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INCIDENT INVESTIGATION REPORT

Notice of incident number	Date of incident	Location of incident
2012161980018	**January 20, 2012**	**19479 Highway 16 East Burns Lake, B.C.**
Lead investigating officer **Paul Orr**	Investigation file number **2012-0013**	Incident outcome **FATAL (2) INJURY (20)**
Report approved by manager, Fatal and Serious Injury Investigations **Steven Ramsden**	Signatures	Date **November 29, 2012, amended August 29, 2013**

PARTIES INVOLVED IN INCIDENT

Employer	Name and address **Babine Forest Products Limited 19479 Highway 16 East Burns Lake, BC V0J1E0**	Employer ID **328321**	Industry classification **714022 Sawmill**
Workers	[redacted]	[X] Deceased	Occupation **#1 Cut-off saw operator**
	[redacted]	[X] Deceased	Occupation **Lead hand, B-shift**
	[redacted]	[X] Injured	Occupation **Eliminator operator**
	[redacted]	[X] Injured	Occupation **Quality control**
	[redacted]	[X] Injured	Occupation **Break relief worker**
	[redacted]	[X] Injured	Occupation **Basement clean-up worker**
	[redacted]	[X] Injured	Occupation **Bin operator**

Workers	[redacted]	[X] Injured	Occupation **Log-deck tender**
	[redacted]	[X] Injured	Occupation **Gang sawyer**
	[redacted]	[X] Injured	Occupation **Edger operator**
	[redacted]	[X] Injured	Occupation **Saw-filer**
	[redacted]	[X] Injured	Occupation **Eliminator operator**
	[redacted]	[X] Injured	Occupation **Watchman**
	[redacted]	[X] Injured	Occupation **Electrician**
	[redacted]	[X] Injured	Occupation **Edger operator**
	[redacted]	[X] Injured	Occupation **Saw-filer**
	[redacted]	[X] Injured	Occupation **Millwright**
	[redacted]	[X] Injured	Occupation **Millwright**
	[redacted]	[X] Injured	Occupation **Trimmer operator**
	[redacted]	[X] Injured	Occupation **Trimmer operator**
	[redacted]	[X] Injured	Occupation **Chip-saw #3 operator**
	[redacted]	[X] Injured	Occupation **Chip-saw #2 operator**

Persons mentioned in report

Name	Known in the report as	Role in the incident/investigation
[redacted]	#1 Cut-off Saw Operator	Employee of Babine Forest Products Limited; was operating the #1 cut-off saw when the incident occurred, and died in the explosion and fire.
[redacted]	Lead Hand	Employee of Babine Forest Products Limited; had just gone down to the basement level when the incident occurred, and died in the explosion and fire.
[redacted]	Saw-filer	Employee of Babine Forest Products Limited; was jogging the bandsaw to set a freshly installed blade when the explosion occurred, and was seriously burnt.
[redacted]	Yardman	Employee of Babine Forest Products Limited; was working in the log yard at the time of the incident, and saw the mill explode.
[redacted]	Basement Attendant 1	Employee of Babine Forest Products Limited; was operating the switch for a waste conveyor when the explosion occurred; saw the fireball coming towards him from the east, and suffered severe burns.
[redacted]	Basement Attendant 2	Employee of Babine Forest Products Limited; normally worked the day shift but was on the afternoon shift the day of the incident; smelled gas in the basement on the day of the incident.
[redacted]	Watchman	Employed as a night watchman by Babine Forest Products Limited; entered the basement of the sawmill in an attempt to locate the source of a fire alarm, and was seriously injured.
[redacted]	Electrician	Employee of Babine Forest Products Limited; was entering the electricians' room at the time of the incident, and was thrown by the explosion from the second floor to the courtyard below.

Name	Known in the report as	Role in the incident/investigation
[redacted]	#1 Edger Operator	Employee of Babine Forest Products Limited; was operating the #1 edger at the time of the incident; felt the explosion come from the east and below his work location, and was injured.
[redacted]	#2 Edger Operator	Employee of Babine Forest Products Limited; was operating the #2 edger at the time of the incident; felt the explosion come from below and behind him, and was injured.
[redacted]	Millwright 1	Employee of Babine Forest Products Limited; had completed his day shift and gone home by the time of the incident; earlier on the day of the incident, investigated a report of gas odour in the basement level of the mill.
[redacted]	Millwright 2	Employee of Babine Forest Products Limited; was working on the debarker at the time of the explosion, and was seriously burnt.
[redacted]	Millwright 3	Employee of Babine Forest Products Limited; a day-shift millwright, had been working along the north wall of the basement level earlier on the day of the incident.
[redacted]	A-Shift Edger Operator	Employee of Babine Forest Products Limited; operated the edger during the day shift on the day of the incident; had smelled gas earlier in the week.
[redacted]	Maintenance Superintendent	Employee of Babine Forest Products Limited; the maintenance superintendent for the sawmill.
[redacted]	#1 Eliminator Operator	Employee of Babine Forest Products Limited; was operating the #1 eliminator when the explosion occurred, and was seriously burnt.
[redacted]	#2 Eliminator Operator	Employee of Babine Forest Products Limited; was operating the #2 eliminator when the explosion occurred, and was seriously burnt.
Bruce MALLORY	President of Babine Forest Products	President of Babine Forest Products Limited; interviewed by WorkSafeBC investigators.

Scope

This incident investigation report sets out WorkSafeBC's analysis and conclusions with respect to the cause and underlying factors leading to the workplace incident of January 20, 2012, at the Babine Forest Products Limited sawmill located at 19479 Highway 16 East in Burns Lake, British Columbia. The purpose of this report is to identify and communicate the findings of this incident to support future preventive actions by industry and WorkSafeBC.

This investigation report does not address issues of enforcement action taken under the *Workers Compensation Act* and the Occupational Health and Safety Regulation. Any regulatory compliance activities arising from this incident will be documented separately.

Synopsis

During the afternoon shift on January 20, 2012, there was an explosion at the Babine Forest Products sawmill at approximately 20:07. A large fireball burst through the roof at the northeast side of the mill, while the explosion travelled east to west through the operating and basement levels. Fire spread throughout the premises, completely destroying the mill. Two workers were killed in the explosion and 20 others were injured.

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1 Factual Information

1.1 Babine Forest Products Limited

The Babine Forest Products sawmill is located on First Nations land approximately 20 kilometres east of Burns Lake, British Columbia (Figures 1 and 2). It was constructed in 1976 and employed approximately 250 local workers in a unionized environment. Appendix 2 shows a site plan.

Previously owned by West Fraser Mills Ltd., Babine Forest Products Limited was acquired by Hampton Affiliates in 2006. Hampton Affiliates holds an 89% interest and the Burns Lake Native Development Corporation holds 11%. Based in Portland, Oregon, Hampton operates seven other sawmill complexes, the majority of them in Oregon and Washington states.

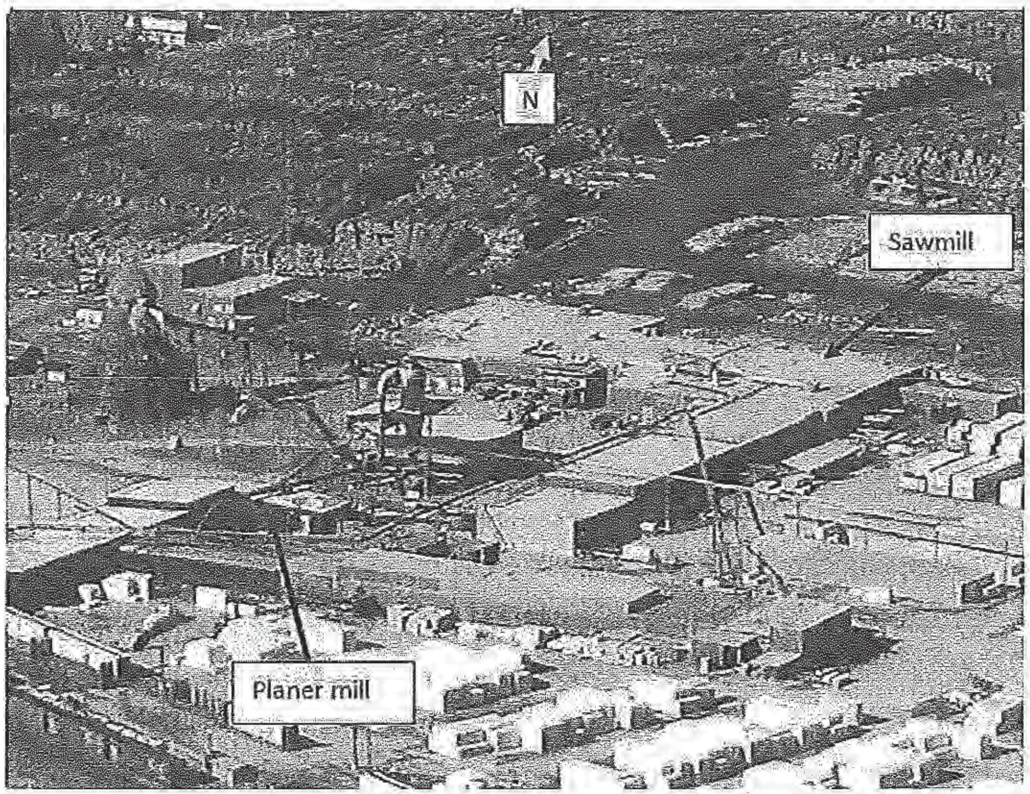


Figure 1: The Babine Forest Products sawmill prior to the incident.
Source: Babine

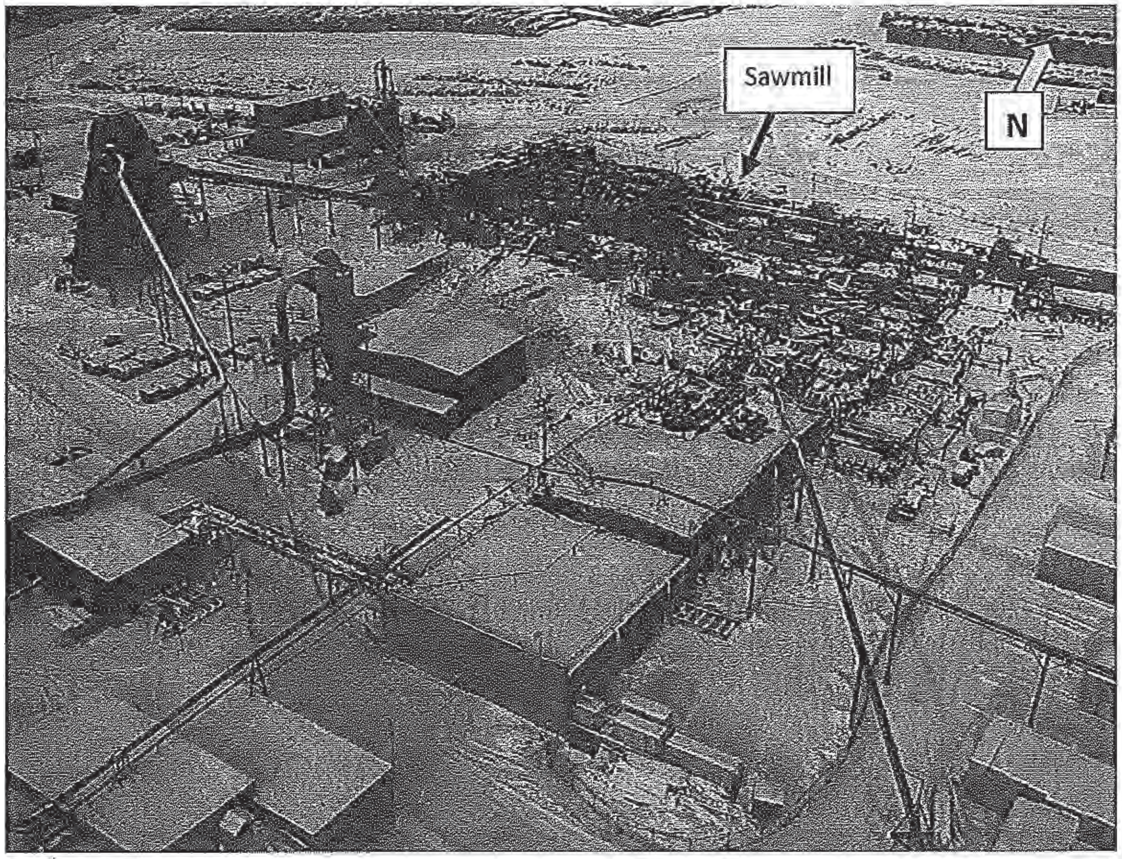


Figure 2: The sawmill after the explosion and fire on January 20, 2012.

1.2 The workforce

The sawmill operated five days a week with two 10-hour shifts per day, for a total of 100 hours a week of production. The production shift scheduling was as follows:

- Day shift – 06:00-16:30
- Afternoon shift – 17:00-03:30

The maintenance shifts were 12 hours a day on the weekend. During the week, there were assigned trades workers on all shifts to ensure that the equipment continued to run.

A five-person clean-up or graveyard shift ran from 03:30 to 12:00 every weekday. This group was restricted to areas where the production equipment was not operating. If the equipment was operating (for example, during a production shift), the clean-up workers would be unable to clean on or near the equipment. Some workers reported that clean-up workers would sometimes be reassigned to production activities. Clean-up workers also stated that the mill was starting the production day shift earlier, at 04:30, which further limited their ability to do adequate clean-up.

1.3 Sawmill layout

The Babine sawmill had two main levels: the operating floor, where most of the processing machine centres were located (Appendix 3), and the basement level, which contained the waste conveyors, mill chippers, hydraulic rooms, and power distribution centre (PDC) (Appendix 4). Throughout this report, grid coordinates in Appendices 3 and 4 will be used to indicate specific locations in the main operating floor and the basement level.

The main operating floor was approximately 6 feet above the existing ground level. Processed lumber travelled from the west to the east side of the operating floor, and then south to be sorted and packaged before being moved out to the storage yard. Along this east side of the sawmill, under the transfer tables that moved lumber from the two eliminators (F-25.5 and F-26.5, Appendix 3) to the sorting areas (B1-26, Appendix 3), there was a half-basement. The half-basement space was approximately 6 feet high under the eliminators and trim-saws and contained some wood waste conveyors.

Beneath the sawmill's main operating floor was a full basement with a total depth from floor slab to ceiling of approximately 14 feet (an additional 8 foot below the half-basement level). The full basement and half-basement were divided by the full basement's concrete wall running north to south from C-25 to J-25(Appendix 4). This is shown in Figure 3.

