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Type B Accident Investigation: Technician Punctures Hand During TRU Waste Remediation Activities

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On June 14, 2010, at the Savannah River Site (SRS), F-TRU Waste Remediation Facility, a Waste Remediation Technician placing a hole-indicating device (i.e., a wire survey flag) into a 1-quart can during transuranic (TRU) waste remediation activities received a puncture wound near the base of his right index finger. Radiation Protection Department personnel surveyed the puncture and detected 300 disintegrations per minute (dpm)/100 cm^2 alpha. The technician was transported to the site medical facility so the wound area could be decontaminated and washed. After multiple decontamination efforts, contamination levels of 200 dpm/100 cm^2 remained, so he was taken to the whole body count facility, where a wound count indicated plutonium (Pu)-238 and americium-241. SRS management appointed a Type B Accident Investigation Board to investigate this event. The Type B Accident Investigation Board report can be accessed at http://www.hss.doe.gov/csa/csp/aip/accidents/typeb/FINAL_Type_B_Report_F-TRU_Puncture_Wound_2010.pdf. (ORPS Report EM-SR--SRNS-CPWM-2010-0008)

Accident Investigation Board Investigation Results

A 55-gallon drum being remediated contained five, 1-gallon waste cans, each of which had a 1-quart waste can in its interior (Figure 1-1). To segregate prohibited items and liquids from transuranic waste items, technicians first punctured the cans and then placed a wire survey flag into the can so that subsequent radiography could verify that it was punctured and not pressurized. The technician had bent the wire survey flag into a "U" shape, with the unprotected end of the flag pointing upward. When he attempted to insert the flag into the can, the wire tip penetrated his personal protective equipment (PPE),

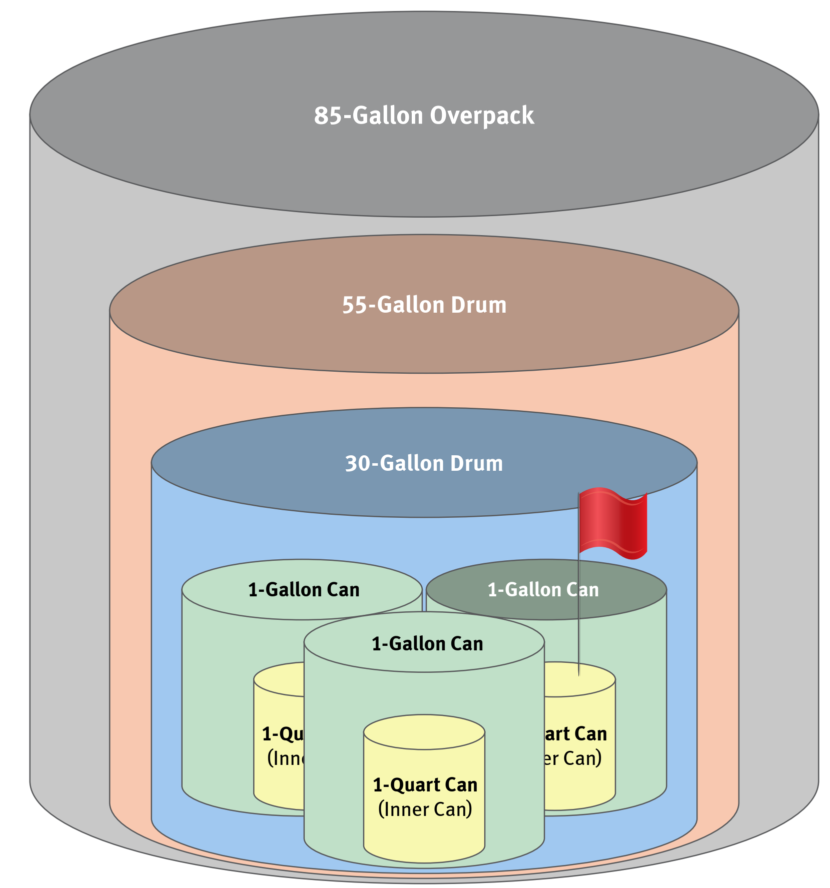

Figure 1-1. Typical container configuration showing wire flag inserted to indicate that the can has been vented (not drawn to scale)

including a leather lineman's glove and surgical gloves, and punctured his right index finger.

