Valve Body with Cylinder Removed

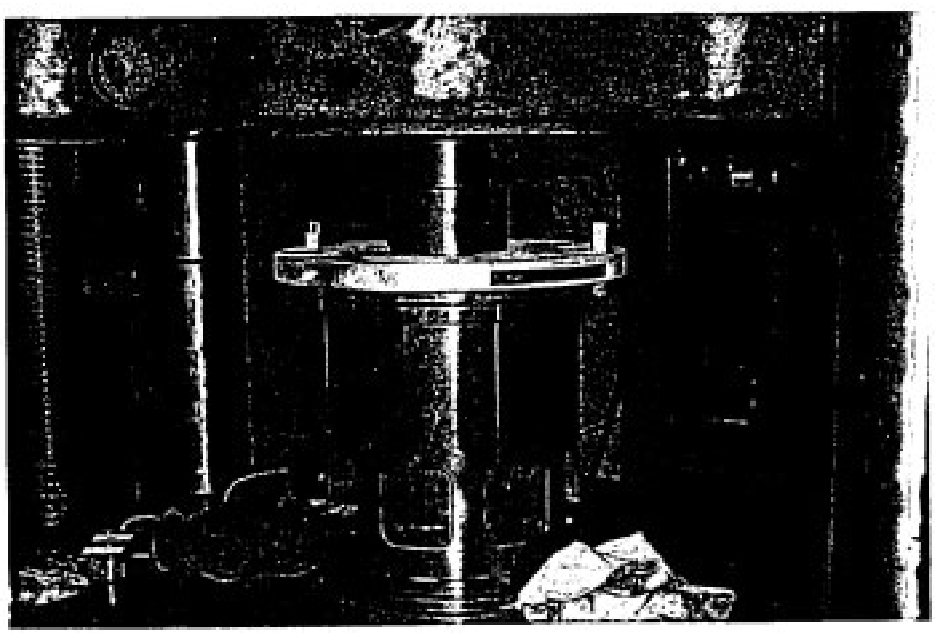


Figure 6.12 Removing Head From Cylinder

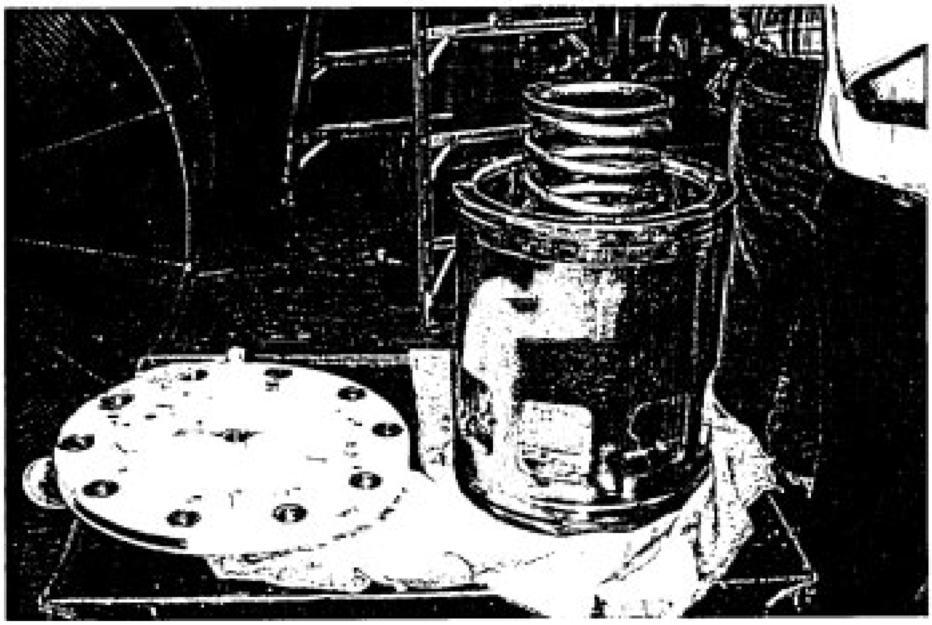


Figure 6.13 Cylinder with Head Removed

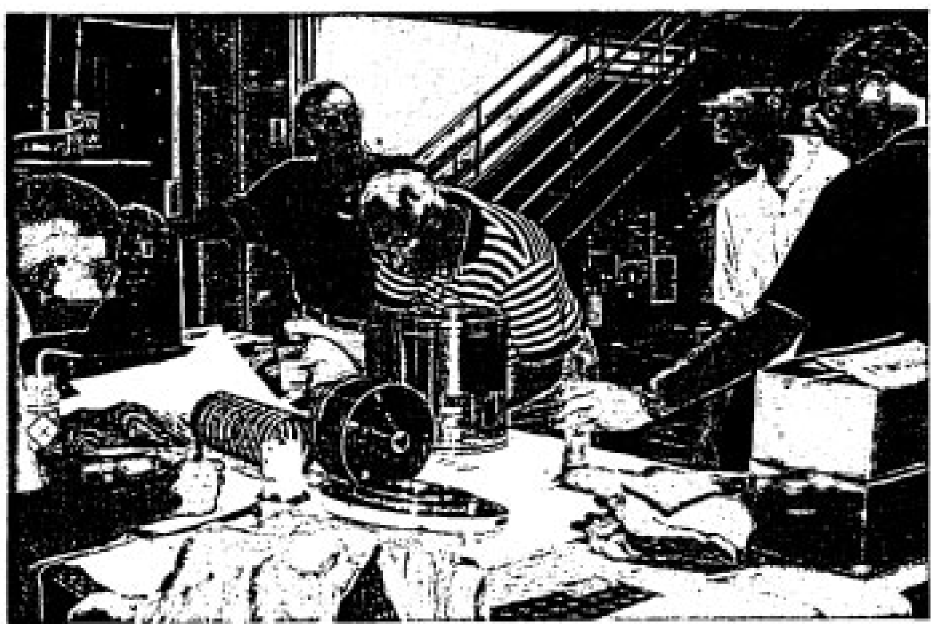


Figure 6.14 Examining Disassembled Relief Valve

At this point, the strainer which had been placed at the outlet of the relief valve in the test set-up was examined. No debris could be seen in the strainer. This is further evidence that there was no debris which would be detrimental to the functioning of the valve present when the valve was received by SES.

6.5 Review of Notes From September 22,2000

Once the examination of the disassembled relief valve was completed, the group reviewed the field notes taken on September 22, 2000 and adjourned.

6.6 Reassembly and Transfer of Relief Valve to DOJ

As a final step in the testing process, the relief valve was reassembled. The valve was reassembled so that it was in as close to the same condition as possible as when it was received at SES. However, if additional testing is done, we would recommend that the cylinder head gasket be replaced and the retaining ring in the pilot valve replaced. Figures 6.15 and 6.16 show the reassembled valve. Once reassembled, custody of the valve was transferred from the NTSB to Louis Scharringhausen of the U.S. Environmental Protection Agency Criminal Investigation Division. Mr. Robert Trainor of the NTSB also turned over to Agent Scharringhausen all of the bagged residue samples and wipes taken during the examination of the three pilot valves and the main relief valve.