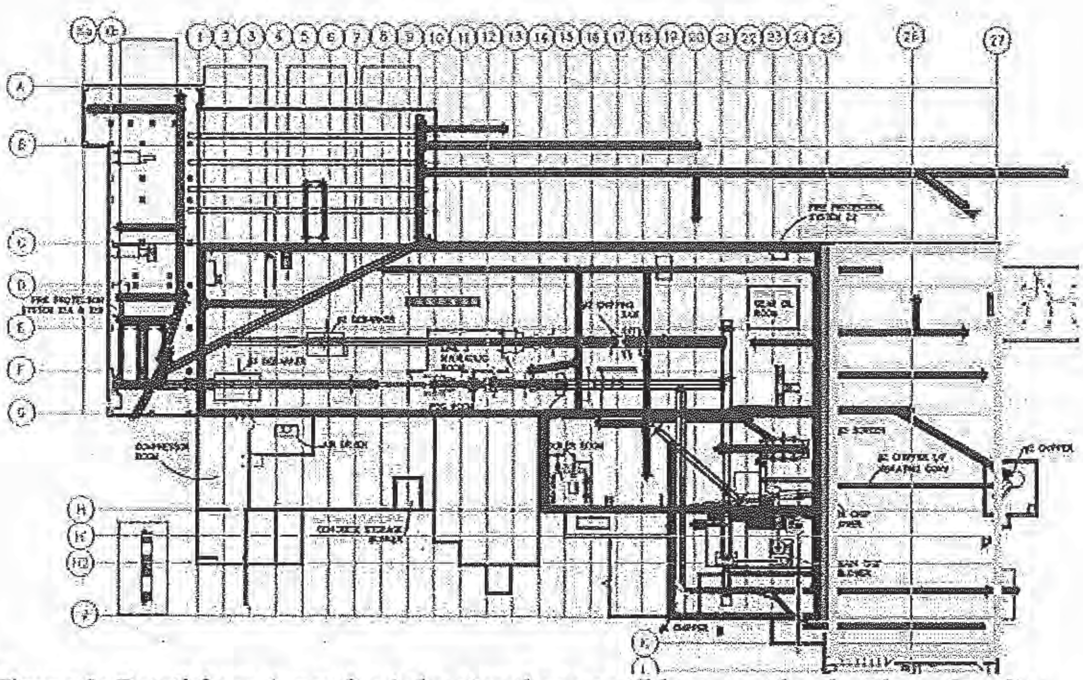


Figure 3: Detail from Appendix 4 showing the sawmill basement levels. The red outline indicates the full-basement; the yellow outline indicates the half-basement referred to in this report. The basement dividing wall is shown in green. North is the top of the drawing.

1.4 Sawmill work process

Over the winter months of 2011, Babine had been processing lumber on a weekly cycle of three days of mountain pine beetle–killed pine and two days of green spruce.

With the use of the log yard's heavy equipment, logs were brought to the mill's four cut-off saws, located along the north wall of the sawmill (see Appendix 3), where the logs were cut to length. The logs then were moved into the sawmill along the log deck conveying system from the cut-off saws. These conveyors moved the cut logs outside the mill's north wall from east to west. At the northwest corner of the mill, the logs were brought into the sawmill and sorted by diameter.

The mill had two separate lines: large logs of up to 22 inches in diameter, and small logs from 4 to 8 inches in diameter. The sorted logs were then processed through either of the sawmill's two debarkers (F-3 and E-6, Appendix 3). Each processing line had its own debarker. From the debarkers, the logs were moved eastward.

- The larger logs were initially dimensioned through a large bandsaw located at G-16 (Appendix 3) and then through the primary saw-lines (H-19, Appendix 3). This lumber was then directed for further processing through other saw equipment before being transferred onto the sorting tables and eventually moved to the stacking and packaging areas at the south end of the sawmill.
- The smaller log line extended from the #2 debarker (E-6, Appendix 3) to the chipping saw (E-17, Appendix 3). the log was processed and then further transferred through processing saws. The then dimensional lumber was then forwarded to the sorting tables and eventually south to the stacking and packaging areas.

The sorting of the lumber began at the sawmill's two eliminators (F-25.5 and F-26.5, Appendix 3). At these eliminators, the lumber was checked and sorted, and in some cases would be rejected and sent back into the mill for further processing, depending on the grade quality and condition of the lumber.

The target production rate for the sawmill was 68,000 board-feet an hour. This was achieved in October and November 2011, and exceeded in December.

The many sawing activities generated a significant amount of wood waste, which would fall to the floor or, in some areas, be sucked away by the mill's dust collection system. The wood dust and debris that fell to the floor was cleaned up periodically by being swept into floor openings to the waste conveyors in the basement level. This dust would be dispersed as it was swept, with some of the coarser dusts settling on the conveyor while the finer dusts had the opportunity to migrate throughout the basement. Some of that wood debris typically went from one wood waste conveyor to another, ending up in either of the mill's two chippers. From the chippers the wood chips would then be conveyed to one of the main waste conveyors and moved out of the mill to outside storage areas and structures.

The #1 chipper was located in the basement at J-19 (Appendix 4). The #2 chipper was located on the east wall of the sawmill basement at G-27 (Appendix 4). Between the two chipper locations, in the general area of H-22 (Appendix 4), there were a number of vibrating screens where wood "fines" (small wood particles) were sorted. Throughout this area, a number of conveyors moved the wood chips and "fines" to and from the screens, chippers, and blower fans. The blower fans were also located in this area and blew some of the wood "fines" out of the mill through piping, into a collection area south of the mill site. Other wood waste and chips were moved on conveyors generally to the north side of the mill basement, where they were dumped onto other waste conveyors which then carried this waste to the west side of the mill and out into the storage bins located there.

1.5 The dust collection system in the sawmill

In 1982, a Prince George–based metal fabrication firm was contracted to install the mill's dust collection system. According to this fabrication company, no design calculations were made when the system was originally installed. The mill owner at the time requested a system to service the trim-saws and edgers, and the baghouse model was selected and installed.

The system had a capacity of 24,000 cubic feet per minute and consisted of equipment collection hoods, ducting, and a baghouse with eight modules. The baghouse was located on the sawmill roof above approximately H-22. Originally, the system was installed to service the trim-saws (J-25 and J-26, Appendix 3) and edgers (H-19 and H-22, Appendix 3).

Each of the eight modules in the baghouse held 36 separate filter bags. The filter bags were suspended in the baghouse and filtered incoming wood dust out of the air. The air passed through the cloth material of the bags and moved into the top area of the baghouse; the now-filtered air was vented from there to the atmosphere. The fine wood dust that caked on the outside of the filter bags was shaken loose periodically with random blasts of air from inside the baghouse, and would settle in the lower hopper section of the baghouse. From there it was periodically dropped through a duct pipe into the sawmill basement and onto a waste conveyor near the #1 chipper (approximately J-20, Appendix 4).

The dust collection pick-up points were changed in 2010; there are no design records for this modification. The service to the trim-saws and edgers was disconnected and new collection ducting was installed to service the bandsaw on the large log line (F-15.5, Appendix 3) and the debarkers on both log lines (E-6 and F-3, Appendix 3). At the bandsaw there were two hoods that covered the top band wheel and acted as guards for the spinning saw blade. Each hood was equipped with a collection duct; however, only one side was connected when the incident occurred. In May 2011, additional work on the collection ducting on the two debarkers was done by a local metal fabrication contractor.

There was no dust collection system along the entire east side of the mill or at the edgers or trim-saws located in the general east-centre areas of the mill.

There are few records available pertaining to the design, modification, and maintenance of the mill's dust collection system. The available invoices from the fabrication company show the following:

- May 29, 2009 – 50% invoicing for pipe fittings and hoods as well as an abort gate and spark detection system.
- June 30, 2009 – 50% invoicing for pipe fittings and hoods as well as an abort gate and spark detection system.
- July 21, 2009 – Installation of all of the above.
- May 2, 2011 – Hoods and piping work on bandsaw and debarkers.
- October 24, 2011 – Inspection of October 21 regarding the spark detection system, with notes saying that (1) the electrical wiring was wrong and it was unsafe to operate the dust collection system; and (2) the filter bags in the baghouse were completely plugged up.
- December 2011 and January 2012 – Ordering of filter bags.

The Maintenance Superintendent stated that the baghouse was undersized for the sawmill operation. A down payment had been made on a used baghouse in Oregon to upgrade the Babine mill but it had not been installed due to an inadequate power supply. Throughout the fall of 2011, the power system was being upgraded, and this would have enabled the mill to upgrade the baghouse and collection systems in 2012.

The dust collection system may not have been working since as early as October 21, 2011, because the filter bags were plugged up and frozen. Millwright 3, who normally serviced and maintained the system, stated that he had replaced the filter bags and restarted the system on or around December 16, 2011. The invoices show that these filter elements were not ordered until December 2011.

1.5.1 Spark detection system

A spark detection system was installed in the dust collection system at the Babine sawmill. The system consisted of sensors located within the system ducting, as well as water suppression nozzles and abort gates. The sensors would detect any sparks travelling with the wood waste through the collection ducting. If sparks were detected, the sensor(s) would signal the control panel, which would activate the water suppression system in an attempt to extinguish the sparks.

The abort gate was downstream from the water suppression system. Upon being activated by the control panel, the spring-loaded gate would close the duct passage and redirect to the atmosphere all materials, including sparks and burning materials, travelling through the ducting. Sparks and potential ignition hazards could be prevented from reaching the baghouse filter elements and igniting the fine dust collected there.

The control panel for the spark detection system was located in the #1 chipper room in the basement level (J-20, Appendix 4).

Babine contacted a fire protection firm about performing an inspection on the mill's spark detection system. In early January 2012, the fire protection firm was contracted to review the system and to gather the information needed for Babine to develop an inspection maintenance program. In mid-January, this firm contacted the manufacturer for this information and supplied photographs and a description of the installation. The manufacturer commented on January 16 that some of the system was installed incorrectly. Over the period January 17–19, the contractor supplied an inspection and maintenance program, by fax, to the mill. It is not known if the system was fully functional at the time of the mill explosion on January 20.

1.5.2 Other wood dust accumulation prevention measures

Babine employed a five-worker clean-up shift daily between 03:30 and 12:00. Each worker was assigned a specific area. The workers swept up and shovelled overflow wood dust and debris onto the waste conveyors, which carried them outside the mill to storage areas. However, the clean-up crew's work around the equipment centres was restricted once the production day shift started work and began operating the equipment. In February 2011, Babine began hiring groups of students on weekends from time to time to perform a more detailed and complete clean-up of the mill.

In February 2011, Babine hired a mechanical contractor equipped with commercial vacuum trucks and equipment to perform weekend clean-up. This work started on February 7 on a weekly schedule throughout 2011 and up to the time of the incident. In addition, a separate contractor worked at the mill February 24–26, doing fire clean-up after a fire in the sawmill on February 23, 2011.

Babine attempted to prevent dust accumulation within the various motor control centre (MCC) panels. In 2011, it contracted an environmental technology company with air systems expertise to install an MCC pressurization system that delivered air through ducting into the electrical cabinets in order to generate positive pressure within them. The purpose of the system was to prevent wood dust from migrating into and accumulating within the panels.

This pressurization system was installed but it was shut down in mid-January 2012 when it was found that the suction side of the fans had been placed at floor level and the fans were actually drawing wood dust from the mill into the MCC cabinets. The filter system for the intake air was ineffective. Whether this was a design problem or incorrect filter application was not pursued during this investigation, as WorkSafeBC investigators did not find evidence of dust ignition within the MCC panels that they examined. However, many of the examined MCC panels showed evidence of wood dust accumulations that had burnt.

Water misting systems were installed on some of the equipment lines, including the edgers and trim-saws. At the time of the incident the misters on the trim-saws were off and a water hose was running water on the edger saws. The mill's water misting system had been upgraded but was not operational due to the extreme cold weather which caused frozen and broken water pipes.

The sawmill had planned to install two new exhaust fans. One had arrived but had not been installed by the time of the incident.

1.6 Sequence of events

1.6.1 Prior to the incident

The week leading up to the day of the incident was extremely cold in Burns Lake, with reported temperatures below –40°C. Some of the water pipes had frozen and the mill was having problems keeping things running due to the cold. The water line to the edger saws had frozen, so a water hose brought in water from a different area of the mill to keep some saws cool.

The months immediately preceding January 2012 had been high-production months. The dust collection system baghouse had been inspected by a contractor on October 21, 2011, and found to be completely plugged up. Babine informed WorkSafeBC investigators that it had been frozen: the mill had run the misters with the dust collection system on and the moisture had collected and frozen the filter bags. The Maintenance Superintendent stated to investigators that the baghouse was out of service for 8 to10 days and then restarted on December 16, 2011.

The day before the incident, the production shift had been shut down halfway through the shift because of numerous plug-up conditions in the basement level (this occurs when waste conveyors get stuck or otherwise stop running because wood debris is interfering with the drive sprockets or other drive conditions). The production shift was sent to the basement to assist with the clean-up. Shortly afterwards, the main waste conveyor (9-35) was shut down so that contractors could work on the main water line along the north wall. This conveyor shutdown stopped the flow of wood waste out of the sawmill.

1.6.2 The incident

The day shift on Friday, January 20, 2012, proceeded normally. There was maintenance work done throughout the day on various frozen water pipes and other production issues. The outside temperature had warmed up to approximately –20°C.

The afternoon shift started at 17:00. Mill management stated that green wood was being processed on the Thursday and Friday (January 19 and 20) of that week. There were problems with water pipes freezing throughout the mill. This had been an ongoing problem during this cold week. After the incident, workers stated that the heaters were not effective in keeping the basement warm.

During the afternoon shift, Millwright 2 attended to a hot bearing at the #3 log sort tail drum and at the #1 chipper outfeed conveyor. In the northwest basement level, he noticed a significant water leak in the main pipe, and isolated the leak at the faucet. He had his lunch between 19:00 and 20:00, then was called to troubleshoot the #3 debarker (F-3, Appendix 3) while this line was stopped for a saw blade change on the bandsaw. He opened the door to the debarker, swinging it eastward, and had begun working in the body of the debarker when an explosion occurred. He reported that the mill went completely dark. Badly burnt, Millwright 2 slid down the debarker waste chute to the waste conveyor in the basement level, and managed to exit the mill along this conveyor.

The Saw-filer was changing the saw blade on the bandsaw (G-16, Appendix 3), at the same time as Millwright 2 was working on the debarker. He had almost completed this work and was operating the start switch to settle the saw blade into position on the band wheels when the floor below him lifted from the explosion. He was engulfed in flames and suffered serious burn injuries. He stated that the explosion came from below him (the basement level).

The Watchman was having his lunch in the mobile shop located immediately to the west, outside of the sawmill, when the fire alarm went off at 20:00. In an attempt to locate the source of the alarm, he entered at the west side of the basement level to check the dry-valve there, and then began travelling east through the basement. He stopped and was about to drink from his water bottle near waste conveyor 9-46 at approximately F-1 (Appendix 4). A few minutes past 20:00, the lights flickered, and a moment later he was hit by the force of the explosion coming towards him from the east. He had no recollection of a fireball but suffered serious burns. He travelled south out of the mill to the courtyard area.

The gas service provider later reported that the natural gas line ruptured at 20:07. The Yardman was in the log yard to the north of the sawmill. He stated that the roof of the sawmill blew off, followed by a fireball.

Basement Attendant 1 was in the basement level trying to restart waste conveyor 2A-14 (approximately F-2, Appendix 4) when the lights went out and he was hit by the explosion pressure. He lost consciousness for a short period of time and awoke with his clothing on fire. He managed to escape out of the sawmill but suffered serious burn injuries.

All but two of the other sawmill workers got out of the mill and assembled in the parking area to the west. Emergency services transported some workers to the Burns Lake Hospital; others were transported by their co-workers. Two workers died in the incident: the #1 Cut-off Saw Operator was found in his operating booth (B-13, Appendix 3); the Lead Hand was found inside the sawmill at a doorway near the round saw filing room (D-27, Appendix 3). A total of 20 other workers were injured, some seriously. See Appendices 5 and 6 for the locations of all the workers and Appendix 7 for a key to their names.

2 Analysis

This analysis of the incident focuses on the following:

- The cause of the incident, an explosion that resulted in fires in various areas of the sawmill
- How the various components required for an explosion were present in the sawmill
- The progression of the explosion and fires
- An analysis of the deaths of the Lead Hand and the #1 Cut-off Saw Operator based on the evidence at the scene
- Changing conditions at the sawmill that may have contributed to the incident
- Health and safety concerns at the sawmill

This investigation considered all witness interviews, eyewitness accounts, and physical evidence to develop hypotheses on how the explosion occurred in the Babine sawmill. The potential ignition and fuel sources were investigated and ruled out or accepted based on the investigation findings. These findings are reported in the following sections.

