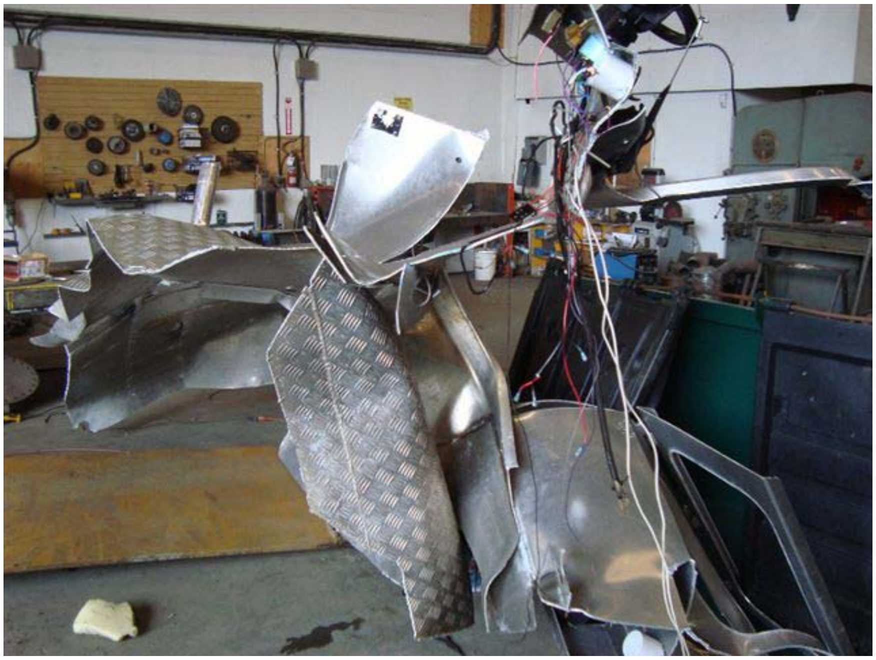
Explosion during welding operation



A young worker was welding on the transom of an aluminum boat. Flammable vapour underneath the deck was not detected and an explosion occurred. The worker was thrown back about 10 to 15 feet (3 to 4.5 metres). The deck of the boat exploded upwards and hit the ceiling. The worker sustained injuries.

Purpose of this report

The purpose of this online incident investigation report is to identify the causes and contributing factors of this incident to help prevent similar incidents and to support preventive actions by industry and WorkSafeBC. This online version is not the official WorkSafeBC report. It has been edited to remove personal identifying information and to focus on the main causes and underlying factors contributing to this incident.

Notice of Incident information

Number: 2010154850011
Outcome: Injury
Core activity: Welding
Region: Northern British Columbia
Date of incident: February 2010

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1 Factual Information

1.1 Workplace

The company involved in this incident is a small business in northern British Columbia. The company performs equipment servicing and repairs, specializing in welding and metal fabrication. There is an office, a large shop, and an outdoor compound; workers sometimes work off-site to perform repairs to marine equipment such as barges. The incident in February 2010 occurred in the shop at the employer's workplace.

In late January 2010, the company was asked to make alterations to an 18-foot (5.5-metre) aluminum boat belonging to a Vancouver-based company that had an outlet in the same northern city. The work involved welding additional aluminum onto the transom to increase the transom height and to prepare the transom to accommodate a different outboard engine.

1.2 Sequence of events

1.2.1 Delivery and storage of the boat

To facilitate the alteration of the transom, the boat-owner removed the outboard engine from the boat before sending the boat for alterations. On February 1, 2010, the boat was delivered with a single-axle boat trailer and it was parked in the outdoor storage compound. The trailer jack and small wheel at the front of the boat trailer were in damaged condition and were inoperable when the boat was delivered.

While the boat was stored in the outdoor storage compound, the temperature dropped below freezing for several nights. Weather records indicate that at 08:00 on February 3, the temperature was –2.6 degrees Celsius.

1.2.2 Employees working off-site

On February 3, some employees were working off-site inside a confined space on a barge. In order to ensure safe working conditions, they needed to initially test the atmosphere in the confined space with a multi-gas monitor, and to retest at intervals as the work progressed. To do the tests, the crew had with them at the barge the company's only multi-gas monitor. The crew included a welder, who was a young worker.

1.2.3 Start of work on the boat: February 3

On the same day at the shop, the foreman moved the boat from the outdoors into the shop at 08:30. At the time, frost coated the upper surfaces of the boat. Because the damaged trailer jack made it difficult to elevate the trailer reach, the foreman positioned the boat in the shop with the trailer reach low to the floor. The lower position of the trailer reach, which made the bow position low and the transom high, happened to position the transom at a convenient height for the work.

After the foreman and the company owner discussed the specifications for the work, the foreman worked on the boat alone. The foreman stated that before he began the work, he performed a "smell-test" around the boat and did not detect any gasoline odour. During the foreman's smell-test, he did not open the access hatches in the floor or deck of the boat.

The foreman began the work by plugging the original engine mounting holes in the transom with aluminum. After completing this, he fabricated a piece of aluminum to add to the transom to increase the transom height. He used a grinder to clean and prepare the transom surface for welding, and then he tack-welded the additional piece of aluminum to the transom (see Figure 1). As the foreman did these tasks, he worked at times from the rear of the transom and at other times from inside the engine well.

