FINAL

SITE INCIDENT AND OBSERVATIONS REPORT

North River WPCP Main Sewage Pump Station Risk Assessment

B&V PROJECT NO. 174406

©Black & Veatch Holding Company 2011. All rights reserved.

PREPARED FOR

New York City Department of Environmental Protection

19 OCTOBER 2011

BLACK & VEATCH
Building a world of difference.

Table of Contents

Table of Contents i
Executive Summary 1
Introduction 5
Site Engineering 6
Operational Event Timeline 11
Sources of Fuel 12
Sources of Ignition 17
Enhancements 20
Opinion of Probable Cause 23
Attachments .....
Appendix A – Fire Investigation Report (T.J. Russo Consultants) A1
Appendix B – Safety Bulletins B1
Appendix C – Fire Tite Valves C1
Appendix D – Emergency Shutoff and Firesafe Valves D1
Appendix E – Flexible Connectors E1
Appendix F – Informational Data
F1 – North River Raw Sewage Pump Trend List F1
F2 – North River WPCP Daily Log Sheet F2
F3 – North River WPCP Raw Sewage Pump Engine No. 1 Operational Data Sheet F3
Appendix G – Laboratory Testing Report and Appendices G1

LIST OF FIGURES

Figure 1. Air Intake System Diagram 7
Figure 2. Fuel Supply Schematic 12
Figure 3. Engine Component Locations 13
Figure 4. Vertical Discharge of Fluid 13

Executive Summary

On July 20, 2011 a fire incident occurred at the North River Water Pollution Control Plant (WPCP) on the Main Sewage Pump (MSP) No. 1 Engine. New York City Department of Environmental Protection (NYCDEP) obtained the services of Black & Veatch (B&V) to perform an analysis to determine the cause of the fire along with an assessment of recommended improvements to improve the reliability of the engine systems. An Engineering Team from Black & Veatch and a Fire Investigator from T.J. Russo Consultants conducted a site investigation of the fire scene in the Engine Room at the North River WPCP on July 26 and 27. Black & Veatch team members returned to the site on July 28 with the T.J. Russo Fire Investigator to remove materials from the engine for further analysis by Affiliated Engineering. Team members returned on August 15 to collect additional material samples for testing. The review of the fire scene focused on potential ignition sources and fuel sources, and observations for reliability improvements. Steps in the assessment process included:

- Field review of the fire damage to the engine and surrounding systems including photographing of all affected areas, observation of the other operating engines noting operational characteristics and measurement of engine system temperatures, and review of the blower engines located in the same Engine Room
- Collection of operational and maintenance data from NYCDEP
- Interviews of NYCDEP staff that were present the day of the fire
- Tagging and removal of pertinent materials for testing as indicated above
- Metallurgical testing of materials removed by Affiliated Engineering and review of results by the B&V/TJ Russo Team, including review by a B&V metallurgist
- Analysis of potential fuel flow/spray from potential sources of fuel
- Review of existing system alarm parameters available at the engine control panel, SCADA system alarm and telemetry interfaces, remote shutdown capabilities, and HVAC system controls
- Additional Q&A and field observation with NYCDEP staff and engine specialists from Vronay during the subsequent engine disassembly process
- Research of similar engine fire incidents in various industries
- Team interactive discussions on potential fire scenarios keying on the fire investigation experience of TJ Russo and the engine experience of B&V
- Multiple progress discussions and input from NYCDEP staff

A review of potential causes for the MSP No. 1 Engine fire yielded the following probable causes:

- Failure of the connector on the fuel injector (jerk) pump discharge line on cylinder number one and the ignition of the diesel fuel by spraying the exterior of the turbocharger.
- Failure of the flexible fuel line connection located downstream of the fuel duplex filter and the ensuing ignition of the diesel fuel by spraying the exterior of the turbocharger.

These potential causes listed above are each viable possibilities of probable cause. It is not possible to determine the exact cause of the fire as crucial evidence may have been destroyed by the fire or destroyed as a result of the fire being extinguished. Our opinion of the most likely probable cause of the fire is the failure of the diesel fuel connector on the discharge side of the fuel injector pump. Because of the lack of physical evidence of initial failure on the stainless steel braid assembly of the flexible fuel line, it is our opinion that the flexible connector is not as likely a probable cause of the fire as the failed fuel injector connector. The fire investigation report included as Appendix A lists additional possible causes that have been eliminated.

It should be noted that immediately after the fire it was evident that the shut off valve in the fuel metering return line for the MSP No. 1 Engine was severed. During initial site investigation it was also discovered that the adjacent fuel metering supply line shut off valve was cracked. Metallurgist testing of these valves revealed the valves failed due to liquid metal embrittlement. This embrittlement most likely occurred due to melted aluminum from the turbocharger air inlet falling on the valve bodies, rapidly causing embrittlement fractures. Thus, our opinion is that these valve failures were not a primary source of fuel for the fire. The fractured valves did become a significant secondary source of fuel for the large fire spread at the floor level around the engine and two additional levels below the Engine Room.

The most likely probable source of initial fuel for the fire ignition, failure of the connector on the fuel injector pump discharge line, potentially occurred from either over torque or under torque of the connection. If the fitting was not fully tightened (possible under torque), it may have loosened under operation, allowing a fuel leak flow. If the fitting was over tightened (possible over torque), thread connections could have been damaged and the mating fitting surfaces may have not seated properly, allowing fuel to flow. Evaluation of this fitting by the metallurgist revealed signs of erosion along the conical mating surface of the fitting, suggesting evidence of fuel flow. The erosion would not be visible unless viewed under a microscope. It was also evident that thread damage had occurred on the final thread on the fuel pump connection to the connector, suggesting the fitting may have been over tightened. In our opinion, the failure of this connector on the fuel injector pump discharge line was not related to improper operation or maintenance of the unit as there are no procedures in the engine Operation and Maintenance manuals indicating proper torque of this connector. It was also noted during progress discussions with NYCDEP staff that the nature and configuration of this connection does not allow for use of a conventional torque wrench device.

A schematic arrangement of fuel supply system components is shown in Figure No. 2 of this report. Engine component locations are also shown in Figure No. 3 of this report. Based on the most probable cause, the likely events may have occurred as follows:

- After repair of a gasket on the duplex filter, at approximately 11:05 am as indicated on the Trend List, the unit was restarted. After the restarting of the unit, fuel from the leaking connector on the fuel injector pump discharge line connection started spraying the turbocharger. The location of the connector is not readily visible from the floor level and no leaking fuel was observed by the plant personnel after restarting the unit.
- As the exterior temperature of the turbo charger increased to its normal high operating temperature, it ignited the diesel fuel spray.
- The fire then started melting a portion of the turbocharger air inlet that is constructed of aluminum.
- The melting aluminum fell onto and around the fuel meter line shut off valves, causing them to become embrittled and rapidly fail. Fuel leaking from the failed valves potentially sprayed the initial fire with additional fuel, further enhancing the fire, and began pooling additional fuel at the floor level.
- MSP #1 Engine then shut down at approximately 11:35 am, as indicated on the Trend List, due to low fuel pressure from the fuel leaking from the embrittled valves. Engine shut down alarm and engine run status indication is available in the control room, but shut down was not observed by any witness in the Engine Room or anyone in the Control Room at this particular time.
- At some point, as the heat from the fire intensified, the liner of the flexible connector on the fuel supply line downstream of the duplex filter, the connectors on the engine driven lube oil pump, and the flexible connector on the turbocharger oil drain line melted. Fuel and lube oil that was not being consumed by the fire then ran out onto the floor around the front of the engine and through floor penetrations to the lower floors below the engine.
- The remote lube oil pump continued to operate and provide fuel for the fire for an additional five (5) minutes after engine shut down. The pump is designed to supply lube oil to the turbocharger blade bearings while the turbocharger spins to a stop after the engine shuts down.
- The remote fuel pumps located on the floor below continued to operate and add fuel to the fire until the power was shut off to the plant.
- The ensuing explosion was due to ignition of the diesel fuel and lube oil that was on the floor around the engine. This explosion caused a rapid increase in thick, black smoke that was evident to witnesses in the surrounding areas.

As a result of the assessments completed, Black & Veatch also recommends the following improvements to increase the reliability of the engines. Each of the recommendations is described in detail in the report.

- Fire-tite manual shutoff valves in fuel oil and lube oil lines
- Emergency shutoff and firesafe valves at room transitions and at header piping take-offs
- Flexible connectors added in additional piping locations
- Relocation of combustion air intake outside or shielding in existing location
- Confirmation of existing inspection and maintenance practices with potential enhancements
- Dry starting (a continuation of existing standard practices) with additional dry starting after consecutive failed restarts
- Remote (control room) emergency stop for fuel oil and lube oil supply in addition to existing engine emergency stop
- Low pressure switch on fuel oil and lube oil supply lines
- Supplemental camera, SCADA, and fire monitoring to enhance the existing SCADA and personnel monitoring already in place
- Turbocharger shield to prevent contact with fuel leak sources
- Fuel supply piping replacement
- Turbocharger high temperature alarm addition
- Relocation of diesel fuel electric shut off valve
- Fuel hood on fuel supply lines
- New automatic safety shut off valves in the gas supply line

A detailed analysis of how to best implement these enhancements will be required. The analysis will require a review of alternatives that are available to implement the enhancements and selection of the alternative that is the most appropriate for the application.

Introduction

PURPOSE

The purpose of this technical report is to document the results of our investigation into the cause of the fire incident that occurred at the North River WPCP on July 20, 2011. This report also provides recommendations for enhanced operational reliability of the Main Sewage Pump (MSP) engine pump drives and Blower engine drives at the North River WPCP.

BACKGROUND

Currently the North River WPCP engine room consists of five (5) engine driven MSP's, five (5) engine driven blowers, and associated equipment. The engine driven pumps are each powered Delaval Enterprise Model DGSR-46 dual fueled engines using either No. 2 diesel fuel or gas fuel (digester gas or natural gas). Each engine has a nameplate rating of 1,700 horsepower at 400 rpm. These engines were purchased in 1983 and were installed in 1986. In the mid 1980s these engines ceased being manufactured and in 1988 Delaval sold the Enterprise aftermarket services to Cooper Industries, currently named Cameron's Compression Systems Division.

On Wednesday July 20, 2011 at approximately 11:30 am, a fire event occurred in the North River WPCP engine room. Extensive damage occurred inside the engine room and MSP engine No.1 and associated equipment were severely damaged by the fire.

NYCDEP contracted with Black & Veatch to evaluate the potential cause of the fire incident and review the existing installation of the MSP engines and blower engines. The review will determine recommended modifications to prevent a similar occurrence, as well as any other observed improvements to increase the safety and reliability of the engines.

North Side of Main Sewage Pump No. 1 Engine

Site Engineering

ENGINE INFORMATION

The diesel fuel consumption for each of the MSP engines can vary depending on the fuel selection process, from 100 percent diesel fuel consumption to approximately 10 percent diesel fuel when being used as a pilot fuel to ignite the digester gas or the natural gas. Diesel fuel is supplied to the engine at approximately 12 gpm at 55 psi from remote fuel transfer pumps that are located on the +5 elevation floor below the Engine Room. These pumps are manually started and stopped by local controls at the pumps.

Each engine has a unit mounted lube oil pump that is driven by the engine, and it has a capacity of 300 gpm as indicated on the Lube Oil Piping Schematic drawing number 09-820-83001.

During site investigations on July 26 and 27, a reading of 0.5 inches of water column pressure drop across the filter elements on MSP engine No. 5 air intake filter was taken while the engine was operating. This reading was taken to evaluate the air intake as a possible location for fuel being sucked into the turbo charger and being ignited.

During operation, the following temperature readings were taken at various locations on MSP No. 5 Engine. This engine is of the same manufacturer and age as MSP No.1 Engine.

Fuel metering return shutoff valve	113 °F
Engine block behind fuel metering return shutoff valve	113 °F
Middle of engine block above fuel metering return shutoff valve	157 °F
Oil drain line from turbocharger	162 °F
Outside to the right of the middle of turbocharger	415 °F

Multiple raw water pumping parameters are actively recorded with the plant SCADA system, including engine running speeds, total flow, and engine system temperatures. Trend List data indicated the exhaust temperature for MSP engine No. 1 prior to the fire event to be in the range of 765 °F and 1100 °F which is not considered abnormal.

Figure No. 1 was taken from the Triodyne Inc. Safety Brief ISSN 1041-9489. It shows a typical air intake system for a 4 cycle system.

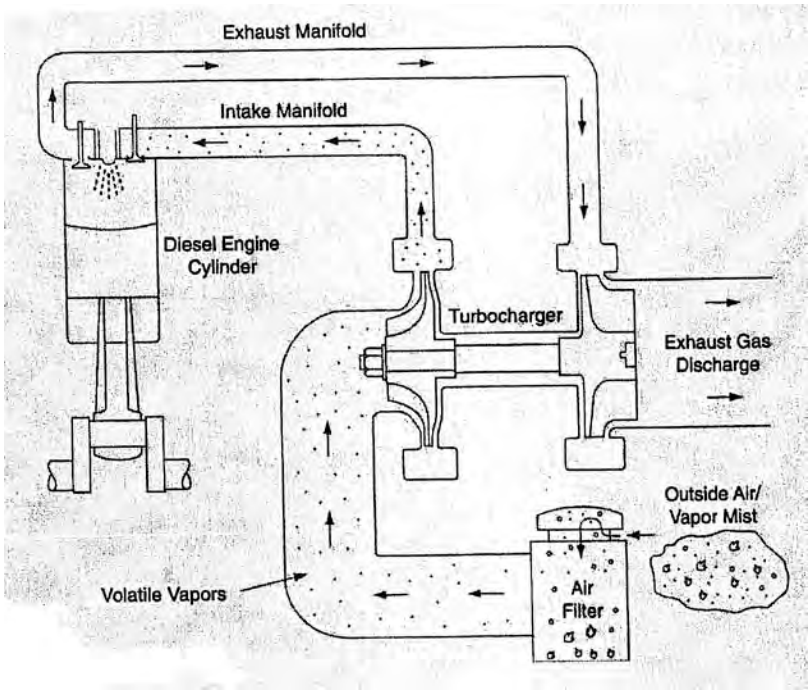


Figure No. 1

ENGINE FLUIDS

The engines and Engine Room contain numerous combustion gases, combustion liquids, and lubrication liquids. The National Fire Protection Agency (NFPA) classifies flammable and combustible liquids based on the flash point temperature of the liquid. Diesel fuel is classified as a Class II Combustible Liquid, since it has a flash point equal to or greater than 100 °F, but less than 140 °F. Lubrication oil is classified as a Class IIIB Combustible Liquid, since it has a flash point equal to or greater than 200 °F.

	Flash Point Temperature	Auto-Ignition Temperature
Natural Gas	-	1,076 °F
Diesel Fuel	125 °F	410 °F
Lubrication Oil	420 °F – 485 °F	465 °F – 815 °F

<u>Definitions:</u>

Flash Point is the minimum temperature that a combustible fluid produces sufficient vapor to yield a combustible mixture.

Auto-Ignition temperature is the temperature at which combustion occurs spontaneously (without an external source of ignition).

Atomization occurs by forcing fuel through a small opening under high pressure to break it into a fine mist.

ENGINE ELECTRICAL CONTROL SYSTEMS

A review of the MSP engine control panel schematics was performed to determine the existing engine controls. The following list of drawings was provided by NYCDEP for review:

Drawings 09-500-83002, sheets 2 – 4, and 6 – 8 of 10, Rev AET-1, Main Sewage Pump Engine Control Schematic Engine 1412-1415, by Advanced Engine Technologies Corp.

Drawing 09-500-83002, sheet 5 of 10, Rev D, Main Sewage Pump Engine Control Schematic Engine 1412-1415, by Transamerica Delaval.

Drawing 09-500-83001, sheet 8 of 11, Rev E, Main Sewage Pump Engine Control Schematic Engine 1411, by Transamerica Delaval.

Drawing 31BD1 7-11 (this is an assumed number as the bottom part of number is not legible), sheet 10 of 11, Rev 3, Main Sewage Pump Engines No. 1411-1415 Air/Fuel Ration Control Sys. Ele. Schematic NYC North River Water Pollution Control Plant, by Advanced Engine Technologies Corp.

The following is a list of shutdown signals that will automatically shutdown the engine upon initiation by the engine instrumentation:

- High temperature lube oil
- Low wet well level
- Overspeed
- Barring device
- High temperature main bearing
- High vibration
- Low pressure control air
- GRI safety
- High temperature jacket water
- Low pressure lube oil
- Low pressure jacket water
- Low pressure fuel oil

- Low pressure turbo lube oil

Additionally, the engine can be shut down by pressing the emergency stop pushbutton located in the control room.

Below are the alarm signals that are annunciated to the engine control panel when the pre-determined setpoint is exceeded. These alarm signals are combined together for a common alarm to the plant control room.

- High temperature lubricating oil
- High temperature jacket water
- High temperature engine cylinders
- High temperature turbocharger intercooler
- High temperature engine cooling water
- High temperature generator winding
- High temperature generator bearing
- High temperature gas booster discharge header
- High temperature gas header
- Low pressure lube oil
- Low pressure turbo lube oil
- Engine cooling water pressure
- Gas header change to fuel oil pressure
- Gas header pressure
- Fuel oil pump strainer A delta pressure
- Fuel oil pump strainer B delta pressure
- Gas booster intake filter delta pressure
- Engine lube oil filter delta pressure
- Starting air header pressure
- Starting air manifold pressure
- Turbo intercooler water pressure
- B&A lubricating oil pump pressure

- Gas mixing tank vacuum pressure
- Gas booster suction header vacuum pressure
- Gas booster cooling water pressure
- Heat recovery silencer water level high
- Heat recovery silencer water level low
- Fuel oil day tank #1 level high
- Fuel oil day tank #1 level low
- Fuel oil day tank #2 level high
- Fuel oil day tank #2 level low
- Lube oil sump tank level low
- Wet well No. 1 level low
- Wet well No. 2 level low
- Ring flush water low flow
- Jacket water standpipe level low
- Low pressure fuel oil standby pump on
- Seal water low flow
- P.C. power failure

A review of the fire alarm and ventilation drawings was also conducted in conjunction with the engine control panels to determine if upon detection of a fire in the engine room there are any interlocks with the ventilation systems. Contracts 7A, 8A, 8B, and 28 were reviewed and smoke detectors are located in the supply duct to de-energize the supply fans upon sensing alarm conditions.

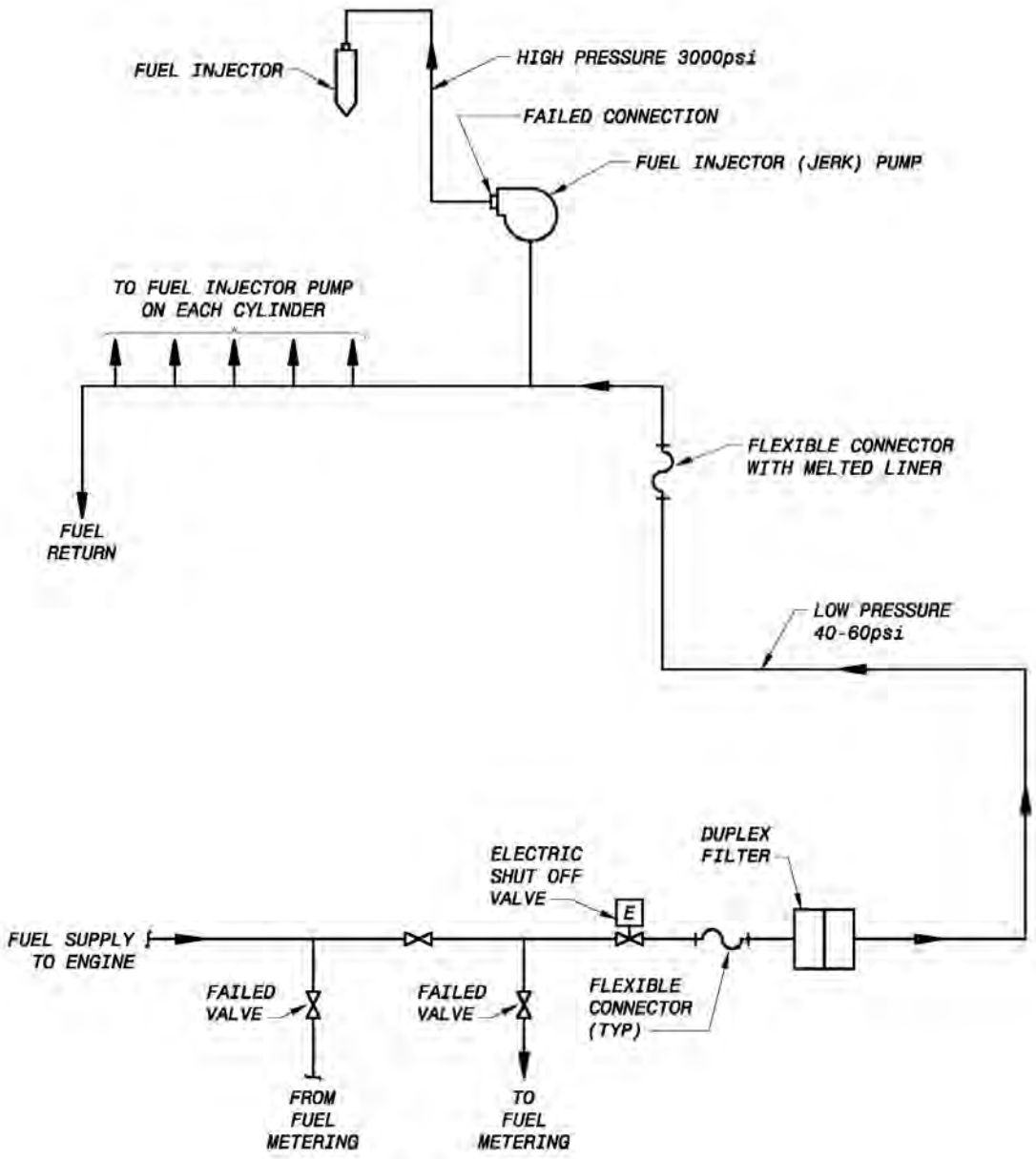
Operational Event Timeline

The following partial list of operational time events, that involved operation of the MSP engines on the day of the fire event, were taken from North River Trend List, daily log sheets, and pump engine operational data sheets:

Recorded Time	Event
9:26 am	Pump operational data sheet indicated MSP #1 shut down due to low fuel pressure
9:30 am	Daily log sheet indicated "C/I #4 MSP as trial run. MSP #1 C/O by itself. Could not start due to fuel oil pressure. Oilers working on #1MSP. #4 MSP flow reading on Trend is not working"
10:00 am	Trend List indicated MSP # 4 and MSP # 5 operating
11:03 am	Trend List indicated MSP #1 rpm at approximately 375
11:10 am	Trend List indicated MSP #5 rpm dropped to zero
11:15 am	Daily log sheet indicated "C/I #1 after fixing oil leak. C/O #5 MSP"
11:35 am	Trend List indicated MSP # 1 rpm dropped to zero and the total station pump output capacity dropped in half
11:47 am	Trend List indicated MSP #4 rpm dropped to zero and the total station pump output capacity dropped to zero
01:30 pm	Power shut down to plant by DEP (approximate time per NYPA load data)

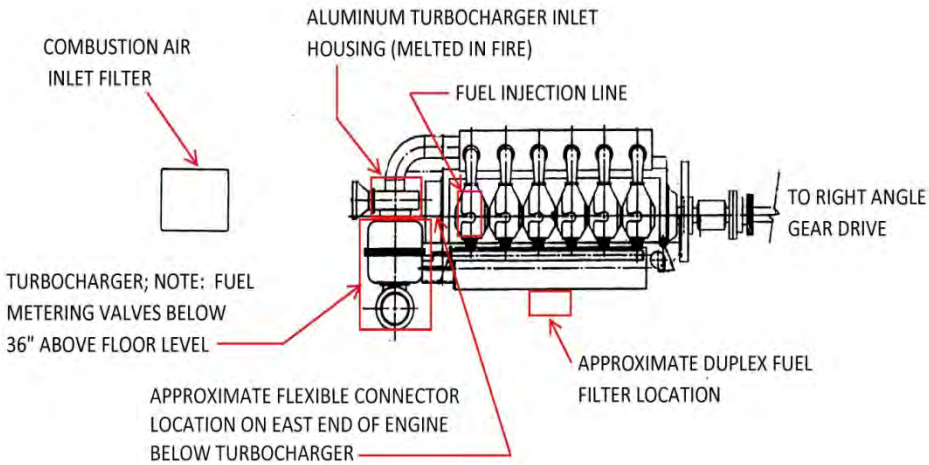
Sources of Fuel

This section evaluates the potential sources of fuel that possibly started and fed the fire that occurred. Figure 2 provides a schematic arrangement of engine fuel supply components. Figure 3 indicates the approximate location of the system components in question.



Engine Fuel Supply Schematic

Figure No. 2



Engine Component Locations

Figure No. 3

FUEL METERING SHUT OFF VALVES

After the fire event, the shut off valve in the fuel meter return line was found to have been severed. During the removal of the return valve for additional testing and inspection it was determined that supply valve adjacent to it also had failed and had a crack in its body. Initially it was thought the valves failed from fatigue due to engine vibration over extended time periods. Inspection and testing of the valves by the metallurgist indicated the valves were embrittled by liquid metal embrittlement. Because both valves failed at approximately the same time and because of the nature of the aluminum penetrating the valve body and fracture surfaces, the metallurgist concluded that the embrittlement and subsequent valve fractures most likely occurred during the fire due to contact from the melting aluminum of the turbocharger air inlet. The failed valves are located on the front of the engine approximately 36 inches above the floor. From the Hydraulic Handbook the following formula can be used to estimate the vertical discharge height of fluid from the failed valve:

Capacity, GPM = $5.68\ KD^2\ H^{1/2}$

D = Internal Diameter (ID) of Pipe, inches

H = Vertical Height of water jets, inches

K = a constant, varying from .87 to

.97 for 2 to 6 in. dia.

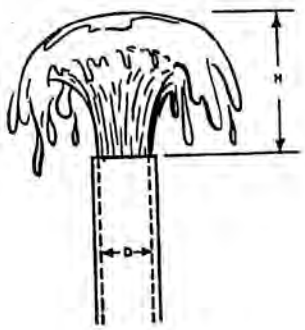


Figure No. 4

For an open pipe, the vertical discharge height would be approximately 35 inches. This is based on the following:

Inside diameter of Schedule 40, ½ inch diameter pipe, which is 0.622 inches.

Pump capacity of 12 gpm provided by NYCDEP

Constant for K of 0.92

Assuming that the separation of pipe is approximately one half the diameter of the pipe and half the flow continues through the pipe and the other half discharges vertically. Based on the following input the vertical discharge would be approximately 25 feet:

Half of Schedule 40, ½ inch diameter pipe minus the wall thickness, which is 0.2565 inches.

Capacity of 6 gpm

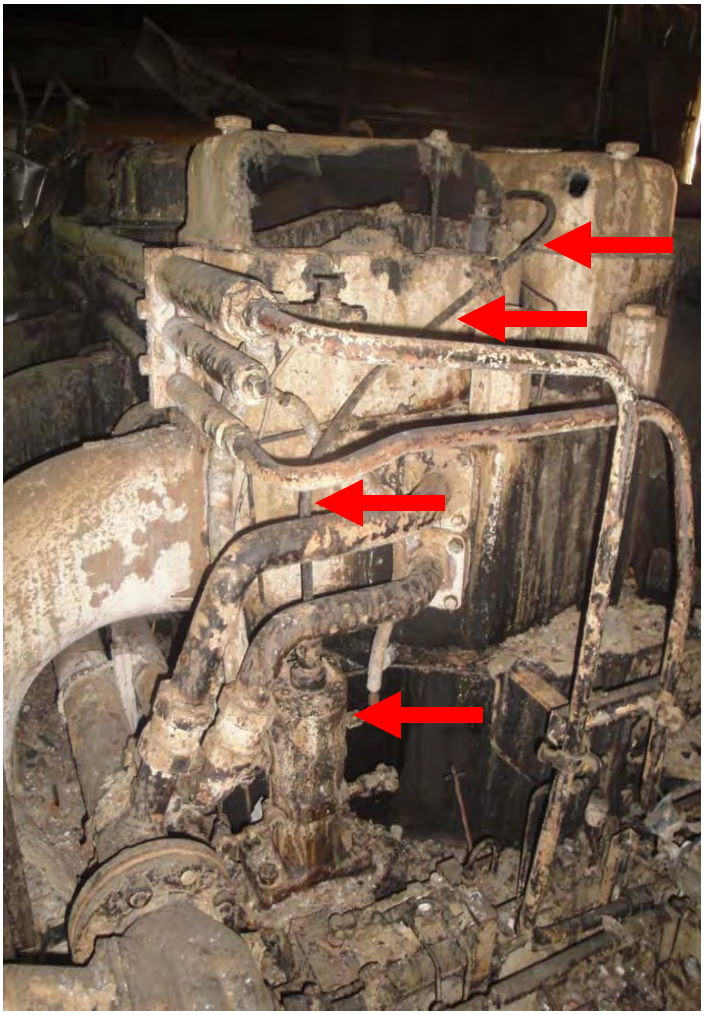
Constant for K of 0.92

This indicates the range at which diesel fuel could potentially discharge vertically from the failed return valve. The turbocharger is located approximately seven feet above the failed shut off valves. This is within the potential vertical discharge height of the fuel. The valve failures were not the likely cause of the fire but continued to feed the fire with fuel until the power to the remote fuel supply pumps was shut off.

MSP No. 1 Engine Fuel Metering Return Valve (circled). Note: The top of the severed valve and vertical piping section above it was removed prior to the B&V site assessment.

FUEL INJECTION SYSTEM

Each cylinder on the engine has an individual fuel injection (jerk) pump and a fuel injector to inject the correct amount of diesel fuel into the cylinder. The fuel supply to each fuel injection pump is from a common header that operates at approximately 55 psi. A separate high pressure line connects each pump to its associated fuel injector. The high pressure lines are located along the side of each head and valve cover. The intended operation of the fuel injector is to open at approximately 3,000 psi which atomizes the diesel fuel into a spray. The findings of the metallurgical report indicated there was a failure of the fuel injector connection fitting to the fuel injector pump. The report revealed damage to the first thread due to potentially over tightening of the connector. It also showed microscopic signs of erosion which indicates a flow of liquid. The spray from a failed connection could be the initial source of fuel for the fire by spraying the exterior of the turbocharger with diesel fuel.



MSP No. 1 Engine Cylinder No. 1 Fuel Injection Pump
and high pressure line (see arrows).

Our understanding is that MSP No. 1 Engine was operating using 90 percent digester gas and 10 percent diesel fuel at the time of the fire. It is not possible to know the size or shape of the failure of the connector on the fuel injection pump. Therefore it was assumed the failure was the size of a pin hole. From the Hydraulic Handbook the following formula was used to determine the amount of flow possible through a hole the size of a pin.

$Q = 19.636Kd^2 H^{1/2}$

Q = Capacity, GPM

K = Discharge coefficient

D = Diameter of the orifice, inches

H = Head at office, feet of liquid

The amount of flow of diesel through an opening the size of a pin hole is approximately one quarter of a cup per minute. This is based on the following:

Diameter of orifice hole of 0.004 inches

Head at orifice of 6,921 feet

Constant for K of 0.61

The separation distance between the connection on the fuel injector pump and the turbocharger is approximately 4'-6", which is within possible distance for a fuel leak to spray the turbocharger. This is not calculated scientifically due to a number of unknown factors concerning the size, shape, and orientation of the hole. The separation between the connection and the turbocharger is well within a plausible distance a small high pressure leak could spray.

DUPLEX FUEL FILTER

The duplex fuel filter located on the north side of the engine was found to be leaking on the left filter at approximately 9:30 am on the day of the fire event. Plant personnel indicated the spray direction from the leaking filter was horizontal and not vertical towards the exhaust system (See Appendix B – Safety Bulletins for a Safety Alert on engine exhaust fires). Log reports indicate the gasket was replaced and confirmed not to be leaking after replacement. The two filter shell assemblies butt up under the duplex fuel filter cap. Each shell assembly contains an air vent screw and a drain cock assembly. The air vent screws were found to be in place after the fire event. Both filter shells contained unburned fuel oil when disassembled after the fire. The areas immediately surrounding the fuel filter assembly did not show the same signs of intense heat damage that were observed near the

Duplex fuel filter assembly

metering valve area and on top of the engine near first cylinder and turbocharger areas. The location of the filter and lack of indication of intense fire in the area make the fuel filter an unlikely source of fuel for the fire.

FLEXIBLE CONNECTOR

The flexible connector is constructed of a liner that is surrounded by braided stainless steel to provide strength. It is located on the front side of the engine and just below the header pipe that supplies fuel to each fuel injector. Upon inspection at the testing laboratory, it was found that the liner located beneath the braiding of the flexible connector was missing. Since it was missing, it is assumed the liner was constructed of a rubber elastomeric material and melted during the fire. Rubber elastomeric materials have a shelf life up to 20 years depending on the rubber type. Exposure to temperatures over 80 °F will decrease the service life of the rubber. Even a small failure in this portion of the line could permit fuel to spray towards the turbocharger that is located approximately 5 feet away. This spray potential is not calculated scientifically due a number of unknown factors concerning the size, shape, and orientation of the hole, but the separation distance is well within a plausible spray distance. Once a fire started, the rubber liner would be destroyed and allow fuel, up to approximately 12 gallons per minute, to discharge through the braided portion of the flexible connector until the engine shuts down. Because of the location and construction of the flexible connector, the spray from a hole in the flexible connector could be the initial source of fuel for the fire by spraying the exterior of the turbocharger. Because of the lack of physical evidence of initial failure on the stainless steel braid assembly, it is our opinion that the flexible connector it is not as likely a probable cause of the fire as the failed fuel injector connection. Flexible connectors from other MSP engines were observed for comparison purposes, but they were from different manufacturers, construction, and age from the one used on the MSP No. 1 Engine, and the only observation that can be used for comparison is that they showed signs of wear from abrasion.

Sources of Ignition

Explosive conditions are possible any time the right mixtures of oxygen, fuel, and heat are available and combined in a room. In addition to the sources of fuel required for the fire to occur, a source of ignition or heat is also required. The source of ignition must be hot enough to ignite the fuel source. Heat sources in the vicinity of the engine, as observed during the site data gathering, included a potentially faulted electrical system and heat sources from the engine such as the exhaust system or turbocharger. Any heat source must be at least as hot as the auto ignition temperature of the fuel present for a fire to start.

Damage to MSP No. 1 Engine from the July 20, 2011 fire event at the North River WPCP was extensive, and included the inlet housing to the turbocharger, which had partially melted and fallen away from the engine. The following are items considered to be possible sources of ignition of the ensuing fire.

BACKFIRE

Backfire is an explosion produced by a combustion engine that occurs in the exhaust system rather than inside the combustion chamber. This occurs when unburned fuel is ignited somewhere along the exhaust system. From the Triodyne Inc. Safety Brief ISSN 1041-9489, "A destructive backfire is evidenced by a damaged turbocharger outlet elbow. Typically, the part is broken off of the turbocharger and "blown" clear of the main fire area." Note that the outlet elbow of the turbocharger on the MSP No. l Engine was still located on the turbocharger and that the inlet housing was missing. Based on this information, a backfire is not a likely source of ignition.

TURBOCHARGER

There are a several possibilities for a turbocharger internal failure. If the bearings for the turbocharger blades were to fail, it would be anticipated that they would produce a loud squealing noise before they would seize. No witness indicated hearing noise from the unit. Another possible cause of a turbocharger failure is when carbon builds up on the turbocharger blades. This occurs if the engine is operated for long periods of time at a reduced load. In these operating conditions, all the fuel will not be consumed, and the unburned fuel will be deposited on the blades. A fire will occur once the unit reaches operating temperatures; the carbon will burn off the turbocharger blades. It is also possible that a failure of a bearing seal in the turbocharger caused a lube oil leak and ignition internal to the turbocharger. These are possible sources of ignition but are not likely as the disassembly of the turbocharger did not indicate any unusual damage. The turbocharger will be re-used in the re-building of the engine. The inspection of the turbocharger blades did not indicate an excessive amount of carbon build up on the blades. Since the carbon build up on the turbocharger blades was on the exhaust side of the turbocharger and since the exhaust side was intact, there is no indication the fire started on the inside of the turbocharger.

As noted in the Sources of Fuel section, the exterior housing temperature of the turbocharger, on the exhaust discharge side, at operating conditions is sufficiently above the auto-ignition temperature to ignite diesel fuel on direct contact. As a result, the exterior housing of the turbocharger is the likely source of ignition. Appendix B – Safety Bulletins, includes a reference Safety Bulletin discussing surface ignition of fuel and oil on turbochargers.

South End of Turbocharger (picture left).
Connecting Aluminum Inlet Melted Away

FUEL CONTROL

A fuel control failure, such as both diesel fuel and digester gas being supplied to the engine cylinder at the same time, was investigated. It is anticipated the detonation would be a catastrophic type failure on the interior of the engine. No visible indication from the outside of engine such as a hole in the engine block or damaged pistons indicated this type of failure. It was thus initially determined that this was not a likely source of ignition. This possibility as a source of ignition was further eliminated during disassembly of the engine as no unusual damage was found inside the engine from an explosion.

COMBUSTION AIR

The location of the combustion air inlet to the engine is such that diesel fuel or lubrication oil vapors could be drawn into the engine air intake if there was a failure in either system. Once the vapors are drawn into the combustion air intake filter, the vapors could travel into the turbocharger, where they could be ignited due to the internal temperature of the turbocharger (See Figure No. 1). Due to the location of the combustion air intake filter with respect to the flexible connector, fuel injection system, and the fuel metering shut off valves, this is a possible source of ignition. However, internal inspection of the turbocharger, as previously indicated, reveals no notable damage from an internal explosive ignition. Therefore, this is not a likely source of ignition in this fire event.

ELECTRICAL SYSTEMS

During the field data gathering, electrical systems were reviewed for potential ignition sources. No potential electrical sources of ignition were found. The electrical systems that were still intact in the vicinity of the fuel sources did not have indications of an electrical fault. Additionally, electrical systems that were damaged during the fire were not in proximity to the fuel sources, nor were there any observed fire patterns indicating that the electrical systems ignited any of the possible fuel sources.

GAS SUPPLY BLOCK & VENT VALVE

The block & vent valve located downstream of the flexible connector on the engine supply line was severely damaged with one end of the valve containing the diaphragm and flange cover found to be completely missing. The valve is not currently vented to the atmosphere and therefore only operates as a shut off valve. On engine shut down it appears the valve closed as intended. Since the valve is not vented, the gas trapped inside the valve and in the gas supply line from the shut off valve to the engine blew off the diaphragm and flange cover. This was due to the increased pressure in the gas line when exposed to the heat from the fire. This was not the cause of the fire, but the damage sustained to this assembly was due to the fire. It is our opinion that the blowing off of the flanged cover did not have sufficient power to be the cause of the explosion that was seen blowing smoke from out of the doorway onto the roadway from the security camera. The valve remaining in the shut off position prevented further gas from escaping into the fire.

Enhancements

Site visits to the North River Water Pollution Control Plant were performed on July 26 and July 27. During these visits several items were observed in the engine room that may enhance the overall operational safety and reliability of the engine drives. These enhancement items were not developed to specifically address any laws or regulations, as this report is not intended to scrutinize these existing engine systems as though they were a new installation. A detailed analysis of how to best implement these enhancements will be required. The analysis will require a review of alternatives that are available to implement the enhancements and selection of the alternative that is the most appropriate for the application. These enhancements are intended to prevent or minimize the impact of a future fire, and are not intended to conclude that this fire event could have been prevented had these measures already been in place.

FIRE-TITE MANUAL SHUTOFF VALVES

Use of fire-tite type shut off valves in the fuel oil and lubrication oil lines. Fire-tite valves utilize a secondary metal seating surface to ensure an acceptable level of shut off of the valve if it is closed and the primary seats of the valve are destroyed by fire. See attached manufacturer catalog information in Appendix C.

EMERGENCY SHUTOFF AND FIRESAFE VALVES

Use of automatic shutoff valves when either fuel oil or lubrication oil changes floors or rooms, and at all take-offs from header piping. These valves are normally open and provide automatic closure in the event of a fire or high temperatures. See attached manufacturer catalog information in Appendix D.

FLEXIBLE CONNECTORS

Installation of flexible connectors in all piping connections to equipment and at locations in the piping system to reduce stress due to equipment vibration and/or thermal stresses. Flexible connectors need to be constructed of all stainless steel. This includes the liner and the braid around the liner. See attached manufacturer catalog information in Appendix E.

COMBUSTION AIR INTAKE

The combustion air intake filter for each engine is currently located approximately 12 feet from the front of each MSP engine. To prevent fuel oil vapors, gas, or lubrication oil vapors from being drawn into the engine, relocate the combustion air intake filter to outside the room or install a divider to shield the air intake filter from any vapors that could be directed toward the filter from the engine. The divider need not be permanent but should be removable to allow access around the unit to change out the air filter elements. It should be noted that the fuel metering system for each engine driven blower is located near the associate combustion air intake filter. Diesel fuel vapors could be potentially drawn into the engine while performing maintenance and/or during any

system failure on the fuel meters. This enhancement is in agreement with the recommendations provided by the New York City Fire Department.

INSPECTION AND MAINTENANCE

Continue and enhance existing inspection and maintenance practices, including engine inspections and maintenance for all engines as indicated in the Transamerica Delaval Instruction Manual Volume 1 Section 5 for the Suggested Maintenance Schedules. Inspections and maintenance include accessory equipment associated with each engine.

DRY STARTING

Continue current engine starting procedures of cranking the engine with the fuel supply shutoff to clear out any unused fuel remaining in the exhaust system. In addition to the current practices, include clearing out (dry starting) the system if an engine fails to start after a couple of unsuccessful start attempts. This prevents a backfire in the exhaust system as unburned fuel is forced out of the engine exhaust system.

EMERGENCY STOP

The function of the engine emergency stop push button in the control room should include stopping of all fuel oil transfer pumps and lubrication pumps, or adjacent fuel oil and lubricating oil emergency stop push buttons should be installed. This enhancement is in agreement with the recommendations provided by the New York City Fire Department.

LOW PRESSURE SWITCH

Installation of a low pressure switch on the engine fuel oil supply and lubrication oil supply headers to shut down pumps in the event of a pipe failure.

SUPPLEMENTAL MONITORING

Monitoring of the engines could be refined by adding remote monitoring of the Engine Room floor via a camera system, increasing the number of alarm points routed to the Plant Control Room, and adding Engine Room fire detection equipment. A combination of these methods permits increased observation capability without placing personnel in harm's way to visually confirm a fire situation. It should be noted that it cannot be determined if this particular fire event would have been prevented with additional monitoring, but increased monitoring combined with the other enhancements included in this section could provide improved evacuation and fire department notification time in the event of a future fire situation. Increased monitoring could include remote indication of all alarms and shutdown signals in the Plant Control Room as well as logging of all engine alarm and shutdown signals by the SCADA system. There is no indication in the Control Room to differentiate why an engine shuts down; only general indication that an engine shut down. Plant personnel have to physically view the local control panel at each engine to determine the cause of the shut down. Fire detection in the Engine Room could be added via monitored heat detectors. Additional fire alarm system recommendations are included in Appendix A - Fire Investigation Report.

TURBOCHARGER SHIELD

Install a shield around the turbocharger to prevent the potential of a fuel or lubrication leak coming into contact with the turbocharger.

FUEL SUPPLY PIPING

Replace all fuel supply piping from the fuel header to the fuel injector using carbon steel pipe and all stainless steel flexible connectors. Also add the frequent inspections of all connections to the maintenance procedures of the units.

TURBOCHARGER ALARMS

Add alarm and shutdown of engine for turbocharger high temperature.

RELOCATION OF DIESEL FUEL ELECTRIC SHUT OFF VALVE

Relocate the diesel fuel electric shut off valve further upstream of the duplex fuel filter in the 1 ½ inch header supply piping. This will reduce engine vibration to the valve and will shut off the fuel before it is routed in front of the engine. In the event the engine shuts down for any reason, or failure of the flexible connector, the electric valve will shut off fuel to the engine.

FUEL HOOD

The New York City Fire Department recommendations also included "Provide a hood over the supply line to prevent any fuel under pressure from reaching turbo." This may not be possible to achieve as the fuel supply has numerous lines that are located at various locations along the side of the engine and up the front of the engine and would include the fuel injector lines.

AUTOMATIC SAFETY SHUT OFF VALVE

Replace the existing block and vent valve with two (2) new automatic safety shut off valves. The new valves should be located in the fuel supply line upstream of the flexible connector. Current NFPA 37 code requirements require two (2) automatic safety shut down valves to close within one (1) second of engine shut down, or one automatic shut down valve is permitted if the gas train includes one of the following:

1. Carburetion valve
2. Zero governor
3. Auxiliary valve

Opinion of Probable Cause

The North River / Trend List: TR1416 Raw Sewage Speed PD 1411-1415 indicated the rpm for MSP No. 1 Engine dropped to zero at approximately 11:35 am (see Appendix F). The individual cylinder temperature Trend List: TR 1411 PUMP ENG #1 shows an exhaust temperature range of 765 F to 1000 F at 11:35 am, which is above the auto ignition temperature of diesel fuel. The Time Line of Fire Event in the Fire Investigation Report (see Appendix A) indicates at 11:42 am that the smoke was barely visible from top of the garage doorway as viewed from the security camera. This could be from the diesel fuel spraying the turbocharger and the early stages of the fire. At 11:43 am the report indicated steady stream of smoke from the top of the doorway which indicates the fire growing in intensity. At 11:45 am the report indicated an explosion blows out of the doorway. This could be due to the fuel and lubrication oil igniting on the floor around the engine from the failure of the fuel metering shut off valves, flexible connector on the turbocharger oil drain line, and the rubber couplings around the engine driven lube oil pump.

It is not possible to determine the start time of the fire in relationship to first indications of smoke, as there were no witnesses or sufficient monitoring to determine when it first started. It is likely the engine shut down as indicated on the Trend List at 11:35 am, since there was no unusual damage found inside the engine due to the engine operating without being properly lubricated. However plant personnel have indicated there was no alarm condition in the Control Room to indicate an engine shut down. In any fire investigation and observation report it is the intent to narrow the possibilities of the failure to those that are most likely the cause. The following possible causes of the fire are plausible based on the information yielded by the investigation:

- Failure of the fitting connection from the fuel injector line to the fuel injector pump which in turn ignited the diesel fuel by spraying the turbocharger.
- Failure of the flexible fuel line and ignition of the diesel fuel by spraying the turbocharger.

These potential causes listed above are both viable possibilities of probable cause. It is not possible to determine the exact cause of the fire as crucial evidence may have been destroyed by the fire or destroyed as a result of the fire being extinguished. Our opinion of the most likely probable cause of the fire, based on site investigation and metallurgical observations and testing, is the failure of the diesel fuel connector on the discharge side of the fuel injector pump. The fire investigation report included as Attachment A lists additional possible causes that have been eliminated.

FUEL INJECTOR SYSTEM FAILURE

Based on the findings of the metallurgical report, the fuel injector fitting to the fuel injector pump likely failed. It is possible for the spray from the fuel injector pump or the failed fitting to be the initial source of fuel for the fire by spraying the exterior of the turbocharger with diesel fuel. The ensuing fire would cause the aluminum inlet on the turbocharger to melt. The melting portion of the falling aluminum would splatter the manual shut off valves in the fuel metering lines causing them to fail due to embrittlement. The failed valves then further sprayed additional fuel onto the turbocharger, enhancing the fire. The failure of the valves would have permitted fuel to continue to

feed the fire because the electric shut off valve for the diesel fuel supply is located downstream of the take off to the fuel meters. Interviews indicated the intense fire continued until power to the plant was shut off. The fuel supply pumps then stopped, which ceased supplying fuel to the fire.

FLEXIBLE CONNECTOR FAILURE

A possible cause is the flexible connector located above the fuel header on the east side of the engine developing a leak and spraying the turbocharger with diesel fuel. The ensuing fire would cause the aluminum inlet on the turbocharger to melt. The melting portion of the falling aluminum would splatter the manual shut off valves in the fuel metering return and supply lines causing them to become embrittled. The embrittled valves would have then failed further spraying fuel onto the turbocharger. The enhanced fire then melted the liner of the flexible connector on the fuel supply line that is located downsteam of the duplex filer, the connectors on the engine driven lube oil pump, and the flexible connector on the on the turbocharger drain line failed permitting the lubrication oil to feed the fire as well. The failure of the valves would have permitted fuel to continue to feed the fire because the electric shut off valve for the diesel fuel supply is located downstream of the take off to the fuel meters. Interviews indicated the intense fire continued until power to the plant was shut off. The fuel supply pumps then stopped which ceased supplying fuel to the fire.

THOMAS J. RUSSO, SR., C.F.I.
MICHAEL W. RUSSO, C.F.I.

PAMELA J. RUSSO
OPERATIONS MANAGER

JOSEPH BANAHAN, C.F.I
RICHARD R. BLOETH, C.F.I.
PETER M. CATAL, C.F.I.
DOUGLAS E. LEIHBACHER, C.F.I.
KEVIN S. PARRETT, C.F.I.
GENE PIETZAK, C.F.I.
SALVATORE J. SALVATO, C.F.I.

HARRY T. HANSEN, C.F.E.I.
DIRECTOR NEW JERSEY
REGIONAL OFFICE

GERARD E. LEDWITH, C.F.I.
DIRECTOR HUDSON VALLEY
REGIONAL OFFICE

STEPHEN M. WENK, C.F.I.
DIRECTOR FLORIDA
REGIONAL OFFICE

DOUGLAS J. MOLLO, ESQ

T.J. RUSSO Consultants
Fire Investigation and Analysis Services

CORPORATE HEADQUARTERS
99 HILLSIDE AVENUE
WILLISTON PARK, NY 11596
TEL: 516-294-8644
FAX: 516-747-1009

E-MAIL: OFFICE@TJRUSSO.COM
WWW.TJRUSSO.COM

NEW JERSEY REGIONAL OFFICE
344 LAFAYETTE ROAD
HARRINGTON PARK, NJ 07640
TEL: 201-750-1948 - FAX: 201-750-8789

HUDSON VALLEY REGIONAL OFFICE
3590 ROUTE 9
COLD SPRING, NY 10516
TEL: 845-809-5245 – FAX: 845-809-5098

FLORIDA REGIONAL OFFICE
P.O. BOX 1376
ZEPHYRHILLS, FL 33539
TEL: 813-788-3240 – FAX: 813-788-3280

OUR FILE NO.: FR-9393-11

October 19, 2011

LOSS: 725 West 135th Street
New York, New York

DATE OF LOSS: July 20, 2011
Wednesday

INSURED: North River Wastewater
Treatment Plant

Mr. Kyriacos Pierides
Black & Veatch
489 Fifth Avenue – Floor 8
New York, NY 10017

Dear Mr. Pierides:

Pursuant to your request, enclosed please find our final report and an invoice for services rendered regarding our examination and investigation pertaining to the above-captioned loss.

Please be advised that at this time we have not received the New York City Fire Marshal's Report regarding this matter. Upon our receipt of this report, we will forward same to you.

Although our file is in closed status, we remain ready to reactivate upon request from your office to render any further assistance you may require in your ongoing analysis of this case. Thanking you for the opportunity of being of service to you, I remain,

Very truly yours,

T. J. RUSSO CONSULTANTS, INC.
Douglas E. Leihbacher

Douglas E. Leihbacher, C.F.I.
Fire Investigator

DEL/cg
Enc.

725 WEST 135TH STREET
NEW YORK, NEW YORK

CASE NO.:

FR-9393-11

POLICY NO.:

Not Provided

CLAIM NO.:

Not Provided

ADDRESS:

725 West 135th Street
New York, New York

DATE OF LOSS:

July 20, 2011
Wednesday

DATES OF EXAMINATION:

Thursday, August 11, 2011;
Monday, August 15, 2011;
Thursday, September 1, 2011 and
Tuesday, September 13, 2011

CONSENT FOR EXAMINATION:

Kathryn Mallon
Deputy Commissioner
NYC Dept. Environmental Protection (DEP)
59-17 Junction Boulevard – 19th Floor
Flushing, NY 11373

EXAMINATION REQUESTED BY:

Kathryn Mallon
NYC Dept. of Environmental Protection

INSURED:

North River Wastewater Treatment Plant

TABLE OF CONTENTS

	Page
Surrounding Properties	1
Exterior Examination	2
Interior Examination	2
Area of Fire Origin	3
Evidence Collected	6
Summary of Metallurgical Findings	6
Pre-Fire Activities	7
Time Line of Fire Event	9
Potential Fire Scenarios Reviewed and Eliminated	10
Consensus Fire Scenario	13
Response of Plant Personnel	14
Response by Fire Department	15
General Fire Safety Recommendations	16
Opinion and Conclusion	17
New York City Fire Department Incident Report	Exhibit “A”
Digital Photographs with Descriptions	

NORTH RIVER WASTEWATER TREATMENT PLANT
725 WEST 135TH STREET
NEW YORK, NEW YORK

In accordance with instructions from **Black and Veatch** on **Monday, July 25, 2011** at approximately **9:55 a.m.**, this firm conducted joint fire scene examinations and interviews at **North River Wastewater Treatment Plant** with **Black and Veatch** on **Tuesday, July 26, 2011, Wednesday, July 27, 2011 and Thursday, July 28, 2011.** Follow-up examinations were conducted on the following dates:

Thursday, August 11, 2011
Monday, August 15, 2011
Thursday, September 1, 2011
Tuesday, September 13, 2011

The purpose of these onsite examinations and interviews was to ascertain the origin and/or cause of a fire which occurred at the aforementioned address on **Wednesday, July 20, 2011.**

This examination was conducted with the prior consent of **Kathryn Mallon, Deputy Commissioner, NYC Department of Environmental Protection (DEP)** and in the presence of **Patrick O'Connor, Director of In-House Design, DEP.** During the course of our examinations, several engine parts, pieces of material and mechanisms were identified for further analysis. These items were extracted on the following dates:

Thursday, July 28, 2011
Monday, August 15, 2011
Thursday, September 1, 2011
Wednesday, September 21, 2011

The items were collected as evidence and taken to **Affiliated Engineering Laboratories, Inc.'s** secure laboratory facility in Edison, New Jersey for metallurgic analysis and testing. Each item of evidence was photographed and labeled in accordance with standard evidence collection procedures. At the request of the DEP, some pieces were returned to the plant for re-use on **Thursday, September 29, 2011**. (Please refer to the evidence list contained within this report).

SURROUNDING PROPERTIES

To the North	:	parkland
To the South	:	West 135th Street
To the East	:	Westside Highway superstructure and access roadway

To the West : Hudson River

EXTERIOR EXAMINATION

Exterior examination revealed a large, masonry and concrete wastewater treatment plant approximately 90' tall (above sea level) designed with architectural archways and encompassing 27 acres with a park on the roof. In the southeast quadrant of the plant were the plant stacks and the primary means of access was on the north side of the plant via a gate and enclosed stairwell. Access for trucks was via a covered roadway along the north and east sides of the plant and access to the rooftop park was via an elevated road and walkway.

NOTE: This plant was partially constructed over the Hudson River and construction was completed in 1985. We were advised that the plant was one of 14 wastewater treatment plants that serve New York City and this was the first known fire incident involving an engine at the plant.

INTERIOR EXAMINATION

Interior examination revealed that the plant contained several waste water processing areas, including the primary settling tanks, aeration and secondary treatment tanks and sludge facilities. Effluent passes through the facility by means of five rotary sewer pumps driven by five, six-cylinder, right angle drive engines located on the engine room floor (aka + 28). Directly below the engine floor is the utility floor (aka +5) containing electrical conduits and the lube oil tanks. Below that level is the venturi floor (aka -15 floor) containing the waste oil tanks and pumps. Below the venturi floor is the pump room floor (aka - 43 floor). The evidence of fire damage was observed on the top three floors (engine, utility and venturi floors) with the greatest volume of fire on the engine floor.

Passing through the north gate provides entry to the northeast stairwell affording access to the top floor of the plant and top floor roadway. A garage door from the roadway provides access to the engine room floor (Photograph No. 5) and on the north side of the top floor are the lobby, administrative offices and the control room. To the south is the engine floor which houses the five 1,700 horsepower, fuel injected, main sewer pump (msp) engines on the east side and five air circulating blowers on the west side. The aforementioned pump engines were diesel/flex fuel manufactured by Delaval / Enterprise. These msp engines are able to operate on a combination of 90% digester gas and 10% diesel (#2 diesel) and pump an average of 100,000,000 gallons of waste water per day. At times when there is normal demand, the procedure is to run two msp engines and keep the others in reserve. Diesel fuel is supplied to the engines by remote fuel transfer pumps located on the utility floor at a rate of approximately 12 gallons per minute each. Procedures

specify that operators start the engines on 100% diesel fuel and then switch over to the fuel combination once running. Similarly, the engines are switched to all diesel when they are shut down. All msp engines came on line in 1986. It was described as a robust engine that had been running properly.

NOTE: The manufacturer, DeLaval / Enterprise, is no longer in business and replacement parts for the engines are purchased from Cooper Cameron Energy who retain the original drawings and machine replacement parts to those specifications. We were advised that there are no material substitutions unless substitution improves upon the part; i.e. there are no material downgrades.

A fuel metering system was installed for each engine in mid 1996 by an outside contractor under contract 31P. The metering system was installed to monitor diesel fuel usage and consisted of .5" pipe with elbow joints and valves. The metering plumbing was mounted close to floor level on the east side of each engine below the turbocharger and was supported at floor level only. The .5" piping contained right angle joints and extended vertically from its header approximately 3' above floor level (Photograph No. 51). During our scene examination, we observed noticeable vibration to the metering system piping on engine # 4 while in use. We were advised that the metering valves do not have to be turned on or off when the engine is shut down or started up but rather work independently when usage readings are desired. We were also informed that the valves could be turned easily by hand and did not require a wrench or excessive pressure to turn. Metallurgic testing disclosed that the valves on msp engine #1 were manufactured by a different manufacturer than those found on other engines. Fuel pressure within the metering lines was 55 psi.

AREA OF FIRE ORIGIN

Our scene examination revealed that the main body of fire was in the region of the #1 msp engine on the northeast quadrant of the engine floor. The fire area extended vertically to the insulated steel "I" beam and concrete roof structure approximately 30' feet above floor level and extended horizontally across the floor east and west of msp engine #1. While the insulation protected the above mentioned "I" beam, we observed deflection of an un-insulated steel "I" beam at ceiling level above msp engine # 1 and spalling of the concrete ceiling above engine #1's turbocharger and exhaust piping (Photograph No. 8). The latter resulted in pieces of concrete falling down onto engine #1 and surrounding piping, apparatus and floor. The area of greatest damage and highest heat intensity was on the east side of msp engine #1 in and around the turbocharger and exhaust piping.

The evidence of extensive heat damage was also observed to the east side and southeast corner of the engine beginning at floor level as well as the control panel and combustion air intake duct (approximately 11’) to the east of the #1 engine. Heat damage in this area is consistent with a floor level fuel oil fire traveling to the floor drain on the south side of msp engine #1. Notwithstanding, damage appeared to be greatest at upper areas where the turbocharger and (aluminum constructed) inlet bell were connected to the combustion air intake duct above the engine block. Intense heat deformation was observed to the insulation on the exhaust piping in the area of the turbocharger and inlet bell housing as well as an un-insulated steel "I" beam to the east and above of the turbocharger. Intense heat was also observed to the west of the turbocharger where the governor and selectomatic valves were mounted (Photograph No. 21) and the #1 cylinder's valve cover whose housing (Photograph No. 22) melted. This area was in alignment with the melted inlet bell.

Finding intense heat in this area led us to inspect the area closely for potential fuel sources. Two potential fuel sources were found, a braided flexible connector and a high pressure fuel injector line. Both were removed and sent for analysis at Affiliated Engineering Laboratories, Inc.

The braided flexible connector (Photograph No. 23) could not be pressure tested because its internal elastomeric liner was destroyed by the fire. Visual inspection showed that there was no indication of a puncture to the outer sheath or damaged threads. However, there was an area of significant narrowing (Photograph No. 24). The DEP had no record of the age of this flexible connector, though it would degrade over time due to age and exposure to elevated temperature, owing to its position on top of the engine and below the turbocharger. This could have resulted in cracking and/or failure of the inner liner resulting in the release of diesel fuel.

Inspection of the high pressure fuel injector line under electron microscope revealed an anomaly on one of the tapered fitting ends where there appeared to be corrosion and erosion forming a small channel (Photograph No. 28). Though invisible to the naked eye, such a channel could have resulted in the release of a fine mist of atomized diesel fuel whose spray could have encompassed the aforementioned components and reached the hot turbocharger surface. Based on this laboratory finding, we believe that this may also have been the source of the initial fuel of ignition.

After analysis, we have determined that the inlet bell melted during the fire event where a quantity of melted aluminum from the inlet bell was observed beneath its location on the pipes (Photograph No. 42) and floor below (east side of #1 engine). In addition, splattered pieces of aluminum (approximate melting temperature – 1,218^{o} F) were found on the top of the engine and on the floor some 30' away (Photograph No. 62). Metallurgic

analysis indicates that aluminum pieces found on the floor had a different chemical composition than melted aluminum deposits found beneath the inlet bell. It should be noted that a partial cleanup of the area of fire origin by a fire restoration company was conducted preceding our scene examination. As a result, the inlet bell housing's transition section was discarded prior to our site visit and was unavailable for inspection. However, our consultation with the NYC Fire Marshal's Office revealed that it was examined immediately after the fire on the floor to the east of the #1 engine, intact. They provided us with a photograph (see Photograph No. 35).

Based on the pronounced heat damage in the upper region of engine #1's east end, we have concluded that the fire originated in the vicinity of the turbocharger, exhaust piping and inlet bell housing through which inflowing combustion air enters the turbocharger. Examination of the interior of the turbocharger (air inlet side) revealed the presence of residue on the blades (Photograph No. 38) and what appeared to be melted aluminum. Samples of both were extracted for analysis primarily to determine the chemical composition of the residue and the source of the aluminum. After laboratory analysis, it was determined that the residue was chemically consistent with diesel fuel and the aluminum sample was the same chemical composition as the aluminum found on the pipe directly below the inlet bell housing. Based on this finding, we believe that as the inlet bell housing melted, fuel spray entered and deposited on the intake side of the turbocharger blade. Sources of fuel include the high pressure fuel injector line, the braided fuel line located below the governor and the metering line valve. Atomized diesel fuel from any of these components could have been the source of the deposit once the aluminum constructed inlet bell melted.

Physical examination of the area of origin also uncovered a break in the metering return line shut-off valve located just above the fuel supply header on the east side of the #1 engine (see Photograph Nos. 43 - 51). This piping carried #2 diesel fuel under pressure. A 4" section of pipe attached to the fractured valve body was collected as evidence and taken along with the metering piping and valves for metallurgical analysis where it was determined that the pipe was low carbon alloyed steel and the valve was brass. No weld or epoxy was found at the connection. It was learned through interviews that the diesel fuel pressure in the return pipe ranged between 55 psi and 70 psi. Such pressure could allow diesel fuel to escape the pipe in both a horizontal and vertical direction and depending on the proximity and angle of the broken halves could form a pressurized stream of semi-atomized diesel droplets. Black and Veatch did an analysis of the potential discharge height and horizontal reach of such a stream of fuel escaping the pipe. Please refer to their report for further details (sent under separate cover). As will be discussed in detail later in this report, we believe this failure occurred during the fire event and served to intensify the fire condition but was not the initiating cause of the fire.

During the course of our scene examination, we took surface temperature readings at several locations on engine #5 while in operation. Based on those readings, we determined that the hottest surface was the exterior turbocharger housing where we received readings of 402-415° F. (see Photograph No. 41). Documents provided by the DEP indicate that the interior turbocharger temperature can reach 900° - 1,000° F. All the aforementioned temperatures are sufficient to ignite atomized #2 diesel fuel vapors whose flashpoint is 126° F - 204° F and ignition temperature range is 351° - 494° F[1] depending on conditions. On the day of the fire New York was experiencing a heat wave with temperatures in the 90's and high humidity.

EVIDENCE COLLECTED

During the course of our analysis, various components and pieces of equipment were removed from the North River Plant for laboratory and/or metallurgical analysis. All evidence was brought to Affiliated Engineering Laboratories, Inc. in Edison, New Jersey. These items included:

1.	Diesel return line nipple - #1 engine
2.	Diesel fuel shut-off valve - #3 engine (exemplar)
3.	Diesel fuel shut-off valve - #3 engine (exemplar)
4 a, b, c	Diesel return line piping and valves #1 engine
5.	Lube oil drain pipe from turbocharger - #1 engine
6.	Scrapings from turbocharger blade
7.	Combustion air filter
8.	Turbocharger flange bolts
9.	Turbocharger internal bolts
10.	Melted aluminum found in turbocharger
11.	Melted aluminum found below turbocharger
12.	Debris found in turbocharger
13.	Melted aluminum on floor 30’ NW of turbocharger
14.	Diesel fuel shut-off valves from engines #2, #3 and #5 (exemplar)
15.	Injector fuel line and braided fuel line from engine #1
16.	Fuel pump and fuel injector from engine #1
17.	Three flexible connectors as exemplars

NOTE: At the request of AETC, the contractor repairing engine #1, Item 16 was returned to the plant on 9/29/11. All other pieces of evidence remain at Affiliated Engineering Laboratories, Inc.

SUMMARY OF METALLURGICAL FINDINGS

A review of the metallurgical findings of Affiliated Labs (reviewed and verified by Black and Veatch metallurgists) revealed the following:

a) No fractures or cracks were observed on bolts attached to the air intake side of the turbocharger.

b) Black oxide and soot deposits on the surface of the cracked metering valves indicate that they failed at some point during the fire event.

c) The fracture surface of the metering valves exhibited grain growth as the result of heat exposure.

d) The fracture mode is consistent with a brittle fracture, not metal fatigue or vibration.

e) The cause of a brittle fracture is most probably liquid metal embrittlement, the result of molten aluminum dripping onto and penetrating into the valves.

f) Such embrittlement can occur instantaneously, resulting in rapid fracturing of the embrittled valve.

g) Laboratory analysis of residue on the south facing turbocharger blade was shown to be consistent with a diesel fuel deposit

h) The flexible connector (braided fuel line) showed a marked decrease in diameter to the outer sheath at the approximate midpoint, however the inner liner was destroyed in the fire and could not be examined for a failure point.

i) Corrosion and material losses were observed by microscope at the tips of both ends of the high pressure fuel injector line as well as within the mating contact surfaces of both the male (pressure line) and female (pump and injector) ends. The tip attached to the fuel pump also exhibited signs of erosion consistent of a high pressure jet escaping at that point.

j) The presence of a broken thread was found on the connection between the fuel pump and the fuel injector line. Such breakage could occur as the result of over tightening in an attempt to control a leak.

NOTE: We were advised that there are no torque standards for that connection.

Metallurgist's conclusion: Given the condition of the contact surfaces of the seal within the fitting and the relatively high pressure (3000 psi), it is **MOST** probable that a diesel fuel leak did occur at that location.

PRE-FIRE ACTIVITIES

Interviews were conducted with over a dozen DEP employees who provided us with logs and narrative accounts of the activities on the engine room floor the morning the fire occurred. Based on the information they provided, we have learned that engines #1 and #4 were running at the time of the fire. Engine #1 was operating on a combination of digester gas and diesel fuel and engine #4 was operating on diesel fuel only. Engines #2 and #5 were not in use and engine #3 was down for a maintenance project (the machinists were installing a connecting rod and cylinder). Blowers #1, #3 and #5 were in operation on the west side of the engine room floor fueled by a combination of digester gas and diesel. Two workers were cleaning the engine room floor on the north side of the plant with a power washer. Their proximity to engine #1 that morning is not known. However, it was pointed out that the Zamboni® floor cleaner was not in use that morning due to charging problems.

Stationary engineers were doing preventative maintenance on the blower engines on the west side of the engine floor and oilers were monitoring the engines periodically. The times given by the employees relative to when they left the engine room floor were approximate. However, lunch hour for the working shift began at 11:00 a.m.

We were advised that msp engine #1 runs on a combination of digester gas and diesel but not natural gas because natural gas makes it knock. According to the log provided, engine #1 cut out (shut down) by itself at approx. 9:26 a.m. due to low fuel pressure, as indicated by an alarm in the control room and at the local control panel. The assigned operations oiler restarted it and brought it up to speed; but when he attempted to load it, it cut out again. It was at this point that the operations oiler noticed fuel oil spraying from the dual canister fuel filter on the north side of the engine, specifically, fuel was spraying horizontally out of the left side of the canister fuel filter. The fuel pressure going into the canister was estimated to be 42 - 44 psi. The canister was temporarily switched to the right side to stop the fuel spray. After fabricating a new gasket "O" ring for the fuel filter, reinstalling the left side canister and tightening it into place, engine #1 was restarted at approximately 11:03 a.m. following normal start-up procedures. We were advised that start-up customarily takes approximately three minutes. After shutting down msp engine #5 and adjusting the rpm on #4, (approx. four - five minutes), the operations oiler returned to engine #1 where he rechecked the lube oil sump and canister fuel filter. No leaks were observed at the filter at that time. Cylinder, oil and water jacket temperature readings were within normal ranges and the operations oiler placed the engine in combination mode (digester gas and diesel fuel) and continued monitoring. Nothing out of the ordinary was noticed, no leaks, odors, sprays or squealing sounds were detected. We were advised that the oilers did not ascend the ladder that provides access to the top of the engine that morning, but focused only on

floor level operations. This would have inhibited the oiler's ability to detect a problem on the upper portion of the engine.

After approximately 10-12 minutes of monitoring engine #1, the operations oiler reported to the control room where he informed the control room engineer of what was done. The operations oiler recalled that he was in the control room for several minutes before he heard and felt an explosion. He reported that no alarm sounded in the control room prior to the explosion indicating an engine shut down nor was there a wet well alarm. After the explosion, the operations oiler attempted to go out on the engine floor to see what the matter was but encountered a wall of thick black smoke coming towards him and retreated to the control room. Our interview with the control room stationary engineer also indicates that an explosion was heard and felt in the control room prior to an engine shutdown signal. The control room engineer recalled that he was monitoring engines #1 and #4 and both appeared to be running normally on the computer. He noted that the only trouble alarm showing on the control room panel was from engine #3 which was down for repairs and there was no trouble alarm for msp engine #1.

NOTE: Based on employee information, msp engine #1 was in use and appeared to be operating properly at the time of the explosion. The Engine Trend List provided to us indicates that engine #1's rpms dropped to "0" at approximately 11:35 a.m. several minutes prior to the explosion. Automatic shut downs can occur for several reasons. This shutdown most likely coincided with the fire event, specifically the embrittlement and failure of the metering valve. Engine #4 continued to operate until 11:47 a.m. when it was shut down from the control room.

Our interviews indicate that no workers were on the engine room floor immediately prior to or during the event because it was lunch time. Only one employee saw the fire area and that was immediately after the explosion. From a vantage point on the north side of the engine room floor, he peered through the hallway door for a split second. He described pockets of orange flames both large and small everywhere on the floor. The employee was not sure if flames reached the ceiling at that time, but he did **not** recall seeing any blue flames (indicative of a methane gas fire).

TIME LINE OF FIRE EVENT

The plant supervisor provided our team with a surveillance video from a camera mounted at ceiling level outside the plant on the upper roadway. The aforementioned camera was facing south and displayed the open garage door leading to the engine floor. A second camera was directed on the northeast exit door.

11:00 a.m.	Lunch hour begins, gasket on msp engine #1 fuel filter replaced
11:03 a.m.	MSP Engine #1 restarted
11:10 a.m.	MSP Engine #5 shut down (trend list)
11:22 a.m.	Operations oiler returned to control room (time approximate)
11:35 a.m.	MSP Engine #1 shut down (trend list)
11:42 a.m.	Wisps of smoke (barely visible) can be seen from top of the garage door bay
11:43 a.m.	Steady stream of smoke from the top of doorway
11:45 a.m.	Explosion blows smoke out of doorway and onto roadway – smoke level lowers
11:46 a.m.	"911" call received at NYC fire dispatch center
11:47 a.m.	MSP Engine #4 shut down (trend list)
11:48 a.m.	Smoke is thicker and banking down - plant supervisor views smoke from roadway and runs back inside to sound alarm and hit E stops
11:49 a.m.	The first workers are seen exiting plant from exit door (second camera)
11:50 a.m.	Smoke visible at northeast exit door (second camera)
01:30 p.m.	Power shut down to plant by DEP (approximate time per NYPA load data)

NOTE: As mentioned above, control room records show that engine #1 shut down at approximately 11:35 a.m. It should be noted that the control room trend list is not necessarily in sync with the clock on the surveillance camera and since the plant lost power for an extended period of time, it is not possible determine the time differential with certainty. It should also be noted that there was an undetermined time delay from when the fire initially started until it became visible to the camera while smoke migrated approximately 150' to doorway.

POTENTIAL FIRE SCENARIOS REVIEWED AND ELIMINATED

When conducting a fire cause analysis, it is essential to objectively consider all possible fire causes and evaluate each in light of the potential fuel and ignition sources present in the area of fire origin. In order for a fire to occur, a fuel source, whether liquid, solid or vapor, must come into contact with a competent ignition source for a sufficient amount of time to raise the fuel to its ignition temperature. Potential fuel sources at the North River Plant comprised diesel fuel, natural gas, digester gas and lubricating oil. Competent sources of ignition included the interior and exterior of the turbocharger and exhaust manifold as well as electrical circuitry in and around msp engine #1 and its control panel.

During the course of our inquiry into the fire cause, engineers from Black and Veatch reviewed potential fire scenarios with Russo Consultants. At the same time metallurgists from Affiliated Engineering Laboratories, Inc. conducted tests on evidence brought to them from the plant. Based on these findings and our ongoing analysis, potential fire scenarios were developed, reviewed and either ruled in or out.

