

At Brookhaven National Laboratory in 1986, four men working in a utility vault were engulfed by steam when waterhammer blew out the gaskets in the steam main. Two men died; two survived. Why?



Surviving a Steam Rupture in an Enclosed Space

By WAYNE KIRSNER, PE,
Kirsner Consulting Engineering, Inc.,
Atlanta, Ga.

If you hear waterhammer banging or popping noises, look for an exit. Waterhammer is *not* a normal or acceptable part of steam system operation. Steam should be isolated from the hammering pipe section and the section drained of condensate. (See “Condensation-Induced Waterhammer,” January 1999, HPAC Engineering.) But, if you must be in a utilidor or manhole, observe the steam distribution piping around you. Visualize your path of escape. Be wary of cast iron valves and traps, corroded condensate lines, flexible expansion joints, and gasketed blind flanges (the gaskets can blow out from between the

flanges). Try to stay between the exit and these elements if you anticipate the possibility of waterhammer. *Always* anticipate waterhammer during startup of cold steam mains.

IF WATERHAMMER STRIKES

If waterhammer strikes and ruptures a high-pressure steam or condensate line entrapping you:

1. Don't panic. Your first imperative must be to avoid inhaling hot steam—it can burn your throat and lungs. Inhalation injury is the number one

cause of fatalities in burn patients.¹ You may have gotten sprayed with hot condensate if you were near the rupture. The condensate can be no hotter than 212 F at atmospheric pressure, and generally, if it's under pressure, flashing will cause the condensate stream to entrain air to cool it.[^] Nevertheless, exposure to water at 156 F for over one second will scald you. If the burns you

[^]300 F condensate emerging from a 1/8 in. orifice cooled to 152 F after 20 in. of travel in 80 F ambient air (see first sidebar).

In the January 1999 HPAC Engineering article “Condensation-Induced Waterhammer,” Wayne Kirsner wrote about workers trapped in an underground utilidor during a steam accident and how they escaped. In July 1995, HPAC Engineering published “What Caused the Steam Accident that Killed Jack Smith”—also by the author—about a steam fitter who died under two feet of hot condensate when a steam valve he was opening blew up in his face.

STEAM RUPTURE

receive are confined to your skin, however, you have an excellent chance of recovery. In a 1981 study of 1914 burn patients, only 7 percent of those with no inhalation injury died. The mortality rate for those with inhalation injury

was 55 percent.²

2. Evacuate an *isolated* manhole as soon as possible. If the pit is heating up or filling with hot condensate and there is no alternate escape route, it's a better bet to evacuate quickly—even if it means

passing through a saturated steam jet—than risking inhaling hot steam and air during an attempt to reach an alternate exit (see sidebar on this page).

This advice was borne out in a 1986 steam accident involving four workers at the Brookhaven National Laboratory. Two steam fitters were standing side-by-side in an isolated manhole when a waterhammer blew out the gaskets from two 10-in. blind pipe flanges. One man darted through the escaping steam and condensate to the exit ladder behind him. He emerged with second- and third-degree burns, but fully recovered, and today is a construction safety specialist at Brookhaven Lab. The other man attempted to crawl beneath the pipes to the exit ladder on the opposite side of the manhole. He became disoriented and took several minutes to emerge during which time he was forced to inhale hot air and steam. He died the following day with burns over 75 percent of his body.³

3. If the manhole is *not isolated*, consider trying to move away from the site of the leak through tunnels to other exits. Cooling air should be drawn from the direction of other openings due to the draft caused by steam and hot air exiting the open manhole above the accident site. Remember, your fellow steam fitters heard the “KA-BOOM!” of the waterhammer, and everyone in the area will have been alerted to the accident by the steam plume billowing out of the manhole. Your co-workers' first instincts should be to isolate the steam main to stop the steam flow. Their second thought should be to open alternate means of egress for you. The additional openings will let fresh air enter the utilidor and keep the steam traveling up and out of the manhole at the accident site.

HOW DANGEROUS Is a High-Pressure Steam Jet?