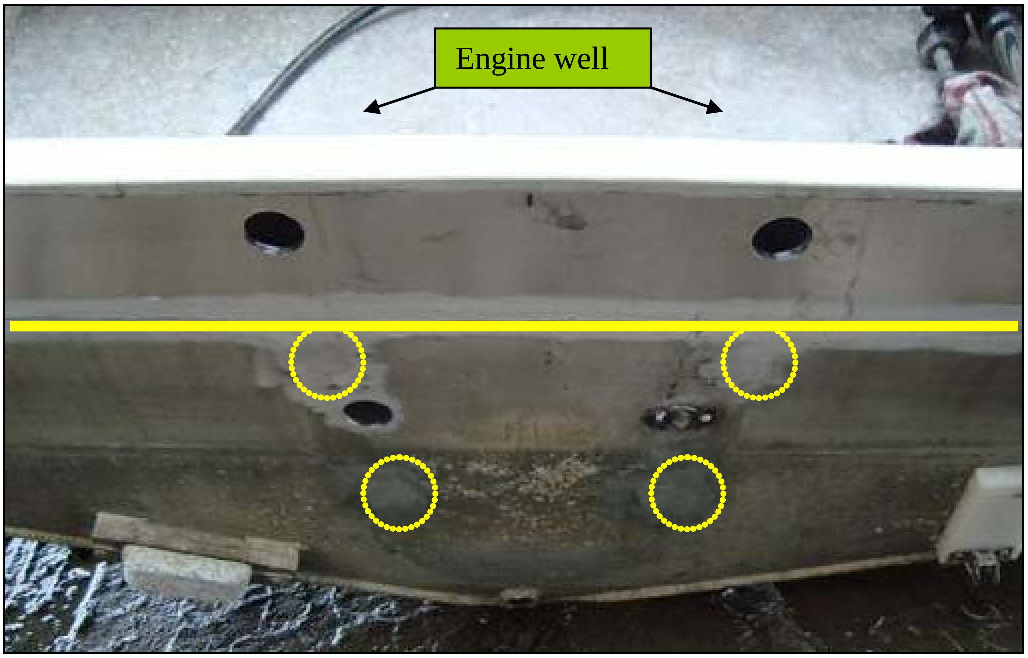

Figure 1: View of the exterior of the transom from the rear of the boat. The four circles indicate the original bolt-hole locations for engine mounting that the foreman plugged with aluminum. The horizontal line indicates the original top height of the transom. The aluminum added to the transom is above the horizontal line. Newly created bolt-holes made by the welder on the following day are visible.

In the mid-afternoon, the foreman received a call from the welder, who informed him that the crew had almost completed the work at the barge. The foreman stopped working on the boat in order to check on the barge project. The boat remained inside the shop.

While the foreman was at the barge, he determined that the multi-gas monitor had developed a low battery level and needed recalibration. A battery-charging problem resulted in less than optimal battery levels, and the device displayed a warning message instructing the user to recalibrate. After the foreman had finished checking the work at the barge, he took the multi-gas monitor back to the shop and tried to recalibrate it. The foreman stated to the investigating officer that the failure of the battery to hold sufficient charge was a recurring problem, and that the device had previously been sent back to the manufacturer for work covered under warranty.

At approximately 16:00, the welder returned to the shop from the barge. The foreman directed the welder to use the last hour of the shift to finish the final length of welding on the new part of the boat's transom. To complete this aspect of the work, the welder was at times standing outside the boat and at times sitting inside the engine well. The welder went home at 17:00. The boat was stored inside the shop overnight.

1.2.4 Explosion: February 4

The owner left the shop early the next morning, February 4, and he took along with him the battery from the multi-gas monitor as he intended to send it away for repair or replacement.

The foreman began to assign work to the crew between 08:00 and 08:30. The foreman directed the welder to carry out the final finishing work on the boat. The foreman did not do another smell-test for gasoline odour on the morning of February 4.

The remaining tasks the foreman assigned to the welder were to create new bolt-holes and insert aluminum rod material, or bungs, to create side supports (stiffeners or spacers) inside the transom at the new bolt-holes. Once the bungs were welded into place, the final bolt-holes would then be drilled through the bungs. The machinist made the bungs on the lathe. The welder stood outside the transom at the rear of the boat and inserted the first bung into one of the new bolt-holes. He tack-welded the first bung into position (see Figure 2.)

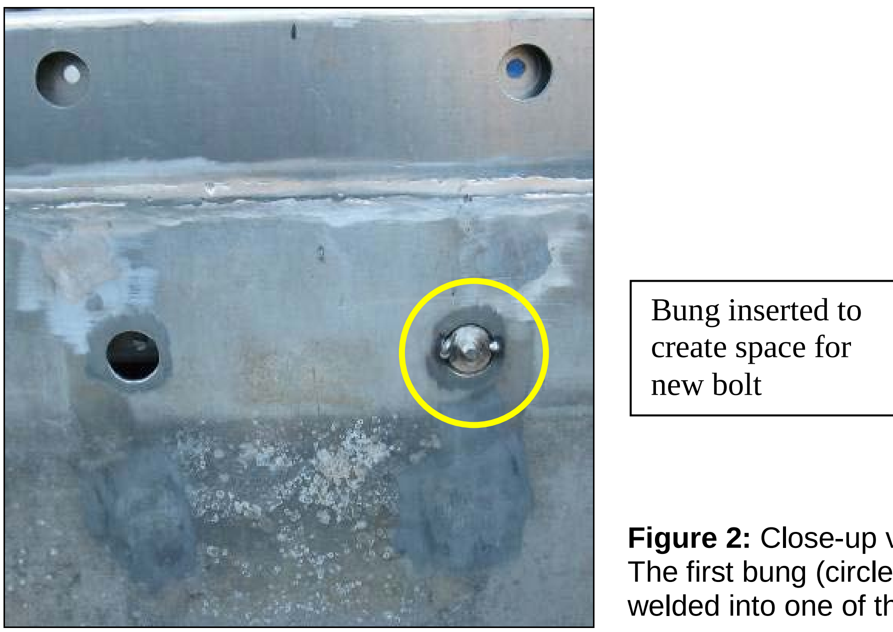

Figure 2: Close-up view of the exterior of the transom. The first bung (circled) has been inserted and tack-welded into one of the four new bolt-holes.

As the welder was performing this work, the foreman and another worker were standing next to a workbench about 10 feet (3 metres) away, with their backs turned to the side of the boat.

The welder had just started to weld the bung fully when an explosion occurred. The boat trailer and boat suddenly rose some distance above the floor, and then landed near where they had originally been. The welded-in deck, dashboard, and windshield detached from the interior of the boat. The detached components flew upward and struck the ceiling of the shop, near the light fixtures and an overhead natural gas heating appliance, before falling to the floor. (See Figure 3.) The ceiling was 25 feet (7.6 metres) high.