1. In the first scenario, we considered the possibility of a backfire of exhaust gases within the turbocharger due to a procedural failure to "blow out" or purge the engine exhaust system. This scenario was considered and eliminated as a potential source of the fire and explosion due to the absence of any fire damage in or around the waste recovery boiler, expansion bellows or damage to the turbocharger outlet elbow. Moreover, such a backfire is internal and not known to cause a fire externally. In addition, there is no physical evidence to support a conclusion that the concussion from an explosion forced breakage of any piping or components that released an ignitable fuel. Examination of the interior of the turbocharger showed no indication of deflection or fracture to the turbocharger blades or other internal components that would have been damaged by an explosion.

2. Backfires and explosions can occur in turbochargers when an ignitable liquid (fuel oil, lubricating oil, etc.) comes into contact with the hot interior surface of the turbocharger in just the right fuel/air mixture. Therefore we considered the possibility that pressurized, preheated lubricating oil escaped from a faulty bearing within the turbocharger and ignited when it came into contact with 900+° F turbocharger parts and exhaust gases within the turbocharger causing a fire that lead to an explosion and melting of the aluminum inlet bell from within.

Often turbocharger failures are preceded by a squealing sound. After the turbocharger was lowered by crane and disassembled, the interior of the exhaust side was made available for inspection on Sept. 8, 2011. That inspection revealed the absence of any evidence of an internal break down, seal failure or backfire. There was no melting, heat deflection or fracturing of internal parts nor was there any oily residue from a failed seal or lubricating oil leak observed by Black and Veatch or Vroney, the repair contractor. On the exterior, there was no significant damage to the turbocharger's expansion bellows or heat recovery boiler. Moreover, the separation plate within the turbocharger would have prevented fire spread to the inlet bell housing. Therefore, we have eliminated an internal turbocharger failure as a potential fire cause.

3. We also considered that a brass valve on the east side of engine #1, close to floor level, in the metering return line failed as the result of impact, over tightening, long term vibration, stress or metal fatigue resulting in the release of diesel fuel under pressure. In this scenario, vibration at the fracture point would have directed escaping fuel in both a vertical and horizontal direction as the two halves offset and continued to vibrate. Combustible fumes and droplets emitted by diesel fuel spraying from the broken valve could then have come into contact with the hot turbocharger housing serving as the source of ignition. This scenario was initially considered carefully as the most likely cause. However, after metallurgical analysis by Affiliated Engineering Laboratories, Inc., it was determined that the failure was **not** due to metal fatigue, etc. but rather liquid metal embrittlement which occurred after the fire started, not before. The embrittlement finding negated the possibility of a progressive failure mode as would be expected if the failure was due to impact, vibration or fatigue. Further, the metering piping and valves are essentially protected from physical damage by piping and engine accessories from all directions as well as top and bottom. Employees informed us that the valves were easy to turn and did not require excessive torque or a wrench. Although the valve clearly fractured and released diesel fuel that created a secondary fire at floor level, it failed after the fire started and was not the initial cause of the fire.

4. An electric arc or short circuit on the control panel ignited combustible fumes. This potential source of ignition was eliminated based on the physical examination conducted by Black and Veatch, Electrical Engineers, who found no physical

evidence of an electrical fault or failure at the control panel or any nearby electrical circuits, wiring or fixtures.

5. A methane or digester gas explosion at the block and vent valve. Although these gases are ignitable, their ignition temperatures are higher than potential sources of ignition in and around the #1 msp engine[2] prior to the fire. In addition, this valve was not vented to the atmosphere and therefore only a limited amount of gas in the valve and riser could have released. Moreover, there was a fire prior to an explosion as indicated by surveillance video. Therefore, we have determined that the damage to the block and vent valve illustrated in Photograph No. 36 occurred as a result of the fire, which heated the valve and was not the cause of the fire.

6. A leak spraying from the duplex fuel filter mounted on the north side of the engine block. A vertical plume of diesel fuel reaching the exhaust manifold could readily ignite and start a fire on the north side of the engine. Employees had discovered a leak at this filter earlier that morning and had replaced a gasket shortly before the engine was restarted. Nonetheless, there are no burn or heat patterns on the north side of the engine in proximity to the duplex fuel filter. In addition, the construction of the fuel filter cap inhibits vertical spray. Although the duplex fuel filter does provide a source of fuel below the exhaust manifold, we do not feel this is a likely fire cause scenario.

7. An intentional act of sabotage. Based on our discussions with plant personnel and after consultation with the NYC Fire Marshals' Office, we see no evidence that indicates an intentionally set fire. Accordingly, we have eliminated incendiary as a potential cause for this fire.

8. We also considered the possibility that the fire resulted from an internal failure of the engine. However, engineers in the process of tearing down the #1 msp engine have found no signs of any damage internally to the engine or its components at this time. The #1 piston was pulled and measurements have been taken which show that it is in undamaged condition according to Vroney engineers. The covers were pulled to expose the other cylinders and no damage has been found there either. There was no erosion of the piston crown or evidence of exhaust gases mixing with lubrication or piston cooling oil. With no observed internal damage, we have ruled out the

possibility of a fire starting due to overheating or an internal engine explosion.

CONSENSUS FIRE SCENARIO

After extensive review and discussion, the members of the Black and Veatch engineering team along with Russo Consultants have concluded that the following is the most plausible fire development scenario.

Fire Scenario: Either the braided flexible fuel line (aka flexible connector) below the turbocharger failed or the high pressure fuel injector line west the turbocharger on msp engine #1 (supplying fuel to the # 1 cylinder) loosened or failed at its connection to the fuel pump. Fuel escaping under high pressure (3,000 psi) expelled droplets onto the valve cover, governor, selectomatic valve and turbocharger. When these atomized droplets contacted the turbocharger surface, a fire ignited on the turbocharger and top of the engine (east end) causing the aluminum inlet bell housing to melt. Dripping aluminum coated the surface of the brass metering valves located below. The hot aluminum caused rapid embrittlement of the valve castings. This caused one of the valves to crack and one to fracture completely and separate. This fracture resulted in the release of diesel fuel from the metering return line. The release triggered a low fuel pressure shut down of the #1 engine at 11:35 a.m. (trend list) while the fire continued to burn in and around the turbocharger. Diesel fuel continued to pump from the fractured metering valve at floor level and a growing pool of diesel fuel accumulated on the floor in the ensuing minutes. Molten aluminum with a surface temperature of over 1,200° F continued to drip from the inlet bell housing onto the growing pool of diesel fuel resulting in the explosive ignition of diesel fuel vapors and causing a second and larger fire at floor level at 11:45 a.m. (camera). Flames from the burning fuel oil on the floor's surface impacted the nearby rubber bellows for the lube oil supply line causing it to fail and add additional combustible liquid fuel to the fire. Similarly, flames impinged on the flexible fuel line attached to the turbocharger lube oil drain and it too released additional lube oil into the flame zone. Heat from the floor level fire also impacted the block and vent valve which, in turn, also failed eventually.

As the fire developed, the diesel and fuel oil pumps continued to operate until the plant's power was shut down, increasing the size of the burning combustible liquid puddle which eventually spread to the floor grate at the southeast corner of the #1 engine. From there, it flowed down through floor openings to the auxiliary floor (aka + 5 floor) spreading fire to cables and conduit close to ceiling level. The sewage line gaskets for msp engine #1 on this level were also destroyed by flowing combustible liquid fire. As diesel and lube oil continued to flow, it pooled on the auxiliary level floor, flowed to and through a floor grate and again dropped down, this time to the venturi level (aka - 15 floor) causing the waste oil reservoir to ignite.

RESPONSE OF PLANT PERSONNEL

On Wednesday, July 20, 2011 there were 88 individuals working at the North River Wastewater Treatment Plant[3]. The fire and explosion occurred during lunch hour when there were no plant employees on the engine floor. This prevented immediate injuries and precluded a hazardous rescue situation. Based on the information provided by plant employees during their interviews, all employees were either in the offices, lunch rooms, parts department, machine shop or the control room when the fire occurred. Most employees either felt or heard the explosion. Some described the sound as a "whoosh"; others as a "boom" like a container was being dropped; others felt the building shake while still others noticed nothing until they heard the alarm signal and/or evacuation order come over the loud speaker.

The evacuation alarm was sounded immediately followed by a voice notification over the loud speaker from the plant supervisor advising all plant personnel to evacuate immediately followed by the statement "this is not a drill." Existing evacuation plans were followed and all plant employees exited the building expeditiously. Supervisors led their personnel to the exterior and conducted head counts to ascertain that all personnel were accounted for, as practiced during quarterly evacuation drills. One area of concern was smoke travel. Several employees reported that smoke entered these exit pathways quickly, diminished visibility and made it difficult to breathe. Moreover, personnel operating in the control room encountered rapidly increasing smoke levels that eventually rendered it untenable to remain there.

During the early stages of the event, certain employees took initiative to activate the alarm, shut off "E-Stop" buttons, shut down digester gas compressors, shut off the natural gas supply to the plant, contact Con Edison to shut off feeder cables (they eventually shut off the electrical service themselves) and activate the zinc burner to light off the waste gas flares. Four employees attempted to enter the engine room to assess the problem but were met with a thick wall of black smoke and had to retreat. One employee called “911” from the control room. One factor that allowed the fire to develop was the inability to cut off the fuel and lubricating oil supply from the control room. We were told that in spite of pressing the emergency stop buttons, these (fuel and lubricating oil) systems continued to operate. In addition, the natural gas, electrical feeder cables and digester gas lines had to be shut off from outside of the plant not from the control room. The delay in shutting off these systems allowed the continued release of diesel fuel and lubricating oil onto the fire until power was shut down to the plant at approximately 1:30 PM. During this time period, some 3,000 gallons of additional diesel fuel may have flowed onto the fire (assuming a rate of 24 gpm). Though the plant supervisor followed the emergency action plan (EAP), there was no fire safety

director nor is there an automatic central station fire alarm. This firm would suggest that a comprehensive fire plan include an enhanced central station automatic alarm system and that an individual be trained to function as a fire safety director for the plant.

RESPONSE BY FIRE DEPARTMENT

Dispatch records show that the New York City Fire Department received a "911" call from the North River Wastewater Treatment Plant reporting a fire at 11:46 a.m. Initial fire suppression operations were conducted under the command of Battalion Chief Sessa of the 16th Battalion. Due to the heavy smoke condition, fire suppression operations began with a search of the plant using life lines to locate the fire which was found on three levels of the plant. Initial size-up uncovered a fuel oil fire. According to Chief Sessa, fire suppression efforts required the use of foam both on the utility level where they encountered flaming fuel oil dropping down from the engine floor and on the engine floor where they encountered the main body of fire.

Foam is customarily utilized in the suppression and extinguishment of flammable liquid fires. After the fire was darkened down on these two levels, fire was found on the venturi level in the waste oil tank. The fire was brought under control at approximately 3:02 p.m. and the Fire Department remained on the scene until after 9:00 p.m.

GENERAL FIRE SAFETY RECOMMENDATIONS

The North River Wastewater Treatment Plant is constructed of steel reinforced concrete and contains steel/metal constructed machinery. The primary fire hazards at this facility are associated with an ignitable liquid or explosive gas release. Such fires are subject to rapid development. The following recommendations are made to enhance fire safety at the plant:

a) Consider appointing and training a fire safety director for the plant

b) Consider installing an automatic central station fire alarm system with enhanced electronic monitoring (heat and smoke detectors, additional surveillance cameras, etc.)

c) The installation of smoke control devices such as self-closing fire doors could be designed into the plant to prevent smoke entry into areas of fire egress and pathways of exit travel.

d) Consider redesigning the control room to be smoke tight and fire resistant for one hour in accordance with standards for Type 1 (fire resistive) construction so that supervisory personnel can work there

safely in the event of an emergency. This recommendation is not meant to circumvent the EAP or suggest that personnel put themselves at risk by remaining inside for extended periods, but to provide enhanced safety while notifications are being made and systems are being shut down.

e) Add an emergency cut-off for ventilation and HVAC system to the control room

f) Add emergency cut-offs for digester gas, lube and fuel oil pumps to control room

g) Conduct a study to identify all hot engine surfaces with thermal imaging cameras and develop shielding wherever temperatures exceed fuel ignition temperatures

h) A comprehensive fire emergency plan could be incorporated into the EAP that encompasses notification, shutdown and isolation procedures

i) Install a fire suppression system over the day tank and waste oil reservoir. Should DEP wish to review fire safety conditions beyond these recommendations, an architectural review by a fire protection design consultant would be advantageous.

****

OPINION AND CONCLUSION

After having reviewed all data gathered to date, which encompassed our scene examination, information provided by plant employees, conferral with Black and Veatch engineers, review of metallurgical data, and after having considered and eliminated the above listed potential fire scenarios, to date we have ascertained the following:

1. Our examination disclosed that the msp engines at the North River Wastewater Treatment Plant are turbocharger enhanced ship engines. A review of literature pertaining to ship engine room fires shows that 56% of all ship engine room fires are caused by oil leakage onto a hot surface[4]. In general terms, we believe that is essentially the cause of the fire at the North River Plant as well.

2. On July 20, 2011, a fire followed by an explosion occurred at the North River Wastewater Treatment facility. A review of the surveillance video showed smoke exiting the engine room

doorway approximately two minutes prior to the explosion. Following the explosion, there was a rapid increase in the amount of smoke generated. Based on this observation, we have concluded that a smoke producing fire originated on the exterior of msp engine #1 preceding the explosion. Fire was intensified, not initiated, by the explosion. Had the fire been caused by a natural gas or digester gas explosion, etc., we would not expect to see smoke showing prior to the explosion. Fire development, as indicated by surveillance video, is consistent with an ignitable liquid release. This fire may have developed for several minutes before smoke migrated to the garage door, approximately 150 feet northeast of msp engine #1 where it was picked up by the camera.

3. No employees were on the engine room floor at the time to witness the fire and there were no surveillance cameras mounted there. Having no eyewitness accounts describing the early stages of fire development, we have based our findings on heat patterns, physical evidence and likely failure points. However, because fire destroys evidence, the absence of eyewitness accounts reduces the degree of certainty in our findings to the levels of probability.

4. Physical examination revealed the greatest heat damage occurred at the east and southeast quadrants of the #1 engine with comparatively greater heat damage to the upper region. Based on the pronounced heat damage in the upper region of engine #1's east end, we believe that the fire originated in the vicinity of the turbocharger, exhaust piping, inlet bell in proximity to and east of the cylinder #1 and that the turbocharger provided the source of ignition.

   Heat measurements taken on the exterior of the #5 turbocharger while in use show that its surface temperature is hot enough to ignite atomized diesel vapors but not methane or digester gas. Two potential sources of readily ignitable diesel fuel in proximity to the turbocharger are the high pressure fuel injector line and the braided flexible fuel line (aka flex connector). The injector line was located in proximity to the governor and selectomatic valve adjacent to the melted valve cover (Photograph No. 22) and approximately 53” from the turbocharger. A leak in the injector line could release a high pressure spray of atomized diesel fuel, up to 3,000 psi. The braided flexible fuel line was located below the turbocharger. If the braided flexible fuel line failed, it could have released a significant volume of fuel oil at a lower pressure (40-55 psi).

5. The braided flexible fuel line exhibited narrowing at a point along its length, but could not be pressure tested due to the extent of heat damage it sustained during the fire, which consumed its elastomeric inner liner. As such it could not be determined if it sustained a failure of the liner. On the other hand, laboratory analysis of the high pressure fuel injector line revealed evidence of corrosion and erosion on the conical tip that mated with the fuel pump (Photograph No. 28). According to Affiliated metallurgists, the erosion pattern is consistent with a high pressure spray passing over the surface of the tip. In addition, they observed thread damage to the connecting nut. This damage is discussed in more detail in the Black and Veatch report.

6. Maintenance records indicate that in June 2011, machinists did preventive maintenance to replace all the fuel injectors on the #1 engine. This would have required the unfastening and then refastening of fuel injector line fittings. There is no torque specification in the Engine O & M manual for the connecting nut over the tip at the fuel pump. Hence, it is possible that during the following month, the nut loosened, allowing a leak.

7. Given the high pressures involved, an atomized stream of diesel fuel spraying from either the flexible connector or the fuel injector tip, reached an ignition source on the surface of the turbocharger and ignited a fire in the upper region of the #1 engine that continued to be fueled by the diesel spray.

8. Heat from the fire impacted the aluminum constructed inlet bell housing causing it to melt. A significant quantity of melted aluminum from the inlet bell was observed beneath its location on the pipes below where the brass metering valves were located. When the melting aluminum from the inlet bell housing fell onto and coated the aforementioned metering valves, a liquid metal embrittlement process occurred resulting in the rapid and complete failure of the valve on the left (south) and subsequent release of diesel fuel at floor level. Spray from the failed valve discharging vertically could have reached the turbocharger and ignited. At the same time, aluminum continued to drip from the melting inlet bell housing. These aluminum drops were also hot enough to ignite the pool of diesel fuel at floor level causing a second and larger fire condition below.

9. The failure of the metering valve likely coincided with the 11:35 a.m. (trend list) shut down of engine #1 on the trend list. Both the operations engineer and the control room stationary engineer reported to us that there was no alarm in the control room prior to the explosion at 11:45 a.m. (camera). The most likely explanation for the absence of an engine shut down alarm is that the signal wires had already been damaged by fire precluding transmission of the signal to the control board.

10. Flames burning at floor level destroyed the rubber bellows of the lube oil supply riser resulting in the release of combustible lubricating oil that intensified the fire. Heat and flames also impinged on the digester gas riser causing the block and vent valve to fail releasing methane into the flame zone. Black and Veatch estimates that there was probably less than one cubic foot of digester gas in the piping leading to the block and vent valve when it blew. Such a limited amount of gas would not be enough to produce an explosion the magnitude of which we observed on the surveillance video.

11. The surveillance video shows an explosion at 11:45 a.m. that pushed a plume of black smoke out of the garage door. The only potential cause of this explosion is the ignition of the diesel fuel at floor level. We believe that the rapid ignition of the pool of diesel fuel on the floor resulted in the explosion seen on the surveillance video (Photograph No. 65).

12. Although the plant supervisor shut down all engines from the control room moments after the explosion, this action did not stop the fuel and lube oil pumps which continued to pump combustible liquid onto the fire. This additional fuel allowed the fire to grow and spread to other floors via floor drains and openings.

13. The burning combustible liquid puddle eventually spread to the floor grate at the southeast corner of the #1 engine from where it flowed down through floor openings to the auxiliary floor (+5) spreading fire to cables and conduit close to ceiling level. As burning diesel and lube oil continued to flow, it pooled on the auxiliary level floor, flowed to and through a floor grate on that level and again dropped down, this time to the venturi floor level, (-15) resulting in two fires there, including the ignition of the waste oil reservoir.

14. In summary, it is our consensus that the most probable cause of this fire is accidental, the result of diesel fuel escaping from a

fitting and coming into contact with a hot surface at the upper (east) section of msp engine # 1.

Although our file is in closed status, we remain ready to reactivate upon request from your office to render any further assistance you may require in your ongoing analysis of this case.

Respectfully submitted,

T. J. RUSSO CONSULTANTS, INC.

Douglas E. Leihbacher

Douglas E. Leihbacher, C.F.I.
Fire Investigator

DEL/cg
October 19, 2011

References:

1.hypertextbook.com/facts/2005/EileenTang.shtml
2.http://www.aristatek.com/newsletter/0606june/techspeak.aspx
3.According to "City Time" payroll records.
4.http://exchange.dnv.com/Documentation/Maritime/FireSafety/FIRE%20mappe%202.qxd.pdf

Fire Department New York
Incident Report

RECEIVED
SEP 01 2011
RUSSO CONSULTANTS

Incident

Incident #	1-0332-0
Status	Closed
Incident Date/Time	07/20/2011 11:46:42
Incident Type	111 - Building fire
Box#	1557
Address	725 W 135 ST Manhattan
Borough	1 - Manhattan
Action Taken1	11 - Extinguishment by fire service personnel
Rescued (civilians)	0
Evacuated (civilians)	0
Property Use	648 - Sanitation utility

Resources

Unit Responsible for Report: BC16

Unit Type	92 - Chief officer car
Action Taken1	81 - Incident command
Dispatch Date/Time	07/20/2011 11:46:53
Enroute Date/Time	07/20/2011 11:47:37
Cleared Date/Time	07/20/2011 21:11:18
Unit Report By	904213 - SESSA RAYMOND D. Battalion Chief
Narrative	Incident Narrative Incident number 07/20/2011-1-0332-0 On Wednesday, July 20, 2011 at 11:46 hours the following units were dispatched to a report of a building fire. The incident location is street address 725 W 135 ST Manhattan NY, 10027. Primary incident actions taken are as follows: Actions taken - extinguished The Times for Incident #07/20/2011-1-0332-0 are as follows: Signal: Time: By Order Of: 10-75 11:54 B-16 B.C. Sessa P.W.H. 14:31 Car 13B D.A.C. Woznica U.C. 15:02 Car 13B D.A.C. woznica Total Time of Incident - 10:24:06 Upon arrival Units operated as follows:

Unit Responsible for Report: BC16

BC16 .
Actions taken - incident command

E059 .
Actions taken - E-59 was third due on the 1st alarm at Box# 1557. Stood Fast until fire was located, proceeded to help stretch 12 lengths of 2/12 hose with E-69 and E-80 and put the1st line into operation. Relieved E-69 at the nozzle and operated that line until E-59 SCBA air was depleted.

E069 arrived at 14:16 hours and cleared at 16:31 hours.
Actions taken - Engine 69 stretched and operated initial hoseline which was 12 lengths 2 1/2" hose. Assisted by E-80 and E-59. Operated on the lower level of plant.

L040 did not arrive.
Actions taken -

E080 did not arrive.
Actions taken -

L028 .
Actions taken - L-28 arrived 1st due.L-28 was ordered to operate in conjunction with Squad-41 and conduct a search for the location of the fire. L-28 used it's search rope as well as Squad-41's in attempting to find the seat of the fire.After searching approximately 400 feet into the fire building,L-28 and Squad-41 had used up most of their breathing air and worked their way back out.L-28 then took a "blow." After a while,L -28 told "Command" that they were available if needed.L-28 eventually relieved L-30 as the "FAST" truck.Later, L-28 was ordered into the second floor to assist 2 members of E-58 who were experiencing symptons of heat exhaustion. L-28 was eventually relieved and ordered to return to quarters once the fire was brought under control.

MR01 arrived at 12:23 hours and cleared at 14:52 hours.
Actions taken - Stand by,ordered to take up

HB01 did not arrive.
Actions taken -

HM01 arrived at 12:13 hours and cleared at 16:48 hours.
Actions taken -

E037 did not arrive.
Actions taken -

E041 did not arrive.
Actions taken -

BC11 .
Actions taken - BN-11 responded as the all hands chief and operated with Rescue 1 to locate the fire on the 1st floor. E80 and E59 operated under the supervision of BN 11 to extinguish the fire on the first floor. E80 and E59 were relieved by E76 and E53 who continued to operate on the 1st floor.

Unit Responsible for Report: BC16

L030 .
Actions taken - Operated as Fast Truck.

E044 arrived at 12:14 hours and cleared at 16:20 hours.
Actions taken - Assigned on 10-75 as Haz Mat Tech Unit. Assigned by Haz Mat Bn to accompany DEP workers to electrical room for plant while they shut down electrical power t fuel pump. Reported back to Command Post that that had been accomplished. Took Members of Haz Mat Co 1 and Eng Co 44 to 2nd floor of plant, where condition of drums of diesel fuel was checked. Found 1 55 gal. barrel with elevated temperatures. Barrel was bulging and fumes were escaping barrel from bung hole. Consulted with Bn 48, and applied water to barrel to reduce temperature. After temperature was lowered, condition subsided. Informed Bn 2 and Haz Mat Bn of action taken. Ordered by Haz Mat Bn to take up.

DC06 arrived at 12:15 hours and cleared at 15:55 hours.
Actions taken - Incident Command

RS01 arrived at 14:30 hours and cleared at 14:32 hours.
Actions taken - Upon arrival, ordered by BN 16 to stand fast outside building. Interfaced with DEP personnel and reviewed floor plans. Located previous search rope and with knowledge taken from floor plans, located the route for handline advancement along with Sq 41. Assisted engine company with advancing 2 1/2 line to fire area. Made assessment of damaged piping and fire on 1st floor fire area and reported back to RB-1. Conducted survey and assessment of fire on upper level which contained fire in combustible stock and fire from over pressurized 55 gallon drum. This drum showed signs of deformity due to heat venting fire under pressure from 7/8" bung hole. Information relayed to Bn 16 and RB-01 and requested 2nd 2 1/2 line to this area.

Note: FF James R. Feeley (0415137) R-1 suffered minor injury to upper back while advancing 1st hose line.

E047
Actions taken - Engine 47 relieved E72 and operated with the hoseline on the exposure 3 side on the 2nd level. We operated till our Vibra Alerts went active and then exited the bldg.

TS01 arrived at 12:23 hours and cleared at 15:27 hours.
Actions taken -

ST02 did not arrive.
Actions taken -

SB01 arrived at 12:18 hours and cleared at 15:11 hours.
Actions taken -

RB01 arrived at 12:25 hours and cleared at 15:30 hours.
Actions taken -

RA01 .
Actions taken - Assist with R and R for members.

L043 arrived at 12:15 hours and cleared at 16:20 hours.

Unit Responsible for Report: BC16

Actions taken -

L017 arrived at 12:24 hours and cleared at 15:31 hours.
Actions taken - Ladder 17 operated with B-26 on 2nd floor of fire building. Ventilation and suppression support.

FC01 arrived at 12:53 hours and cleared at 15:43 hours.
Actions taken - FCU 1 reported to the command post and worked with the incident command to relay information back to the Manhattan dispatchers.

E076 arrived at 12:13 hours and cleared at 15:16 hours.
Actions taken - E-76 responded on 2nd alarm and stood fast until ordered to relieve E 80 on the 1st handline. E76 operated until relieved by E 74.

E072 arrived at 12:29 hours and cleared at 16:08 hours.
Actions taken - E-72 relieved E-69 on 2 1/2 foam line on second floor until relieved by E-47

E058 arrived at 12:18 hours and cleared at 15:06 hours.
Actions taken - Engine 58 responded 2nd due engine on the 2nd alarm. E-58 was ordered to stretch a 2nd line 2 1/2 to the 2nd floor. E-58 stretched 12 lengths of 2 1/2 and was backed up by E-60. E-58 operated the line on the 2nd floor extinguished the fire and cooled down 3 - 55 gallon drums. FF Donaghy , B/U and FF Flanagan nozzle were exhausted and dehydrated. They were assisted to the ambulance and transported to the hospital. E-58 was relieved by E-47 and E-72. E-58 returned to quarters.

BC10 arrived at 12:20 hours and cleared at 15:34 hours.
Actions taken - PERFORMED DUTIES OF RESOURCE UNIT LEADER. SUPERVISED FIELDCOMM UPON THEIR ARRIVAL.

BC26 arrived at 12:28 hours and cleared at 17:22 hours.
Actions taken - Responded on 2nd alarm as Safety Officer. Assisted with supervising operations on Second level-North end to extinguish fire on that level.

E095 arrived at 12:36 hours and cleared at 17:25 hours.
Actions taken -

F095 .
Actions taken - FO 95 supplied two foam lines into fire area

E009 arrived at 12:43 hours and cleared at 15:40 hours.
Actions taken -

ST01 arrived at 12:43 hours and cleared at 15:40 hours.
Actions taken -

E096 arrived at 12:44 hours and cleared at 16:30 hours.
Actions taken -

F096.
Actions taken - E96 reported to staging area & stood fast. Upon orders

Unit Responsible for Report: BC16

by B13, reported to command post to assist in taking up hose.

E325 did not arrive.
Actions taken -

FT01 did not arrive.
Actions taken -

E033 arrived at 12:43 hours and cleared at 15:18 hours.
Actions taken -

P229 did not arrive.
Actions taken - take action other

E229 did not arrive.
Actions taken -

P033 did not arrive.
Actions taken - take action other

BC48 arrived at 12:46 hours and cleared at 16:06 hours.
Actions taken -

CT01 arrived at 12:16 hours and cleared at 14:47 hours.
Actions taken - take action other

BC02 arrived at 12:27 hours and cleared at 17:16 hours.
Actions taken -

E060 arrived at 12:25 hours and cleared at 18:18 hours.
Actions taken -

E238 arrived at 12:53 hours and cleared at 15:54 hours.
Actions taken -

E039 arrived at 12:41 hours and cleared at 18:20 hours.
Actions taken -

HR02 did not arrive.
Actions taken -

RE01 did not arrive.
Actions taken - take action other

BC12 arrived at 12:59 hours and cleared at 18:00 hours.
Actions taken -

E053 arrived at 13:04 hours and cleared at 16:21 hours.
Actions taken -

L047 arrived at 13:09 hours and cleared at 16:18 hours.
Actions taken -

L026 did not arrive.
Actions taken -

Unit Responsible for Report: BC16

E307 arrived at 13:03 hours.
Actions taken -

BC13 arrived at 13:06 hours and cleared at 16:16 hours.
Actions taken - assigned to sector commander, provide manpower and take action other

E074 arrived at 13:01 hours and cleared at 17:48 hours.
Actions taken - hook line up to hydrant, extinguished and assist engine company with stretching handline

E262 arrived at 13:05 hours and cleared at 16:16 hours.
Actions taken - E262 acting E93 was ordered to relieve E72 and operate a foam handline. E262 was then ordered to stand fast with a handline under the control of E74. E262 took up upon orders of Batt 16 and returned to company qrts.

BC49 did not arrive.
Actions taken -

MK01 did not arrive.
Actions taken - provide an air supply

E061 arrived at 13:27 hours and cleared at 15:50 hours.
Actions taken -

BC04 did not arrive.
Actions taken -

E016 arrived at 13:18 hours and cleared at 17:01 hours.
Actions taken -

L021 arrived at 13:20 hours and cleared at 17:53 hours.
Actions taken -

L014 did not arrive.
Actions taken -

E091 arrived at 13:29 hours and cleared at 17:08 hours.
Actions taken -

E092 arrived at 13:20 hours and cleared at 16:23 hours.
Actions taken -

E093 arrived at 13:32 hours and cleared at 18:22 hours.
Actions taken -

BC46 did not arrive.
Actions taken -

L022 arrived at 13:23 hours and cleared at 16:27 hours.
Actions taken - L-22 relieved L-30 as FAST truck

RA03 did not arrive.
Actions taken -

Unit Responsible for Report: BC16	
	L002 arrived at 13:50 hours and cleared at 17:16 hours. Actions taken - RA04 did not arrive. Actions taken - E288 did not arrive. Actions taken - E274 did not arrive. Actions taken - L005 did not arrive. Actions taken - E034 did not arrive. Actions taken - DC06 arrived at 17:36 hours and cleared at 21:00 hours. Actions taken - HB01 arrived at 19:55 hours and cleared at 21:16 hours. Actions taken - HM01 arrived at 19:59 hours and cleared at 21:29 hours. Actions taken - E041 arrived at 19:56 hours and cleared at 22:10 hours. Actions taken - Agency Onscene - Building Department, O.E.M. and D.E.P. Reporting Member: 904213 RAYMOND D SESSA Unit Responsible: BC16

Fire	
Acres Burned	56
Cause of Ignition	5 - Cause under investigation
Case	10538
Area Of Origin	UU - Undetermined
Heat Source	UU1 - Heat source under investigation
Item First Ignited	64 - Flammable liquid/gas in container or pipe
Condition on Arrival	3 - Flame and Smoke Showing
Factor Contributing To Ignition1	23 - Leak or break
On Site Material1	511 - Gasoline, diesel fuel
On Site Material Storage Use1	1 - Bulk storage or warehousing
On Site Material2	541 - Hazardous chemicals
On Site Material Storage Use2	1 - Bulk storage or warehousing

Fire

Suppression Factor1	325 - Flammable/combustible liquid hazard
Equipment Involved Type	375 - Internal combustion engine (nonvehicular)
Equipment Involved Portability	2 - Stationary
Mobile Property Involved	None

Structure

Structure Type	1 - Enclosed building
Building Type	1 - Fireproof Structure
Building Status	2 - In normal use
Floors Above Grade	2
Floors Belows Grade	3
Building Length	2500
Building Width	500
Story of Fire Origin	2
Fire Spread	4 - Confined to building of origin
Flame Spread Item	64 - Flammable liquid/gas in container or pipe
Flame Spread Material	25 - Kerosene, No.1 and 2 fuel oil, diesel fuel
Building Type	1 - Fireproof Structure
Stand Pipe System Type	2 - Dry
Stand Pipe System Operation	2 - Standpipe present but not used
Stand Pipe System Present	Yes
Detector Presence	1 - Present
Detector Type	5 - More than one type present
Detector Power	7 - Multiple detectors and power supplies
Detector Operation	U - Undetermined
AES Presence	N - None Present
Stories Minor Flame	1
Stories Significant Flame	0
Stories Heavy Flame	1
Stories Extreme Flame	1
Stories Minor Smoke	0
Stories Significant Smoke	0
Stories Heavy Smoke	1
Stories Extreme Smoke	1
Stories Minor Water	0
Stories Significant Water	1

Structure

Stories Heavy Water	1
Stories Extreme Water	1

Fire Service Casualty (1)

Photographs

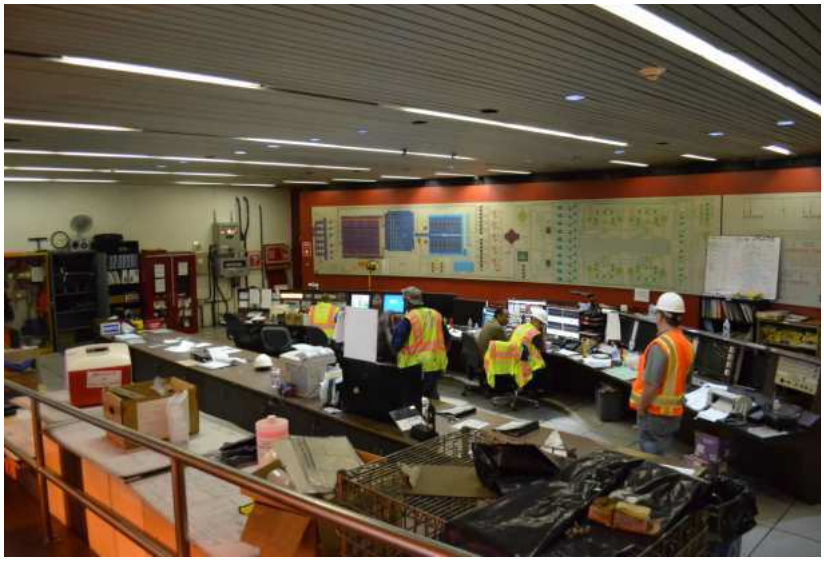
1

This photograph was taken with the camera facing south and depicts the entrance into the North River Wastewater Treatment Plant

2

This photograph was taken with the camera facing west and depicts the staging area on the north side of the plant.

Photographs



3

This photograph depicts an overall view of the control room.

4

E-Stop switches on the console in the control room.

Photographs

5

Doorway from roadway in northeast quadrant of plant leading to engine room floor.

6

This photograph was taken from the north end of the engine room floor with the camera facing south and depicts an overall view of same with msp engine #1 in foreground.

Photographs

7

This photograph depicts a closer view of the north side of the #1 msp engine. The control panel is on the left side of the photo (arrow).

8

This photograph depicts the ceiling above the # 1 engine. Note the spalled concrete, exposed re-bar, the hot spot on the steel and the bent ceiling "I" beam (arrows)

Photographs

9

Closer view of north facing side of #1 msp engine. Location of dual fuel filter indicated by arrow.

10

Dual fuel filter located on north facing side of engine #1, approximately four feet west of the metering line. Work was done to repair a leak at this filter the morning of the fire.

Photographs

11

Overall view of control panel for engine #1

12

Pattern on right side of control panel (discharge cone valve controls) closest to fractured metering line valve

Photographs

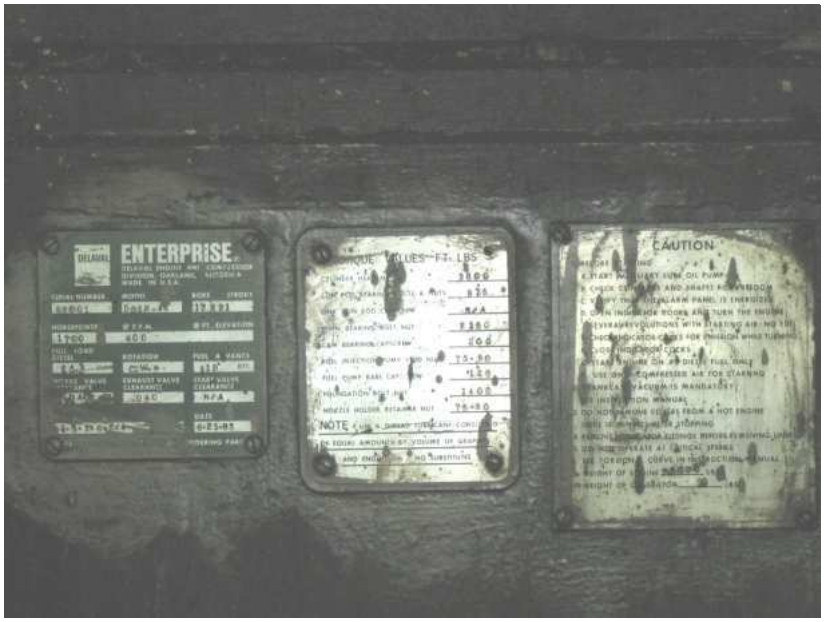
13

View of west side of msp engine #1 with camera facing east

14

View of south side of engine #1 with camera facing northeast

Photographs



15

Manufacturer's plates on south side of engine #1

16

Heat recovery boiler to the south of engine #1 exhibits no significant damage.

Photographs

17

The east side of engine #1 with the camera facing northwest with lube oil, air intake and digester gas pipes in the foreground.
.

18

Another view of the east side of engine #1 with lube oil, air intake and digester gas pipes in the foreground.

Photographs

19

Closer view of the east side of engine #1 with the camera facing southwest

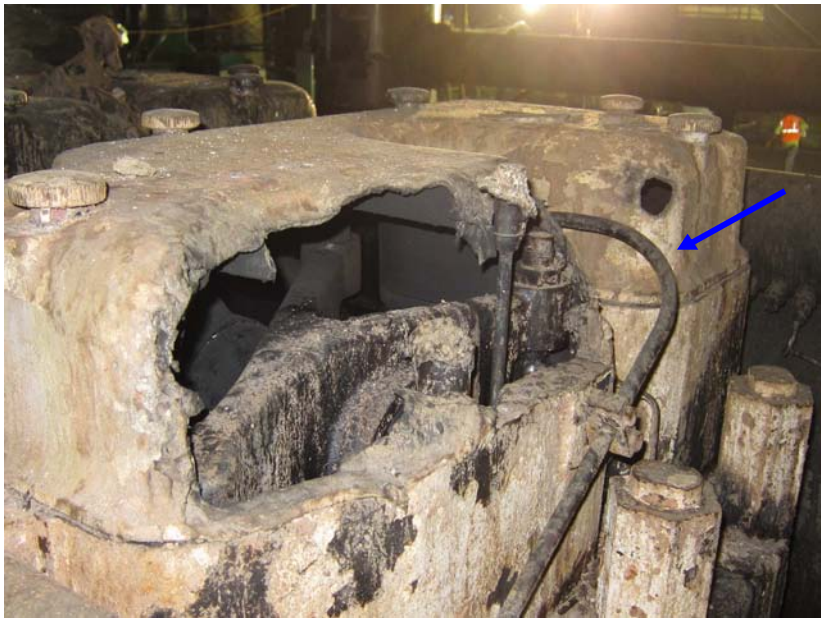
20

Another view of the east side of engine #1. Note paint burned off and splattered aluminum on side of block. (failed metering valve in foreground).

Photographs

21

Selectomatic valve in close proximity to turbocharger sustained intense heat



22

Cylinder head in proximity to turbocharger sustained intense heat and melted. High pressure fuel injector line (arrow) was taken for analysis. (see photograph No. 25)

Photographs

23

Braided fuel line aka flexible connector in proximity to turbocharger was removed and sent for analysis.

24

Tapered section of braided fuel line measured

25

Fuel injector pump, high pressure fuel line (arrow) and injector removed from msp engine #1

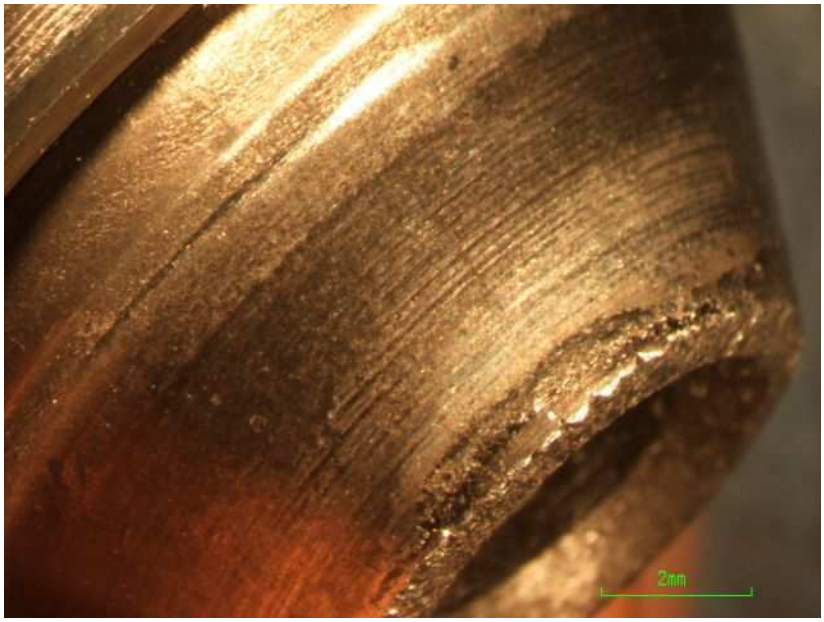
26

High pressure fuel injector line

Photographs

27

High pressure fuel injector line where it enters fuel pump (arrow) on msp engine #1



28

Tip of high pressure fuel injector line shows signs of erosion and corrosion. (photo courtesy of Affiliated Engineering)

Photographs

29

View of msp engine #1 from above depicts the exhaust piping on east side of same.

30

View of turbocharger (arrow) above the east side of engine #1 (arrow) with the camera facing west and upward. Inlet bell melted and transition section is missing

Photographs

31

View of exhaust side of turbocharger and transition section. Note that mounting bolt is bent (arrow).

32

Undamaged exemplar turbocharger mounted above msp engine #2

Photographs

33

Another view of the turbocharger from floor level without inlet bell and transition section

34

View of undamaged inlet bell and transition section from engine #2 as exemplar

Photographs

35

Inlet bell transition section found on floor beneath where it was mounted. (photo courtesy of NYC Fire Marshal's Office). This piece was discarded prior to our examination.

36

Isolation and block and vent valve in digester gas line

Photographs

37

View of turbocharger from on top of engine #1.

38

View of residue on blade of turbocharger (arrow). Scrapings were taken as evidence for laboratory analysis.

Photographs

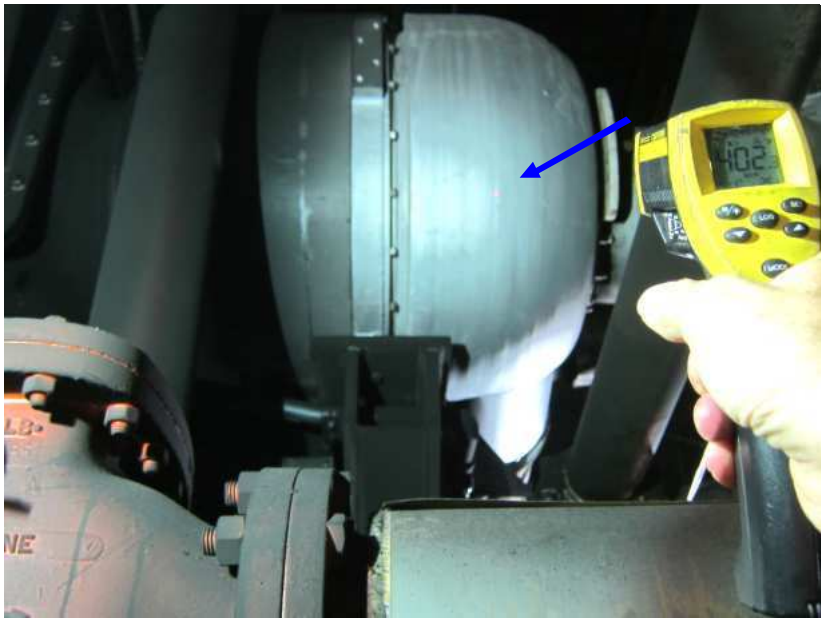
39

Interior of turbocharger after disassembly. Note presence of melted aluminum (arrow).

40

Turbocharger blade shows no evidence of fractures or deflection.

Photographs



41

Heat gun reading on turbocharger of engine #5 while running. Temperature reads 402°F. on the surface (red dot).

42

Melted aluminum on 6" pipe directly below where the inlet bell was mounted to the turbocharger (arrow)

Photographs

43

Metering pipes and valves at east end of engine #1 (arrow)

44

Failed pipe valve in metering return line

T.J. Russo Consultants
Fire Investigation and Analysis Services

Photographs

45

Another view of fractured valve through which diesel fuel escaped

46

Pipe nipple that was found by DEP at fracture site

47

View of fractured valve with pipe nipple replaced

48

View of fractured surface

Photographs

49

Horizontal fracture found in adjoining metering valve (arrow) as valves were being removed as evidence

50

Closer view of fracture

Photographs

51

Overall view of metering piping from engine #2 as exemplar

52

Failed bellows in lube oil line on east side of engine #1. This rubber bellows caught fire and burned, releasing combustible lube oil.

Photographs

53

Combustion air intake duct approximately 11' east of metering lines

54

Another view of combustion air intake duct

Photographs

55

Another view of combustion air intake with louvered door open

56

Opening in floor on east side of engine #1 through which burning diesel and lube oil flowed to floor below (arrow)

Photographs

57

Another opening in floor on east side of engine #1 through which burning diesel and lube oil flowed to floor below (arrow)

58

Fire damage to the upper areas of the auxiliary level (the floor below the engine room floor)

Photographs

59

Fire damage to the upper areas of the auxiliary level - burned wiring at ceiling level

60

Burn patterns on the waste oil tank located on the venturi level, (two floors below engine room floor)

Photographs

61

Fire damage to the venturi level, (two floors below engine room floor)

62

Melted aluminum found on engine room floor approximately 30' northwest of turbocharger

Photographs

63

Fire alarm panel in control room

64

Two of four feeders, each carrying 13KV of power into the plant

65

Smoke plume from explosion exits garage doorway and is captured by surveillance camera at 11:45:31

Safety bulletin

Mines Inspectorate
www.dme.qld.gov.au

Safety bulletin 83
Published 2 July 2008

Diesel Engine - Turbocharger Fires

Mine Type: All Mines

Incident: Fires with the engine turbocharger as the source of ignition.

Equipment: Any turbocharged diesel engine.

Hazard: Potential personal injury, fire.

Cause: Diesel engine turbochargers are increasingly acting as ignition sources for fires at surface coal mines.

The Mines Inspectorate has noticed an increase in the occurrence of these fires and has analysed the last 18 months' incident data supplied by the coal industry. The analysis shows excavators recorded 30% of all turbocharger fires, followed by track dozers (15%) and rear dump trucks (12.5%).

Sixty per cent of the fires resulted from hydraulic or engine oil spraying on the turbocharger. Eleven per cent of the fires were caused by engine fuel contacting the turbocharger and 13% from turbocharger failure.

Comments: The surface temperature of turbochargers can exceed 500 degrees Celsius during the normal operating cycle, and this temperature can rise to beyond 600-700 degrees following engine shutdown. Irrespective of whether the turbochargers are heat shielded, the turbocharger's surface temperature is hot enough to ignite fuel or oil when it comes into contact with it.

When did your operation last conduct a mock emergency with an engine bay fire as the scenario?

Recommendations: All mines are advised to review the occurrence of this type of incident at their mine site. Review your prevention, monitoring and contingency controls to ensure the risk from turbocharger fires is adequately controlled.

Consider:

- Heat shielding turbochargers
- Deflection barriers separating the oil hoses and fuel lines from an engine's turbocharger
- Contain fuel lines and hydraulic hoses to prevent spray onto hot surfaces.

Gavin Taylor
Chief Inspector of Coal Mines

Contact: Mark Moffat, Inspector of Mines, +61 7 4967 0865

Please ensure all relevant people in your organisation receive a copy of this Safety bulletin. Any such advice supplied to site should reach those who require it, and it should also be placed on the mine notice boards.
See more Safety alerts and Safety bulletins at www.dme.qld.gov.au/mines/safety_information___bulletins.cfm

MMS Safety Alert

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Notice No. 046

July 9, 1976

OCS Operations Safety Alert

Fire -- Lube Oil on Engine Exhaust

A fire recently occurred on an offshore platform drilling rig when lubricating oil dripped onto an engine exhaust.

The rig was circulating a well when oil lubricating the drawworks chains leaked through a faulty chain guard gasket and dripped into the engine room and on a hot exhaust manifold. The hot manifold apparently vaporized the oil and the oil vapors entered a diesel engine turbocharger and ignited. The fire was extinguished in less than two minutes. There were no injuries to personnel and only minor damage to the turbocharger air intake and filter.

To prevent a recurrence of this type of accident the operator is making the following recommendations:

1. Stop all oil leaks and inspect all potential sources a minimum of twice daily to insure that engine vibration has not caused a leak to develop.

2. Insulate or shield manifolds and exhausts to prevent ignition of oil if a leak should occur undetected.

[signed] D.J. Bourgeois

for D.W. Solanas

Oil and Gas Supervisor

Field Operations

Gulf of Mexico Area

1/2" – 2-1/2" (DN 15 – 65) STANDARD PORT AND 1/2" – 2" (DN 15 – 50) FULL PORT SERIES 4000 BALL VALVES

Threaded End – Socket Weld – Butt Weld

The Jamesbury® Series 4000 ball valves offer the three most desirable attributes of high-quality valves: exceptional performance, great versatility, and economical cost.

This valve line includes both standard-port valves (to 2-1/2" [DN 65]) and full-port valves (to 2" [DN 50]) with three available end connections-threaded end, socket weld, and butt weld.

There are two basic groups of Series 4000 valves.

Fire-Tite® Valves

The first consists of *Fire-Tite* valves fire-tested to meet API 607, Edition 5 and British Standard BS6755-Part 2 requirements. They are ideal for handling petroleum products and other flammable or hazardous substances, as well as for an extremely broad range of normal and corrosive services. These Series 4000 valves are available in materials conforming to NACE MR0103 requirements, and specifically prepared for oxygen or high-vacuum service. They are also available to conform to ANSI, API, BS and MSS standards.

Standard body and trim materials for *Fire-Tite* valves are carbon steel with 316 stainless steel trim and all 316 stainless steel. Seat material options are PTFE (T) and Xtreme® (X) for applications involving chemicals, petrochemicals, acids, caustics and steam. Delrin® (R) seats are for higher pressures, while PFA (B) seats resist the effects of polymerizing monomers such as butadiene and styrene. Metal (D) seats are also available for use with high-temperature fluids, saturated steam, and other heat-transfer media at pressures to 300 psi (20.7 bar)and temperatures to 600˚F (316˚C).

Non *Fire-Tite* Valves

Non *Fire-Tite* valves are available in the same body and trim materials as *Fire-Tite* valves with a wider range of seat material options. The standard seat material is *Xtreme* (X), while PTFE (T), UHMW (U) polyethylene seats and Peek (L) seats are also available.

*ANSI Class 400 standards for 2" (DN 50) full-port and 2-1/2" (DN 65) standard-port valves.

FEATURES AND BENEFITS

- New *Xtreme* seat provides longer life, expanded performance boundaries, and greater value.
- Polymeric flexible lip-seat design offers tight shut-off in either direction and extended cycle life with minimum maintenance.
- Available to meet ANSI Class 600 standards per B16.34, B31.1, B31.3, and B31.4.
- 3-piece construction facilitates servicing
- *Fire-Tite* version with non-metallic seats meets API 607, Edition 5, and BS6755-Part 2 requirements
- NACE MR0103 compliance available

NEW FEATURES AND BENEFITS

For 1/2" – 2" (DN 15 – 50) standard port and 1/2" – 1-1/2" (DN 15 – 40) full bore valves

- New stem seal system is live loaded and engineered to assure long sealing life – patent pending.
- ISO 5211 Bonnet for global conformity.
- CE Marking option.
- New stainless steel linkage for VPVL, V-Series and ADC-Series actuators has a guided coupling to align topworks during assembly and eliminate side load stress on stem seals for long life, clean environment and reduced maintenance.

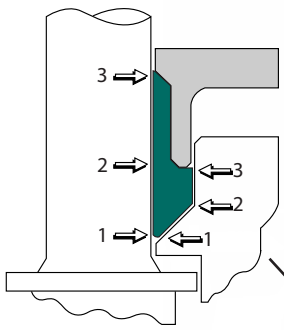
jamesbury

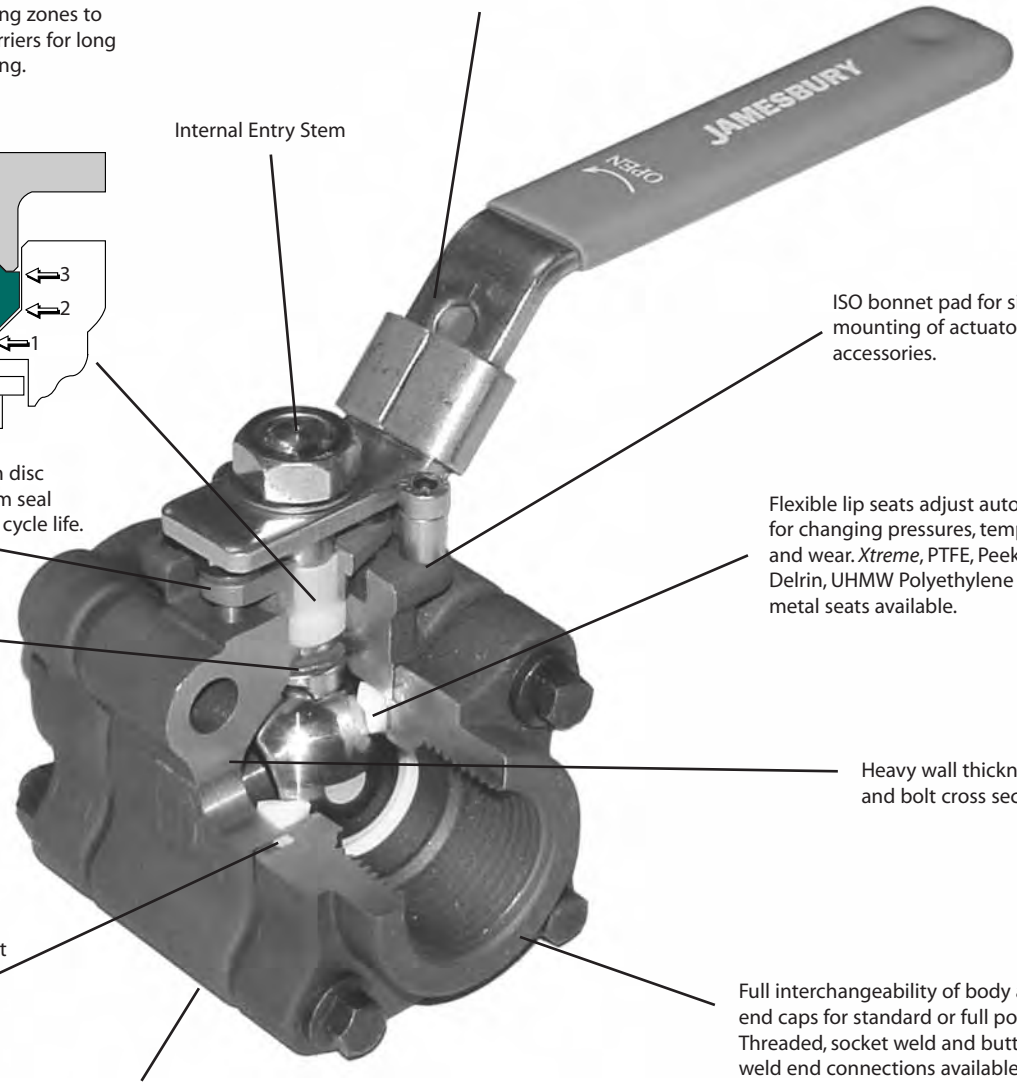
B105-1EN • 7/2011

metso
Expect results

Valve Performance and Value

1/2" – 2" (DN 15 – 50) Standard Port and 1/2" – 1-1/2" (DN 15 – 40) Full Bore Valves





Patented stem seal (70017915) has 3 engineered sealing zones to provide multiple barriers for long term sealing.

Handle with Slide Lock

Internal Entry Stem

ISO bonnet pad for simplified mounting of actuators and accessories.

Compression plate with disc springs for uniform stem seal compression to extend cycle life.

Flexible lip seats adjust automatically for changing pressures, temperatures and wear. *Xtreme*, PTFE, Peek, PFA, Delrin, UHMW Polyethylene and metal seats available.

Thrust bearings.

Heavy wall thickness and bolt cross section.

Composite PTFE and graphite seals for a tight joint that outperforms API 607 5th edition requirements.

Full interchangeability of body and end caps for standard or full port. Threaded, socket weld and butt weld end connections available.

Permanently attached corrosion resistant metal nameplate for positive identification on all ANSI and API valves.

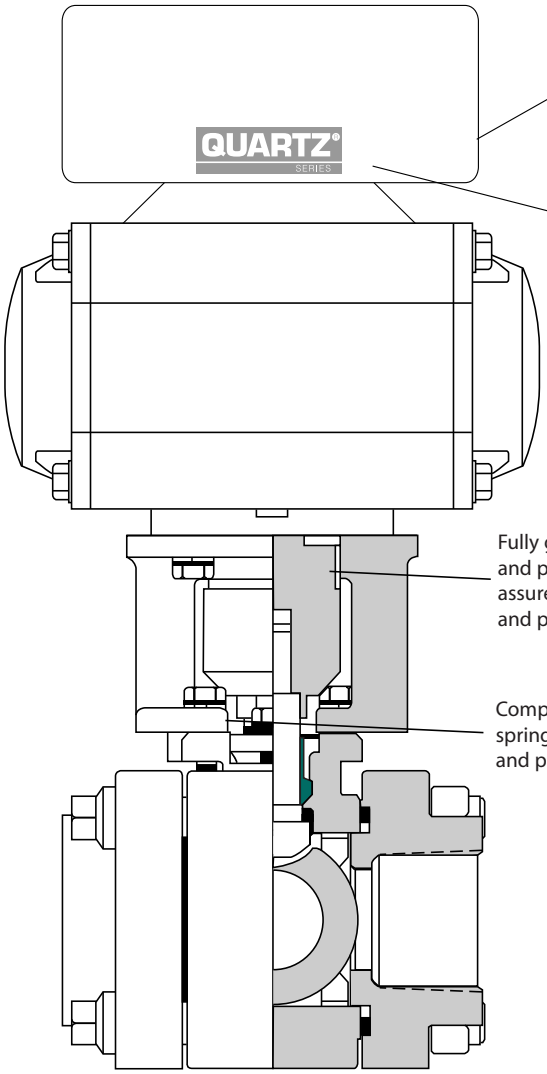
For 2" (DN 50) full bore and 2-1/2" (DN 65) standard port, refer to page 6.
All constructions marked comply with MSS SP-25.

Xtreme Performance and Value

Xtreme seats provide longer life, expanded performance boundaries, and the greatest possible value. *Xtreme* is a unique material that resulted from a technological breakthrough in our polymer research lab. The material is a fluoropolymer-based blend proprietary to *Jamesbury* that provides superior quarter-turn performance.

Jamesbury 'The Ultimate Process Automation Package' for VPVL Pneumatic Actuators, V-Series and ADC-Series Electric Actuators

For 1/2" – 2" (DN 15 – 50) Standard Port and 1/2" – 1-1/2" (DN 15 – 40) Full Port Series 4000

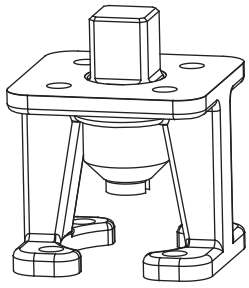


Digital valve communication terminals for full automation capability

Available for general purpose and hazardous duty service

Fully guided stem, coupling and precision bracket assures optimum form, fit and performance

Compression plate and disc springs to accomodate thermal and pressure cycles.



Stainless steel linkages for *Jamesbury* ISO Actuators

- Self aligning
- Engineered for optimum stem seal performance

Automation Performance and Value

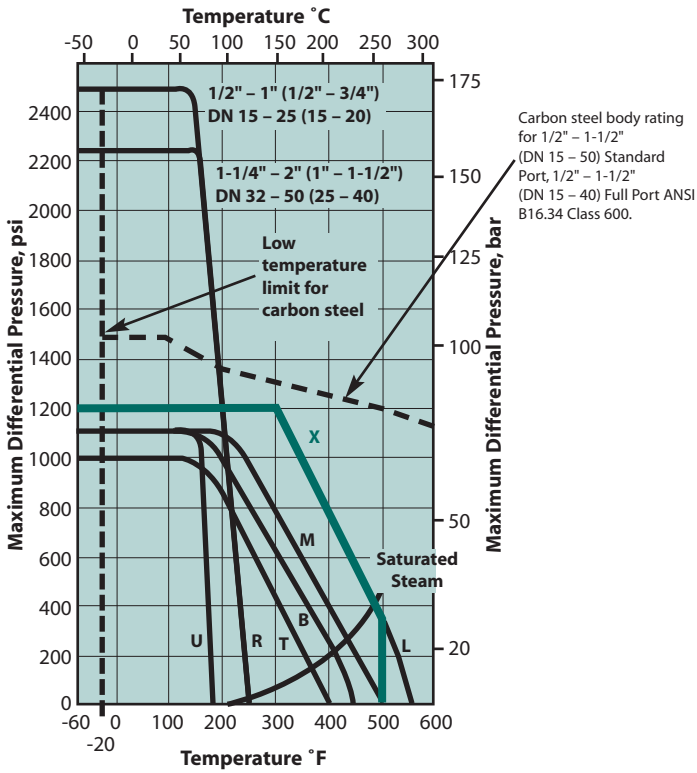
Series 4000 valves combined with *Jamesbury* actuators, network capable valve monitors and communication devices offer a total value and performance package. Available with pneumatic Valv-Powr® VPVL actuators, V-Series and ADC-Series electric actuators and with Stonel® Quartz®, Eclipse®, and Hawkeye® digital monitors or VCTs, the packages have a wide range of applications. Visit our website at **www.metso.com/automation.**

Valve Seat Ratings

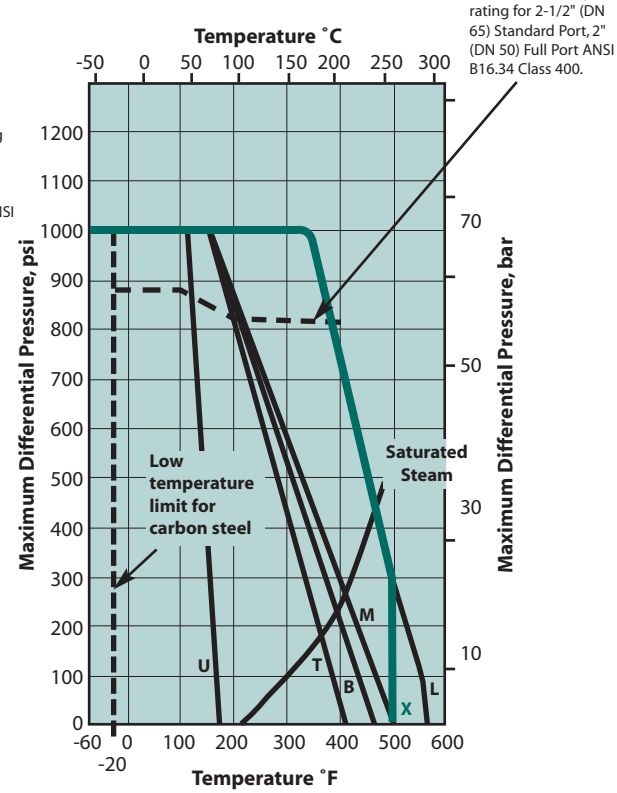
These ratings are based on differential pressure with valve ball in the fully closed position and refer to seats only. Refer to valve body ratings on page 5 to be sure that all components are satisfactory for the application.

Valves in carbon steel are suitable for service to -20˚F (-29˚C), valves in 316 stainless steel to -60˚F (-51˚C) or -40˚F (-40˚C) with Delrin seats. Lower temperature limits for body boltings are B7: -20˚F (-29˚C), B7M: -50˚F (-46˚C), L7M: -60˚F (-51˚C), B8: -60˚F (-51˚C).

1/2" – 2" (DN 15-50) Standard Port, 1/2" – 1-1/2" (DN 15-40) Full Port Valves

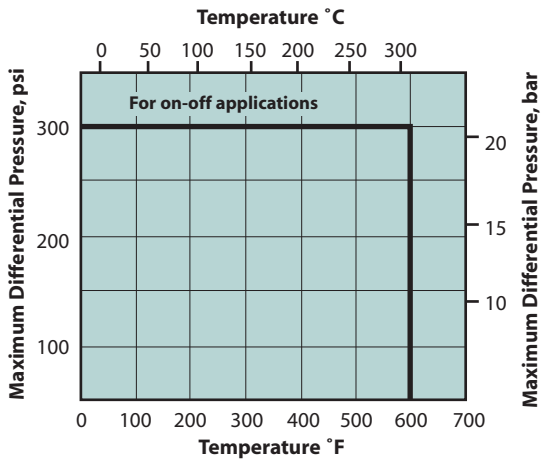


2-1/2" (DN 65) Standard Port, 2" (DN 50) Full Port Valves



X–Xtreme T–PTFE M–Filled PTFE R–Delrin L–Peek
U–UHMW polyethylene B–PFA
*Full port sizes in parenthesis.
Note: All 1/2" (DN 15) Series 4000 valves have 1/2" (DN 15) port.

Metal-Seated Valves



SPECIFICATIONS

Series 4000 valves are available in types that meet the following industry specifications.

Specification	Description
ANSI B1.20.1	Pipe Threads
ANSI B16.11	Steel Fitting Socket Welding & Thread
ANSI B16.25	Buttwelding Ends
ANSI B16.34	Valves-Flanged and Buttwelding Ends
ANSI B31.1	Power Piping
ANSI B31.3	Chemical Plant & Petroleum Refining Piping
ANSI B31.4	Liquid Petroleum Piping
API 598	Valve Inspection & Testing
API 607-5	Fire Test for Soft-seated Valves (Div. of Refining)
API 608	Metal Ball Valves - Flanged, Threaded and Welding End
BS 21	Specification for pipe threads for tubes and fittings where pressure-tight joints are made on the threads (metric dimensions)
BS 6755-Part 2	Testing of Valves – Specification for Fire Type-Testing Requirements
BS 5351	British Standard Specification for Steel Ball Valve for the Petroleum, Petro-chemical and Allied Industries
DIN 2999-1	Pipe threads for tubes and fittings; parallel internal thread and taper external thread; tread dimensions
ISO 7-1	Pipe threads where pressure-tight joints are made on the threads -- Part 1: Dimensions, tolerances and designation
MSS SP-25	Standard Marking System for Valves
MSS SP-55	Quality Standard for Steel Fittings for Valves
MSS SP-72	Ball Valves with Flanged or Buttweld End
NACE MR0103	Materials Resistant to Sulfide Stress Cracking in Corrosive Petroleum Refining Environments

Valve Body Ratings

These are the maximum working pressure ratings of the valve body only. The seat ratings on page 4 determine the practical pressure limitation in actual service. Working pressure rating is at -20˚F to +100˚F (-29˚C to +38˚C).

Standard Version - Body Rating

Valve Size*		Working Pressure - Body Material: Carbon Steel and 316 Stainless Steel	
Inches	DN	psi	bar
1/2 – 1 (1/2 – 3/4)	15 – 25 (15 – 20)	2500	172
1-1/4 – 2 (1 – 1-1/2)	32 – 50 (25 – 40)	2250	155
2-1/2 (2)	65 (50)	1000	69

*Full-port sizes in parentheses

Flow Data

The table below provides flow coefficients, Cv, of Series 4000 valves. The Cv values represent the flow of water at +60˚F through the valve in U.S. gallons per minute at a pressure drop of 1 psi.

Valve Size		Standard port Cv*	Full port Cv*
Inches	DN		
1/2	15	13	13
3/4	20	33	40
1	25	44	65
1-1/4	32	46	90
1-1/2	40	95	135
2	50	111	251
2-1/2	65	216	—

*Cv =1.167 Kv.

Maximum Leakage Rates

All series 4000 valves are factory tested with air. Polymeric seated valves are verified to be bubble tight using 100 psi air. Metal seats are also tested with air to ensure that leakage does not exceed the rates shown below.