Throughout this report and in the appendices are drawings and illustrations that assist in explaining the investigation findings. Some of the drawings contain blast vector indication arrows to show the direction of the explosion pressure when it damaged or disturbed specific physical objects or structures (Appendices 8 and 9). In Appendices 5 and 6, the worker locations are represented by yellow boxes with one pointed side. The point indicates the direction the worker was facing at the time of the explosion. Some of the workers' directions are unknown and are represented by only a square box with no pointed side. It was impossible, however, to determine which direction the two deceased workers were facing. Appendix 7 provides a key to the identity of the workers.

2.1 Did an explosion occur in the sawmill?

The initial evidence consisted of various worker accounts of the events leading up to and during the explosion:

- The Saw-filer had just completed a saw blade change on the bandsaw (G-16, Appendix 3). He was operating the start switch to settle the blade on the band wheels when he heard a pop, the floor beneath him rose up, and he was engulfed in flames coming from below.
- The Yardman was working in the log yard north of the sawmill. He reported seeing the mill roof blow off and the fireball going through the mill from east to west.
- Both the #1 and the #2 Edger Operators were at their work stations (approximately H-19 and H22, Appendix 3), both were facing west, when the fireball burst up through the floor behind them from the east, seriously burning them.
- The Electrician was entering the electricians' room at approximate H-2 (Appendix 3) when the explosion pressure threw him out of the second floor to the courtyard below. He looked back and saw that some areas of the mill were gone or on fire.

- After entering the basement level to check on a fire alarm, the Watchman was leaving the fire protection system dry-valve 21 area (D-Xb, Appendix 4) and moving east through the basement. A few minutes past 20:00, he was at approximately F-1 (Appendix 4) when the lights flickered and he was hit by the force of the explosion coming towards him from the east.
- Millwright 2 was working on the #3 debarker (F-3, Appendix 3), when the explosion and fireball coming from the east hit him. He slid down the debarker waste chute to the waste conveyor in the basement level, and exited the mill along this conveyor.
- Basement Attendant 1 was operating the switch for the 2A-14 waste conveyor (approximately F-2, Appendix 4) when the lights went out. He was facing north at the time and saw the fireball coming towards him from the east through the basement level. He later stated that there was a loud boom behind the fire. The pressure wave slammed him into the wall. He lost consciousness for a while and woke up in flames. He escaped through the northern area of the sawmill with serious burns.

Aerial photographs of the mill site were taken and reviewed after the incident. These photographs show a large oval breach in the roof members of the building structure, as well as the path that the pressure wave took through the sawmill (Figures 4 and 5). From the breach, the gluelam (glued laminated timber) roof beams and steel members were pushed west. To the east of the breach the gluelam and steel beams have been thrown up and piled at the edge of the roof crater. At the northern end of the sawmill structure the outer walls were pushed out. Most of the other wall structures including the sorter and packaging areas of the mill were burnt but not displaced.

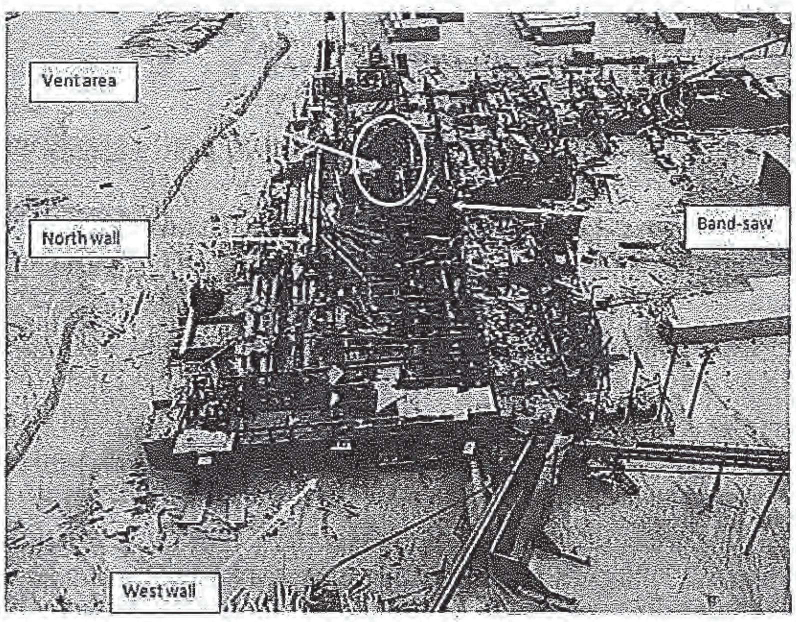


Figure 4: *The sawmill as seen looking east. The vent area is shown by the yellow oval.*

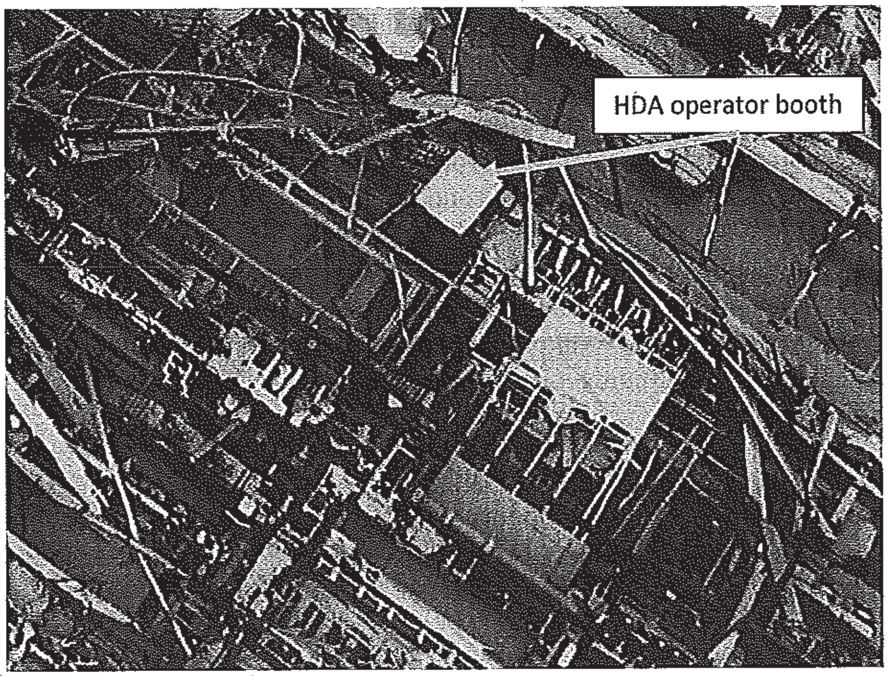


Figure 5: Close-up of the explosion vent area. Note the beams thrown out around this area. North is at top of the photograph; the horizontal double arbor (HDA) booth shown is located at D-19 (Appendix 3).

The workers who were initially interviewed stated that after the initial explosion and fireball they evacuated the mill and gathered outside. Some workers stated that only spot fires were burning, whereas others stated that some areas were burning furiously. They reported that the roof was gone in some areas and that they had heard a loud boom immediately before or during the fireball. These statements, the extensive damage to the sawmill, and the clear blast patterns (see Appendices 8 and 9) confirm that an explosion had occurred and had resulted in fires in many areas of the mill. These initial fires consumed the available fuel throughout the mill and eventually burned down the mill.

Based on the evidence of these witnesses and a review of aerial photographs of the destroyed sawmill, the WorkSafeBC investigation began in the courtyard area of the mill so that access to the bandsaw, the boiler room, and specific electrical components could be made. The investigation then focused on the physical blast damage throughout the mill. There was clear evidence of blast damage in the general area of H-25 (Appendix 4), with blast direction radiating outward from this area. The analysis then considered the available fuels and ignition sources at the mill that would have made an explosion possible.

An explosion is a violent and extremely rapid release of energy accompanied by very high temperatures and pressures in a contained area. The explosion may remain subsonic (less than the speed of sound) in what is referred to as a "deflagrating explosion". The pressure waves travel at less than the speed of sound (343 metres per second), and the explosion is normally propagated through thermal conductivity (burning materials heat and ignite the next layer of materials). Deflagration produces a blast-pressure wave, which is followed by a flame front. In the case of the sawmill, these pressures continued to build and expand during the explosion. The explosion may also undergo a transition from deflagration speed to detonation, which occurs when the pressure wave reaches and exceeds the speed of sound.

When an explosion occurs, the available fuel in the immediate area will be consumed or displaced as the developing explosion pressurizes and super-heats the surrounding particles and which in turn feed the growing deflagration. The explosion pressure wave will expand in all directions outward from the ignition point unless it is deflected by immoveable objects or structures.

The four components needed to initiate and maintain an explosion are fuel, oxygen, containment, and an ignition source (Figure 5). When all these components come together under the right conditions, an explosion may result. In this incident, oxygen was available in the air throughout the sawmill. Ignition sources, fuel, and containment are described in detail in the following sections.

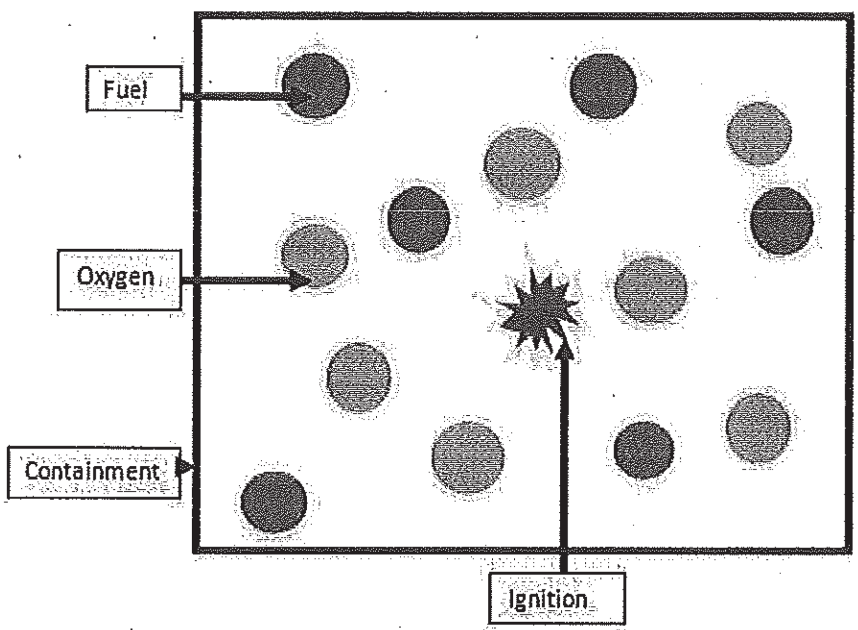


Figure 6: *The basic requirements for a typical explosion.*

2.2 Potential ignition sources in the sawmill

Throughout the sawmill there were numerous areas with the potential for sparks, high temperatures, and fire. The investigation into the ignition sources encompassed a large section of the southern and central sections of the mill, as ignition could have taken place in one part of the mill with the flame then travelling to the area where the explosion itself occurred.

Many potential ignition sources were examined in these areas. The mill's three boilers and air compressors were reviewed. The boilers were turned off and locked out at the time of the incident and were determined not to be an ignition source for the explosion. The air compressors were also reviewed and ruled out as ignition sources.

2.2.1 Welding or cutting operations

Babine had a hot-work permit system at the sawmill. The system required that a permit be issued and that a spark-watch and extinguishing system be in place and available before a worker performed any welding or cutting operations at the mill. During the investigation, permits up to and including January 18, 2012, were received. Permits following this date were reported as having been destroyed in the explosion and fire. WorkSafeBC investigators obtained the following information with regard to welding and cutting on the day of the incident:

- The Watchman reported that he had received one hot-work permit when he began his 18:00 shift on January 20. The permit was for the #2 eliminator area.
- Millwright 2 stated that he performed some cutting work on the end-scrambler for the #2 eliminator (F-26.5, Appendix 3). At this location, the end-scrambler was jammed and some metal sections had to be cut away so it could resume operation. Before Millwright 2 started cutting, he cleared 2 inches of wood dust off the beams where the work was to be done. This cutting work was done without a spark-watch present. The work was completed at approximately 16:30; Millwright 2 recalls the time because the break-time horn had just sounded. Before leaving the area, he checked for smoke or fire and found none. At approximately 19:00 (a little over an hour before the explosion), he returned to the area and checked again for smoke or fire; again, there was no sign of either.

Following the incident, the area around the #2 eliminator end-scrambler was examined. There was no evidence of ignition and no blast damage radiating from this area. Explosion evidence showed that the blast direction was towards this area from the southern portion of the sawmill (see H-25, Appendix 8). Millwright 2's work did not initiate the sawmill explosion. This cutting work was done without a spark-watch present.

WorkSafeBC investigators were not able to find any evidence that would indicate that welding or cutting activities provided the ignition source for the explosion.

2.2.2 Static electricity

Static electricity is generated when two surfaces in close proximity are moved relative to each other. There was a constant risk of static electricity in the mill because of all the moving parts in conveyors, V-belts, transfer chains, and so on, but controls were in place to prevent the accumulation of static charge, such as bonding and grounding of equipment and the use of conductive materials for the conveyor belt systems.

The area where the explosion is believed to have initiated (H-25, Appendix 4) was examined closely. The conveyors and motor centres were mounted securely on steel framing, which in turn was positively secured to the basement floor, grounding this equipment. The possibility that static electricity was present at the time of the explosion cannot be eliminated.

2.2.3 Smoking

A no-smoking policy was in effect inside the sawmill. There was no suggestion in the many worker interviews that anyone was likely to be smoking inside the mill.

2.2.4 Metal halide lighting

Metal halide lighting was used in various areas of the sawmill. These lamps have a history of problems, particularly the extreme heat. When fully lit, the element of a metal halide lamp will reach an internal temperature of approximately 1,100°C and operate at a vapour pressure of 70-90 pounds per square inch (psi). In normal use, metal halide lamps are turned off very rarely, if at all. The constant heat takes a toll on the glass of the inner and outer cone, causing them to deteriorate and possibly break. When the lamps break, extremely hot fragments may fall to the ground, possibly landing on combustible materials.

One intact metal halide lamp was found in its fixture directly in front of the motor control centre MCC-10 (H-16, Appendix 4), while several broken lights were found throughout the mill (Figure 7). No metal halide lamps were found in the immediate area where the explosion is believed to have originated (H-25, Appendix 4). A fluorescent fixture approximately 30 feet north of this possible point of origin had been flattened against the ceiling by the blast. The bulbs, which were lying on the floor below the fixture, were examined and discounted as an ignition source.

The available evidence did not support the hypothesis that a metal halide lamp failed catastrophically and initiated the explosion. In the areas where such lamps were present, there was no clear blast damage or blast directional indicators. The initial area where the investigation began, near the boiler room and MCC-10 electrical panel (H-16, Appendix 4), did contain metal halide lighting, but the bulb found in its fixture directly in front of the MCC-10 panel would likely not have survived intact if the explosion had originated near here or the full force of the explosion had reached this area.