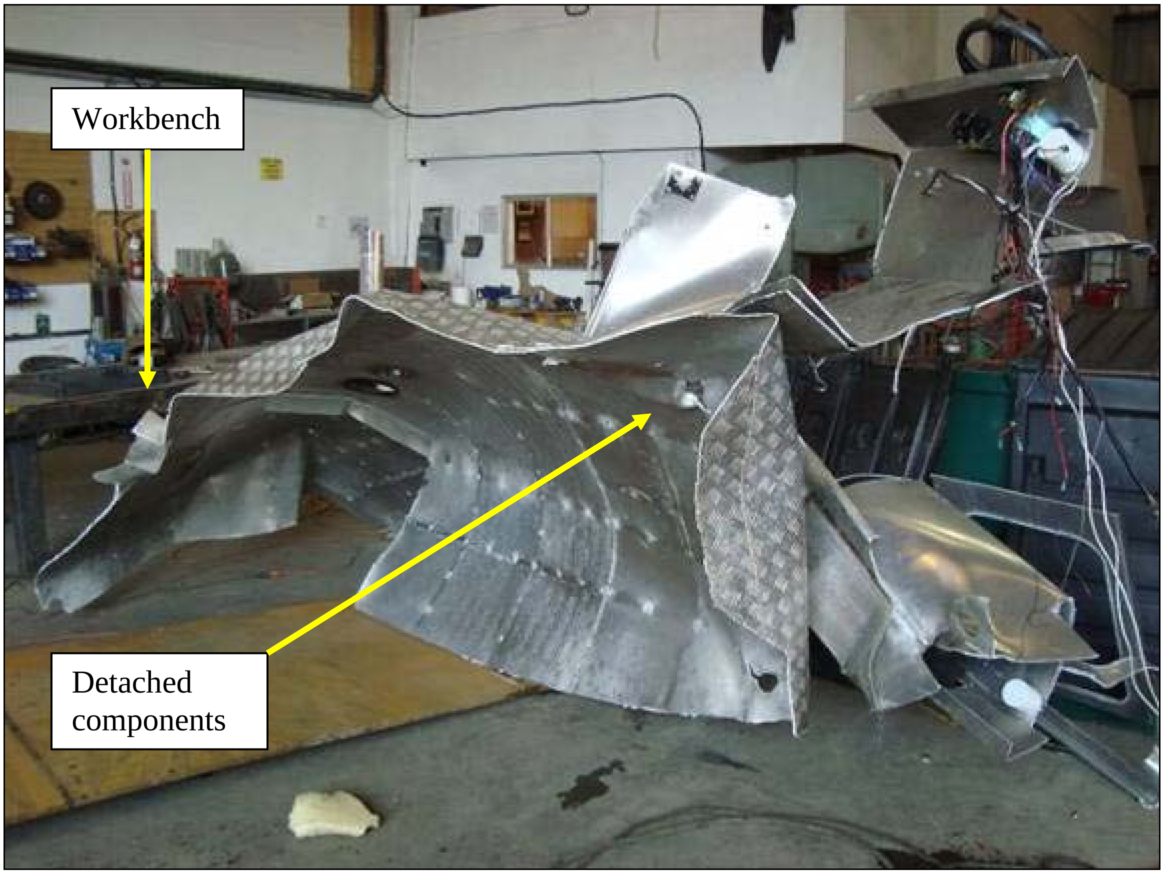

Figure 3: Photograph showing where the detached boat components fell after the explosion.

The force of the explosion threw the welder backward approximately 10–15 feet (3– 4.5 metres) from where he had been standing. His welding helmet came off his head. Although the force of the explosion startled him and affected him physically, the welder had a direct view of what occurred, and he observed the detached boat components falling to the shop floor. As the components fell, they struck the two welding cylinders that the welder had been using, damaging the cylinders' valves and valve handles.

Flotation foam that lined the inside of the boat hull was burning and the shop was filling with smoke. The foreman, the welder, the machinist, and the other worker ran to get fire extinguishers to put out the fire, but the four that they tried were empty. At this point, the foreman ordered everyone to evacuate the shop. The welder opened the overhead bay door, went outside with the others, and sat down on a pallet.

The workers were very apprehensive about the fire in the boat and feared that the leaking gas cylinders still inside the shop could make the fire bigger or cause another explosion. They used an outdoor water hose to try to douse the flames, but the fire did not go out completely. Three workers went back into the shop and wheeled the boat trailer and boat outside the building, where they extinguished the fire with the water hose. They also dragged the leaking gas cylinders outside. (See Figure 4.)

Figure 4: The boat and trailer parked outside the shop after workers wheeled the trailer through the overhead bay door. The damaged trailer jack and the bent small wheel components on the reach of the trailer are seen within the dashed rectangle.

1.2.5 Post-incident events

Shortly after the boat was parked outside the building, the company owner returned. Once the owner learned what had occurred, he shut off the valve supplying natural gas to the building. The owner took the welder to hospital.

A heating contractor came to the shop and examined the natural gas line and overhead heating appliance for leaks or damage. Although the boat components had struck and damaged one light fixture adjacent to the heating appliance, and pierced through the shop's steel roof cladding in one area, there was no damage to the natural gas line or the heating appliance.

After the incident, the boat and trailer were moved farther from the shop and parked in the outdoor compound. Because of the damaged trailer jack, the position of the bow was low once again. A few days later, the company owner went near the boat and smelled a strong gasoline odour. He observed that gasoline had backed up into the filler line and was spilling out from the fuel cap over the side of the boat (the fuel cap had partially melted from the effects of the fire). The owner had the gasoline tank siphoned as a precautionary measure.

1.3 Fuel conveyance system

To fill the gasoline tank, a user would remove the fuel cap and insert a fuel hose into the large-diameter filler line located at the starboard gunwale of the boat. From the fuel tank, there are two other connecting hoses: a small-diameter ventilation hose that vents gasoline vapour to an outlet near the filler line cap, and a sending hose that delivers gasoline to the motor. The ventilation hose runs alongside the filler line (see Boxes 3 and 4 in Figure 5).