The Board determined that the puncture wound injected approximately 40 nanocuries of transuranics (i.e., Pu-238 and americium-241) into the technician's hand and that Pu-238 was the main radionuclide of concern. The technician began receiving chelation therapy (see textbox) and tissue excisions shortly after the injury to try to remove the transuranics from his body. Figure 1-2 shows the technician's hand following three excisions. The estimated dose range the technician received from the intake was between 5 rem and 50 rem committed effective dose (CED) to the whole body and between 166 and 1,657 rem committed equivalent dose to the bone surface.

The technicians were informally trained (via demonstration) to hold the survey flag at the midpoint with their hands, insert the flag downward into the can, and bend it over at the top of the can. However, in practice, the technicians used at least five alternative methods to install the flags, modifying them with no understanding of the potential hazards they were creating. The Board determined that the alternate technique developed by the technician involved in the accident resulted in the sharp, cut end pointing upwards so that it was pointing towards his fingers. When he applied force to insert the flag into the can, the sharp end punctured his finger.

Chelation Therapy

Chelate means to "bind" or "grab." In chelation therapy, chelating agents/drugs, such as diethylenetriamine-pentaacetate (DTPA), are administered by medical professionals to "exchange" the associated calcium or zinc salt with an element of higher binding power, such as plutonium or americium, and form a stable "chelate" complex. Once this chelate is formed, it is quickly transported to the renal system, where it is promptly cleared via urinary excretion. The efficiency of the chelation process is dependent on the solubility and retention properties of the transuranic material.

The root cause of this accident was a less than adequate graded approach used for the high-hazard transuranic waste remediation work. The approach did not coincide with the discipline warranted for high-hazard work. The Board found, for example, that installing survey flags was not considered to be a critical step or a hazardous activity by management and that no risk analysis was performed for conducting the remediation work in an enclosure versus other alternatives.

Figure 1-2. Technician's hand after excisions

Contributing factors included the following: a formal hazard analysis for use of the hole-indicating devices was not conducted; the overall procedure did not identify a method for installing hole-indicating devices; and training was not provided on installing survey flags in 1-quart cans. Technicians did not follow the demonstrated method because they were concerned the flags would fall out of the 1-quart cans, but they did not notify management. Therefore, management was unaware that unapproved flag installation methods were being used. In addition, management did not reinforce the importance of using timeouts and discussing issues during pre- and post-job briefings with the technicians.

The Board also had concerns about several post-event issues, including the need to ensure that contractors provide initial dose estimates as soon as possible after notification of an intake and the need to preserve accident scenes in accordance with procedures. In particular, the Board had concerns about protocols for patient instructions associated with chelation therapy. Because the technician did not make himself available for therapy on the second day post-accident, an opportunity to remove additional contamination was missed.

The Board concluded that the scope of work for the remediation and repackaging task was not fully defined and that management did not develop and implement adequate controls to protect the technicians during TRU waste remediation. The report contains 10 Judgments of Need (JONs), including the need to ensure that hazards are adequately identified, properly analyzed, and incorporated into technical work and the need to enforce the expectation that work is conducted in accordance with procedures. Examples of specific JONs include providing more effective pre- and post-job reviews and ensuring that critical (irreversible) steps in procedures are identified so that precautions can be taken. The JONs also address the need to perform more in-depth reviews of corrective actions to ensure that they are adequate to prevent the recurrence of previously identified deficiencies. For specific results and the associated actions to be taken, please go to the Type B Accident Investigation Report at http://www.hss.doe.gov/csa/csp/aip/accidents/typeb/FINAL_Type_B_Report_F-TRU_Puncture_Wound_2010.pdf.

KEYWORDS: Type B Accident Investigation, puncture wound, survey flag, transuranics, decontamination, excision, chelation, work planning

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

No Way Out—Five Workers Die in Confined-Space Tunnel Fire

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On October 2, 2007, at Xcel Energy's Cabin Creek 324-megawatt (MW) hydroelectric plant in Georgetown, Colorado, a remote mountain location 45 miles west of Denver, contractors from RPI Coating, Inc., were painting a 1,530-foot steel portion of a 4,300-foot enclosed penstock (tunnel) when a chemical fire broke out. Five of the contractors died in the fire, and three others were injured. The contractors were using waterproof epoxy to resurface the tunnel walls and floor when the fire erupted. The cause of the fire is believed to be a static spark that ignited flammable solvent used to clean the epoxy application equipment in the open penstock atmosphere. Figure 2-1 shows the overall layout of the Xcel plant, and Figure 2-2 shows the configuration of the penstock, which directs water from an elevated reservoir to the turbines in the powerhouse.