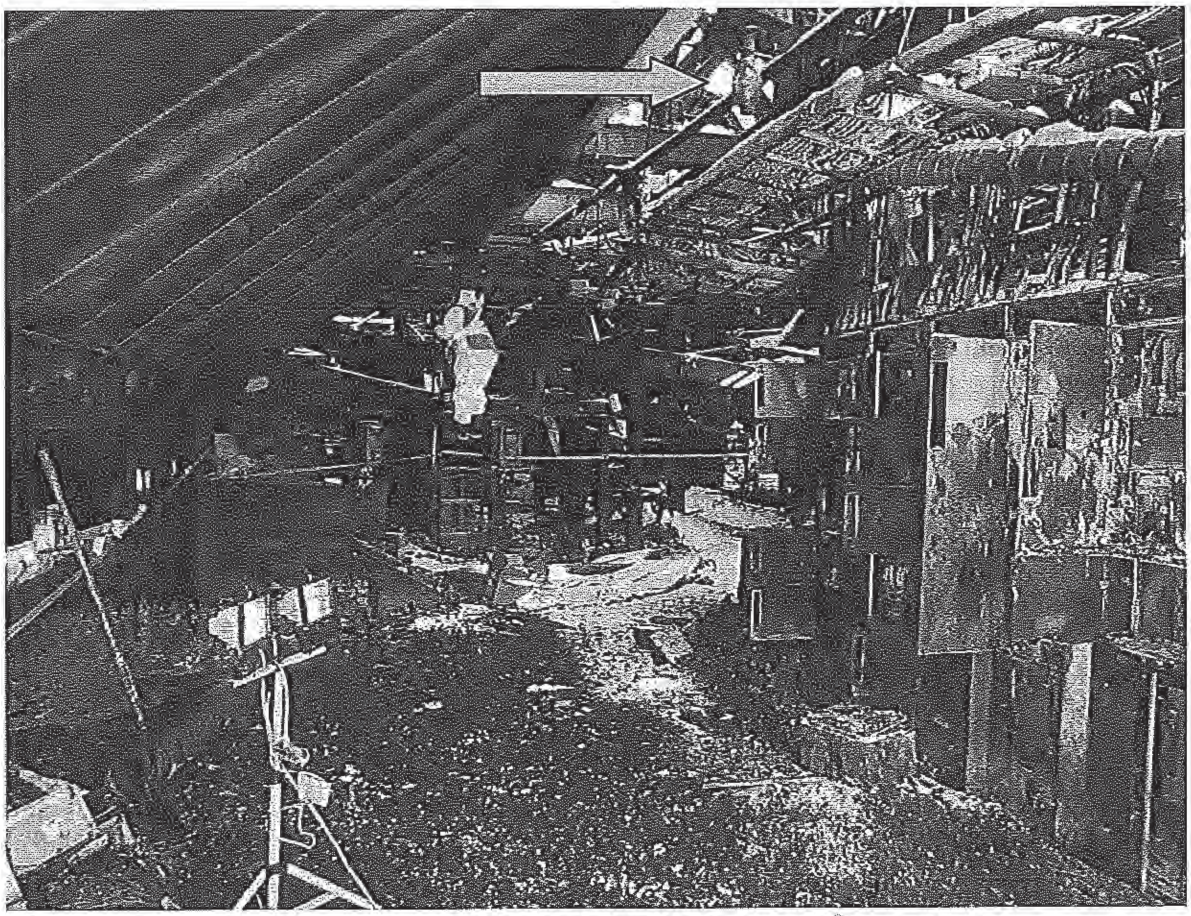


Figure 7: This view looking east from in front of the boiler room (G-15, Appendix 4) shows the MCC-10 electrical cabinet on the right and conveyor 9-92 on the left. The metal halide bulb (yellow arrow) is intact.

2.2.5 Sawmill electrical systems

The sawmill's electrical system consisted of two power distribution centres (PDCs) located in one room at F-10 (Appendix 4), numerous motor control centres (MCCs), overhead cable trays, and numerous switches and electrical disconnect boxes. Two transformers were located outside the sawmill. Nothing remarkable was found on either.

Throughout 2011, there had been problems with the north PDC main breaker, which would trip repeatedly. The mill's operations were using the maximum power available and work was beginning on an upgrade to the electrical system. A contract had been awarded for the PDC and capacitor upgrading, and some preliminary work had been completed. The main electrical installation was scheduled for the May 2012 long weekend.

The PDC and many of the accessible MCC panels were examined during the investigation. Many of the MCCs on the mill operating floor were not safe to access. Much of the electrical equipment was completely destroyed by fire, including most of the PDC switching components and many of the MCC components.

The British Columbia Safety Authority conducted an investigation into the incident as well. Their electrical inspector reported the following:

- Some of the cabinet doors on MCC-10 were found open and unlatched.
- Some of the electrical equipment that was examined – including lights, motors, disconnects, switches, and push buttons – were not certified for use in a hazardous combustible dust environment.
- Some cabinets and electrical boxes were found to contain significant levels of wood dust, enough to interfere with the equipment's safe operation.
- No evidence of arcing or electrical failure was found in the electrical equipment that was examined.

MCC-9 and MCC-10 were examined as this was the original area of interest. A number of the cabinet doors on the MCC-10 panel were found open and displayed burn damage, both external and from an internal source. The switching equipment inside the MCC was heavily damaged, more so near the top of the cabinets. There was no indication of arcing on the cabinet doors or in the electrical debris found within the MCC cabinet. The cabinets did contain wood dust in some areas. An explosion within the MCC-9 or MCC-10 panel was ruled out due to the lack of any pressure damage to the light metal doors or cabinet framework and the lack of arc damage or arc splatter on the inside of the cabinet doors. The area immediately in front of MCC-10 contained an intact metal halide light bulb, which likely would not have survived an explosion in this area or originating from this cabinet. As well, there were excessive accumulations of wood dust under the conveyor directly in front of this cabinet that was in direct line with any explosion originating within the cabinets. These accumulations would have been affected by any explosion in this area. The investigation into whether any of the many electrical cabinets and electrical equipment were an ignition source was inconclusive. There were no obvious signs of arcing or catastrophic electrical failure; at the same time, many MCC panels were not examined because of the hazards associated with reaching them.

The spark detection system control panel in the #1 chipper room in the basement level (in the area of J-20, Appendix 4) was completely destroyed by the fire. No information was available regarding the system's spark and flame detection activities immediately before the explosion.

2.2.6 Dust collection system

The dust collection system was examined during the investigation. The filter elements and wood dust had been consumed by the fire following the explosion. One of the two abort gates showed blast damage where the explosion pressure had broken off the gate from the assembly structure. No blast damage was seen inside the baghouse, but the baghouse had been displaced southward away from its original position. There was no evidence at either the debarker or bandsaw dust collection hoods and associated ducting to indicate that the explosion had originated in those locations and then travelled up into the baghouse or that the explosion had originated in the baghouse and exited the ducting at those locations.

WorkSafeBC investigators were not able to find any evidence to suggest that a spark or other hot material ignited within the dust collection system and baghouse creating this explosion.

2.2.7 Sawmill production equipment

The sawmill production equipment was run by electrical motors and pneumatic and hydraulic equipment. Hundreds of electrical motors of all sizes were found throughout the mill, and many of them were damaged by fire during the incident. The investigation reviewed the safely accessible motors and associated equipment that were identified as being in the vicinity of the explosion, that were reported by workers to be problematic, that were identified through maintenance records as being problematic, or that were suspected to be in any way involved in the explosion.

Some of these motors were found buried in wood debris from production activities and/or from the structure fire damage. Of particular interest – and the focus of this section – was the 7.5-horsepower (hp) electric motor and gear reducer that comprised the drive unit for the #2 sequenced-edger optimizer (SEO) waste conveyor, identified by the mill as 8R-25 (Figure 8). These were found to be significantly burnt, with blast damage radiating in all directions away from their mounted location (H-25, Appendix 4). In addition, there was a steel guard mounted over the motor's V-belt drive (incorrectly labelled "8R-26" by the installer or mill staff). The guard has two small inspection holes, and above and around these holes are fire and smoke patterns.

The motor was located in the half-basement, immediately below the #1 eliminator outfeed table, an area that was known to be very dusty. Because the output speed of the electrical motor (1,750 rpm) was too fast for the conveyor speed, the motor had been coupled with the 40:1 gear reducer to slow it down to a speed at which the driven conveyor could operate. The motor drove the gear reducer by means of two V-belts; in turn, the gear reducer turned the head-spool of the SEO waste conveyor by means of sprockets and a chain drive.

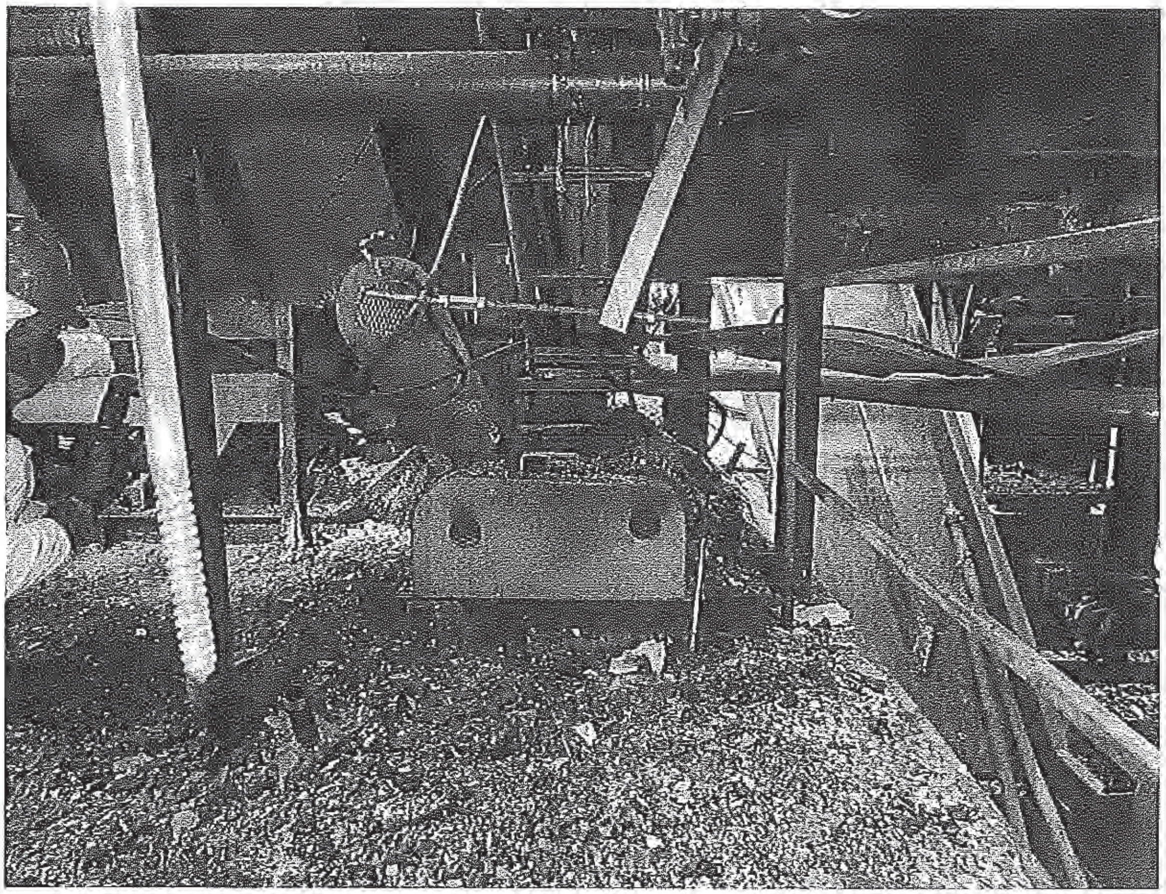


Figure 8: The motor and gear reducer assembly with guard, seen from north looking south. The drop to the full basement is at the right of the photograph.

The guard was removed on-site (Figure 9) and the following observations were made:

- The rear of the guard showed heavy burn damage in the centre area.
- The interior showed heavy fire damage, especially along the top.
- Within the interior of the guard, there were definite lines in the fire patterns. These lines angle away from the gear reducer sheaves and climb up the inside of the guard towards the motor sheaves.
- On the interior walls, there was evidence of very compacted wood dust residue.
- The two V-belts were burnt away between the motor and reducer.
- The V-belt remains were still sitting on the equipment sheaves.
- There was some un-burnt wood dust on the mounting plate within the guard.
- The front of the guard showed fire and smoke patterns emanating from the two inspection holes.
- The area outside the guard between the motor and reducer was significantly burnt.

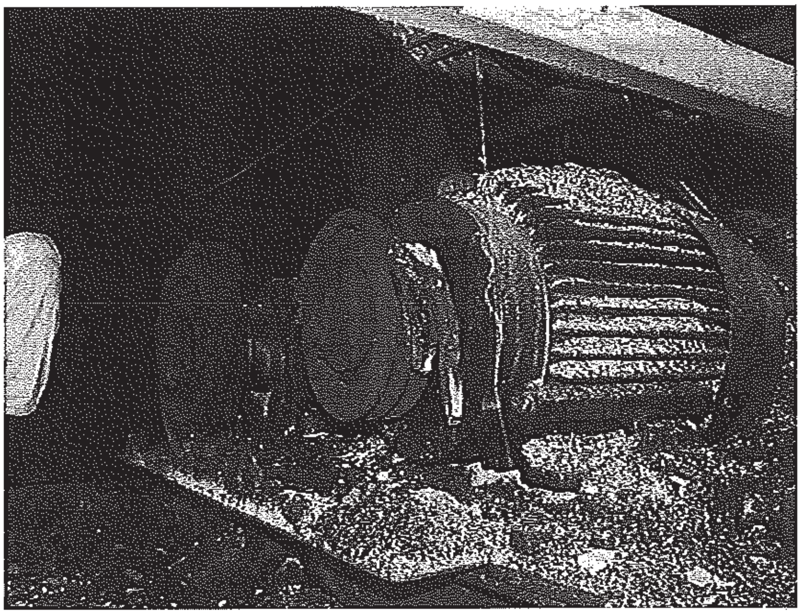


Figure 9: Motor and gear reducer assembly shown with guard removed.

The area behind the motor and gear reducer, which is under the head-spool of the #2 SEO waste conveyor, contained excessive amounts of wood dust (Figures 10 and 11).

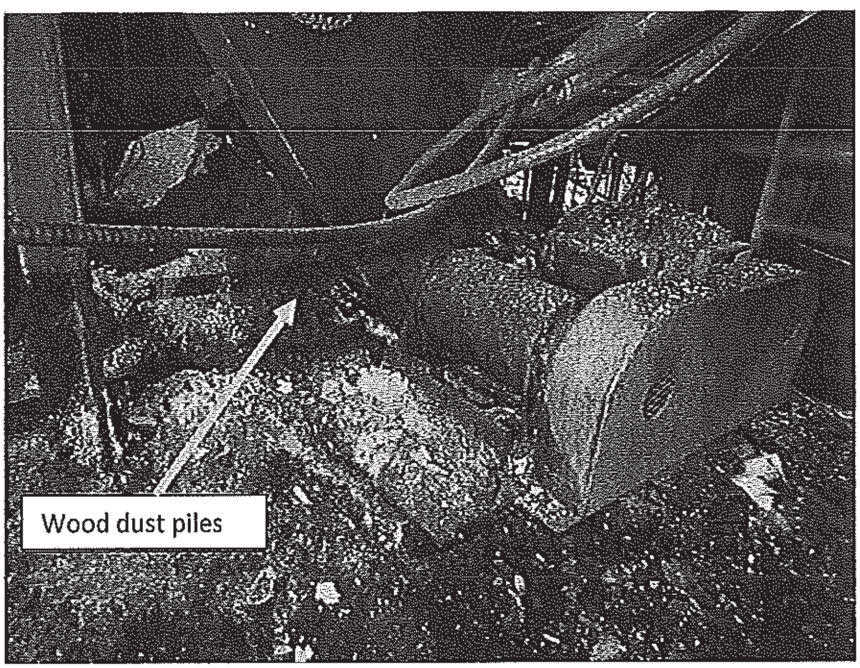


Figure 10: Excessive waste build-up was found under the eastern end of the #2 SEO waste conveyor 8R-25.