Valve Size - inches		Leakage Rate - scfm at Differential Pressure		
Standard Port	Full Port	100 psi	200 psi	300 psi
1/2	1/2	5.0	7.0	8.6
3/4	—	7.0	9.9	12.1
1 - 2	3/4 – 1-1/2	9.0	12.7	15.5
—	2	11.0	14.0	17.0

Valve Size - DN		Leakage Rate - m^3/hr Differential Pressure		
Standard Port	Full Port	7 bar	14 bar	20 bar
15	15	8.5	11.9	14.6
20	—	11.9	16.8	20.6
25 – 50	20 – 40	15.3	21.6	26.3
—	50	18.7	23.8	28.8

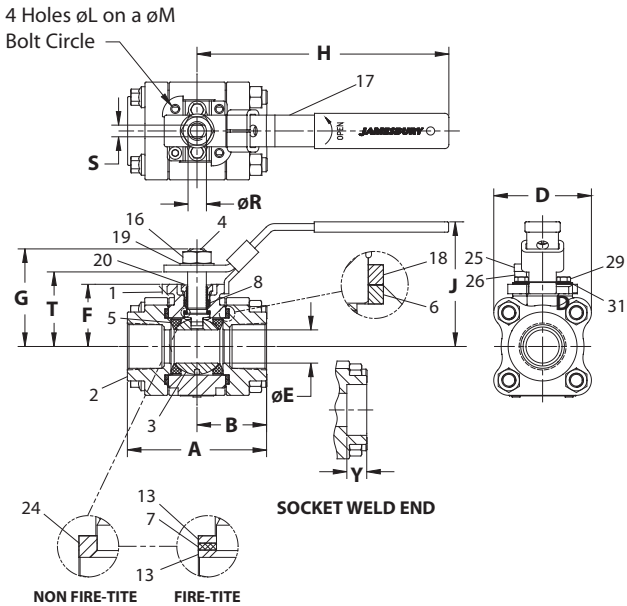
ANSI Version - Body Rating

Temperature	ANSI Class 600 1/2" – 2" (DN 15 – 50) Standard Port 1/2" – 1-1/2" (DN 15 – 40) Full Port		ANSI Class 400 2-1/2" (DN 65) Standard Port 2" (DN 50) Full Port	
	Carbon Steel	Stainless Steel	Carbon Steel	Stainless Steel
˚F	psi	psi	psi	psi
-20 to +100	1480	1440	990	960
200	1360	1240	900	825
300	1310	1120	875	745
400	1265	1025	845	685
500	1205	955	800	635
Shell Test Pressure	**2250**	**2200**	**1500**	**1500**

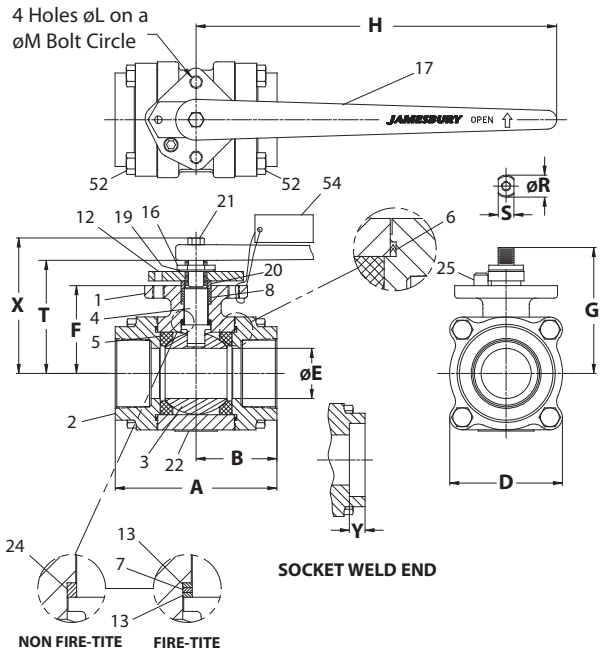
Temperature	ANSI Class 600 1/2" – 2" (DN 15 – 50) Standard Port 1/2" – 1-1/2" (DN 15 – 40) Full Port		ANSI Class 400 2-1/2" (DN 65) Standard Port 2" (DN 50) Full Port	
	Carbon Steel	Stainless Steel	Carbon Steel	Stainless Steel
˚C	bar	bar	bar	bar
-29 to +38	102.1	99.3	68.3	66.2
100	93.2	84.4	61.9	56.2
150	90.2	77.0	60.3	51.2
200	87.6	71.3	58.5	47.6
250	83.9	66.8	55.7	44.4
Shell Test Pressure	**154**	**150**	**103**	**100**

DIMENSIONS

1/2" – 2" (DN 15 – 50) STANDARD PORT
1/2" – 1-1/2" (DN 15 – 40) FULL PORT VALVES



2-1/2" (DN 65) STANDARD PORT
2" (DN 50) FULL PORT VALVES



Approximate Dimensions - Inches																		
Valve Size	Screwed End & Socket Weld Valves		Butt Weld Valves		Common Dimensions													Approx. Weight
inches	A	B	A	B	D	E	F	G	H	J	L	M	R	S	T	X	Y	lb
Standard Port																		
1/2	2.59	1.29	2.80	1.40	2.06	0.50	1.06	1.63	5.00	2.36	M5	1.42	0.31	0.18	1.28	–	0.41	1.9
3/4	3.01	1.50	3.36	1.68	2.25	0.69	1.22	1.79	5.00	2.52	M5	1.42	0.31	0.18	1.43	–	0.53	2.7
1	3.69	1.85	3.90	1.95	2.59	0.88	1.65	2.58	6.50	3.29	M5	1.65	0.50	0.31	1.99	–	0.53	4.8
1-1/4	4.22	2.11	4.56	2.28	2.84	1.00	1.78	2.71	6.50	3.42	M5	1.65	0.50	0.31	2.12	–	0.53	6.3
1-1/2	4.58	2.29	5.40	2.70	3.33	1.25	2.08	3.30	8.00	4.27	M6	1.97	0.62	0.37	2.54	–	0.53	9.8
2	5.11	2.55	5.90	2.95	3.66	1.50	2.26	3.49	8.00	4.46	M6	1.97	0.62	0.37	2.73	–	0.64	12.7
2-1/2	6.47	3.22	–	–	4.50	2.00	2.26	5.00	14.00	–	1/2–13	3.00	0.88	0.63	4.38	5.38	0.64	25.5
Full Port																		
1/2	2.59	1.29	2.80	1.40	2.06	0.50	1.06	1.63	5.00	2.36	M5	1.42	0.31	0.18	1.28	–	0.41	1.9
3/4	3.69	1.85	3.90	1.95	2.59	0.88	1.65	2.58	6.50	3.29	M5	1.65	0.50	0.31	1.99	–	0.53	5.2
1	4.22	2.11	4.56	2.28	2.84	1.00	1.78	2.71	6.50	3.42	M5	1.65	0.50	0.31	2.12	–	0.53	6.8
1-1/4	4.58	2.29	5.40	2.70	3.33	1.25	2.08	3.30	8.00	4.27	M6	1.97	0.62	0.37	2.54	–	0.53	10.3
1-1/2	5.11	2.55	5.90	2.95	3.66	1.50	2.26	3.49	8.00	4.46	M6	1.97	0.62	0.37	2.73	–	0.53	13.7
2	6.19	3.09	6.19	3.09	4.50	2.00	2.26	5.00	14.00	–	1/2–13	3.00	0.88	0.63	4.38	5.38	0.64	25.3

Approximate Dimensions - mm																		
Valve Size	Screwed End & Socket Weld Valves		Butt Weld Valves		Common Dimensions													Approx. Weight
DN	A	B	A	B	D	E	F	G	H	J	L	M	R	S	T	X	Y	kg
Standard Port																		
15	66	33	71	36	52	13	27	41	127	60	M5	36	8	5	33	–	10	0.9
20	76	38	85	43	57	18	31	45	127	64	M5	36	8	5	36	–	13	1.2
25	94	47	99	50	66	22	42	66	165	84	M5	42	13	8	51	–	13	2.2
32	107	54	116	58	72	25	45	69	165	87	M5	42	13	8	54	–	13	2.9
40	116	58	137	69	85	32	53	84	203	108	M6	50	16	9	65	–	13	4.4
50	130	65	150	75	93	38	57	89	203	113	M6	50	16	9	69	–	16	5.8
65	164	82	–	–	114	51	57	127	356	–	1/2-13	76	22	16	111	137	16	11.6
Full Port																		
15	66	33	71	36	52	13	27	41	127	60	M5	36	8	5	33	–	10	0.9
20	94	47	99	50	66	22	42	66	165	84	M5	42	13	8	51	–	13	2.4
25	107	54	116	58	72	25	45	69	165	87	M5	42	13	8	54	–	13	3.1
32	116	58	137	69	85	32	53	84	203	108	M6	50	16	9	65	–	13	4.7
40	130	65	150	75	93	38	57	89	203	113	M6	50	16	9	69	–	13	6.2
50	157	78	157	78	114	51	57	127	356	–	1/2-13	76	22	16	111	137	16	11.5

BILLS OF MATERIALS AND PARTS LIST

***Fire-Tite* 1/2" – 2" (DN 15 – 50) Standard Port, 1/2" – 1-1/2" (DN 15 – 40) Full Port Valves**

Part No.	Part Name	Body Material	
		Carbon Steel (22)	**316 Stainless Steel (36)**
1	Body	Carbon steel ASTM A216 Type WCB	316 Stainless steel ASTM A351 Type CF8M
2	Body Cap	Carbon steel ASTM A216 Type WCB	316L Stainless steel ASTM A351 Type CF3M
3	Ball	316 Stainless steel, Monel, Hastelloy C	
4	Stem	316 Stainless steel, 17-4 PH Stainless steel, Monel, Hastelloy C	
5	Seat	PTFE, *Xtreme*, 17-4 PH, PFA, Delrin®#, UHMW polyethylene, as specified	
6/18	Body Seals	PTFE & Graphite, Spiral wound 316 Stainless steel graphite/PTFE (with Peek, metal seats or configuration L)	
7	Secondary Stem Seal	Graphite	
8	Primary Stem Seal	PTFE, TFM® (*Xtreme*-Seated Valves), Graphite (w/metal seats), UHMWPE (w/UHMWPE seats)	
10	Stem Guide	Peek (Metal-Seated Valves)	
13	Stem Bearing	Filled PTFE (Peek when metal-seated) (Delrin when Delrin-seated), UHMWPE (w/UHMWPE seats)	
16	Hex Nut	316 Stainless steel	
17	Handle	Carbon steel (zinc plated)	300 Series Stainless steel
19	Lock Washer	300 Series Stainless steel	
20	Compression Plate	316 Stainless steel	
25	Socket Cap Screw	316 Stainless steel	
26	Handle Stop Spacer	316 Stainless steel	
29	Hex Cap Screw	316 Stainless steel	
31	Disc Springs	Inconel	
52	Body Bolt/Tie Rod	ASTM A193 Gr. B7	ASTM A193 Gr. B8M
53	Hex Nut	ASTM A194 Gr. 2H	ASTM A194 Gr. 8
54	Weld End Tag	Paper	

Requires 17-4 PH stem

Non *Fire-Tite* 1/2" – 1-1/2" (DN 15 – 40) Full Port & 1/2" – 2" (DN 15 – 50) Standard Port Valves

Part No.	Part Name	Body Material	
		Carbon Steel (22)	**316 Stainless Steel (36)**
1	Body	Carbon steel ASTM A216 Type WCB	316 Stainless steel ASTM A351 Type CF8M
2	Body Cap	Carbon steel ASTM A216 Type WCB	316L Stainless steel ASTM A351 Type CF3M
3	Ball	316 Stainless steel, Monel, Hastelloy C	
4	Stem	316 Stainless steel, 17-4 PH Stainless steel, Monel, Hastelloy C	
5	Seat	PTFE, Peek #, as specified	
6/18	Body Seal	PTFE & Graphite, Spiral wound 316 Stainless steel graphite/PTFE (with Peek seats or configuration L)	
8	Primary Stem Seal	PTFE, Graphite (with Peek seats)	
10	Stem Guide	Peek (Peek seated valves)	
13	Stem Bearing	Filled PTFE (Peek when Peek-seated)	
16	Hex Nut	316 Stainless steel	
17	Handle	Carbon steel (Zinc plated)	300 Series Stainless steel
19	Lock Washer	300 Series Stainless steel	
20	Compression Plate	316 Stainless steel	
24	Stem Bearing	Filled PTFE (Peek when Peek-seated)	
25	Socket Cap Screw	316 Stainless steel	
26	Handle Stop Spacer	316 Stainless steel	
29	Hex Cap Screw	316 Stainless steel	
31	Disc Springs	Inconel	
52	Body Bolt/Tie Rod	ASTM A193 Gr. B7	ASTM A193 Gr. B8M
53	Hex Nut	ASTM A194 Gr. 2H	ASTM A194 Gr. 8
54	Weld End Tag	Paper	

Requires 17-4 PH stem

BILLS OF MATERIALS AND PARTS LIST			
***Fire-Tite* 2" (DN 50) Full Port and 2 1/2" (DN 65) Standard Port Valves**			
Part No.	**Part Name**	**Body Material**	
		Carbon Steel (22)	**316 Stainless Steel (36)**
1	Body	Carbon steel ASTM A216 Type WCB	316 Stainless steel ASTM A351 Type CF8M
2	Body Cap	Carbon steel ASTM A216 Type WCB	316L Stainless steel ASTM A351 Type CF3M
3	Ball	316 Stainless steel	
4	Stem	316 Stainless steel or 17-4 PH Stainless steel	
5	Seat	PTFE, *Xtreme*, 17-4 PH, as specified	
6	Body Seal	Spiral wound 316 Stainless steel graphite/PTFE	
7	Secondary Stem Seal	Graphite	
8	Stem Seal	PTFE, TFM (*Xtreme*-Seated Valves)	
12	Indicator Stop	316 Stainless steel	
16	Stem Nut	Carbon steel	Stainless steel
17	Handle	Ductile Iron	
19	Shakeproof Washer	Carbon steel	
21	Compression Ring	316 Stainless steel	
22	Identification Tag	Stainless steel	
24	Stem Bearing	Filled PTFE (Peek when metal-seated)	
25	Hex Cap Screw**	ASTM A193 Gr. B7, B7M, A320 Gr. L7M	ASTM A193 Gr. B7, B8, A453 Gr. 660
52	Body Bolt/Tie Rod**	ASTM A193 Gr. B7, B7M, A320 Gr. L7M	ASTM A193 Gr. B7, B8, A453 Gr. 660
53	Hex Nut**	ASTM A194 Gr. 2H, 2M, 7M	ASTM A194 Gr. 2H, 2M, A453 Gr. 660
54	Weld End Tag	Paper	
** A193 Gr. B7 Body Fasteners unless otherwise specified.			

Non *Fire-Tite* 2" (DN 50) Full Port and 2-1/2" (DN 65) Standard Port Valves			
Part No.	**Part Name**	**Body Material**	
		Carbon Steel (22)	**316 Stainless Steel (36)**
1	Body	Carbon steel ASTM A216 Type WCB	316 Stainless steel ASTM A351 Type CF8M
2	Body Cap	Carbon steel ASTM A216 Type WCB	316L Stainless steel ASTM A351 Type CF3M
3	Ball	316 Stainless steel	
4	Stem	316 Stainless steel* or 17-4 PH Stainless steel (PEEK-seated valves)	
5	Seat	PTFE, *Xtreme*, Peek, UHMW PE, as specified	
6	Body Seal	Spiral wound 316 Stainless steel graphite/PTFE, EPT (UHMWPE seated valves)	
8	Stem Seal	PTFE, TFM (*Xtreme*-Seated Valves), UHMW PE (UHMW PE-seated valves)	
12	Indicator Stop	316 Stainless steel	
16	Stem Nut	Carbon steel	Stainless steel
17	Handle	Ductile Iron	
19	Shakeproof Washer	Carbon steel	
21	Compression Ring	316 Stainless steel	
22	Identification Tag	Stainless steel	
24	Stem Bearing	Filled PTFE (*Xtreme* and PTFE seats) same as seat material for Peek and UHMW PE Seats	
25	Hex Cap Screw**	ASTM A193 Gr. B7, B7M, A320 Gr. L7M	ASTM A193 Gr. B7, B8, A453 Gr. 660
52	Body Bolt/Tie Rod**	ASTM A193 Gr. B7, B7M, A320 Gr. L7M	ASTM A193 Gr. B7, B8, A453 Gr. 660
53	Hex Nut**	ASTM A194 Gr. 2H, 2M, 7M	ASTM A194 Gr. 2H, 2M, A453 Gr. 660
54	Weld End Tag	Paper	
** A193 Gr. B7 Body Fasteners unless otherwise specified.			

VALVE TORQUE DATA

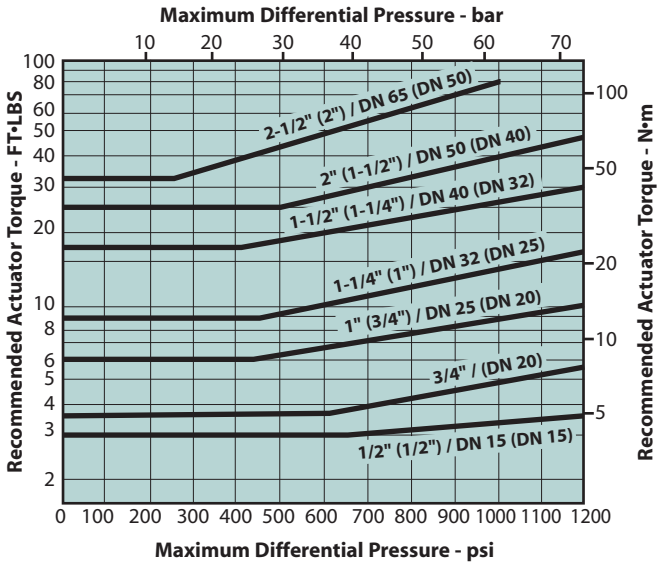
Use these torque charts for Series 4000 valves as a guide for actuator selection. For torque output values and actuator selection tables refer to actuator bulletins.

Additional requirements may be imposed by media characteristics, trim, and frequency of valve operation.

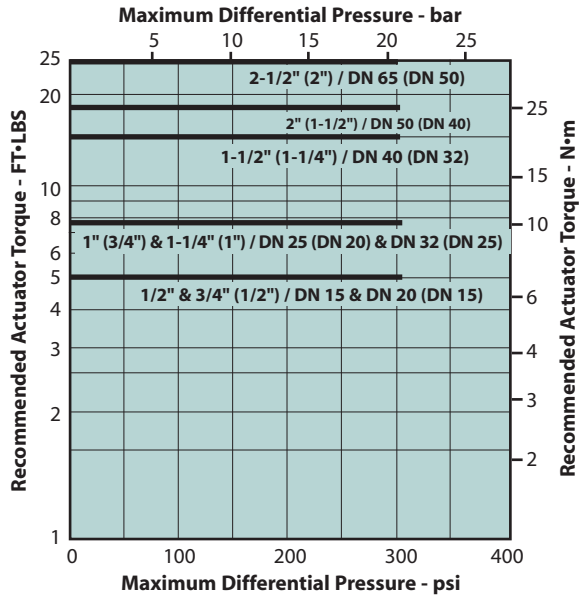
For difficult service (slurries, semi-solids) increase values by 50%. If in doubt, select a larger actuator.

Values shown in the charts are based on using standard factory procedures for valve-actuator assembly.

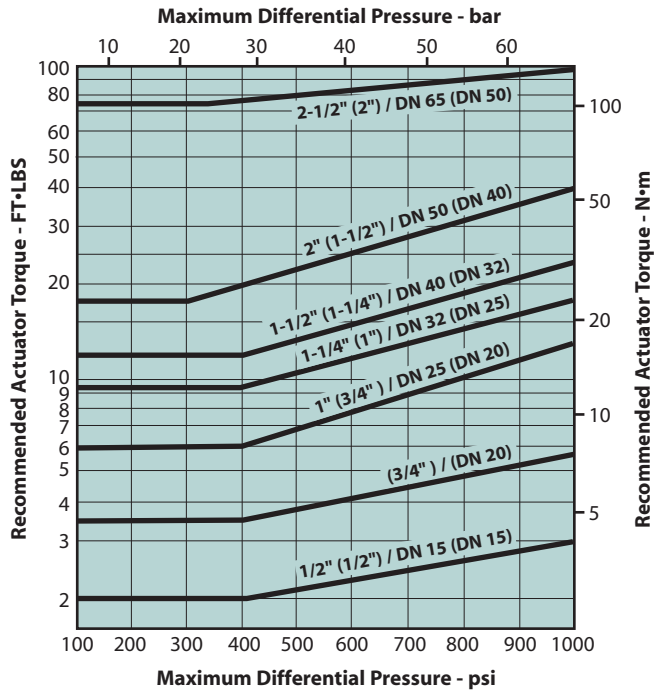
Xtreme (X) Seated Standard-Port Valves (Full-port sizes in parentheses)



Metal (D) Seated Standard-Port Valves (Full-port sizes in parentheses)

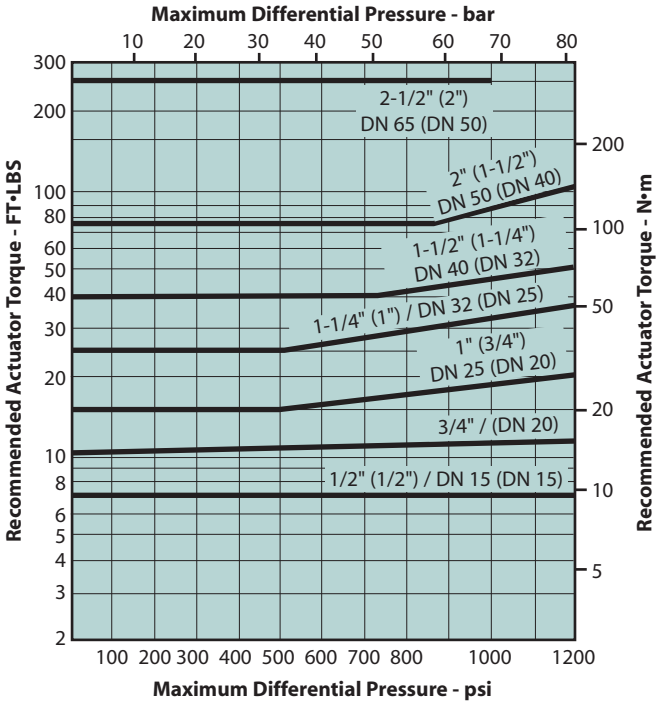


PTFE (T) Seated Standard-Port Valves

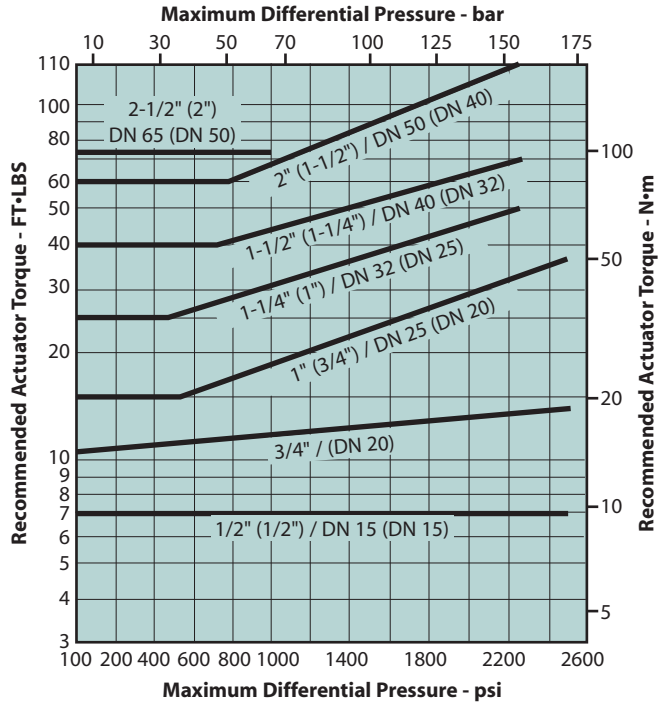


VALVE TORQUE DATA (CONTINUED)

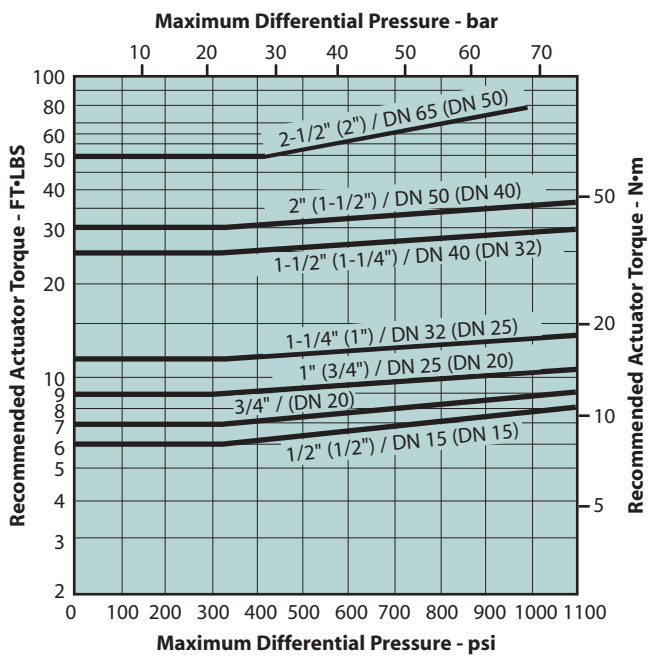
Peek (L) Seated Standard-Port Valves (Full-port sizes in parentheses)



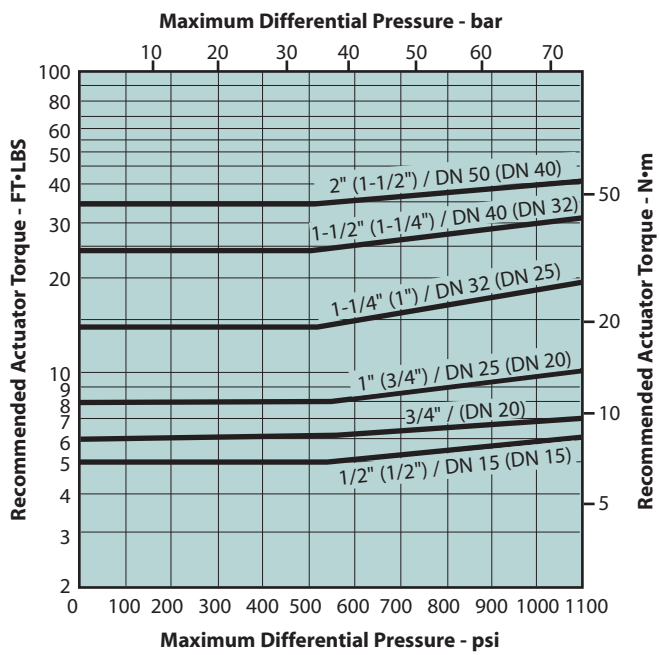
Delrin (R) Seated Standard-Port Valves (Full-port sizes in parentheses)



UHMW (U) Polyethylene Seated Standard-Port Valves (Full-port sizes in parentheses)



PFA (B) Seated Standard-Port Valves



ACTUATORS

Metso offers a full line of integrally designed actuators for automated systems or for easier control of inaccessible or remote valves. Pneumatic actuators that include double-acting and spring-return piston, vane, and rack and pinion units, spring-diaphragm types, and electric actuators are available for all valves. Electric actuators are available with both watertight and hazardous location enclosures.

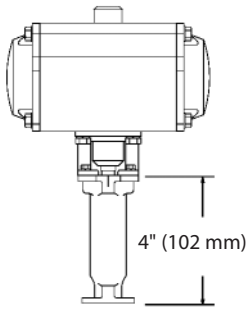
For further information on actuators for Series 4000 valves, see the following:

Type	Bulletin
Spring-Diaphragm Actuators	A110-4
VPVL Mod D Actuators	A111-5
V-Series Electric Actuators	A200-1
ADC-Series Electric Actuators	A201-1

ACCESSORIES

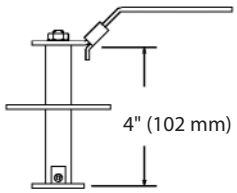
Bonnet/Stem Extensions SE-096, 097 & 098

4" (102 mm) bonnet/stem extensions are available for applications that require insulated pipe, particularly useful for automated products, extension can also be used to prevent interference between actuators and companion pipelines and equipment. They are ideal as extension that require locking lever or locking oval handle capability. Stainless steel construction offers the option of using the extension to complement the carbon steel stem extension (SE-093, 094 & 095) offerings.



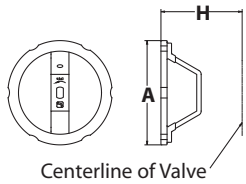
Stem Extensions SE-093, 094 & 095

A standard 4" (102 mm) stem extension is offered for Series 7000 valves (1/2" – 2") for improved accessibility, particularly when used in insulated pipelines. Stem extension kits can be ordered factory-mounted or shipped separately for field mounting.



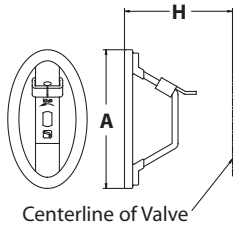
Round Handles

Series 4000 ball valves have optional round handles available. To order handles separately, specify the part number shown in the accessories table below.



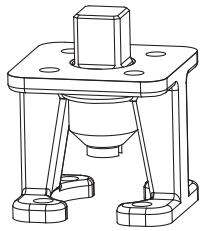
Oval handles with slide-lock

Optional oval handle saves space and may be padlocked to retain the valve in the open or closed position.



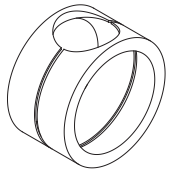
Stainless steel linkages for *Jamesbury* ISO Actuators

- Self aligning
- Engineered for optimum stem seal performance



Cavity Fillers

Cavity fillers are available in 4000 series full bore valves. The fillers are PTFE and used for sanitary applications and in processes where cross contamination is a concern. Food processing, pharma-chemicals, cosmetics, paints, solvents, finishes and dyes are typical applications where fillers are employed.



Accessories Table - inches (DN/mm)									
Valve Size*		Bonnet/Stem† Extension	Stem Extension	Locking Oval	Round	Round/Oval Handle		Allowable Max. Torque FT•LBS (N•m)	
Standard Bore	Full Bore					Dimension A	Dimension H	Round	Oval
1/2" (15)	1/2" (15)	SE-096	SE-093	112-0108-30	112-0105-30	4.00 (101.6)	2.96 (75.2)	9 (14)	9 (14)
3/4" (20)	—	SE-096	SE-093	112-0108-30	112-0105-30	4.00 (101.6)	3.11 (79.0)	9 (14)	9 (14)
1" (25)	3/4" (20)	SE-097	SE-094	112-0109-30	112-0106-30	4.50 (114.3)	3.70 (94.0)	18 (25)	18 (25)
1-1/4" (32)	1" (25)	SE-097	SE-094	112-0109-30	112-0106-30	4.50 (114.3)	3.83 (97.3)	18 (25)	18 (25)
1-1/2" (40)	1-1/4" (32)	SE-098	SE-095	112-0110-30	112-0107-30	5.75 (146.0)	4.75 (120.7)	25 (34)	25 (34)
2" (50)	1-1/2" (40)	SE-098	SE-095	112-0110-30	112-0107-30	5.75 (146.0)	4.94 (125.5)	25 (34)	25 (34)
2-1/2" (65)	2" (50)	—	—	—	—	—	—	—	—

* Specify LD 64 when a locking device is required for 2" (DN 50) full bore and 2-1/2" (DN 65) standard port valves.
† For valves with Peek (L), Delrin (R) or 17-4 PH SS (D) seats.

HOW TO ORDER SERIES 4000 BALL VALVES

To specify a Series 4000 valve, select the body style, the combination of body and trim material, the proper seat material, and the appropriate body bolts for the application. Code numbers are fully descriptive of a valve. They are made up of size and a figure designation based on the following coding:

EXAMPLE: This order code calls for a 3/4" standard-port NPT *Fire-Tite* valve with carbon steel body, 316 stainless steel ball and stem, *Xtreme* seats and PTFE seals, and ASTM A193 Gr. B7 bolts with ASTM A194 Gr 2H nuts.

1	–	2	3	4	–	5	6	7	–	8	9
3/4		4A	–	–		22	36	XT		B	1

1	Size - 1/2 – 2-1/2 (DN 15-65) Standard Port, 1/2 – 2 (DN 15-50) Full Port						
inches	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2
DN	15	20	25	32	40	50	65

2	Body Style
4A	Standard Port NPT
4B	Full Port NPT
4C	Std. Port socket weld
4D	Full port socket weld
4F	Std. port butt weld Schedule-5
4G	Std. port butt weld Schedule-10
4H	Std. port butt weld Schedule-40
4J	Full port butt weld Schedule-5
4K	Full port butt weld Schedule-10
4L	Full port butt weld Schedule-40
4M	Std. port NPT x soc. weld ends
4N	Full port NPT x soc. weld ends
4P	Full port butt weld Schedule 80
4Q	Std. port butt weld Schedule 80
4R	Std. port ISO 7 Rp (BS21 parallel DIN 2999)
4S	Std. port ISO 7 Rc (BS21 taper)
4T	Full port ISO 7 Rp (BS21 parallel DIN 2999)
4U	Full port ISO 7 Rc (BS21 taper)

3	Configuration
–	(no entry if *Fire-Tite*)
X	Non-*Fire-Tite*
B	ANSI B16.34, B31.1, B31.3, and 31.4
M[3]*	ANSI B16.34 & BS5351 Class 600 with metric nameplate

4	Special Service
–	(no entry if standard)
N	NACE MR0103 w/exposed body fasteners
O	Oxygen (specify w/ANSI configuration B)
Q	PTFE Cavity Filler (Full Bore, 316 SS only)
V	High vacuum (specify w/ANSI configuration B)
VC	High vacuum certified (specify w/ANSI configuration B)
C	Chlorine (specify w/ANSI configuration B)
TG	Top Ground
STGR	Top and Bottom Ground
LA	Standard Emission Pak w/o Leakoff Connection
LL	Standard Emission Pak with Leakoff Connection

5	Body Material
22	Carbon steel
36	316 Stainless steel

6	Ball and Stem Material
00	Same as body (Carbon steel not available)
36	316 Stainless steel
HB	316 Stainless steel ball, 17-4 PH stem (required for RT & LG seats & seals)
71	Monel
73	Hastelloy C (non NACE MR0103 valves)

7	Seat and Seal Material	
	Seats	**Seal**
	Standard *Fire-Tite* Options	
XT	*Xtreme*	TFM & Graphite
TT	PTFE	PTFE & Graphite
DH	17-4 PH Stainless steel	Graphite
UU	UHMW Polyethylene*	UHMW PE & Graphite
RT[2,4]	Delrin*	PTFE & Graphite
BT	PFA	PTFE & Graphite
	Non *Fire-Tite* Options	
TT	PTFE	PTFE
UB	UHMW Polyethylene	UHMW Polyethylene & EPT
LG[2,4]	Peek*	Peek & Graphite
LT[2,4]	Peek**	PTFE & Graphite

8	Valve Model
B	Series 4000 Model B

9	Body Fasteners	
	Bolts or Tie Rods	**Nuts**
1	ASTM A193 Gr. B7	ASTM A194 Gr. 2H
2	ASTM A193 Gr. B8M*	ASTM A194 Gr. 8, 8C, 8M. BT, or 8F
5[1]	ASTM A193 Gr. B7M	ASTM A194 Gr. 2HM
7[1]	ASTM A320 Gr. L7M	ASTM A194 Gr. 7M
8[1]	ASTM A453 Gr. 660	ASTM A453 Gr. 660

* For 1/2" – 2" (DN 15 – 50) standard port and 1/2" – 1-1/2" (DN 15 – 40) full bore valves
** For 2" (DN 50) full bore and 2-1/2" (DN 65) standard port only.
1 Exposed bolting options for NACE MR0103 service.
2 Requires high strength stem.
3 Valves larger than 1" (DN 25) are CE marked.
4 Not a self-relieving seat design.

TFM is a registered trademark of Dyneon Co.
Delrin is a registered trademark of DuPont Co.

Subject to change without prior notice.

Metso Automation Inc.
Europe, Vanha Porvoontie 229, P.O. Box 304, FI-11301 Vantaa, Finland.
Tel. +358 20 483 150. Fax +358 20 483 151
North America, 44 Bowditch Drive, P.O. Box 8044, Shrewsbury, MA 01545, USA.
Tel. +1 508 852 0200. Fax +1 508 852 8172
South America, Av. Independência, 2500- Iporanga, 18087-101, Sorocaba-São Paulo Brazil. Tel. +55 15 2102 9700. Fax +55 15 2102 9748/49
Asia Pacific, 20 Kallang Avenue, Lobby B, #06-00, PICO Creative Centre, Singapore 339411, Singapore.
Tel. +65 6511 1011. Fax +65 6250 0830
China, 19/F, the Exchange Beijing, No. 118, Jianguo Lu Yi, Chaoyang Dist, 100022 Beijing, China.
Tel. +86-10-6566-6600. Fax +86-10-6566-2575
Middle East, Roundabout 8, Unit AB-07, P.O. Box 17175, Jebel Ali Freezone, Dubai, United Arab Emirates. Tel. +971 4 883 6974. Fax +971 4 883 6836
www.metso.com/automation

metso

EMERGENCY SHUTOFF AND FIRESAFE VALVES FIGURE 1075

The Jamesbury FM (Factory Mutual) approved Emergency Shutoff and Firesafe Valves Figure 1075 are manual assemblies consisting of the Jamesbury Fire-Tite® valves and the Jamesbury Torque Handles®. These assemblies provide automatic closure of a normally open valve in the event of a fire or excessive temperature. These assemblies are used for all types of media including flammable gases, liquids, and toxic fluids.

Figure 1075 assemblies carry FM approval as Firesafe Valves, specifically designed for flammable liquid service. To meet the requirements of this category, the Jamesbury *FIRE-TITE* valves have been tested and qualified to resist direct exposure typical of uncontrolled fire for at least 15 minutes.

Included in the line of Figure 1075 Emergency Shutoff Valve assemblies are 1/2"-2" (DN 15-50) Series 5150 flanged ball valves and 1"-2" (DN 25-50) Series 2000 Clincher® screwed-end ball valves equipped with *TORQ-HANDLE* spring-return handles and a choice of fusible links for specific temperature requirements.

FEATURES

- Automatic closure in the event of a fire.
- FM approved for Emergency Shutoff service.
- FM approved as Firesafe Valves for flammable liquid service.
- Quarter-turn operation for quick shutoff in the event of an emergency.
- Flexible-lip seat design for reliable long-lasting sealing.
- PTFE seats and seals for easy cycling, even when operated infrequently.

ACCESSORIES

Limit switches can be provided for remote indication of valve position or for various electrical interlocks. Switch arrangements available with these assemblies are:

Designation	Switch Type	Enclosure
EW2	(2) SPDT	Dustight, Watertight [1]
32EX6	(2) SPDT	Watertight, Hazardous Location [2]
34EX6	(2) DPDT	Watertight, Hazardous Location [2]

Note 1: Meets NEMA 4 specifications.
Note 2: Meets NEMA 4, 7 - Groups C and D, and 9 - Groups E, F, and G specifications.

Unless otherwise specified, assemblies with limit switches are adjusted at the factory so that one switch is actuated when the valve is closed, and the other when the valve is fully open.

Spring-return handles may be specified with optional accessories when FM approval is not a consideration. Locking devices to padlock the handle in position or electrothermal links to allow connection to a remote device like a smoke or heat detector are available. See Bulletin B160-1 for non-FM-approved standard spring-return handles and various accessories.

jamesbury Bulletin B132-1 Issue 9/2001

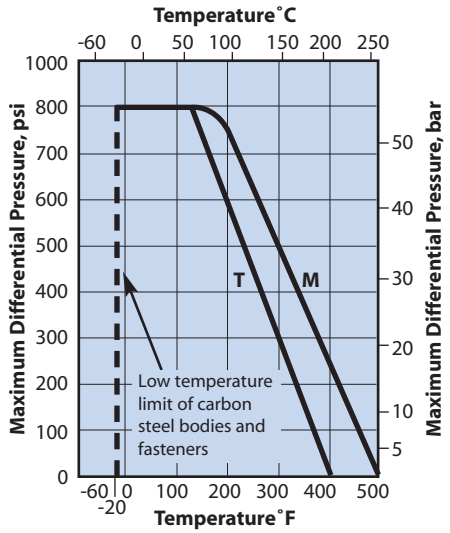
metso automation

SPECIFICATIONS

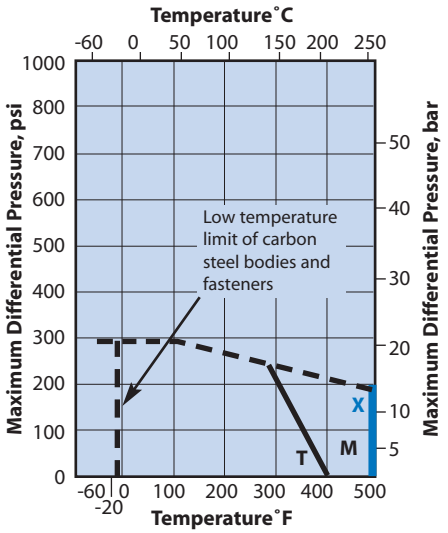
Valve Seat Ratings

Seat ratings, indicated by solid lines in the charts, are based on differential pressure with the valve ball in the fully closed position and refer to seats only. In the charts below the dotted lines indicate maximum working pressures for carbon steel valve bodies. Maximum working pressure of 316 stainless steel bodies are shown below. The combination of dotted and solid lines indicates the maximum valve rating at specific pressure and temperature conditions. Valves with PTFE, XTREME ™ and filled PTFE seats can be used in service to -60˚F (-51˚C) provided the valve body material and body fasteners are suitable for such temperatures. **Note:** Fasteners for FM-approved Series 2000 valves are rated for -20˚F only.

1"-2" (DN 25-50) Series 2000 Valves



1/2"-2" (DN 15-50) Series 5150 Valves



T - PTFE **M - Filled PTFE** ***X - XTREME***

VALVE BODY RATINGS

These are maximum working pressure ratings of the valve body only. The seat ratings, shown above, determine the practical pressure limitations according to actual service conditions. Test pressures are for hydrostatic test with ball half open.

1"-2" (DN 25-50) Series 2000 Valves Body Ratings				
Parameter	˚F	˚C	Carbon Steel or 316 Stainless Steel Body with ASTM A193 Gr. B7 Body Bolts	
			psi	bar
Working pressure	-20 to +100	-29 to +38	800	55
Test pressure			1200	83

1/2"-2" (DN 15-50) Series 5150 Valves Body Ratings						
Parameter	˚F	˚C	Carbon Steel		316 Stainless Steel	
			psi	bar	psi	bar
Working Pressure	-20 to +100	-29 to +38	285	20	275	19
	200	93	260	18	240	17
	300	149	230	16	215	15
	400	214	200	14	195	13
	500	260	170	12	170	12
Test Pressure			450	31	425	29

FLOW DATA

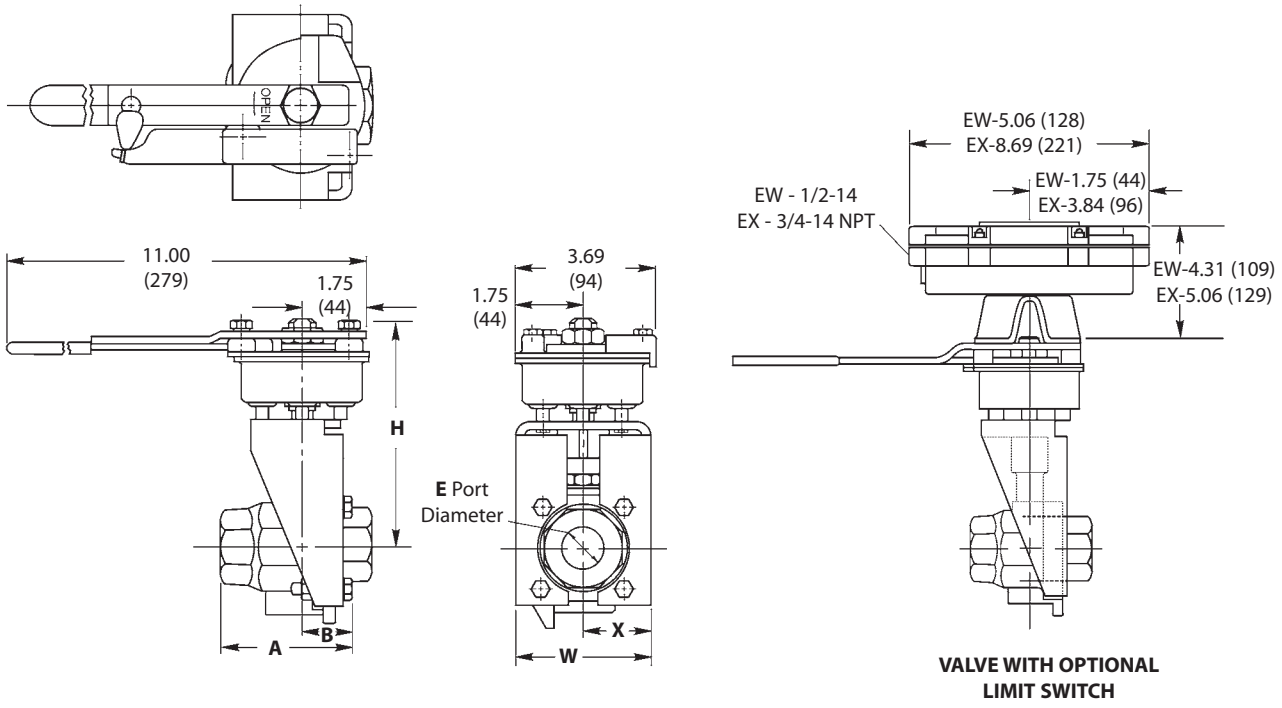
The tables to the right provide flow coefficients for *JAMESBURY* valves covered in this section. The C_v values represent the flow of water at +60˚F through the valve in U.S. gallons per minute at a pressure drop of 1 psi. The metric equivalent, K_v, is the flow of water at 16˚C through the valve in cubic meters per hour at a pressure drop of 1 kg/cm³. To convert C_v to K_v, multiply by 0.8569

Series 2000 Valves		
Valve Size		C_v
Inches	DN	
1	25	49
1-1/4	30	49
1-1/2	40	100
2	50	115

Series 5150 Valves		
Valve Size		C_v
Inches	DN	
1/2	15	9
3/4	20	19
1	25	45
1-1/2	40	125
2	50	165

DIMENSIONS

Series 2000 1"-2" (DN 25-50) *CLINCHER* Screwed-End Valves - inches (mm)

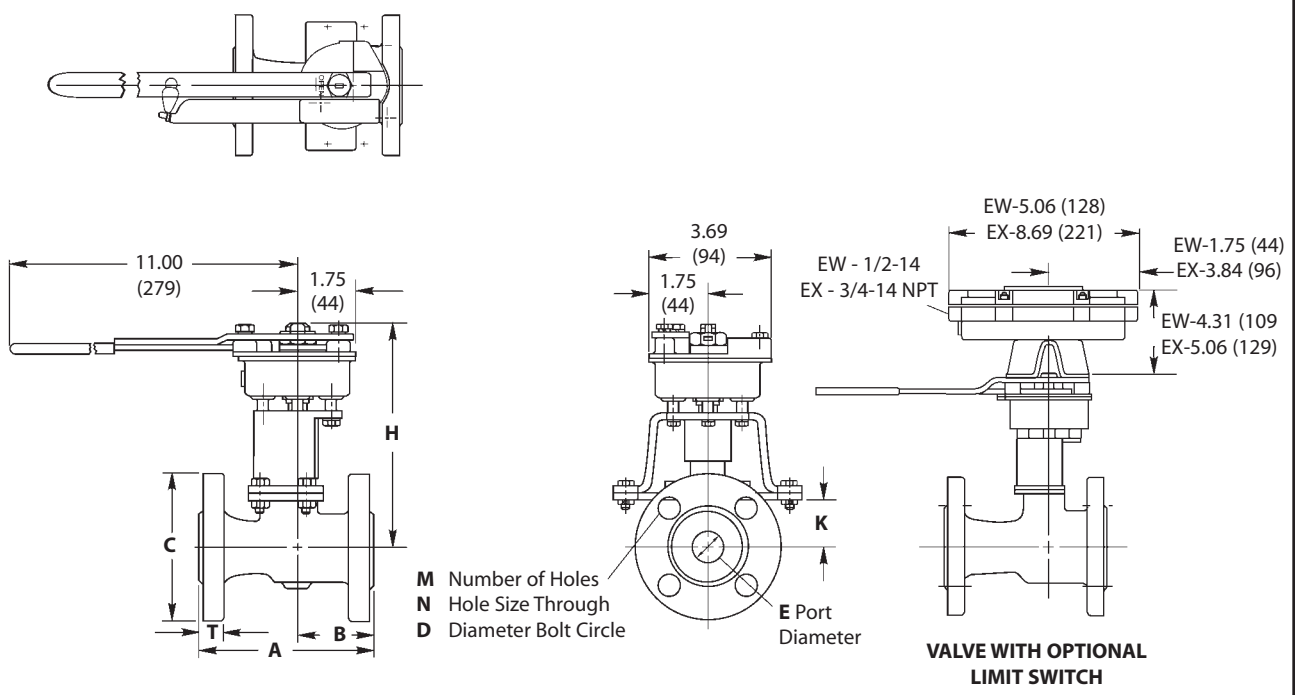


Approximate Dimensions - inches							
Valve Size inches	**A**	**B**	**W**	**X**	**E**	**H**	**Approx. Weight lb.**
1	3.41	1.70	3.63	1.81	0.88	6.13	7.6
1-1/4	3.75	1.88	3.63	1.81	1.00	6.25	9.2
1-1/2	4.03	2.02	3.88	1.94	1.25	6.75	11.3
2	4.38	2.19	4.25	2.13	1.50	7.00	13.3

Approximate Dimensions -mm							
Valve Size DN	**A**	**B**	**W**	**X**	**E**	**H**	**Approx. Weight kg.**
25	87	43	92	46	22	156	3
30	95	48	92	46	25	159	4
40	102	51	99	49	32	171	5
50	111	56	108	54	38	178	6

DIMENSIONS

Series 5150 1/2"- 2" (DN 15-50) ANSI Class 150 Flanged Valves - Inches (mm)



Approximate Dimensions - inches											
Valve Size inches	A	B	C	D	E	H	K	M	N	T	Approx. Weight lb.
1/2	4.25	1.81	3.50	2.38	0.50	6.25	0.88	4.00	0.63	0.44	8.1
3/4	4.63	2.00	3.88	2.75	0.68	6.38	1.00	4.00	0.63	0.44	9.1
1	5.00	2.19	4.25	3.13	0.88	6.88	1.38	4.00	0.63	0.63	12.9
1-1/2	6.50	2.44	5.00	3.88	1.25	7.75	2.19	4.00	0.63	0.63	16.5
2	7.00	2.44	6.00	4.75	1.50	7.88	2.38	4.00	0.75	0.69	21.1

Approximate Dimensions - mm											
Valve Size DN	A	B	C	D	E	H	K	M	N	T	Approx. Weight kg.
15	108	46	89	60	13	159	22	102	16	11	4
20	118	51	99	70	17	162	25	102	16	11	4
25	127	56	108	30	22	175	35	102	16	16	6
40	165	62	127	99	32	197	56	102	16	16	7
50	178	62	152	121	38	200	60	102	19	18	10

HOW TO ORDER EMERGENCY SHUTOFF AND FIRESAFE VALVES

The designation for Emergency Shutoff Valves is made up of numbers and letters that fully describe all features of the available variations of these units. Coding is as follows:

Figure 1075

Valve Size		
	Inches	DN
3*	1/2	15
4*	3/4	20
5	1	25
6**	1-1/4	30
7	1-1/2	40
8	2	50

Body Style	Body and Trim Materials
1– Series 2000 screwed end	Carbon steel with 316 stainless trim
2– Series 5150 flanged end	Carbon body with 316 stainless trim
3– Series 2000 screwed end	316 Stainless steel
4– Series 5150 flanged end	316 Stainless steel

Seat Material
T - PTFE
M- Filled PTFE
X - *XTREME*

Temperature Rating of Fusible Link
0– 165˚F (74˚C)
1– 135˚F (57˚C)
2– 212˚F (100˚C)
3– 286˚F (141˚C)

Torq-Handle® Release Mode
1- Spring-to-close
2- Spring-to-open

Optional Limit Switch
0 - No switch
1 - EW2
2 - 32EX6
3 - 34EX6

* Series 5000 valves only ** Series 2000 valves only

Example: A 1-1/2" (DN 40) Emergency Shutoff Valve Assembly Series 2000, screwed end in carbon steel with 316 stainless trim and PTFE seats with +165˚F (74˚C) fusible link and *TORQ-HANDLE* set for spring-to-close operation without limit switches is designated as Figure 1075-71T010.

Available Sizes by Valve Type and Seat Material				
Style	X* and T Seats		M Seats	
	Inches	DN	inches	DN
2000 5150	1-2	25-50	1-1-1/4	25-30
5150	1/2-2	15-50	1/2-1	15-25

* Series 5000 valves only

Installation Instructions, Maintenance and Operation

IMO's (Installation, Maintenance and Operating instructions) are shipped with the products. Additional copies of these instructions are available. Call your local Metso Automation Distributor, or visit our website.

Metso Automation, Field Systems Division
Europe, Levytie 6, P.O.Box 310, 00811 Helsinki, Finland. Tel. int +358 20 483 150. Fax int. +358 20 483 151
Europe (UK), 8 Pipers Wood Industrial Park, Waterlooville, Hampshire PO7 7XU UK. Tel. int +44 (0)23 9223 8500. Fax int. +44 (0)23 9223-8510
North America, 44 Bowditch Drive, P.O.Box 8044, Shrewsbury, Massachusetts, 01545-8044 USA. Tel. int. +1 508 852 0200. Fax int. +1 508 852 8172
North America, 3100 Medlock Bridge Road, Suite 250, Norcross, GA 30071, USA. Tel. int. +1 770 446 7818. Fax int. +1 770 242 8386
Latin America, Av. Central, 181- Cháracas Reunidas, 12238-430, São Jose dos Campos. Tel. int. +55 12 335 3500. Fax int. +55 12 335 3535
Asia Pacific, 501 Orchard Road, #05-09 Wheelock Place, 238880 Singapore. Tel int. +65 735 5200. Fax int. +65 735 2955
www.jamesbury.com • www.metsoautomation.com

B132-1-9/01
© 2001 Metso Automation
Printed in U.S.A.-M-J

CORRUGATED HOSE PROCESS

HYDROFORMED CORRUGATION PROCESS

TUBE

The manufacturing process of corrugated metal hose starts with a stainless steel strip that is rolled and the edges welded together to form a thin-walled, gas-tight tube. Hose Master offers:

High quality steel strip

Rolled steel to form a tube

Strong, clean, non-oxidized seam weld

HOSE

After the tube has been welded, corrugations are formed into the tube to make it flexible. There are two corrugation profiles, annular and helical.

Annular Profile
Independent corrugations, straight and parallel

Helical Profile
One continuous corrugation that spirals around the hose

Corrugations are formed into the tube either mechanically or hydraulically (Hydroforming)

Hydroformed
Evenly distributed stresses

Mechanically Formed
Concentrated stresses

Hydroforming enhances flexibility and cycle life, maintains wall thickness, reduces concentrated residual stress, and minimizes work hardening. Hydroforming is a clean process, using water to form the hose, while most other processes require lubrication.

CORRUGATION PROCESS FOR EXTRAFLEX AND HYDRAFLEX PRODUCTS

In addition to our line of annular, corrugated hose, Hose Master offers two helical hoses that are specially designed to maximize performance without the drawbacks of traditional, mechanically-formed helical hose. Rather than welding a tube and mechanically forming the corrugation, these products are made from a stainless steel strip that is formed before welding. Because it is not mechanically formed from a tube, this hose is extremely flexible and does not contain the residual stresses found in traditional mechanically-formed helical hose.

Extraflex Profile

Hydraflex Profile

Both Extraflex and Hydraflex are made by pre-forming the stainless steel strip, overlapping the material, and continuously resistance-welding the seam together. While Extraflex is made with one ply of stainless steel, Hydraflex is made with two plies for higher pressure ratings.

800-221-2319 • www.hosemaster.com

HYDROFORMED DIFFERENCE

HYDROFORMED FEATURES & BENEFITS

- Feature - Hydroforming induces a minimum of residual stress in the hose wall, as compared to other methods of manufacturing
  Benefit - Increased resistance to stress minimizes hose failures and significantly increases cycle life

- Feature - A characteristic of hydroformed hose is a very uniform metal thickness throughout the corrugation profile. Mechanical forming can result in significant variations in metal gauge
  Benefit - Uniform wall thickness promotes even distribution of strain during flexing, thereby increasing hose longevity

- Feature - The hydroformed manufacturing method incorporates three separate tests of the butt-welded hose seam
  Benefit - Ensures highest-quality hose and reduces premature product failure

- Feature - Hydroforming minimizes work hardening of the alloy during the corrugating process
  Benefit - Results in a more flexible hose and maintains proper alloy yield strength

- Feature - Proprietary manufacturing process, combined with skilled workmanship, allow for the use of lighter gauge metals
  Benefit - Allows for proper wall thickness, maximizing cycle life and flexibility

BRAIDING PROCESS

To give corrugated hose the ability to withstand pressure, stainless steel wire is braided over the hose. Hoses may be single braided (one layer of braid) or double braided (two layers of braid) to achieve even greater working pressures. Braided braid is used on large-diameter hose.

Designing the proper braid for each type of corrugated hose requires sophisticated engineering to maintain the proper balance between the braid strength and the hose's flexibility. Hose Master's braid packages offer several advantages:

1. High Percentage Braid Coverage - Hose Master flexible hose has the highest percentage of braid coverage, yielding better cycle life and protection against damage to the hose.

2. Machine Braided Hose - Hose Master weaves the braid directly onto the hose, ensuring that the braid fits tightly against the hose, preventing potential hose deformation or squirm. Machine braided hose also offers repeatable performance and longer cycle life.

HOSE PERFORMANCE CHART

HOSE TYPE	Number of Braids	Inside Diameter (in.)																	
		1/4		5/16		3/8		1/2		5/8		3/4		1		1 1/4		1 1/2	
		Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)
ANNUFLEX Standard Product T321, T316L, T304L See page 9	0 1 2	90 1800 2700	4.5	n/a	n/a	70 1558 2336	5.0	70 1186 1779	5.5	57 1205 1808	7.0	43 898 1347	8.0	43 718 1077	9.0	43 645 968	10.0	28 531 797	11.0
MASTERFLEX Most Flexible T321, T316L, T304L See page 10	0 1 2	90 1800 2700	3.7	n/a	n/a	70 1558 2336	4.0	70 1186 1779	4.4	57 1205 1808	5.6	43 898 1347	6.4	43 718 1077	7.1	43 645 968	7.9	28 531 797	8.7
PRESSUREFLEX High Pressure T321 See page 11	0 1 2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	220 1100 1650	8.0	190 1000 1400	9.0	200 900 1350	12.0	90 750 1200	13.0
PRESSUREMAX HP® Ultra-High Pressure T321 See page 12	0 1 2 3 4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	250 2650 3600 n/a n/a	4.5 10.0 10.0 n/a n/a	180 2500 3000 n/a n/a	7.0 11.0 11.0 n/a n/a	190 1775 2600 3000 n/a	9.5 12.5 12.5 14.0 n/a	110 1450 2200 n/a n/a	11.5 13.0 13.0 n/a n/a
CHEMKING® Chemical Resistance 276 See page 13	0 1 2	n/a	n/a	n/a	n/a	n/a	n/a	70 1186 1779	5.5	n/a	n/a	43 898 1347	8.0	43 718 1077	9.0	n/a	n/a	28 531 797	11.0
FORMAFLEX Stay-Put Application T321, T316L See page 15	0 1 2	90 900 n/a	n/a	n/a	n/a	70 800 n/a	n/a	70 665 n/a	n/a	57 500 n/a	n/a	43 380 n/a	n/a	43 355 n/a	n/a	43 280 n/a	n/a	28 264 n/a	n/a
BRONZEFLEX Bronze Alloy See page 16	0 1 2	n/a	n/a	n/a	n/a	60 704 936	6.0	50 566 753	7.0	n/a	n/a	30 468 622	8.0	26 334 444	10.0	16 306 407	12.0	15 297 395	13.5
EXTRAFLEX Helical/Flexible T321 See page 17	0 1 2	71 1778 2489	2.2	43 1422 1991	2.4	36 1138 1707	2.8	28 910 1422	3.1	28 910 1422	3.9	14 711 1138	5.1	11 569 910	6.3	9 455 711	7.9	7 356 569	9.4
HYDRAFLEX Helical/High-Pressure T316L See page 18	0 1 2	n/a 4600 5800	5.0	n/a 4000 4800	5.1	n/a 3800 4000	5.5	n/a 2600 3700	5.7	n/a 2400 2700	6.1	n/a 2000 2200	6.5	n/a 1500 2000	7.9	n/a 1100 1600	9.4	n/a 1000 1500	12.2

Product specifications are subject to change without notice.

800-221-2319 • www.hosemaster.com

HOSE TYPE	Number of Braids	Inside Diameter (in.)																	
		2		2 1/2		3		4		5		6		8		10		12	
		Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)	Working Pressure (psi)	Dynamic Bend Radius (in.)
ANNUFLEX Standard Product T321, T316L, T304L See page 9	0 1 2	14 449 674	13.0	14 417 626	16.0	14 346 519	18.0	14 299 448	22.0	14 275 412	28.0	11 210 315	32.0	3 250 360	29.0	4 175 310	34.0	3 185 325	44.0
MASTERFLEX Most Flexible T321, T316L, T304L See page 10	0 1 2	14 449 674	10.3	14 417 626	12.8	14 346 519	14.5	14 299 448	17.4	14 275 412	21.9	11 210 315	25.0	n/a	n/a	n/a	n/a	n/a	n/a
PRESSUREFLEX High Pressure T321 See page 11	0 1 2	105 800 1150	15.0	46 575 900	17.0	36 550 800	20.0	28 330 495	25.0	28 331 n/a	34.0	23 285 n/a	40.0	n/a	n/a	n/a	n/a	n/a	n/a
PRESSUREMAX HP® Ultra-High Pressure T321 See page 12	0 1 2 3 4	100 1100 1675 n/a n/a	12.0 14.0 14.0 n/a n/a	46 700 1050 n/a n/a	14.5 16.0 16.0 n/a n/a	36 600 900 1200 n/a	16.0 20.0 20.0 75.0 n/a	23 525 875 1200 n/a	19.0 26.0 26.0 n/a 96.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CHEMKING® Chemical Resistance 276 See page 13	0 1 2	14 449 674	13.0	n/a	n/a	14 346 519	18.0	14 299 448	22.0	14 275 412	28.0	11 210 315	32.0	n/a	n/a	n/a	n/a	n/a	n/a
FORMAFLEX Stay-Put Application T321, T316L See page 15	0 1 2	14 221 n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BRONZEFLEX Bronze Alloy See page 16	0 1 2	10 210 279	17.0	8 194 258	22.0	5 166 221	24.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
EXTRAFLEX Helical/Flexible T321 See page 17	0 1 2	6 284 455	11.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
HYDRAFLEX Helical/High-Pressure T316L See page 18	0 1 2	n/a 750 1100	14.6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Product specifications are subject to change without notice.

ANNUFLEX

ANNUFLEX is the foundation of Hose Master's extensive line of annular hydroformed products. The hydroforming process produces a hose with minimal residual stress, uniform wall thickness throughout the corrugations, and minimal work hardening. This process creates a very flexible, long-lasting corrugated metal hose.

Explanation of Annuflex Part Numbers

AF _____ 7 _____

Material Code Braid Code

Material Codes
- 4 - T321 Stainless Steel
- 6 - T316L Stainless Steel
- 7 - T304L Stainless Steel

Braid Codes
- 00 - Unbraided
- 50 - T304 Single Braid
- 55 - T304 Double Braid

T316 Braid available upon request

Example: AF4750 = T321 stainless steel, annular corrugated metal hose with a single T304 stainless steel braid

Inside Diameter (in.)	Number of Braids (#)	Outside Diameter (in.)	Static Minimum Bend Radius (in.)	Dynamic Minimum Bend Radius (in.)	Maximum Working Pressure (psi)	Burst Pressure (psi)	Weight Per Foot (lbs.)
1/4	0	0.41	1.0	4.5	90	n/a	0.04
	1	0.47			1800	7233	0.11
	2	0.53			2700	9100	0.18
3/8	0	0.65	1.2	5.0	70	n/a	0.10
	1	0.71			1558	6230	0.20
	2	0.77			2336	9345	0.30
1/2	0	0.77	1.5	5.5	70	n/a	0.11
	1	0.83			1186	4743	0.22
	2	0.89			1779	7115	0.33
5/8	0	0.96	1.8	7.0	57	n/a	0.17
	1	1.02			1205	4820	0.33
	2	1.08			1808	7230	0.49
3/4	0	1.16	2.1	8.0	43	n/a	0.19
	1	1.22			898	3591	0.37
	2	1.28			1347	5387	0.55
1	0	1.47	2.7	9.0	43	n/a	0.26
	1	1.53			718	2872	0.50
	2	1.59			1077	4308	0.74
1 1/4	0	1.75	3.1	10.0	43	n/a	0.29
	1	1.83			645	2581	0.61
	2	1.91			968	3872	0.93
1 1/2	0	2.08	3.9	11.0	28	n/a	0.47
	1	2.16			531	2125	0.85
	2	2.24			797	3188	1.23
2	0	2.61	5.1	13.0	14	n/a	0.59
	1	2.69			449	1797	1.11
	2	2.77			674	2696	1.63
2 1/2	0	3.40	6.8	16.0	14	n/a	0.84
	1	3.50			417	1669	1.64
	2	3.60			626	2504	2.44
3	0	3.88	7.8	18.0	14	n/a	1.18
	1	3.98			346	1384	2.06
	2	4.08			519	2076	2.94
4	0	4.96	9.8	22.0	14	n/a	1.41
	1	5.06			299	1194	2.47
	2	5.16			448	1791	3.53
5	0	6.00	12.8	28.0	14	n/a	2.18
	1	6.12			275	1099	3.61
	2	6.24			412	1649	5.04
6	0	7.01	14.8	32.0	11	n/a	2.69
	1	7.13			210	839	4.44
	2	7.25			315	1259	6.19
8*	0	9.04	18.0	29.0	3	n/a	4.88
	1	9.32			250	1000	8.21
	2	9.60			360	1446	11.53
10*	0	11.34	21.0	34.0	4	n/a	7.42
	1	11.56			175	700	11.05
	2	11.78			310	1247	14.67
12*	0	13.45	27.0	44.0	3	n/a	11.04
	1	13.73			185	745	16.71
	2	14.00			325	1306	22.38

* 8 inch, 10 inch and 12 inch diameter AF4750 are supplied with braided braid

- The minimum bend radius is measured from the centerline of the hose
- The working pressure decreases with temperature - obtain derating factor on page 33 in Technical Information
- For rapid pressure fluctuations, consult factory

45° & 90° SAE (JIC)

Alloys	Stainless Steel, Carbon Steel
Size Range	1/2" - 2"
Schedules	n/a

Sanitary Flange

Alloys	T304 & T316 Stainless Steel
Size Range	1"- 3"
Schedules	n/a

Slip-On Flange

Alloys	T304 & T316 Stainless Steel, Carbon Steel
Size Range	1/2" - 12"
Schedules	150#, 300#

Plate Flange

Alloys	T304 & T316 Stainless Steel, Carbon Steel
Size Range	1/2" - 12"
Schedules	150#

Weld Neck Flange

Alloys	T304 & T316 Stainless Steel, Carbon Steel
Size Range	1/2" - 6"
Schedules	150#, 300#

TTMA Flange

Alloys	T316 Stainless Steel, Carbon Steel
Size Range	2" - 6"
Schedules	n/a

C-Stub with Floating Flange

Alloys	T304 & T316 Stainless Steel
Size Range	1/2" - 10"
Schedules	10

A-Stub with Lap Joint Flange

Alloys	T304 & T316 Stainless Steel, Carbon Steel, 276
Size Range	1/2" - 8"
Schedules	10, 40

APPENDIX E - FLEXIBLE CONNECTORS

FITTINGS

TTMA C-Stub Swivel

Alloys	T304 & T316 Stainless Steel
Size Range	4" - 6"
Schedules	10

Part A & Part D (Cam-Lock)

Alloys	T316 Stainless Steel, Brass, Aluminum
Size Range	1/2" - 8"
Schedules	n/a

Tube End

Alloys	T304, T316 & T321 Stainless Steel, Carbon Steel
Size Range	1/8" - 12" (seamless or welded)
Schedules	Various

Short & Long Radius Elbows (45° & 90°)

Alloys	T304 & T316 Stainless Steel, Carbon Steel, 276
Size Range	1/4" - 12"
Schedules	Various

Reducer

Alloys	T304 & T316 Stainless Steel, Carbon Steel
Size Range	3/4" - 12"
Schedules	10, 40 (carbon steel)

Beveled Pipe End

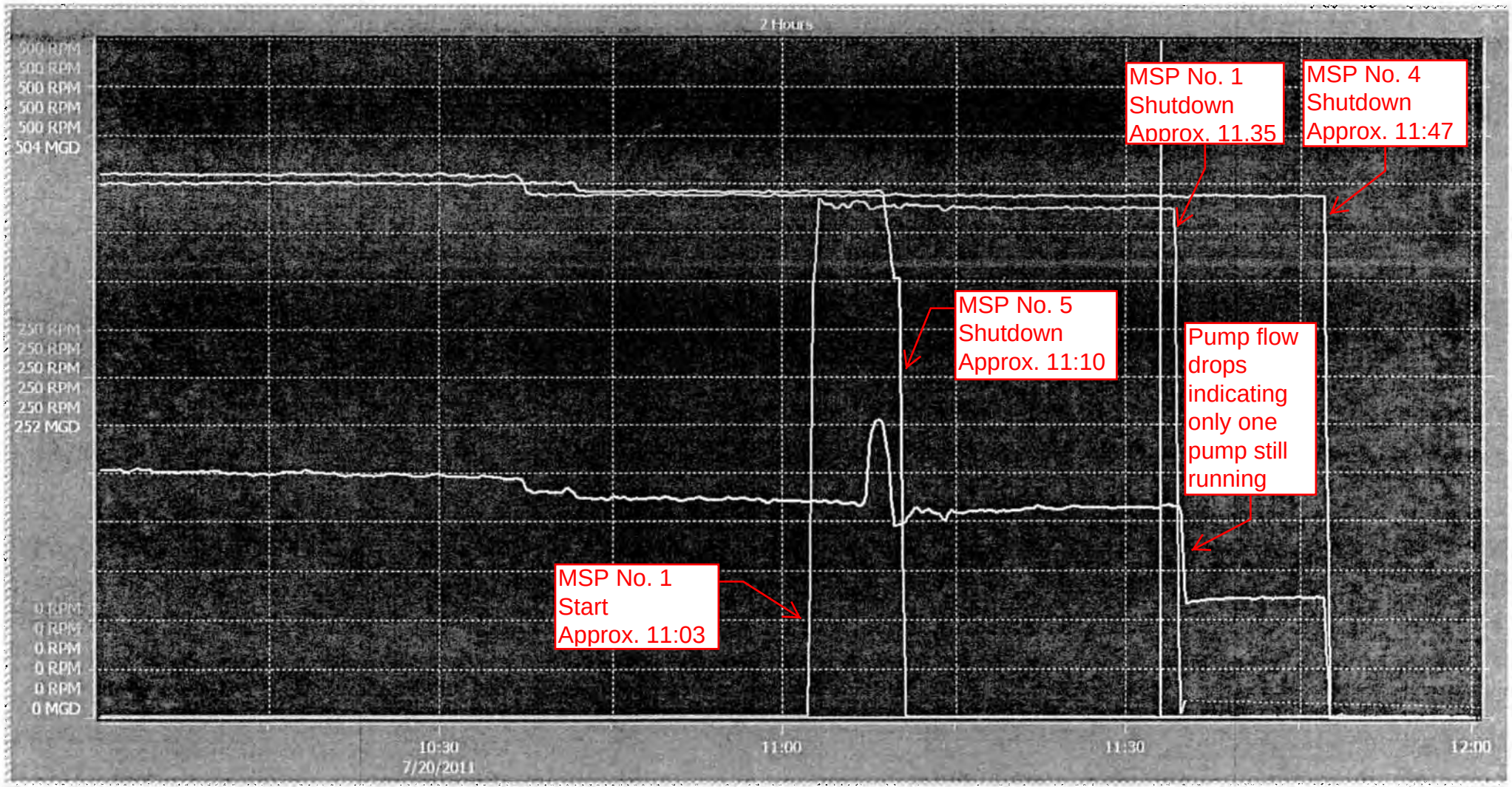
Alloys	T304 & T316 Stainless Steel, Carbon Steel, 276
Size Range	1/8" - 12"
Schedules	Various

Ground Joint Female

Alloys	Carbon Steel
Size Range	1/2" - 4"
Schedules	n/a

Specialty Gas Nuts

Alloys	Brass
Size Range	A, B, C, & D
Schedules	SAE & BSP



2 Hours 7/20/2011 11:00:32 AM

	Visibl	Stat	Trac	Object Name	Object Description	Current	Low	High	Ruler Time	Ruler Value
1	☑			SIRS01:OUT	RAW SEWGENG SPD 1411	-89.91	0.00	500.00	7/20/2011 11:33:01	375 RPM
2	☑			SIRS02:OUT	RAW SEWGENG SPD 1412	-117.72	0.00	500.00	7/20/2011 11:33:01	0 RPM
3	☑			SIRS03:OUT	RAW SEWGENG SPD 1413	-0 RPM	0.00	500.00	7/20/2011 11:33:01	-0 RPM
4	☑			SIRS04:OUT	RAW SEWGENG SPD 1414	370 RPM	0.00	500.00	7/20/2011 11:33:01	384 RPM
5	☑			SIRS05:OUT	RAW SEWGENG SPD 1415	375 RPM	0.00	500.00	7/20/2011 11:33:01	0 RPM
6	☐			NORTWWL:	NORTH WTWLL LVL	-48.00	-48.00	-21.00		
7	☐			SOUTWWL:	SOUTH WTWLL LVL	-48.00	0.00	-21.00		
8	☑			FYRS01:OU	MSP TTL FLOW BACK-UP SYS	-118.63	0.00	504.00	7/20/2011 11:33:01	155 MGD

7/26/2011 5:56:42 PM

ERVATION: FAXED REPORT.

H. C.

OILER - W. MAJOR.

CO FINAL - CASTOR.

ROSWELL CAMPLE - PARKER.

(#4 E/S ONLY) #2 + 4 BLOWERS

#2 + 4 + 6 THICKNERS.

ESPOR. #4 + 5 + 6 HYPO TANKS.

S. #3611 R. SLUDGE PUMP.

#1 + 6 MAIN GATES FULLY OPEN.

CLOSED. R. SLUDGE WASTING

1.6 mg/L. #4 SEC.

TRANSFER FROM #4 SEC.

AND C/O AT 1 45 PM.

CUT OUT. #1 MSP OFF-GAS

ALS. HYPO TO SOUTH ODOR.

IONAL HYPO.

ONE 5000 GALS. AND 3000

ON AS WE GET ENOUGH

DGE. 150 TO 160 G.P.H

3-11 SHIFT FROM SOUTH.

THIRER.

WEATHER: CLEAR. WEDNESDAY 20 JULY

STACK OBSERVATION:

SHIFT - 7-3. WATCH - R.

SEC - FRANCIS SSTW - BOI OILER - W. MAJOR.

SCREEN - DONATO. PRI + AREA - COLO FINAL - SANTANA.

THICK + DIG - FITZGIBBON. THICK + BOAT - BUTCHER. SAMPLE - PARKER.

O/S #4 + 5 BAR SCREENS. #3 MSP (#4 E/S ONLY) #2 + 4 BLOWERS.

#7 PRI - TANK. #9 FINAL TANK. #2 + 4 + 6 THICKNERS.

#7 DIGESTER. #5 & 6 GAS COMPRESSOR. #4 + 5 + 6 HYPO TANKS.

#3503 + 05 WASTE SLUDGE PUMP. #3611 R. SLUDGE PUMP. GAS HOLDER.

T/O KEYS RADIOS.

T/S #1 + 5 MSP. #1 + 3 + 5 BLOWERS. #1 + 2 + 6 MAIN GATES FULLY OPEN.

OPERATIONS. SEC. BY PASS GATES CLOSED. R. SLUDGE WASTING

1600 G.P.M. TARGET RESIDUAL 1.6 mg/L HYPO TO R. SLUDGE

150 G.P.H. #4 SEC. DIGESTER. STARTED SLUDGE TRANSFER

AT 7 30 AM.

9 30 AM. C/I #4 MSP AS TRIAL RUN. #1 MSP C/O BY ITSELF

AT THE SAME TIME - COULD NOT START DUE TO FUEL OIL

PRESSURE. OILERS WORKING ON #1 MSP. #4 MSP FLOW

READING ON TREND IS NOT WORKING. JAY & GIACOMO WORK-

11 15 AM ING ON IT. C/I #1 MSP AFTER FIXING FUEL OIL LEAK. C/O #5

MSP.

11 30 AM C/O SLUDGE TRANSFER.