The fire quickly grew as it ignited the buckets of solvent and substantial amounts of combustible epoxy material used in the project. Five of the 11 workers were blocked from accessing the single point of escape within the penstock, a flame-cut access door made by the contractors for moving supplies and equipment into the tunnel. See Figure 2-2 for a graphic of the door's location in relation to the plant configuration (upper right inset), and Figure 2-3 for a photograph showing the actual construction. Workers not trapped by the fire scrambled for extinguishers at the tunnel's entrance, but were unable to fight the thick smoke and intense heat. Fourteen community response teams responded to the incident. The five trapped workers used handheld radios to communicate with co-workers and emergency responders for approximately 45 minutes before they succumbed to smoke inhalation.

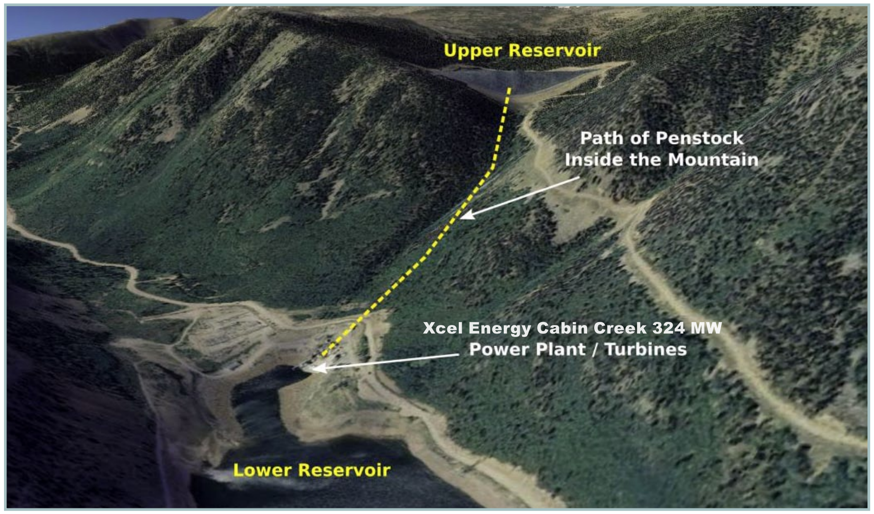

Figure 2-1. Arrangement of power plant, reservoirs, and penstock pathway

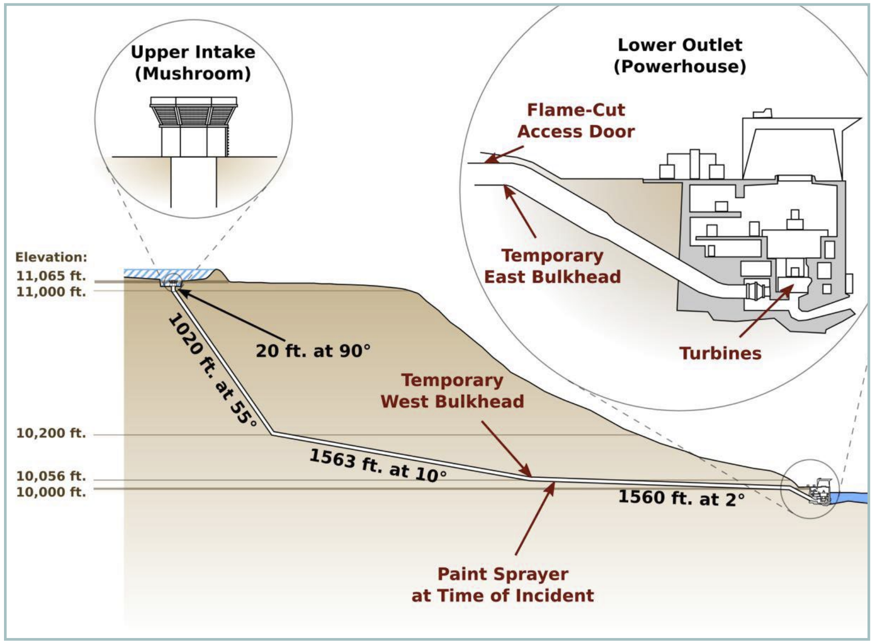

Figure 2-2. Overall penstock configuration (upper right inset shows location of flame-cut access door—the only traversable escape route in the penstock)

Figure 2-3. Access door cut into penstock for recoating work

The Chemical Safety Board (CSB) investigated this accident. The final CSB report (issued in August 2010) can be found at http://www.csb.gov/assets/document/Xcel_Energy_Report_Final.pdf. A video reenactment of the accident scene and circumstances can be found at http://www.csb.gov/videoroom/detail.aspx?VID=46.