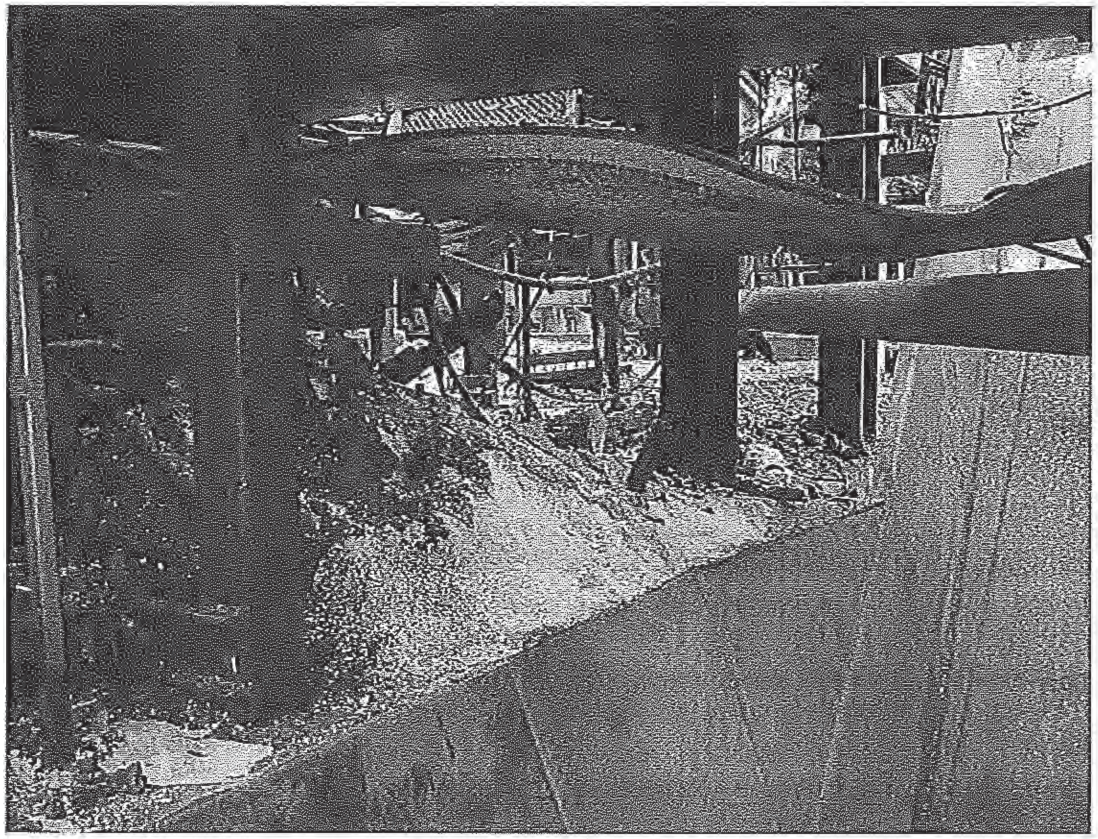


Figure 11: Excessive wood waste build-up was found behind the motor assembly.

The motor was tested at a Lower Mainland electrical facility, which reported that the 7.5 hp motor was found to be operating normally.

The gear reducer, V-belts, and guard were removed and at WorkSafeBC's request, examined by a forensic engineering firm that reported the following:

- Reducer – found to be operating normally.
- Two V-belts were burnt through in the centre areas, sections that had remained on the sheaves were found to have small particles of burnt and un-burnt wood dust imbedded into the belt where it contacted the sheaves. The V-belts burnt once the motor had stopped turning following the explosion.
- Fire was present within the guard assembly and the conditions within the guard were ideal for pyrolysis and smouldering in the presence of frictional heating.
- The presence of compressed sawdust, a confined space with limited oxygen, and a possible friction source through belt slipping, is an ideal combination for a smouldering fire.
- This smouldering fire within the guard preceded a flaming fire of short duration.

Internal measurements of the guard were taken and compared with the original design drawings for the available interior clearances and fit. The original design drawings indicate that there was a designed 1.5-inch circumferential clearance between the sheaves on the gear reducer and the interior wall of the guard (Figure 12). The actual clearance measured between the sheaves and the interior wall, however, was only between 0.125 and 0.5 inch (Figure 13), based on the slot cut into the rear of the guard where it was fitted over the shafts of both the motor and gear reducer. This is significantly smaller than the original design clearance for this area of the guard.

The construction of the guard was unusual in that it was made of steel plate; normally these types of guards in a sawmill environment are constructed using expanded metal, which permits visual inspection of the belts and equipment without removing the guard and also provides ventilation. The other guards observed throughout the sawmill were the expanded metal type. This guard, along with the motor and reducer assembly, was part of a conveyor project completed by a Prince George fabrication and engineering contractor in September 2011. The project involved repositioning two conveyors that serviced the two edgers and installing a new conveyor that carried wood waste from these two conveyors and transferred the wood waste to the #2 chipper's vibrating infeed conveyor, 8R-23. This area had restricted access, and the purpose of the guard was not to protect workers but rather to protect the equipment from falling wood and debris, or in the event that workers may have used the equipment as a step.

Babine submitted to WorkSafeBC the maintenance and work order records for the motor and reducer set. The records show that conveyor 8R-25 was a recent modification that was designed and installed by an outside contractor in late summer 2011. The motor and drive unit was installed by the contractor but the wiring was done by mill electricians. The conveyor was re-tensioned in October 2011; subsequently, a replacement guard for the chain drive had to be constructed because the chain was making contact with the inside of the original guard.

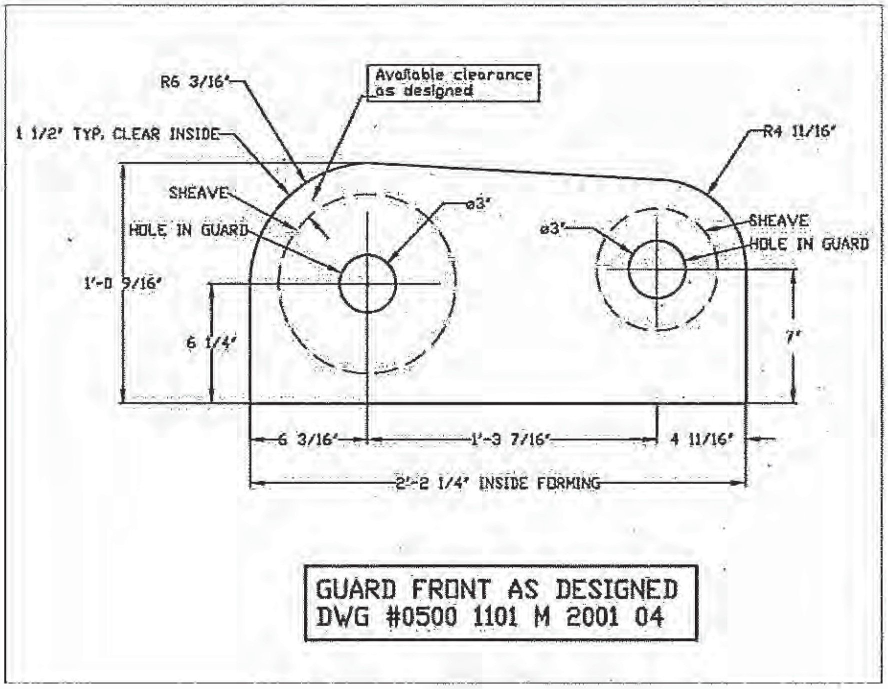


Figure 12: *The original design drawing as re-created by WorkSafeBC. The red circles represent the sheaves within the guard. The gear reducer is to the left, while the motor is to the right.*

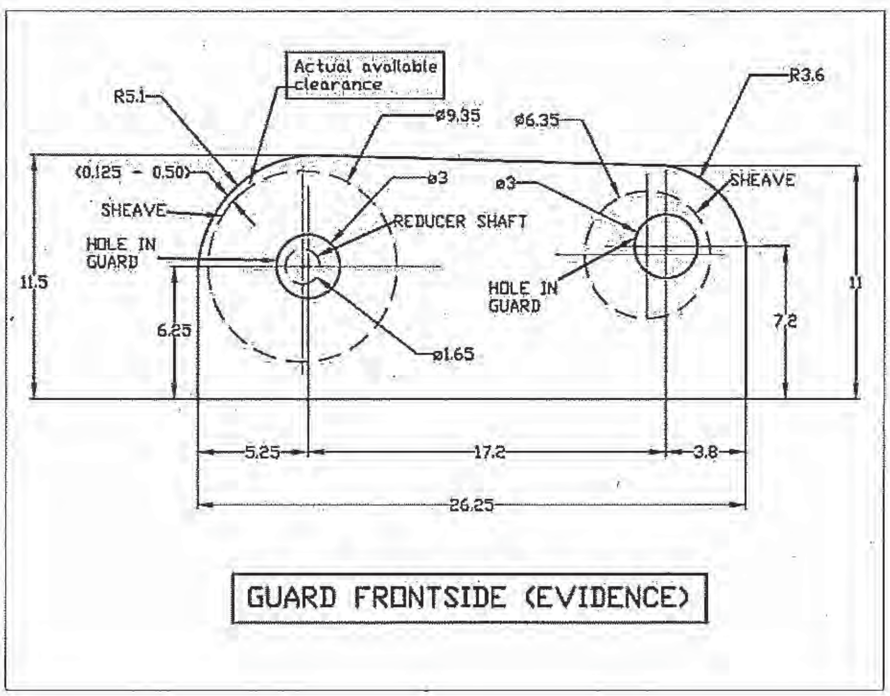


Figure 13: *The actual clearance available within the guard as calculated by WorkSafeBC.*

2.2.8 Summary of ignition findings

In this incident at the Babine sawmill, the most likely ignition source was a fire within the space enclosed by the guard covering the drive motor-reducer sheaves and V-belt assembly of waste conveyor 8R-25. All blast vectors radiate from the immediate area (see Appendices 8 and 9) of the motor-reducer assembly indicating that it was the epicentre of the initial explosion. The examination of the guard indicates that smoke and fire had occurred within it and had emitted from the front inspection holes. The area immediately behind the assembly contained excessive amounts of sawdust, some of which survived the explosion as this area was protected by the conveyor structure above it. Over-flow of wood dust from the conveyor most likely covered the motor-reducer assembly prior to the explosion. This wood dust was exposed to the explosion pressures and most of it was displaced or consumed during the primary explosion. What remained on the equipment became tightly packed within the cooling vanes of the motor-reducer assembly.

The motor-reducer assembly was protected from burning materials from above by the high conveyor skirting and from the side by the guard's tight fit onto the metal mounting plate. It is not likely that the fire migrated from other areas and into the guard. The excessive accumulations behind and on the motor-reducer assembly would likely have shown much more fire damage if the fire had started there and migrated towards the guard. The post-incident testing of both the motor and the reducer did not support either as a cause or an ignition source.

The investigation looked at what most likely happened inside the guard to cause the primary explosion.

The constant vibration of the motor-reducer assembly and nearby conveyors facilitated the migration of wood waste, particularly the fine particles, through the back of the guard, through the drive shafts slots, and into the confined area, where the dust particles accumulated. This process can be compared to what happens when sand is piled higher and higher and the leading edge slides forward into any available space.

The motor-reducer assembly was located directly below where waste conveyor 8R-25 dumped debris into the #2 chipper's vibrating infeed conveyor 8R-23. There was constant vibration in this area and wood waste kept overflowing, covering both the motor-reducer assembly and the area beneath conveyor 8R-25. Wood dust was continually agitated and settled into the free spaces behind the guard, where the slots for the drive shafts were located, and it eventually built up within the guard over time. The dynamics of the rotating V-belts drew the wood dust to the east side within the guard, where the reducer sheaves were located. There was little available clearance within the guard itself, and the wood dust was compacted against the sheaves, the inner walls of the guard, and the rotating V-belts.

Figure 14 illustrates the likely sequence of events within the guard.

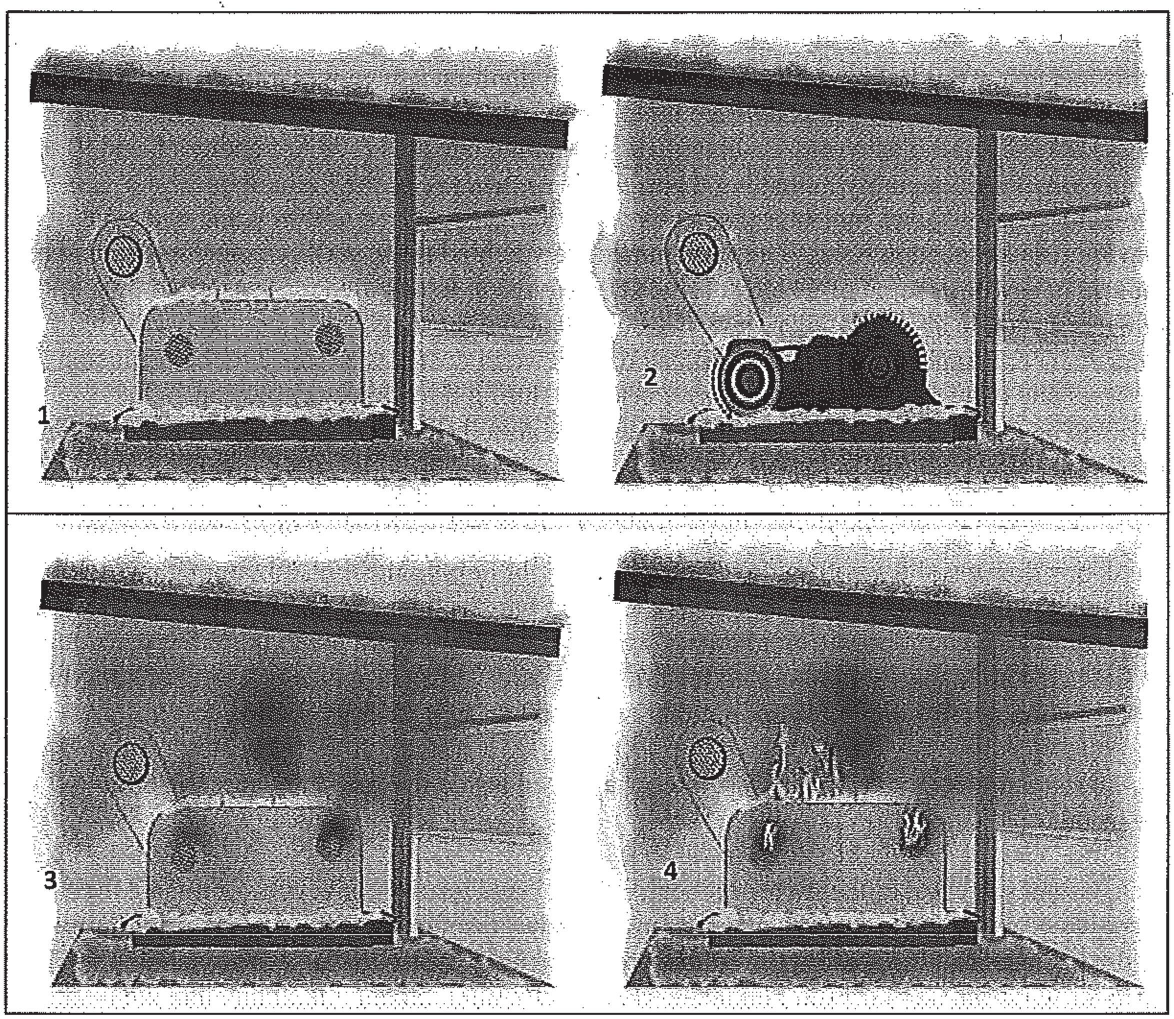


Figure 14: *An artist's depiction of the most likely sequence of events within the V-belt guard:*
(1): The motor-reducer assembly in place.
(2) The rotation of the V-belts and the build-up of saw dust (with the guard is removed for clarity)
(3) The smouldering fire created by the frictional heating of the V-belts through the compacted sawdust.
(4) The smoulder reaching areas where oxygen is available and a full flame develops. The explosion of the wood dust in the surrounding air followed.

