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H. L. Debban
L. E. Eyre

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**CONDENSATE INDUCED WATER HAMMER IN A STEAM DISTRIBUTION
SYSTEM RESULTS IN A FATALITY**

Herb L. Debban
Larry E. Eyre

ICF KAISER HANFORD COMPANY
RICHLAND, WASHINGTON

ABSTRACT

Water hammer events in steam distribution piping interrupt service and have the potential to cause serious injury and property damage. Conditions of condensation induced water hammer are discussed and recommendations aimed to improve safety of steam systems are presented. Condensate induced water hammer events at Hanford, a DOE facility, are examined.

Key words: STEAM PIPING, CONDENSATE, WATER HAMMER, SAFETY PRINCIPLE, RECOMMENDATIONS.

INTRODUCTION

The Hanford Site covers 560 square miles along the Columbia River in southeastern Washington State. Developed by the federal government beginning in 1943, Hanford's primary mission for 45 years was to produce plutonium for national defense. In the mid 1960's the need for economic diversification of the region was recognized. The end of the Cold War brought the shutdown of Hanford's major facilities and halted plutonium production.

Today, Hanford's mission is focused on three mission elements: Site cleanup, science and technology, and economic diversification. These mission elements directly align with three of the five business areas defined in the Secretary of Energy's Strategic Plan -- Environmental Quality, Science and Technology, and Industrial Competitiveness.

To accomplish the missions, both past and present, the Hanford Site utilizes several steam distribution networks with miles of piping.

Steam distribution networks used at Hanford are similar to those used in many cities, government facilities and private institutions to distribute centrally generated steam for heating, cooling and process use. In normal operation these systems are safe, efficient means of distributing energy. But, under certain circumstances, this energy can be amplified by water hammer to exceed the strength of the piping system. Condensate induced water hammer, commonly called a steam explosion by the media, can result in fatalities to workers or to the public and can result in significant property damage.

Typically, condensation induced water hammer occurs when steam is introduced into a pipe that is partially filled with condensate. However, condensate induced water hammer can occur when large quantities of sub-cooled condensate

is rapidly introduced into a steam filled section of piping. An accident of this type took place on June 7, 1993 at Hanford, Washington, and resulted in one fatality and interrupted steam service to several critical process facilities. =

June 7, 1993 Accident

On June 7, 1993, at about 7:00pm, a Westinghouse Hanford Company Journeyman Power Operator received critical steam burns and lung injuries while opening an 8-inch main steam line isolation valve, MSS-25, (see figure 1) in the steam valve (U-3) pit in the 300 Area of the Department of Energy Hanford Site. The U-3 pit is a part of a process steam supply system using steam at about 350 degrees fahrenheit and 120 psi.

Conditions in the steam system included a large quantity of condensate (approximately 1500 gallons) backed up in a 840-foot run of the main steamline between valve MSS-25, which is the lowest point in the system and the next isolation valve. The condensate was fairly cool since this portion of the piping system is underground and had been inactive for 8 months. Steam was on the downstream side of MSS-25 with a functioning steam trap in this section of the line. The upstream side of the valve was also pressurized to allow steam flow to the 331 building. The operator entered the pit, unlocked and opened the 8 inch isolation valve, MSS-25. Indicators are that he opened the valve over 50 percent in 1 to 2 minutes. Condensate rushed into the steam filled downstream piping, filling the vertical leg and when sufficient quantity had entered the next upper horizontal section a water hammer ensued. This initiated a severe thermal-hydraulic transient, resulting in a condensate induced water hammer with pressures up to about 2300 lbf/in² in the pit piping. The transient was terminated quickly by a rupture of a 6-inch cast iron, blind flanged isolation valve in the upper section of the pit. The rupture created an instantaneous release of high pressure water and steam into the pit.

The operator exited the pit on his own, stating that he was burned. He died one week later, due to, his burns and lung damage.

An investigation board was convened to determine casual factors and make recommendations to preclude accidents of this type. These recommendations resulted in an action plan.

