Operating Experience Summary

U.S. Department of Energy
Office of Health, Safety and Security
OE Summary 2006-11
October 6, 2006

Inside This Issue

- *Inadequate work package results in water hammer in steam system* 1
- *Life-threatening illness due to heat stress* 5
- *Explosions and fire at UK oil storage facility caused by overfilled tank* 8

Inadequate Work Package Results in Water Hammer in Steam System

1

On September 28, 2005, at the Los Alamos National Laboratory (LANL), a water hammer occurred in a steam line during restoration of an isolated steam system following routine maintenance. The water hammer caused the catastrophic failure of a blind flange, the rupture of an expansion joint, and the release of steam at a temperature of approximately 340°F. Pipefitters were using a general startup procedure to restore the steam system rather than a task-specific procedure that would have properly drained water from the steam lines. There were no injuries as a result of this event. (ORPS Report NA--LASO-LANL-PHYSTECH-2005-0010; final report filed February 2, 2006)

The pipefitters were tasked with performing routine maintenance on an expansion joint and repairing a steam valve that had a leaking bonnet. The valve and expansion joint were located in a manhole. Before beginning the maintenance work, the pipefitters isolated steam to the manhole by closing appropriate steam valves in the surrounding manholes. They used double block and bleed procedures because some of the isolation valves leaked and could not completely isolate the steam.

After the maintenance had been completed, the pipefitters attempted several system blowdowns to remove any water and then began to recharge the piping with steam. As the last steam isolation valve was being cracked open, the pipefitters heard noises indicating a problem and they quickly backed away. The sounds became worse until a blind flange located in another manhole fractured, releasing large amounts of steam. The pipefitters quickly isolated the release by shutting remote valves in other manholes. Steam plant recorders indicated that the duration of the steam release was approximately 5 minutes. The damaged blind flange and ruptured expansion joint are shown in Figures 1-1 and 1-2. Water (condensate) had accumulated in the steam piping upstream of the isolation valve; when the valve was opened, the condensate flashed, causing extremely high-pressure pulses in the steam piping.

Investigators determined that the work package preparation was inadequate. The Integrated Work Document and Work Order were valid, but the procedure used to perform the work was a general "Steam Startup" procedure, which was not specifically tailored to the job the pipefitters performed. If the pipefitters had used a specific procedure, the condensate collected upstream of the isolation valve would have been drained off, and the water hammer would have been prevented.

Figure 1-1. Failed blind flange

Figure 1-2. Ruptured expansion joint shown after removal

A contributing factor was that the 1950s-era flange that failed was made of cast iron with a maximum pressure failure rating of 125 psi. LANL engineering standards require all steam system flanges to be steel with a maximum failure pressure of 150 psi. As a corrective action, LANL Utilities personnel are conducting a system-wide survey to identify and replace all nonconforming flanges.

Water hammer, also known as steam hammer, is a pressure or momentum transient in a closed system caused by a rapid change in fluid velocity. Types of water hammer include the following:

- Flashing-induced;
- Void-induced;
- Valve-induced;
- Steam-propelled water slug; and
- Condensate-induced.

Condensate-induced water hammer is the most frequently reported type of water hammer at DOE facilities. Figure 1-3 shows the distribution of water hammer occurrences reported in ORPS from January 1990 through July 2006.

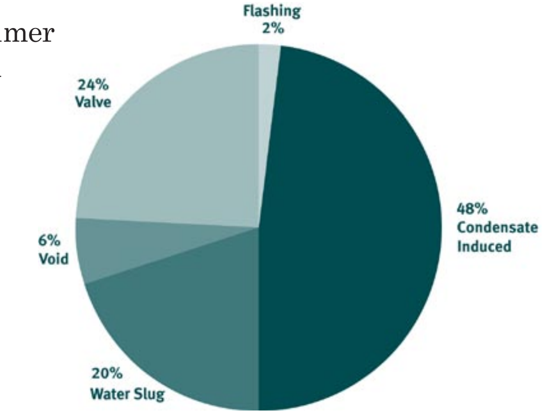

Figure 1-3. Types of water hammer events

Condensate-induced water hammer is caused by rapid condensation of steam by subcooled water. The most common type of condensate-induced water hammer is caused by steam flowing over subcooled water. The flow of steam causes ripples in the water surface. If these ripples touch the top of the pipe, a pocket of steam can momentarily be sealed off, which then condenses and collapses, causing a pressure wave (Figure 1-4).