As the wood dust built up within the guard, it was broken down into smaller and finer particles as a result of continual contact with the rotating belts. Eventually, on January 20, 2012, the friction from the rotation of the sheaves and V-belts within the compacted, combustible wood dust caused the wood dust to begin smouldering within the guard. A defined flame probably did not occur for some time because of the lack of oxygen within the guard (air was limited because of the extremely small inspection ports).

The compacted wood dust had likely become so thick that the V-belts were fully in contact with it all the time, and sufficient friction was generated to ignite the wood dust. The wood dust was compacted (layered) at an angle within the guard as the V-belts pushed it against the interior walls of the guard.

The smouldering continued for some time and travelled through the compacted wood dust in the direction in which the V-belts pushed the available oxygen. It eventually reached a point near the guard inspection ports, where oxygen was more readily available. The smoulder quickly transformed into an open flame, which probably lasted for some minutes. A layered ignition test (LIT) performed on wood dusts from the sawmill indicated that the layered dust could ignite at a temperature as low as 310°C (see section 2.5.2).

It is likely that the smouldering and flame lasted for some minutes before the explosion and set off the fire alarm bell at dry-valve (DV) 22, outside the mill's north wall (C-23, Appendix 4), as it escaped through the guard inspection holes. There were three alarm bells on the outer walls of the sawmill: DV-21 on the west wall, DV-22 on the north wall, and DV-23 on the east wall at the south end of the sorting building. Each dry-valve has a sprinkler and piping system for its area of the sawmill. DV-22 serviced the centre area, beneath the eliminators. Operators in this area stated that they could not hear this alarm when the sawmill was running and the processing equipment was in operation.

The Watchman reported that he responded to a fire alarm from within the sawmill at approximately 20:00. He was in the mobile shop to the west of the sawmill when the alarm went off, and he had to physically go to each alarm to determine which one had activated. He went to DV-21 first (D-Xb, Appendix 4) and found that it was not activated. He had begun travelling east through the basement level when the explosion occurred.

The operating conveyors, screens, and other equipment in this area were agitating the fine dust particles and dispersing them into the air. The SEO waste conveyor 8R-25 was transferring wood waste and "fines" into the #2 chipper's vibrating infeed conveyor, and screens were separating out the "fines" and wood chips immediately to the west, as were a number of other vibrating conveyors in the area. All these conveyors were open, some were vibrating and moving, and materials were being transferred from one to another. The wood dust concentration in the air may also have been affected by a timed dump of wood "fines" from the baghouse onto nearby conveyors. At a certain point, the dust in the air was ignited by the flame within guard of the motor-reducer assembly, deflagration of the dust took place, and a catastrophic explosion occurred.

2.3 Potential sources of fuel in the sawmill

The sawmill had a number of potential fuel sources for an explosion. These were examined to determine if they contributed to this incident. The findings are summarized below.

2.3.1 Thermal oil heating system

The Babine sawmill was serviced by a thermal oil heating system. System piping from the energy system building east of the mill and was routed across the mill's roof before descending to the heat exchangers at H2-17 (Appendix 3). The thermal oil did not enter the mill proper but was used to transfer heat to the water and glycol heating system which was distributed through piping to heaters throughout the mill.

After the incident, the thermal oil lines were found damaged by the explosion and were displaced from their original location on the roof; they were also leaking in some areas near the south wall of the mill. Some of the thermal oil as well as water and glycol were collected for further laboratory testing to determine whether their flash points and flammability might have contributed to the explosion or subsequent fires. Testing was based on American Society for Testing and Materials (ASTM) D3065, "Standard Test Methods for Flammability of Aerosol Products," modified to study hot pressurized liquid sprays. The results are shown in Figure 15.

Sample	Temperature (°C)	Pressure (psig)	Autoignition?	Ignitable?	Fuel a fire?
Glycol EXH #559	57	30	No	No	Yes
Hot Oil Sample EXH #561	232	50	No	Yes	–

Figure 15: *Laboratory test results for thermal oil and glycol flammability.*

Based on characteristics, WorkSafeBC investigators ruled out thermal oil and glycol as the fuel for the explosion although they may have contributed to the fire following the explosion.

2.3.2 Natural gas

There was natural gas service to the sawmill. The service came from the east, to a regulator mounted on the eastern outer wall of the sorter building at approximately V-27 (Appendix 3). The gas line was routed up the wall to the roof, and then across the sawmill to approximately H-15 (Appendix 3). It was routed down to a ground-level regulator and valve assembly, entering the boiler room just north of this point and then branched off to service the four make-up air units. There was also an underground service line running through the property to other areas.

Some workers reported to investigators that in the weeks leading up to the incident they had detected a gas odour at various areas of the mill. Earlier in the day on January 20, a worker reported over the radio that he had smelled gas in the basement level.

The main gas service piping into the boiler room was cut by investigators outside the sawmill foundation, so the valve and regulator could be examined. The piping came away freely from within the boiler room. There was no resistance even though the other end of the piping should have been connected to the boiler with a threaded pipe connector. In the section of pipe that was removed, the bottom (boiler) end of the pipe section was found to be completely plugged with ice. The end of the piping extending out from the boiler was also found to be completely plugged with ice.

The main valve in this removed pipe section was found in the off position. British Columbia Safety Authority (BCSA) personnel and the service provider performed a field test on this valve. This test involved adding pressure to the pipe section and observing whether the pressure escaped and/or bypassed the valve. The valve flanges were found to be leaking and some pressure was bypassing the valve. The section was removed and examined at the forensic engineering facility at the request of WorkSafeBC. The following findings were reported:

- There was no leakage at the valve or flanges when pressurized for a 15-minute period.
- The threaded connector could not be threaded onto the boiler pipe extension the way it was supposed to.
- The threads on the boiler pipe extension were very rounded and damaged. They did not show evidence of being sheared or tensioned by being pulled apart.

There are several possible reasons why there was leakage in the field but not in the laboratory. The field testing was done in extremely cold conditions, which may have affected the materials, the valve lubricants, or the manner in which the testing was done. Alternatively, the valve and piping had been exposed to the elements for some time and corrosion had taken place. The corrosion could have fortuitously plugged any leaking areas prior to the laboratory testing.

The boiler was serviced by a local contractor on December 3 and 10, 2011. On December 10, the burner plate was removed and cleaned by being blown out, and then reassembled. Normally, the gas service is disconnected before removal of the burner plate and then reconnected after reassembly. The connector nut was found unconnected, with no damage to indicate that it had been pulled apart.

No leakage was detected in the other gas lines to the make-up air units. The regulators of the make-up air units located at the west wall (approximately C-Xb, Appendix 4) were mounted outside, on the wall. From time to time, these regulators expelled small amounts of gas to the atmosphere, as they were designed to do. The gas odour from these events was known to migrate into the mill.

Several workers reported smelling gas in various areas of the mill prior to the incident:

- One clean-up worker stated that she smelled gas quite often in the courtyard areas when walking from the parking lot at the south side of the mill.

- The A-Shift Edger Operator stated that he smelled gas the day before the incident, while working in the basement below the vertical double arbour (VDA) gang-saw (E-23, Appendix 4).
- Basement Attendant 2, the day-shift basement attendant who was working the afternoon shift on January 20, reported over the radio on the day of the incident that he smelled gas in the basement areas, but he could not be interviewed to determine the locations in question. Basement Attendant 2 also reported occasional gas smells. His work area was around the #1 chipper (J-20, Appendix 4) and throughout the basement.
- Millwright 3 reported to investigators that the outside regulators for the make-up air units located at the west wall of the basement would occasionally vent and would migrate back into the mill.

Millwright 1 normally looked after the gas and boiler systems at the sawmill. When he heard the January 20th report of a gas smell, he walked the length of the entire gas system and found no leaks or gas odour in any area of the mill. He theorized to investigators that the gas system had flexible joints and that the change from extreme cold the week before the incident to higher temperatures on the day of the incident may have resulted in expansion of these joints and small, brief leaks. WorkSafeBC engineers researched this and found that a 1-metre long steel component would increase by 0.3 mm in length if temperature increased from –40°C to –20°C. This is a plausible explanation.

The boiler gas service was at a very low volume. If the valve had been leaking, gas would have accumulated in the boiler room, where the valve was located and where this section of piping joined to the boiler. However, Millwright 1 was in the boiler room the day of the incident and detected no gas odour. Other mill workers and a contractor had gone in and out of the boiler room while repairing a leaking water line in the days before the incident, and they reported no gas odour either.

A break in the underground service line was found in a ditch approximately 130 feet southwest of the sawmill building. The break was leaking at a very low volume and it is very unlikely that there was migration of gas to the mill from this area. Workers travelling near this area may have detected gas odour from time to time.

A sufficient concentration of natural gas vapour in the air to ignite and create an explosion would have been readily detected. The odour would have nauseated the workers in the immediate area; however, various workers travelled throughout the mill on the day of the incident and reported no gas odour. The British Columbia Safety Authority reported that the odour level of the natural gas supply was adequate to easily alert workers to the presence of gas. There was no source found for the odours reported by some workers in the weeks leading up to the incident.

Natural gas has been ruled out as a main fuel source for the explosion, as the quantity that would have had to have been available and confined inside the mill would have been easily detected by workers during their regular shift work, and the concentration and odour of the gas would most likely have made them ill. Gas did play a role in the fire following the explosion, however. The gas service line to the mill above the regulator mounted on the east wall of the sorter wing at V-27 (Appendix 3) was recorded as broken at 20:07 due to the explosion, and gas continued to flow freely until it was shut off at 20:47. This uncontrolled release of natural gas at 60 psi into the sorter wing of the mill fuelled the fire in this area, which ended up being one of the worst damaged areas of the sawmill structure (Figure 16). Natural gas was therefore a contributing fuel for the fire following the explosion in this incident.

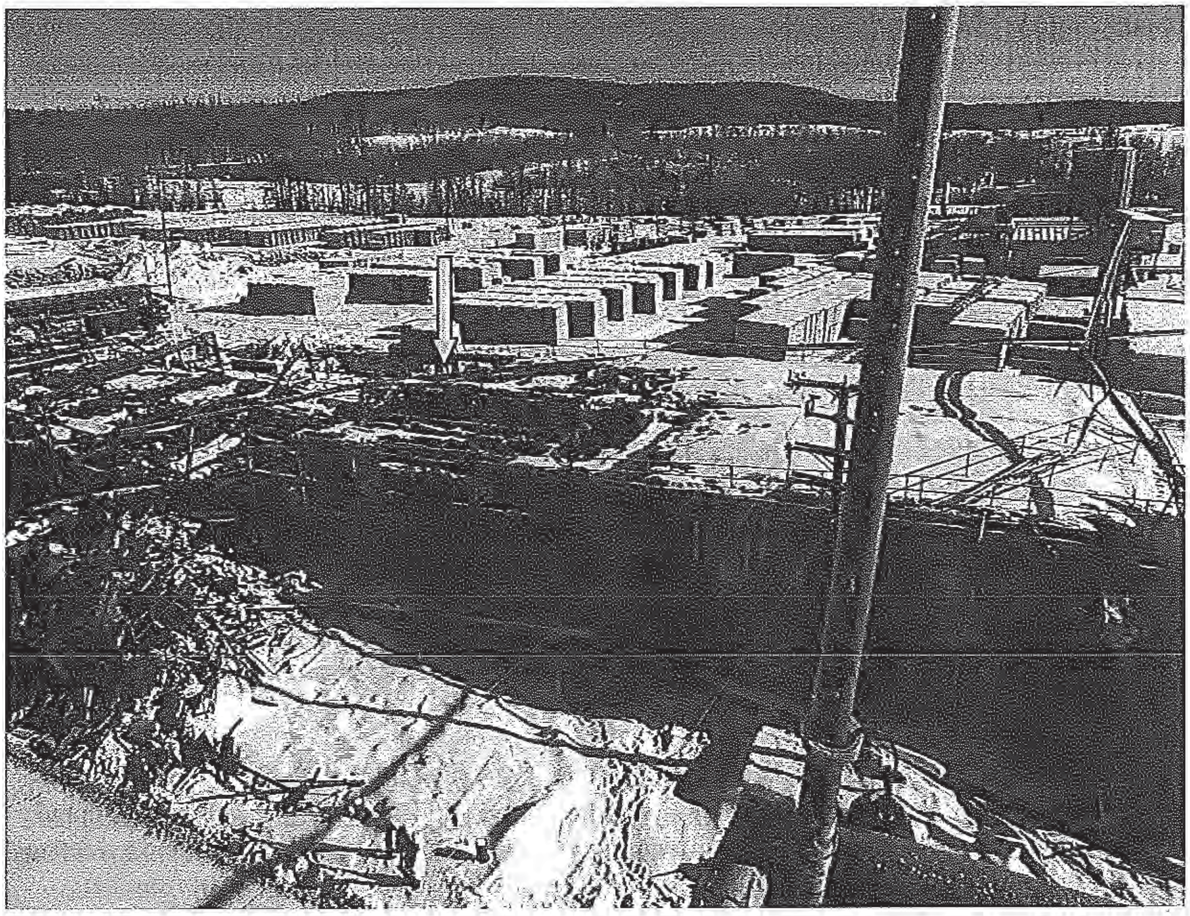


Figure 16: *View of the sorter wing of the sawmill, looking east. The yellow arrow indicates approximately where the natural gas line broke. The fire damage near this location is evident.*

2.3.3 Welding and cutting gases

Oxygen and acetylene bottles were mounted on carts throughout the sawmill. Some of these were inaccessible; others were viewed from a distance. When not cart-mounted, the bottles were placed in a storage area outside the south wall of the sawmill, in the courtyard area. These bottles were unremarkable and did not contribute to the explosion. On a raised storage platform near structural column H-25 (Appendix 3), a number of stored bottles had tumbled and upset. They were not ruptured but it could not be determined whether or not they had vented. The explosion vented through the sawmill roof near this area, approximately 50 feet to the northwest. It is unknown whether these bottles contributed to fuelling the explosion.

One oxygen/acetylene torch set mounted on a cart was found at D-21 (Appendix 4), with the gas hoses and cutting torch strewn on the ground. This was unusual as normally the hoses were wrapped onto the cart after use. This cutting set was removed for laboratory analysis to determine its possible involvement in this incident. The main valves were marked prior to removal to record their original position. After removal, the oxygen bottle valve was found to have moved from the marked position by an approximately 3/4 turn of the main valve handle towards the open position.

The laboratory examination of the oxygen bottle found the following:

- The oxygen bottle was empty, and the main valve was slightly open. This could mean that if it had contained oxygen when it was exposed to high heat, the safety release device had operated as designed and released the oxygen before the tank could explode. Alternatively, the oxygen may have leaked out or the bottle was empty before the explosion and fire.
- The hose from the oxygen bottle to the cutting torch was also burnt through and the gas may have escaped through this opening.

The acetylene bottle was also examined and the following was found:

- It had completely vented through both safety releases. The fact that venting occurred means that the tank's safety features had activated when exposed to high heat. These features are located immediately below the main valve handle and regulator.
- The main valve was approximately one-third open.
- The main valve handle was melted away where the bottle "candled," indicating that it still contained gas when the tank vented. (Candled refers to the gas burning as it escapes upwards, resembling a candle.)