ACTION PLAN STRATEGY

A very detailed plan provided the direction for developing and completing the actions necessary to correct Hanford's steam system operations.

Four areas of weakness were cited in the accident investigation report and were addressed in the plan:

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1. Conduct of Operations - make a step change in the way the steam plants are operated.
2. Technical - evaluate the overall steam system design, establish an effective configuration management program, establish a steam system in-service inspection program, provide as-built drawings and a labeling program and develop a system for operating all steam valves in pits remotely.
3. Safety Standards and implementations - establish a safety program to ensure a safe workplace environment is provided to the employees and visitors.
4. Personnel Training - improve training in the recognition of condensate induced water hammer and other hazards. Establish a training program that addresses rapid isolation in the event of a steam line or component rupture.

A project manager was established to ensure effective implementation of this plan. Responsibilities, other than organize and manage resources, were to benchmark other facilities to identify best practices, oversee the conduct of training for operations and maintenance personnel as well as evaluating the technical safety reviews.

A laboratory analysis was conducted to identify the causes and provide visual indication of condensate induced water hammer. This analysis utilized glass pipes, in various configurations, enabling the viewers to actually see the effect of filling a pipe with water in the presence of steam. A video of this laboratory analysis was made and is used in the condensate induced water hammer training program. Additionally, the training incorporated a "steam board," a table top working model using glass pipes and steam traps. Operators could now "see" what was actually happening in relation to the sounds they were hearing with a stethoscope or the from temperature readings from a hand held pyrometer.

A WAKE UP CALL

Significant accomplishments were made in implementing the action plan. However, on June, 16, 1994 (one year after the fatality), another condensate induced water hammer was experienced at Hanford. At a site, 20 miles North of the previous water hammer, during a steam restoration evolution at the 284E powerhouse a condensate induced water hammer occurred when the operators began to "crack open" the main 12" limitorque valve (see Figure 2), which would initiate steam flow and begin the heat up process. A horizontal section of piping from the road riser, up to the East general limitorque valve, filled with condensate, during a two week outage. Approximately 700 gallons of condensate collected in the pipe. No personnel were injured, but moderate damage was sustained by the piping supports and three elbows on the 12" steam line exceeding their yield stress. Also, a 12" flex gasket failed due to

stressing of the flange bolts, breaking system integrity, which caused water and steam to be discharged.

When the limitorque valve was cracked open, condensate, under steam pressure of 225 psig, flowed into the powerhouse piping system. When the level in the lower horizontal section decreased to create a void between the condensate surface and the top of the pipe steam flowed into this space and set up the condition for the condensate induced water hammer, which lasted between 5-6 minutes.

Investigation later revealed that the condensate build up was due to a 15 psi trap being installed in the 225 psi system. The trap could not function to discharge condensate in this condition.

During the course of the investigation of this event, it became painfully obvious that the previous actions were not effective in communicating the cause and means of correcting condensate induced water hammer. The focus on correcting the conditions for a condensate induced water hammer became fuzzy in the hundreds of action items. Fortunately, a core of experts had emerged from the year long effort and were able to identify the action plan shortfall. Training, as a result of the 1993 incident, led personnel to believe that slow operation would prevent water hammers. The corrective action plan had placed significant emphasis on better control of the operation of valves and components. Laboratory simulations had shown that condensate induced water hammer severity does not decrease with slow valve operation.

From these events we learned that we must improve our communication of the causes and corrective actions to prevent condensate induced water hammer.

LESSONS LEARNED

A comparison of the 1993 and 1994 events validated that substantial progress had been made, but there was much left to do. Additionally, it was recognized that the focus on preventing water hammer needed to be regained and redirected. Specifically:

1. A clear, understandable safety principle was developed along with thirteen (13) recommendations for preventing condensate induced water hammer. This principle provides the cornerstone for training, procedures and hazard analysis. The safety principle states, *"Do not mix steam with water, either by injecting water into a steam system or steam into a system containing water. Steam and water cannot be mixed safely in a piping system without risking the occurrence of Condensate Induced Water Hammer. Condensate should be assumed to be in all low points and dead legs until proven otherwise."* (see Figure 3)
2. Revitalized the training program, placing particular emphasis on:

- Assuring understanding of the safety principle of water hammer, recommended safe operations, and design practices. The training was given to all personnel who interface with steam, not just the operators. We increased the use of hands-on sessions to increase practical experience. We are insistent upon obtaining assurance that the training has been successfully learned.
 - The training emphasized that there is no safe way to introduce steam flow into or from a pressurized system containing any significant amount of condensate. The only safe action is to depressurize and drain the system, then control the warm up and slow pressurization of the piping while removing condensate via drains, blowdowns, and traps.
3. Developed and use a standard steam procedure guide to ensure basic lessons learned and the safety principles are incorporated into facility procedures.
 4. Developed a means of identifying non-routine operations and specified actions to take for serious risk/frequency levels.
 5. Conducted an inspection to ensure that the correct steam traps are installed in existing systems and improved systems to assure that correct traps continue to be installed.
 6. Continued to place significant emphasis on Conduct of Operations, particularly in the areas of preplanning and recognition of abnormal indications.

CONCLUSION

Condensation Induced Water Hammer is fatally serious and is preventable in piping systems if designers and operators understand and apply the safety principle and the 13 recommendations.

The Safety Principle is an effective cornerstone in preventing condensate induced water hammer. It effectively ties training, design, planning, procedure development and management oversight into an integrated approach to steam system safety. Hundreds of successful, safe steam evolutions have validated its effectiveness.