Nearly the entire length of the sending hose is inside a white polyvinyl chloride (PVC) pipe that runs from the fuel tank to the battery compartment on the starboard side of the engine well, and from there to the engine through a hole in the sidewall of the engine well (see also Figures 6 and 7).

The sending hose has a one-way valve that prevents fuel siphoning from the tank when a user disconnects the sending hose from the motor. When a user disconnects the sending hose from the motor, only a very small amount of fuel is released from the end of the sending hose.

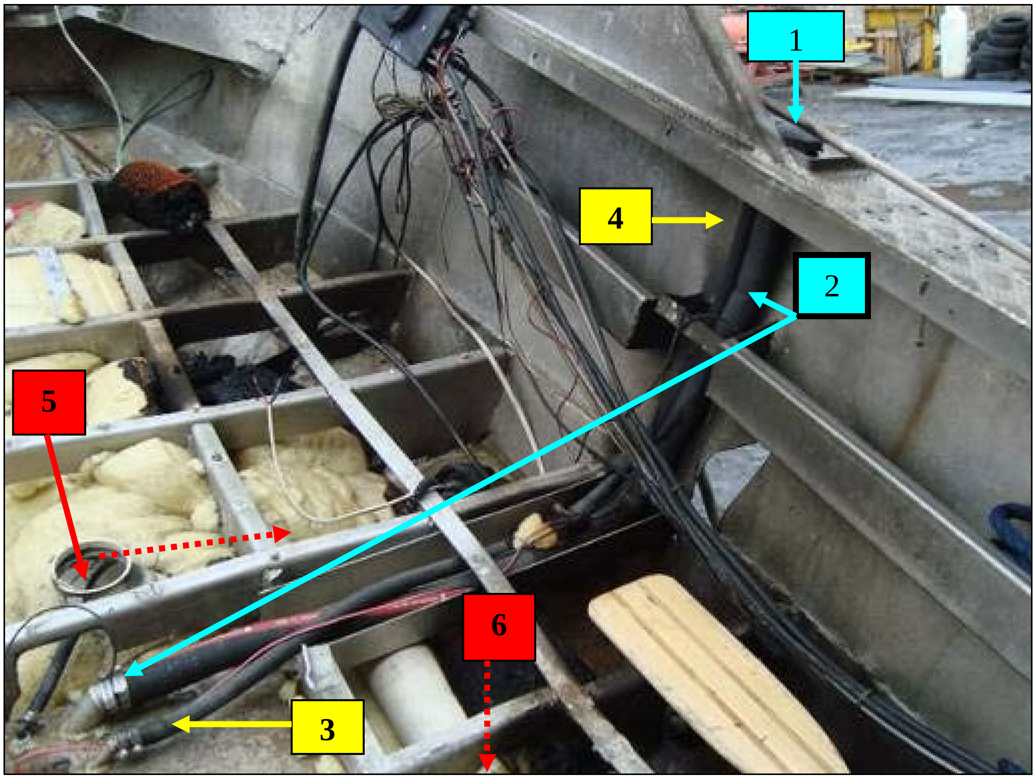

Figure 5: Box 1 indicates the fuel cap on the starboard gunwale of the boat. The vapour ventilation outlet is adjacent to the fuel cap. Box 2 and its arrows indicate the intake portion of the filler line and the filler line connection to the fuel tank. Box 3 indicates the ventilation hose connection to the fuel tank. Box 4 indicates the ventilation hose near the vapour exhaust outlet. Boxes 5 and 6 indicate the sending hose. The sending hose connects to the fuel tank near Box 5 and runs into PVC pipe covered by foam (underneath the dotted line) and then inside the white PVC pipe (indicated by Box 6) to the stern.

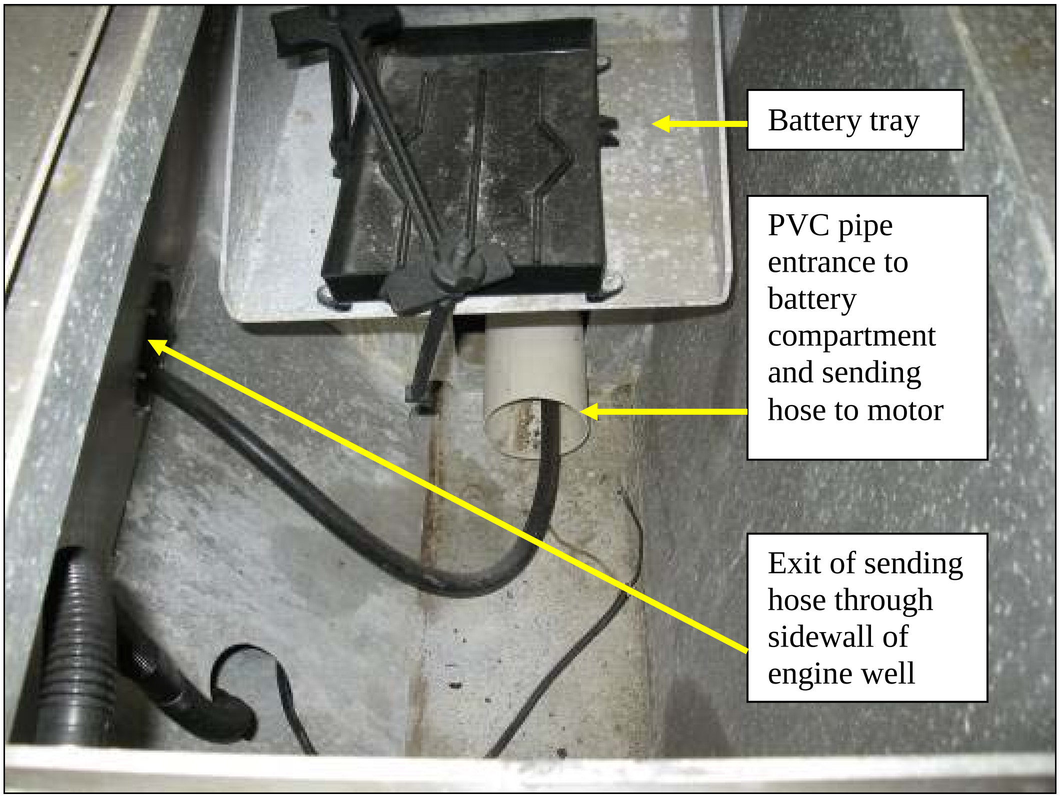

Figure 6: Photograph of an identical but undamaged vessel, showing the entrance of the PVC pipe (which contains the sending hose) to the battery compartment at the stern.