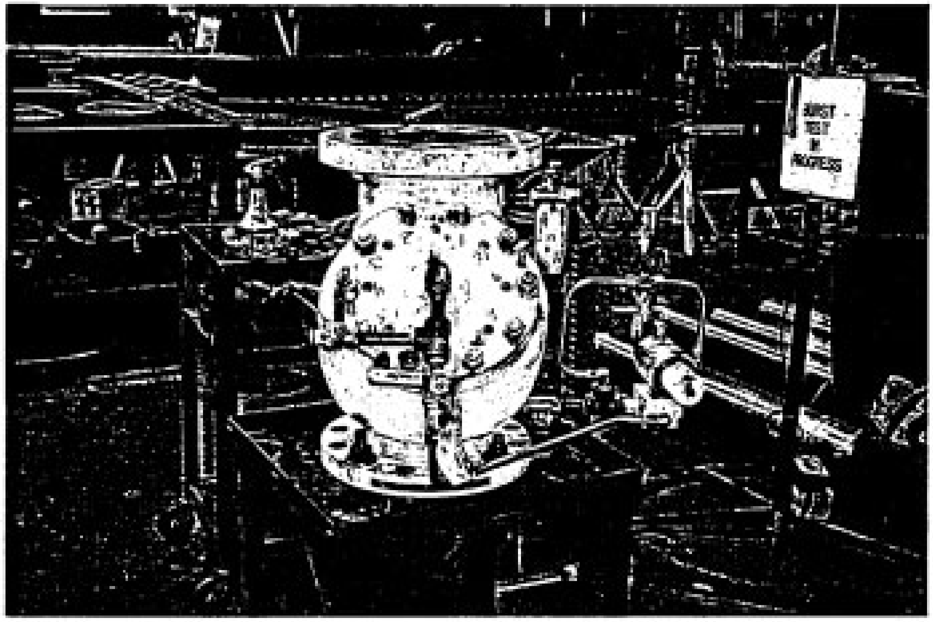


Figure 6.15 Reassembled Relief Valve

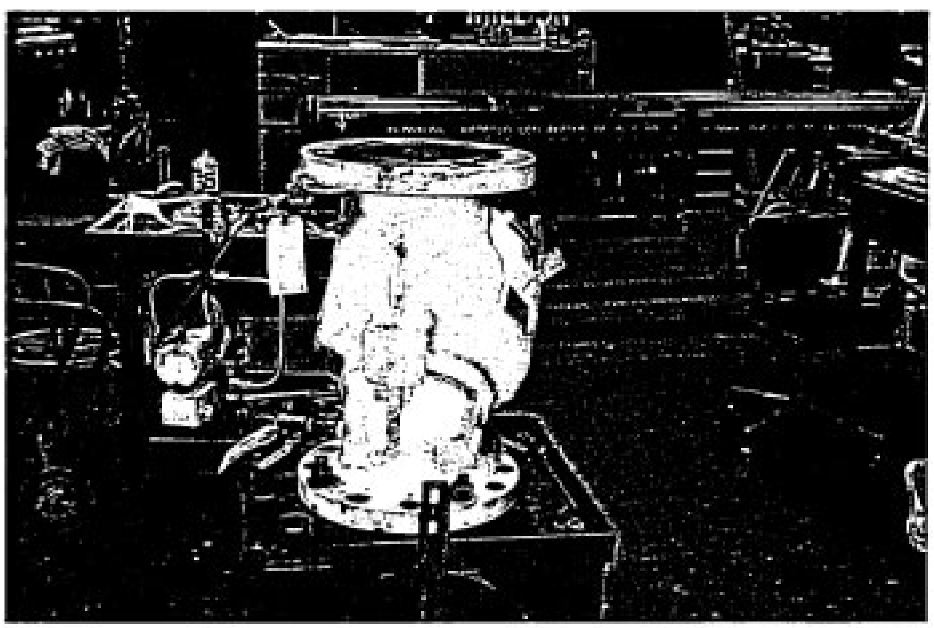


Figure 6.16 Reassembled Relief Valve (View 2)

7.0 CONCLUSIONS

From this test program it can be concluded that an attempt was made to modify a LP pilot valve to operate as a HP pilot valve and the steps taken for this modification were not adequate. Although the damping spring in the accident valve was shorter than the damping springs in the LP and HP exemplar, it is not clear whether the spring was original equipment or a replacement spring. The accident pilot valve behaves like a LP pilot valve with no modifications other than tightening the adjustment screw.

For the LP exemplar pilot valve to mimic the behavior of the accident pilot valve, the adjustment screw had to be tightened nearly all the way. This resulted in an unpredictable behavior of the pilot valve (i.e., the valve would open during a dead weight test, but not when pressure tested on the relief valve). This same behavior was observed with the accident pilot valve. This indicates that there are conditions where the relief valve could have operated in service and conditions where the valve could have failed to operate.

Pressures in the dead weight test were applied more slowly than in the test with the pilot valve on the relief valve. This means that there could be a rate dependence for the pilot valve when adjusted beyond the manufacture's specifications. In other words, the pilot valve may open if subjected to a slow increase in pressure but may fail to open when subjected to a rapid increase in pressure. This means that the relief valve could operate in an unpredictable manner, could open at pressures lower than intended set point, or fail to open at pressures much higher than the intended set point.

The components in the relief valve and accident pilot valve were in good condition. In addition, there were no debris or blockages in the valves, lines, or small valves in the lines which would prevent the valve from operating. Finally, when fitted with an exemplar HP pilot valve, the relief valve operated properly. This indicates that the failure of the relief valve to open and relieve pressure when the accident or adjusted LP exemplar pilot valves were installed is due to *the* failure of *the* pilot valves to open.