Steam Valve Pit U-3

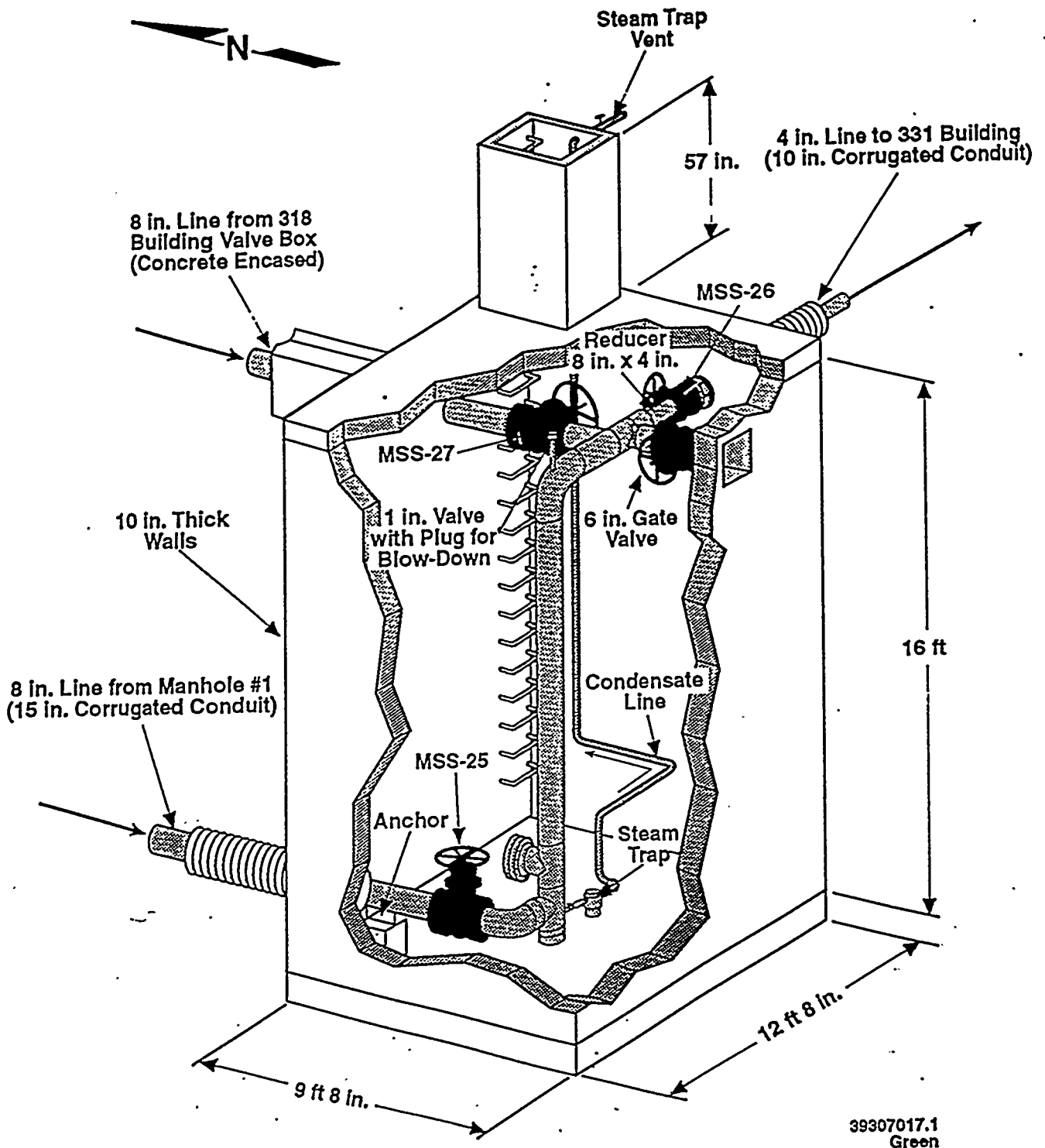


FIGURE 1

284 E POWERHOUSE SYSTEM DIAGRAM

Eas Genero
Lim torque
MOV

Flange
that leaked

~36' Rise

About 80'

50'