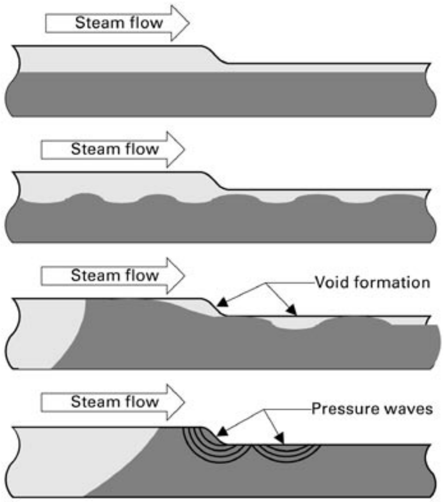

Figure 1-4. Condensate-induced water hammer in a horizontal pipe

The water hammer event at LANL was most likely caused by flashing of the condensate. Flashing-induced water hammer can occur when water moves through a pressure drop to a region where the pressure is less than the vapor pressure of the water. Some water will flash to steam and can propel slugs of water, generating a pressure wave or momentum change (Figure 1-5).

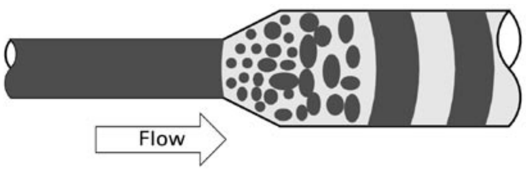

Figure 1-5. Condensate flashing in a section of piping

Although rare, water hammer events have resulted in fatalities at DOE facilities. On June 7, 1993, a water hammer caused a valve rupture and fatal injury at Hanford. (ORPS Report EM-RL--WHC-WHC300EM-1993-0022) A Type A Accident Investigation Board identified inadequacies in operating practices and procedures, lessons learned, training, safety implementation, design, and oversight.

In 1986, a condensate-induced water hammer at Brookhaven National Laboratory resulted in two fatalities and two severe injuries. A Type A Accident Investigation Board determined that steamfitters used an in-line gate valve to remove condensate rather than the drains installed for that purpose. There were no written instructions for warming and activating the steam lines, and no formal training was provided to the steamfitters involved in the accident.

Most water hammer events occur in steam systems; however, it is not uncommon to experience this phenomenon in non-steam fluid systems. For example, at Hanford, a water hammer occurred when an operator quickly closed a quarter-turn ball valve after flushing fire hydrants. The pressure wave resulted in minor equipment damage. (ORPS Report EM-RL--WHC-CENTPLAT-1994-0049)

At the Nevada Support Facility, a water hammer occurred in the cold loop side of the HVAC cooling system, rupturing a 14-inch supply pipe, a 10-inch return pipe, and several 8-inch pump lines. The initial cost estimate ranged from $60,000 to $100,000. The cause has not been determined. (DP-NVOO--GONV-GONV-2000-0007)

Preventing Water Hammer

- Do not introduce steam into piping without verifying that there is no liquid water present.
- Warm cold steam piping slowly, keeping steam trap blowdown valves open.
- Walk down steam systems and check for proper location, distribution, and sizing of steam traps and blowdown valves for startup and operation.
- Inspect steam traps frequently for proper operation.
- Be cautious when cracking open valves to avoid condensation-induced water hammer because steam-propelled water slugs can be formed at very low flow conditions.
- Verify that steam traps are operating properly before opening steam line valves. On startup, open blowdown valves fully and leave them open until liquid stops flowing.
- When feasible, operate valves remotely using mechanical extension linkages, reach rods, or power-operated valves. Ensure that reach rods and extension linkages are properly maintained.
- Inspect piping systems for sagging. If necessary, install steam traps at low points or repair the sag.
- Check and repair piping insulation to reduce condensate formation in the piping and to save energy.
- All isolation valves should have bypass systems. Remember that bypass operations do not prevent water hammer if condensate is present.