Figure 7: This photograph of an identical but undamaged vessel shows the sending line (black hose with a fuel priming bulb) entering the engine well through the hole from the battery compartment.

2 Analysis

An explosion will occur if all of the following conditions exist concurrently:

- There is an explosive concentration of flammable gases (fuel).
- There is an adequate concentration of oxygen to support combustion of the flammable gases.
- There is an ignition source.
- There is sufficient molecular energy to sustain the explosive reaction.

This analysis examines the following:

- Why did no one detect the presence of gasoline vapour?
- What contributed to the presence of gasoline vapour in the hull of the boat?
- What was the likely source of ignition?
- Why did the explosion occur so far from the welding arc?
- Why did the explosion occur only on the second day of welding?
- What contributed to the great degree of force in this explosion?
- What contributed to deficient information, instruction, training and supervision?

2.1 Presence of gasoline vapour was undetected

2.1.1 Use of sense of smell to detect gasoline vapour

The presence of gasoline vapour underneath the deck was not detected prior to the explosion. The covers to the access hatches in the deck were not removed on either February 3 or 4, and no effort to ventilate the area below the deck was made. Humans can smell gasoline when it is present at very low levels (0.12– 0.15 parts per million).[1] This level is far below the level of gasoline vapour concentration that results in flammability risks. Had anyone removed the hatch covers to check for fuel leaks or vapour, it might have been possible to smell gasoline immediately or as the work progressed. However, the sense of smell does not indicate when flammable vapour is present in concentrations that pose risk of fire and explosion. To reliably determine the presence and concentration of a flammable vapour, use of a testing instrument is essential.

When the boat was outdoors from February 1 up to the morning of February 3, the cold temperatures would have reduced the amount of gasoline expansion in the fuel tank and the amount of vapour emitted from leaked gasoline. The flotation foam may have acted in a manner similar to that of a frozen sponge, absorbing the gasoline and containing the vapour. As the boat warmed up after it was moved into the shop, the foam would have been slower to thaw due to its location between the aluminum deck and bottom of the hull. These possibilities, along with the fact that the access hatches were not opened, may have reduced the ability of workers to smell gasoline.

[1] From OSH Answers, 4–"Working Safely with Gasoline," Canadian Centre for Occupational Health and Safety, http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/gasoline/working_gas.html#_1_5

2.1.2 Requirements to test for flammable substances

The Occupational Health and Safety Regulation contains specific requirements that apply to doing "hot work" such as welding, cutting, and grinding near flammable or explosive substances. Part 12 of the Regulation, "Tools, Machinery and Equipment," contains the following prescriptive requirements under the portion titled "Welding, Cutting and Allied Processes":

> Section 12.116: Flammable and explosive substances
> (2) Burning, welding or other hot work must not be done on any vessel, tank, pipe or structure, or in any place where the presence of flammable or explosive substance is likely until
> (a) tests have been made by a qualified person to ensure the work may be safely performed, and
> (b) suitable safe work procedures have been adopted, including additional tests made at intervals that will ensure the continuing safety of workers.

The company owned a multi-gas monitor that is capable of detecting combustible gases and of ongoing monitoring and identification of the levels of combustible gases, oxygen, hydrogen sulphide, and carbon monoxide. The device can be set to alarm the user if a gas is present at a certain percentage in the air tested. The monitor was not used on either February 3 or 4, however, and the presence of flammable vapour was not detected before or during the work on the boat. On February 3, the monitor was off-site and was being used at the barge project. On February 4, the monitor was initially available at the shop in the morning; according to the foreman, it was operable despite the recurrent battery charging issue. When the explosion occurred, the company owner had the battery for the monitor with him in order to send it out for examination by the manufacturer.

2.2 Presence of gasoline vapour under the deck

The following factors may have contributed to the presence of gasoline vapour in the hull of the boat, under the deck:

- The position of the boat when it was moved into the shop the day before the incident
- Expansion of gasoline in the full tank
- Possible leakage of gasoline due to a loose hose clamp at the filler line fuel intake area
- Accumulation of gasoline in flotation foam underneath the deck
- Limited ventilation under the deck

2.2.1 Bow-down position of boat

The foreman moved the boat into the shop on the morning of February 3. Because the damaged trailer jack made it difficult to elevate the trailer reach, he positioned the boat with the trailer reach low to the floor. With the bow of the boat facing downward, gravity would have caused the gasoline to move forward within the fuel tank. As the tank was full, and the front of the tank and the tank attachment point of the filler line were in a downward position, gravity would have caused the fuel to enter the filler line and back upward into the filler line toward the intake.

2.2.2 Expansion of gasoline in the full fuel tank

Since the fuel tank was full of gasoline at the time of the incident, there was no room for oxygen or flammable vapour inside the tank. This precluded the conditions required to support combustion and was why the tank did not explode. As the boat warmed up inside the shop, the volume of gasoline in the full tank did expand. These factors, along with the bow-down position of the boat, increased the likelihood that gasoline flowed upward into the filler line. When the boat was outside the shop in the days after the explosion, gasoline expanded in volume sufficiently to spill out of the fuel intake as the sun warmed the fuel tank, hoses, and fuel.

2.2.3 Loose clamp at filler line intake area

If hose clamps do not secure a fuel hose tightly enough, a fuel leak may occur quite readily. A small amount of fuel may dribble down a loosely secured hose and collect in a low point. Over time, even a small fuel leak of this nature can create a significant fire risk.