On the day of the accident, workers had finished sand blasting the old epoxy from the tunnel walls and floor and shifted to applying new epoxy in the afternoon. After moving 95 buckets of epoxy and cleaning solvent methyl ethyl ketone (MEK, see textbox) into the confined space, the RPI painters began applying the epoxy with wands connected to the spraying equipment (Figure 2-4), but quickly found that the epoxy was not adhering evenly.

Because they believed the epoxy applicator lines were clogged, the painters repeatedly flushed the epoxy sprayer system with the MEK, as is customary in epoxy application; what is not customary is that this process took place in a confined space.

The Nature of Methyl Ethyl Ketone (MEK)

- MEK is an organic chemical compound often used as a solvent in painting activities
- The National Institute of Occupational Safety and Health (NIOSH) lists MEK as highly flammable with a flash point below 73°F (23°C) and boiling point at or above 100°F (38°C)
- A mixture of MEK and air can be ignited under almost all ambient temperature conditions (NIOSH, 1998; NFPA 2007b, Table 6.2)

Figure 2-4. Depiction of contractors working with the sprayer immediately prior to the flash fire

Though several possible ignition sources were examined, according to the CSB's final accident investigation report, it was concluded "that the fire inside the penstock was most likely ignited by a static spark that originated from the electrically isolated (ungrounded) metal swivel connector, attached to one end of the non-conductive hose hand held inside the base hopper of the sprayer as MEK was being flushed through." The CSB calculated that the MEK concentration in the vapor surrounding the connector was well within flammable limits, leading the board to finally conclude that "MEK circulation flow through the sprayer was likely capable of developing a charging current, accumulating stored energy on the electrically isolated metal swivel connector and producing incendiary sparks of sufficient magnitude to ignite the flammable MEK vapor."

"Confined Space" vs. "Permit-Required Confined Space"

CSB investigators determined that Xcel had approved RPI's plan to use flammable solvents as cleaning agents in the penstock atmosphere, but neither company had applied for "permit-required" status of the confined space, which would have required a rescue team trained in confined space rescue and flammable solvent fire treatment to be on immediate standby at the penstock entry point. The Occupational Safety and Health Administration (OSHA) defines "confined space" (see textbox) as an area that has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or a floor that slopes downward and tapers to a smaller cross-section. OSHA regulations stipulate that once a hazardous substance is brought into this defined area, the classification of a confined space must be upgraded to a "permit-required confined space."

Single Point of Escape

Weeks prior to commencing work, Xcel's consulting engineer had identified the need for a second entrance, which resulted in the 4-foot by 6-foot, flame-cut access door being built into the side of the penstock (Figure 2-3), near the base of the horizontal section, and 1,450 feet from where the work was being conducted. According to the CSB, this new entry apparently mitigated the concern raised by Xcel's consulting engineer about there being only a single point of escape for workers, since the only other possible escape route was an existing 24-inch manhole at the top of the penstock's mushroom access hatch, a 2,300-foot climb to the top at a 55-degree angle. On the day of the incident, there was no climbing equipment available to facilitate an escape through the manhole entry point, so, given the narrow configuration of the tunnel and the burn radius of the fire, the workers who were trapped from reaching the newly cut entry door had no other way out.

"Confined Space" and "Permit-Required Confined Space"

OSHA's general industry standard, 29 CFR 1910.146, defines a **confined space** as having three attributes:

1) large enough to enter and perform work;
2) limited access and egress; and
3) not designed for continuous occupancy.

A **permit-required confined space** is defined as having one or more of the following characteristics:

1) contains, or has the potential to contain, a hazardous atmosphere;
2) contains material that has the potential for engulfing an entrant; and
3) has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly converging walls or by a floor that slopes downward and tapers to a smaller cross section; or
4) contains any other recognized serious safety or health hazard.

CSB Findings

In its 15-point finding, the CSB recounted that Xcel and RPI failed to conduct adequate hazardous work planning before authorizing contractors to use a flammable solvent as a cleaning agent in a confined space without applying for permit-required confined space status of the area. The CSB also found that Xcel provided inadequate contractor selection when it chose RPI, a contractor with a zero safety performance rating by Xcel's own bid evaluation standards, to perform the work.

Other causal factors leading to the Xcel Cabin Creek 324-megawatt hydroelectric plant fatalities and injuries as identified by the CSB included the following.