Water hammer events are commonly caused by the following failures.

- Failure to ensure that water (condensate) has been removed using steam traps and drains before admitting steam into the piping system.
- Failure to properly maintain steam traps, drain, and blowdown valves in an operable condition.
- Failure to ensure that an adequate number of steam traps and drains have been installed at locations conducive to condensate removal.
- Failure to operate system valves properly and failure to use bypass valves to safely warm system piping downstream of isolation valves.
- Failure to use procedures specifically written for the restoration and operation of the steam system.

These events underscore the importance of safely operating fluid systems in order to prevent water hammer, which can cause severe piping and equipment damage. Water hammer can also result in the uncontrolled release of hazardous energy (e.g., hot water and steam), causing serious injury or death. These types of events can be prevented with proper job planning, adequate procedures, correctly designed and maintained equipment, and sound understanding of steam and water conditions.

KEYWORDS: *Water hammer, pipe break, steam leak, rupture, procedure, work package, maintenance*

ISM CORE FUNCTIONS: *Define the Scope of Work, Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls*

Life-Threatening Illness Due to Heat Stress

2

On June 15, 2006, during the annual Security Protection Officer Training Competition at the National Training Center, three injuries occurred as the result of exertional heat illness. One person was hospitalized, and two others were examined and released. (ORPS Report SO---CTAW-CTA-2006-0001)

Two of the people who became ill requested medical assistance and were treated and released from the emergency room. The individual who was hospitalized was not released from the hospital until June 23, 2006, following a diagnosis of rhabdomyolysis and surgery to correct compartment syndrome, both of which are described below.

- **Rhabdomyolysis** is a breakdown of muscle fibers that results in the release of a protein (myoglobin) into the bloodstream. The presence of myoglobin in the bloodstream can be toxic to the kidneys and may cause kidney damage or failure. Risk factors can include severe exertion, heat intolerance, or heat stroke.
- **Compartment syndrome** involves the compression of nerves and blood vessels, leading to impaired blood flow and muscle and nerve damage. Muscle groups in the arms and legs are separated by fascia membranes. These membranes compartmentalize groups of muscles, nerves, and blood vessels. Any swelling within these fascia compartments can cause the compression that is known as compartment syndrome. The primary symptom is severe pain that does not respond to pain remedies or elevation of the affected extremity. Surgical intervention involves making long incisions in the fascia to release the pressure. Without intervention, death may result.

Due to the severity of the injury, an accident investigation was initiated on June 20, 2006. The investigation was completed on July 13, 2006. One key finding was that the conditions that can result in exertional heat illness, as opposed to the more commonly recognized classical heat illness, have not specifically been recognized by DOE, nor has information about the potential safety concerns of this illness been disseminated throughout DOE.

On the day of the June 15, 2006, injury, outside temperatures were ranging from 86°F to 90°F; relative humidity varied from 4 percent to 21 percent. The planned training exercise involved timed movement among multiple stages that incorporated a series of running, lifting, jumping, and climbing demands intended to induce stress interspersed with marksmanship activities requiring concentration and precise physical control of rifles and handguns.

In Stage 1 of the exercise, participants were required to carry a 158-pound, human-like dummy up four flights of stairs. The investigation revealed that this task had been completed by the person who later became gravely ill. After completing this task, he ran with the team 408 yards to Stage 2 of the exercise. Upon completion of Stage 2, the team ran another 337 yards to Stage 3. It was at this point that the employee began to exhibit signs of fatigue. He was permitted to continue with the exercise; however, paramedics were notified by radio to be ready in case his condition worsened. As he proceeded with Stage 3 of the exercise, he collapsed and was unresponsive. He was taken by helicopter ambulance to a local emergency room and admitted to the hospital.