After the incident, the hose clamp that attached the filler line to the fuel intake below the starboard gunwale was loose enough to be easily hand-turned (see Figure 8). It is impossible to determine whether the clamp was already loose before the explosion or whether the force of the explosion loosened it. The fact that all the other fuel hose connections at the tank remained tightly secured after the explosion suggests that this particular clamp may already have been loose before the explosion, allowing gasoline to leak out of the filler line.

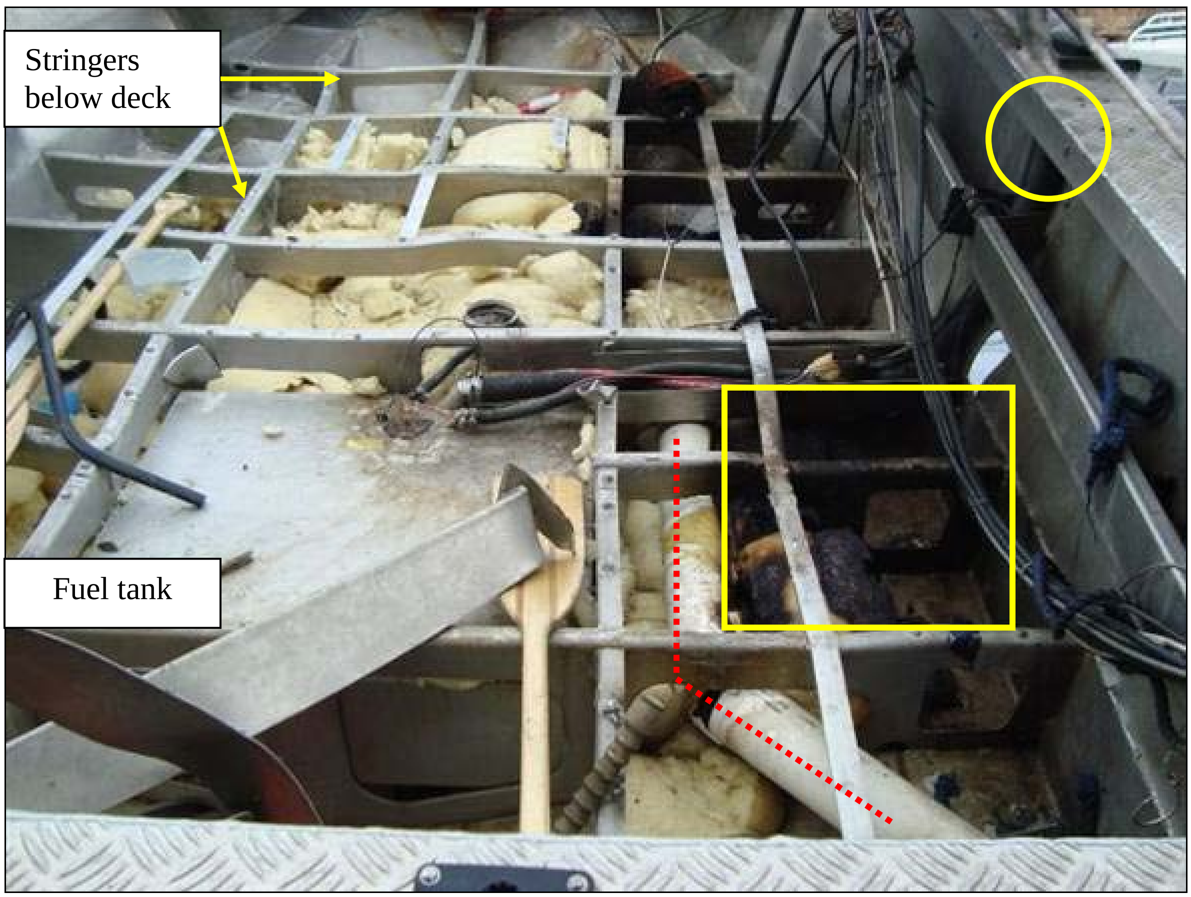

Figure 8: Interior of the damaged boat. The circle indicates the location under the starboard gunwale where a hose clamp on the filler line was loose. The area that was most burned was to the right of the fuel tank (enclosed by the square). The dotted line indicates portions of the white PCV pipe that contain the sending hose.

2.2.4 Suspected spill of gasoline into foam

If gasoline leaked because of a loose filler line hose clamp connection, it is very likely that it would have soaked into a piece of flotation foam underneath the deck.

It is notable that the most charred portion of flotation foam was immediately adjacent to the area below the filler line (shown in Figure 8). It is very likely that gasoline leaking from the loose filler line dripped into this section of flotation foam. The foam burned more on the bottom surface than on the top surface, suggesting that gasoline pooled in the hull and saturated the bottom portion of the foam (see Figure 9). This may have been partly why it proved difficult to put out the fire by spraying water onto the top of the foam: most of the fuel was underneath the foam and absorbed by the foam.

Figure 9: Flotation foam removed from the hull of the boat. The arrows point to where the investigator removed the pieces of foam. The bottom surface of the charred foam was more burned where it had contacted the surface of the hull.

2.2.5 Limited ventilation under deck

With the access hatch covers closed, there was no ventilation of the space below the deck. This allowed vapours to accumulate in the air space. If all the access hatches had been open, some passive ventilation would have occurred, but passive ventilation alone might not have been enough to reduce the risk by removing enough of the vapour. It would have been possible to vent the vapour from the space through mechanical ventilation, however. This would have enhanced safety significantly.

2.3 Ignition source

The evidence indicates that welding was the likely ignition source that ignited flammable gasoline vapour.

The investigating officer determined there were no other sources of ignition (such as open flame or other welding activities) that were factors in the explosion. Although the battery and the boat's electrical system could have provided an ignition source from sparking, shorting, or discharge of static electricity, there was no evidence that any of these had occurred during the work. The boat's ignition key was not energizing the electrical system. No one had touched the battery or electrical system during the work. While the boat was in the shop, the battery compartment lid covered the battery. Nevertheless, as the battery was a potential ignition source and was very close to the areas where hot work was being done, the battery should have been removed as a precautionary measure prior to starting the job.