If the oxygen bottle was leaking prior to the incident it likely would have gone unnoticed but if the bottle vented oxygen when exposed to the deflagration and fireball, the oxygen would have increased the strength of the explosion. The same is true of the acetylene gas. Here the evidence suggests that there was still gas within the bottle when it was exposed to high heat from the deflagration and fireball, and this would certainly have fuelled the explosion and subsequent fire.

When the oxygen bottle valve was marked, it was already slightly open. It is known that some workers who use cutting torches turn off the torch and not the main valve when they have finished their work. Millwright 3 stated that the contract crews working with him along the northern basement wall on the day of the incident were using this particular oxygen/acetylene torch set. The workers were installing heat tape on the main water line running along the north wall of the sawmill, and they were using the torch to warm their hands. This would explain why the valve was only cracked open: the workers would not want a cutting flame on the torch – just a small flame to help them keep warm.

In summary, neither oxygen nor acetylene was an ignition source for, or a cause of, the explosion; rather, the explosion originated south of where the bottles were found and then passed over and beyond their location. When exposed to the high explosion temperatures, however, the bottles vented as designed, and the gases (if they contained gases), fuelled and increased the violence of the explosion. Immediately above this area is where the Yardman reported the sawmill roof being blown off.

Finally, a 20-pound propane tank was found in the mill following the explosion. This tank had a heater attached to it and was being used by Millwright 1 on the day of the incident. It was found behind MCC-10 (H-16, Appendix 4). Its main valve was fully closed and the safety release had vented due to the high heat resulting from the explosion and fire. Approximately 1 pound of propane was left in the tank. It was not an ignition source or a causal factor in this incident. No other welding or cutting sets were found near the explosion's point of origin.

2.3.4 Hydraulic systems

The Babine mill had three main hydraulic power-pack rooms servicing various equipment centres. These rooms contained the hydraulic oil reservoirs, pumps, and motors necessary for the system to function.

The line-3 room was located in the basement level under the log-turner and chip-saw infeed belt (F-11, Appendix 4). The room was approximately 25 feet by 16 feet and was enclosed with drywall (on the inside of the room), stud walls (outside the room), and ceiling. It was supplied with air through three separate inlets to maintain positive pressure and prevent wood dust from entering. A single steel door on the east side swung outward; double steel doors on the west side also swung outward from the room. During the investigation, the room was partially dug out and examined. It was determined that the walls and roof of this room had collapsed on top of the hydraulic equipment and electric motors, preserving the conditions below this. There was no evidence of an explosion originating in this area. The condition of the doors indicates that a pressure wave moved from east to west through this area. The doors on the west side were pushed to the west. The oils in this room may have fuelled the fire following the explosion.

Another hydraulic room was located outside the north wall of the sawmill (C-15, Appendix 4) and serviced the equipment centres in that area. This room was also approximately 25 feet by 16 feet, with concrete walls. After the incident, the room was buried in collapsed steel members and equipment, and significant overhead hazards made it impossible to access. The conditions observed and the lack of blast damage radiating from this area rule out this room as containing the fuel source for the explosion, although the oils here may have fuelled the fire following the explosion.

The third hydraulic room was located on the ground level at H2-18 (Appendix 4) and serviced the edger equipment centres above it. This part of the building was steel-framed, with concrete floors and wooden walls within a steel column structure. There was no obvious blast damage in this area, other than walls and exterior equipment being pushed out by pressure from within the sawmill, but the hydraulic room and equipment suffered severe fire damage following the explosion. A number of oil storage tanks were located here, and many hydraulic and oil lines ran up to the edger equipment centres above. These lines were damaged and severed by the explosion, and because of the partial collapse of the structure, gravity fed the oil back into the fire that followed the explosion. This area also contained sections of thermal oil piping that had been displaced southward from its original rooftop position, also potentially fuelling the fire following the explosion.

2.3.5 Other oils

A gear oil room was located in the basement level (E-23, Appendix 4). This area was directly below the location where the explosion vented through the roof of the sawmill. The oxygen/acetylene set discussed in section 2.3.3 was found 10 feet west of this room. The walls of the gear oil room were pushed westward, and one of the large reservoir tanks had been moved from its original location. The deflagrating explosion expanded outward from the 8R-25 motor-reducer assembly location (H-25, Appendix 4) and was guided into this area by all the restrictions created by the various conveyors and equipment. The condition of the walls and displacement of the tank are evidence that the pressure front came from the south and east and did not originate at the gear oil room.

Above this area on the operating floor, significant quantities of sawdust had been generated by the VDA gang-saw and the nearby HDA gang-saw. These dusts settled through the floor openings near this gear oil room as well as in the area above on the operating floor. When the deflagration reached this area, it grew tremendously with all the available wood dust fuel and vented through the operating floor level and through the sawmill roof.

The contents of the gear oil room were examined and discounted as an ignition source or as a significant fuel source for the explosion. The oils may have contributed to the fires following the explosion.

2.3.6 Methane

Methane gas is produced naturally. It is an organic compound and a major component of natural gas. At room temperature and standard pressure, methane is a colourless, odourless gas. It is flammable over only a narrow range of concentrations (5–15%) in air. That is, there needs to be at least 5% methane in air to ignite (the lower explosive limit). If the concentration exceeds 15% (the upper explosive limit) the methane concentration is too rich to ignite. Methane is lighter than air and rises and disperses easily. It must be contained (or a major release must occur) if it is to reach dangerous levels. It can be produced under certain conditions where wood waste decomposes, such as in landfill sites and large wood waste stockpiles. It is unlikely that small wood waste/sawdust piles would have the right conditions (sufficient time and anaerobic [no oxygen] conditions) to produce the decomposition gases, such as methane, in a large enough quantity to have been a fuel source for the explosion.

There was no history of the presence of methane gas or any problems associated with it at the Babine sawmill, or any evidence that methane was involved as a fuel in the explosion.

2.3.7 Sawdust and wood waste

The sawmill's two saw-lines processed approximately 65,000 board-feet per hour of lumber. These numbers and slightly higher production volumes were reached only in the latter part of 2011, from September through December. The mill had been processing mountain pine beetle–killed pine from Monday through Wednesday and shifting to green spruce on Thursday and Friday. The Maintenance Superintendent stated to investigators that the dust from the beetle-killed pine was totally different from the dust from green wood. Beetle-killed pine is extremely dry and brittle, and generates a significant amount of fine wood dust during processing.

The Maintenance Superintendent stated to investigators that the biggest issue with the mill was the basement conveyors; they were under-sized and subsequently had a hard time moving debris out of the mill. The President of Babine Forest Products stated to investigators that the mill was not designed for processing beetle-killed wood because of the breakage and wood waste. He further stated that there had been some work done in the basement to improve the conveyor systems and on the processing floor to open up areas for the waste to drop through to the basement conveyors.

Various workers and supervisors commented on the conditions:

- "We have an undersized baghouse."
- "Lots of complaints about dust."
- "The dust in the mill was bad. . . . When we're running [dust was] in the air, and then it would settle in the basement. . . the dust was worse down there."
- "[Bugwood is] a totally different dust than any sawmill dust that I've ever seen. . . .almost looks like a dirt dust."
- "The dust [piles] on top of those [disconnect] boxes themselves were probably 8 inches deep."
- "Those [sawdust] piles [were] just way over my head."
- "But the bugwood would create the worst [air]. Sometimes you couldn't see across [the mill floor]."
- "You'd have to go into sawdust piles four feet high to go work on something. And you're working in these sawdust piles."
- "There were . . . mountains of broken debris and sawdust everywhere."
- "The basement's a different story, it was horrendous."
- "You could always see a dusty haze through the whole mill."
- "[The sawdust was] really fine. . . . The stuff . . . flies around and it gets up there."
- "There was a lot of dust in there. . . . Sometimes we could barely see [across the mill]."
- [The sawdust build-up was] everywhere on beams, handrails, stairs, the floor even."

- "All around these debarkers . . . were the hardest to [walk] around, because there' just so much waste. . . . In the basement . . .there's piles over here. Piles over there. . . . All around here was piles of waste."

Figures 17 to 24 illustrate the unacceptable problem with dust accumulation at the sawmill.

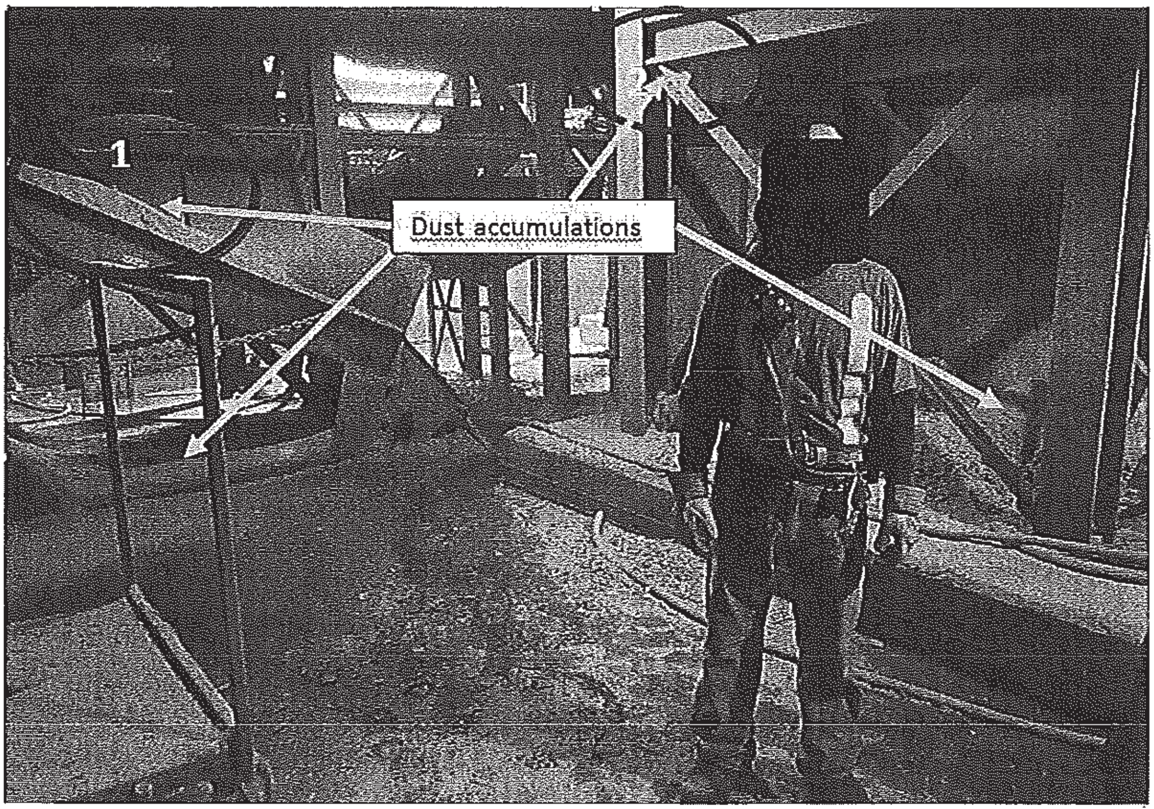


Figure 17: *Dust accumulations in the basement level of the sawmill. (Photograph by WorkSafeBC, November 22, 2011.)*

Figure 18: Dust on the conveyor labelled (1) in Figure 17. (Photograph by WorkSafeBC, November 22, 2011.)

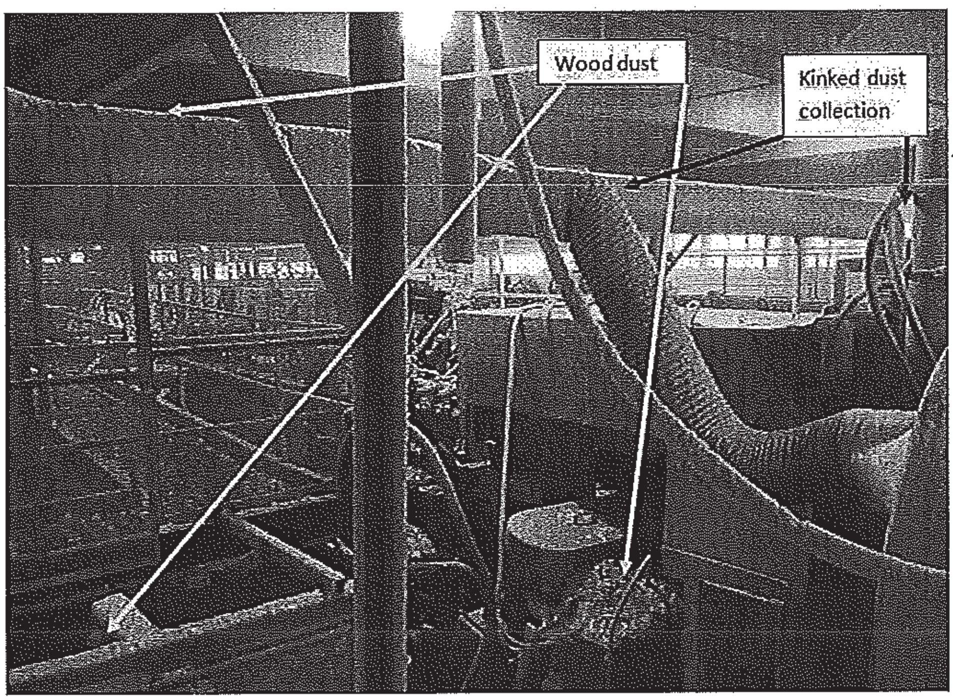


Figure 19: Wood dust on bandsaw equipment and ducting as well as the kinked areas which restrict flow. (Photograph by WorkSafeBC, November 23, 2011.)