Exertional heat stress is distinguished from other heat-related illnesses in that it is brought on by overexertion when temperatures are high. It normally occurs in the summer months and affects laborers and athletes. It is a medical emergency, requiring immediate intervention (see text box).

Heat-related injuries and illnesses have been reported at DOE sites in the past. However, those occurrences are markedly different from the June 15, 2006, incident. Reports of these past events describe what may be called "heat exhaustion" or "heat stroke," which may be caused by dehydration and sodium depletion, or both, with symptoms ranging from fatigue and malaise to nausea, vomiting, anxiety, and confusion. When caused by dehydration, there may be increased thirst, fatigue, dry oral mucosa, and decreased urinary output. Sodium depletion may cause symptoms such as weakness, fatigue, and headache. Fainting has also occurred.

The most recent similar event involving heat-induced illness occurred on May 2, 2005, at the Kansas City Plant, where an employee fainted while working in a paint booth. Manufacturer specifications supplied with the paint required application at temperatures above 85°F. The painter worked inside the paint booth, where the temperature was approximately 94°F, for approximately 2 hours. He was wearing the proper PPE (Tyvek® and airline respirator) to provide protection from chemical hazards; however, no consideration had been given to how the use of different types of clothing might contribute to raising his body temperature. Before he fell ill, the painter felt lightheaded and activated his emergency pager. When responders found him, they opened the doors to cool him down, and he regained consciousness. He was taken to the hospital, where he was treated and released. (ORPS Report NA--KCSO-AS-FMTNM-2005-0003)

What to Do for Heat-Related Illness

- Call 911 (or local emergency number) at once.

While Waiting for Help to Arrive:

- Move the worker to a cool, shaded area.
- Loosen or remove heavy clothing.
- Provide cool drinking water.
- Fan and mist the person with water.

It is important to recognize early symptoms of heat exhaustion. A person showing signs of it must be made to rest in a cool place and given liquids slowly. Failure to intervene can result in the onset of more severe heat-related illnesses, including exertional heat stress. It should be noted that the employee who became gravely ill during the June training exercise had been permitted to continue with the activity, despite the recognition of possible illness and preliminary notification to paramedics.

Heat-related events can occur, even when the hazard is known and identified. When warning signs are not promptly heeded, a situation can worsen very rapidly. On May 19, 1998, at Argonne National Laboratory-East, a worker became ill after performing decontamination work. Paramedics were called, and he was treated at a local hospital. Despite planning and prior knowledge of the hazard, the worker remained in the work area for 55 minutes beyond the established time limit for work. (ORPS EM-CH-AA-ANLE-ANLEPFS-1998-0014)

Subsequent evaluation of the event found that workers were aware of the potential for heat-related illnesses. Investigators also learned that temperatures were near 90°F, which was 20 degrees above normal for the time of year, and that the established work time for the area was 45 minutes, due to the potential for heat illness.

Personal ice cooling systems (PICSs) are also an option for guarding against heat-related illnesses. (DOE Lessons Learned identifier: INEEL-1999-421) A PICS consists of a suit with tubes sewn inside, a 2-liter bottle of ice, and a battery-operated pump (Figure 2-1). The ice and pump unit is in a nylon pack with a waist or shoulder strap harness. Ice-chilled tap water flows past an ice reservoir, then through the tubes, cooling the worker. Workers control the rate of cooling by controlling the flow rate of water with a two-position switch. With 2 liters of ice and water, the suit weighs only 12 pounds.

Figure 2-1. PICS with cooling tubes sewn into the fabric

Workers at the INEEL evaluated the PICS favorably. They found that they were significantly cooler, more comfortable, more productive, and able to stay in the work area longer. The systems were also evaluated by the DOE in 1998 (Innovative Technology Report, DOE/EM-0393–*Personal Ice Cooling System [PICS]*). The full report can be accessed at http://apps.em.doe.gov/ost/pubs/itsrs/itsr1898.pdf.

Another resource that can be provided to alert workers to the signs of heat stress and its treatment is available from OSHA at http://www.osha.gov/Publications/osha3154.html or http://www.osha.gov/Publications/osha3154.pdf.