2.3.1 Location of explosion far from the ignition source

The focal point of the explosion was a section of the boat's hull adjacent to the area below the filler line. The welder was standing outside the rear of the boat's transom and had just started to weld the first bung fully when the explosion occurred. Figure 10 shows the entire boat and gives an indication of the distance between the transom where the welder was using the welding arc (the ignition source) and the focal point of the explosion.

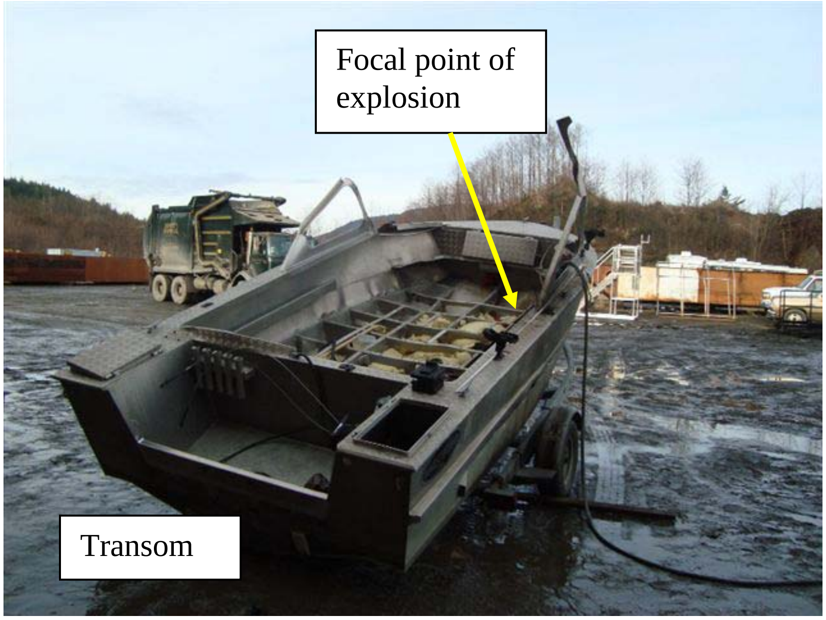

Figure 10: The damaged boat was moved outside after the incident. The explosion occurred while the boat was inside the shop.

Why did the explosion occur so far from the welding arc?

The PVC pipe, the opening for the PVC pipe into the battery compartment, and the openings from the battery compartment to the engine well (see Figures 5 and 6 on pages 8 and 9) created a conduit for vapour. The newly cut bolt-holes, along with the boat's drain hole at the very bottom of the hull on the transom, also created conduits for vapour to the outside of the transom. When this "vapour trail" contacted the ignition source (the welding arc), the resulting fire "flashed back" some distance along the vapour trail to the fuel source, causing the explosion to occur there rather than at the ignition source.[2] The fact that the engine well and the battery compartment were not damaged in the incident indicates that ignited vapour travelled rapidly through these compartments to the area below the deck where the fuel source was located.

2.4 Factors affecting the explosion

Numerous safety information sources explain the factors that influence the occurrence of fire and explosion. The Canadian Centre for Occupational Health and Safety provides such information on its website.[3]

The amount of flammable vapours given off from a liquid, and therefore the extent of the fire or explosion hazard, will depend largely on the temperature of the liquid, its volatility, how much of the surface area is exposed, how long it is exposed for, and air movement over the surface. Other physical properties of the liquid, such as the flashpoint, auto-ignition temperature, viscosity, lower explosion limit, and upper explosion limit, give further variables and reactions.

2.4.1 Why the explosion occurred on the second day of welding rather than the first

An environmental factor that was different between the first and second days of welding was that the boat had warmed up considerably by the second day. The temperature may have had a large influence on why the explosion occurred not long after the start of welding on the second day but not on the first day, even though much more "hot work" took place on the first day.

The overhead bay door was closed when the welder began work on the second day, February 4. The boat was parked close to the area heated by one of the ceiling-mounted natural gas heating appliances. The heat produced by the heating appliances overnight was still contained within the shop as the large bay door had not been opened that morning. The increased temperature of the gasoline created higher-risk conditions for the ignition of vapour than had existed on the preceding day, when the boat's components and the fuel source were colder.

Another factor that changed from the first to the second day of work was the passage of time. This may have been a significant factor. As time passed, more fuel may have leaked and resulted in a greater amount of flammable vapour being present on the second day.

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[2] From "Flammable & Combustible Liquids—Hazards," Canadian Centre for Occupational Health and Safety, http://www.ccohs.ca/oshanswers/chemicals/flammable/flam.html#_1_7: "Vapours can flow from open liquid containers. The vapours from nearly all flammable and combustible liquids are heavier than air. If ventilation is inadequate, these vapours can settle and collect in low areas like sumps, sewers, pits, trenches and basements. The vapour trail can spread far from the liquid. If this vapour trail contacts an ignition source, the fire produced can flash back (or travel back) to the liquid. Flashback and fire can happen even if the liquid giving off the vapour and the ignition source are hundreds of feet or several floors apart."

[3] From "OSH Answers: Flammable and Combustible Liquids—Hazards," Canadian Centre for Occupational Health and Safety, http://www.ccohs.ca/oshanswers/chemicals/flammable/flam.html.

2.4.2 *Factors contributing to the force of the explosion*

Fire requires three elements: heat, fuel, and an oxidizing agent (usually oxygen). A fire naturally occurs when the elements are combined in the right mixture.

There are factors that limit flammability. Flammable vapour will ignite only if the air composition lies between certain limits—if too much or too little gasoline vapour is present, ignition will not take place.[4]

The conditions present underneath the boat deck on the morning of February 4 created the right mixture of gasoline vapour and air in that area (vapour in air between 1.4% and 7.6%) to result in an explosive range of flammability.