NYC Environmental Protection

North River WPCP
Pump Engine # 1

N.Y.C. Department of Environmental Protection
Bureau of Wastewater Treatment
Day W Date 07/29/11 (M M D D Y Y)

Document Control #: NR-10-18393

PRESSURES

TIME	RPM	DIG. GAS	NAT. GAS	CRANK CASE VAC.	LUBE OIL ENGINE	LUBE OIL TURBO	JACKET WATER IN	RING FLUSH WATER	PUMP DISCH.	COMB. AIR	FUEL GAS	LUBE OIL FILTER IN	LUBE OIL FILTER OUT	FUEL OIL FILTER IN	FUEL OIL FILTER OUT	RIGHT ANGLE DRIVE OIL PRESS.	RIGHT ANGLE DRIVE OIL TEMP.	ENGINE OIL SUMP #	GOV OIL LEVEL
PREV.	340	100	0	.1	56	15	19	O/S	O/S	O/S	O/S	62	62	47	12	48	104	60	OK
8 AM	355	–	–	.1	59	16	20					65	64	47	12	58	106	66	OK
10 AM										C/O	AT	0926	HRS	Due	To	Low	Fuel	Pre	
NOON																			
2 PM																			
4 PM																			
6 PM																			
8 PM																			
10 PM																			
MID																			
2 AM																			
4 AM																			
6 AM																			

TEMPERATURES

TIME	CYL. 1	CYL. 2	CYL. 3	CYL. 4	CYL. 5	CYL. 6	EXHST	JACKET WATER IN	JACKET WATER OUT	LUBE OIL IN	LUBE OIL OUT	COMB. AIR	TURBO AIR	SHAFT BEARING # 1	SHAFT BEARING # 2	PUMP BEARING # 1	PUMP BEARING # 2	STACK GAS
PREV.	669	650	838	884	787	957	O/S	157	162	167	171	82	137	O/S	108	84	81	388
8 AM	718	807	746	763	765	733		159	163	167	173	82	146		106	83	81	406
10 AM								Shut	down	Due	To	Low	Fuel	Pressure		AT	0926	HRS	
NOON																		
2 PM																		
4 PM																		
6 PM																		
8 PM																		
10 PM																		
MID																		
2 AM																		
4 AM																		
6 AM																		

FUEL OIL METER	
PREV.	
8 AM	

NATURAL GAS METER	
PREV.	
8 AM	

6 AM ELAPSED TIME	
PREV.	9101
TODAY	

LUBE OIL ADDED		
7 - 3	3 - 11	11 - 7

7 - 3 OILER [illegible]

3 - 11 OILER

11 - 7 OILER

7 - 3 SEE

3 - 11 SEE

11 - 7 SEE

APPENDIX F - NORTH RIVER WPCP RAW SEWAGE PUMP ENGINE NO. 1 OPERATIONAL DATA SHEET

AFFILIATED ENGINEERING LABORATORIES, INC.

Engineering Consultants

Physical Location:
777 New Durham Road
Edison, NJ 08817

P.O. Box 3300
Edison, NJ 08818-3300

Phone (732) 429-1200
Fax (732) 429-1201
www.affiliatedinc.net

October 18, 2011

Black & Veatch Corporation
489 Fifth Avenue
12th Floor
New York, New York 10017

Attention: Kyriacos Pierides, Ph.D., P.E.

Re: North River Waste Treatment Plant
Insurance Claim No. FR-9393
Our File No. T-1962

Dear Dr. Pierides:

Pursuant to your request, Affiliated Engineering Laboratories conducted a metallurgical evaluation on various items that were submitted pertaining to the above referenced matter. On 7/20/11, an explosion and fire was reported to have occurred with Diesel Engine No. 1 in the diesel engine room of the North River Waster Treatment Plant located at 725 West 135th Street, New York, NY. The result of the damage was the release of untreated waste water into the Hudson River. It was reported that one of the two valves, which was the return line connected to the diesel fuel meter, was found completely fractured while the return line valve to the diesel fuel meter exhibited a crack. The valves were located within a short distance of the turbocharger intake manifold. Initially, it was alleged that one or both valves had fractured during operation of the engine, resulting in the release of high pressure diesel fuel which was sucked into the turbocharger and ignited above the engine. Affiliated Engineering Laboratories, Inc. was given four objectives as part of the evaluation in order to prove or disprove the aforementioned allegation. Testing was performed on the submitted items as per the 7/29/11 test protocol. However, after the metallurgical evaluation was performed on the submitted items, it was proven that the fractured valves failed as a result of the fire and was not the cause for the fire. Therefore, additional items were submitted. Based on the testing of the additional items, the writers concluded that two plausible leak scenarios may have occurred, either in the high pressure fuel line connection to the fuel pump or within the braided fuel line. The results of the evaluations were conveyed on an interim basis via email as well as via weekly teleconferences with Black & Veatch and the following shall serve as confirmation of the findings.

On 7/28/11, John P. Gashinski, P.E., CFEI conducted a general site inspection as directed by Black & Veatch and documented the items that were removed for testing, (See Appendix A for selected photographs from the site inspection). All photographic documentation from the 7/28/11 site inspection and the subsequent metallurgical testing are included in the enclosed CD-ROM for your file.

Given the aforementioned allegation, the following objectives were requested:

A. Characterize the failure mode of the incident valves.
B. Determine whether there is evidence of diesel fuel ignition in the turbo charger of the subject waste treatment engine.
C. Compare the collected samples of aluminum to determine whether they originated from the turbo charger casing
D. Identify cracking, if any, in the collected bolts

SUBMITTED ITEMS

Appendix B contains photographs of the submitted items taken in the as-received condition.

1 Diesel return line nipple
2 Diesel fuel s/o #3 Engine exemplar
3 Diesel fuel s/o #3 Engine exemplar
4A Diesel return piping & valves #1 Engine
4B Diesel return piping #1 Engine
4C Diesel fuel return line #1 Engine
5 Lube oil drain pipe – turbo #1 Engine
6 Turbo blade scrapings
7 Ventilator filter
8 Turbo charger flange bolts
9 Turbo interior bolts
10 Aluminum found in turbo
11 Aluminum found below turbo
12 Debris found in turbo
13 Melted aluminum on floor approx. 29' N.W. of turbo

TESTING

A. Characterize the failure mode of the incident valves.

A metallurgical evaluation of the fractured valves from Engine No. 1 (Items Nos. 1, 4A, and 4C) was performed along with comparative studies with that of the exemplar valves from Engine No. 3 (Item Nos. 2 and 3).

Appendix C contains select photographs obtained during the metallurgical evaluation of the submitted valves.

A.1. Visual Examination

It was reported that Item No. 1 was reportedly removed from Engine No. 1 upon initial investigation of the fire/explosion. Item No. 1 consisted of a 3-inch long threaded steel nipple with a portion of the diesel return line valve still attached to one end. The valve fractured through its female threaded portion where the end of the nipple had been threaded. In fact, the end of the threaded nipple was found flush with that of the fracture plane of the valve. No plastic deformation was observed in the material adjacent to the fracture. Some tool marks were found on the pipe nipple as well as the valve portion. However, the tool marks did not appear to intersect the fracture plane. The fracture on the valve portion matched that of the fractured end of the valve identified as 4A-2, as described below. Once Item No. 1 was documented in the as-received condition, the fractured portion of the valve was carefully removed from the nipple for further examination. It was observed that the nipple had engaged five (5) threads of the valve. The nipple appeared to be of standard construction with eight (8) complete tapered threads on either end.

Item No. 4A was a piping assembly consisting of threaded steel pipe/nipples, couplings, and brass valves that reportedly attached Engine No. 1 to the fuel metering station with two branch lines; one served as the feed line to the diesel fuel meter while the other served as the return line back to the engine. Each ½-inch branch line consisted of a ½-inch brass turnoff gate valve attached to the piping assembly with a 3-inch long threaded ½-inch steel nipple. The valves were arbitrarily identified as 4A-1 and 4A-2 for documentation purposes. It was suspected that gate valve 4A-1 was part of the return line from the diesel fuel meter station while 4A-2 was the feed line to the meter.

It was reported that a crack was found in the gate valve 4A-1 after the reported loss but was not completely separated. However, upon retrieval, it was reported that the cracked portion of the valve separated completely and remained attached to the corresponding nipple. Examination of the fracture plane showed that a portion of the fracture surface was fresh and bright while the majority of the surface was covered with a black oxide/soot deposit, indicating that this portion of the crack was open to the atmosphere during the fire event. The final fracture, i.e. the fresh and bright colored surface, was induced when the piping was dismantled after the reported event. No mechanical damage or corrosion was observed adjacent to the fracture plane. Further, no mechanical deformation was found along the fracture plane. Tool marks were also observed on the valve.

Gate valve 4A-2 was found completely separated after the reported event was initially investigated. Investigators alleged that since the valve was found completely separated it may have failed prior to the fire and caused a rapid release of diesel fuel. The fracture plane was found to be perpendicular to the longitudinal axis of the threaded end between the fifth and

sixth thread of the female end. As noted above with Item 1 (mating fractured portion of the valve that remained attached to the corresponding threaded pipe nipple), the fracture occurred flush with the end of the threaded nipple engagement. No mechanical damage or corrosion was observed adjacent to the fracture plane. Examination of the valve seal showed that it was stuck in the open position with re-solidified aluminum deposited in between the valve stem and the body as well as inside the valve chamber. The appearance of the deposits suggested that the molten aluminum flowed into the valve stem area of the valve body.

Item 4C consisted of an additional piping assembly with a fractured portion of a ½-inch brass valve attached to a 3-inch long steel nipple. The fractured brass valve section matched to that of the fractured end of gate valve 4A-1. Therefore, it was believed that Item 4C was a portion of the return line from the metering station that was tied back into Engine No. 1. Unlike the fracture plane of valve 4A-2 where the fracture occurred within the internal threaded region of the valve, valve 4A-1 fractured in the body itself beyond the internal female threads near the valve seal. After documenting the position of the nipple and brass valve portion, the threaded nipple was removed from the assembly for further examination. It was observed that four (4) threads of the nipple were engaged in the fitting of the piping assembly. It may be noted that the nipple was easily removed without much force applied to it. The valve portion was then removed from the nipple. The nipple was engaged with the fractured portion of the valve up to four (4) threads as well. The nipple appeared to be of standard construction with up to nine (9) or ten (10) complete tapered threads on either end.

Visual inspection of the two fractured valves (4A-1 and 4A-2 and their corresponding fractured ends Item Nos. 1 and 4C-1) and the two "exemplar" valves (Item Nos. 2 and 3) revealed that both fractured valves were identical in terms of model and manufacturer but the so-called "exemplar" valves were found to be different. The following table contains the product information obtained from the valve bodies and handles:

ITEM NUMBER	PRODUCT MARKINGS
No. 2 Diesel fuel s/o #3 Engine exemplar	Milwaukee, ½, 125, 2015
No. 3 Diesel fuel s/o #3 Engine exemplar	Crane, 1/2 , 1255, 200 CWP
No. 4A Diesel return piping & valves #1 Engine	Waldworth, ½, 125
No. 4C Diesel return piping & valves #1 Engine	Waldworth, ½, 125

As can be seen in the above table, the two "exemplar" valves are NOT true exemplars since they are from different manufacturers (Crane and Milwaukee) than that of the fractured valves from Engine No.1. Nonetheless, a comparison between the submitted valves was deemed important.

A.2. Fractographic Studies

The fracture surfaces of both failed valves (4A-1 and 4A-2 bodies and their corresponding fractured sections 1 and 4C-1) were covered with black oxidation product and soot, thereby masking the topographical features. Therefore, the fracture surfaces were cleaned in Alconox solution in an ultrasonic bath. Fractographic studies of the mating fracture surfaces of both failed valves were performed via stereomicroscopy and Scanning Electron Microscopy (SEM) after cleaning.

The fracture plane for each incident valve was mostly transverse to the longitudinal axis of the female threaded end and was found to be rather jagged along the circumference, suggesting intergranular fracture. In fact, fractographic studies of the mating fracture surfaces of the two incident valves showed brittle intergranular mode fracture with no indication of plastic deformation. There was no evidence of a progressive mode or fatigue crack propagation, on either fractured valve. Therefore, with the exception of the final fracture induced during retrieval of 4A-1, it was concluded that the failure mode of both valves was a one-time brittle overload fracture.

In addition, large-sized grains were observed on the fracture surface, suggesting grain growth as a result of exposure to a high temperature, most likely induced during the reported fire. Further, the fracture surface exhibited random distributions of aluminum that covered some of the exposed grain boundaries (see the Microstructural Studies section for more information).

A 2-inch long strip of material was cut from each of the two intact valves from Engine No. 3 and subjected to a three-point bending load in order to introduce intentional overload fracturing under laboratory conditions. It may be noted that when the strips fractured, plastic deformation was observed. The mating fracture surfaces were then examined for comparative studies to that of the fracture surfaces found on the incident valves. The failure mode for the Engine No. 3 valves was ductile overload with micro-void coalescence.

A.3. Chemical Analysis

Qualitative chemical analysis of the fracture surface of the fractured valves was performed via Energy Dispersive Spectroscopy (EDS). A comparative analysis of a cut cross-section from both exemplar valves was also conducted. EDS analysis of all four fittings showed that they were fabricated from similar leaded high copper alloy.

Bulk chemical analysis was performed on both fractured valves (Item Nos. 4A-1 and 4A-2) as well as the two submitted intact valves collected from Engine No. 3 for comparative purposes via ICP-OES in accordance with ASTM E478. The following table contains the results (wt%):

ELEMENT	2	3	4A-1	4A-2
Silicon	0.004	0.004	0.005	0.004
Phosphorous	0.043	0.036	0.039	0.041
Sulfur	0.040	0.046	0.050	0.049
Nickel	0.78	0.57	0.61	0.60
Copper	85.73	85.81	85.14	85.55
Zinc	4.94	4.23	4.23	4.19
Cobalt	0.005	0.004	0.006	0.005
Aluminum	0.001	0.004	0.004	0.002
Tin	4.30	4.00	4.44	4.34
Lead	4.02	5.01	5.12	4.86
Iron	0.05	0.09	0.23	0.24
Antimony	0.07	0.16	0.11	0.10
GRADE	**C83600**	**C83600**	**C83600**	**C83600**

All four (4) valves were fabricated from C83600 leaded red brass (copper casting alloy), which is typically used for applications such as valves, flanges, pipe fittings, etc.

A.4. Microstructural Studies

Microspecimens were prepared from both incident valves as well as from the valves of Engine No. 3 using standard metallographic procedure and were examined in both the unetched and etched conditions in accordance with ASTM E3.

The microstructures of all four valves were consistent with that of leaded cast red brass. However, it was evident that valves 4A-1 and 4A-2 were subjected to high temperatures resulting in grain growth. Both fractured valves exhibited grain growth due to high temperature exposure. The observed grain growth indicated that the material was exposed to temperatures above its recrystallization temperature, which was estimated to be approximately 350/360°C. The grains along the fracture plane showed no plastic deformation or any indication of a progressive mode or fatigue crack propagation. The appearance of the grains along the fracture further confirms that the valves failed in brittle intergranular fracture. Further, aluminum was found penetrating into the material along the grain boundaries as well as along the fracture plane. The presence of the aluminum at the grain boundaries suggests that the material was subjected to liquid metal embrittlement (LME). The fact that both valves, which were cast from inherently ductile material, failed in brittle mode intergranular fracture with aluminum at the grain boundaries, strongly suggested that they failed as a result of LME. No other metallurgical phenomenon is known that could explain the localized grain growth and intergranular fracture.

According to ASM International Metals Handbook Vol. 13A, *Corrosion: Fundamentals, Testing, and Protection*, LME is described as follows:

LIQUID METAL INDUCED EMBRITTLEMENT (LMIE), also known as liquid metal embrittlement, is the reduction of the fracture resistance of a solid material during exposure to a liquid metal. References in the literature to liquid metal embrittlement were first made over 100 years ago (Ref). Commonly, LMIE is described as the catastrophic brittle failure of a normally ductile metal when coated with a thin film of a liquid metal and subsequently stressed in tension. The fracture mode typically changes from a ductile to a brittle intergranular or brittle transgranular (cleavage) mode; however, there is no change in the yield and flow behavior of the solid metal. As shown in Fig. , embrittlement manifests itself as a reduction in fracture stress, strain, or both. Fracture can occur well below the yield stress of the solid. The stress required to propagate a sharp crack or a flaw is significantly lower than that necessary to initiate a crack in the liquid metal environment. In most cases, the initiation or the propagation of cracks appears to occur instantaneously, with the fracture propagating through the entire test specimen. The velocity of crack or fracture propagation can be as large as 10 to 100 cm/s (4 to 40 in./s) (Ref, , ,). Examination of LMIE fracture surfaces shows complete coverage by the liquid metal. Liquid metal is in intimate contact with the solid and is usually difficult to remove. The fracture mode becomes apparent when special techniques are used to remove the liquid (Ref). It should be emphasized that gross amounts of liquid are not necessary; even micrograms of liquid lead can cause LMIE in 75 mm (3 in.) thick steel tubes (Fig.). In fact, one monolayer is sufficient to cause LMIE (Ref). The fracture is usually brittle intergranular, with little indication of crack branching or striation to indicate slow crack propagation. The presence of liquid at the moving crack tip appears necessary for fast fracture. However, in high-strength brittle metals, a crack initiated in the presence of liquid may propagate in a brittle manner in the absence of liquid. In low-strength metals, a transition may occur from brittle-to- ductile failure under similar circumstances. Although far less frequent than brittle fracture, embrittlement can also occur by a ductile dimpled rupture mode in certain steels, copper alloys, and aluminum alloys. The embrittlement then manifests itself as the degradation of the fracture properties of the solid metal. Embrittlement is not a corrosion, dissolution, or diffusion-controlled intergranular penetration process but is considered to be a special case of brittle fracture that occurs in the absence of an inert environment and at low temperatures. Time- and temperature-dependent processes are not considered to be responsible for the occurrence of LMIE. Also, in most cases of LMIE, little or no penetration of liquid metal into the solid metal is observed. The embrittlement of the solid metal coated with liquid metal or immersed in the liquid does not depend on the time of exposure to the liquid metal before testing (Fig.) or on whether the liquid is pure or presaturated with the solid. Usually, one of the prerequisites is that the solid has little or no solubility in the liquid and forms no intermetallic compound to constitute an embrittlement couple (Ref). However, exceptions to this empirical rule have been noted (Ref).

A.5. Microhardness Survey

A micro-hardness survey was performed across the microspecimens using a Vickers indenter with the appropriate load in accordance with ASTM E384. The following table contains the results (HV) of the survey:

Reading No.	2	3	4C-1	1
1	87	145	83	70
2	81	142	80	73
3	84	140	76	78
AVERAGE	**84**	**142**	**80**	**74**

Since no requirements were specified, the above results are for information purposes only.

B. Determine whether there is evidence of diesel fuel ignition in the turbocharger of the subject waste treatment pump system.

Appendix D contains select photographs of deposits that were submitted for testing.

A chemical analysis of the black colored deposits collected from the turbocharger fan blades (Item No. 6) and of the debris found in the turbocharger (Item No. 12) will be performed via Energy Dispersive Spectroscopy (EDS) and Gas Chromatography Mass Spectroscopy (GCMS) with headspace.

A sampling of both items was taken and examined in the Scanning Electron Microscope (SEM) with chemical analysis via Energy Dispersive Spectroscopy (EDS). The texture and compositions of both samples indicated that the material was burn residue of a carbonous substance, most likely diesel oil.

Once the EDS analysis was completed, the samples were then submitted to an independent testing laboratory for GCMS with headspace. GCMS with headspace confirmed the findings from the aforementioned qualitative EDS analysis of both samples. Both Items contained burned diesel fuel residue (see report from Edison Analytical in Appendix D for a more in depth commentary of the findings).

C. Compare the collected samples of aluminum to determine whether they originated from the turbocharger casing

Appendix E contains select photographs of the aluminum samples that were submitted for testing.

A sampling of the collected aluminum samples (Item Nos. 10, 11, and 13) as well as from the surface of Item No. 4A was taken for further studies. Microspecimens were prepared from each sampling using standard metallographic procedure and were examined via light optical microscopy (LOM) in accordance with ASTM E3. Item Nos. 4A, 10, and 11 consisted of similar microstructures showing resolidified aluminum silicon metal. However, the microstructure of Item No. 13, which was the sample collected approximately 29 feet from the front of the incident engine, appeared to be mostly aluminum with much less silicon content. Semi-quantitative chemical analysis was performed on each microspecimen via Energy Dispersive Spectroscopy (EDS). EDS analysis confirmed that the

composition of Item No. 13 was different than that of the other three (3) items. Item Nos. 4A, 10, and 11 were found to be similar in composition regarding aluminum and silicon contents.

In order to further characterize the aluminum samples, chemical analyses were performed via Optical Emissions Spectroscopy (OES) in accordance with ASTM E34. The following table contains the results (wt%) of the analyses:

ELEMENT	4A	10	11	13
Manganese	0.10	0.14	0.13	0.007
Silicon	6.34	4.43	3.24	0.45
Chromium	0.018	0.060	0.050	0.003
Nickel	0.031	0.020	0.007	0.006
Copper	1.33	0.30	0.20	0.02
Zinc	0.72	0.28	0.36	0.059
Titanium	0.05	0.11	0.10	0.01
Tin	0.11	<0.01	0.04	<0.01
Lead	0.01	<0.01	<0.01	<0.01
Magnesium	2.70	0.19	0.22	0.53
Iron	0.41	0.35	0.20	0.21
GRADE:	---	---	---	---

As can be seen in the above table, the sample collected approximately 29 feet from the front of the incident engine was a different aluminum than the other three (3). Item Nos. 4A, 10, and 11 may have originated from the same component or components with similar compositions. The alloy designation for each Item could not be ascertained, most likely due to contamination as the metals melted and solidified. Since the aluminum casing for the turbo charger melted, the molten aluminum most likely picked up contamination as it dripped to the floor so the composition of each sample may have been altered as a result.

Although requested, no material specifications or information was provided regarding the construction of the turbo charger casing. Therefore, the above results are for information purposes only. No requirements were specified. However, it can be reasonably concluded that the aluminum from Item Nos. 4A, 10, and 11 originated from the same component or ones with similar compositions while Item No. 13 was most likely from a different aluminum source.

D. <u>Identify cracking, if any, in the collected bolts</u>

Appendix F contains select photographs of the bolts that were submitted for evaluation.

The bags labeled Item Nos. 8 and 9 contained three (3) turbo charger flange bolts and nine (9) turbo charger interior bolts, respectively. Each bolt within each bag was arbitrarily numbered for documentation purposes. Visual examination of the surfaces of each submitted bolt did not reveal any fracturing or mechanical deformation along the shanks. No cracking was discernible in the bolts in

their as-received conditions due to the presence of caked-on fire debris and deposits. Therefore, the bolts were cleaned in Alconox solution in an ultrasonic bath. All of the loose deposits were easily removed during the cleaning process. However, the re-solidified aluminum deposits remained tightly adhered to the surfaces, mostly near the heads of the bolts.

The threads of each bolt were carefully examined visually as well as via stereomicroscopy. No cracks were observed. The threads were further examined for cracks using Liquid Dye Penetrant (LDP) method. LDP confirmed that no cracks were present in any of the submitted threads.

In an attempt to determine what temperature was experienced by the bolts, a microspecimen was prepared intersecting the bolt head where the aluminum had deposited using standard metallographic procedure and was examined via light optical microscopy (LOM) in accordance with ASTM E3. The bolt showed a heavily cold worked microstructure with banding. The interface between the bolt head and the re-solidified aluminum deposit showed no localized melting of the bolt material but rather a barrier layer, possibly caused by the alloying of the aluminum with the galvanized layer (zinc) of the bolt. The bolt material adjacent to the adherence of the aluminum deposit exhibited recrystallization as a result of the high temperature of the aluminum melt (aluminum melting point: 660° C). It may be noted that the recrystallization temperature ranges between 600 to 700° C (approximately) depending on the amount of plastic deformation.

SUMMARY OF FINDINGS (as per the 7/29/11 test protocol)

- Both incident valves were from the same manufacturer – Waldworth
- Intact valves from Engine No. 3 were from two (2) other manufacturers – Crane and Milwaukee
- The incident brass valves were fabricated from a high copper alloy (Cu, Sn, Zn, Pb, Ni), not the typical 60/40 type brass.
- No indication of progressive mode or fatigue fracture
- The failure mode was brittle mode fracture for both incident valves.
- Both incident valves exhibited intergranular brittle fracture across the fracture surface. Since the alloy is inherently ductile, the material had to have been embrittled.
- Simulated forced fracture of the exemplar valves showed pure ductile overload fracture
- Metallographic examination showed aluminum in the grain boundaries of the fracture surface of the incident valves which suggests liquid metal embrittlement (LME). LME seems to be the only plausible cause of embrittlement
- Grain growth was observed in the microstructure of the incident valve, indicating an exposure above recrystallization temperature (above 350/360 °C, approx.).
- It appears that the fracturing of the two incident valves was the result of the fire event due to the embrittlement of the material. It is imperative to note that two valves failed at the same time in the same manner.
- The use of three different manufacturers for the four (4) valves might suggest that repairs had been performed over the years.

- Evidence of diesel fuel residue was found within the turbocharger, indicating that the fuel had burned inside the turbocharger itself.
- The aluminum samples collected in the vicinity of the failed valves were of similar microstructure and composition and may have originated from the turbocharger casing, which was consumed by the fire. The sample collected approximately 29 feet in front of Engine No. 1 was found to be different from the other three samples collected underneath the turbocharger. The exact composition of the turbocharger casing was not known. The results of the comparative studies were inconclusive in determining whether the resolidified melt that was collected approximately 29 feet away originated from the casing.
- None of the submitted turbocharger bolts exhibited lateral bending or cracking in the threads.

PART 2 – ADDITIONAL ITEMS

All of the aforementioned findings were conveyed via interim teleconferences as well as in various correspondences. As a response to the final teleconference regarding the evaluation of the fractured valves, it was understood that representatives from Black & Veatch and Russo & Associates revisited the site in an attempt to identify any other possible location where a fuel leak may have occurred. The re-inspection of Engine No. 1 identified the following items, which were submitted for evaluation as follows:

SUBMITTED ITEMS

Appendix G contains photographs of the additional items taken in the as-received condition.

14	#2 Pump Engine Quantity (2) Fuel Oil Return
	#3 Pump Engine (1) Fuel Line
	#5 Pump Engine (2) Fuel Oil Return Line (Received 8/16/11)
15	Length of Fuel Injector Piping Fuel Line Injector Bracket
	Length of Braided Piping Fuel Line (Received 8/16/11)
16	Fuel Pump (Received 9/1/11)
17	Injector (Received 9/1/11)
18	(2) Blue and (1) Black Flex Hoses (Received 9/22/11)

The following objectives regarding the above described submitted items were given as follows:

E. Determine whether or not any of the intact valves could be considered exemplar valves in order to examine the mechanical properties and microstructure of similar valve material that was not exposed to fire and high temperatures (Item No. 14).

F. Determine whether a leak may have developed in the braided piping fuel line (Contained in ITEM No. 15).

G. Determine whether a leak may have developed at the connections of the high pressure fuel line between the fuel pump and the injector (Contained in ITEM Nos. 15 through 17).

TESTING

E. Determine whether or not any of the intact valves could be considered exemplar valves in order to examine the mechanical properties and microstructure of similar valve material that was not exposed to fire and high temperatures (ITEM No. 14)

Visual inspection of the additional valves revealed that that none of them were manufactured by Waldworth, which was identified as the manufacturer of the failed valves that were testing according to Objective A (see table below showing markings on valves).

ITEM No. 14	PRODUCT MARKINGS
#2 Pump Engine Quantity (1 of 2) Fuel Oil Return (gray)	FF, ½. CRANE
#2 Pump Engine Quantity (2 of 2) Fuel Oil Return (black)	½, 150 300, USA, FF, 0 15 DB
#3 Pump Engine (1) Fuel Line	1255 200 CHP, ½ CRANE
#5 Pump Engine (1 of 2) Fuel Oil Return Line (gray)	1255 200 CHP, CRANE
#5 Pump Engine (2 of 2) Fuel Oil Return Line (black)	1255 200 CHP, ½ CRANE OBTA

Since the markings on the valve bodies clearly showed that the valves were not manufactured by Waldworth (as in the case with the failed valves in Item Nos. 4A-1 and 4A-2), there was no practical reason to further test these intact valves.

F. Determine whether a leak may have developed in the braided piping fuel line (Contained in Item No. 15).

Appendix H contains photographs of the braided piping fuel line.

The braided fuel line consisted of a 20-inch long braided section with 4 ½-inch long fittings on either end. The average diameter of the braided hose was measured to be 7/8-inch. However, the braided hose exhibited a reduced diameter of ½-inch approximately 7 ½-inches from one of the fittings while another portion of the braided hose appeared to have expanded. It was evident that the braided hose was altered as a result of the fire and collapsed on itself in one region, possibly deformed by falling debris while heated, thereby pushing the braiding outward in another region resulting in the localized reduced cross-section in one area of the hose and the expanded cross-section in another area.

Originally, it was requested that a low pressure test (55 psi) be conducted on the braided fuel line. However, visual examination of the braided section revealed that the rubber/polymeric liners, which provided a sealed channel within the hose for the fuel to pass was, completely consumed by the reported fire. Therefore, no pressure test could be performed.

All of the strands were found intact with no evidence of fracture, which could have served as a possible leak location. Since the braiding spacing was altered and the rubber/polymeric liners were consumed as a result of the fire event, no conclusion could be drawn from the visual inspection regarding whether a leak had occurred in the fuel line.

However, on 9/22/11 additional fuel lines from a different engine were submitted for visual comparative purposes only (Item No. 18). Appendix L contains the photographs of three additional fuel lines. The conditions of the submitted fuel lines were found to be in disrepair and warranted replacement. Melting of the metal fittings as well as the rubber/polymeric sheathing was found along the lengths of each fuel line. It is conceivable that if the braided fuel line from Engine No. 1 exhibited a similar condition, it is conceivable that a leak could have developed. Therefore, Engine No. 1's braided piping fuel line is a plausible location for a fuel leak if it was damaged more severely than that of the additional fuel lines (Item No. 18). As noted above, there is no way of confirming whether an actual leak had occurred in braided hose due to its condition after the fire incident.

Just for documentation purposes, a strand was removed from the braided hose and was then subjected to a chemical analysis via Energy Dispersive Spectroscopy (EDS). EDS analysis confirmed that the braided hose was fabricated from a 300-series stainless steel.

After the above findings were discussed with Black & Veatch, no further testing of the intact hoses was requested.

G. Determine whether a leak may have developed at the connections of the high pressure fuel line between the fuel pump and the injector (Contained in Item Nos. 15 through 17)

The following is a list of the Appendices that contain the photographs of the corresponding components:

- Appendix I Fuel Injector and Pump in the as-received condition
- Appendix J Pressure Testing of the Fuel Line
- Appendix K Evaluation of the High Pressure Fuel Line fittings

G.1. Visual Examination

The 43½-inch long fuel line consisted of a ½-inch diameter steel tube with flare joint- type fittings on either end. The flare joint-type fittings were comprised of male flared ends that were affixed to either end of the steel tube and a female threaded fitting that slides over each end. The male

flare end would then be inserted into the corresponding end of either the fuel pump or injector and the female fitting would tighten the two mating surfaces together thereby providing a mechanical seal. As the fitting is tightened, the sealing surfaces of the corresponding steel male end of the fuel line and female end of either the fuel pump or injector mechanical deform against each other thereby creating a tight seal.

The surface of the tubing was covered with burn debris but no indication of a leak was visually detected.

It was originally requested that the fuel line be subjected to a 3000-psi pressure leak test. In order fabricate a test rig that would accommodate the fuel line's fittings, an attempt to locate mating female fittings was made. However, no markings were found on the fuel line itself and the manufacturer could not be identified. In spite of contacting several possible companies, the manufacturer could not be conclusively determined. The purpose for identifying the manufacturer was to obtain new mating fittings for pressure testing the fuel line and, if possible, locate detailed drawings of its construction. Since no manufacturer was identified, it was proposed to Black & Veatch that a machine shop would be contracted to fabricate fittings. However, it was then reported to the writers that the actual fuel pump and injector were still available.

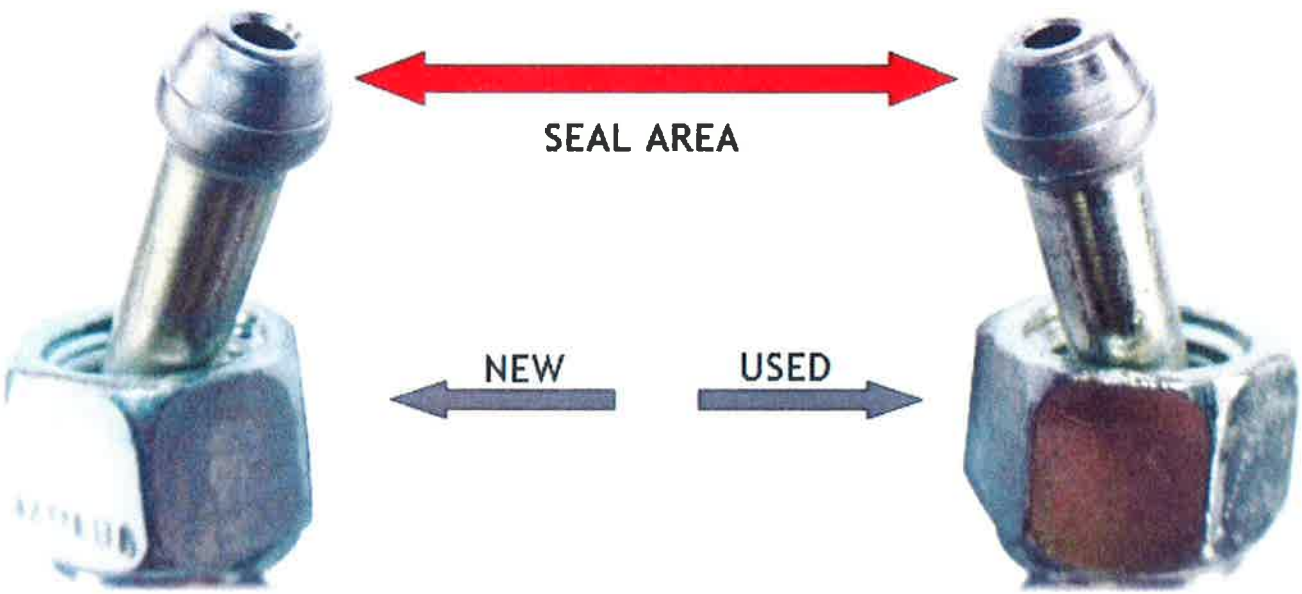
On 9/1/11, both the fuel pump and injector were delivered to Affiliated Engineering Laboratories, Inc. With the aid of Doug Leihbacher of T. J. Russo Associates, the corresponding ends of the fuel line were matched to that of the fuel pump and injector.

The surface of the injector near its working end exhibited corrosion damage with material loss. The service history of the injector was not known at the time of the evaluation but given the condition of the surface it was believed that it had been exposed to a corrosive environment for some time. It is suspected that the diesel fuel was contaminated, possibly with water, which caused the corrosion of the steel injector. Due to the limited scope of work, the injector was not dismantled. Examination of the fuel line fitting on the inlet end of the injector showed burned material and the orifice was found somewhat clogged.

The fuel pump showed high temperature heat exposure towards one side of its body. When the cap screws and the flange were removed from the fuel pump body (end where the fuel line is attached), it was observed that the paper gasket had been consumed as well. It should be noted that approximately one-half the circumference of the gasket was burned for a much longer time as evident by the white powdery consistency of the gasket remnants while the remaining portion of the gasket exhibited a black carbonous consistency. Typically, when an organic material, such as paper, is burned it will turn black as a result of the organic material being consumed leaving carbon but if that same material is heated for an extended period of time, the material turns white as the carbon is also burned/consumed. The white fire product coincided with that of the high temperature heat exposure of the fuel pump body. In reference to a discussion with Doug Leihbacher of T. J. Russo Associates, the aforementioned side of the fuel pump body was in direct line with that of an ignition source of Engine No. 1.

The flare joint ends of the fuel line and corresponding mating surfaces of the fuel pump and injector were examined as well. It was observed that the sealing surface of fuel line to fuel pump connection was not symmetrical and/or disturbed, suggesting that the joint had been readjusted or disturbed at some point. The following in excerpt from an article (http://www.forddoctorsdts.com/articles/article-07-04.php) discussing why the fuel line is for one-time use and that it should not be disturbed.

⚠ ***WARNING!*** *All of the steel fuel lines that are used to transfer high pressure fuel from the high pressure fuel pump to the fuel rails on each cylinder head and the lines connecting to each fuel injector are for one time use only! Anytime one of these lines is disturbed (loosened or removed) for any reason they MUST be replaced! Lets take a closer look.*



Comparing the fuel lines shown above you should notice the difference between the new fuel line and the used fuel line. The used line has been crushed and molded to fit tightly inside the fitting it was mated to. This is evident by the visible shiny ring on the flared end where the seal was actually made. The new fuel line is uncrushed and does not have a ring around the flare. Since the used line is already crushed and conformed to a fitting a new seal cannot be effectively formed therefore the line is not reusable.

Further, an unusual radial pattern with material loss was observed on the flat surface of the fuel line's male end that penetrated from the ID surface to the OD conical surface of the tip. In addition, it appeared that material loss also occurred on the conical surface adjacent to the tip of the male end as well. Also, heat tinting was found on one side of the cylindrical surface of the male end near the steel tube. When the fuel line was matched up to that of the fuel pump, it was observed that the heat tinting coincided with the side of the fuel pump body, which was in direct line an ignition

source on Engine No. 1 (where evidence of high temperature heat exposure was noted above). In order to further study the aforementioned features, the end had to be cut/removed.

Further examination of the fitting on the fuel pump end of the fuel line revealed that the last thread of the fuel pump male nipple had sheared off and remained attached to the female thread of the corresponding fitting on the fuel line. There were two possible causes for the damaged thread:

1. The material was heat affected and weakened as a result of the fire and when the fitting was dismantled, the thread broke.
2. The thread was over torqued thereby fracturing the thread.

In order to determine which of the possible causes actually occurred, destructive testing was required. However, if the fuel line was to be pressure tested while utilizing the threaded nipple portion of the fuel pump as part of the test rig, there was a good possibility that the threading would be further damaged and destroy important features of the broken thread.

Given the conditions of the fittings on either end of the fuel line and that of the mating fittings on the fuel pump and fuel injector, it was concluded that there was no reliable manner of reattaching the line to the fuel pump and fuel injector that would reconstruct the pre-fire event assembly. Due to the observed features and damage to the threading, the writers could not reasonably assume that the connection that would be made in-house would be identical to that of how it was installed prior to the fire. In other words, the pressure testing could yield erroneous results. In addition, there was concern that any attempts at reconnecting the fittings of the fuel line could damage or alter the current conditions of the sealing surfaces, which could hamper further microscopic studies of the features. The aforementioned opinion was given during the 9/6/11 teleconference and it was unanimously agreed that said high pressure testing would not provide reliable results that could be applied to a pre-fire condition. The writers suggested that a low pressure test of the steel tube within the fuel line could be performed and then the fitting ends would be subjected to destructive testing in order to confirm the initial visual observations.

G.2. Pressure Testing (Low Pressure)

Appendix J contains the photographs taken during the pressure testing of the fuel line.

Vacuum hose tubing was attached to both ends of the fuel line. One end, the injector side, was plugged while the fuel pump side was attached to a regulated air compressor. The pressure was set at 30-psi while the fuel line was immersed in water. No leaks were detected in the fuel line, further confirming that the integrity of the steel tubing of the fuel line was sound.

G.3. Scanning Electron Microscopy (SEM)

Appendix K contains the SEM photographs taken during the evaluation of the fuel line.

The tip of the fuel line that was originally attached to the nipple of the fuel pump was further examined via SEM. The flat portion of the tip exhibited significant erosion that created radiating lines or gouges spanning the surface from the ID to the OD. In fact, deep ridges were observed along the edge of adjacent cylindrical surface. The extent of the erosion suggested that the fuel had been escaping/spraying to the cylindrical surface for some time. In addition to the flat portion, the cylindrical surface was also examined. Both erosion and corrosion were observed on the cylindrical surface, further confirming that fuel had been spraying out of the fuel line and along the cylindrical surface. As noted with the fuel injector, corrosion was also found near the working end of the injector suggesting that water or some other contamination had occurred in the fuel line. Finally, the stepped/ridge of the tip, which is where the tip comes in contact with the end of the fuel pump threaded portion, exhibited erosion as well.

G.4. Microstructural Studies

A microspecimen was prepared from the male threaded portion of the fuel pump fitting intersecting the fuel line orifice and corresponding threads using standard metallographic procedure and were examined via light optical microscopy (LOM) in accordance with ASTM E3. The microstructure of the threaded portion consisted of ferrite and Pearlite phase, typical for a medium carbon steel. Examination of the microstructure of the material at the broken threads revealed significant plastic deformation of the grains, indicating that the fitting was over-tightened during service.

CONCLUSIONS

OBJECTIVE A - Characterize the failure mode of the incident valves.

The valves did not fail prior to the reported fire/explosion event but rather failed as a result of said event. Both valves failed by a one-time brittle mode intergranular fracture. Valve 4A-2 fractured completely while Valve 4A-1 cracked along most of its circumference. Neither valve failed by progressive mode of failure or fatigue crack propagation. It should be noted that the valves were fabricated from a high copper alloy, which is inherently ductile in nature. The fact that the valves failed in brittle mode indicated that the material had embrittled. Aluminum was found penetrating into the grain boundaries of the cast material as well as covering facets of the grains at the fracture surface. The cause for the valve failures found to be most likely liquid metal embrittlement when the molten aluminum from the turbocharger casing dripped onto them. **Further, the probability of two identical failures occurring at the same time on two different valves is unlikely.**

OBJECTIVE B - Determine whether there is evidence of diesel fuel ignition in the turbo charger of the subject waste treatment engine.

Evidence of diesel fuel residue was found within the turbocharger, indicating that the fuel had burned inside the turbocharger itself.

OBJECTIVE C - Compare the collected samples of aluminum to determine whether they originated from the turbocharger casing

The aluminum samples collected in the vicinity of the failed valves were of similar microstructure and composition and may have originated from the turbocharger casing, which was consumed by the fire. The sample collected approximately 29 feet in front of Engine No.1 was found to be different from the other three samples collected underneath the turbocharger.

OBJECTIVE D - Identify cracking, if any, in the collected bolts

None of the submitted turbocharger bolts exhibited lateral bending or cracking in the threads.

OBJECTIVE E - Determine whether or not any of the intact valves could be considered exemplar valves in order to examine the mechanical properties and microstructure of similar valve material that was not exposed to fire and high temperatures (Item No. 14).

None of the additional valves could be considered as exemplar valves to that of those tested as per the 7/29/11 test protocol.

OBJECTIVE F - Determine whether a leak may have developed in the braided piping fuel line (Contained in Item No. 15).

Due to the damage to the hose as a result of the incident fire, the findings were inconclusive regarding whether a leak had occurred prior to the reported loss. However, examination of intact hoses reportedly removed from other engines at the site showed significant melting and damage, which is detrimental to the integrity of the hoses. Should such damage have occurred to Engine No. 1's braided fuel line, it is plausible that a leak could have occurred.

OBJECTIVE G - Determine whether a leak may have developed at the connections of the high pressure fuel line between the fuel pump and the injector (Contained in Item Nos. 15 through 17).

It is plausible that a leak may have occurred at the flare joint connection between the fuel line and the fuel pump. Significant erosion and corrosion was observed at the tip as well as along the conical surface of the male portion of the fuel line that mated with that of the fuel pump nipple. It was evident that a leak had been occurring for some time to cause the amount of erosion that was found on the male end of the fuel line. Further, it was observed that the sealing region between the conical surface of the fuel line and that of the fuel pump nipple was not uniform, suggesting that the connection had been altered or disturbed at some point during its service life. The aforementioned observation was further confirmed by the presence of a broken thread on the fitting that made up that connection. Microstructural studies showed that the thread had fractured due to over torque. Since the original connection could not be reconstructed, a pressure test could not be performed with reliable results. Therefore, it can only be concluded that the connection is a plausible location where a

significant leak had occurred. The presence of erosion and corrosion on the sealing surface confirmed that a leak had occurred but the magnitude of that leak could not be measured. It may be noted; however, a broken thread resulting from over torque suggests that a leak may have been observed at some time during the operation of Engine No. 1 and the fitting was subsequently further tightened in order to remedy the leak. The aforementioned theory can only be taken as speculation at this point.

In review of the findings from all of the testing of the various submitted items, only two plausible leak scenarios can be concluded:

- The braided fuel line was damaged while in service thereby causing a perforation. Visual examination of similar fuel lines showed extensive damage.
- The sealing surface between the fuel line and that of the fuel pump was compromised by corrosion and erosion thereby causing a high pressure (3000-psi) leak of diesel fuel.

Very truly yours,

John P. Gashinski, P.E., CFEI
Metallurgical Engineer

D. Pattanayak

Dan Pattanayak, Ph.D.
Chief Metallurgist

DESCRIPTION OF TESTING

Energy dispersive x-ray spectroscopy (EDS) is an effective method for analyzing for the main components as well as low-level (nominally 0.1%) contaminants in relatively thick (several micron) layers. A focused beam of electrons is used to bombard a solid in order to knock out electrons from inner electron orbital shells of atoms in the near surface region of the sample. Electrons from outer shells can move into the inner shell vacancies as replacements for the ejected electrons. For each such atomic relaxation transition the energy difference between the outer and inner shell electrons is released by the atom. This energy is emitted either as a characteristic x-ray or as an outer shell electron which has absorbed the energy released by the atomic relaxation process. EDS spectra display intensity versus energy plot of x-rays emitted by the sample bombarded by the electron beam of the SEM. The vertical scale is x-ray intensity at each energy position. Since each element emits x-rays of characteristic energies it is a simple matter to relate an x-ray peak to its corresponding element using a table of major x-ray emission energies. Only those elements sodium and heavier in the periodic table are included in this study. The EDS technique has poor sensitivity for x-rays originating from the light elements. The electron beam may be scanned in a raster on the sample while the spectra are collected or the beam scan may be disabled to allow analysis of a particular spot usually noted on a corresponding micrograph if applicable.

Elemental distribution maps can be obtained to show the distribution on the sample of an element of interest. The brightness of the recording CRT is modulated such that a series of dots appears on the micrograph with the density related to the concentration of the element, i.e. more dots indicate more of the element. The elemental distribution shown on the micrograph (dot map) can then be related to the sample topography shown in an SEM secondary electron micrograph taken of the same area. It should be emphasized that only differences in dot density are significant since some dots will be produced by the white radiation background.

Gas chromatography (GC) is a method which fractionates a sample into its components with each peak on the recorded chromatogram representing a single component. The analytical separation involves passing the sample through a column which is packed with a polar immobile phase. Individual sample components migrate through the column at different rates. The horizontal scale of the chromatogram is a measure of the retention time of each component in the column. The area under each particular peak, when normalized to the total area under all peaks, is a measure of the volume percent of that component in the sample. Temperature is accurately controlled. The detection system is generally by flame ionization. Combined with **Mass Spectrometry (MS)**, the total mass of the unknown compound is normally indicated by the parent peak and the value of this parent peak can then be used to fit with a chemical formula obtaining the various elements which are believed to be in the compound. Once a chemical formula has been matched to the spectrum, the molecular structure and bonding can be identified.

Metallography describes all variations of the sample preparation procedure which generally starts with cutting a sample cross section, mounting in epoxy or Bakelite, grinding with SiC or diamond,

polishing with diamond and/or alumina, etching and photographing. The term includes all materials and composites (not just metals), many variations of the procedure depending on the specific situation and all kinds of documentation techniques from photomacrography/microscopy to electron microscopy/microanalysis.

Micro-hardness testing is particularly suitable for determining the mechanical properties of very thin sections and of different phases within a multi-phase metallurgical structure. An area is selected under a light microscope and an indenter is forced into the selected area by a pre-selected load applied at a controlled rate. After the load is removed, the impression left by the indenter is measured in μm under the light microscope and the dimension is converted into a hardness number from reference tables. Values are reported in conventional hardness scales by reference to conversion tables.

Optical emission spectroscopy (spark source) involves vaporization of the sample in graphite electrodes and optical dispersion of the resulting light emission. Semi-quantitative interpretation can give elemental concentrations for the 35 analyzed elements in decade ranges (e.g. 0.01-0.1%) while full calibration can give concentrations directly. Some elements would not be detected by emission spectroscopy including carbon, oxygen, sulfur and the halides.

Scanning electron microscopy (SEM) uses a highly focused electron beam (less than 10nm diameter) which can be scanned in a raster on the sample surface. Interactions between the samples and the incident electrons lead to the ejection of low energy secondary electrons about the location of the incident electron beam. The intensity of secondary electrons produced at each point is used to form a picture of the sample. Magnification factors from 10X to 300,000X can be obtained. The depth field is inherently quite large which allows the micrographs to be in focus at all points across a rough surface. In addition, the SEM does not suffer from the light microscope problem of light reflecting off at odd angles and being lost from view. Electrons detected for correlation with beam position to produce the image of the specimen can originate from various sample regimes. Secondary electrons originate from the top 10nm (100A) of the surface and are the most commonly employed for production of images in the scanning electron microscope. Backscattered electron images (BEI) can also be collected in the SEM by measuring the intensity of high energy elastically backscattered electrons emitted from each point on the surface scanned by the electron beam. Backscattered electrons can originate from up to about 1μm below the sample surface (depending on the material) and are affected by coating with surface layers of dissimilar material and by the atomic weights of the various components present in the imaged area. This results in grey level variations which can give some indication of the compositions present at the various locations on the sample. These images provide some information about the composition of a specimen since more electrons are elastically scattered from denser regions of the solid (producing brighter areas in the micrograph).

APPENDIX A

7/28/11 SITE INSPECTION PHOTOGRAPHS

Re: North River Waste Treatment Plant
October 18, 2011

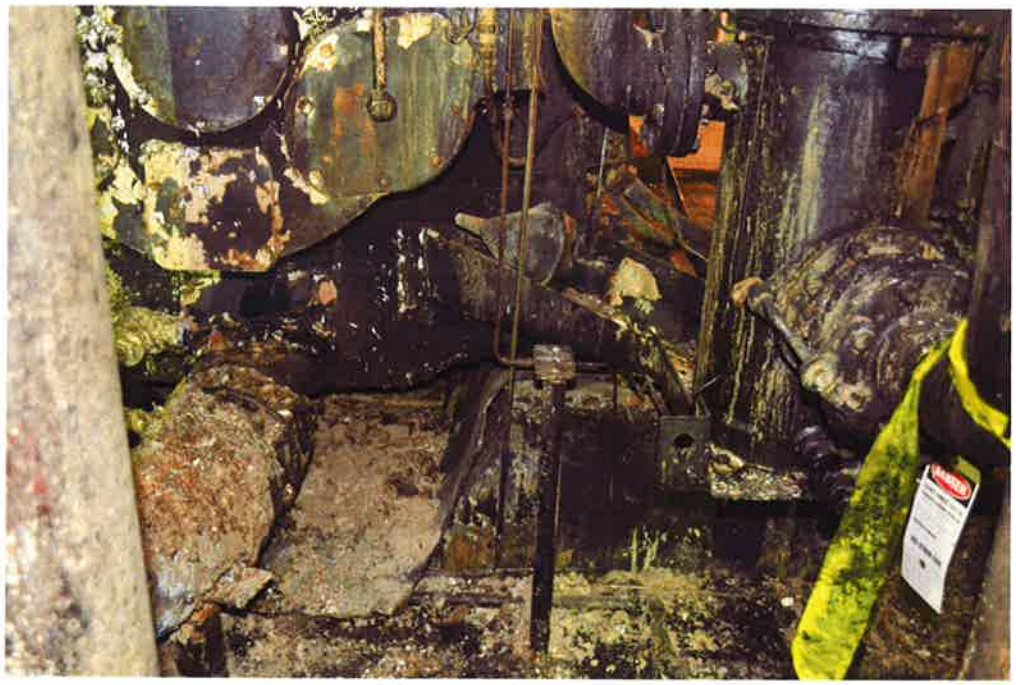
APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-1

Photograph No. A-2

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX A
7/28/11 Site Inspection Photographs



Photograph No. A-3

Photograph No. A-4

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-5

Photograph No. A-6

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-7

Photograph No. A-8

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-9

Photograph No. A-10

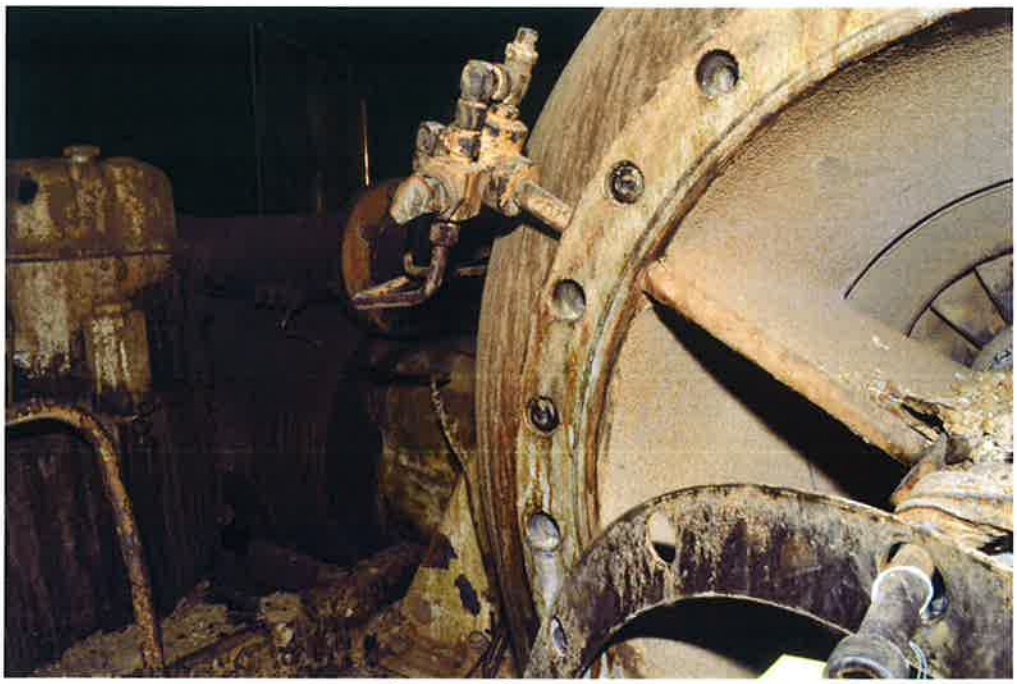
APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-11

Photograph No. A-12

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-13



Photograph No. A-14

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-15

Photograph No. A-16

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-17

Photograph No. A-18

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-19

Photograph No. A-20

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-21

Photograph No. A-22

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-23

Photograph No. A-24

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-25

Photograph No. A-26

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-27

Photograph No. A-28

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-29

Photograph No. A-30

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-31

Photograph No. A-32

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-33

Photograph No. A-34

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-35

Photograph No. A-36

APPENDIX A
7/28/11 Site Inspection Photographs

Photograph No. A-37

Photograph No. A-38

APPENDIX B

SUBMITTED ITEMS

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX B
Submitted Items

Photograph No. B-1

Photograph No. B-2

APPENDIX B
Submitted Items

Photograph No. B-3

APPENDIX C

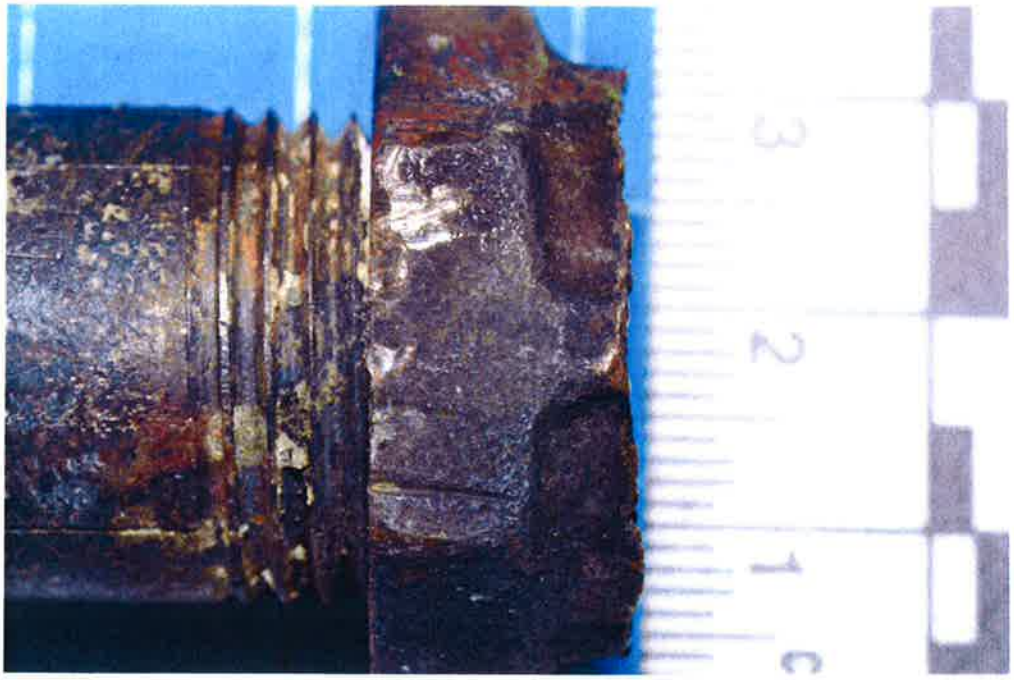
VALVE EVALUATION

APPENDIX C
Valve Evaluation

Photograph No. C-1
Item 1 – As-received condition

Photograph No. C-2
Item 1 – As-received condition

APPENDIX C
Valve Evaluation



Photograph No. C-3
Item 1 – As-received condition

Photograph No. C-4
Item 1 – As-received condition

APPENDIX C
Valve Evaluation

Photograph No. C-5
Item 1 – As-received condition

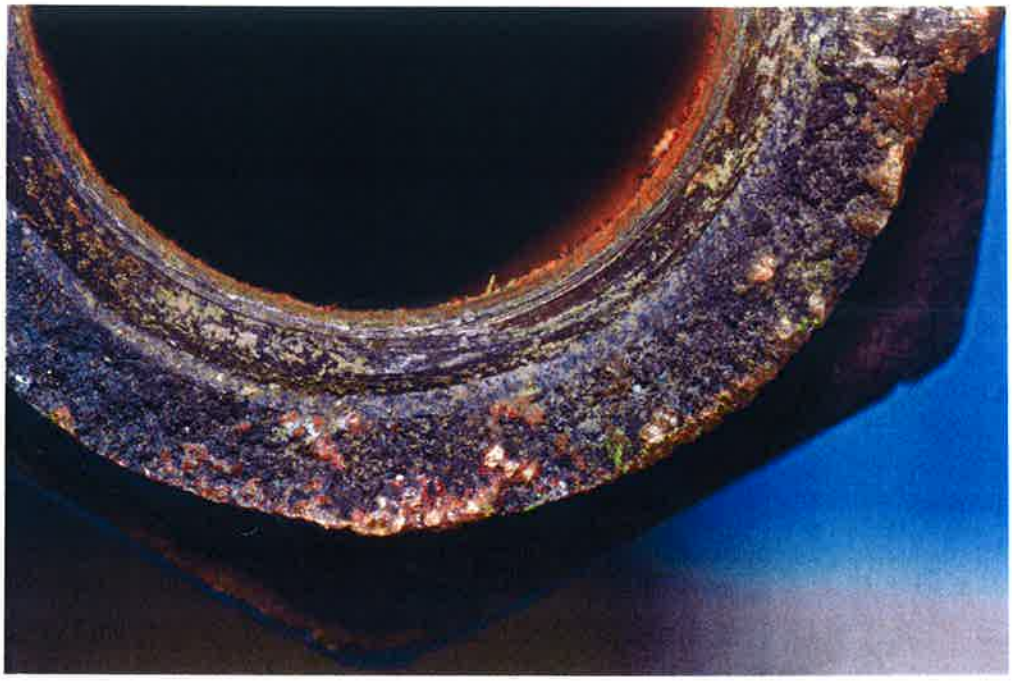
Photograph No. C-6
Item 1 – As-received condition

APPENDIX C
Valve Evaluation

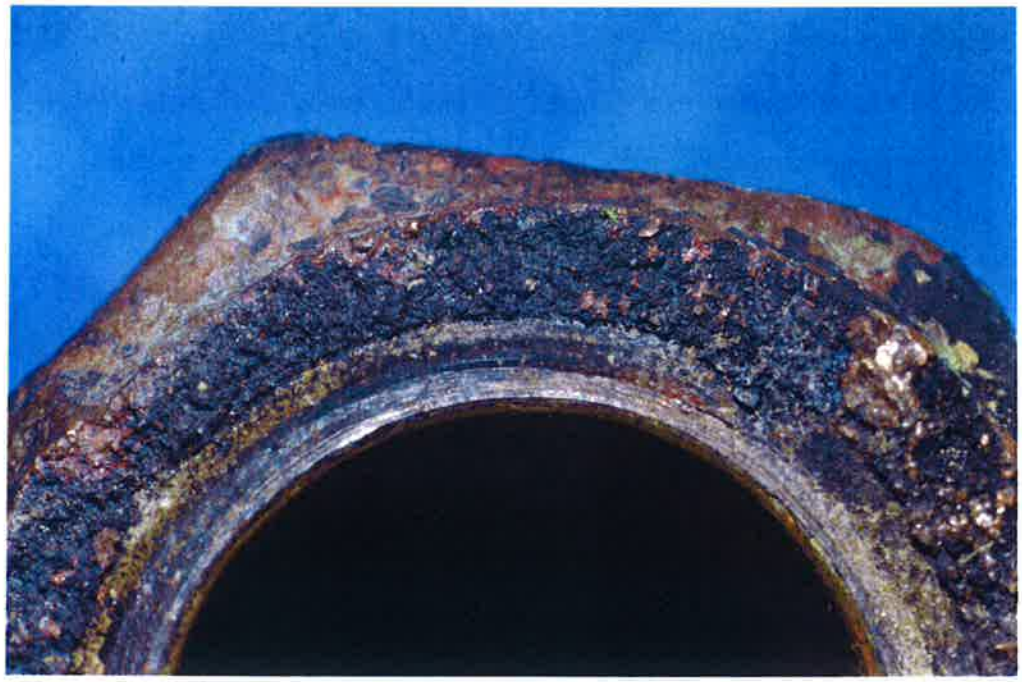
Photograph No. C-7
Item 1 – As-received condition

Photograph No. C-8
Item 1 – As-received condition

APPENDIX C
Valve Evaluation

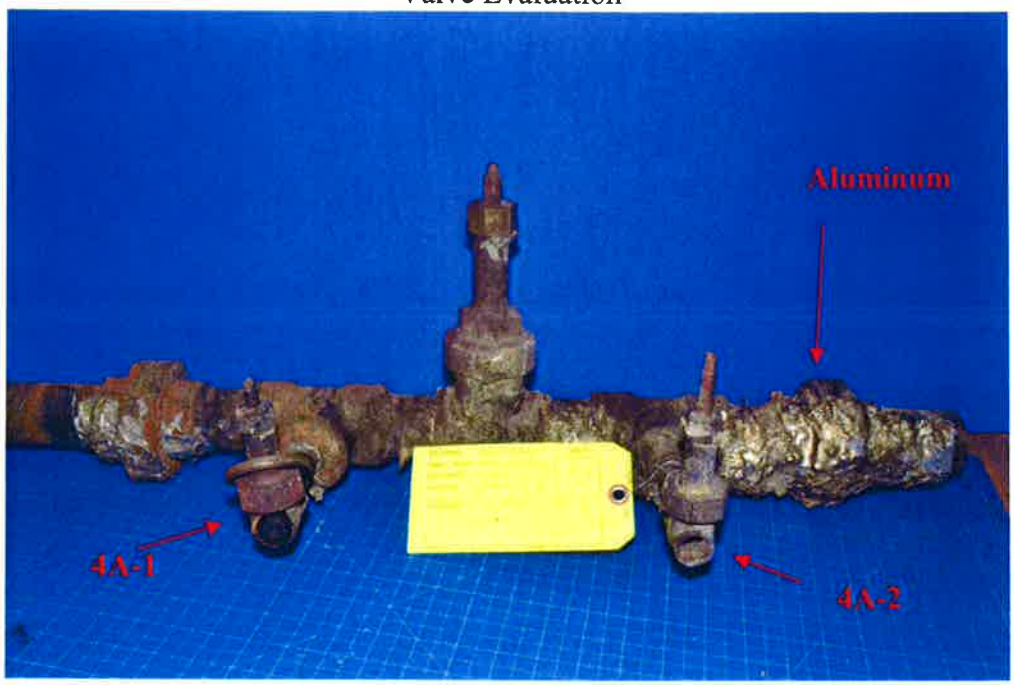


Photograph No. C-9
Item 1 – As-received condition



Photograph No. C-10
Item 1 – As-received condition

APPENDIX C
Valve Evaluation



Photograph No. C-11
Item 4A – As-received condition

Photograph No. C-12
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

APPENDIX C
Valve Evaluation

Photograph No. C-13
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

Photograph No. C-14
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

APPENDIX C
Valve Evaluation

Photograph No. C-15
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

Photograph No. C-16
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

APPENDIX C
Valve Evaluation

Photograph No. C-17
Item 4A – As-received condition
Valve arbitrarily identified as 4A-2

Photograph No. C-18
Item 4A – As-received condition
Valve arbitrarily identified as 4A-1

APPENDIX C
Valve Evaluation

Photograph No. C-19
Item 4A – As-received condition
Valve arbitrarily identified as 4A-1

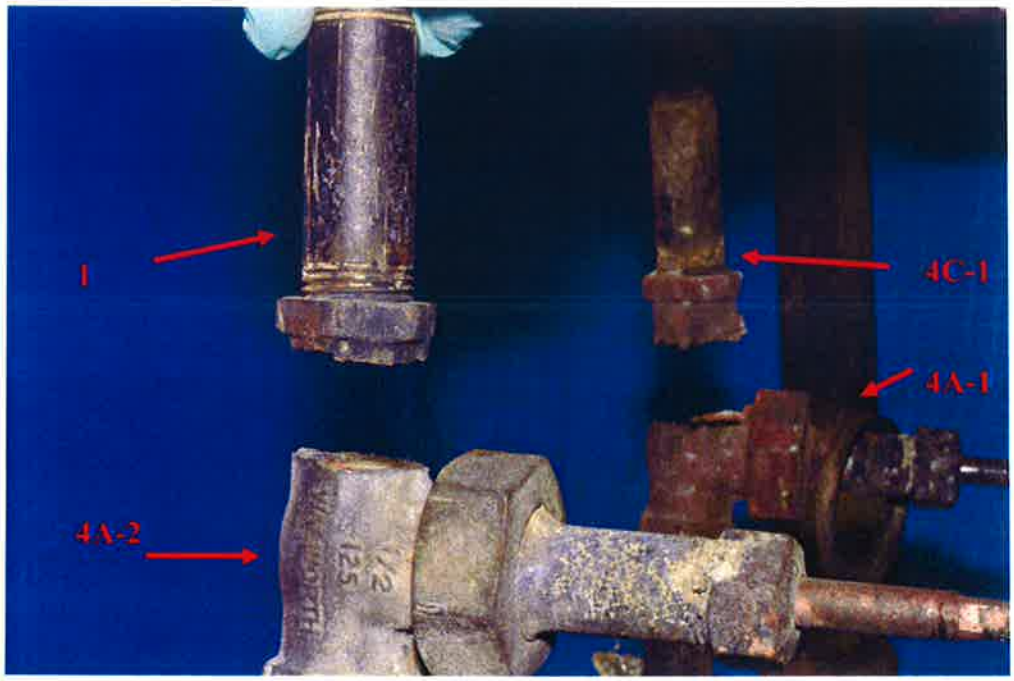
Photograph No. C-20
Item 4A – As-received condition
Valve arbitrarily identified as 4A-1

APPENDIX C
Valve Evaluation

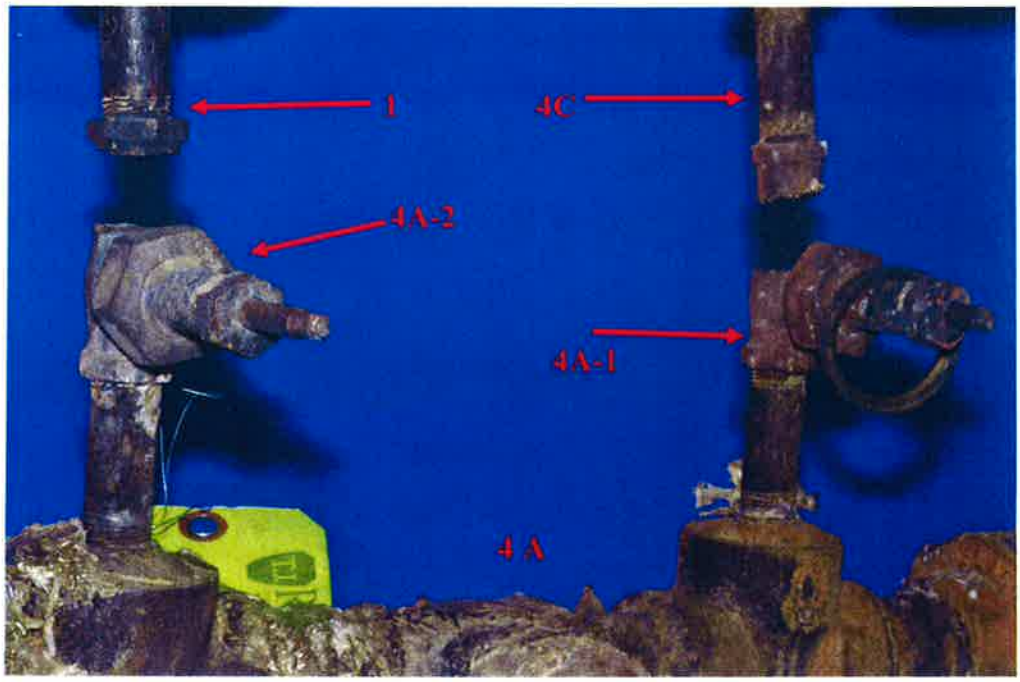
Photograph No. C-21
Item 4A – As-received condition
Valve arbitrarily identified as 4A-1

Photograph No. C-22
Item 4A – As-received condition
Valve arbitrarily identified as 4A-1

APPENDIX C
Valve Evaluation

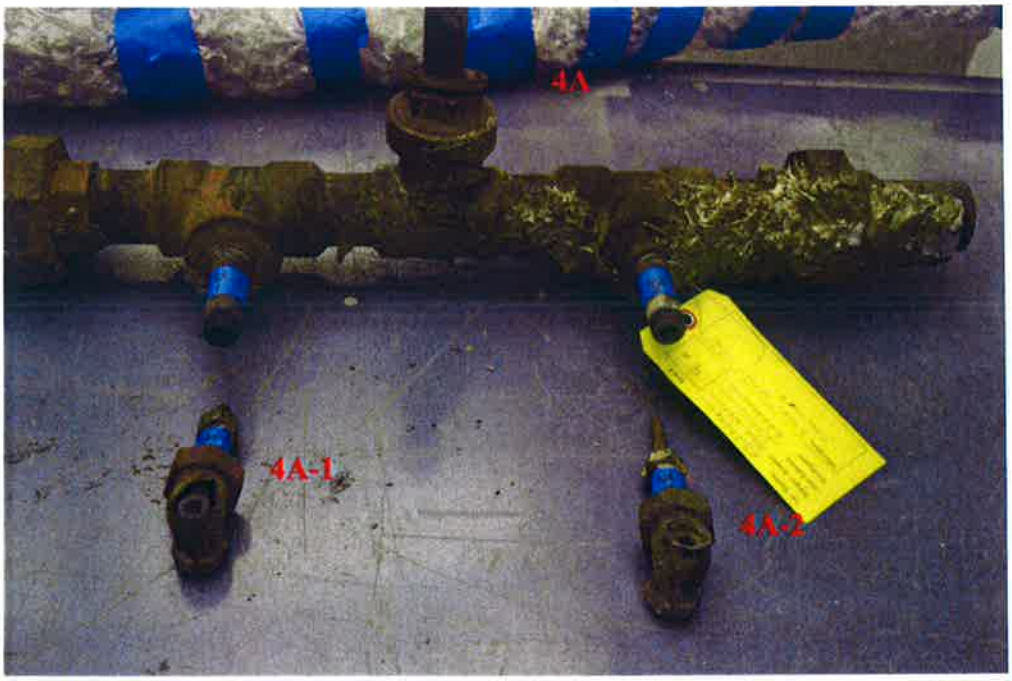


Photograph No. C-23
Re-construction of installation

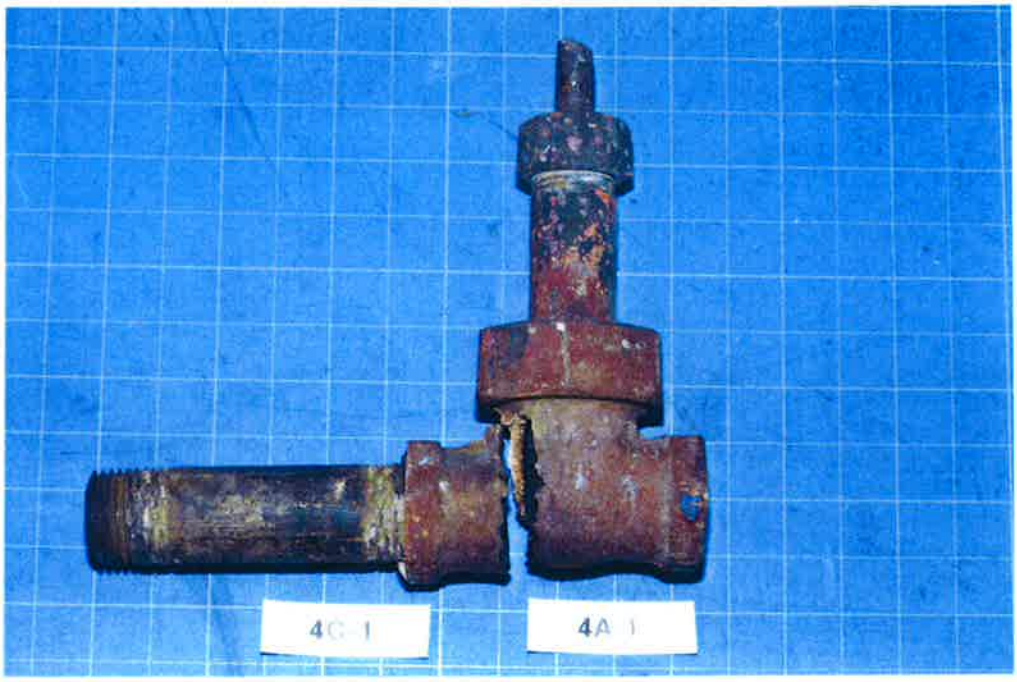


Photograph No. C-24
Re-construction of installation

APPENDIX C
Valve Evaluation



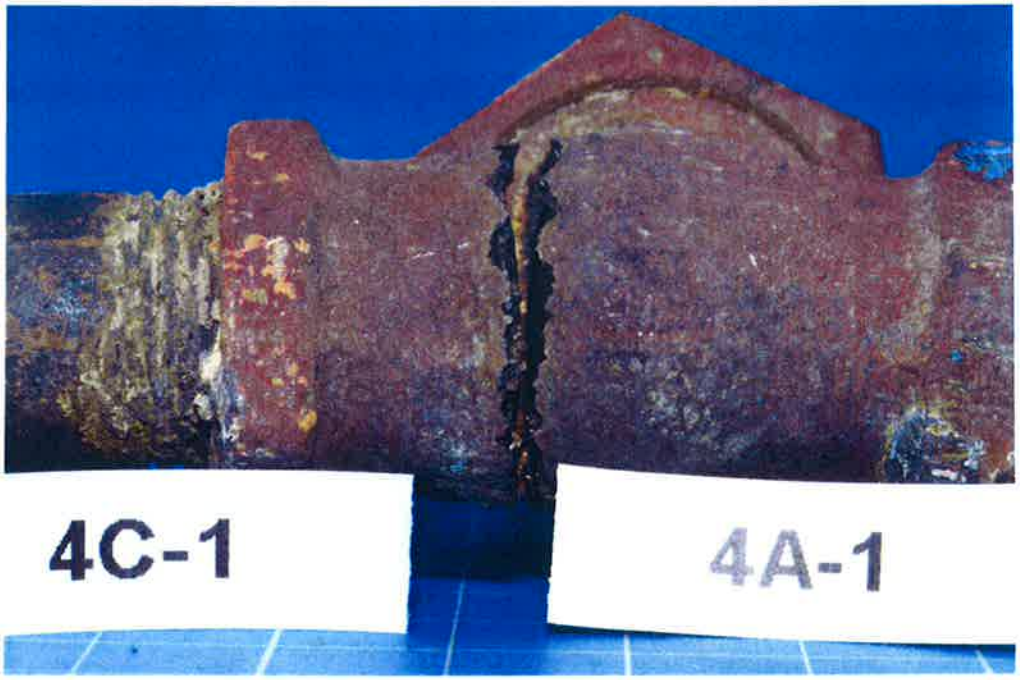
Photograph No. C-25
Removal of 4A-1 and 4A-2 from Item 4A