An OSHA QuickCard that provides tips on identifying and treating signs of heat stress can be downloaded from the site. The QuickCard can be distributed to employees who work in environments where heat-related illness is an identified hazard and is available in both English and Spanish.

This event shows that an effective job hazard analysis should take into consideration ambient temperatures, job strenuousness, and the additional warming effects of clothing and PPE. Procedures should be in place for responding to signs of illness, and the signs of illness should be clearly communicated and reinforced when such a hazard is present. While PICS technology may not be suitable for all activities, PICSs can be worn under PPE, thereby reducing the added heat stress posed by the PPE.

KEYWORDS: *Heat stress, personal injury, exposure, ambient temperature extremes, personal ice cooling system, cool suit*

ISM CORE FUNCTIONS: *Analyze the Hazards, Develop and Implement Hazard Controls*

Explosions and Fire at UK Oil Storage Facility Caused by Overfilled Tank

3

At about 6:00 a.m. on Sunday, December 11, 2005, at the Buncefield oil storage and transfer depot in Hemel Hempstead, England, gasoline spilling from an overfilled gasoline storage tank created a vapor cloud that ignited and caused a series of massive explosions. The explosions resulted in a fire (shown in Figure 3-1) that engulfed 20 storage tanks, caused injuries to 43 people, extensively damaged nearby buildings, destroyed the onsite pumping station (thereby hindering emergency response), and caused the release of large quantities of contaminated water and black smoke to the environment.

The British Health and Safety Commission appointed an investigation board to examine the accident's causes and offer recommendations for improvement. The Board's initial report cited faulty hazard analysis and inadequacies in the containment design, high-level alarm, and interlock, as well as inadequate storage site planning.

Tank filling operations began at about 7 o'clock the previous evening. At a routine check, completed at 1:30 the next morning, nothing unusual was noted. Investigators estimate that at about 3:00 o'clock, the level indicator for the tank ceased to display the accurate volume; however, the tank continued to receive gasoline at the rate of about 550 cubic meters per hour. At that rate, the tank would have been completely full at about 5:20 a.m.

Figure 3-2 is a graphic rendering of the tank and the trajectory of the excess gasoline as it overflowed the tank. As the diagram shows, gasoline spilled out of the tank and onto a wind

Figure 3-1. Fire in progress

girder, which redirected the stream outward from the tank, fragmenting it and creating more vapor, which ignited a little over a half-hour later.

One significant finding that the investigation uncovered was that the worst credible fire scenario involved liquid fuel that could pool and catch fire — not a vapor cloud arising from spilled fuel, which is much more flammable than liquid fuel. Investigators also learned that although operators knew that the tank was being filled, no one noticed or questioned why the level indicator stopped rising. Another finding was that the storage facilities were located very close to other buildings. As a result, many of these buildings were severely damaged in the explosion (Figure 3-3).

The explosions at Buncefield bear similarity to the explosions that killed 15 workers and injured 170 at the BP America