Although the flotation foam in the hull took up much of the space available for air, air pockets existed below the deck due to unevenly applied foam. Some forward areas did not contain foam at all. Many of the stringers underneath the deck had openings cut into them that allowed air to move between different sections of the hull (see Figure 8 on page 12).

It is unknown how much gasoline was present and how long the fuel had been leaking into the hull. Sufficient gasoline vapour was present, however, to result in a very forceful explosion with the introduction of the ignition source (the welding arc). The explosion released sufficient energy to lift approximately 2,500 pounds (1,135 kilograms) of material several feet off the floor. There was sufficient energy involved to tear out many feet of continuous welds. The released energy violently detached the deck, dashboard, and windshield, and propelled these with great force 25 feet (7.6 metres) to the ceiling. The force of the explosion strongly indicates that even though no one smelled any gasoline vapour, a significant amount of gasoline was involved.

2.5 Inadequate instruction, training, and supervision

The company owner and the foreman had knowledge of gas-testing requirements and possessed equipment to perform the tests. The owner stated that during the June 2009 alteration work on the boat involved in the explosion, the crew had used the multi-gas monitor to test for flammable vapour. Interviews of the foreman established, however, that the foreman was unaware of the boat's access hatch covers, which had to be removed in order to use the multi-gas monitor effectively. The welder did not know how to use the multi-gas monitor. The welder stated that during work on boats that he had observed in the shop, the multi-gas monitor had not been used. The employer had not provided the foreman or workers with written procedures containing safety instructions for the work they performed.

Given that work activity at two different places required atmosphere testing and monitoring for safety reasons, the owner and foreman had two options. One option was to reschedule the welding work on the boat until the gas-testing device was available at the shop. Another option was to obtain a second gas-testing device to enable testing and monitoring at each site. The company owner and the foreman did not provide evidence that they had considered either of these options before directing the work to proceed.

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[4] **Upper Limits of Flammability**—too much air and not enough vapour for ignition to take place. The upper flammability limit for gasoline is a concentration of 7.6% gasoline vapour in air.
Lower Limits of Flammability—too much vapour and not enough air for ignition to take place. The lower flammability limit for gasoline is a concentration of 1.4% gasoline vapour in air.
Explosive Range of Flammability—the point where the vapour and the air are sufficiently mixed that the introduction of an ignition source (spark, hot surface, or flame) will ignite the vapour/air mixture either by a momentary "flash" or for a more sustained period (fire point).

Information that the owner, foreman, and welder provided indicated that they had some knowledge of the type of risks involved with welding near flammable materials. Despite this knowledge, however, they did not fully appreciate the potential for an explosion when they commenced work on the boat without first conducting tests. A greater awareness of the very severe risks might have made them reluctant to do the work in the manner it was performed.

3 Conclusions

3.1 Findings as to causes

3.1.1 Explosion during welding alterations to an aluminum boat

An explosion occurred as the welder was making welding alterations to the transom of a small aluminum boat. The welder was thrown to the floor some distance from where he had been standing, and sustained minor injuries. Parts of the boat hit the shop ceiling and fell to the floor without striking anyone.

3.2 Findings as to underlying factors

3.2.1 Presence of flammable vapour and ignition source

The welding arc outside of the transom ignited flammable vapour near the stern. The ignited vapour followed the vapour trail through the various openings in the boat back to the source of the vapour underneath the boat deck. The combination of flammable vapour, air, and an ignition source (the welding arc) created the conditions that caused the explosion.

3.2.2 Inadequate assessment of risk and hazard control

There was inadequate assessment of the potential for flammable vapour ignition and explosion. Instrument testing for the presence of flammable vapour was not done before commencement of the “hot work” of grinding, cutting, and welding. Passive or mechanical ventilation of the areas containing the boat fuel tank and hoses was not done either. There was an inappropriate reliance only on the sense of smell to identify the potential presence of flammable vapour.

3.2.3 Inadequate instruction and supervision

Although the foreman and the company owner had knowledge of gas-testing requirements and possessed equipment to perform the tests, they did not conduct the required testing. They permitted the work to proceed without ensuring that workers could do it safely. The employer did not provide the foreman or the workers with the required safe work procedures for doing “hot work” near flammable or explosive substances.

4 Orders Issued after the Investigation

WorkSafeBC issued orders to the employer after the investigation. An order requires an employer to take steps to comply with the *Workers Compensation Act* or Occupational Health and Safety Regulation, to take measures to protect worker health and safety, or to fix a hazardous condition. An order is intended to ensure that unsafe conditions are identified and corrected and that the employer complies with the Act and the Regulation. An employer may ask the Review Division to review an order; the Review Division may confirm, vary, or cancel an order.

In addition to issuing orders, WorkSafeBC may recommend proceeding with an administrative penalty against an employer. Penalties are fines for health and safety violations of the *Workers Compensation Act* and/or the Occupational Health and Safety Regulation. For information on when penalties are considered and how the amount of the penalty is calculated, see the penalty FAQs on WorkSafeBC.com. Companies that have been penalized are also listed on the web site.

4.1 Orders to the employer

This section summarizes two of the orders issued to the employer.

The investigation found that this employer was in contravention of the *Workers Compensation Act*, section 115(2)(b)(i), which states that an employer must ensure that the employer's workers are made aware of all known or reasonably foreseeable health or safety hazards to which they are likely to be exposed by their work.

The investigation also found that this employer was in contravention of the *Workers Compensation Act*, section 115(2)(e), which states that an employer must provide to the employer's workers the information, instruction, training, and supervision necessary to ensure the health and safety of those workers in carrying out their work and to ensure the health and safety of other workers at the workplace.

5 Health and Safety Action Taken

In addition to the specific actions below, employers, workers, or others in industry may have taken measures to prevent a recurrence of this type of incident. Employers are expected to comply with any orders issued. At WorkSafeBC, the Lessons Learned committee examines recommendations from incident investigations to see what can be done to prevent similar incidents.

5.1 WorkSafeBC

WorkSafeBC produced a slide show on this incident. It is available on WorkSafeBC.com:
http://www2.worksafebc.com/Publications/Multimedia/SlideShows.asp?ReportID=36721