- Highly flammable MEK was used in proximity to ignition sources that were not eliminated or controlled.
- Xcel and RPI managers did not perform a hazard evaluation of the full epoxy recoating work and, thus, did not evaluate or implement effective controls.
- Neither Xcel nor RPI re-evaluated work hazards in the space when activities shifted from abrasive blasting in the morning to epoxy application in the afternoon.
- Neither Xcel's nor RPI's corporate confined-space programs adequately addressed the need for a monitoring plan or the need for continuous monitoring in the work area where flammables were being used.
- The CSB also determined that none of the 14 teams responding to the Xcel accident had the appropriate training for confined space rescue and flammable solvent fire handling.

Similar Events

Events involving confined space entry have also occurred within the Department of Energy (DOE). The results of a 2000–2007 review of confined space events reported to the DOE Occurrence Reporting and Processing System (ORPS) over a 7-year period indicated that nearly 50 percent of the events were attributable to confined space entry requirements not being established or followed. The review is discussed in *Operating Experience Summary* (OES) 2008-1, "Confined Space Events Result in Industry Fatalities," found at http://www.hss.energy.gov/csa/analysis/oesummary/oesummary2008/2008-01-01.pdf.

Other OE Summaries that discuss the challenges of confined space work include OES 2004-22, "Confined Space Can Kill" (http://www.hss.doe.gov/csa/analysis/oesummary/oesummary2004/oe2004-22.pdf), and OES 2009-06, "Careful Work Planning Required for Tasks in Confined Spaces" (http://www.hss.energy.gov/csa/analysis/oesummary/oesummary2009/2009-06-02.pdf).

A 2009 review of confined space issues at DOE's Savannah River Site submitted to the DOE Lessons-Learned database (Lessons Learned ID: 2009-SR-SRNS-0007) assigned numerous causal factors for confined space accidents and injuries, including the following.

- Hazardous conditions were not recognized.
- Hazards of confined space entry were not discussed with workers.
- Attendant responsibilities were not upheld (workers assumed someone else was watching).
- Work scope changed after work planning was complete and controls were established.
- Controls were inadequate based on historical knowledge of the task or confined space conditions.
- Although "entry" means any part of the body entering the confined space, workers were likely to think that if their entire body had not entered the confined space, then they had not "entered" it.
- Air monitoring was not performed for a variety of reasons, including failure to recognize hazardous conditions and insufficient resources (equipment and trained personnel).

The very nature of confined space work requires additional planning for potential hazards per OSHA's Permit-Required Confined Space Rule. RPI workers had moved from blasting activities to recoating work in the space of 2 hours on the day of the accident, yet CSB investigators found that the pressure to continue work without re-assessing the hazards associated with the change in processes and tasks had exposed workers to a number of hazardous conditions within the penstock, including dust from abrasive blasting, flammable atmospheres from the use of solvents, welding fumes from hot work, and accumulated toxic carbon monoxide fumes from the internal combustion engine of an all-terrain vehicle used in the penstock to transport materials to the work area. Each time one of these hazards was introduced or encountered in the confined space, work permits should have been updated to reflect the hazard and the appropriate safeguards to protect entrants and ensure that proper entry conditions were maintained.

Introducing a flammable solvent into the confined space where electrical equipment is in use and oxygen is limited increases the potential for creating a hazardous environment in which workers could easily be overcome, as was the case in the Xcel incident. Although it is standard practice to use cleaning solvents to flush sprayer equipment and lines, when working in confined spaces, less hazardous cleaning agent alternatives should be considered. One such option, cited by the CSB, is citrus-based solvents, which have higher flash points than flammable solvents.

Another hazard control that should have been implemented was cleaning epoxy application equipment *outside* of the confined space. The epoxy application equipment used by contractors at the Cabin Creek site was repeatedly flushed *inside* the confined space, some 1,400 feet from the single usable point of escape.

Lessons Learned

This event reinforces the need for proper escape planning that factors in the "What if's" of confined space work before entry. Questions that managers and workers should ask include: what is the work to be done, what equipment and materials am I taking in and how do they "behave" in a closed environment, what if the work changes or is added to after entry, and what is the escape plan in case of an emergency. In addition, appropriate training of emergency management personnel for all possible emergencies related to the planned work activity should be verified prior to starting work.

KEYWORDS: Confined spaces, CSB, emergency planning, epoxy, fatality, fire, flammable solvents, methyl ethyl ketone (MEK), hazardous materials, pre-job work planning, safety planning, permit-required confined space, training

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

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