Photograph No. C-26
Items 4A-1 and 4C-1 showing fracture pattern

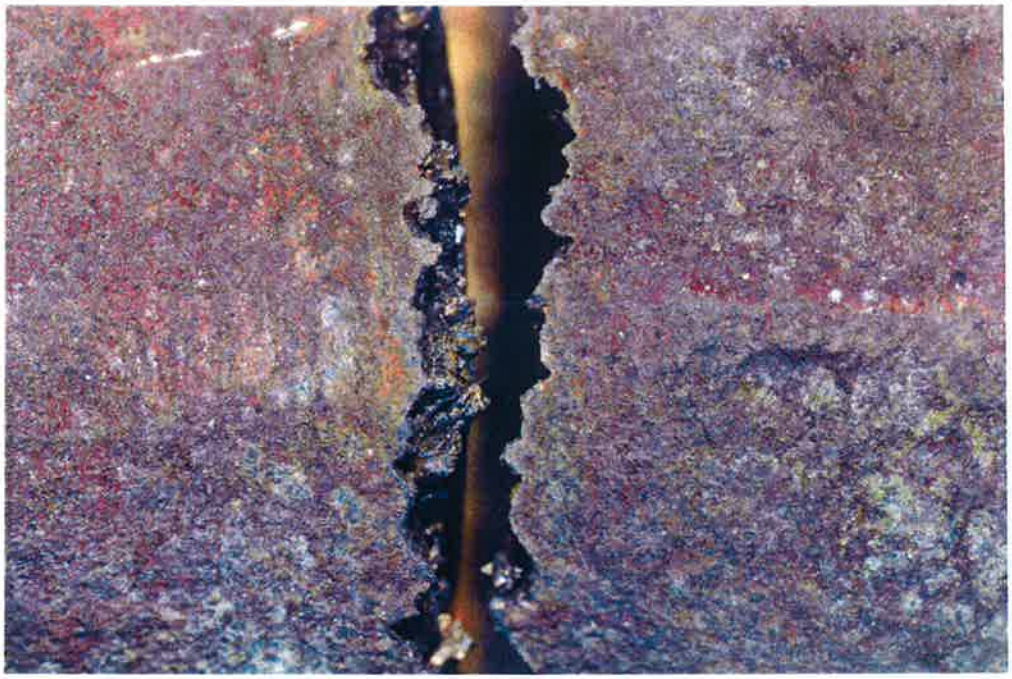
APPENDIX C
Valve Evaluation

Photograph No. C-27
Items 4A-1 and 4C-1 showing fracture pattern
Note: jagged fracture



Photograph No. C-28
Items 4A-1 and 4C-1 showing fracture pattern
Note: jagged fracture

APPENDIX C
Valve Evaluation



Photograph No. C-29
Items 4A-1 and 4C-1 showing fracture pattern
Note: jagged fracture

Photograph No. C-30
Items 4A-1 and 4C-1 showing fracture pattern
Note: jagged fracture

APPENDIX C
Valve Evaluation

Photograph No. C-31
Item 4C-1 – As-cleaned
Note: fresh fracture (arrow)

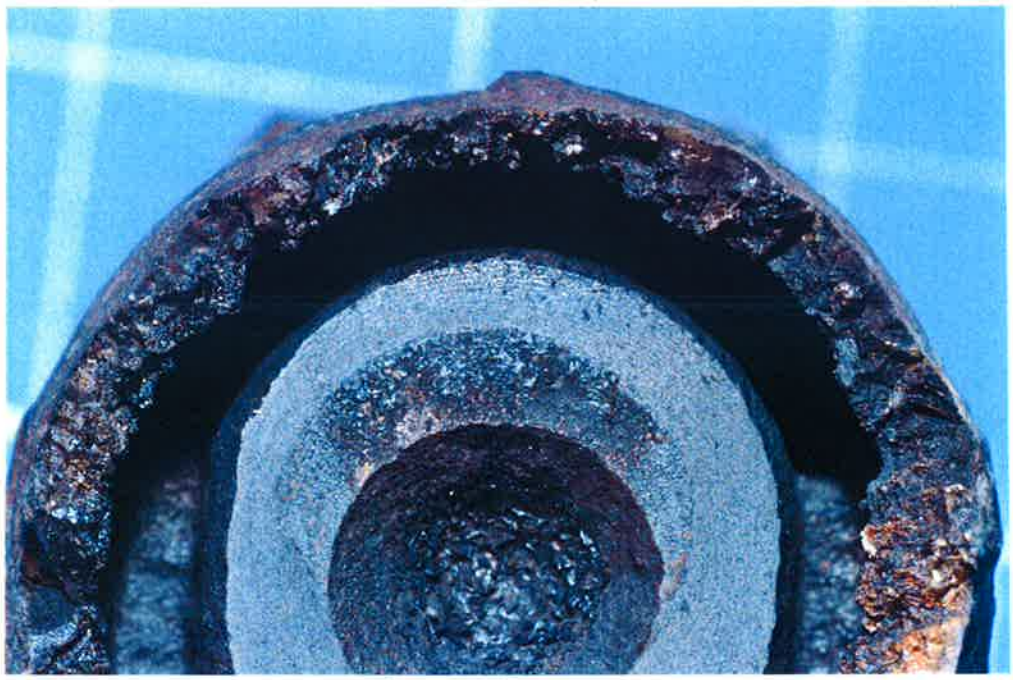
Photograph No. C-32
Item 4C-1 – As-cleaned
Note: brittle fracture

APPENDIX C
Valve Evaluation

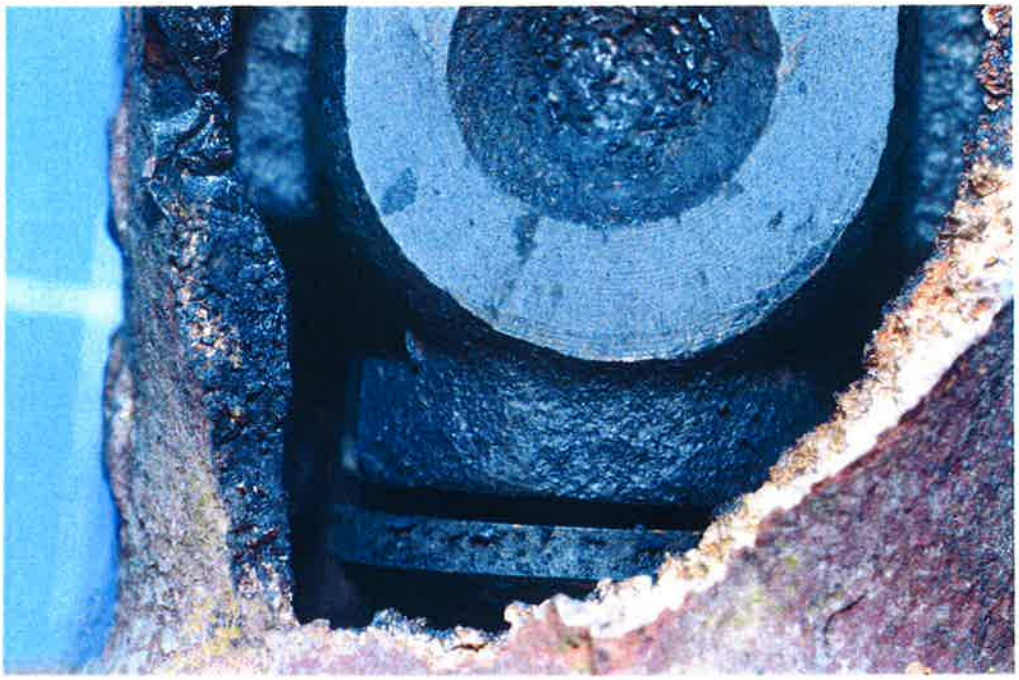
Photograph No. C-33
Item 4C-1 – As-cleaned
Note: brittle fracture and large grains

Photograph No. C-34
Item 4A-1 – As-cleaned
Note: fresh fracture (arrow)

APPENDIX C
Valve Evaluation

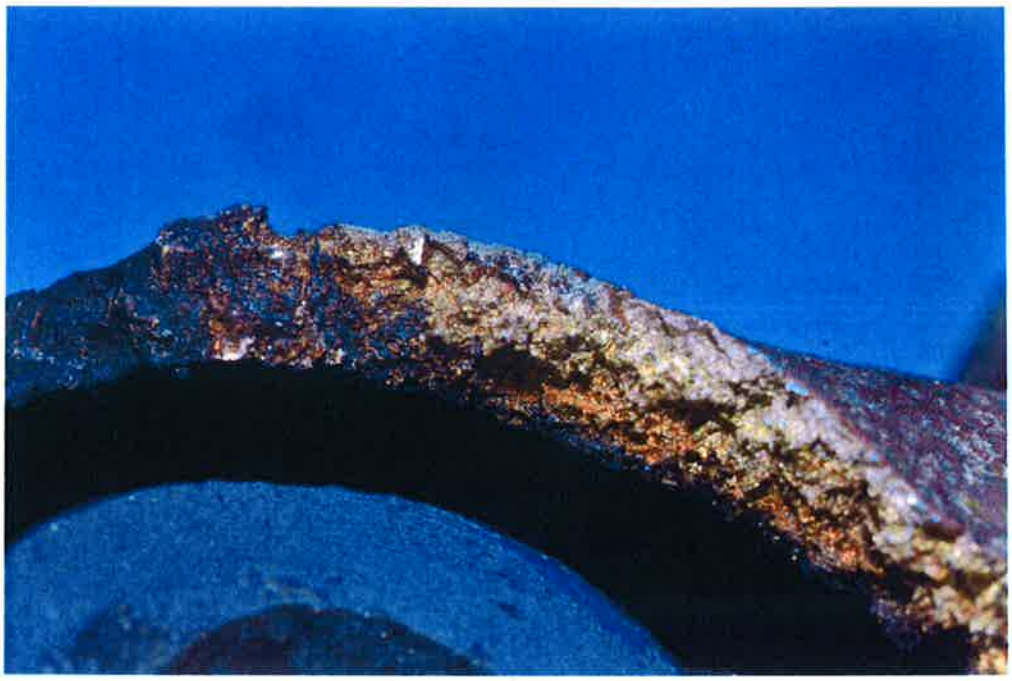


Photograph No. C-35
Item 4C-1 – As-cleaned
Note: brittle fracture and grain growth



Photograph No. C-36
Item 4C-1 – As-cleaned
Note: brittle fracture

APPENDIX C
Valve Evaluation



Photograph No. C-37
Item 4C-1 – As-cleaned
Note: fresh fracture

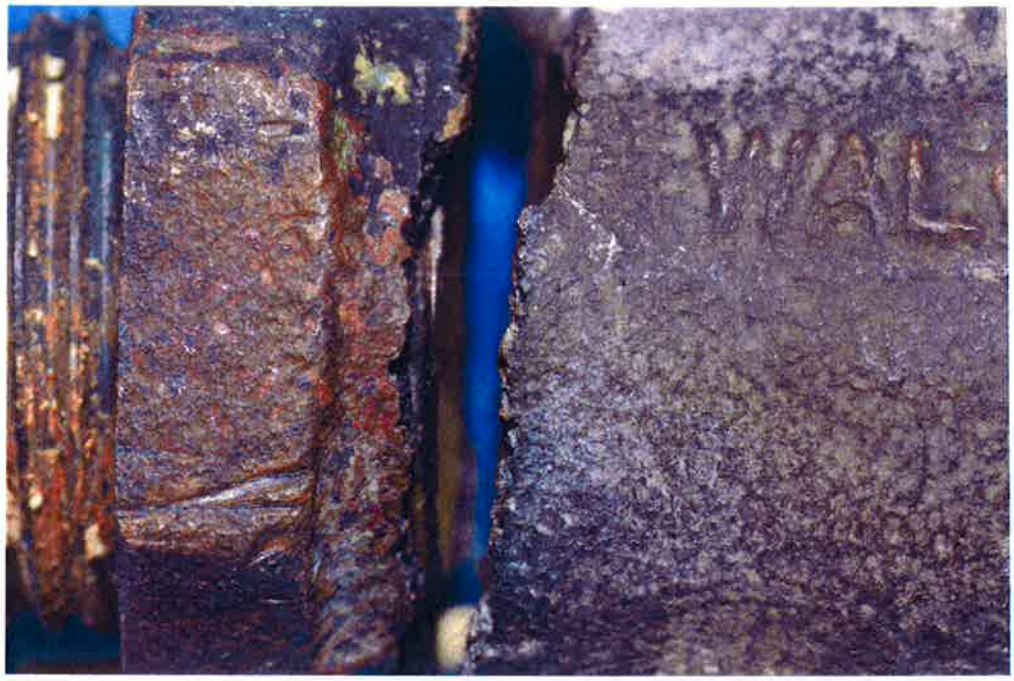
Photograph No. C-38
Item 4C-1 – As-cleaned
Note: brittle fracture

APPENDIX C
Valve Evaluation

Photograph No. C-39
Items 1 and 4A-2 showing fracture pattern
Note: jagged fracture

Photograph No. C-40
Items 1 and 4A-2 showing fracture pattern
Note: jagged fracture

APPENDIX C
Valve Evaluation

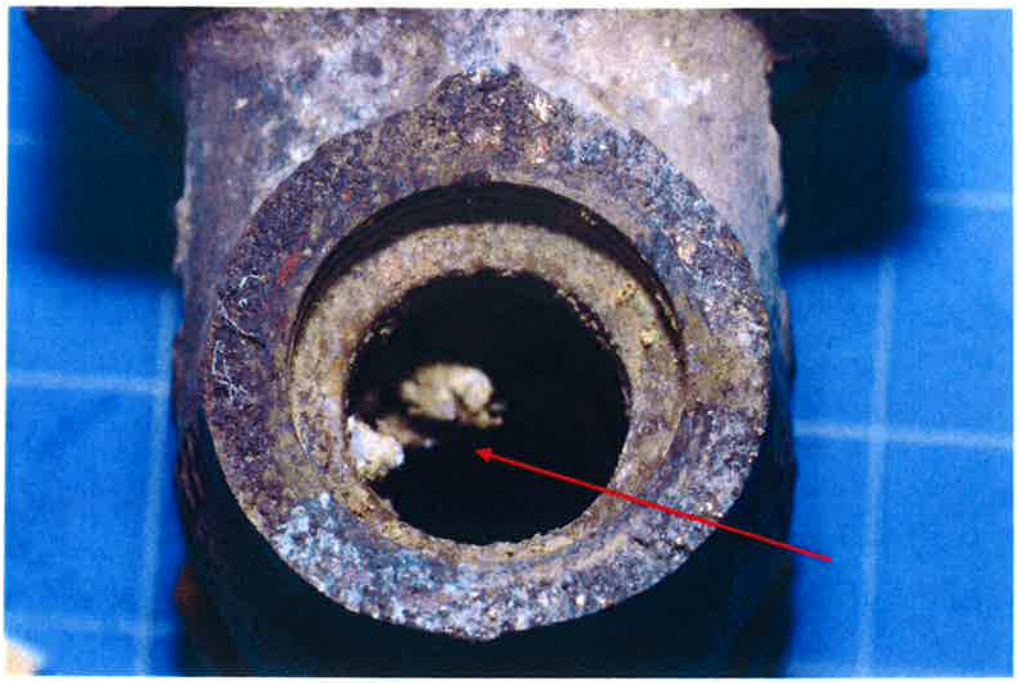


Photograph No. C-41
Items 1 and 4A-2 showing fracture pattern
Note: jagged fracture

Photograph No. C-42
Items 1 and 4A-2 showing fracture pattern
Note: jagged fracture

APPENDIX C
Valve Evaluation

Photograph No. C-43
Items 1 and 4A-2 showing fracture pattern
Note: jagged fracture



Photograph No. C-44
Item 4A-2
Note: Re-solidified aluminum found inside valve (arrow)

APPENDIX C
Valve Evaluation

Photograph No. C-45
Item 4A-2
Note: Re-solidified aluminum found inside valve (arrow)

Photograph No. C-46
All four submitted valves
Note: the two intact valves were from two different manufacturers

APPENDIX C
Valve Evaluation

Photograph No. C-47
Failed valve (Item 4A-1)
"Walworth"

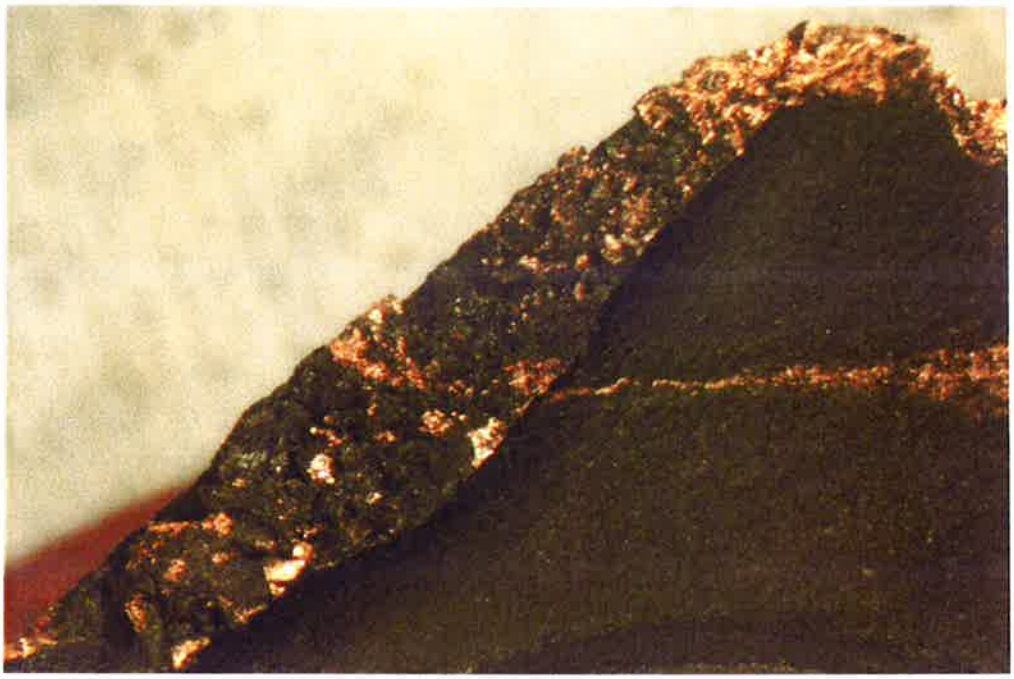
Photograph No. C-48
Failed valve (Item 4A-2)
"Walworth"

APPENDIX C
Valve Evaluation

Photograph No. C-49
Intact valve (Item 2)
"Milwaukee"

Photograph No. C-50
Intact valve (Item 3)
"Crane"

APPENDIX C
Valve Evaluation



Photograph C-51
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: brittle fracture

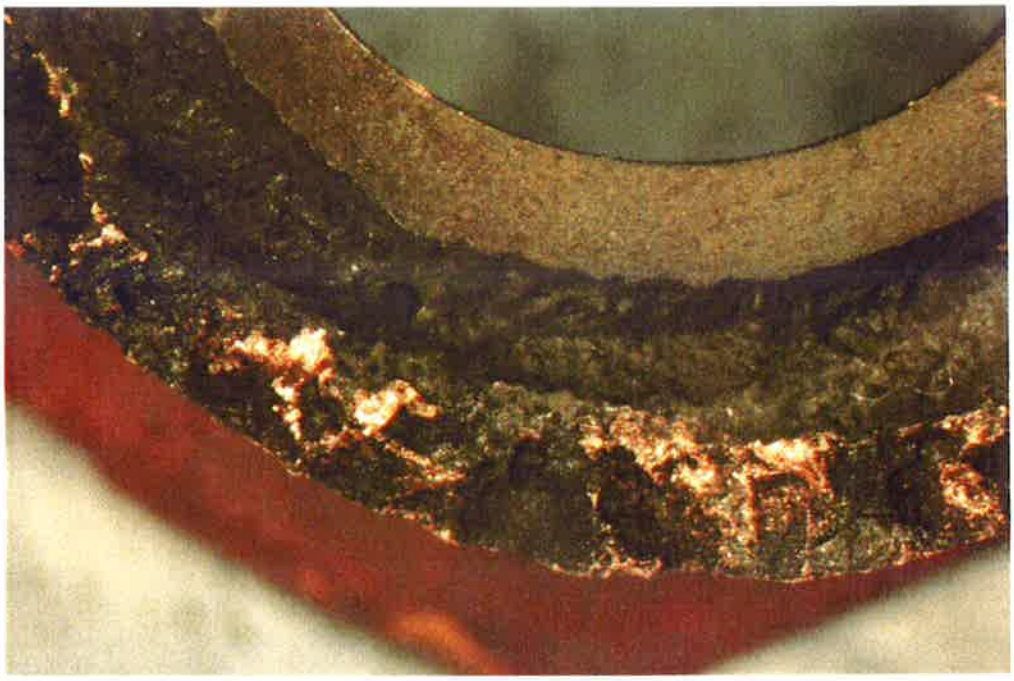
Photograph No. C-52
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: brittle fracture and grain growth

APPENDIX C
Valve Evaluation

Photograph No. C-53
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: brittle fracture and grain growth

Photographs No. C-54
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: brittle fracture

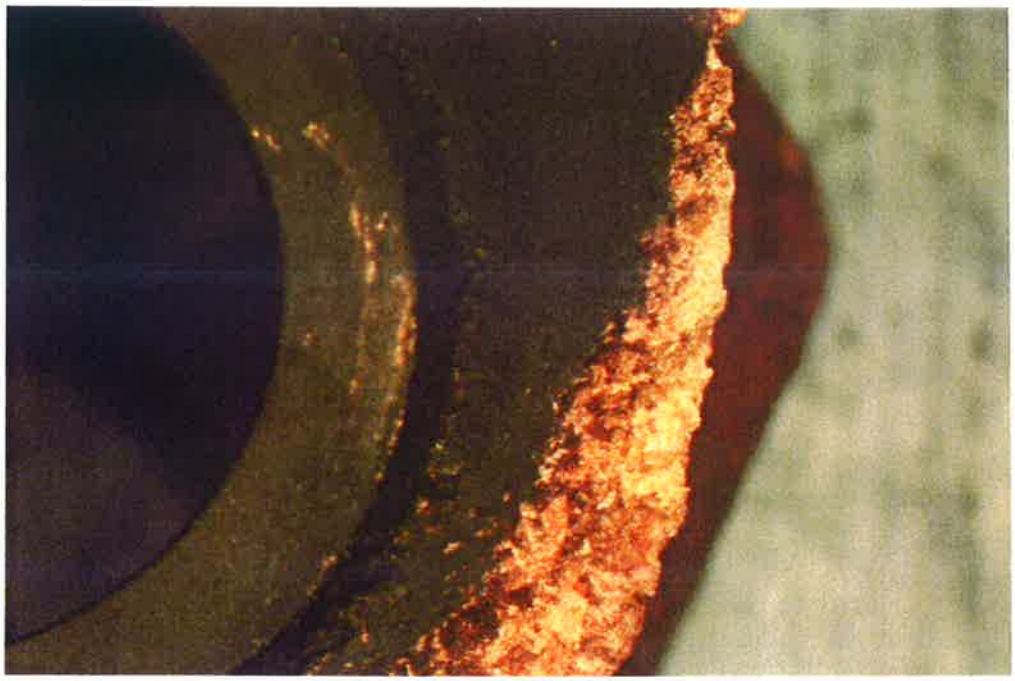
APPENDIX C
Valve Evaluation



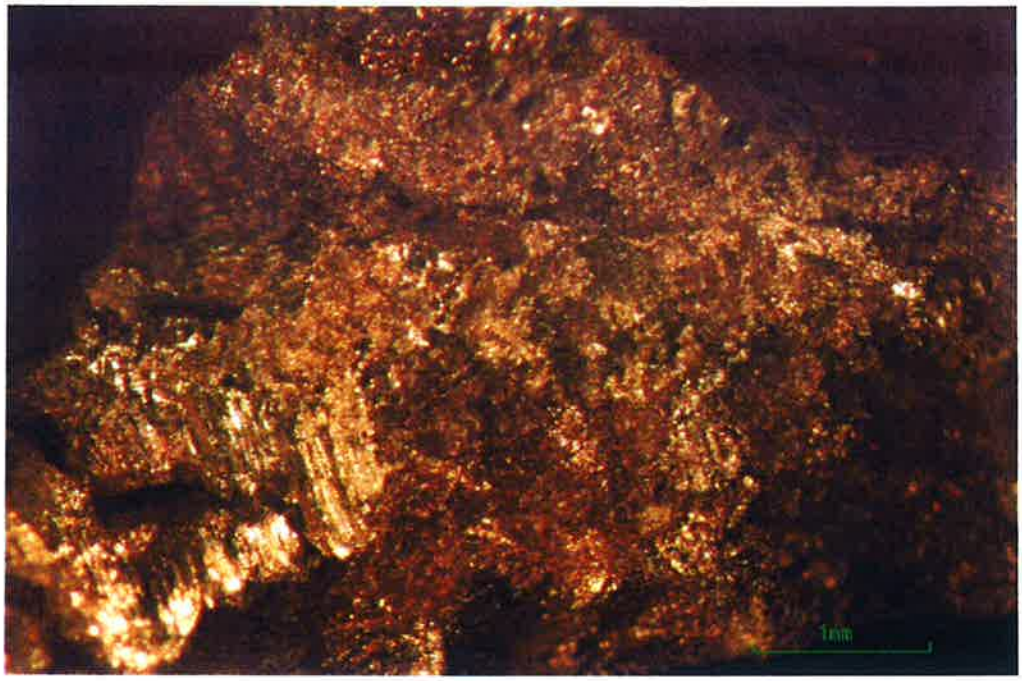
Photograph No. C-55
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: brittle fracture and grain growth

Photograph No. C-56
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: fresh fracture

APPENDIX C
Valve Evaluation



Photograph No. C-57
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: fresh fracture



Photograph No. C-58
Stereophotomicrograph of the fracture surface of Item 4C-1 (as-cleaned)
Note: fresh fracture

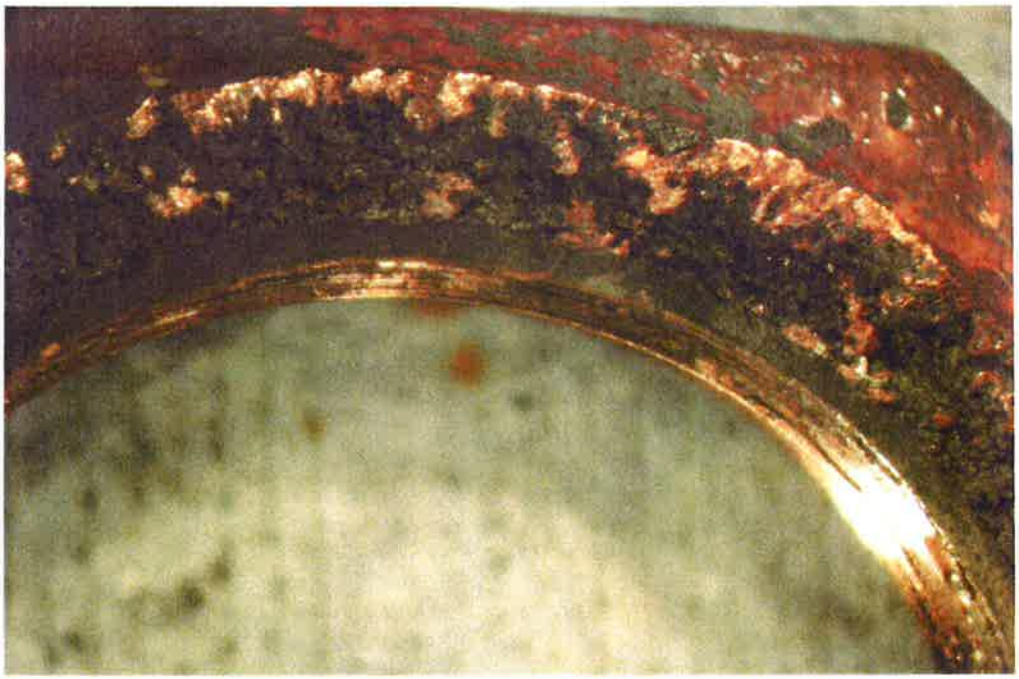
APPENDIX C
Valve Evaluation

Photograph No. C-59
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture

Photograph No. C-60
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture

APPENDIX C
Valve Evaluation

Photograph No. C-61
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture



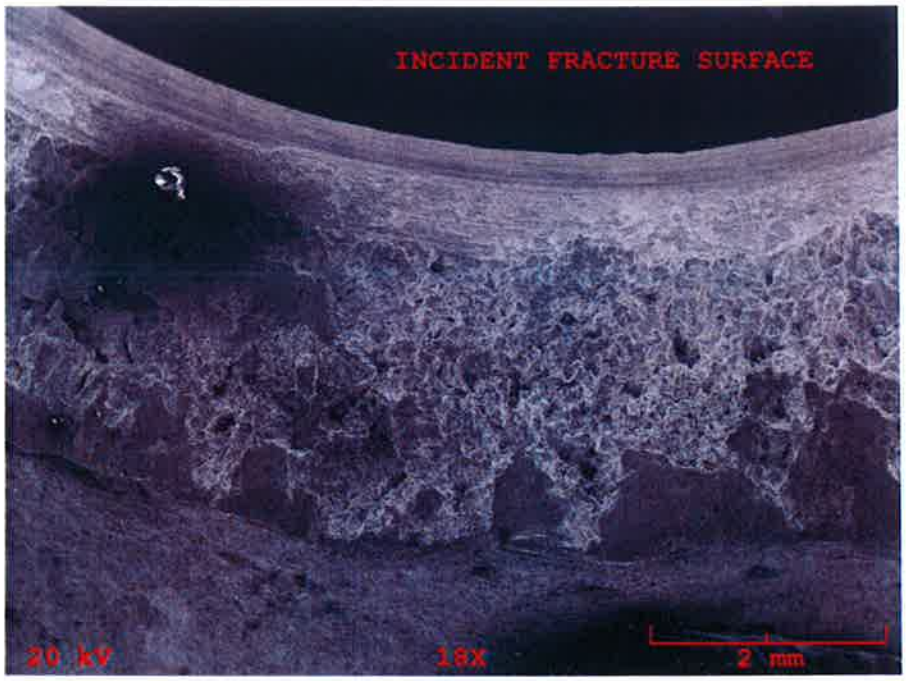
Photograph No. C-62
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture

APPENDIX C
Valve Evaluation

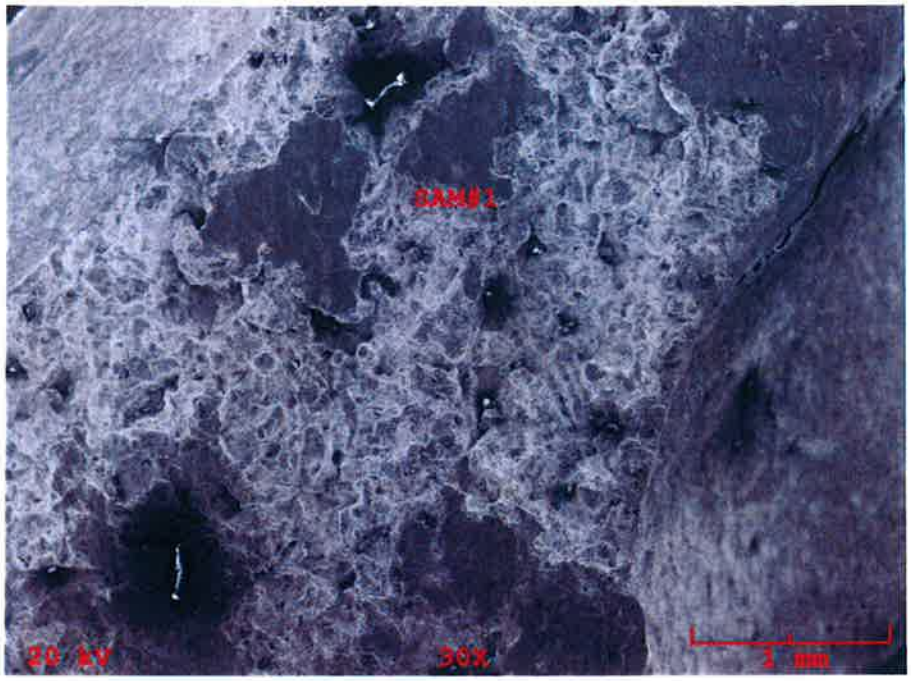
Photograph No. C-63
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture

Photograph No. C-64
Stereophotomicrograph of the fracture surface of Item 1 (as-cleaned)
Note: brittle fracture

APPENDIX C
Valve Evaluation

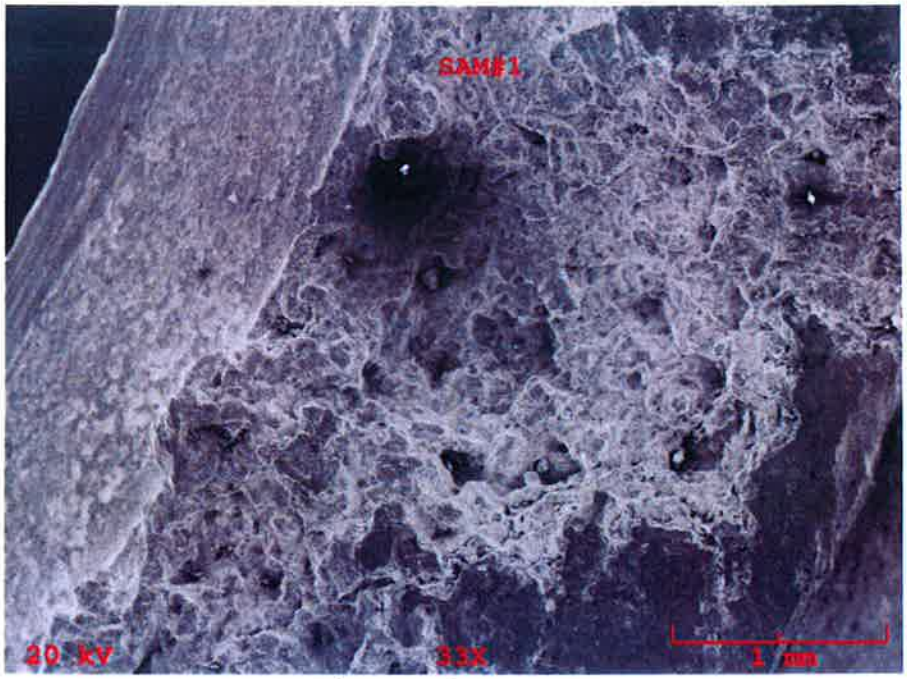


Photograph No. C-65
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture



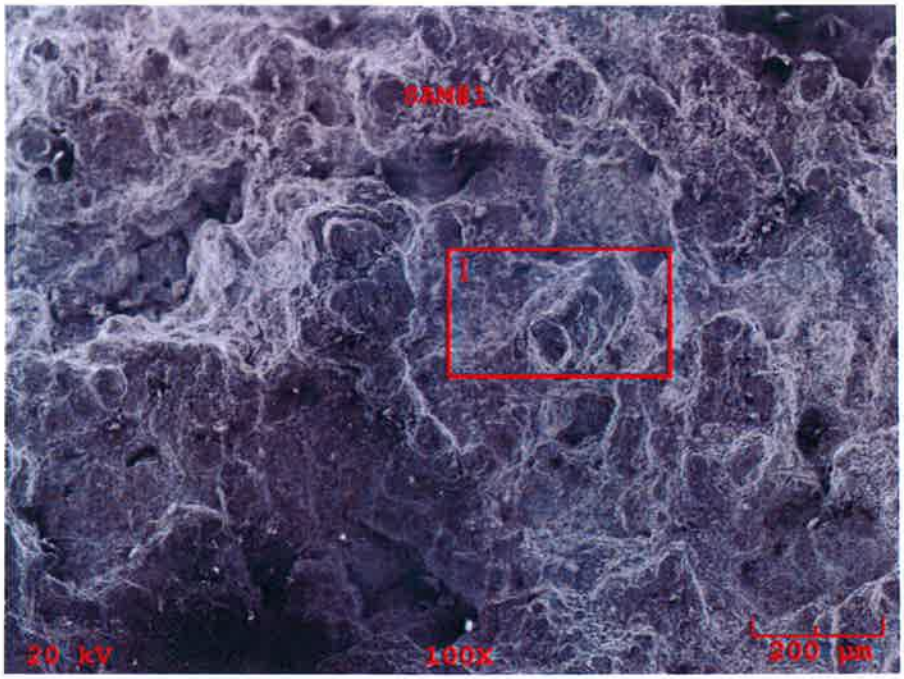
Photograph No. C-66
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture

APPENDIX C
Valve Evaluation

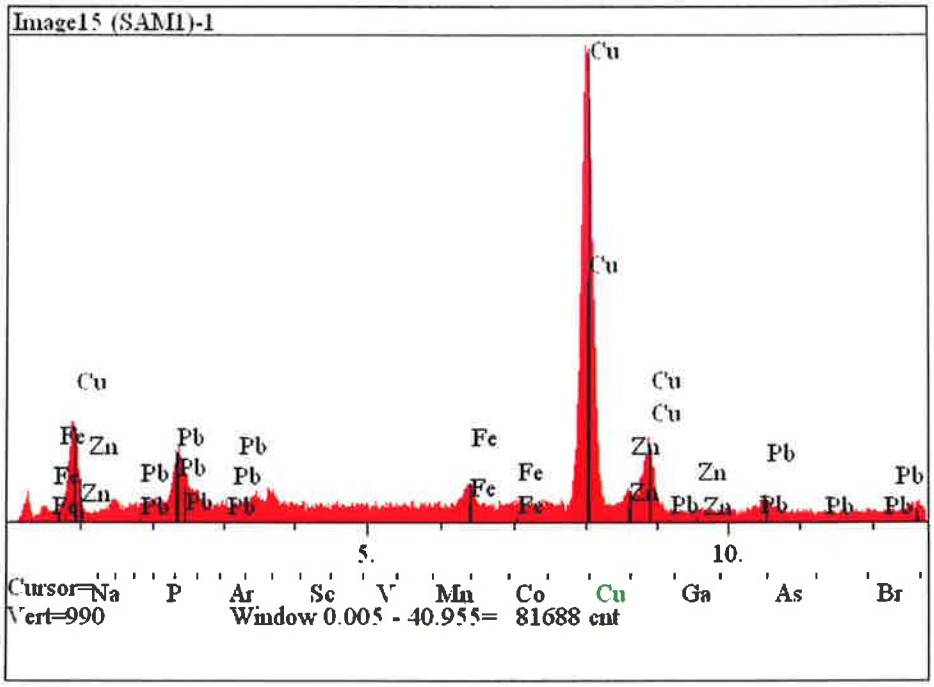


Photograph No. C-67
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture

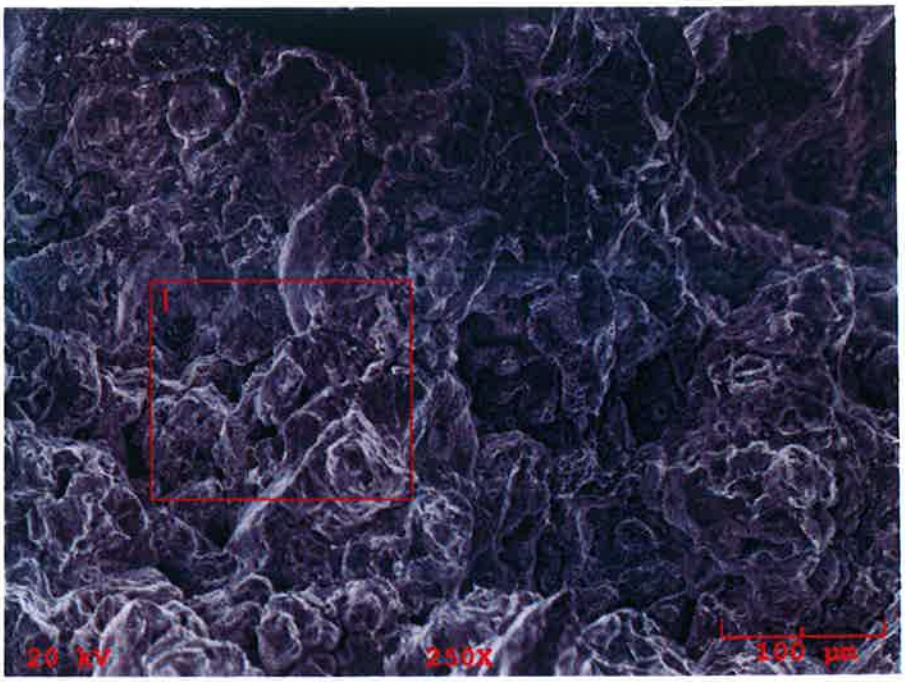
APPENDIX C
Valve Evaluation



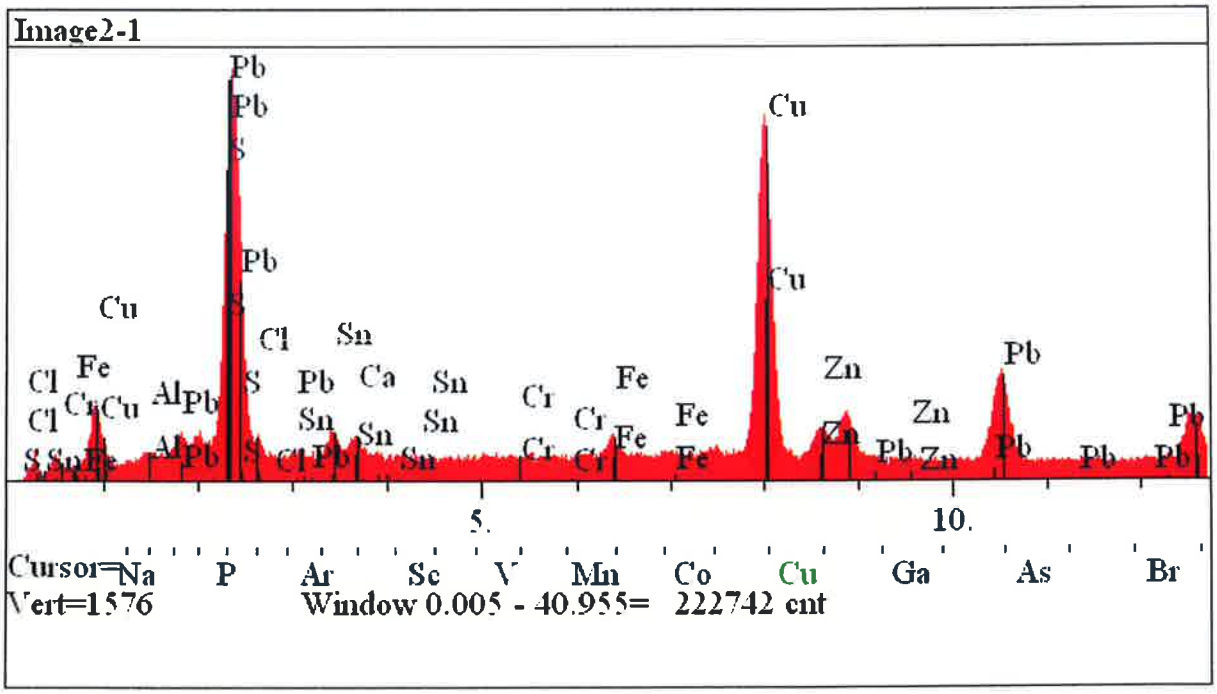
Photograph No. C-68
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture and EDS spectra obtained from area inside red box is given below



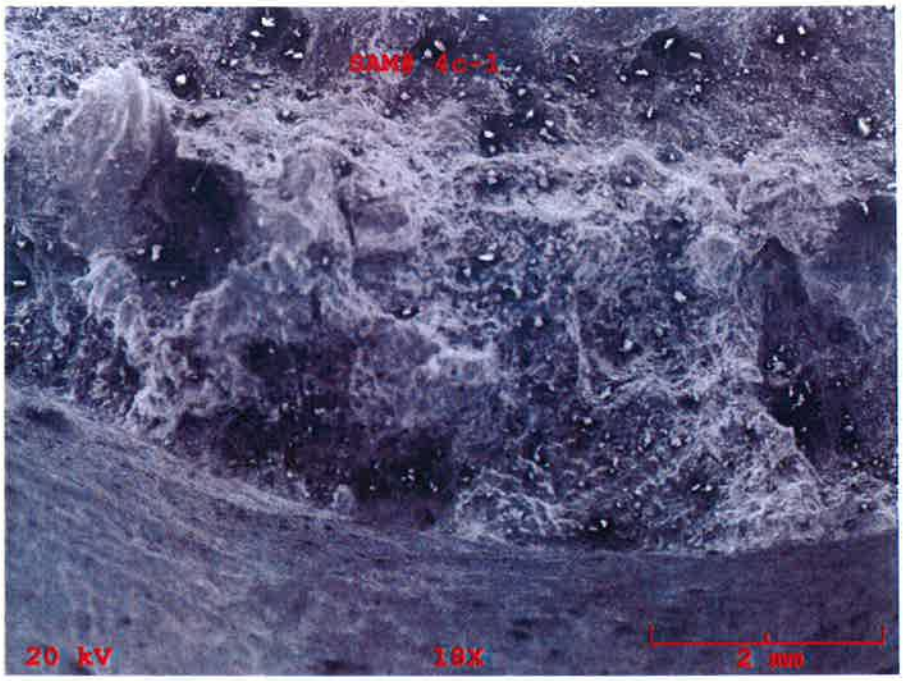
APPENDIX C
Valve Evaluation



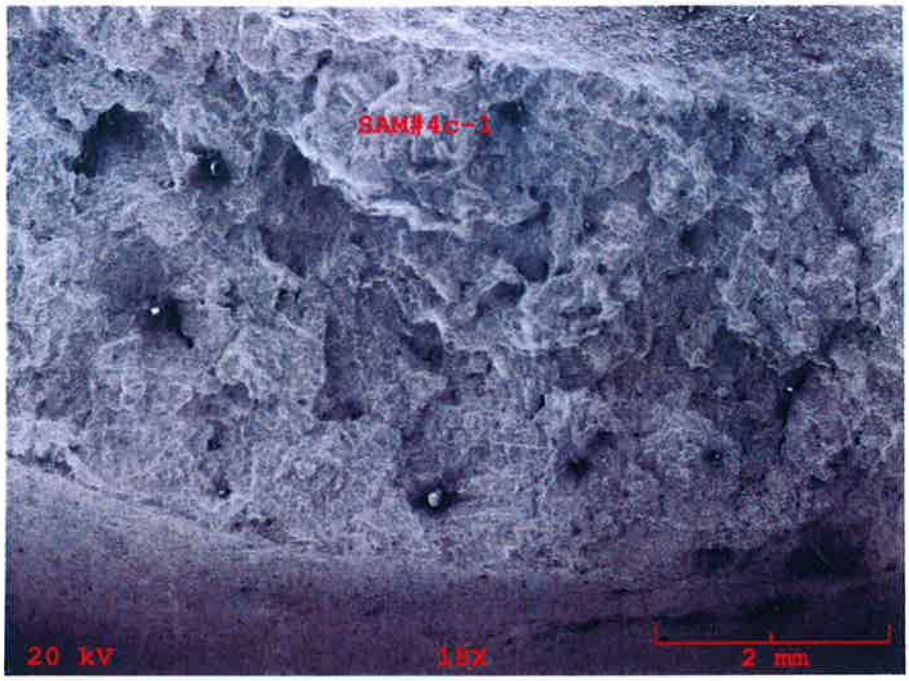
Photograph No. C-69
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture
EDS spectra obtained from area inside red box is given below



APPENDIX C
Valve Evaluation

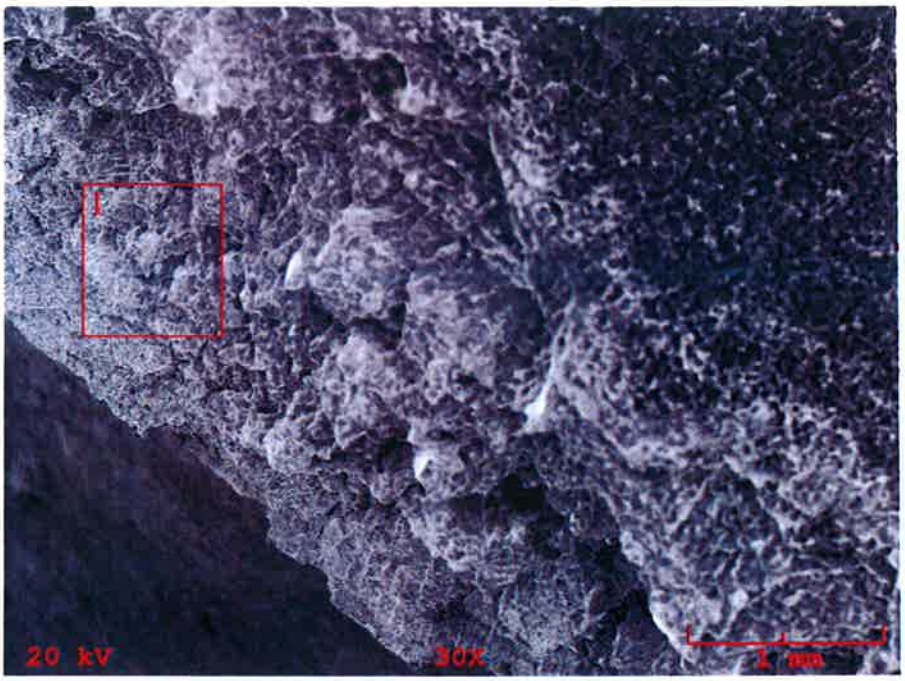


Photograph No. C-70
SEM photomicrograph of the fracture surface of Item 4C-1
Note: brittle fracture

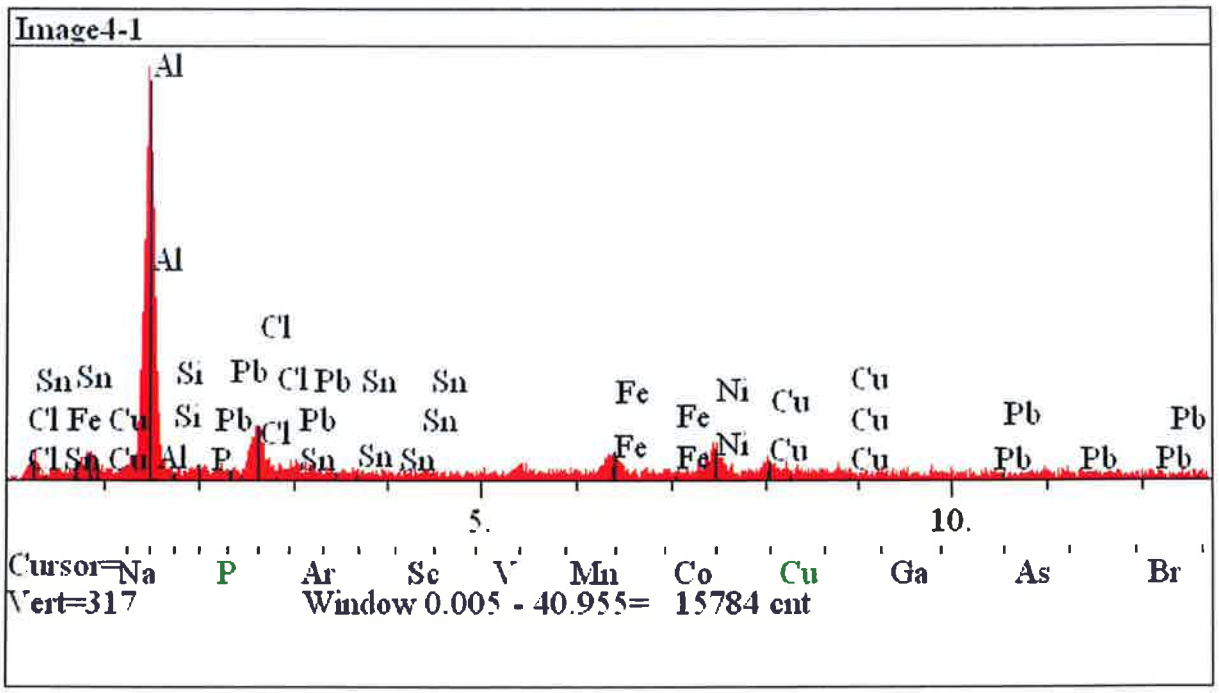


Photograph No. C-71
SEM photomicrograph of the fracture surface of Item 4C-1
Note: brittle fracture

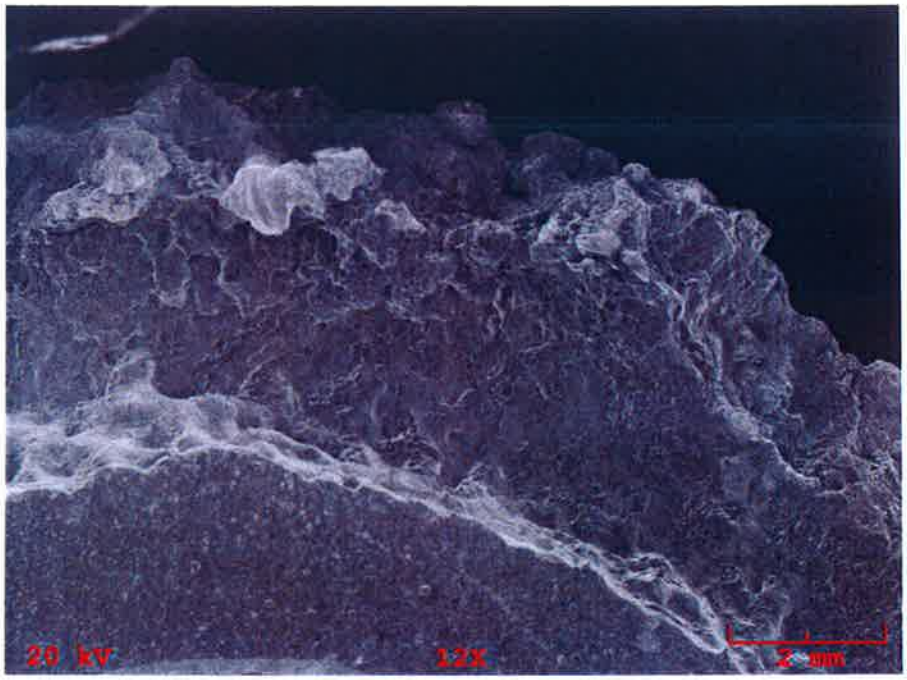
APPENDIX C
Valve Evaluation



Photograph No. C-72
SEM photomicrograph of the fracture surface of Item 4C-1
Note: brittle fracture
EDS spectra obtained from area inside red box is given below

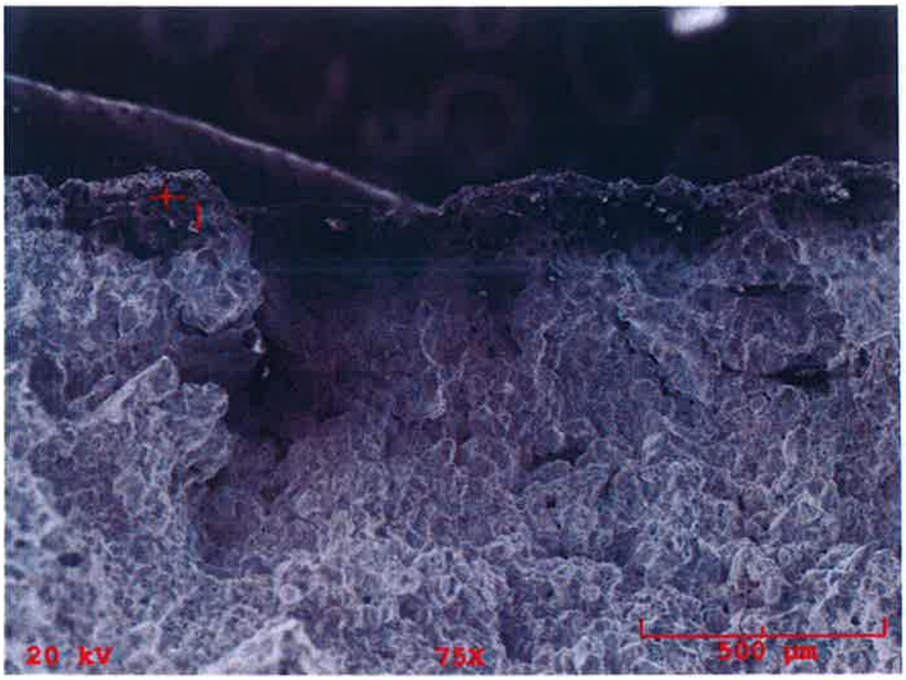


APPENDIX C
Valve Evaluation

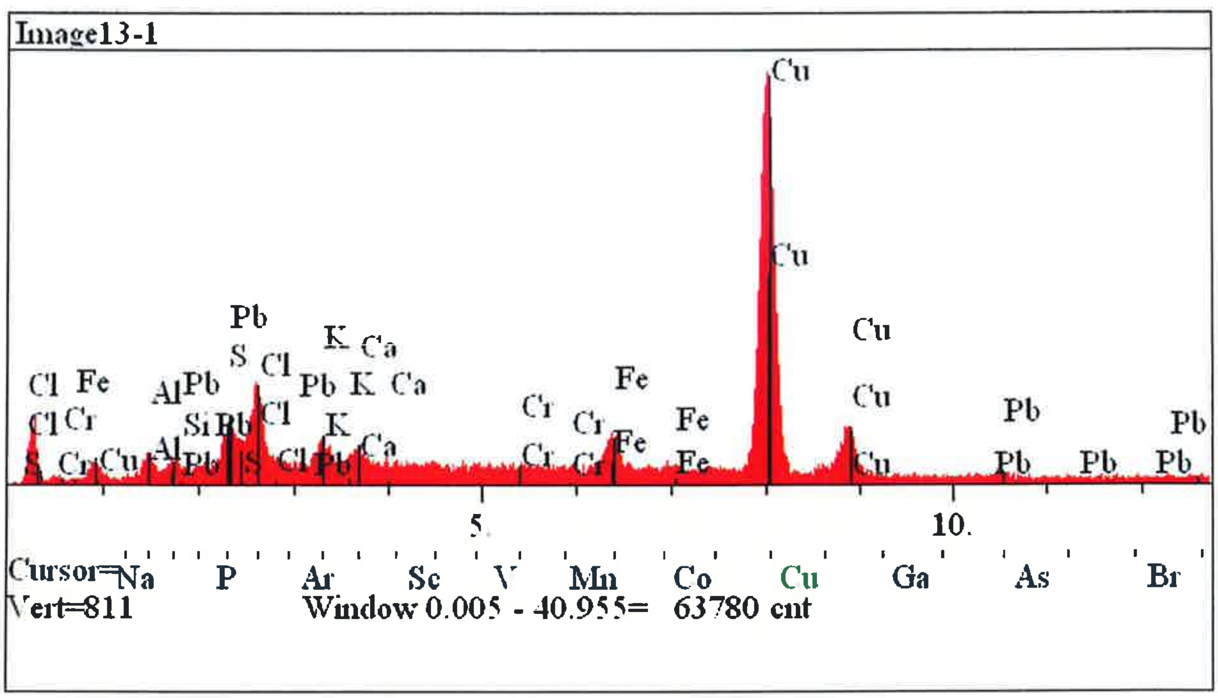


Photograph No. C-73
SEM photomicrograph of the fracture surface of Item 1
Note: brittle fracture

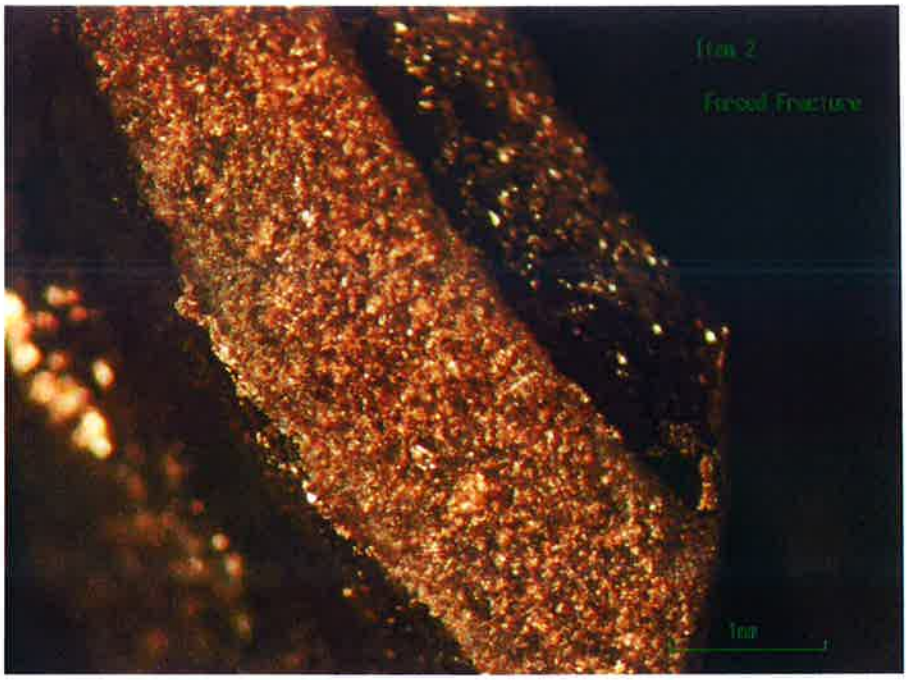
APPENDIX C
Valve Evaluation



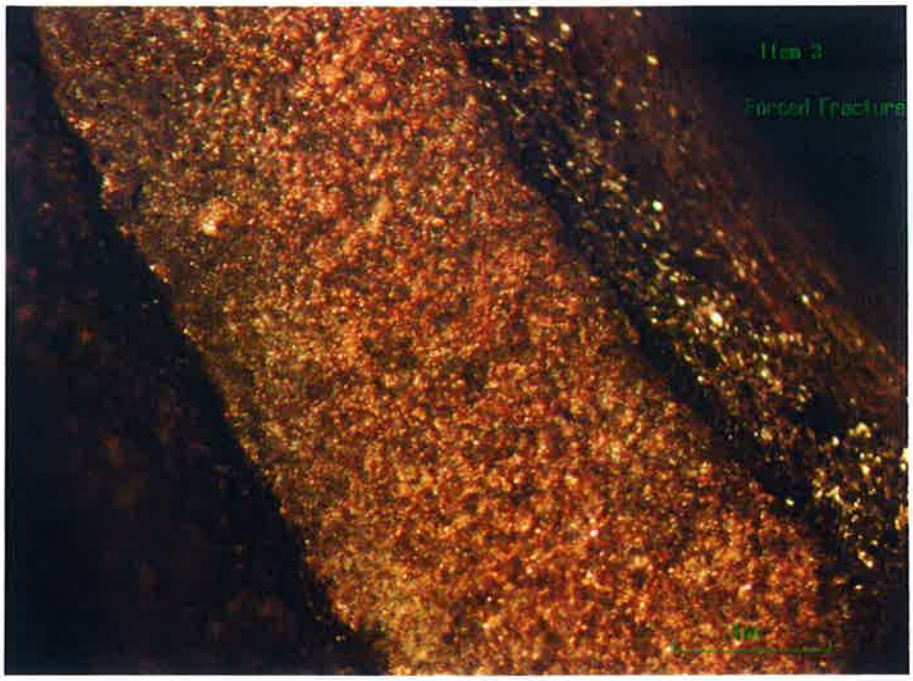
Photograph No. C-74
SEM photomicrograph of the fracture surface of Item 4C-1
Note: brittle fracture
EDS spectra obtained from area marked 1 is given below



APPENDIX C
Valve Evaluation

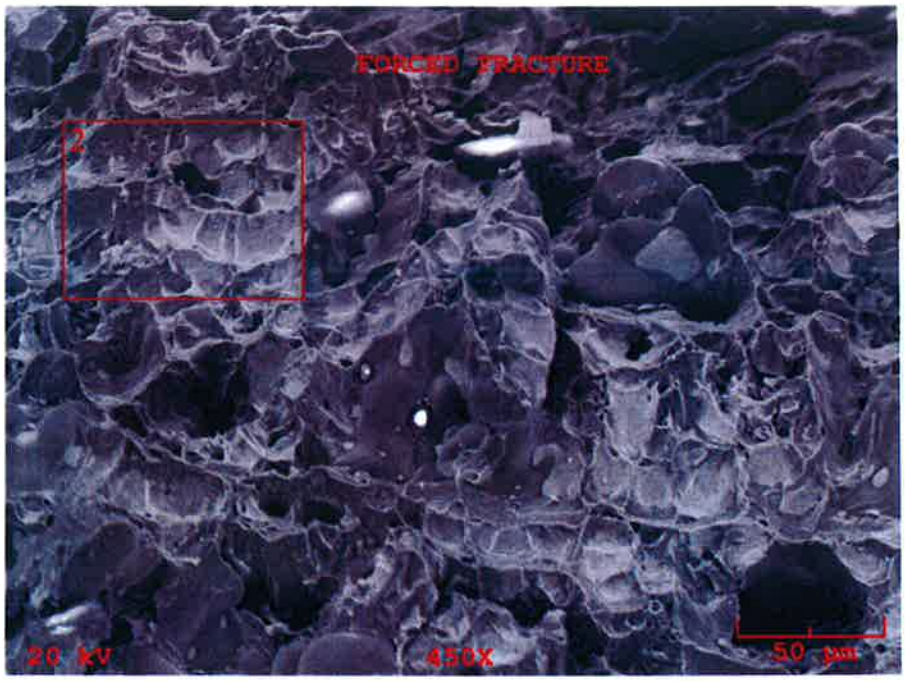


Photograph No. C-75
Stereophotomicrograph of Item 2 fracture surface after forced fracture
Note: ductile fracture

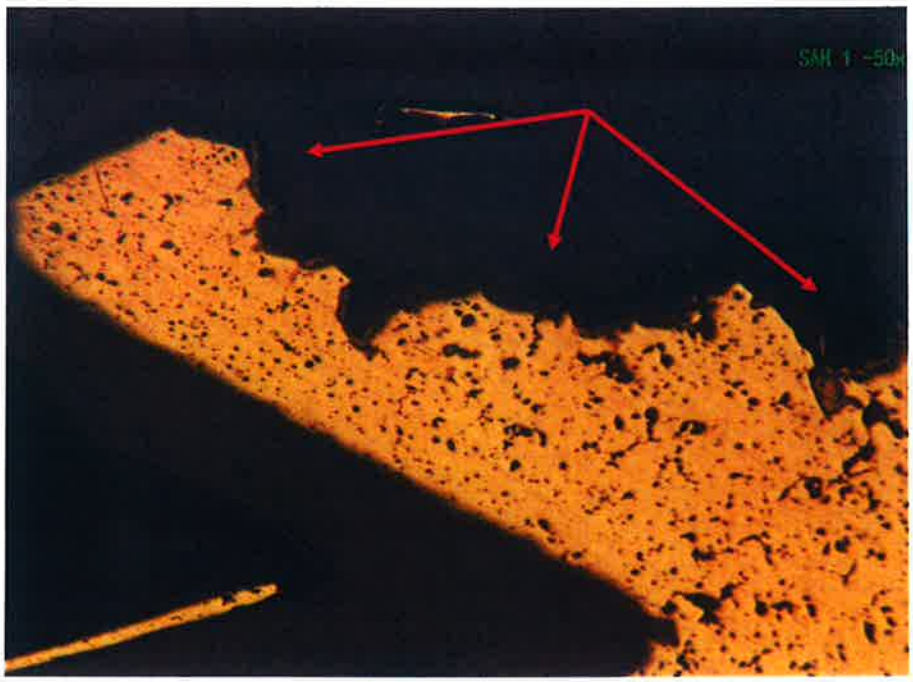


Photograph C-76
Stereophotomicrograph of Item 3 fracture surface after forced fracture
Note: ductile fracture

APPENDIX C
Valve Evaluation

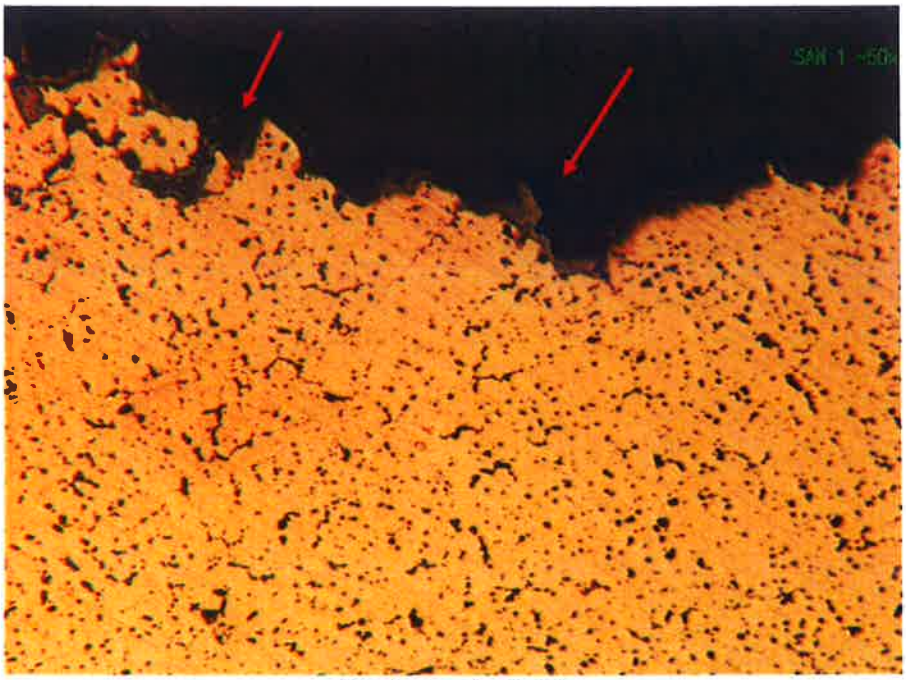


Photograph C-77
SEM photomicrograph of Item 3 fracture surface after forced fracture
Note: ductile fracture