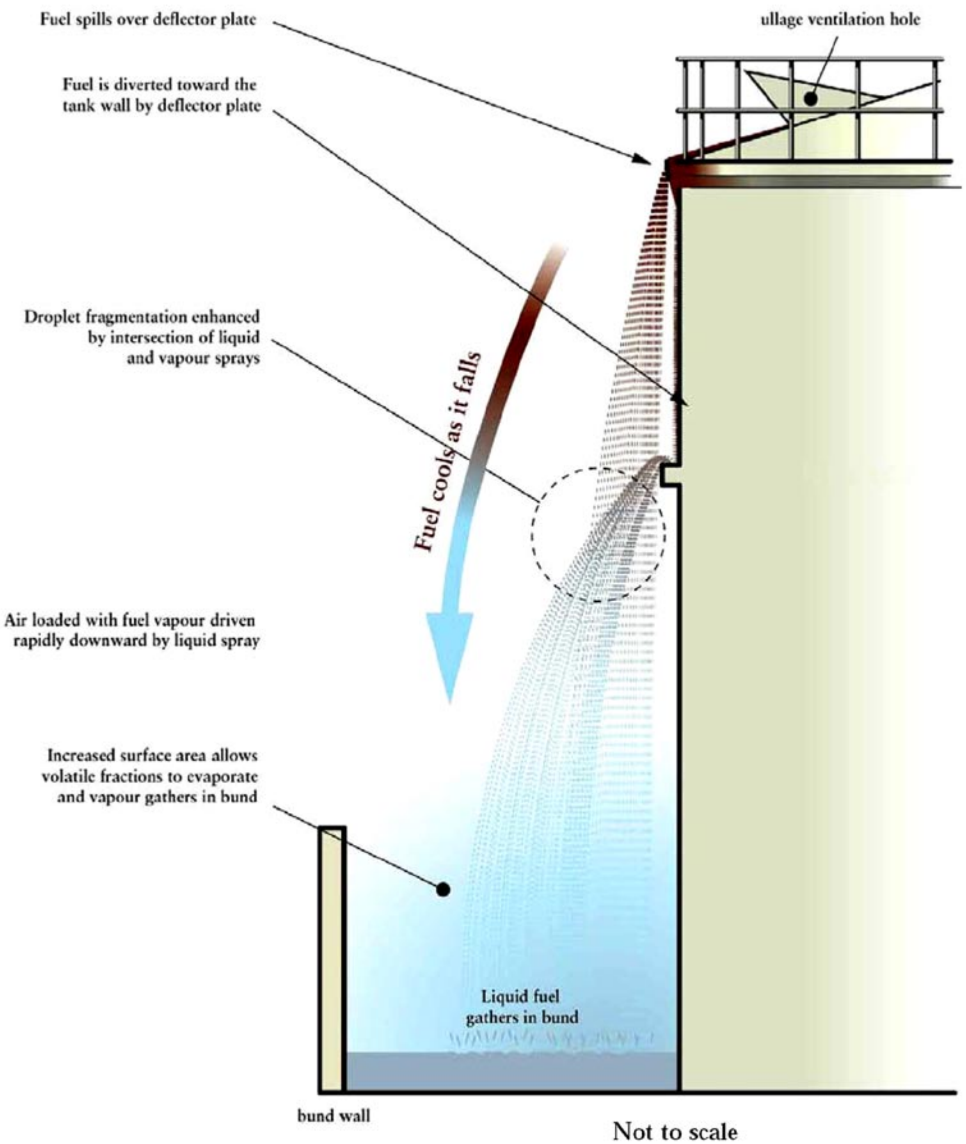

Figure 3-2. Diagram of the fuel dispersion pattern (from the investigation report)

Texas City Refinery in March, 2005. The U.S. Chemical Safety and Hazard Investigation Board is currently completing its investigation of this accident and has a web page that provides further details, including videos and a preliminary findings report. OSHA fined BP North America $21,361,500 (the largest fine it has ever levied) for 303 willful safety violations, 26 serious safety violations, and 3 other-than-serious safety violations. The DOE Office of Environment, Safety and Health published a Safety Advisory, Safety Bulletin, and an Operating Experience Summary article that discuss various safety aspects of the accident.

Fortunately, an explosion and fire of this magnitude has not occurred at a DOE site. However, the ORPS database contains numerous descriptions of tank transfer errors and inattention to level indicators. Reports on a handful of fires resulting from fuel filling operations can also be found in ORPS. The event described on the following page is a fairly recent example.

Figure 3-3. Damage to an adjacent building

Near midnight on April 2, 2005, at the Fernald Closure Project, gasoline vapors ignited as a laborer refilled a gasoline-powered water pump while the engine was still hot. The laborer threw the gasoline can, which resulted in a second water pump catching fire. Laborers used a fire extinguisher and water from a mud puddle to put the fire out instead of contacting the site fire department. (ORPS Report EM-OH-FN-FFI-FEMP-2005-0009)

Investigators determined that the laborer failed to comply with the construction traveler requiring that all gasoline-powered equipment be allowed to cool down before refueling. A contributing cause was that the laborers and their supervisor, aware that a major fire had not occurred at Fernald in over 10 years, had underestimated the potential for fire. When the fire occurred, they improperly tried to extinguish it themselves. The investigation also revealed misunderstandings about how and when to contact site emergency response personnel.