Being sprayed with high-pressure steam can be less serious than contact with hot water even though the steam may initially be hotter. A jet of high-pressure steam spraying through a crack or small orifice at high velocity expands and entrains the air surrounding it. If the air is cool, it rapidly dilutes the temperature

of the steam jet.^B In a series of experiments reported in ASHRAE Transactions, 1966, 300 F saturated steam spraying from a 1/8 in. diameter orifice into 80 F ambient air cooled to 106 F after only 15 in. of travel⁴—cool enough to stick your hand in. The rate of cooling was insensitive to steam pressure.^C

In a confined space, however, even a small steam leak will warm the surrounding ambient air rapidly.^D As the ambient air heats, its temperature-diluting effect on the steam jet is diminished. This is one big reason why steam ruptures in confined spaces, especially warm confined spaces, are much more dangerous than those in open spaces with good air circulation.

Another reason is that steam permeates

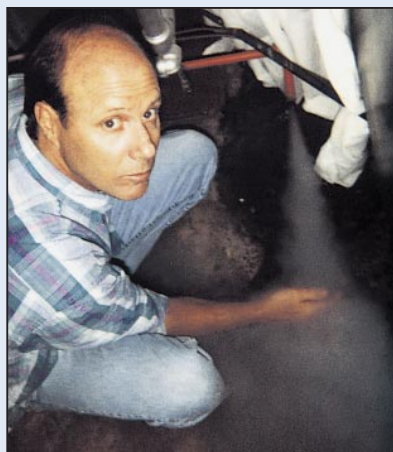
the space quickly. Condensing steam has a high heat transfer coefficient. This makes it a penetrating heat. Below 12 percent steam by volume in a steam-air mixture, the condensing temperature of steam is below 120 F. Thus, steam condensing on your skin deposits condensate at a temperature below 120 F. (The pain level for most people as well as the temperature at which the hot condensate will start to burn you is 120 F.) Thus, steam hotter than 120 F remains a gas, which is relatively benign since it has a very low heat transfer coefficient. You can withstand dry steam and air temperatures above 200 F. As the percent of steam (by volume) in the air surpasses 12 percent, as it will quickly in a confined space, the condensing temperature rises above 120 F. Above 120 F, condensing steam will burn.

The above facts suggest different courses of action for escape from isolated manholes versus utilidors connected by tunnels. Isolated manholes must be evaluated immediately. It also suggests that forced ventilation of confined spaces can save lives in the event of a steam accident.

^BExpansion cools the jet somewhat. I calculate Isentropic Expansion to Mach 1 at $.58P_o$, cools the gas 5 percent of its Rankine temperature. Non-isentropic expansion from $.58P_o$ to P_{exit} will cool it somewhat further.

^CSteam cooled to 12 percent of its initial temperature difference at 15 in. from the nozzle for steam pressures between 50 and 142 psig.

^DA 100 psig steam leak through a 1/8 in. orifice would warm 1000 cfm of air from 80 to 200 F in as little as 30 seconds.



One-half in. pipe emitting 18 ft long jet of 115 psig saturated steam. Hand is 15 in. from outlet.

HEY, I'M ALIVE— SAGA OF A STEAM ACCIDENT SURVIVOR

Conventional wisdom held that Arland “Dean” Stackpole had a one-in-three chance of survival. Twice in the span of the first six hours after the accident, a fast-acting Emergency Medical Technician (EMT) and two quick-thinking doctors had to act to save his life.

Dean, a steam fitter and operator with 32 years of experience at the Brunswick Naval Air Station in Brunswick, Me., entered steam pit D-3 in October 1997 to open a 14 in. cast iron valve. The steam system was being energized for the season. The power plant had already achieved close to its full-operating pressure of 110 psig when he climbed down the ladder into the 8 x 8 ft steam pit. He had hardly put his hands on the cast iron valve's handwheel when it erupted in an explosion of steam and condensate. The force of the steam struck Dean full in the face, destroying the flesh from the right side of his head to his nose. The 8 x 8 ft pit filled rapidly with condensate, immersing the lower half of Dean's body in 212 F scalding water.