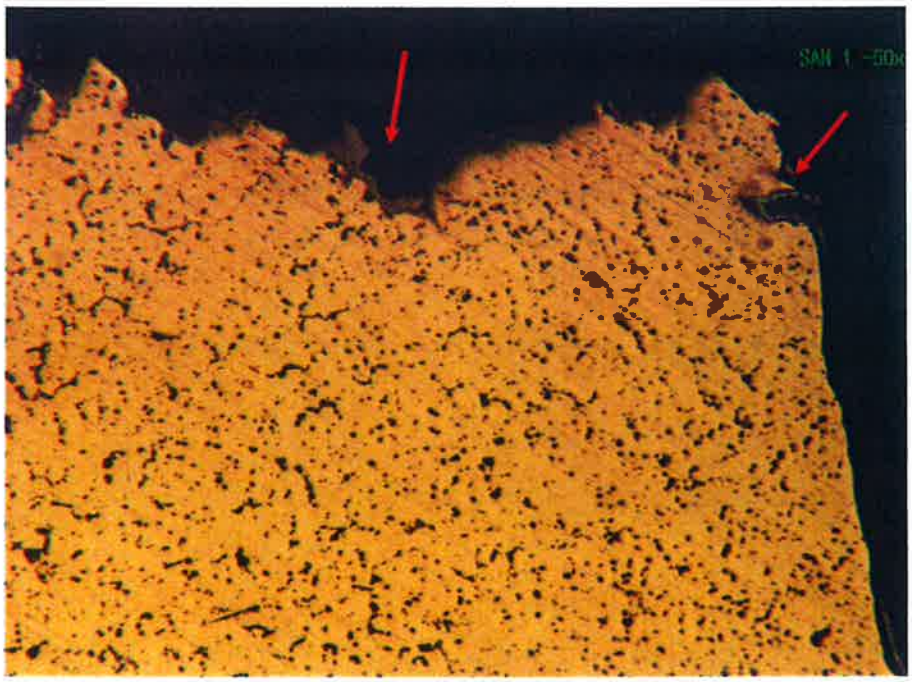


Photograph C-78
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture

APPENDIX C
Valve Evaluation

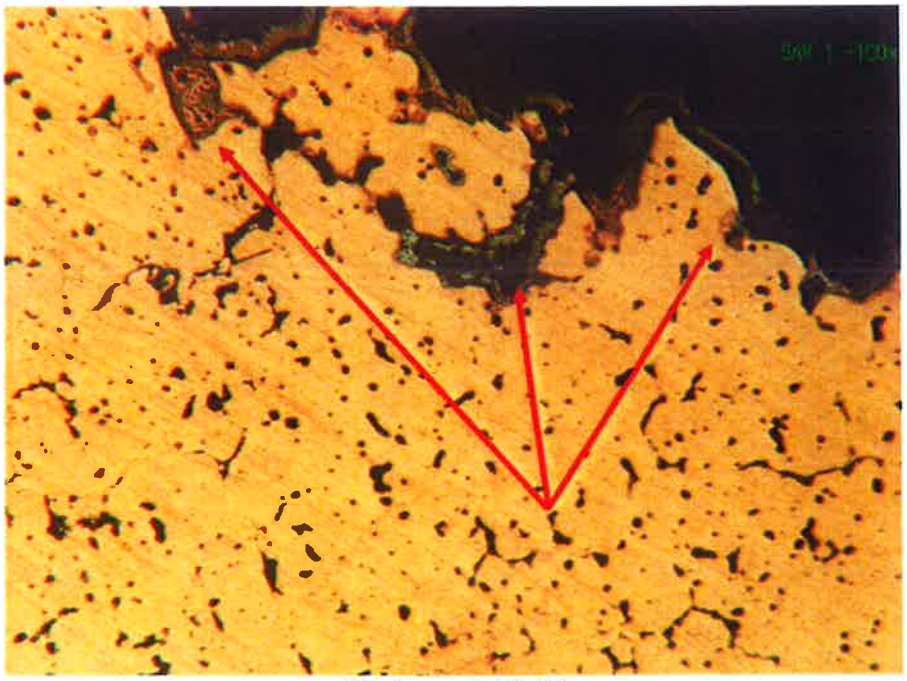


Photograph C-79
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

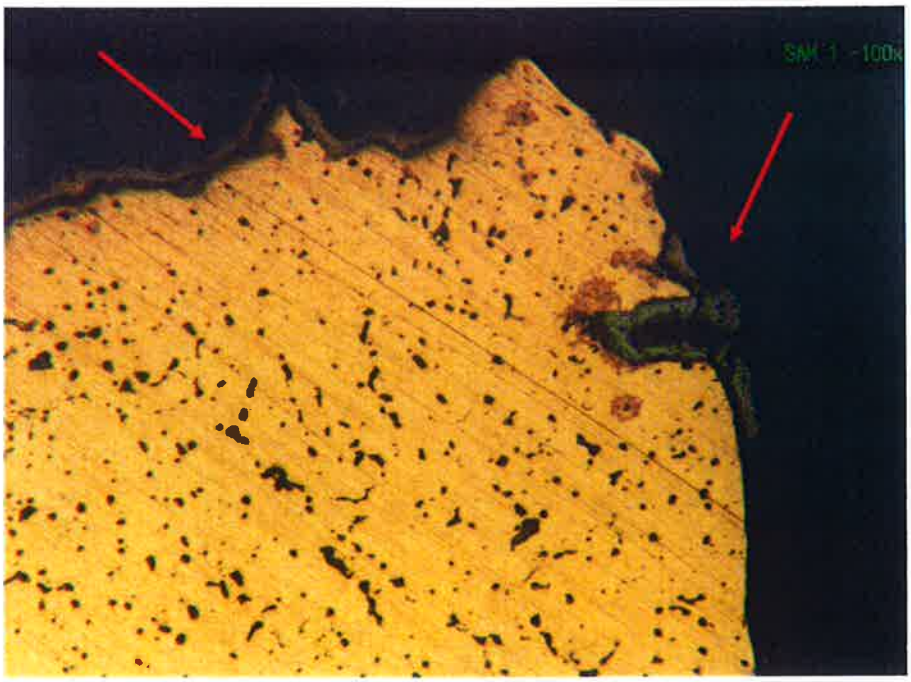


Photograph C-80
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

APPENDIX C
Valve Evaluation

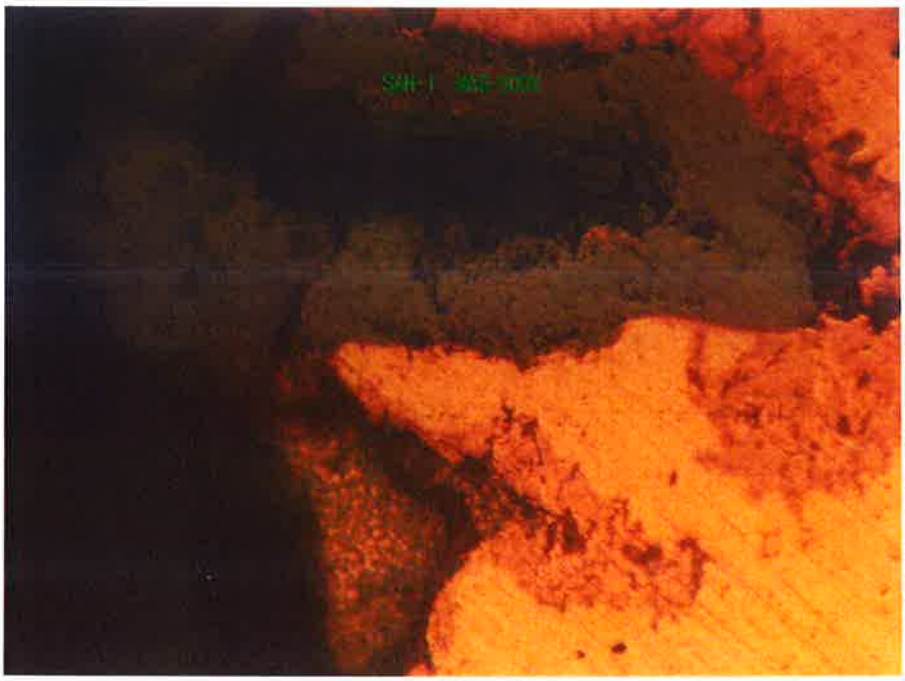


Photograph C-81
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture



Photograph C-82
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

APPENDIX C
Valve Evaluation



Photograph C-83
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

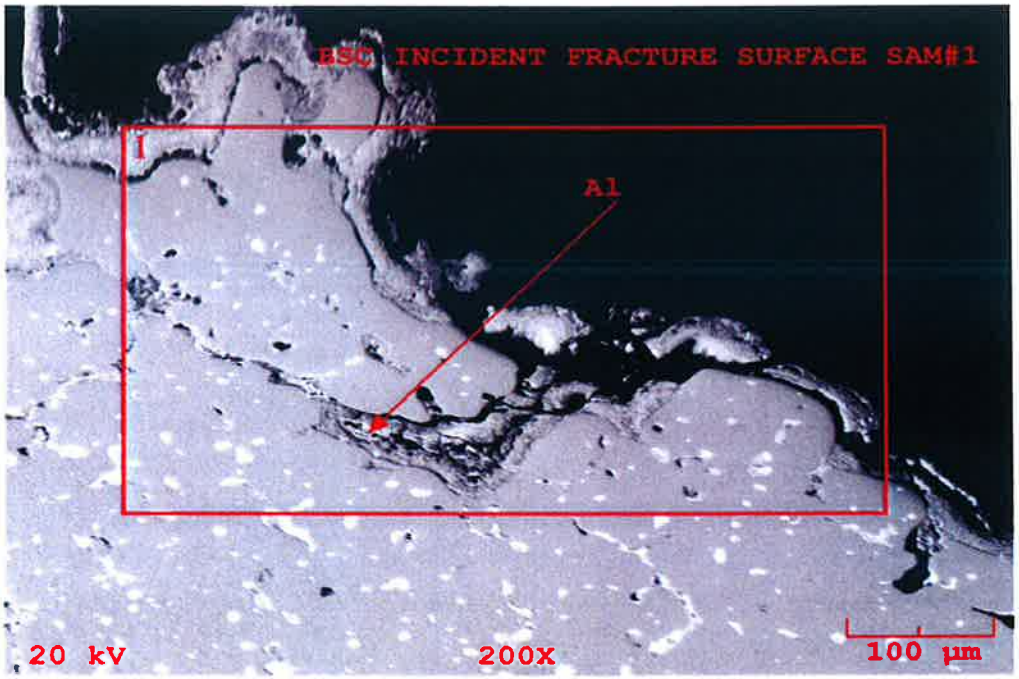
Photograph C-84
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

APPENDIX C
Valve Evaluation

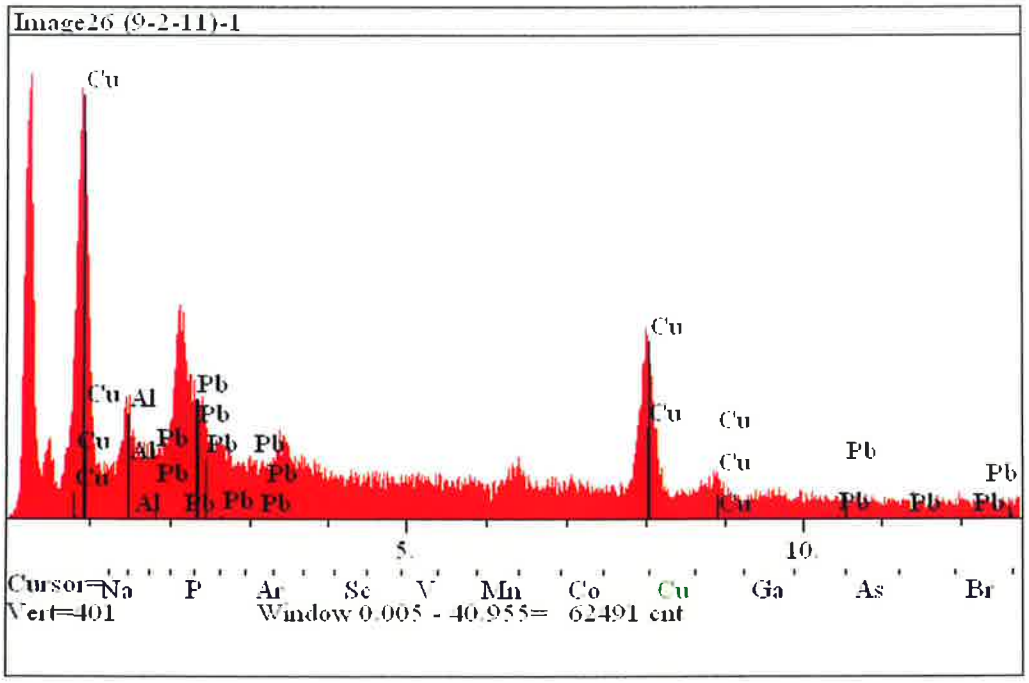
Photograph C-85
Microstructure of Item 1 (mating piece to valve 4A-2) intersecting the fracture surface
Note: intergranular fracture and aluminum along the grains at fracture

Photograph C-86
Microstructure of Item 4C-1 valve intersecting the fracture surface
Note: intergranular fracture

APPENDIX C
Valve Evaluation



Photograph C-87
SEM photomicrograph of the microstructure of Item No. 1 (corresponding Valve 4A-1) intersecting the fracture surface
Note: aluminum penetrating into the grain boundaries



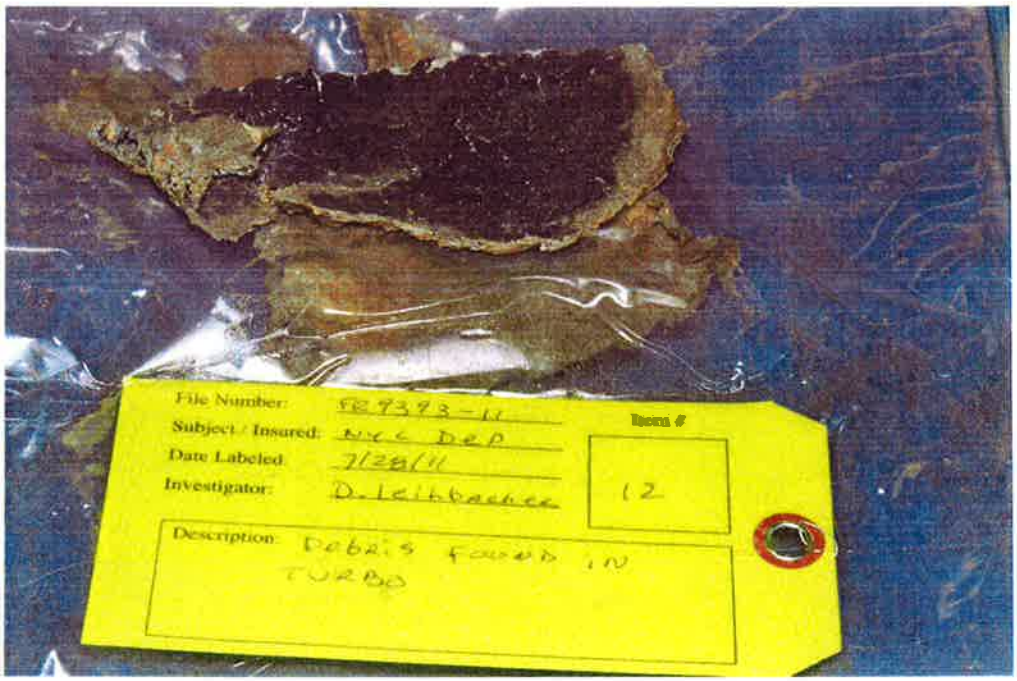
APPENDIX D

TURBOCHARGER DEPOSIT SAMPLES AND GCMS RESULTS

EDISON ANALYTICAL LAB REPORT

Re: North River Waste Treatment Plant
October 18, 2011

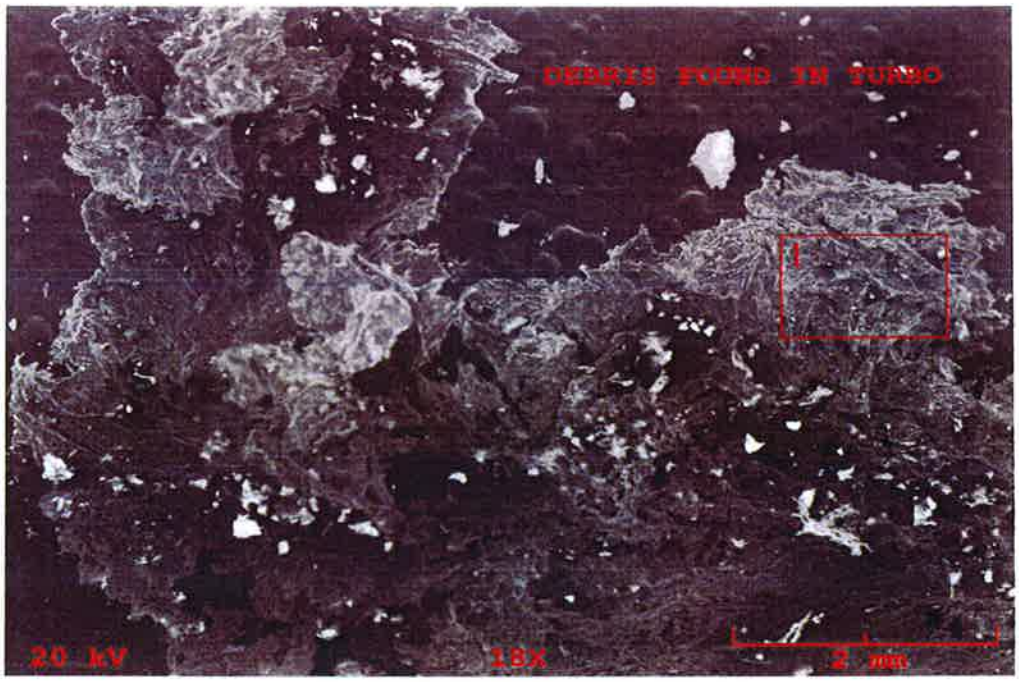
APPENDIX D
Turbocharger Deposit Samples and GCMS Results



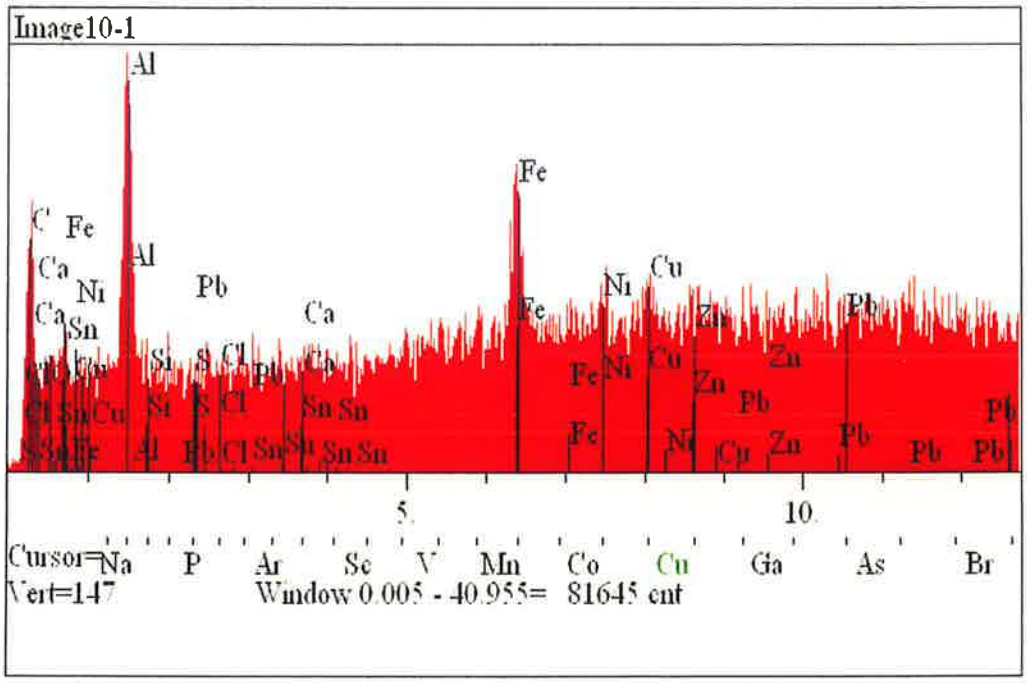
Photograph No. D-1

Photograph No. D-2

APPENDIX D
Turbocharger Deposit Samples and GCMS Results

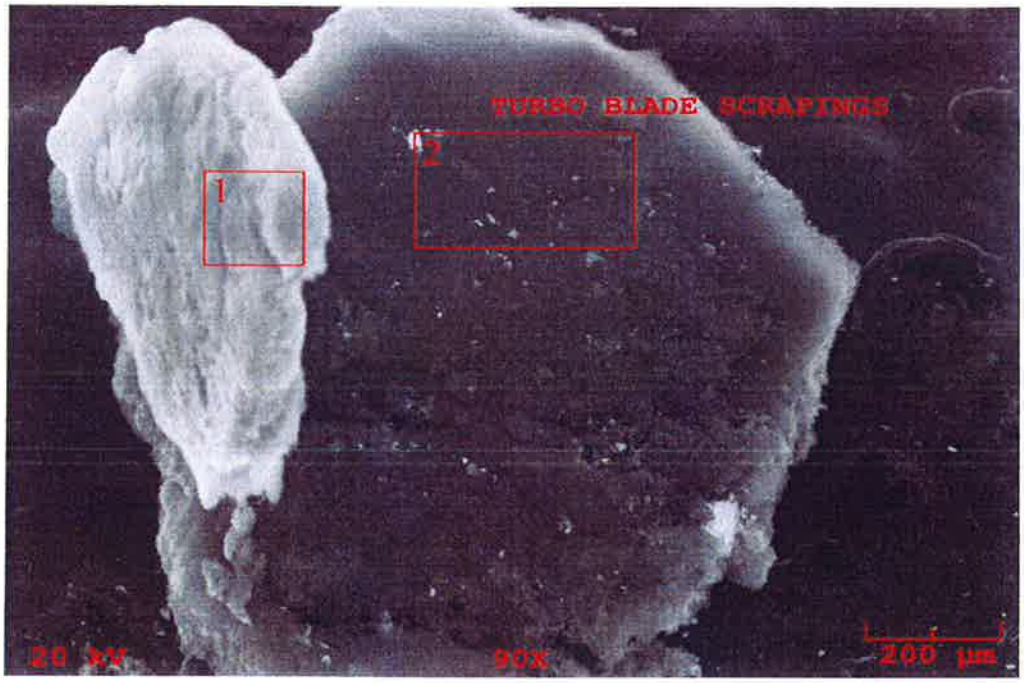


Photograph D-3
SEM photomicrograph of the debris found in the turbocharger (Item 12)
Note: EDS analysis (red box area in photo) is given below



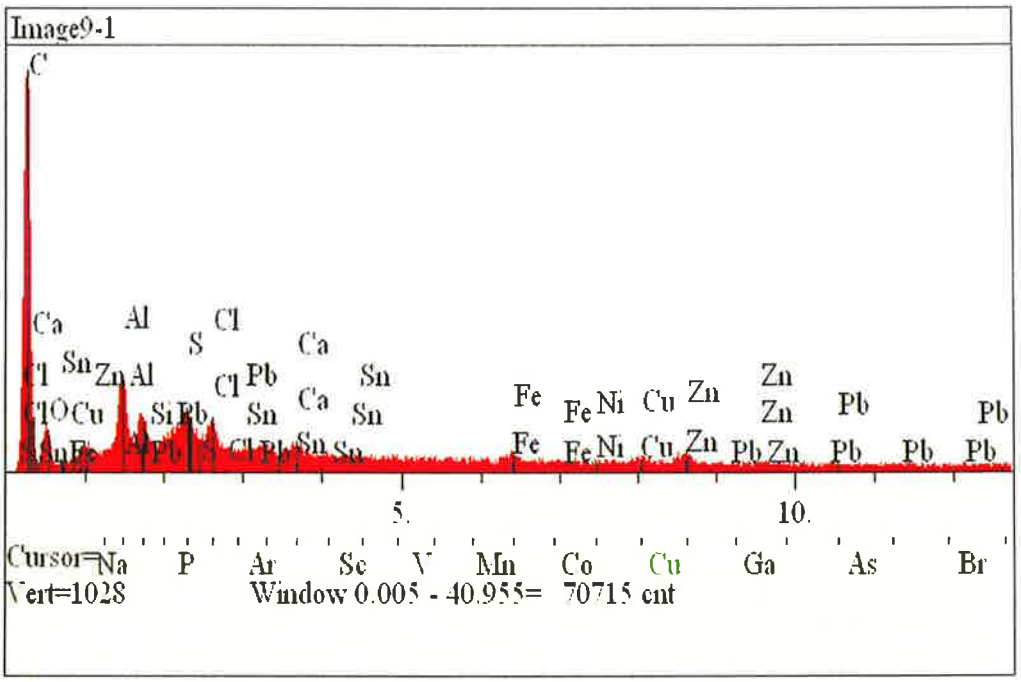
APPENDIX D
Turbocharger Deposit Samples and GCMS Results

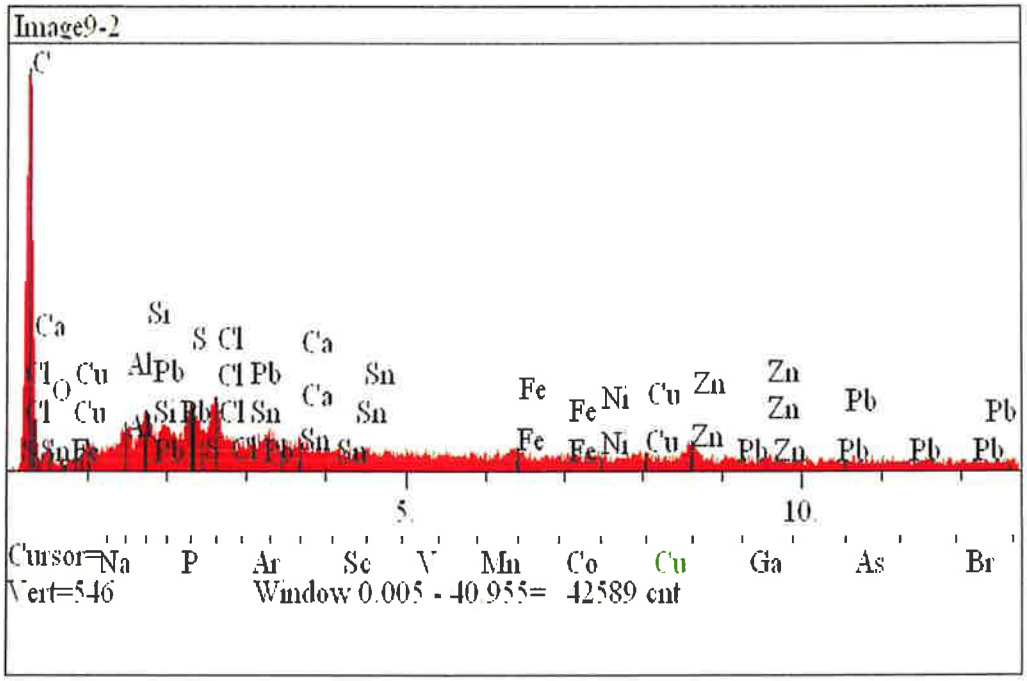
Photograph No. D-4



Photograph No. D-5
SEM photomicrograph of the scrapings from the turbocharger (Item 6)
Note: EDS analyses (red box areas 1 and 2 in photo) are as follows

APPENDIX D
Turbocharger Deposit Samples and GCMS Results





Edison Analytical Laboratories, Inc.

7-B Avis Drive
Latham, NY 12110
Carnahan@Edison-labs.com

Phone: (518) 785-2700

HTTP://www.Edison-labs.com

Mr. John P. Gashinski, P.E.
Metallurgical Engineer
Affiliated Engineering Laboratories
777 New Durham Road
Edison, NJ 08818-3300

August 18, 2011

Mr. Gashinski,

This report describes headspace-GCMS of residue and debris samples.

Sample ID: The samples were submitted in poly bags. The samples were labeled:

"Item No. 6 Burned Residue removed from turbo charger" This consisted of a small amount of black sticky powder.

"Item #12 Debris fond near turbo charger with burned residue" This consisted of what appears to be an aluminum sheet with tan and black residues.

The samples will be referred to as #6 and #12.

Experimental:

The bag containing the #6 sample was treated with many shots from a Static master ionizer to reduce static cling. The black powder in the bag was teased to a corner which was cut off and a specimen of the black material was transferred to a 15 ml screw capped headspace vial with a PTFE coated silicone septum. The sample weight was 8.81 milligrams.

The large metal sheet in sample #12 was cut to provide several narrow strips that were representative of the adhering debris. A portion of the debris powder in the bag was added and some of the blackened region was scraped to add more carbon to the specimen. The material was treated the same as the previous sample. The total sample weight (includes some aluminum) was 1.456 grams.

A heated block with holes the size of the sampling vials was heated to 70°C and the vials inserted to a ¾" depth. This heats the specimen but leaves the top of the vial relatively cool. A Solid Phase Micro-extraction fiber (SPME) was used to sample the headspace for 30 minutes and then desorbed into the GCMS inlet. The SPME fiber was a Supelco 50/30 um DVB/Carboxen/PDMS StableFlex. Part No. 57328-U.

The Item #6 sample was spiked with a known amount of toluene-D8 internal standard and rerun under the same conditions. This allows presentation of the results in terms of micrograms/gram or PPM.

The GC-MS is an HP5890 GC connected to an HP5972 mass selective detector. The GC column was a 30 meter ZB-1 with an ID of 0.32mm and a phase thickness of 1.0 microns. The temperature program was an initial isothermal hold for 5 minutes at 40°C followed by a linear ramp at 20°C/min to 300°C with a 10 minute hold. The injector temperature was 270°C and the injection mode was splitless with a narrow bore SPME specific inlet liner. The interface to the MSD was open split and the interface temperature was 280°C.

Library search was carried out using the Wiley-NIST mass spectral database.

Results and Discussion:

Item #6 . The total ion chromatogram is shown in Figure 1 (minus water and air). This is a fairly low intensity trace and we see larger silicone oligomer peaks due to column and fiber bleed. The dominant linear alkanes in diesel fuel have mass 57 fragments and an ion chromatogram, which is a plot of mass 57 intensity vs. time is shown in Figure 2. This focuses mainly on linear hydrocarbons. Ion chromatograms for mass 105 and mass 134 for alkyl benzenes are shown in Figures 3 and 4. These can be compared to the distributions seen in authentic diesel fuel. The total ion chromatogram was integrated and the major peaks matched against the Wiley-NIST database. The approximate concentration was determined by ratioing the peak areas to that for the toluene-D8 spike and dividing by the sample weight to give values in micrograms/gram. The results are summarized in Table 1. Note that the silicones are system related and likely not from your sample.

Table 1. Summary of Headspace-GCMS for Item No. 6.

Retention Time (min)	Approx. Conc. (ppm)	Peak ID (Item #6)
7.213	11.4	toluene
7.702	4.8	unidentified mass 44,56
8.527	172.9	D3 cydic siloxane
9.102	8.7	xylene isomer
10.846	167.9	D4 cydic siloxane
11.653	100.6	2-ethylhexanol
12.259	26.8	2-ethylhexylacetate
12.447	252.6	silicone oligomer
12.86	32.9	dodecane
13.708	132.3	tridecane
13.949	65.6	silicone oligomer
14.486	77.5	tetradecane
14.97	65.6	branched hydrocarbon
15.217	76.0	pentadecane
15.9	102.0	branched hydrocarbon
16.256	38.3	2,3,10-trimethylpentadecane ?
16.629	60.5	2,6,10,14-tetramethylpentadecane ?
17.274	11.4	branched hydrocarbon

We see some aromatics (toluene, xylene) and a series of linear hydrocarbons that are in the correct range for Diesel fuel. The 2-ethylhexanol may be a product of pyrolysis of phthalate plasticizers, such as DOP, in nearby wiring or other plasticized PVC components.

Item No. 12. This sample gave the total ion chromatogram in Figure 5 and the ion chromatograms for mass 57, 105 and 134 in Figures 6-8 . We see similar patterns but with lower silicones since the total volatiles level is much higher. The apparent concentration is lower due to the non-contributing weight

from the metal sheeting. Taking tridecane as a marker and ratioing raw peak areas, this sample has about 4X the hydrocarbon weight as Item No. 6.

Note that there is a similarity in the volatiles spectrum of the two samples.

Table 2. Summary of headspace GCMS analysis of Item #12.

Retention Time (min)	Approx. Conc. (ppm)	Peak ID (Item#12)
1.704	0.1	acetone
3.087	0.3	ethylacetate
7.212	0.2	toluene
8.527	1.0	D3 cyclic siloxane
9.102	0.2	xylene isomer
9.636	0.5	2-butoxyethanol ?
10.902	1.6	decane
11.41	2.4	unidentified 57,70,105,83,134 (alkyl benzene)
11.941	1.8	undecane
12.132	0.3	C-4 alkyl benzene
12.261	1.2	octyl acetate
12.449	0.9	silicone oligomer
12.551	0.6	unidentified 43,57,71,85,104
12.866	4.1	dodecane
13.003	0.4	2,6-dimethylundecane ?
13.072	0.4	unidentified 57,70,104,91,133
13.507	0.5	unidentified 57,71,118,131
13.708	3.1	tridecane
13.954	0.3	2,7-dimethyltetralin + silicone oligomer
14.146	0.2	unidentified 55,83,118,145,166
14.484	0.4	tetradecane

A sample of authentic diesel fuel (Mobil) was obtained locally and analyzed in the same fashion. This gave the total ion chromatogram in Figure 9 and ion chromatograms for mass 57, mass 105 and mass 134 in Figures 10-12. Mass spectra from the peak at 13.7 minutes in all three runs are shown with library search results in Figures 13-15.

The match of the spectra and retention times indicates the presence of an alkane mixture in the samples Item No. 6 and Item No. 12. This mixture has a similar distribution of alkanes and alkyl benzenes to that found in commercial diesel fuel.

If you have any questions, feel free to call us at 518-785-2700

Sincerely yours,

James Carnahan, Ph.D.

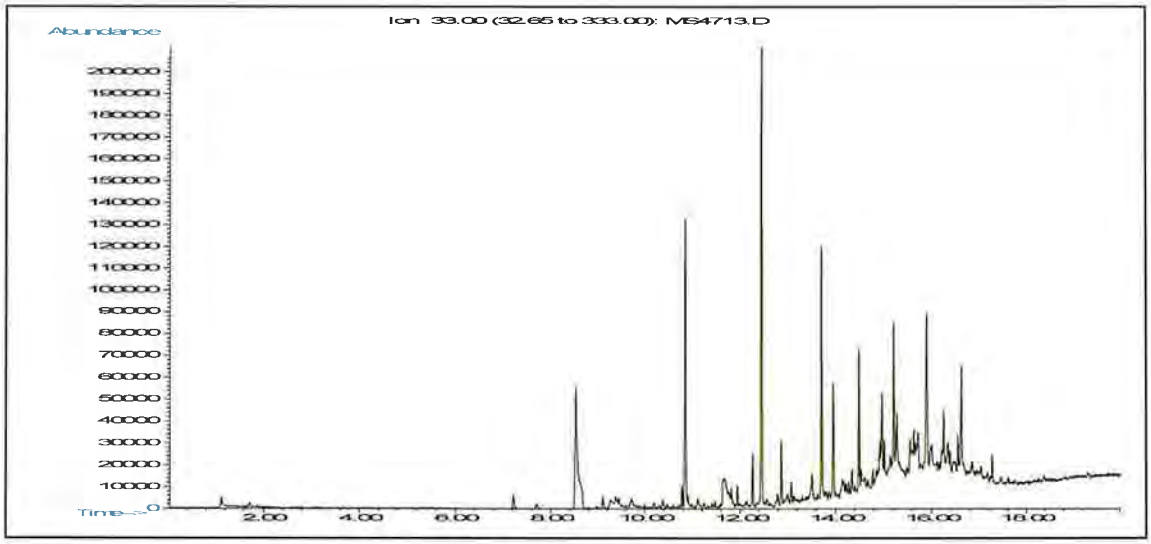


Figure 1. Total ion chromatogram for headspace-GCMS of Item No. 6.

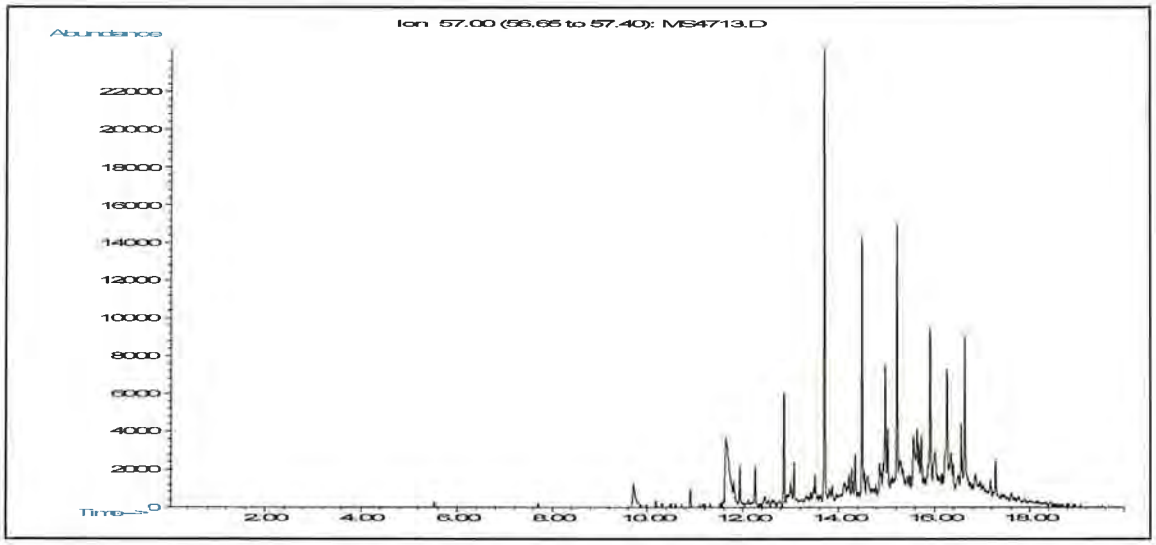


Figure 2. Ion chromatogram for mass 57 (alkanes) for headspace-GCMS of Item No. 6.

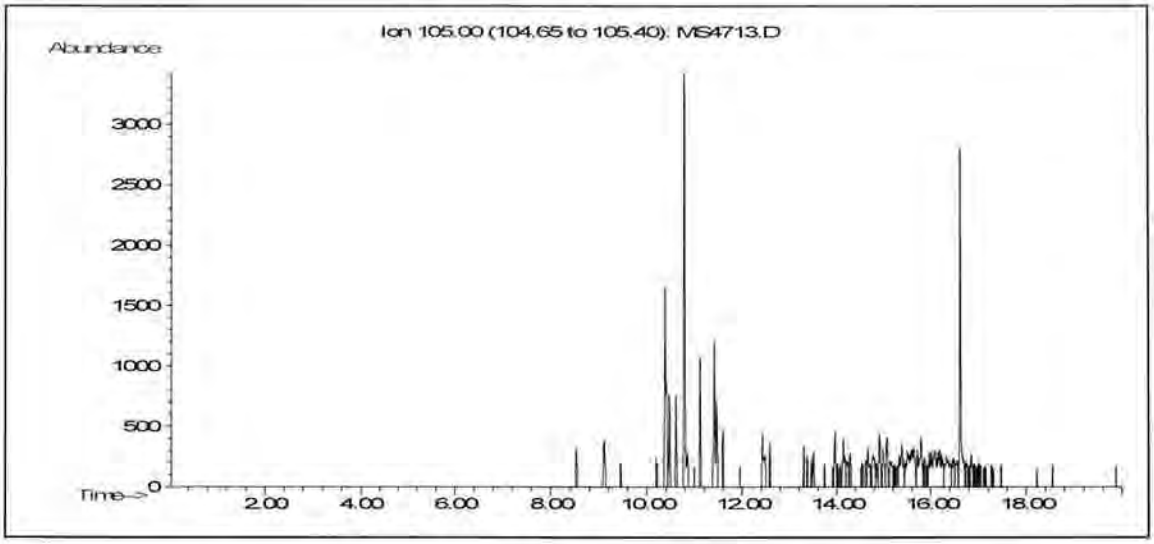


Figure 3. Ion chromatogram for mass 105 (alkyl benzenes) for headspace-GCMS of Item No. 6.

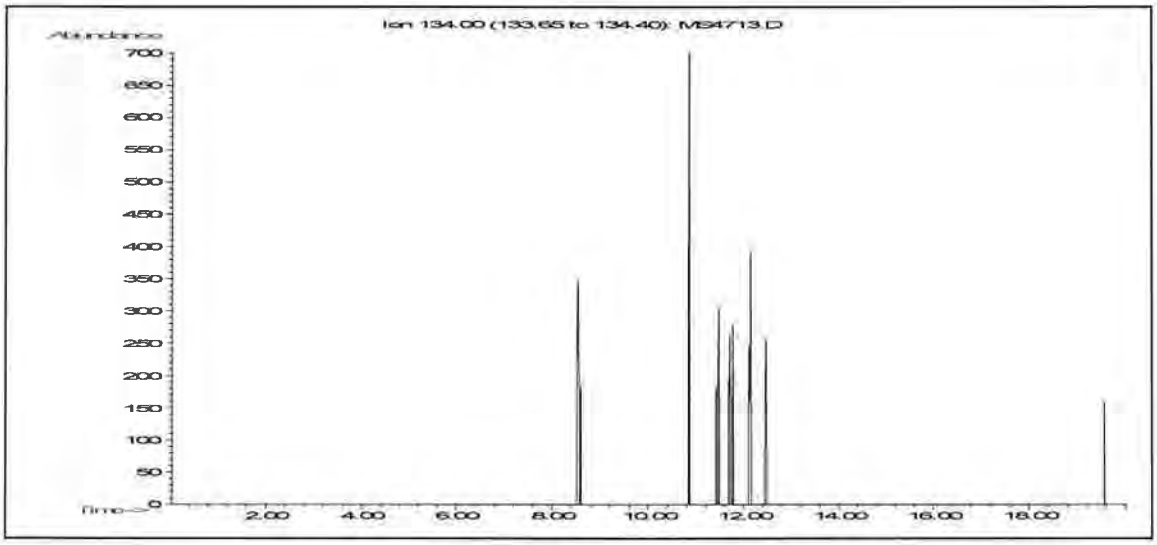


Figure 4. Ion chromatogram for mass 134 (alkylbenzenes) for headspace-GCMS of Item No. 6.

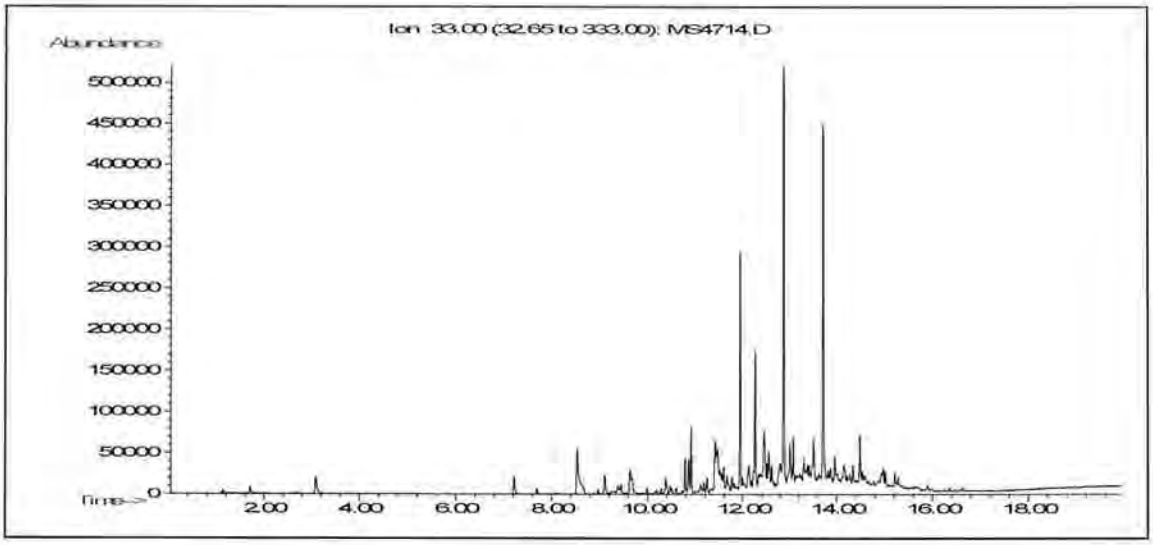


Figure 5. Total ion chromatogram for headspace-GCMS of Item No. 12.

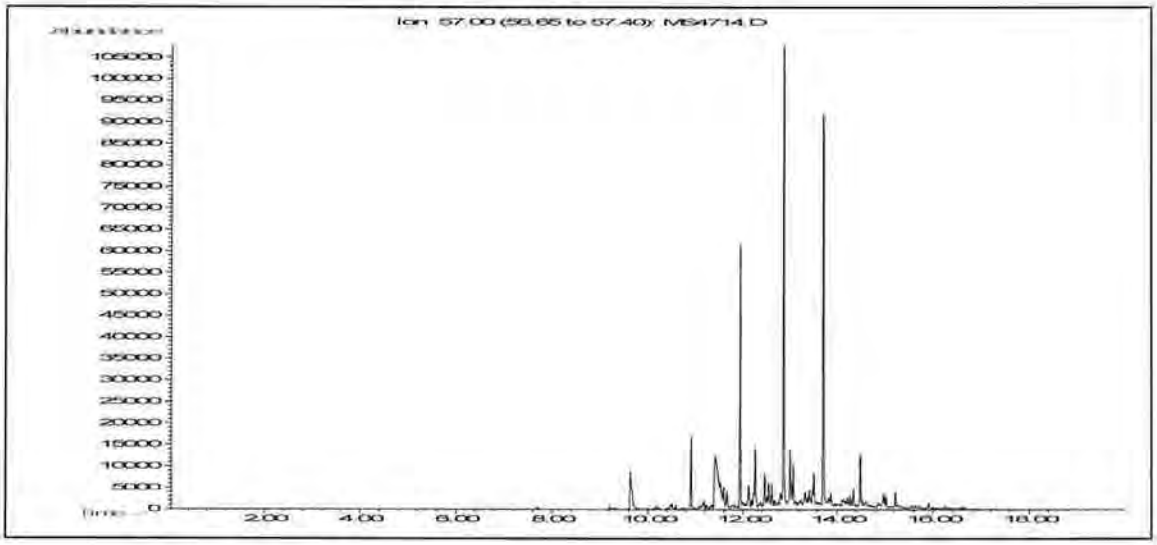


Figure 6. Ion chromatogram for mass 57(alkanes) for headspace-GCMS of Item No. 12.

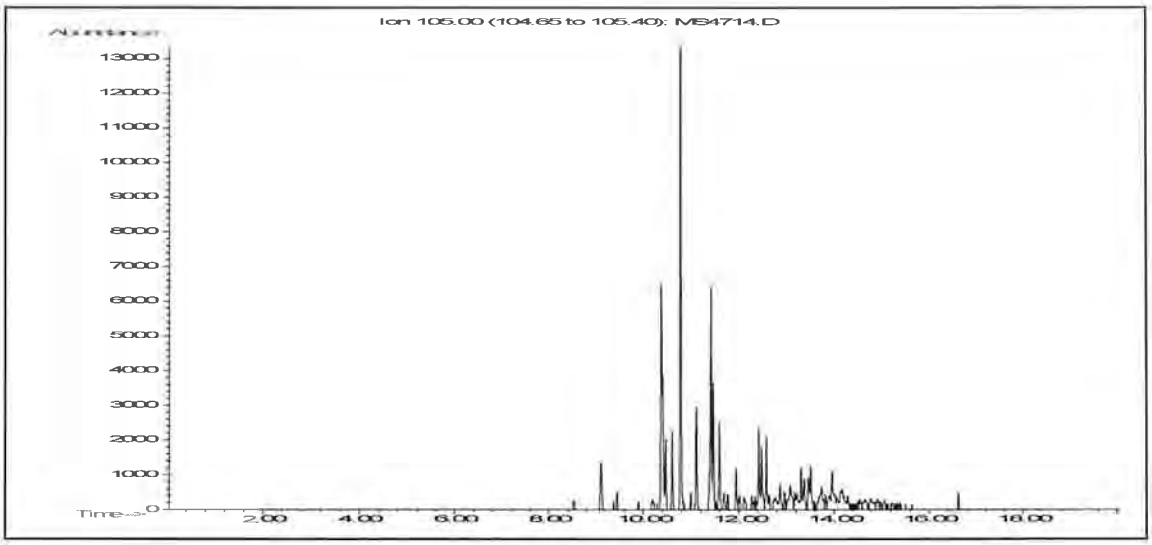


Figure 7. Ion chromatogram for mass 105(alkylbenzenes) for headspace-GCMS of Item No. 12.

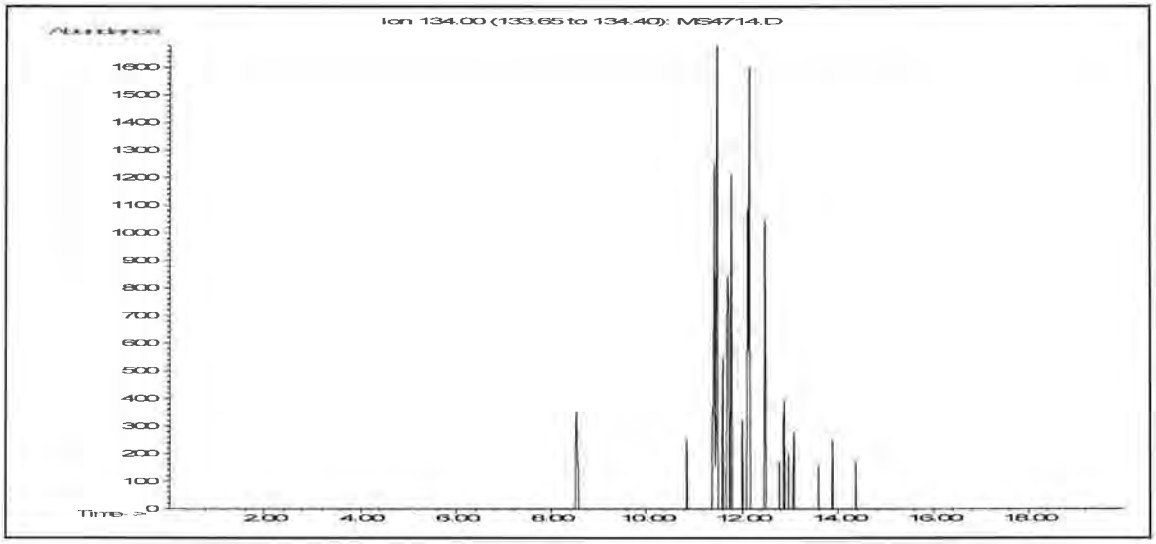


Figure 8. Ion chromatogram for mass 134(alkylbenzenes) for headspace-GCMS of Item No. 12.

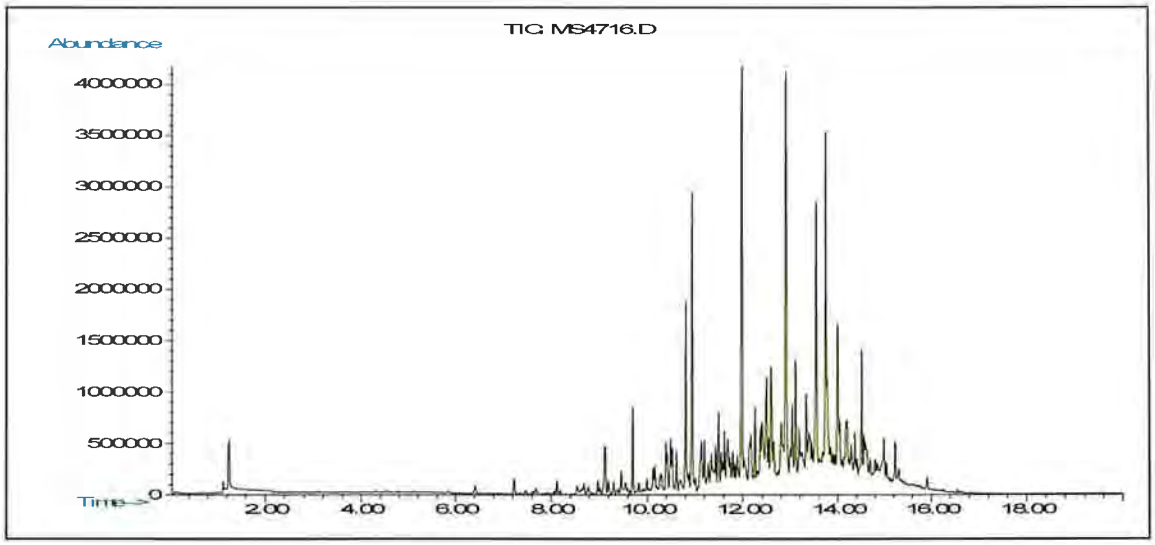


Figure 9. Total ion chromatogram for reference diesel fuel sample.

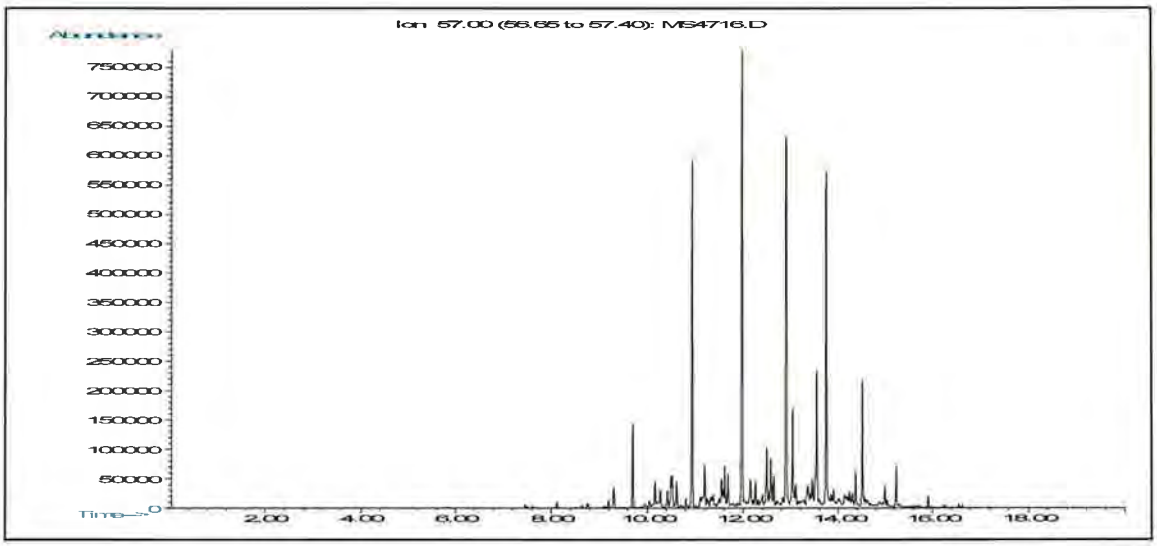


Figure 10. Ion chromatogram for mass 57(alkanes) for headspace-GCMS of reference diesel fuel.

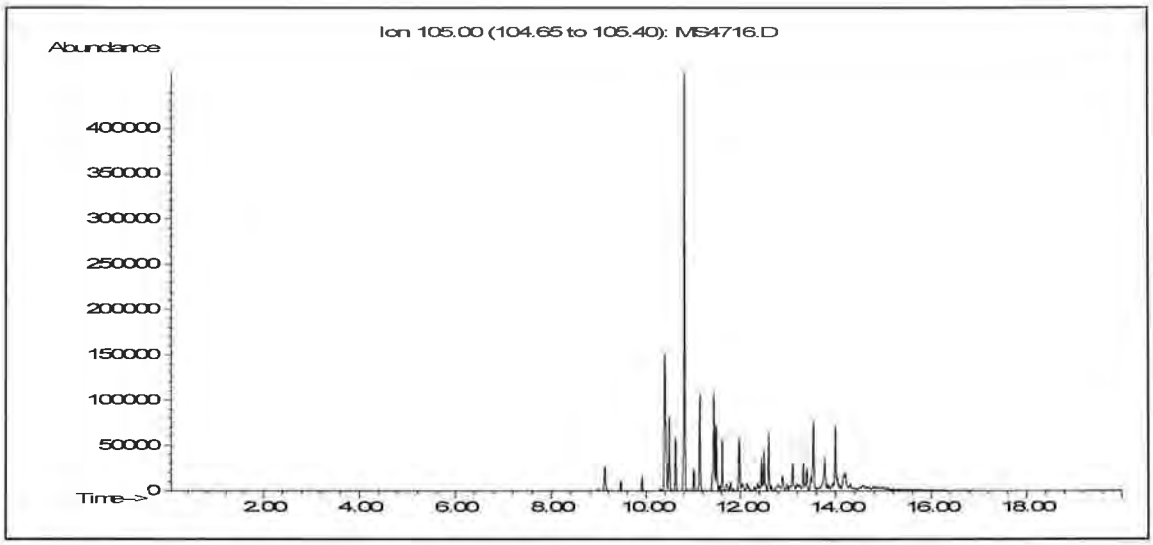


Figure 11. Ion chromatogram for mass 105(alkylbenzenes) for headspace-GCMS of reference diesel fuel.

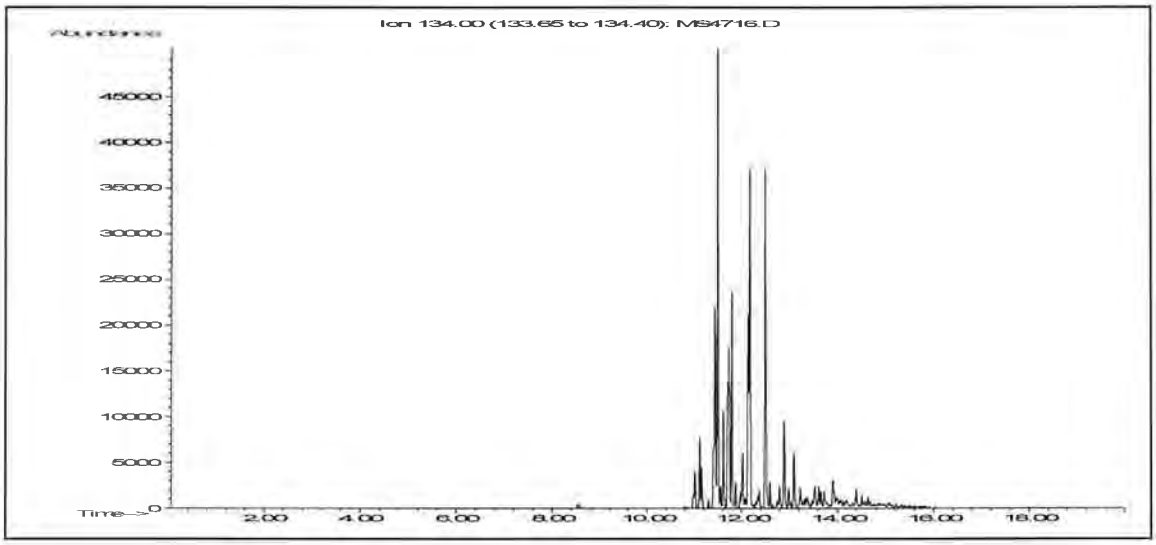


Figure 12. . Ion chromatogram for mass 134(alkylbenzenes) for headspace-GCMS of reference diesel fuel.

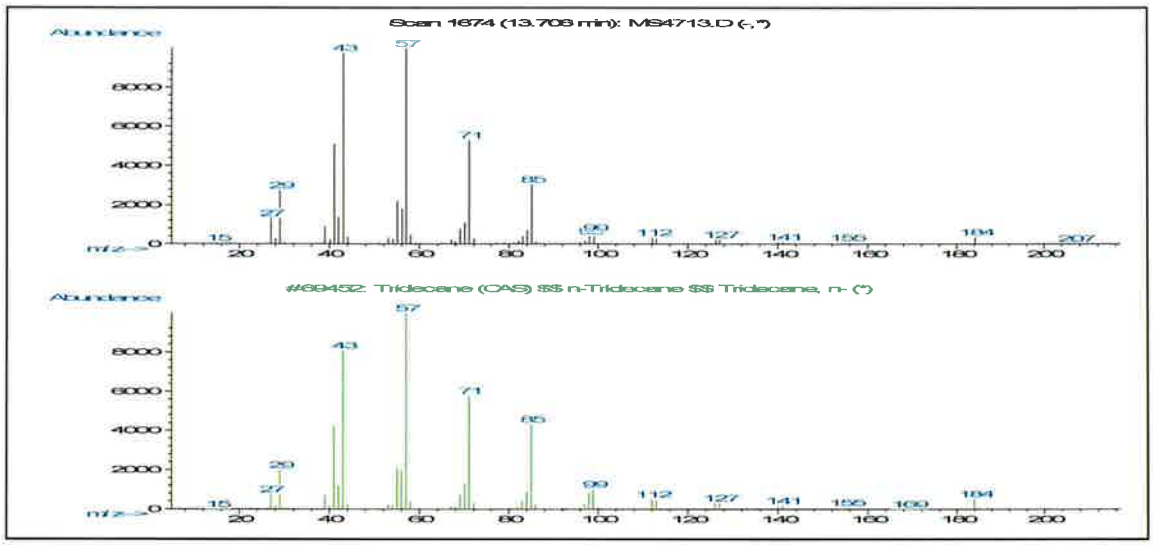


Figure 13. Mass spectrum and library search result for peak at 13.7 min. in GCMS of Item #6 headspace.

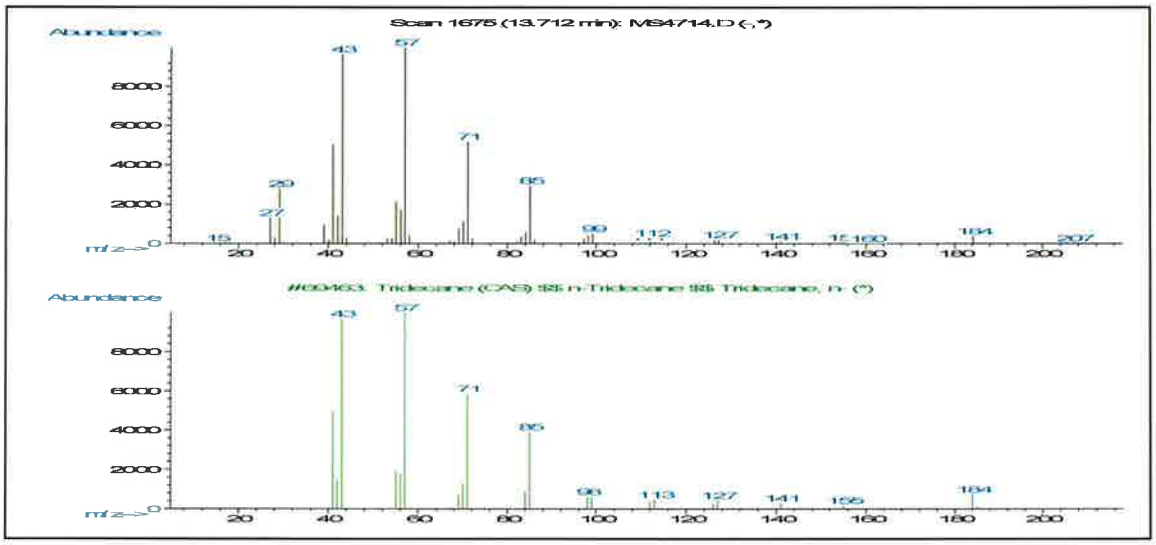


Figure 14. Mass spectrum and library search result for peak at 13.7 min. in GCMS of Item #12 headspace.

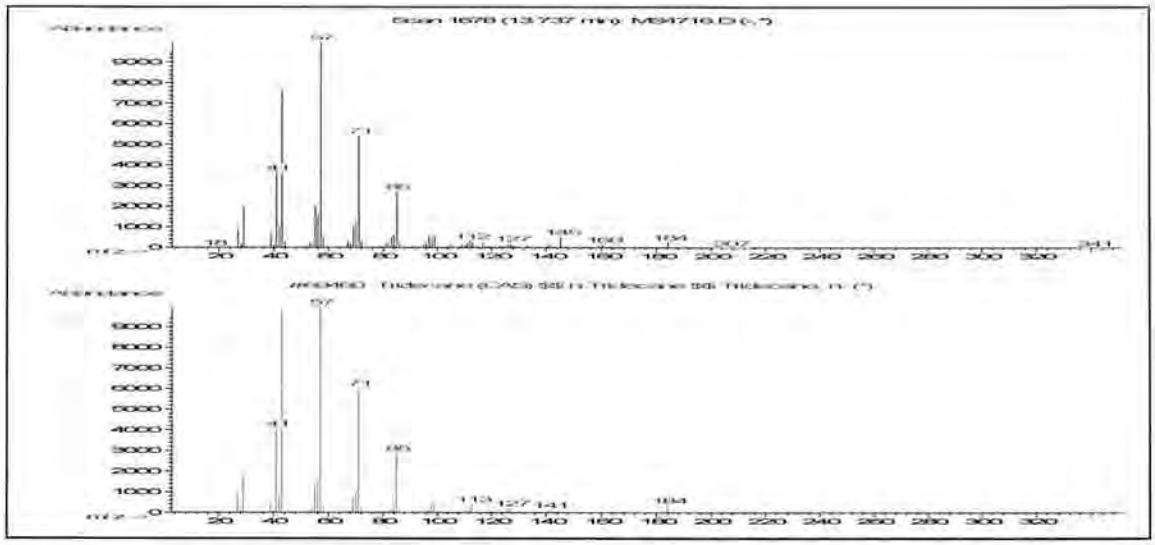


Figure 15. Mass spectrum and library search result for peak at 13.7 min. in GCMS of reference diesel fuel headspace.