The accident at Buncefield illustrates the extreme fire hazard posed by gasoline vapors. It is important that those who store and use gasoline do not overlook any potential ignition sources and that they fully analyze all potential hazards associated with fuel storage and handling.

DOE fire safety criteria, including those specified in DOE O 420.1B, Facility Safety, *require that a Fire Hazards Analysis (FHA) be performed for facilities (including yard areas and tank farms) that pose a significant risk. An FHA must be updated when conditions change. Additional guidelines on the development of an FHA, including model FHAs, can be found on the DOE fire protection website at: http://www.eh.doe.gov/fire.*

Preventing Tank Overflows

- When manipulating valves, double-check to be sure you are sending the right material to the right place.
- Periodically check level indicators during tank transfers to see that levels are increasing or decreasing as expected.
- Make sure interlocks and safety alarms are kept in good working order.

KEYWORDS: *Gasoline, vapor, fire, explosion, emergency response*

ISM CORE FUNCTIONS: *Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls*

The Office of Health, Safety and Security (HSS), Office of Analysis publishes the Operating Experience Summary to promote safety throughout the Department of Energy complex by encouraging the exchange of lessons-learned information among DOE facilities.

To issue the Summary in a timely manner, HSS relies on preliminary information such as daily operations reports, notification reports, and conversations with cognizant facility or DOE field office staff. If you have additional pertinent information or identify inaccurate statements in the Summary, please bring this to the attention of Ray Blowitski, (301) 903-9878, or e-mail address Ray.Blowitski@eh.doe.gov, so we may issue a correction. If you have difficulty accessing the Summary on the Web (URL http://www.eh.doe.gov/paa), please contact the Information Center, (800) 473-4375, for assistance. We would like to hear from you regarding how we can make our products better and more useful. Please forward any comments to Ray.Blowitski@eh.doe.gov.

The process for receiving e-mail notification when a new edition of the OE Summary is published is simple and fast. New subscribers can sign up at the Document Notification Service web page: http://www.eh.doe.gov/dns/ehdns.html. If you have any questions or problems signing up for the e-mail notification, please contact Ray Blowitski by telephone at (301) 903-9878 or by e-mail at Ray.Blowitski@eh.doe.gov.

Commonly Used Acronyms and Initialisms

Agencies/Organizations	
ACGIH	American Conference of Governmental Industrial Hygienists
ANSI	American National Standards Institute
CPSC	Consumer Product Safety Commission
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
INPO	Institute for Nuclear Power Operations
NIOSH	National Institute for Occupational Safety and Health
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
SELLS	Society for Effective Lessons Learned

Units of Measure	
AC	alternating current
DC	direct current
mg	milligram (1/1000th of a gram)
kg	kilogram (1000 grams)
psi (a)(d)(g)	pounds per square inch (absolute) (differential) (gauge)
RAD	Radiation Absorbed Dose
REM	Roentgen Equivalent Man
TWA	Time Weighted Average
v/kv	volt/kilovolt

Job Titles/Positions	
RCT	Radiological Control Technician

Authorization Basis/Documents	
JHA	Job Hazards Analysis
JSA	Job Safety Analysis
NOV	Notice of Violation
SAR	Safety Analysis Report
TSR	Technical Safety Requirement
USQ	Unreviewed Safety Question

Regulations/Acts	
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
D&D	Decontamination and Decommissioning
DD&D	Decontamination, Decommissioning, and Dismantlement
RCRA	Resource Conservation and Recovery Act
TSCA	Toxic Substances Control Act

Miscellaneous	
ALARA	As low as reasonably achievable
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilation, and Air Conditioning
ISM	Integrated Safety Management
MSDS	Material Safety Data Sheet
ORPS	Occurrence Reporting and Processing System
PPE	Personal Protective Equipment
QA/QC	Quality Assurance/Quality Control
SME	Subject Matter Expert