His first thought was to try for the ladder on the other side of the pit. After a few steps, however, his pants leg caught on a submerged pipe fitting, ensnaring him in the pit. “Maybe I'm gonna die here,” he thought. But with a yank strong enough to rip denim, he ripped open the pants leg, freeing himself. But, which way was it to the ladder? Steam pouring into the pit obscured everything. He was lost in the 8 x 8 ft vault. Desperately, he headed for the nearest wall. He had to breathe. The vault wall was 8 ft high. Dean stands 5 ft 11 in. At 50 years of age, he jumped, grabbed, and did the most important pull-up of his life. With an elbow over the rim, he dragged himself up and out of the pit, rolling out onto the ground.

Dean doesn't remember hearing the valve rupture. Others described the sound as that of a plane crashing or a bomb going off. Lucy Behnke, an EMT, heard the blast and ran to help. When Dean emerged, he and his clothes were steaming. Lucy immediately began cutting off the boiling hot clothing and called 911 for an ambulance. Then she called for cool water to be brought to quench the unbearable pain racking Dean's body. The whole time Lucy kept Dean talking while watching for signs of shock. Talking was important to insure Dean's airway was open.

Moments later, an ambulance arrived. The on-board EMTs thought they were responding to a coffee scalding. What they saw sickened them. Dean had lost all the skin below his waist. Muscle and bone were exposed beneath his knees, on the side of his head, and on his hands. His face was badly burned. Lucy accompanied Dean to local Parkview Hospital, keeping him talking all the way. They arrived just in time. Recognizing that Dean's air passage was closing, emergency physician Dr. Van Derputten saved Dean's life by intubating him just before his throat closed off completely. Dean was airlifted by Navy helicopter to a burn unit in Portland Me. within 30 min and, from there, driven to Boston's Brigham and Women's Hospital burn unit. There his lungs failed, but by now, he was in the hands of Dr. Robert Demling, who saved his life once again. For the next several weeks, Dean was sedated and breathed through a respirator. For another month after that, he had to breath through a tube down his throat. He required skin grafts over 70 percent of his body and re-constructive surgery to his face and hands. The process went slowly since there was twice as much burned area to graft to as healthy skin to harvest. Today, a year and a half later, Dean speaks with a hoarse and whispery, but enthusiastic, voice. He does volunteer work with other burn victims. The man who wasn't supposed to live wasn't supposed to ever work again, either. He starts back to work at the Naval Base Monday, albeit in a different job.

How does Dean sum up his experience? “Hey. I'm alive!”

SPECIFIC INSTRUCTIONS TO THOSE ISOLATING THE MAIN:

- Open manhole covers at adjacent manholes to allow cool air to be drawn into utilidors. If your co-worker is trapped, this may save him.
- Isolate the steam main as close to the site of the accident as possible. Shutting down the steam at the boiler plant is okay, but it will take longer for steam mains to empty of steam. Isolating and venting close to the accident is best, if there's no unreasonable delay.
- Vent the isolated section of steam main to relieve the steam pressure—open the bleed valves and trap strainers.

FIRST-AID

If a co-worker emerges from a steam pit with second- and third-degree burns, you've got two imperatives after calling for professional medical care: keep the wounds from being exposed to infection, and treat for shock. Specifically:

- Peel off clothes soaked with hot condensate if still scalding hot *except* where clothing is involved in open wounds.
- Lay the victim down and, assuming no evidence of spinal injury and no discomfort, elevate his feet about 1 ft to treat for shock.
- Ask if his throat or airways are burned. (If so, EMTs must be prepared to intubate should the victim's air passage close off.) Advise the arriving EMTs.
- Get cool water, not cold or ice water, to apply to first and second degree burn areas to reduce pain. Do not induce shivering. Do not apply ointments. Do not touch the wounds.
- Do not attempt to remove material adhering to the burn. **HPAC**

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