APPENDIX E

ALUMINUM SAMPLES

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX E
Aluminum Samples

Photograph No. E-1

Photograph No. E-2

APPENDIX E
Aluminum Samples

Photograph No. E-3
Microstructure of aluminum sample from Item 4A

Photograph No. E-4

APPENDIX E
Aluminum Samples

Photograph No. E-5
Microstructure of aluminum sample from Item 10

Photograph No. E-6

APPENDIX E
Aluminum Samples

Photograph No. E-7

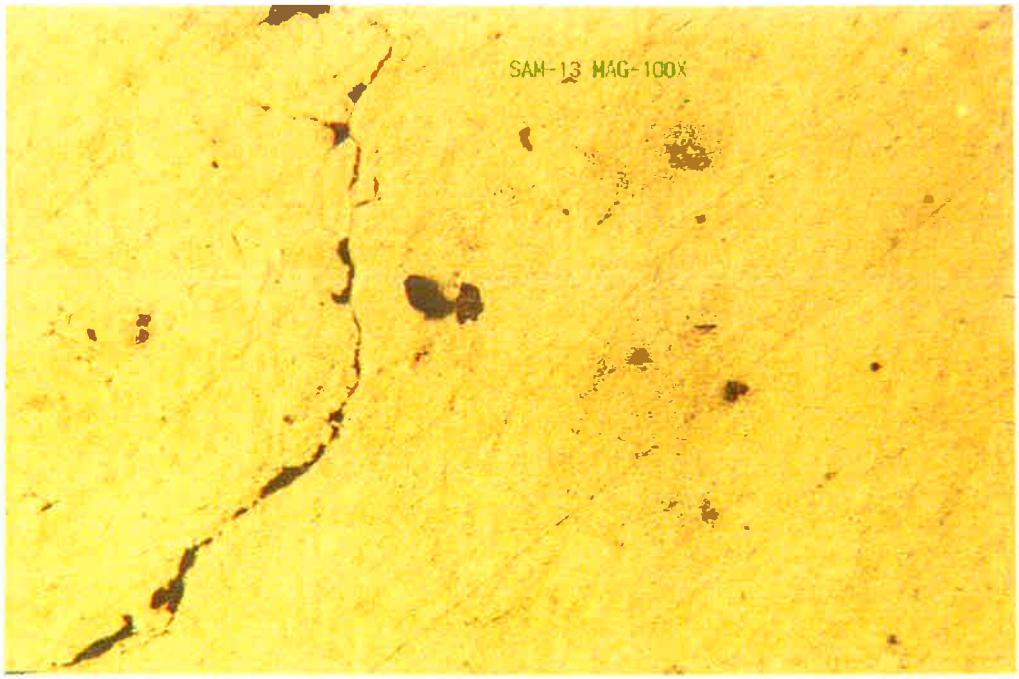
Photograph No. E-8
Microstructure of aluminum sample from Item 11

APPENDIX E
Aluminum Samples

Photograph No. E-9

Photograph No. E-10

APPENDIX E
Aluminum Samples



Photograph No. E-11
Microstructure of aluminum sample from Item 13

APPENDIX F

EVALUATION OF TURBOCHARGER BOLTS

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX F
Evaluation of Turbo Charger Bolts

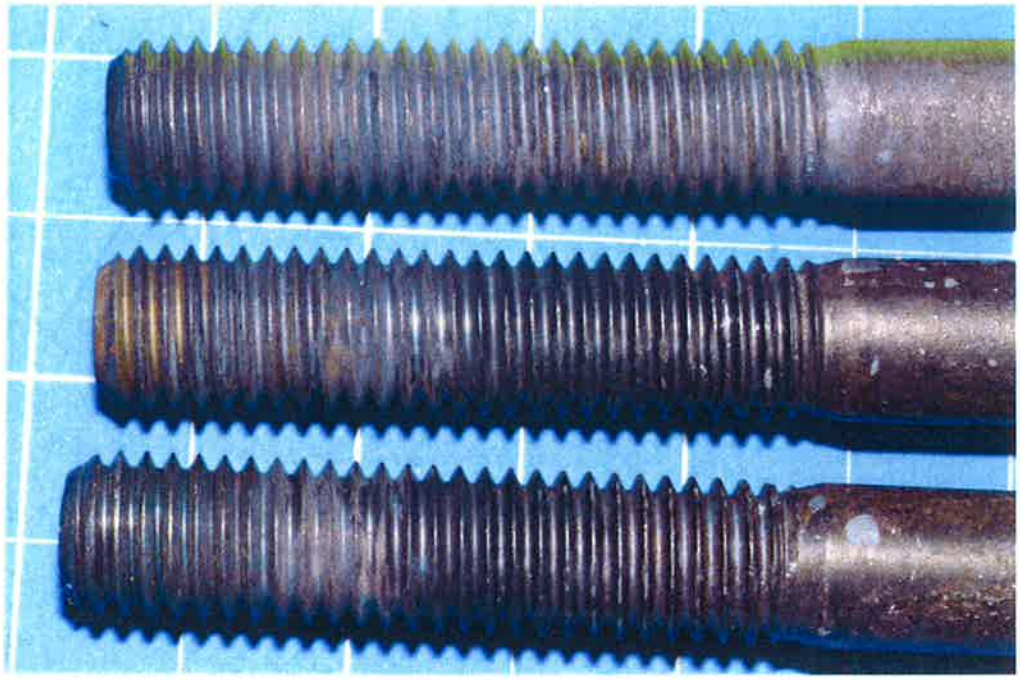
Photograph No. F-1
As-received

Photograph No. F-2
As-received

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX F
Evaluation of Turbo Charger Bolts

Photograph No. F-3
As-cleaned



Photograph No. F-4
As-cleaned

APPENDIX F
Evaluation of Turbo Charger Bolts

Photograph No. F-5
As-received

Photograph No. F-6
As-received

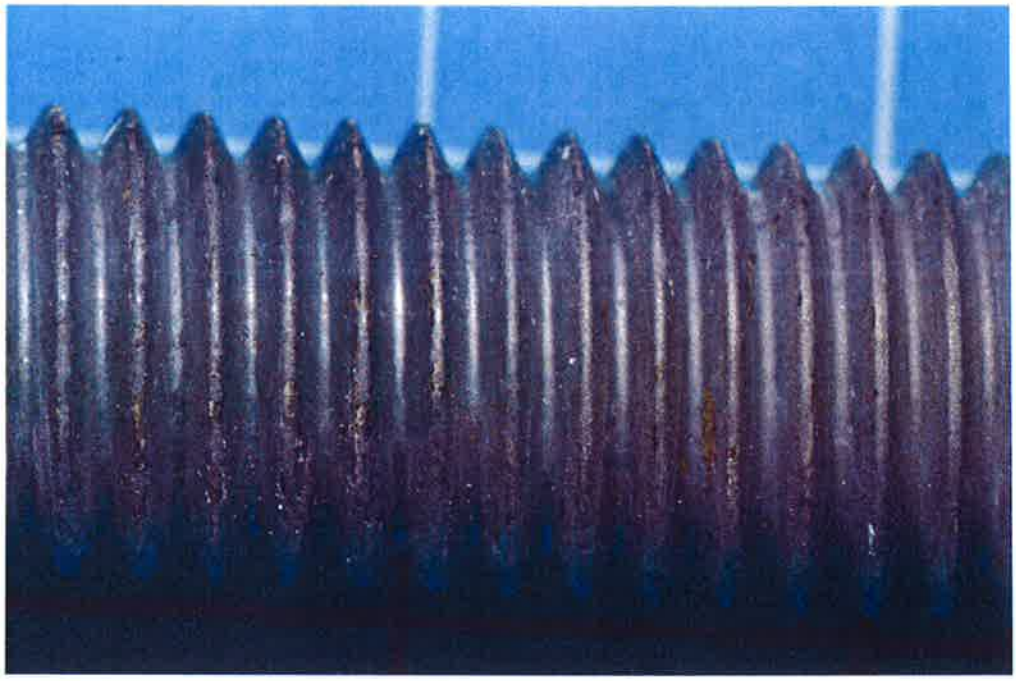
Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX F
Evaluation of Turbo Charger Bolts

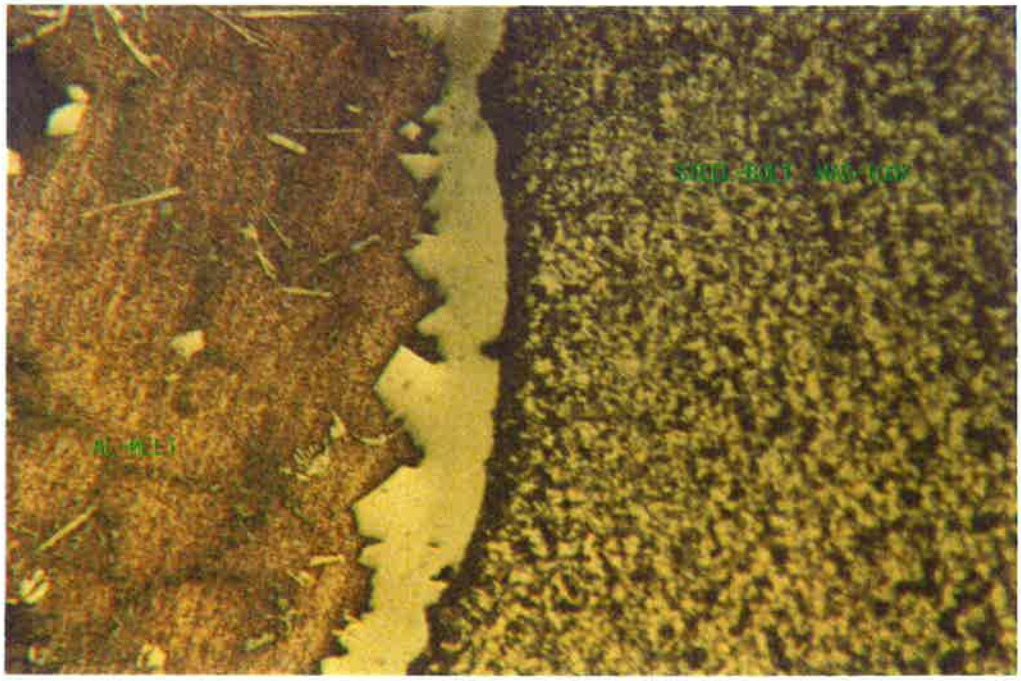
Photograph No. F-7
As-cleaned

Photograph No. F-8
As-cleaned

APPENDIX F
Evaluation of Turbo Charger Bolts



Photograph F-9
As-cleaned

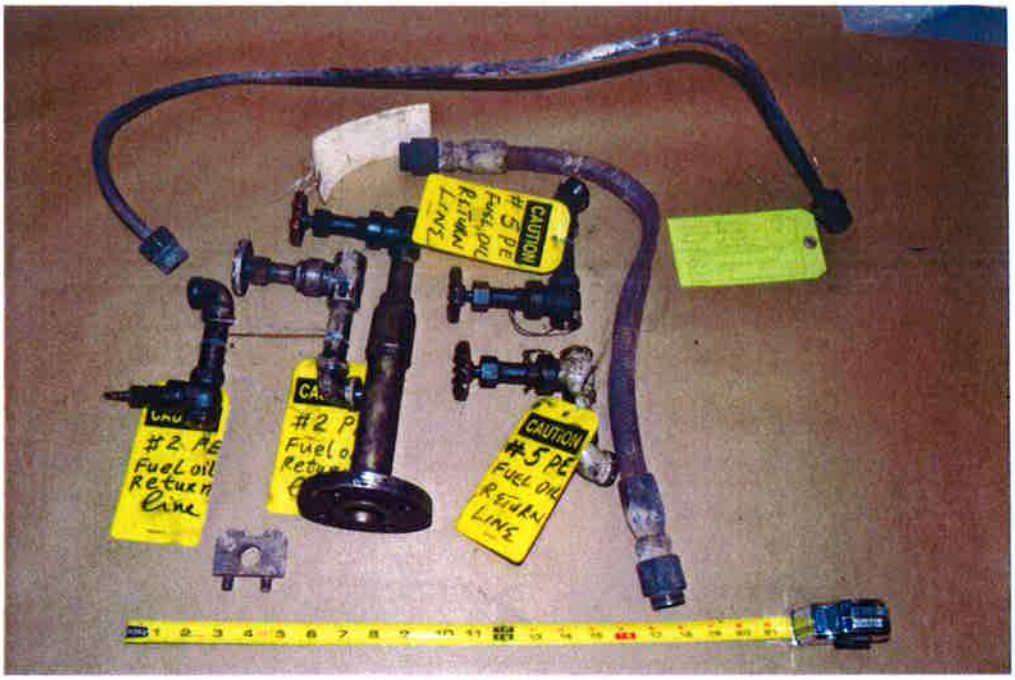


Photograph F-10
Photomicrograph of the bolt microstructure intersecting the re-solidified aluminum melt.
Note: zinc layer sandwiched between the aluminum and the steel

APPENDIX G

ADDITIONAL ITEMS IN THE AS-RECEIVED CONDITION

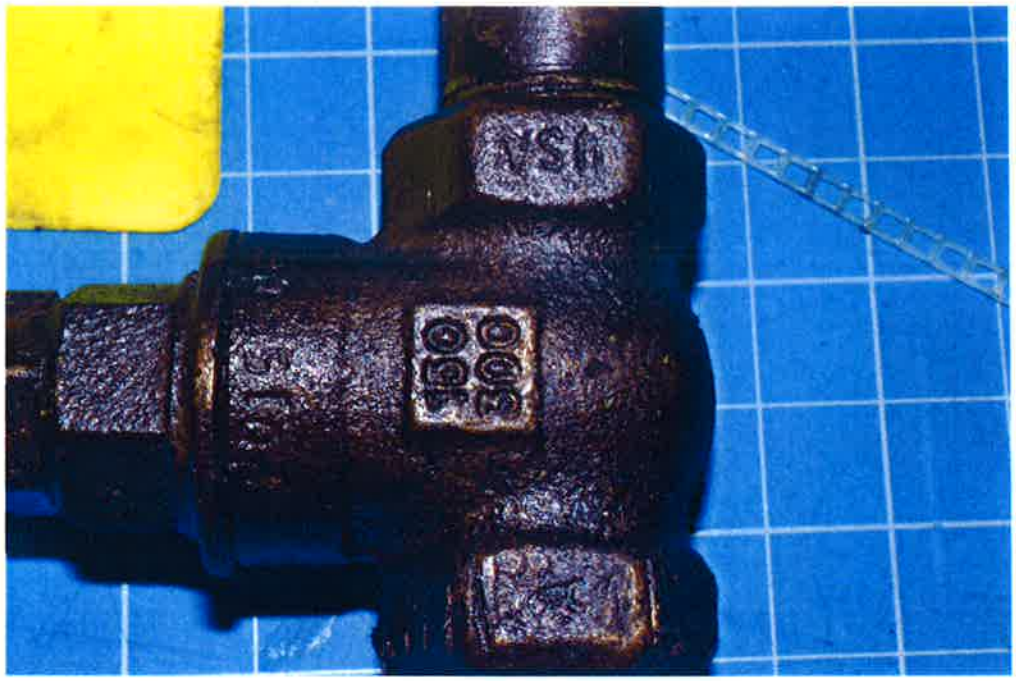
APPENDIX G
Additional Items in the As-Received Condition



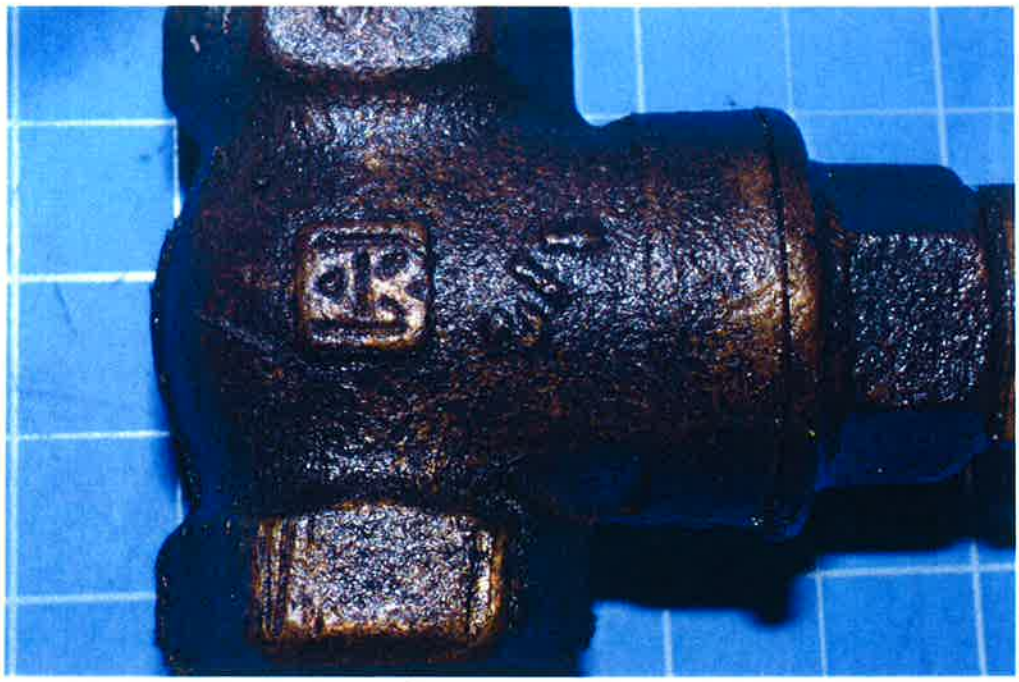
Photograph G-1

Photograph G-2

APPENDIX G
Additional Items in the As-Received Condition

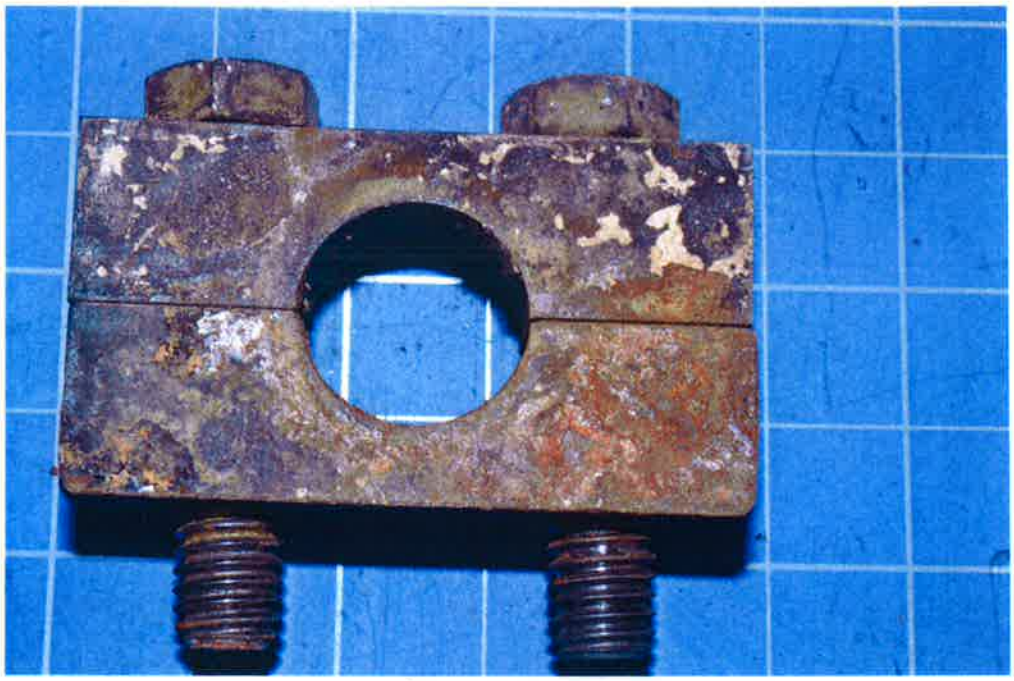


Photograph G-3



Photograph G-4

APPENDIX G
Additional Items in the As-Received Condition



Photograph G-5

Photograph G-6

APPENDIX G
Additional Items in the As-Received Condition

Photograph G-7

Photograph G-8

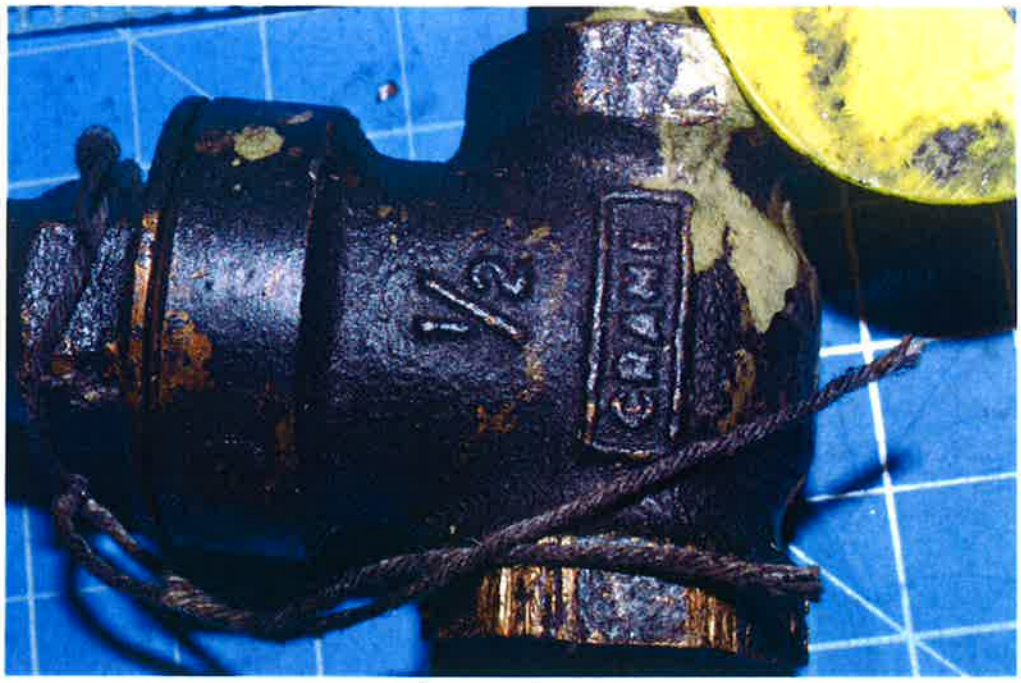
APPENDIX G
Additional Items in the As-Received Condition

Photograph G-9

Photograph G-10

APPENDIX G
Additional Items in the As-Received Condition

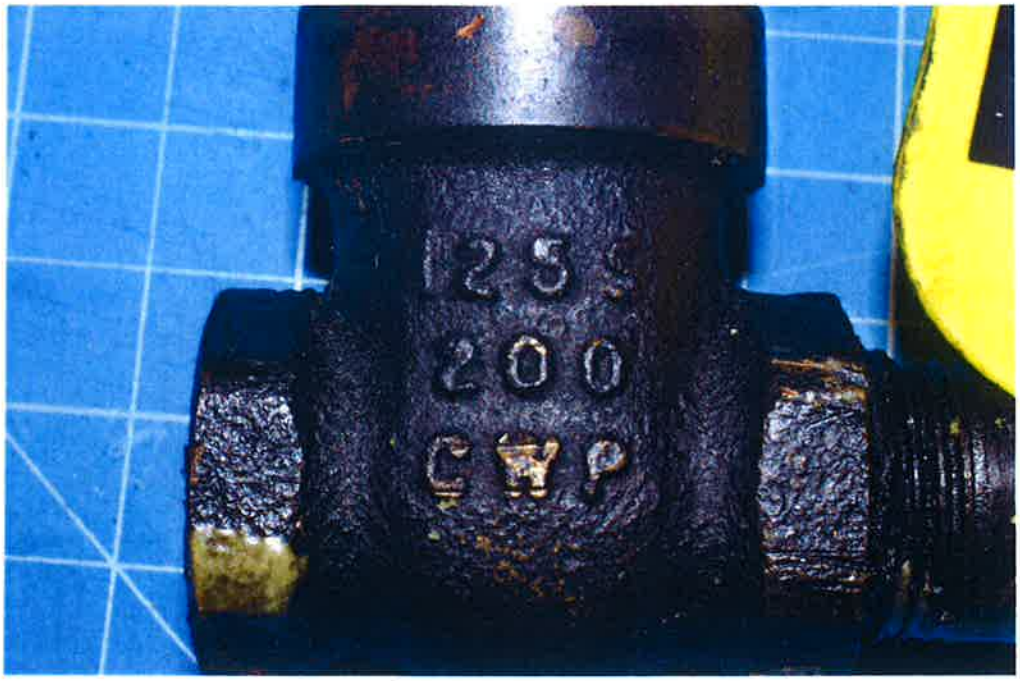
Photograph G-11



Photograph G-12

APPENDIX G
Additional Items in the As-Received Condition

Photograph G-13



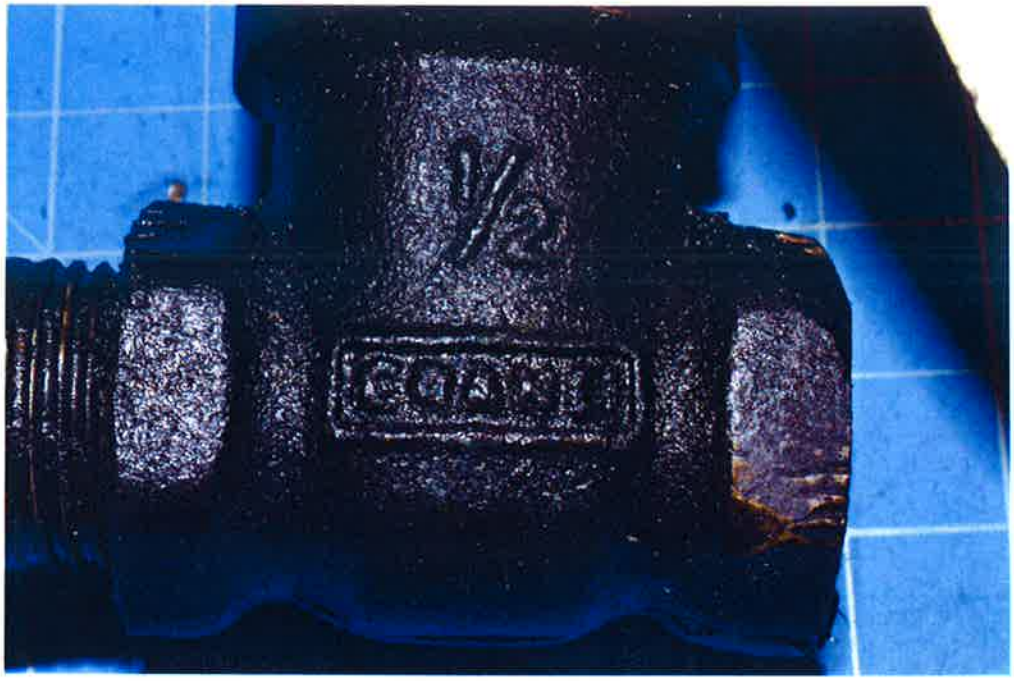
Photograph G-14

APPENDIX G
Additional Items in the As-Received Condition

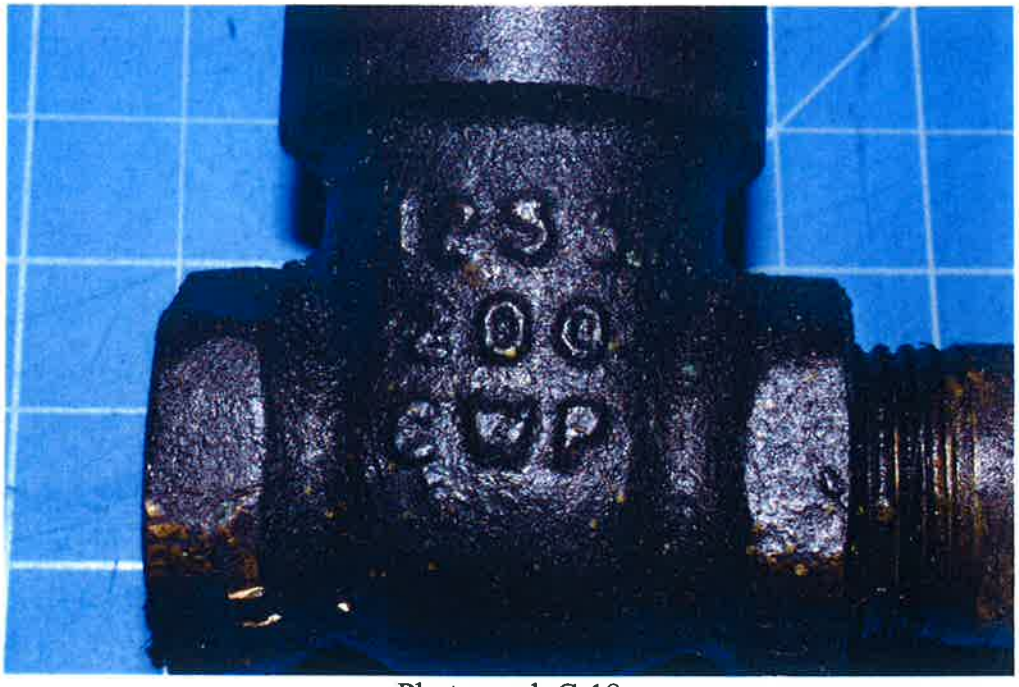
Photograph G-15

Photograph G-16

APPENDIX G
Additional Items in the As-Received Condition



Photograph G-17



Photograph G-18

APPENDIX G
Additional Items in the As-Received Condition

Photograph G-19
Braided Fuel Line

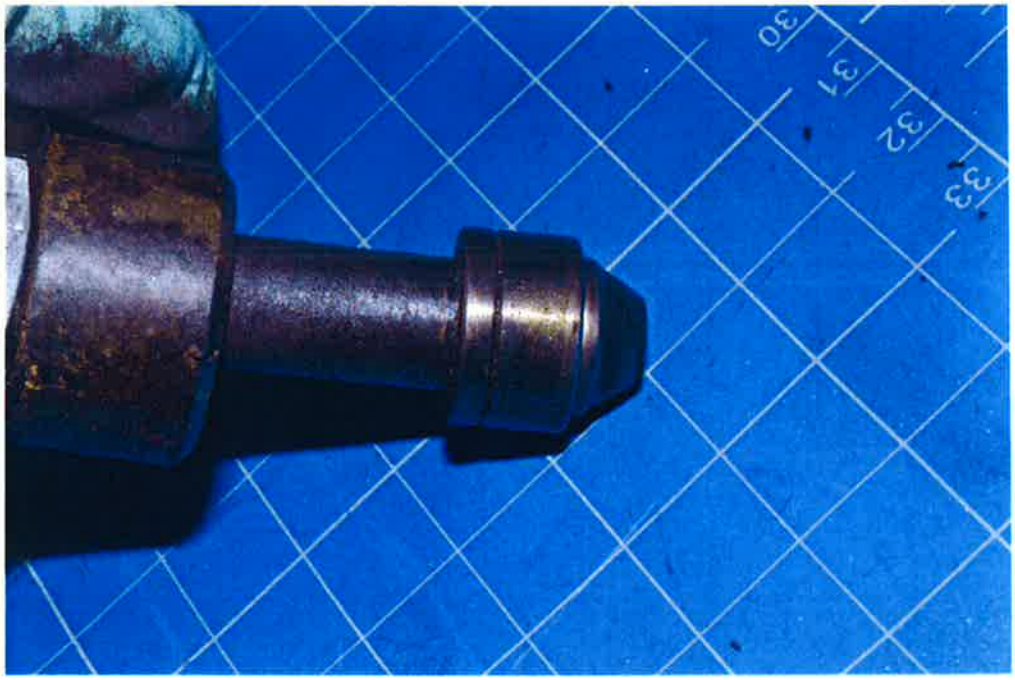
Photograph G-20
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition

Photograph G-21
High Pressure Fuel

Photograph G-22
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition



Photograph G-23
High Pressure Fuel

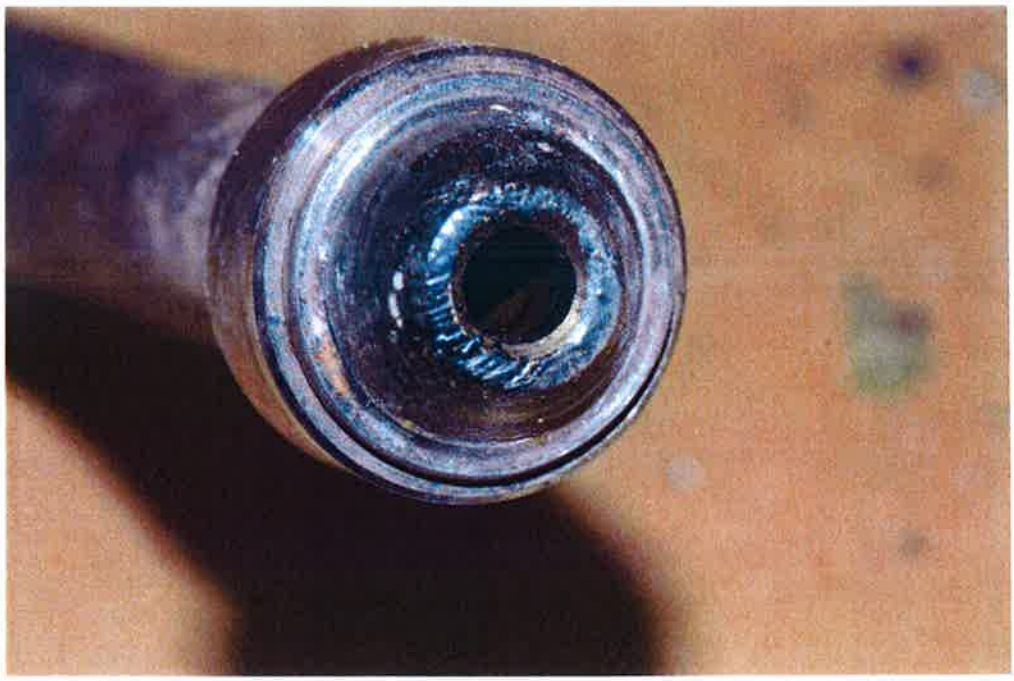
Photograph G-24
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition

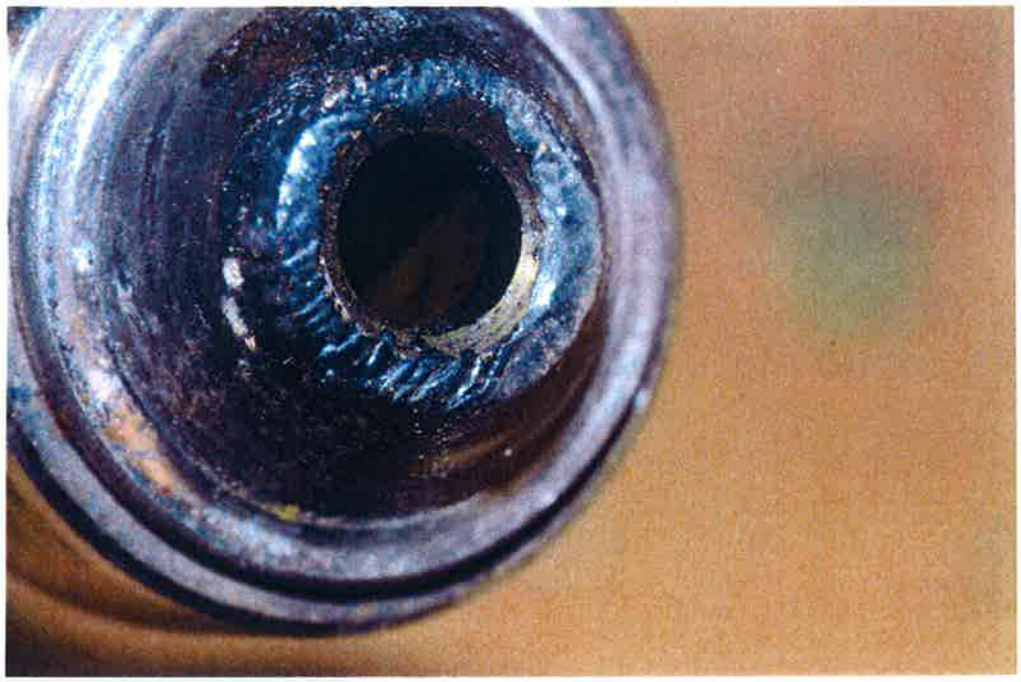
Photograph G-25
High Pressure Fuel

Photograph G-26
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition



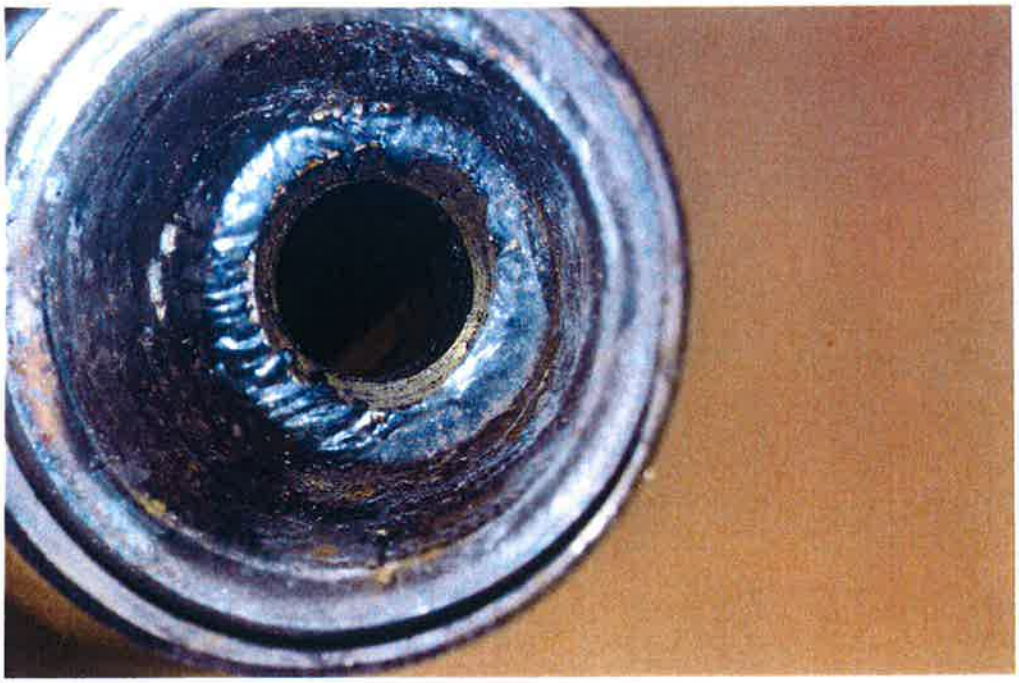
Photograph G-27
High Pressure Fuel



Photograph G-28
High Pressure Fuel

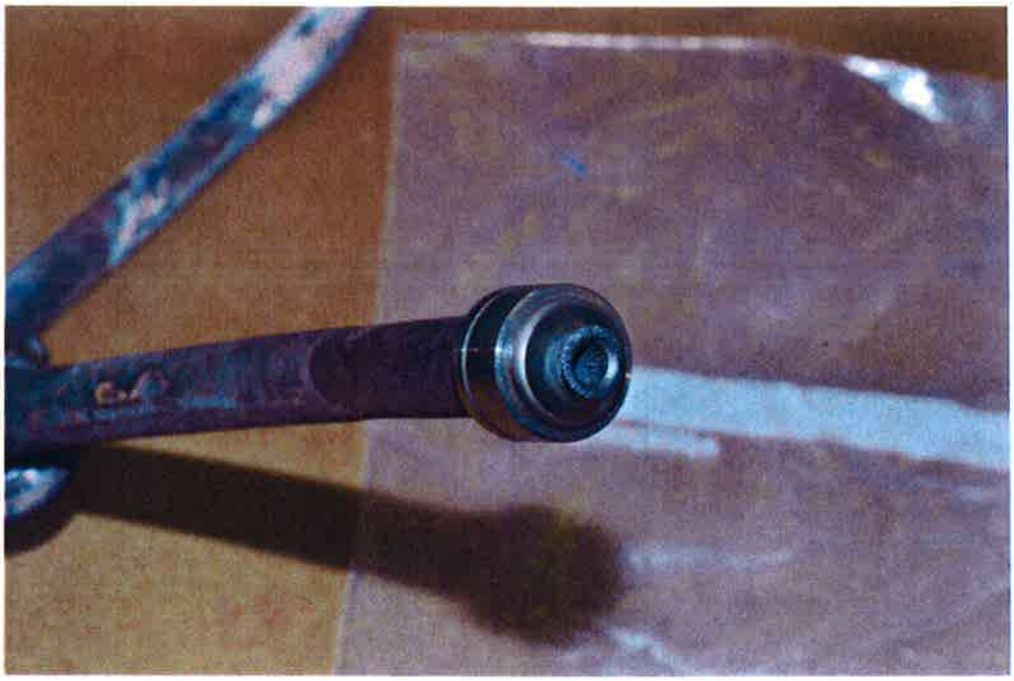
APPENDIX G
Additional Items in the As-Received Condition

Photograph G-29
High Pressure Fuel

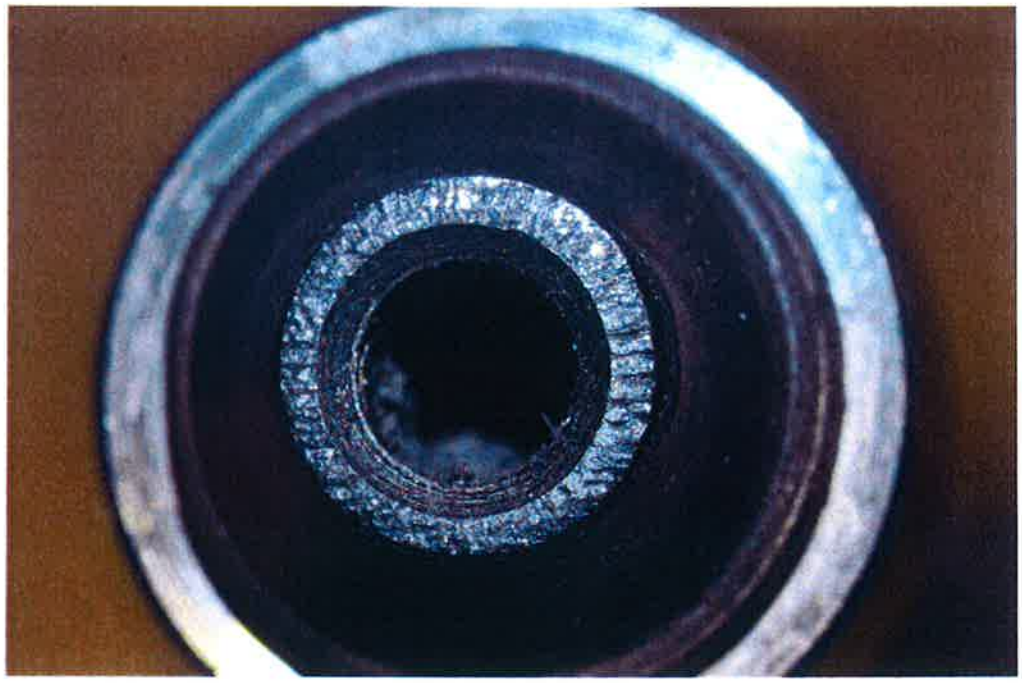


Photograph G-30
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition



Photograph G-31
High Pressure Fuel



Photograph G-32
High Pressure Fuel

APPENDIX G
Additional Items in the As-Received Condition

Photograph G-33
High Pressure Fuel

APPENDIX H

BRAIDED HOSE IN THE AS-RECEIVED CONDITION

APPENDIX H
Braided Hose in the As-Received Condition

Photograph H-1
Note: Reduction of Cross-Section

Photograph H-2
Note: Reduction of Cross-Section

APPENDIX H
Braided Hose in the As-Received Condition

Photograph H-3

Photograph H-4

APPENDIX H
Braided Hose in the As-Received Condition

Photograph H-5

APPENDIX I

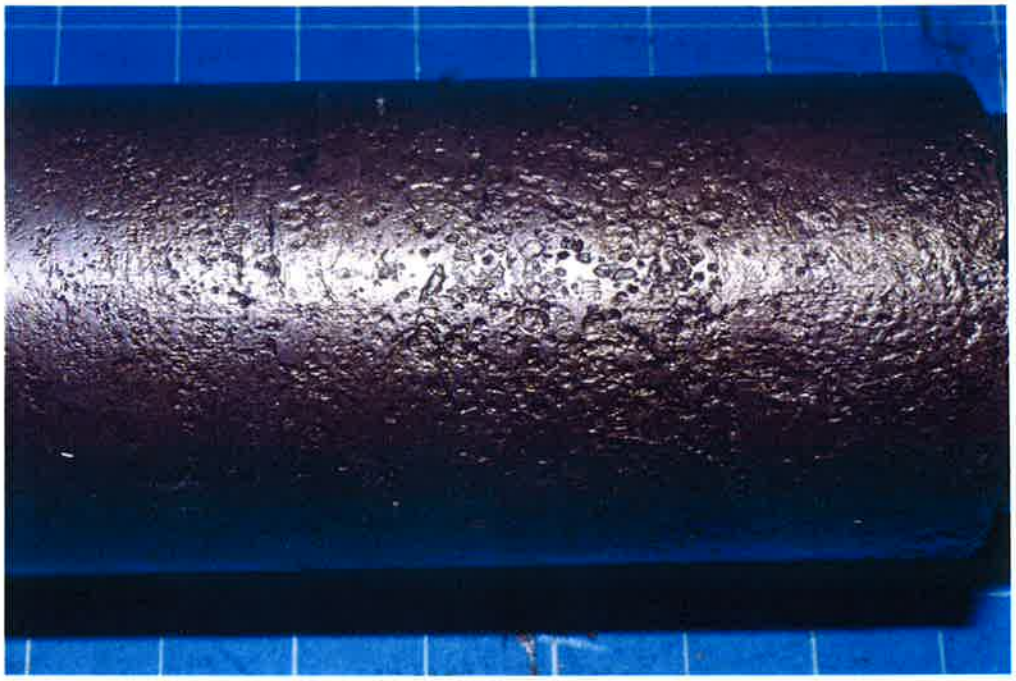
FUEL INJECTOR & PUMP IN THE AS-RECEIVED CONDITION

APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-1
Fuel Injector

Photograph I-2
Fuel Injector
Note: Corrosion

APPENDIX I
Fuel Injector & Pump As-Received Condition

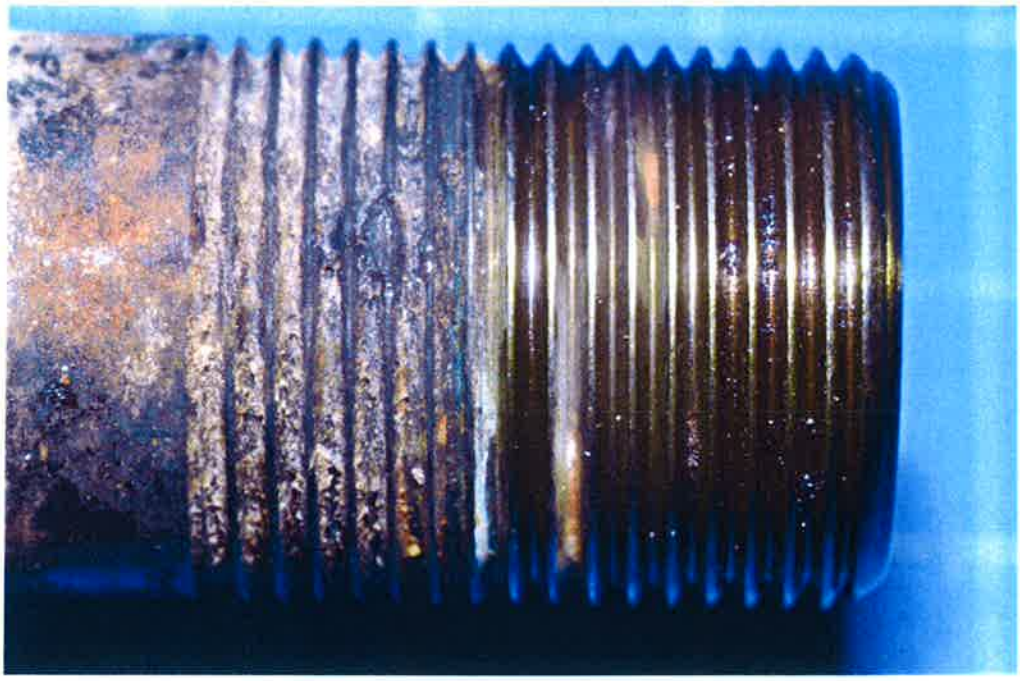


Photograph I-3
Fuel Injector
Note: Corrosion

Photograph I-4
Fuel Injector
Note: Nipple for connection to fuel line

APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-5
Fuel Injector
Note: Nipple for connection to fuel line



Photograph I-6
Fuel Injector
Note: Nipple for connection to fuel line

APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-7
Fuel Injector
Note: Nipple for connection to fuel line

Photograph I-8
Fuel Injector
Note: Nipple for connection to fuel line

APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-9
Fuel Injector
Note: Nipple for connection to fuel line

Photograph I-10
Fuel Pump

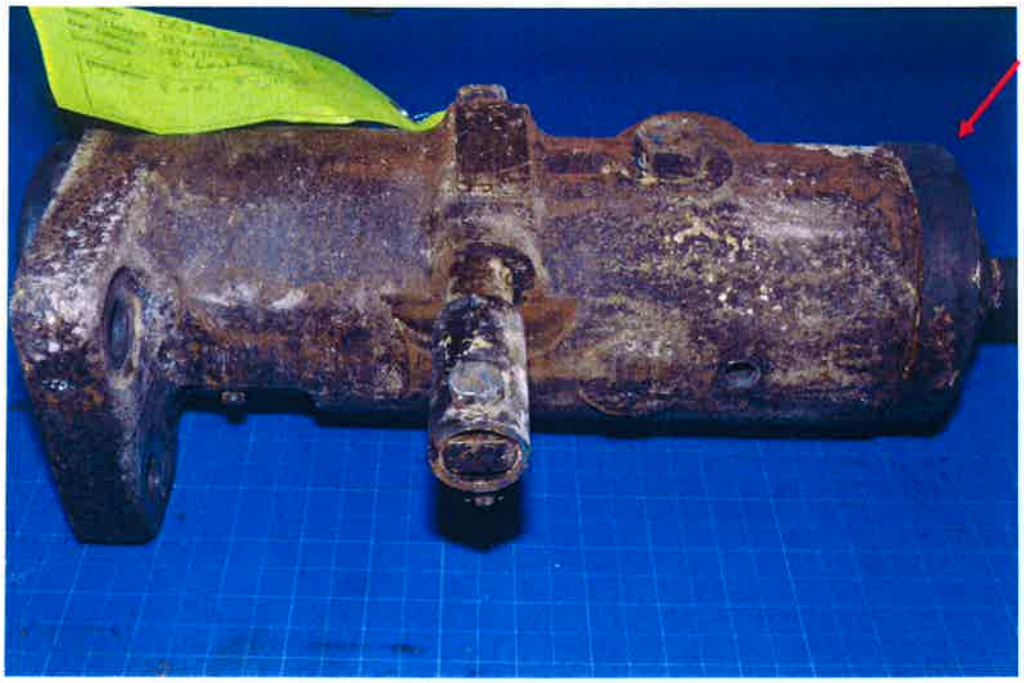
APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-11
Fuel Pump

Photograph I-12
Fuel Pump
Note: Heat affected area of body

APPENDIX I
Fuel Injector & Pump As-Received Condition

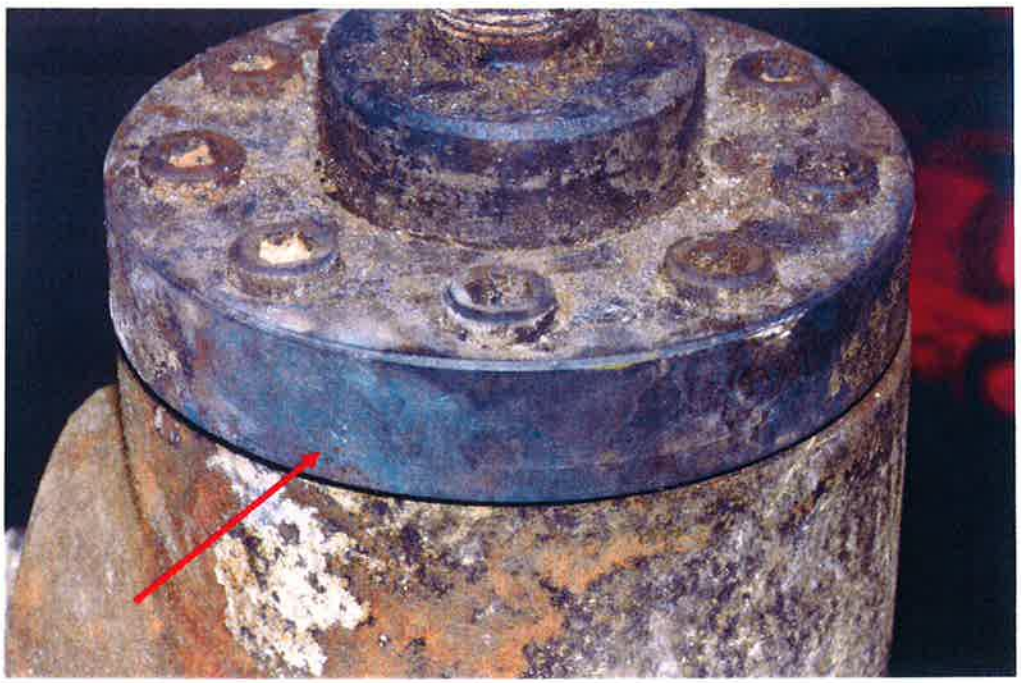
Photograph I-13
Fuel Pump



Photograph I-14
Fuel Pump
Note: Heat affected area of body

APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-15
Fuel Pump
Note: Heat affected area of body



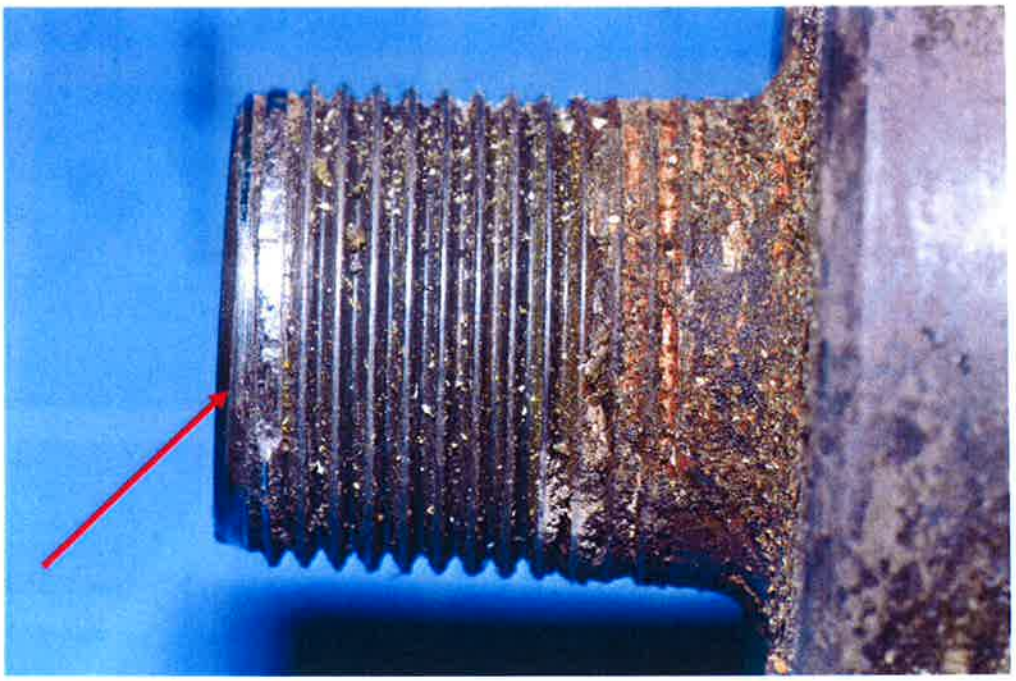
Photograph I-16
Fuel Pump
Note: Heat affected area of body

APPENDIX I
Fuel Injector & Pump As-Received Condition

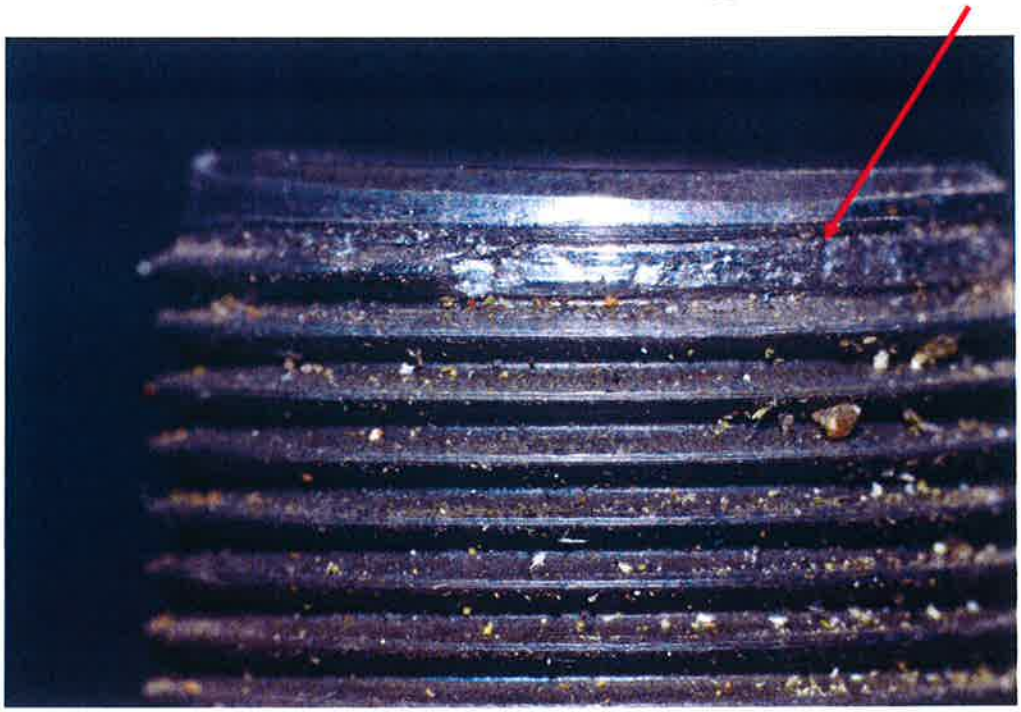
Photograph I-17
Fuel Pump
Note: Heat affected area of body

Photograph I-18
Fuel Pump
Note: Broken thread on fuel line nipple

APPENDIX I
Fuel Injector & Pump As-Received Condition

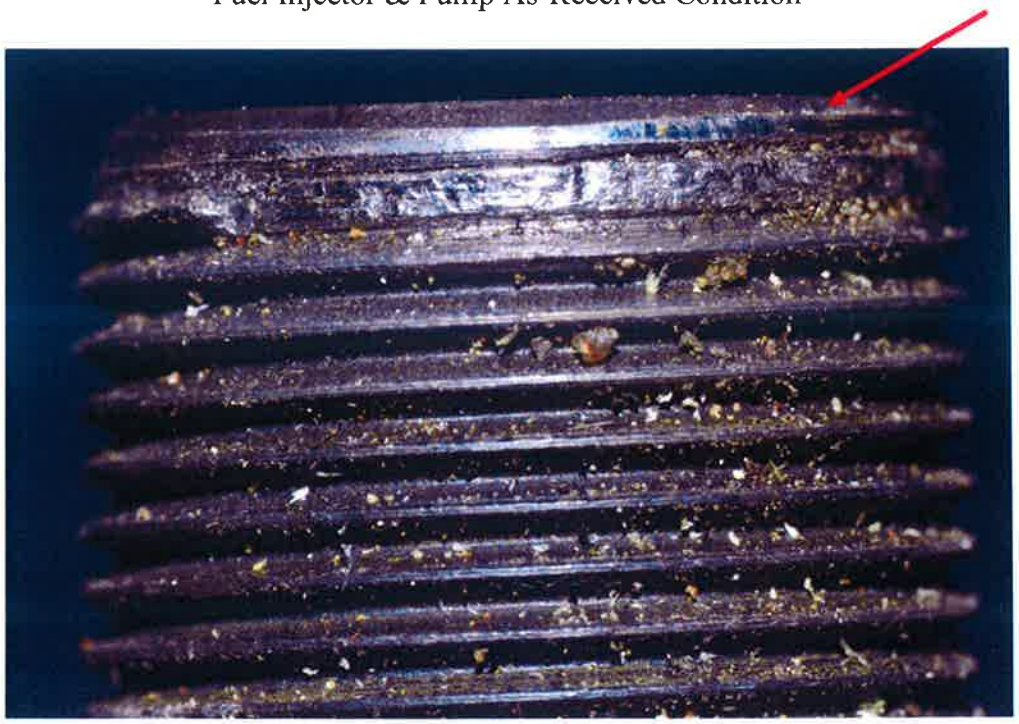


Photograph I-19
Fuel Pump
Note: Broken thread on fuel line nipple

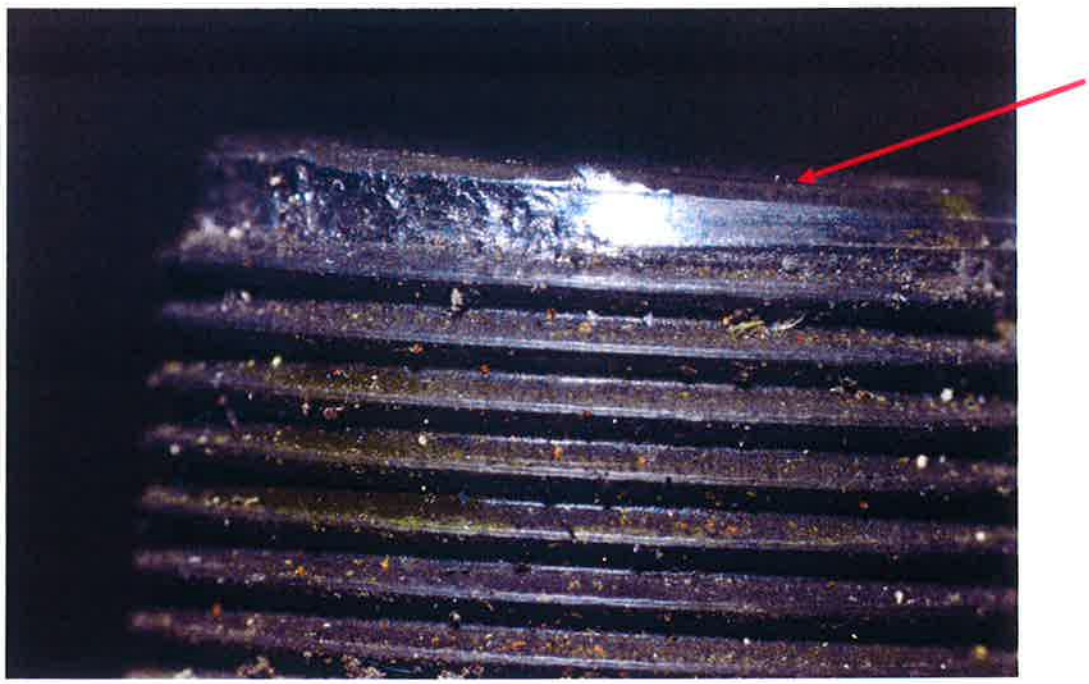


Photograph I-20
Fuel Pump
Note: Broken thread on fuel line nipple

APPENDIX I
Fuel Injector & Pump As-Received Condition

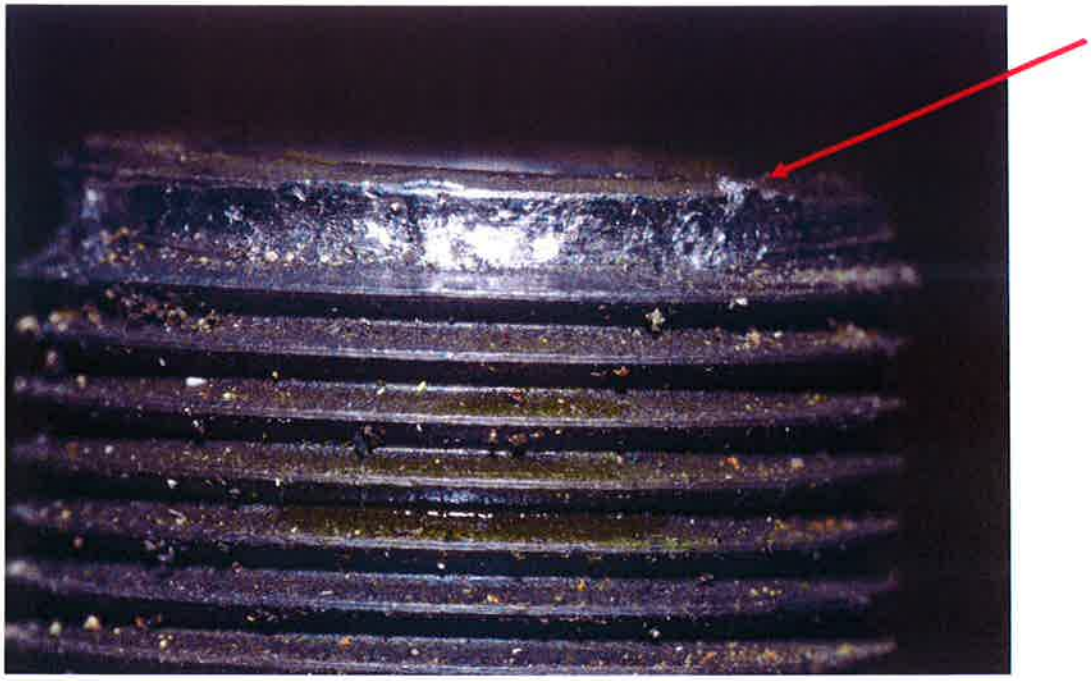


Photograph I-21
Fuel Pump
Note: Broken thread on fuel line nipple



Photograph I-22
Fuel Pump
Note: Broken thread on fuel line nipple

APPENDIX I
Fuel Injector & Pump As-Received Condition



Photograph I-23
Fuel Pump
Note: Broken thread on fuel line nipple

Photograph I-24
Fuel Pump
Note: Fuel Pump Nipple

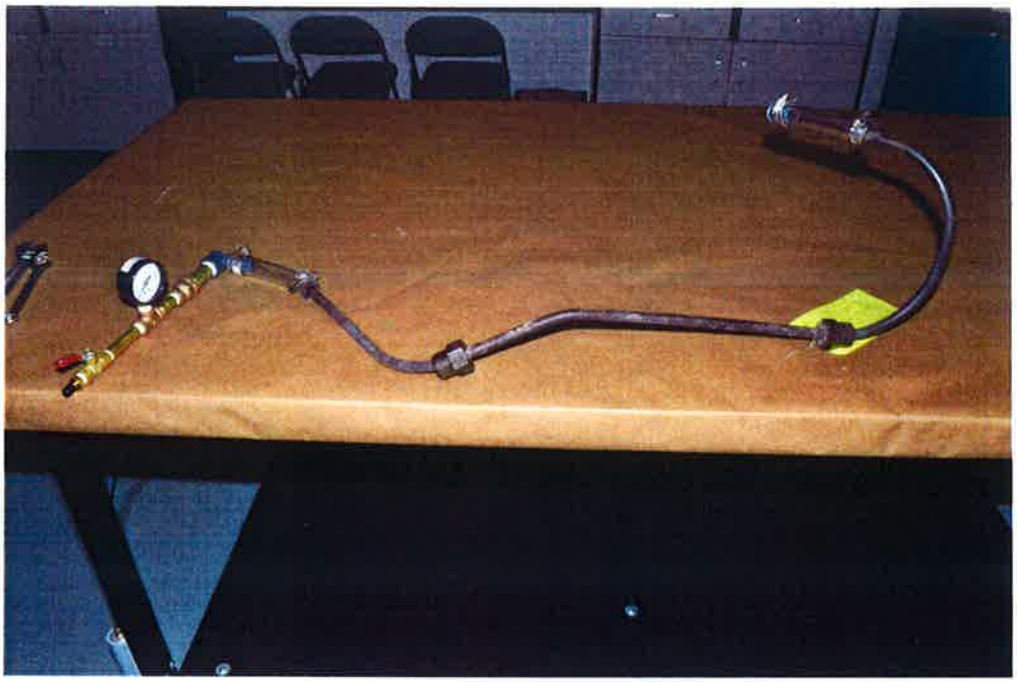
APPENDIX I
Fuel Injector & Pump As-Received Condition

Photograph I-25
Fuel Pump
Note: Fuel Pump Nipple

APPENDIX J

PRESSURE TESTING OF THE FUEL LINE

APPENDIX J
Pressure Testing of the Fuel Line

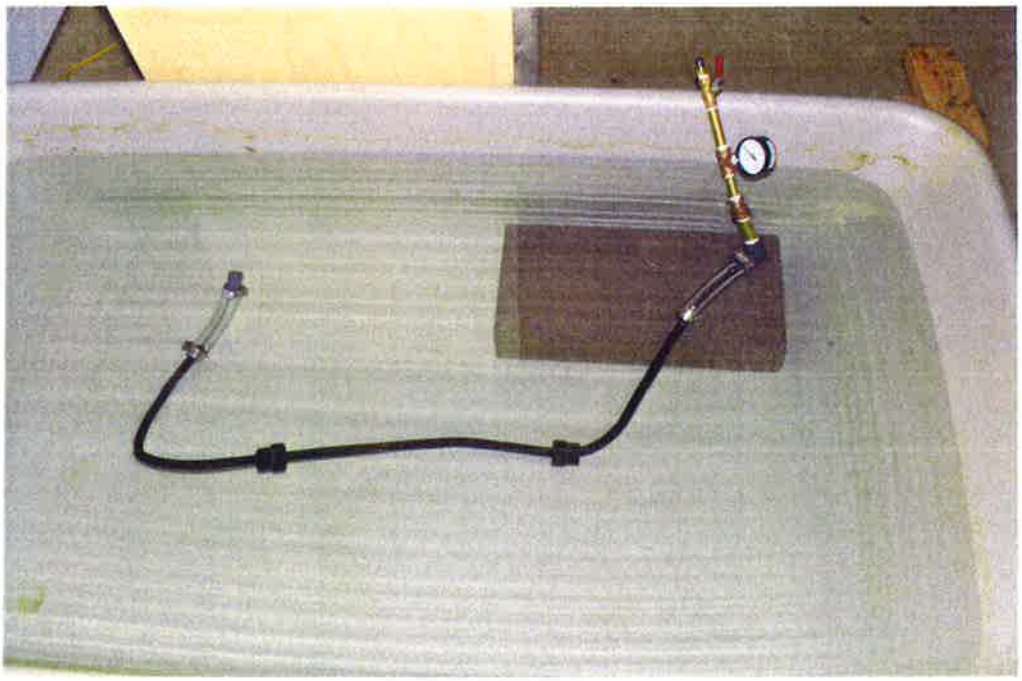


Photograph J-1

Photograph J-2

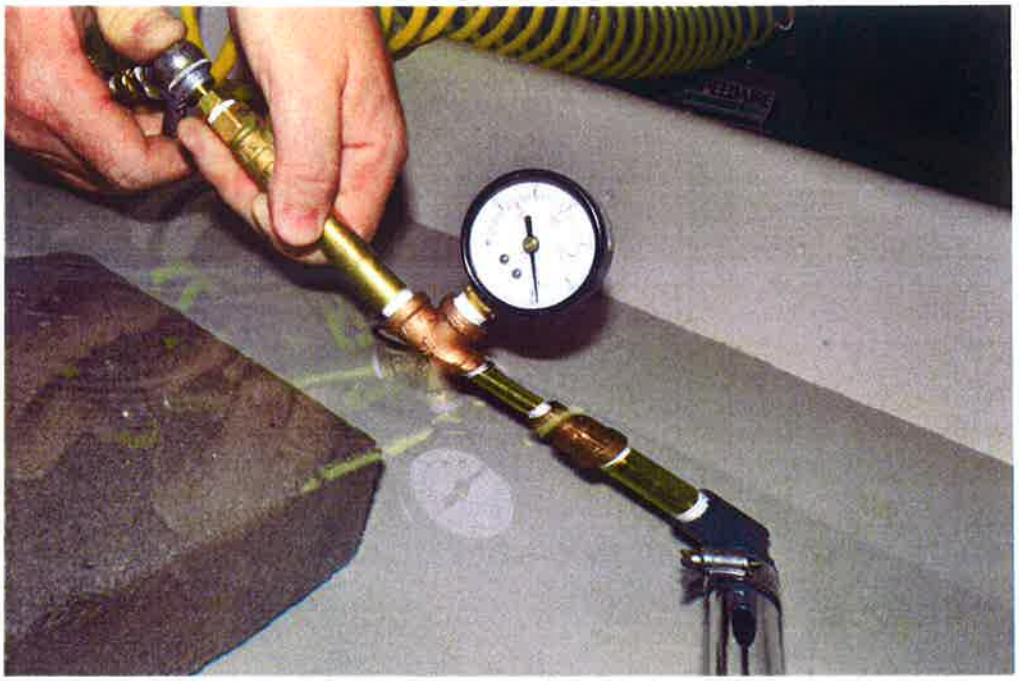
APPENDIX J
Pressure Testing of the Fuel Line

Photograph J-3

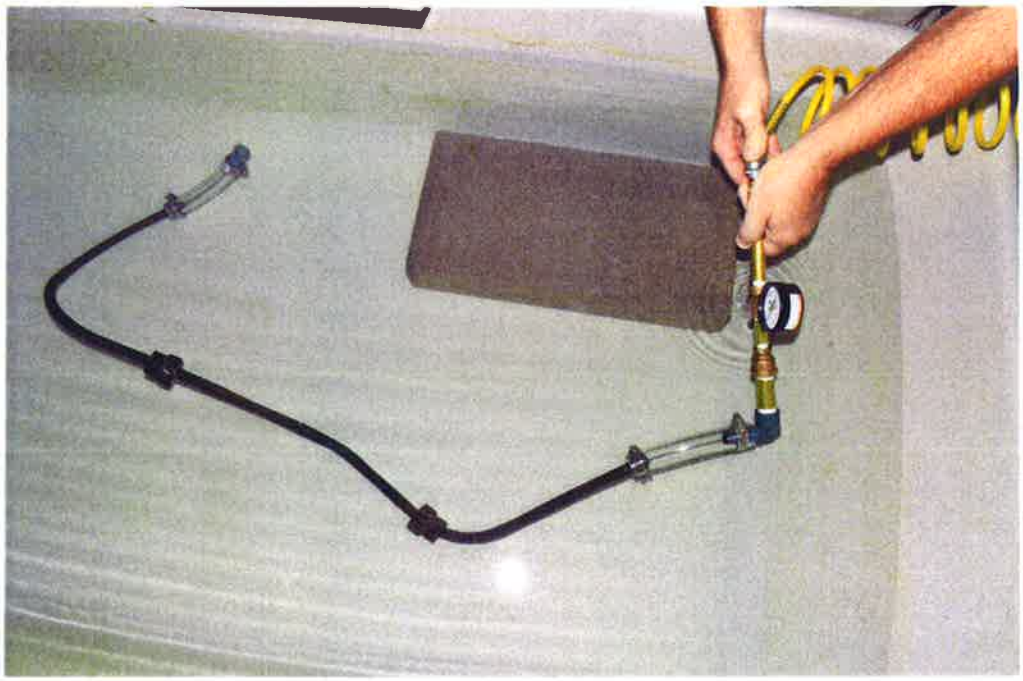


Photograph J-4

APPENDIX J
Pressure Testing of the Fuel Line

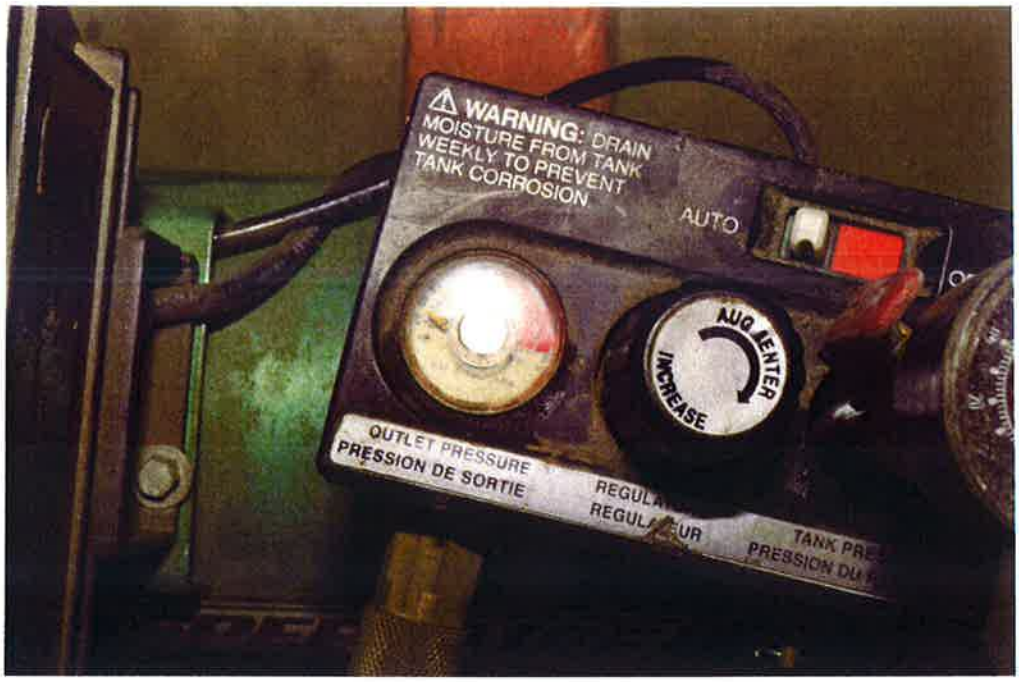


Photograph J-5



Photograph J-6

APPENDIX J
Pressure Testing of the Fuel Line

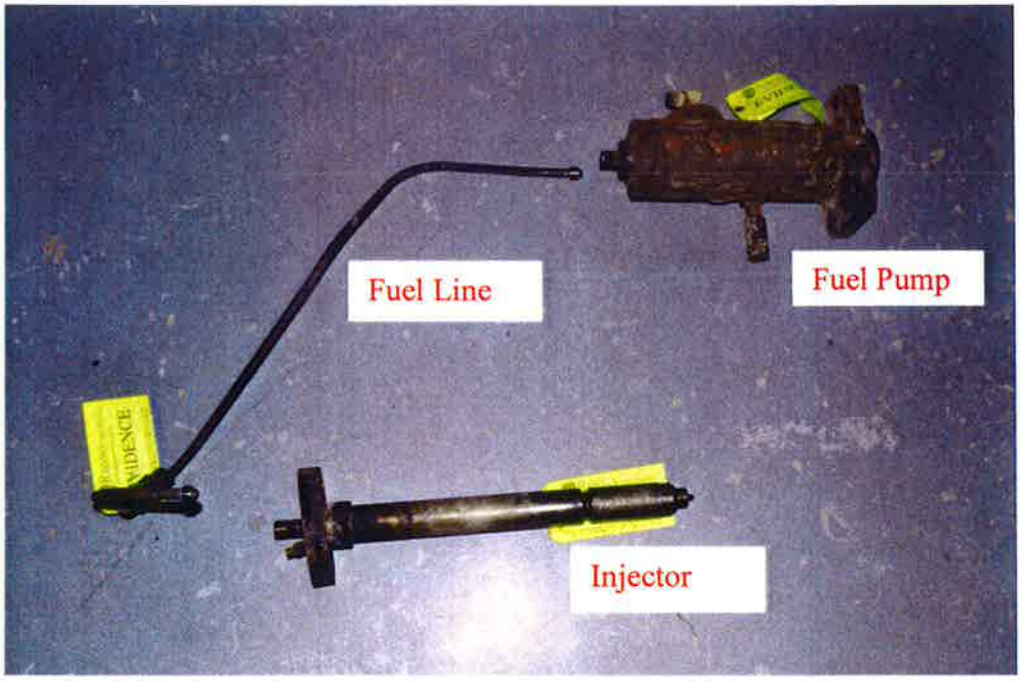


Photograph J-7

APPENDIX K

EVALUATION OF THE HIGH PRESSURE FUEL LINE FITTINGS

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-1

Photograph K-2
Fuel Line to Fuel Pump Connection

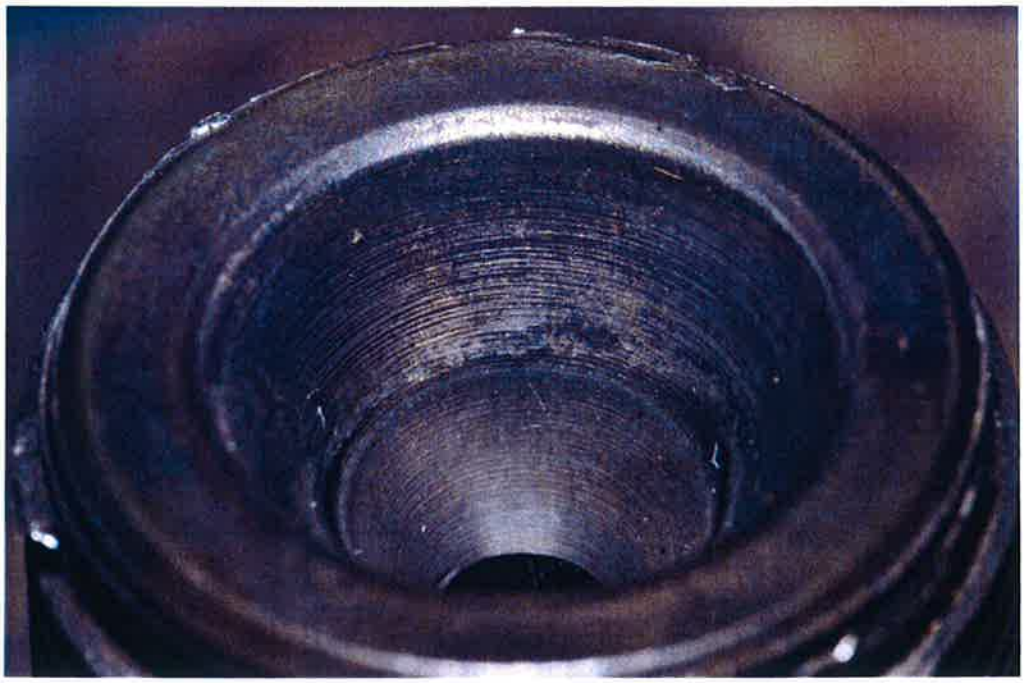
APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-3
Fuel Line to Injector Connection