~18' Rise

Trap and Blowdown

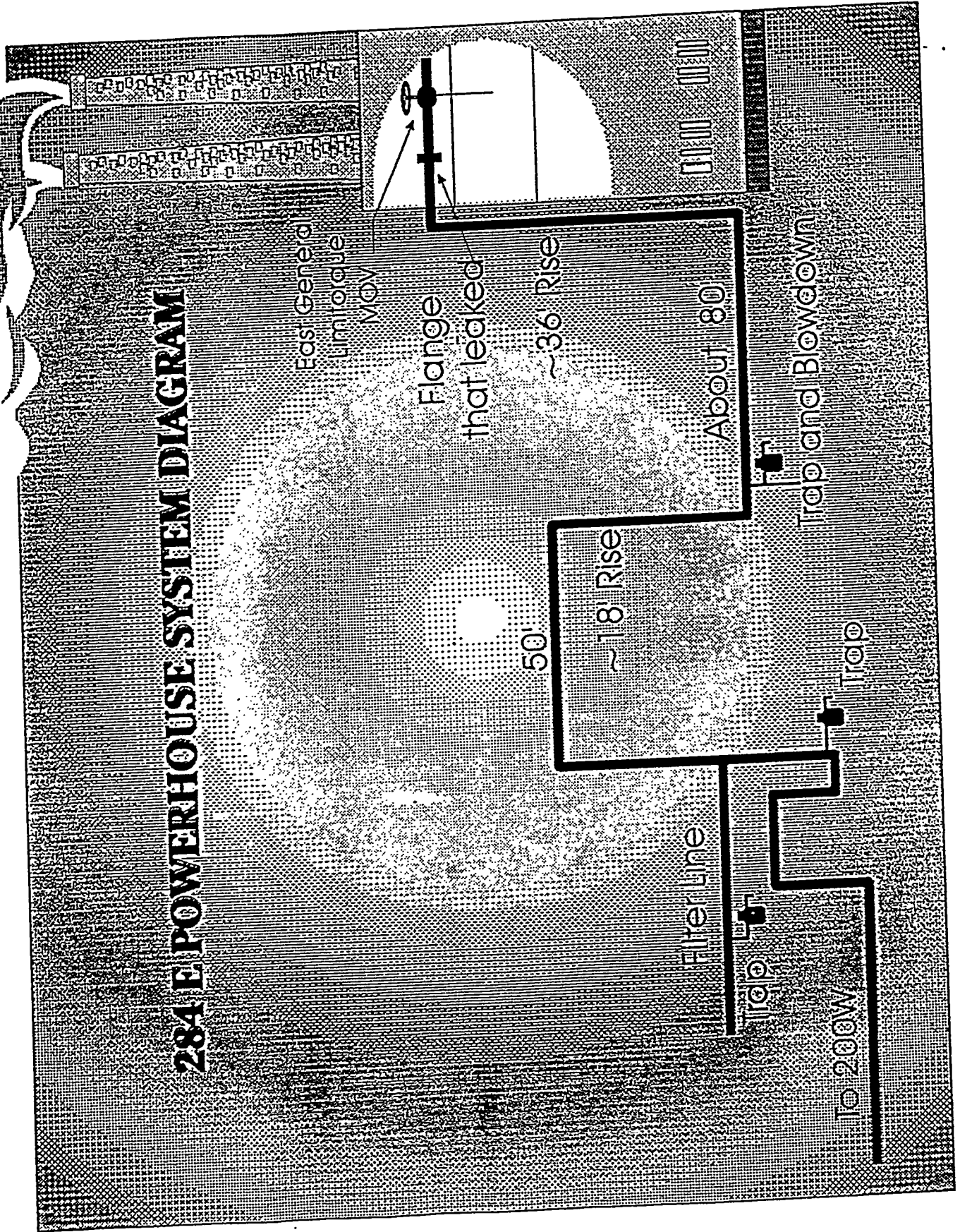
Filter Line

Trap

To 200W

Trap

FIGURE 2



CONDENSATE INDUCED WATER HAMMER

SAFETY PRINCIPLE

*STEAM AND WATER CANNOT BE SAFELY MIXED
IN A PIPING SYSTEM WITHOUT RISKING
CONDENSATE INDUCED WATER HAMMER. DO NOT
MIX STEAM WITH WATER EITHER BY INJECTING
WATER INTO A STEAM SYSTEM OR STEAM INTO A
SYSTEM THAT INCLUDES WATER (CONDENSATE).
CONDENSATE SHOULD BE ASSUMED TO BE IN ALL
LOW POINTS AND DEAD LEGS UNTIL PROVEN
OTHERWISE.*

RECOMMENDATIONS

- 1 Review and inspect all steam systems to ensure proper distribution and sizing of cold traps for startup, and operation, and that all low points have steam traps. Give maintenance the highest priority.
- 2 Frequently inspect all steam traps to ensure that they operate properly and that no condensate accumulates. Immediately repair or replace erratic steam traps. Use thermocouples where feasible to locate condensate accumulation.
- 3 Do not use the method of "CRACKING OPEN" the valve to avoid condensation induced water hammer. This will not guarantee safe operation. The formation of a condensation induced water slug can occur at very low condensate flow conditions.
- 4 Valves in pipe lines which lack properly positioned steam traps should remain open at all times or preferably should be removed from the piping system.
- 5 Before opening valves in steam lines, check for adequate placement of steam traps. Verify that the steam traps can operate properly, and fully open the bleed valves, using a reduced system pressure to remove any remaining condensates.
- 6 Where feasible operate the valves remotely using mechanical extension linkage, reach rods, or adequately controllable power operated valves.
- 7 Inspect the piping system for sagging, where necessary install steam traps or repair the sagging.
- 8 Check and repair the piping insulation, it will save energy and reduce the accumulation of condensate in the piping system.
- 9 Activation of cold steam piping should be performed slowly at reduced pressure and with trap bleed valves continuously open.
- 10 The above list of recommendations should be followed regardless of piping size. Do not exclude small pipe sizes without an appropriate analysis.
- 11 All isolation valves are to have bypass systems. However, bypass operation will not prevent water hammer if condensate is present.
- 12 Placement of blowdown valves before and after a vertical rise (such as over-the-road) is required to prevent possible condensate accumulation.
- 13 Improperly designed steam/water systems should not have the incorrect features overcome by operational methods. The systems must have the incorrect features corrected.

FIGURE 3