Photograph K-4
Fuel Pump as-cleaned

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

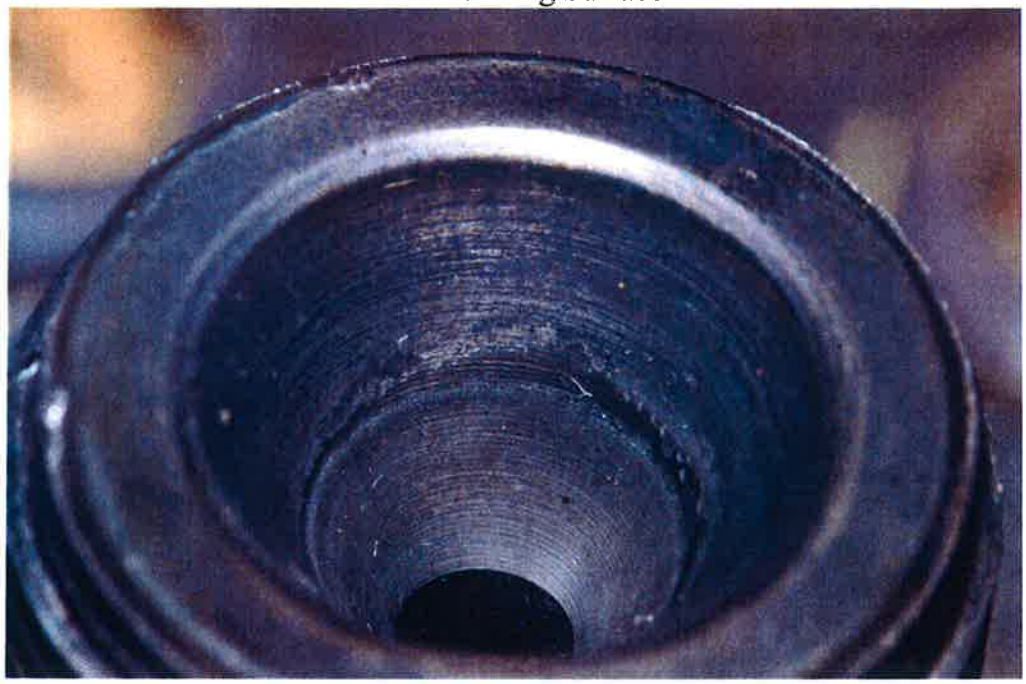
Photograph K-5
Fuel Pump as-clean
Note: Sealing Surface



Photograph K-6
Fuel Pump as-clean
Note: Sealing Surface

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-7
Fuel Pump as-clean
Note: Sealing Surface



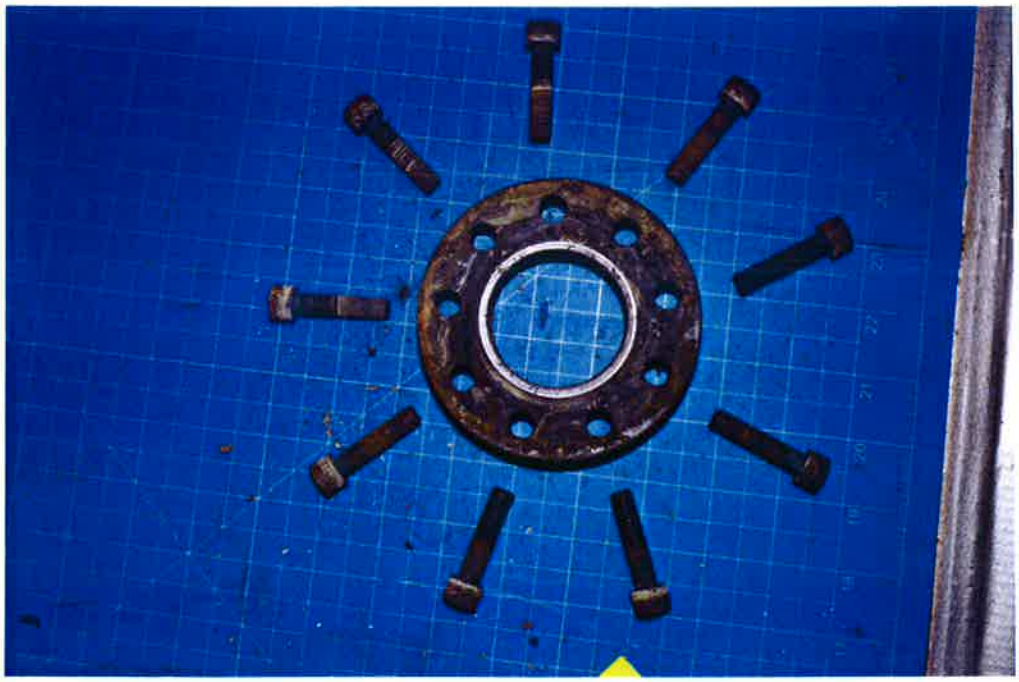
Photograph K-8
Fuel Pump as-clean
Note: Sealing Surface

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-9
Fuel Pump as-clean
Note: Sealing Surface

Photograph K-10
Removal of cap screws on Fuel Pump

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-11
Removal of cap screws on Fuel Pump

Photograph K-12
Underside of Fuel Pump flange

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-13
Gasket remnants after flange removal
Note: white burn debris

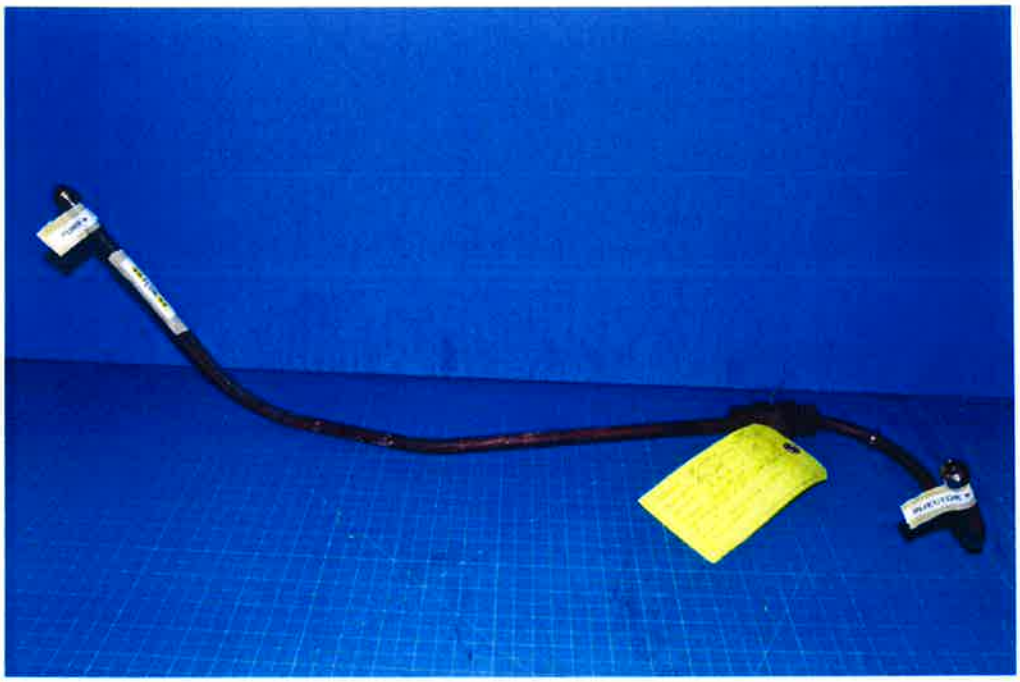
Photograph K-14
Gasket remnants after flange removal
Note: white burn debris

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-15
Note: black burn debris in this area of the gasket

Photograph K-16
Gasket remnants after flange removal
Note: white burn debris

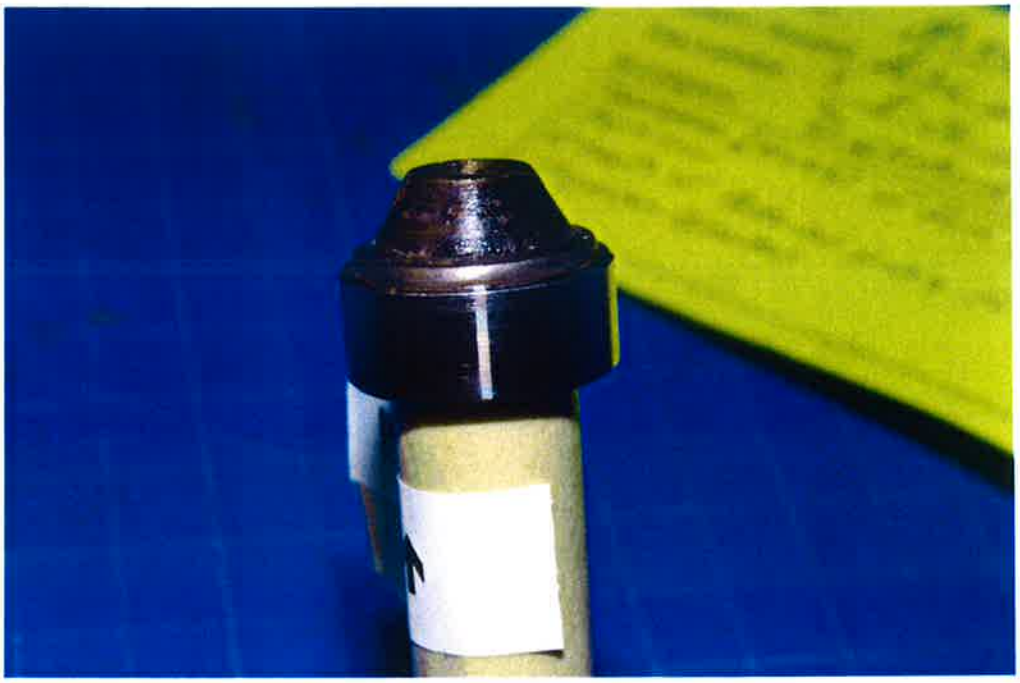
APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-17
Fuel Line with ends identified

Photograph K-18
Fuel Line Injector End

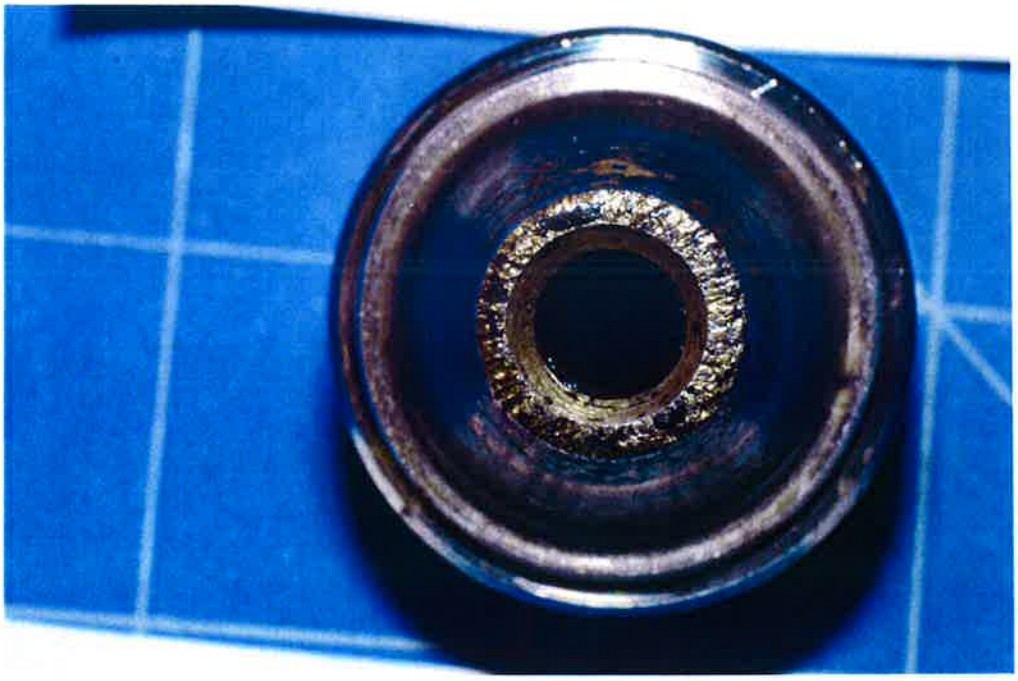
APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-19
Fuel Line Injector End

Photograph K-20
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

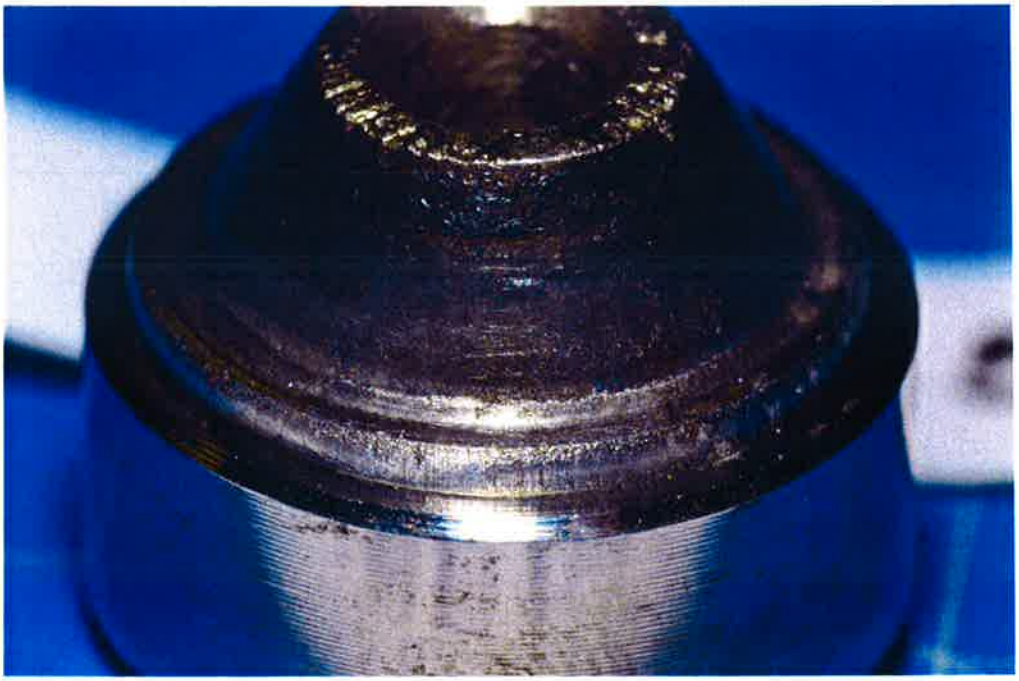
APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-21
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

Photograph K-22
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-23
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

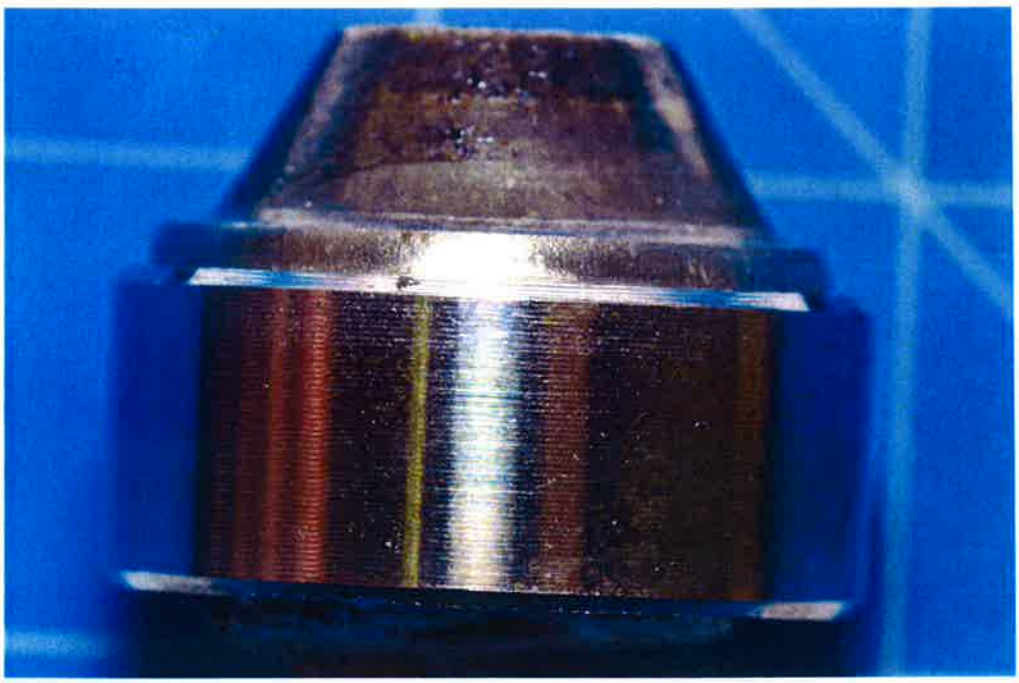
Photograph K-24
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-25
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

Photograph K-26
Fuel Line Injector End after removal and further cleaning
Note: radial grooves at tip

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-27
Fuel Line Injector End after removal and further cleaning
Note: no heat tinting

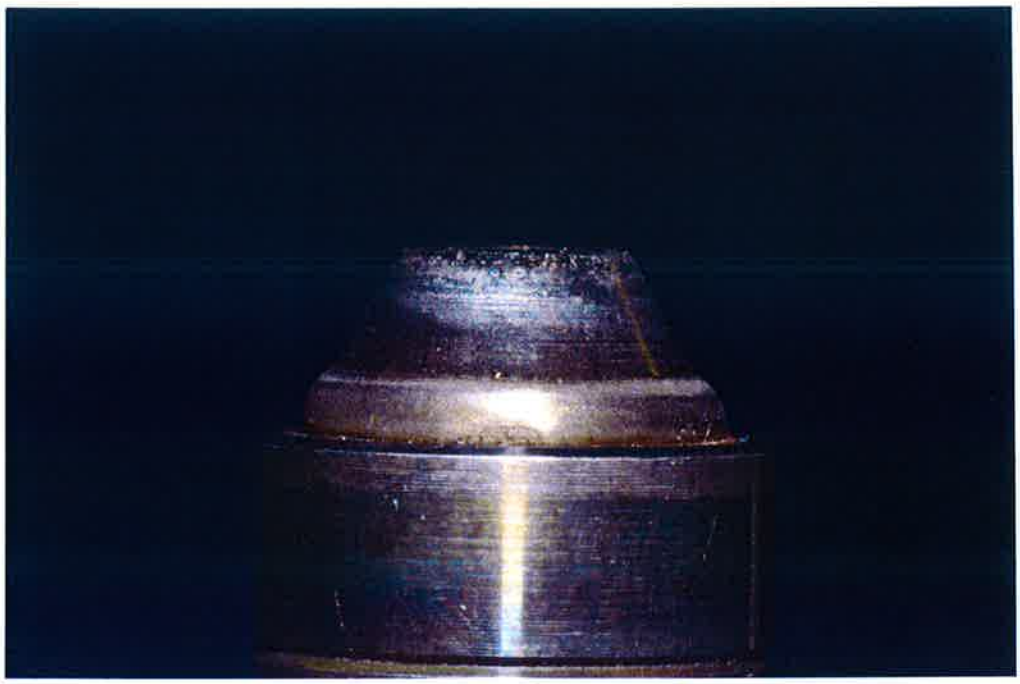
Photograph K-28
Fuel Line Fuel Pump End

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-29
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

Photograph K-30
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-31
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

Photograph K-32
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-33
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

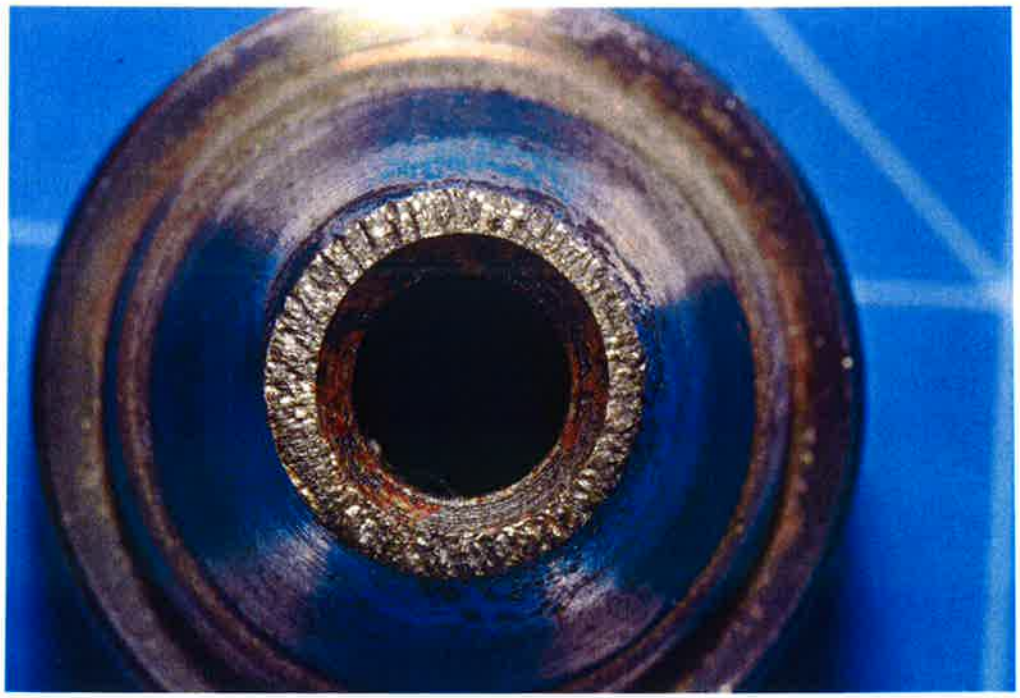
Photograph K-34
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-35
Fuel Line Fuel Pump End
Note: sealing surface, radial grooves at tip, and heat tinting

Photograph K-36
Fuel Line Fuel Pump after removal and further cleaning
Note: radial grooves

APPENDIX K
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-37
Fuel Line Fuel Pump after removal and further cleaning
Note: radial grooves

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-38
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

Photograph K-39
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-40
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

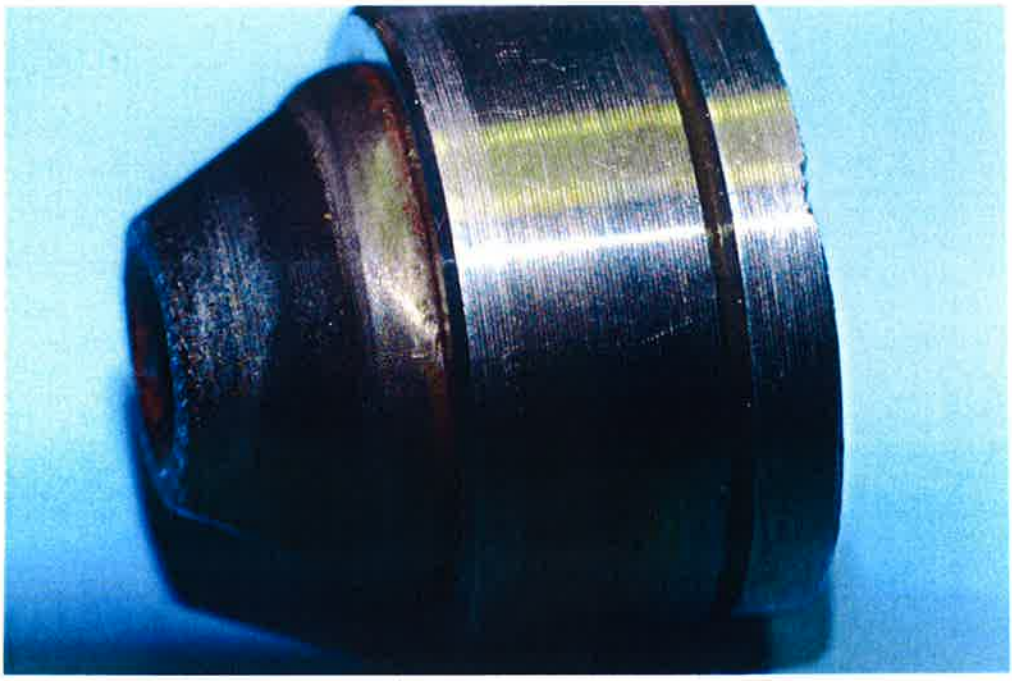
Photograph K-41
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-42
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

Photograph K-43
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-44
Fuel Line Fuel Pump after removal and further cleaning
Note: radial lines and pattern on sealing surface

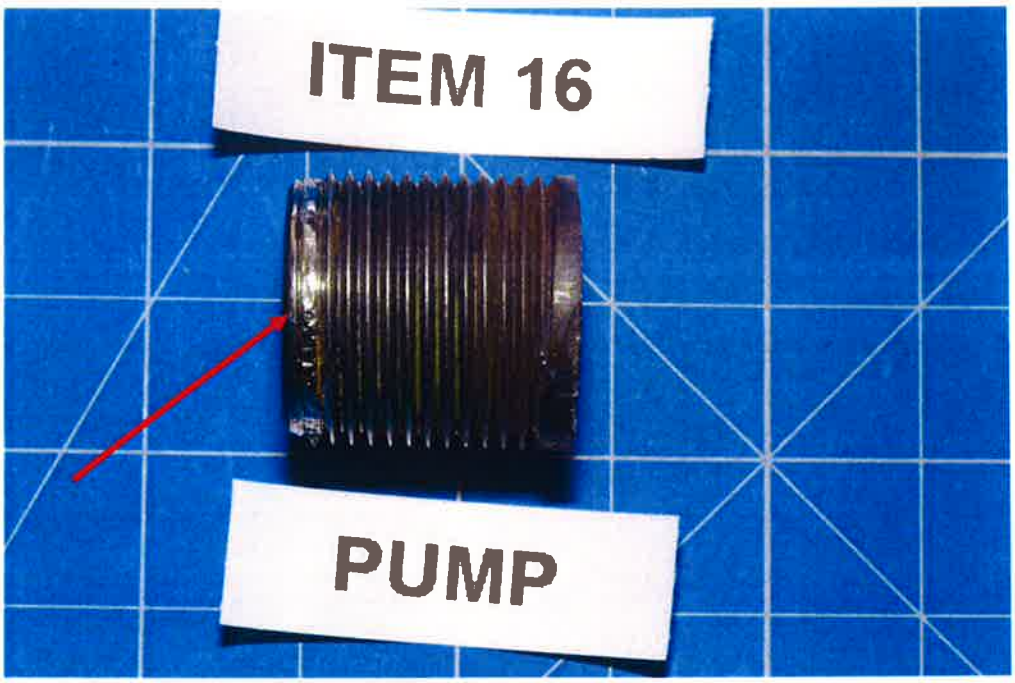
Photograph K-45
Fuel Pump Nipple after removal and further cleaning
Note: Sealing Surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

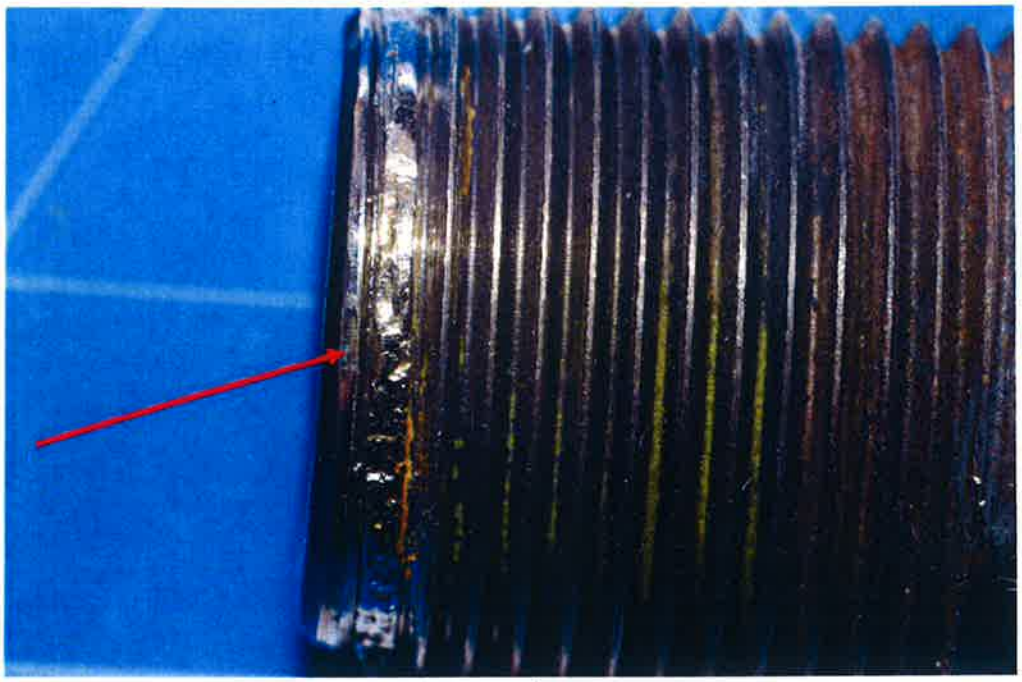
Photograph K-46
Fuel Pump Nipple after removal and further cleaning
Note: Sealing Surface

Photograph K-47
Fuel Pump Nipple after removal and further cleaning
Note: Sealing Surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

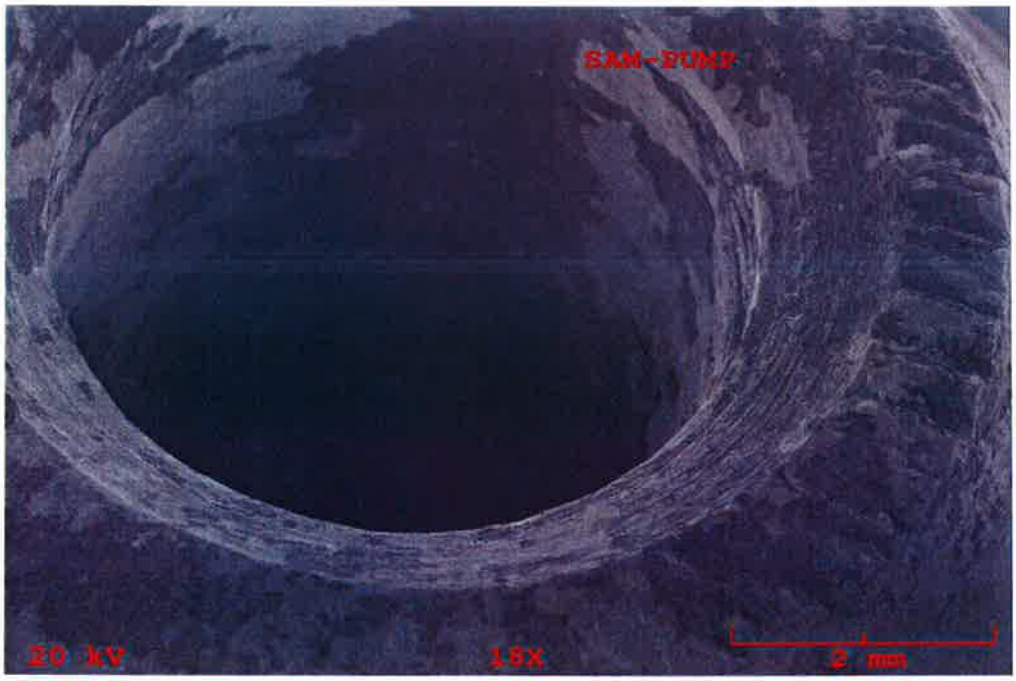


Photograph K-48
Fuel Pump Nipple after removal and further cleaning
Note: broken thread

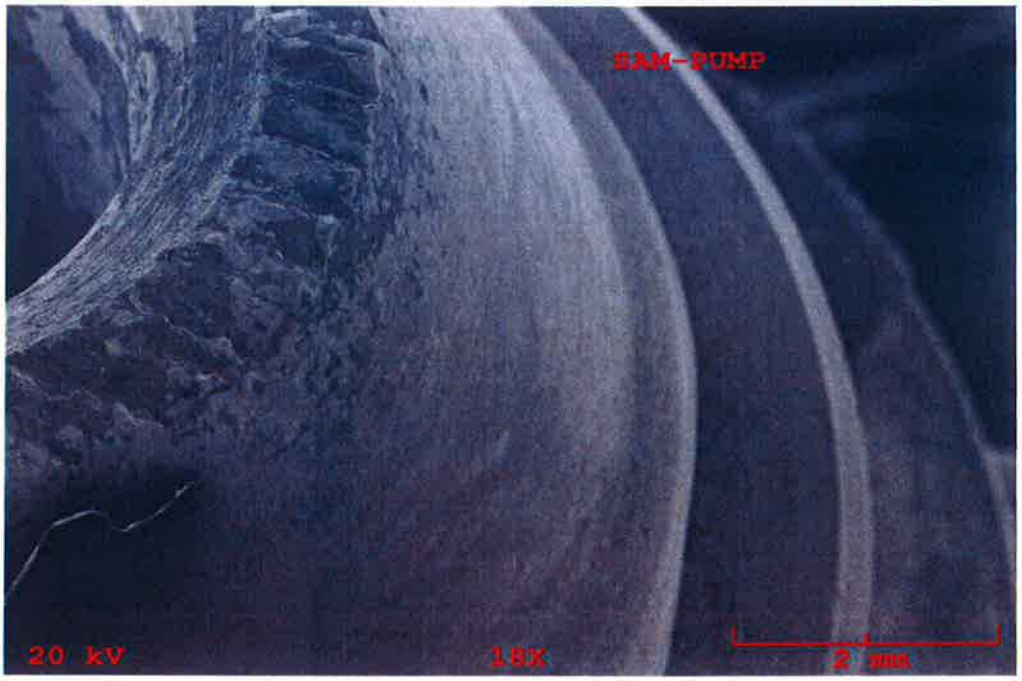


Photograph K-49
Fuel Pump Nipple after removal and further cleaning
Note: broken thread

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings



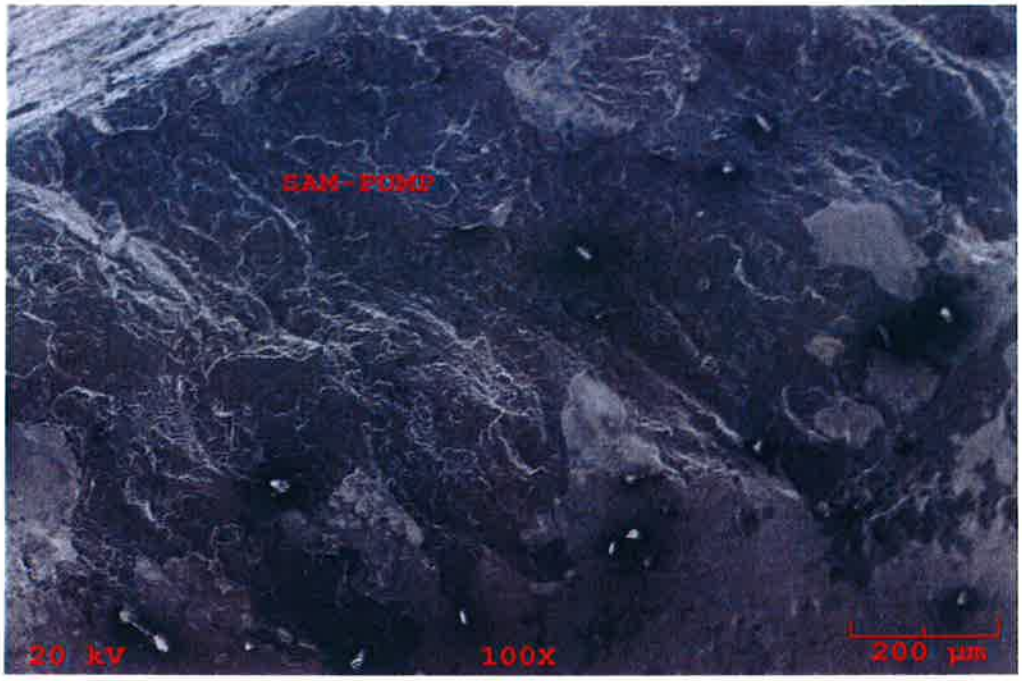
Photograph K-50
SEM photomicrograph of the tip of the fuel line end to the fuel pump
Note: erosion forming radial grooves in the tip to the conical surface



Photograph K-51
SEM photomicrograph of the tip of the fuel line end to the fuel pump
Note: erosion forming radial grooves in the tip to the conical surface

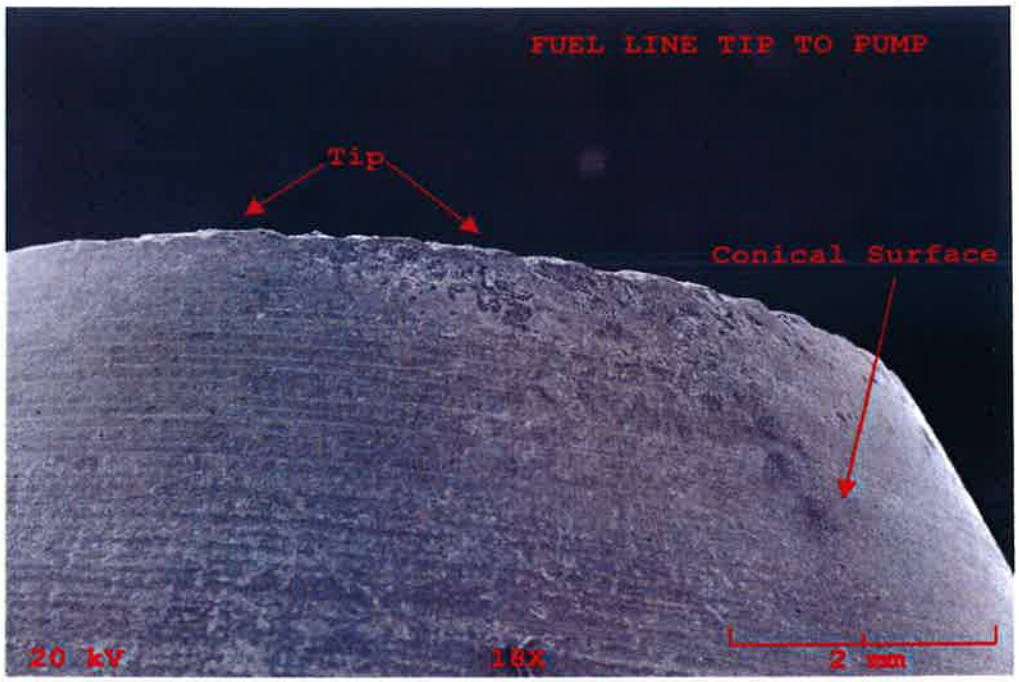
APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

Photograph K-52
SEM photomicrograph of the tip of the fuel line end to the fuel pump
Note: erosion forming radial grooves in the tip to the conical surface

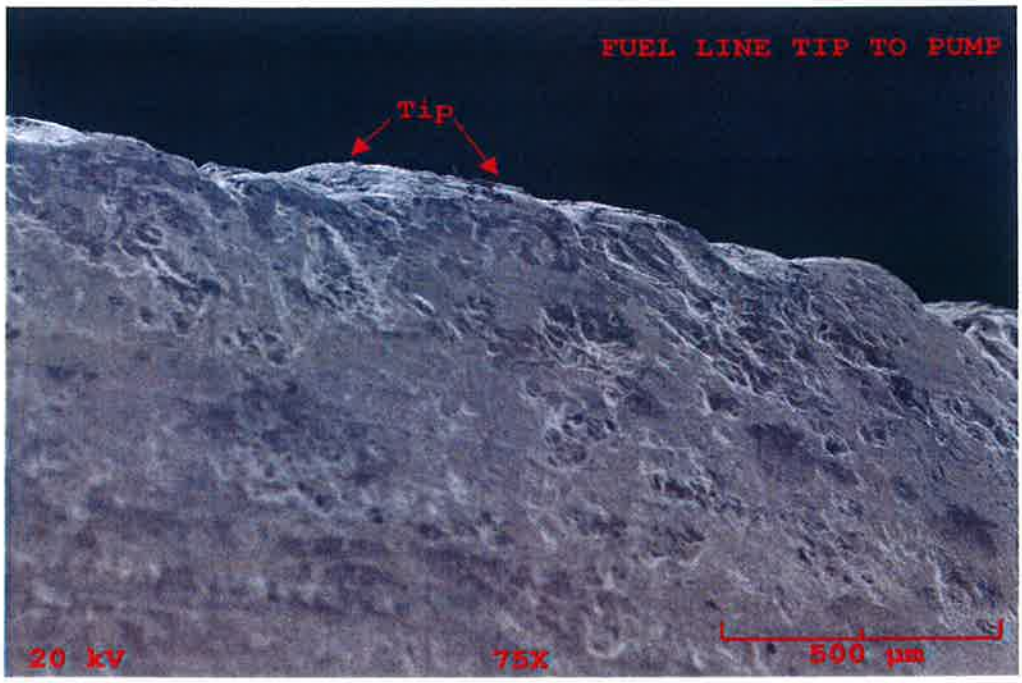


Photograph K-53
SEM photomicrograph of the tip of the fuel line end to the fuel pump
Note: erosion forming radial grooves in the tip to the conical surface

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

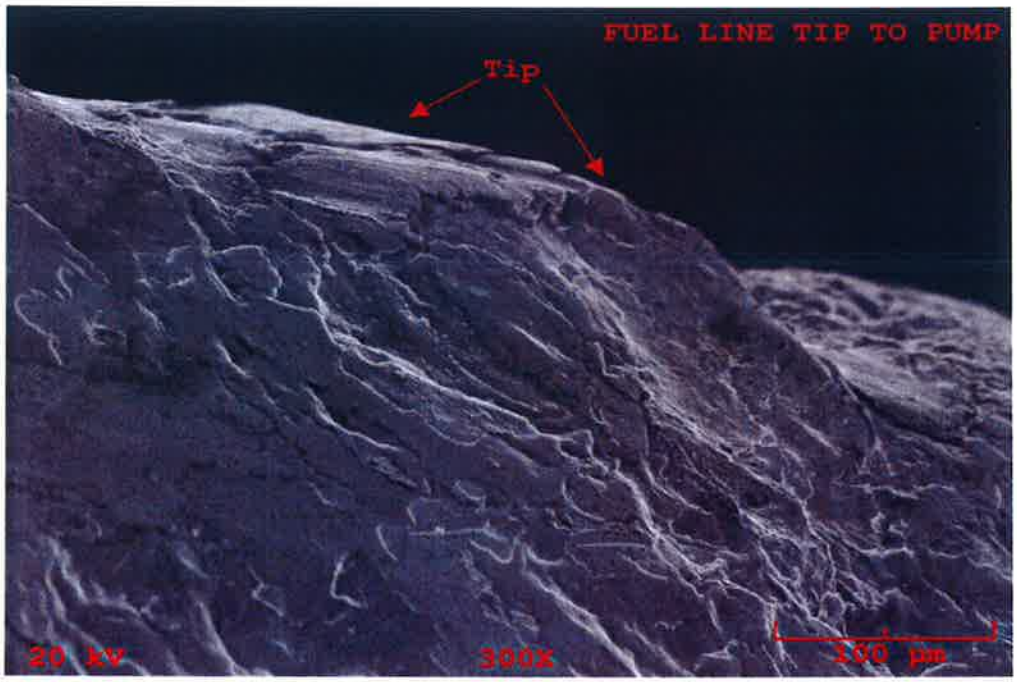


Photograph K-54
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

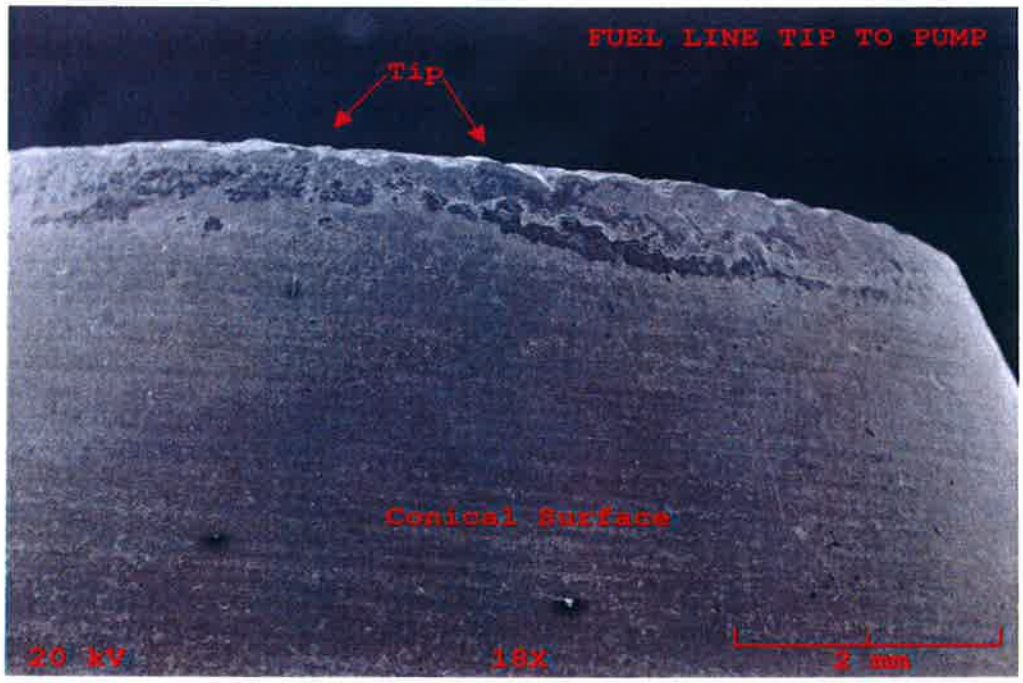


Photograph K-55
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

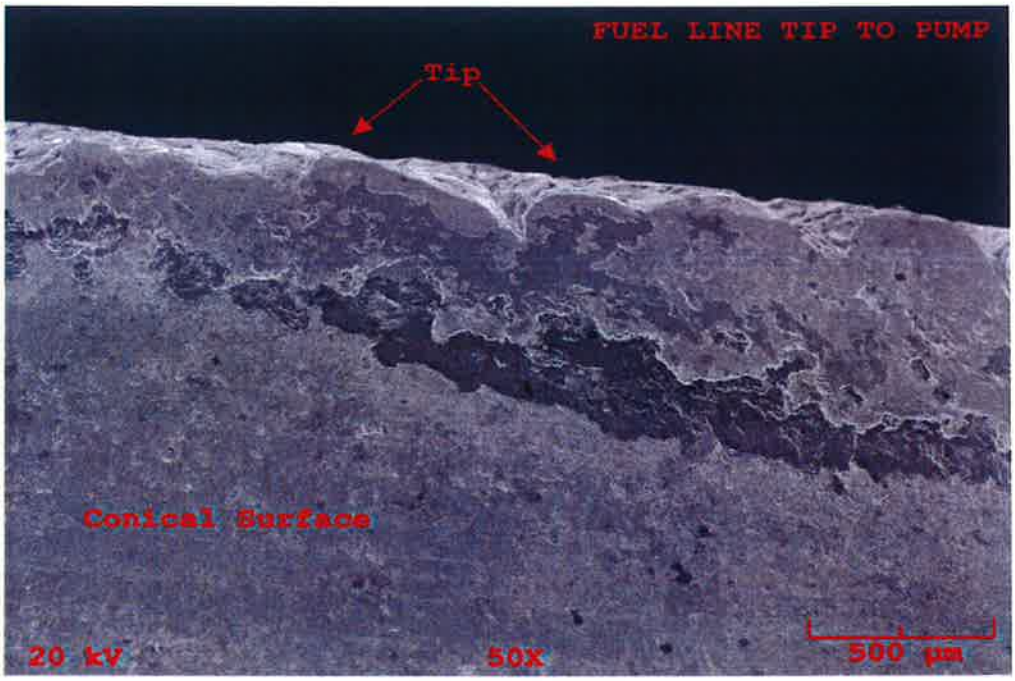


Photograph K-56
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

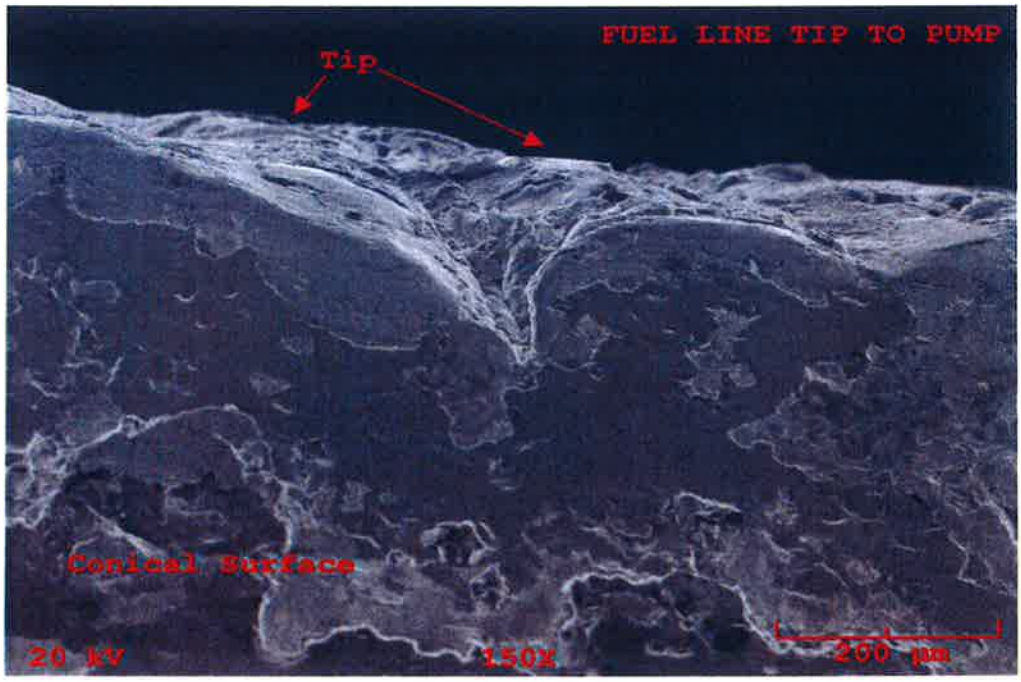


Photograph K-57
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

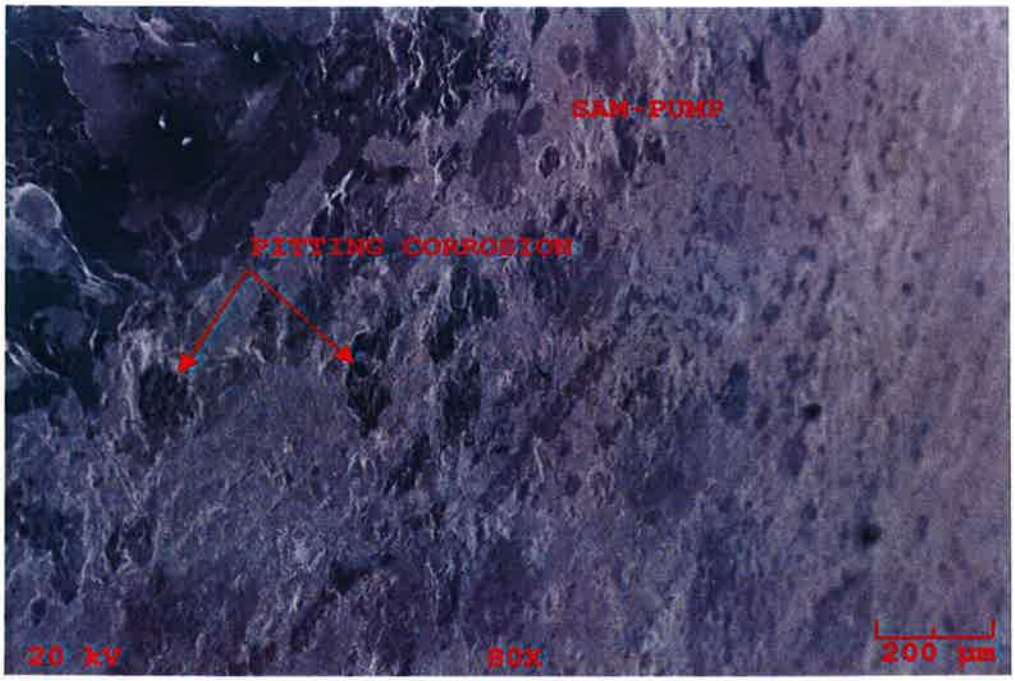


Photograph K-58
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

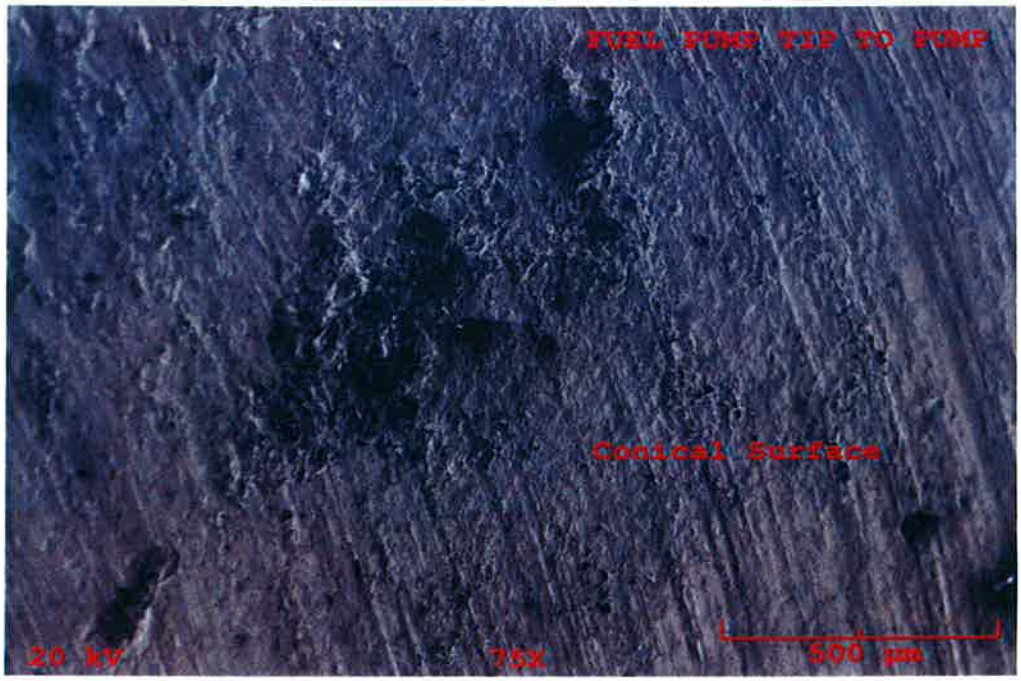


Photograph K-59
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

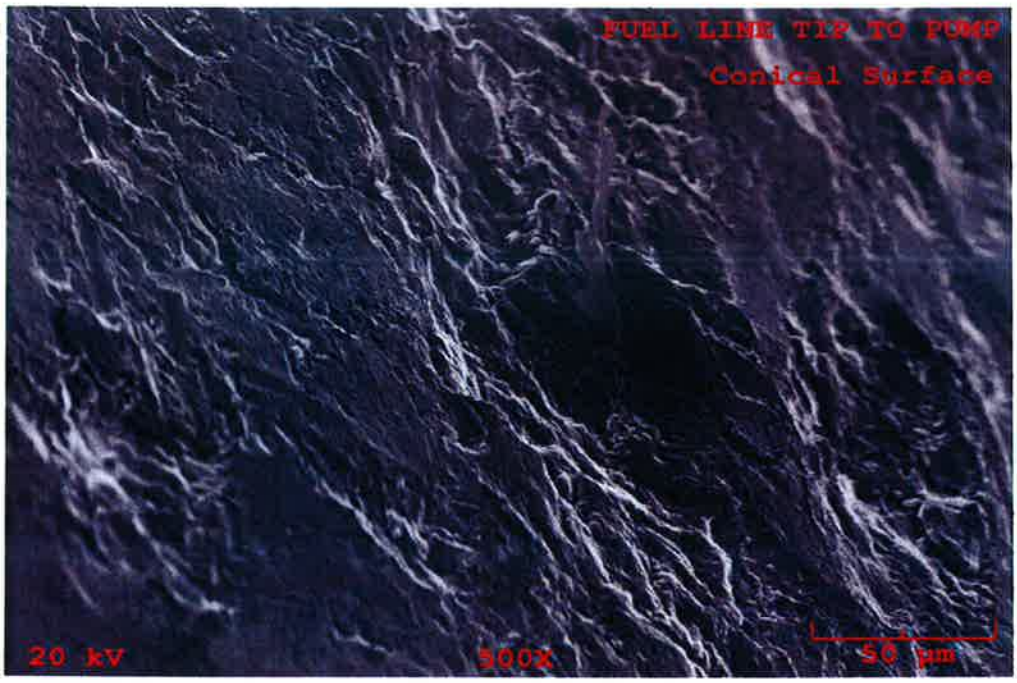


Photograph K-60
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion

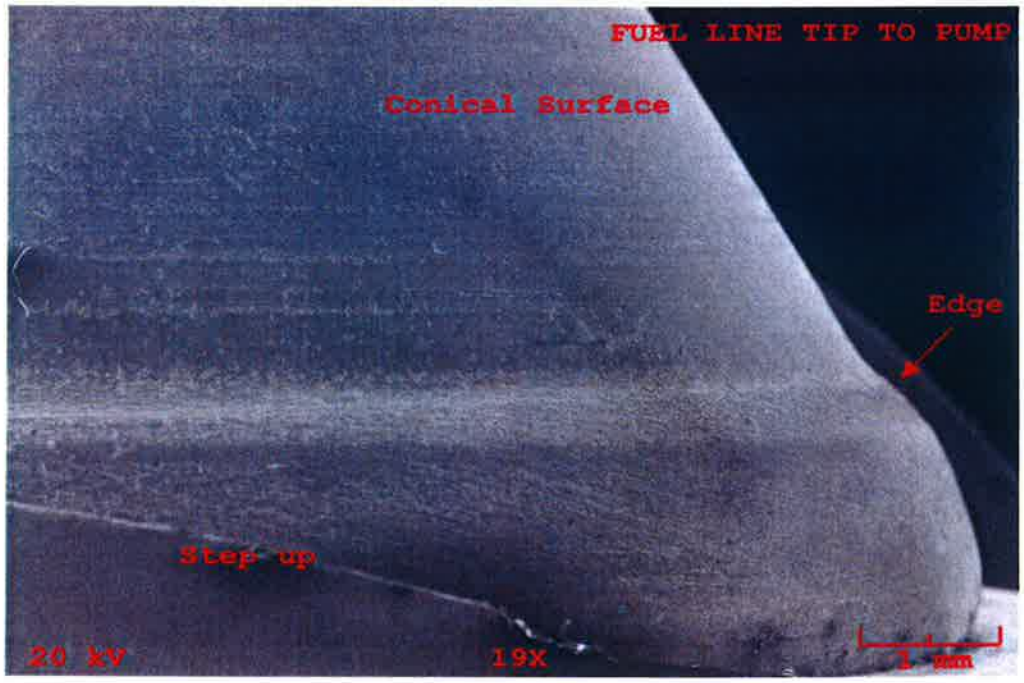


Photograph K-61
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

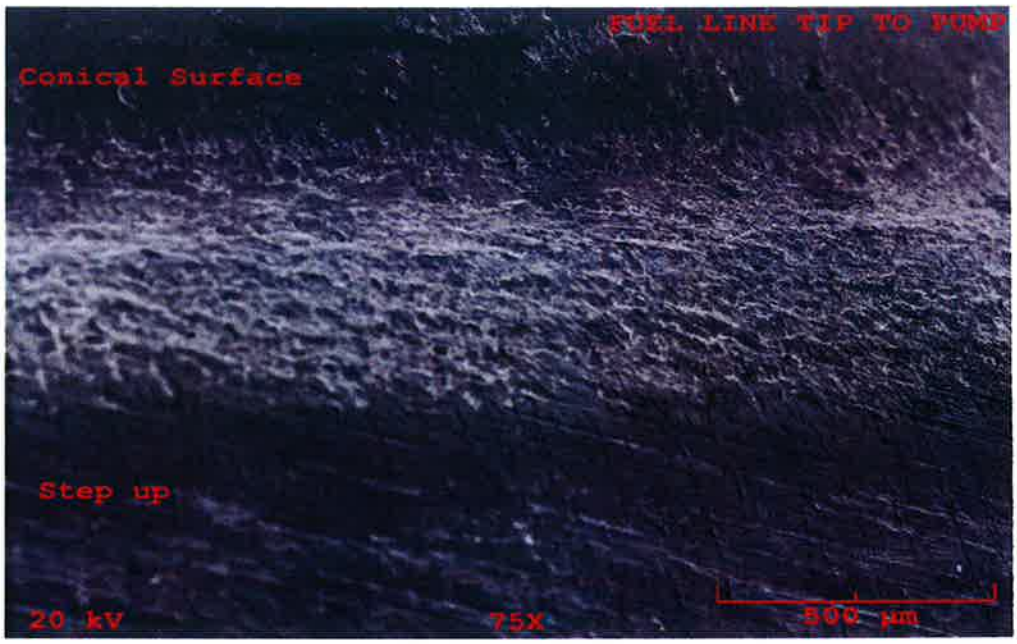


Photograph K-62
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: corrosion and erosion



Photograph K-63
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: erosion at step/ridge of the tip where the tip contacts the end of the fuel pump nipple

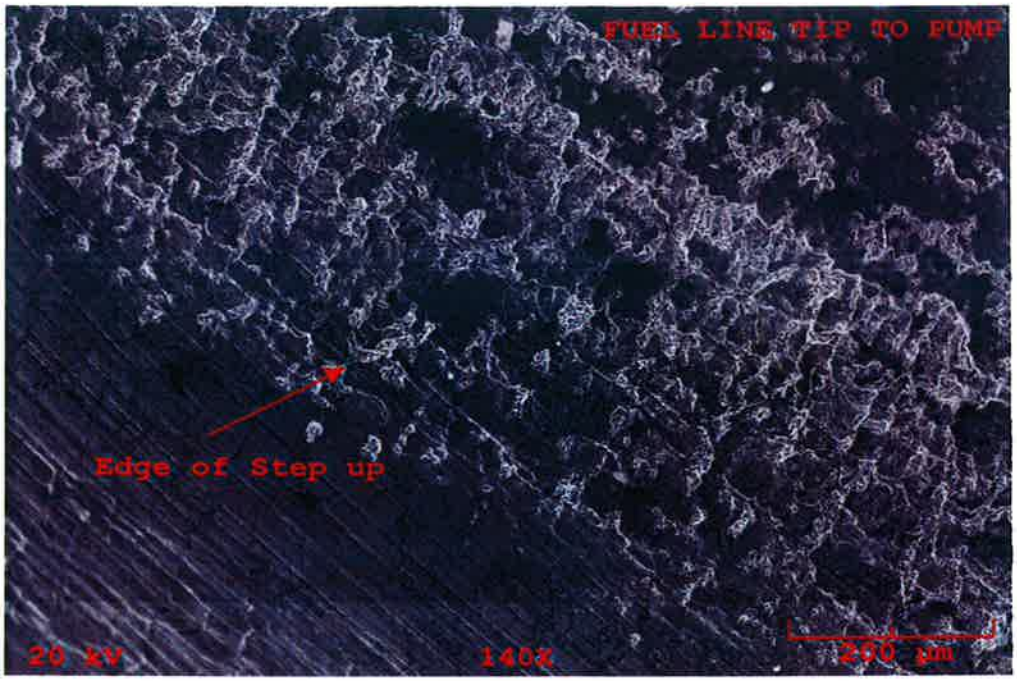
APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings



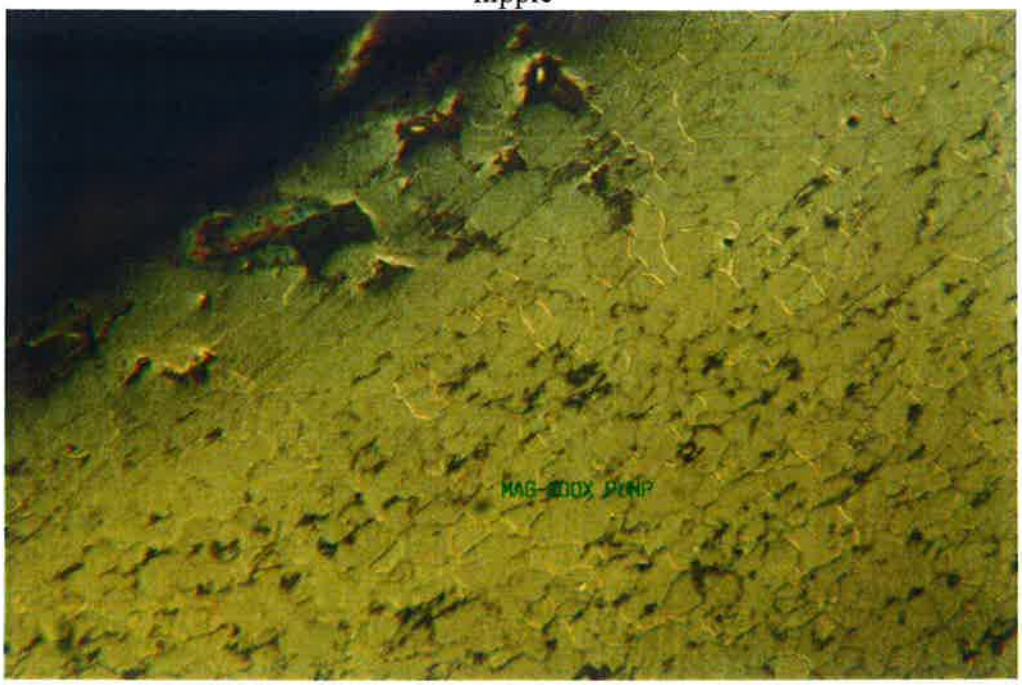
Photograph K-64
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: erosion at step/ridge of the tip where the tip contacts the end of the fuel pump nipple

Photograph K-65
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: erosion at step/ridge of the tip where the tip contacts the end of the fuel pump nipple

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings

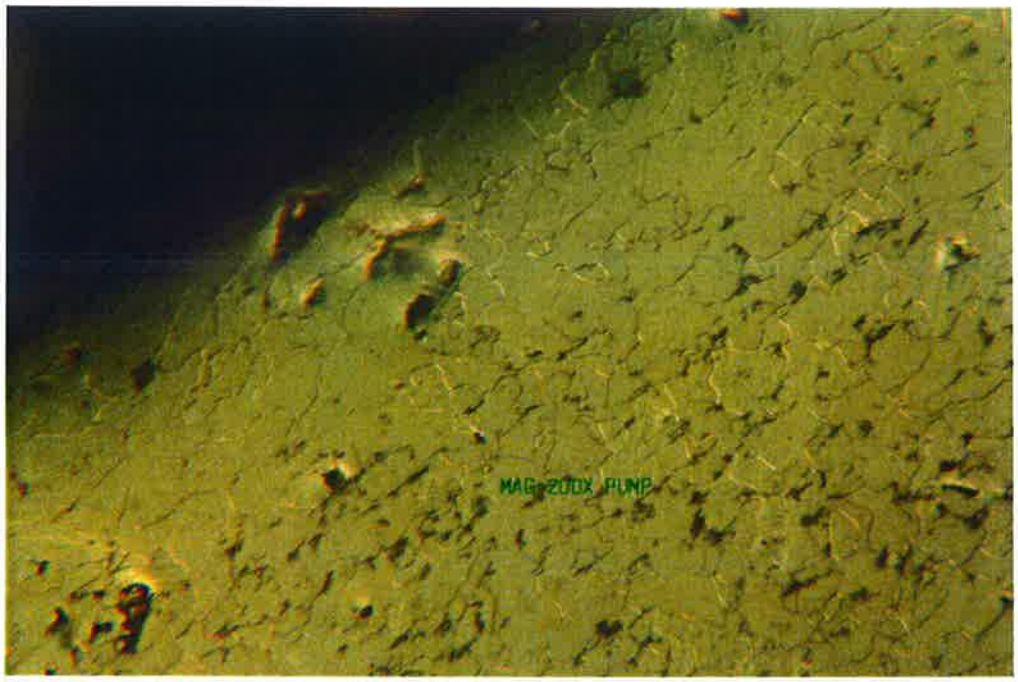


Photograph K-66
SEM photomicrograph of the conical surface of the fuel line tip to the fuel pump
Note: erosion at step/ridge of the tip where the tip contacts the end of the fuel pump nipple



Photograph K-67
Photomicrograph of the microstructure of the fuel line tip showing recrystallization and grain growth

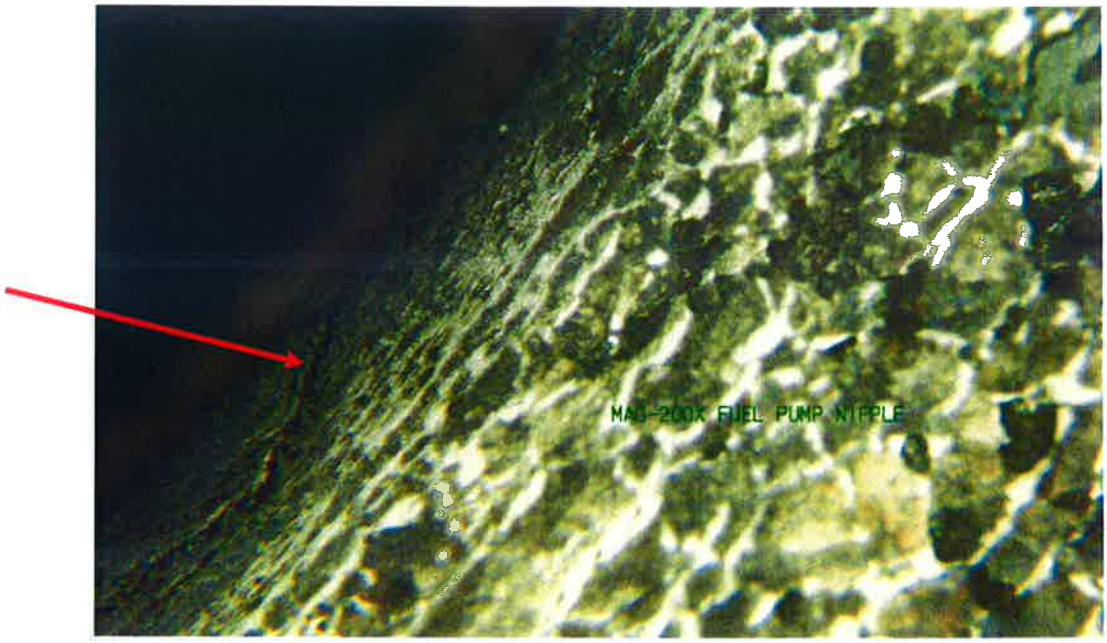
APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings



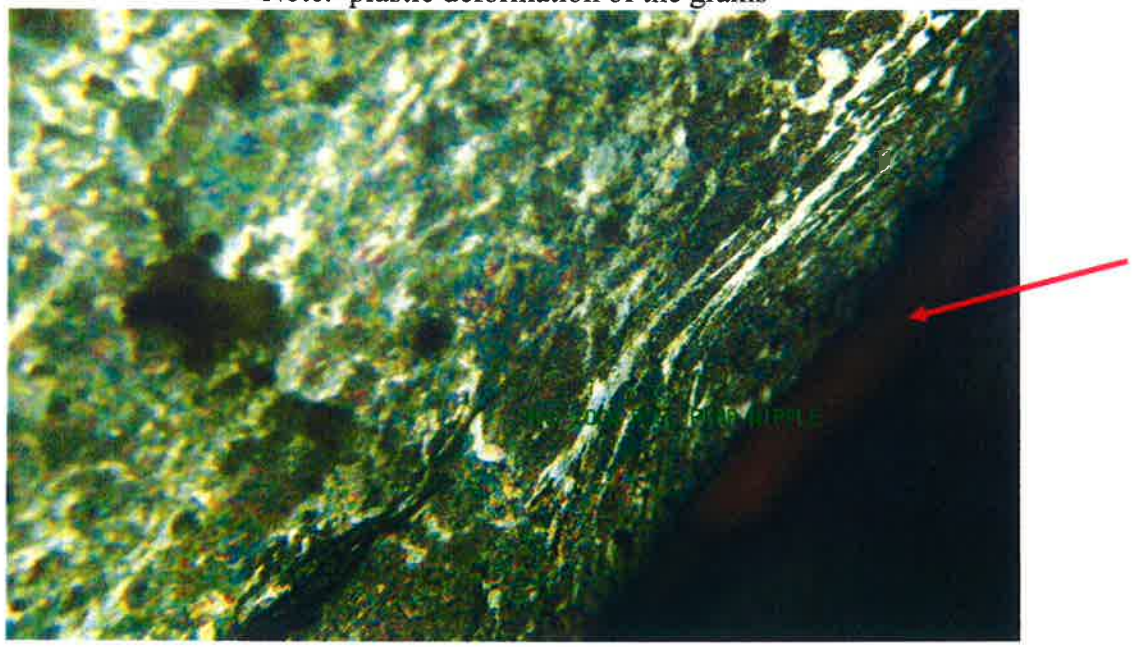
Photograph K-68
Photomicrograph of the microstructure of the fuel line tip showing recrystallization and grain growth

Photograph K-69
Photomicrograph of the microstructure of the fuel pump nipple intersecting the broken thread
Note: plastic deformation of the grains

APPENDIX K2
Evaluation of the High Pressure Fuel Line Fittings



Photograph K-70
Photomicrograph of the microstructure of the fuel pump nipple intersecting the broken thread
Note: plastic deformation of the grains



Photograph K-71
Photomicrograph of the microstructure of the fuel pump nipple intersecting the broken thread
Note: plastic deformation of the grains

APPENDIX L

INTACT FLEXIBLE HOSES FROM A DIFFERENT ENGINE

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-1

Photograph No. L-2

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-3

Photograph No. L-4

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-5

Photograph No. L-6

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-7

Photograph No. L-8

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-9

Photograph No. L-10

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-11

Photograph No. L-12

Re: North River Waste Treatment Plant
October 18, 2011

APPENDIX L
Intact Flexible Hoses From A Different Engine

Photograph No. L-13

Photograph No. L-14