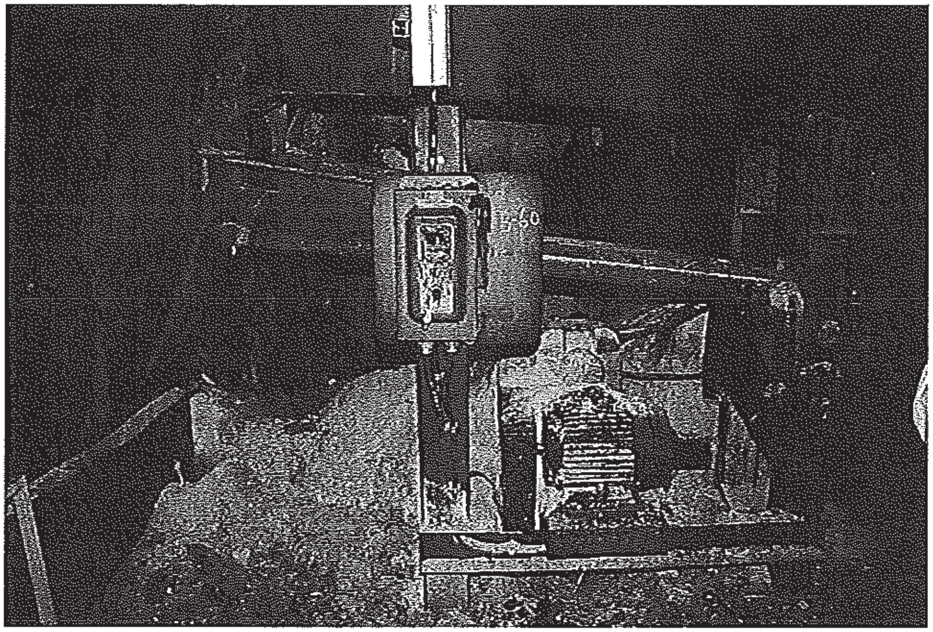


Figure 20: *Wood dust and waste accumulations around the head-spool of waste conveyor 9-36 where it terminates and dumps into the main north wall waste conveyor 6-53 (C-25, Appendix 4). This wood waste was protected from the explosion travelling west over the conveyor structure. (Photograph by WorkSafeBC, following the explosion.)*

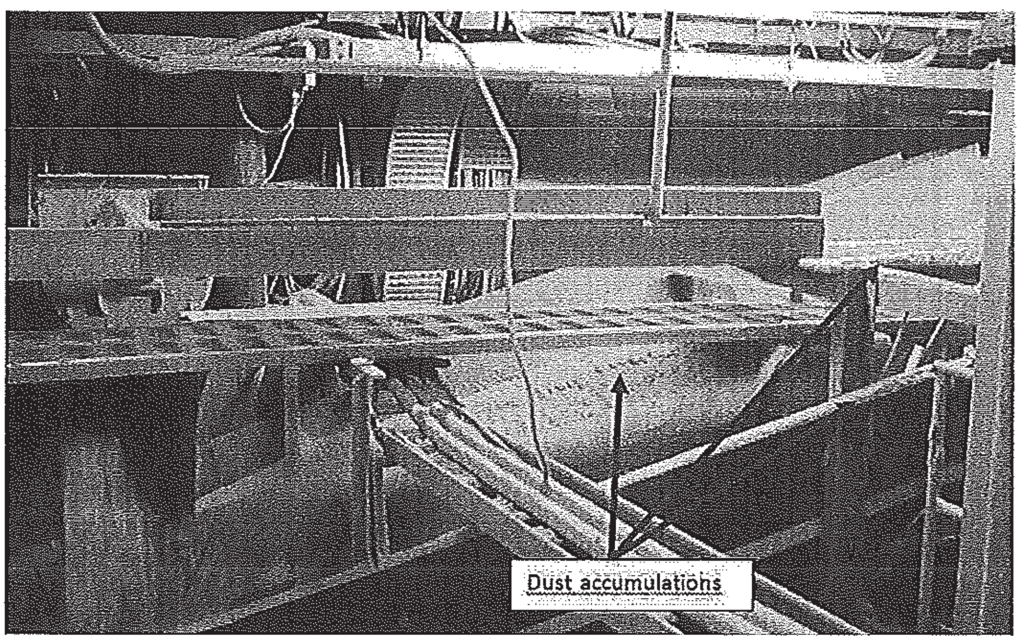


Figure 21: *Dust accumulations near H1-23 (Appendix 4). (Photograph by WorkSafeBC, November 22, 2011.)*

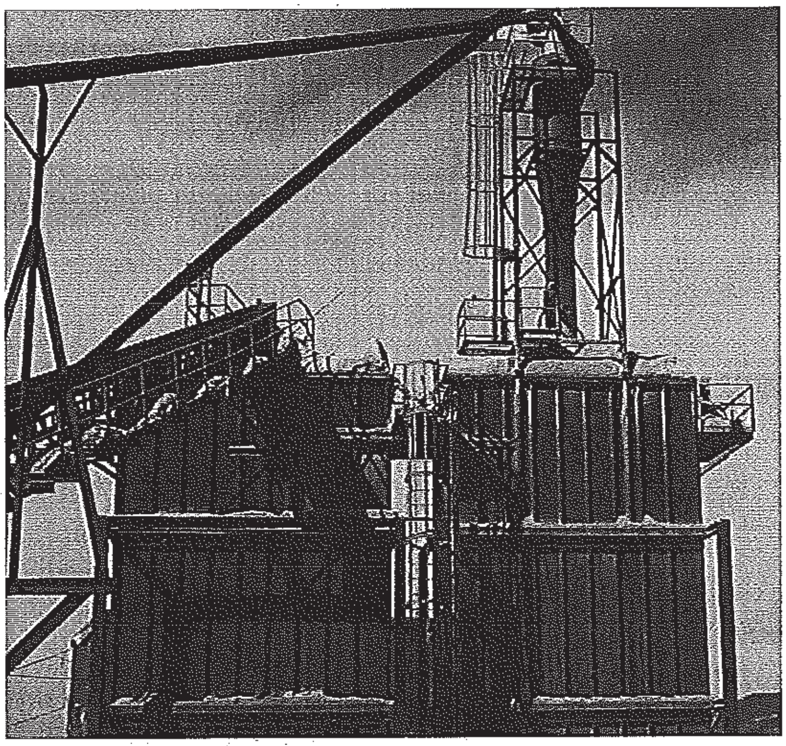


Figure 22: *Storage bins to the west of the sawmill, with dust accumulations 2 to 3 feet high. (Photograph by WorkSafeBC, after the incident.)*

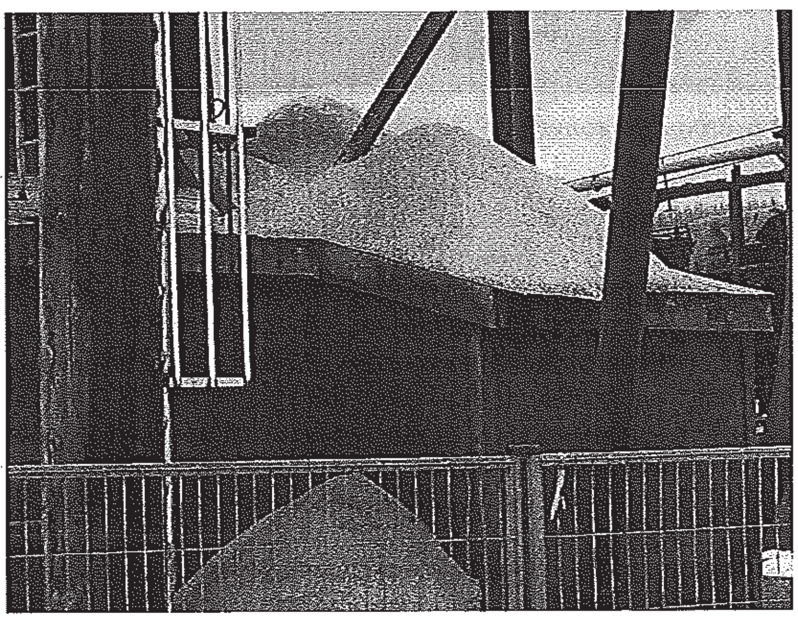


Figure 23: *Dust accumulations in the area immediately south of the sawmill, beside the sorter wing. (Photograph by WorkSafeBC, after the incident.)*

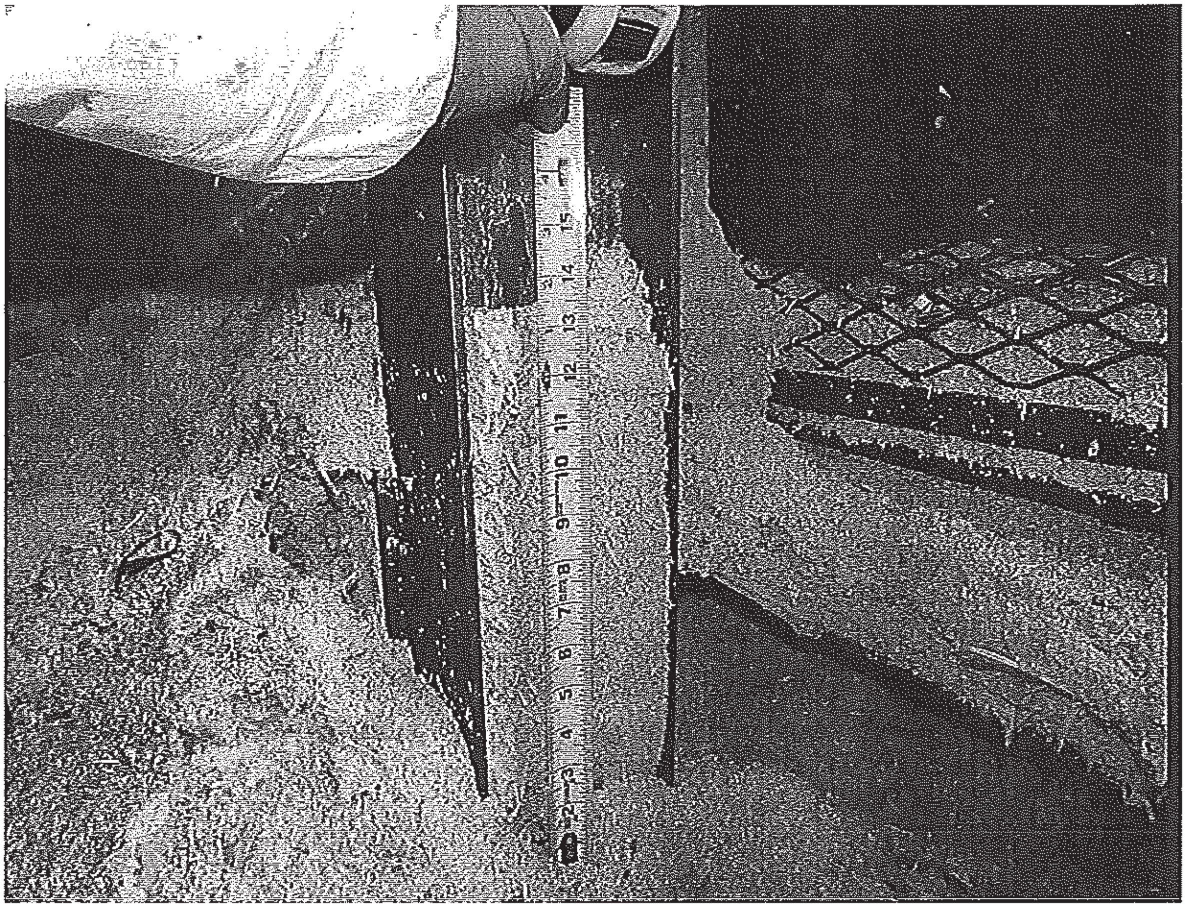


Figure 24: Dust accumulation in the area near conveyor 9-32 (C-25, Appendix 4. Photograph by WorkSafeBC, following the explosion.

2.3.8 Summary of fuel findings

The evidence shows that wood dust was the primary fuel for the explosion in the Babine sawmill on January 20, 2012. The day before the incident, the production shift had been shut down halfway through the shift because the basement waste conveyors were completely overwhelmed with sawdust accumulations. The water from the frozen and broken lines got into the sawdust piles in some areas of the basement. This resulted in some of the dust in some of the areas on the floor and conveyors freezing. This was not the case in all areas of the mill. The whole crew assisted with clean-up and with breaking up the frozen sawdust accumulations and shovelling them onto conveyors for transfer out of the mill. Some of the workers used jackhammers to break up frozen accumulations, which in turn would disperse more dust into the air. The clean-up was interrupted shortly after it began, however, because of work on the main water line along the north wall, which could not proceed while waste conveyor 9-35 (the main waste conveyor carrying wood waste out of the mill) was running. The accumulations remained in the mill basement and were added to when production resumed the following day, the day of the incident.

2.4 Containment of the primary explosion

An additional component required for an explosion is containment. Without containment the components would simply be combustion resulting in fire with no pressure development. If these components are contained and ignition occurs, the pressure develops to a degree that typically is violent and destructive. WorkSafeBC investigators looked at the blast pattern evidence to determine direction (Appendices 8 and 9). This direction was evident in blast patterns, or vectors, radiating out from what was determined to be the point where the explosion first began or originated. Once the location of the motor-reducer assembly was considered to be the most likely ignition area, WorkSafeBC investigators were able to identify the containment zone.

The motor-reducer assembly area where the explosion originated was below the #1 eliminator lumber transfer deck, in the half-basement level, slightly above H-25 (Appendix 4). There were a number of structures here that provided the containment zone required for an explosion. The ceiling of the half-basement level was formed by the steel-plate transfer tables, which were approximately 6 feet above the point of origin. The point of origin was also contained on different sides by the following:

- To the south by the #2 chipper's vibrating infeed conveyor 8R-23, which was skirted and formed a near solid wall blocking the half-basement on the south side.
- To the north by the #2 chipper outfeed conveyors 13-24 and 8R-22, which were angled upward and skirted, forming a near solid wall in that direction.
- To the east by the eastern exterior wall of the sawmill and the #2 chipper room.
- To the west by the many conveyors, vibrating screens, and other structures that effectively contained that side. The dividing wall between the half-basement where the area or origin was located and the full basement was immediately beside the location of the motor-reducer assembly. The main wood waste conveyor 9-32 was within the full basement area and ran south to north along the dividing wall.

This area within the directional boundaries as outlined above was estimated to be approximately 15,000 cubic feet.

With all of the conveyor walls and equipment structures surrounding the 8R-25 motor-reducer assembly, the dispersed wood dust in the immediate vicinity was sufficiently contained to enable the deflagrating explosion to occur.

2.5 Evidence pointing to a dust explosion in the sawmill

The investigation found that the four components required for an explosion were all present in the sawmill. This section looks at the evidence for that explosion being a dust explosion.

2.5.1 What is a dust explosion?

The National Fire Protection Association (NFPA) defines an *explosion* as the sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high-pressure gases then do mechanical work, such as moving, changing, or shattering nearby materials. The four basic ingredients for an explosion are an ignition source, fuel, confinement, and oxygen. In a dust explosion, the fuel component – dust – must be dispersed and suspended in the air at sufficient density (Figure 25). This fifth component is called dispersion.

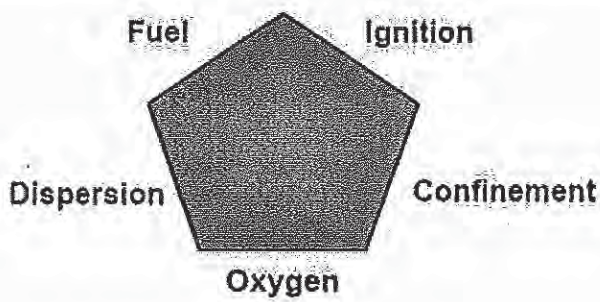


Figure 25: The dust explosion pentagon.

There is no doubt that a dust explosion occurred at the Babine sawmill on January 20, 2012. It is likely that the hazardous situation had arisen at the sawmill many times previously, perhaps in many areas of the sawmill, without incident because one or more of these five components was absent. On the day of the incident, however, all components were present and the explosion occurred.

In many dust explosions, the initial or primary explosion may be relatively minor, but the disturbance is sufficient to stir up and disperse other layered dusts that may have settled on the structure or equipment, thereby creating more dust clouds. The movement through the air of the pressure wave from the primary explosion causes this disturbance of the settled dusts, lofting the dust ahead of it. The flame front, or fireball, follows the pressure front, causing secondary or continuous deflagrating explosions. These secondary explosions are normally much more violent than the primary explosion. (*Deflagration* is defined by the NFPA as the propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium. *Detonation,* on the other hand, is the propagation of a combustion zone at a velocity greater than the speed of sound in the unreacted medium.) The thermal front of wood dust explosions can reach a temperature range of 2,000-3,500° Kelvin (1,725-3,225°C).

The density of wood dust in the air at the time of the explosion in the mill is unknown, but the minimum required for an explosion is typically 40 grams per cubic metre. Workers stated that the area beneath and around the eliminators was very dusty. In the area of the basement level where the initial explosion occurred, many conveyors were dumping wood waste from one to another with a lot of movement and vibration, and the fine wood dust would have been agitated and suspended in the air.

Section 3.3.27.1 of NFPA Standard 664 (2012), *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities,* describes deflagrable wood dust as wood particulate that will propagate a flame front, thus presenting a fire or explosion hazard, when suspended in air, with a mass median particle size of 500 microns or smaller, and with a moisture content of less than 25%. Section 3.3.27.2 describes dry, non-deflagrable wood dust as wood particulate with a mass median particle size greater than 500 microns and with moisture content of less than 25%. (One micron is equal to one-thousandth of a millimetre. Grains of table salt are generally between 150 and 850 microns and wood dust as particles 500 microns [0.5 mm] or smaller.)

The NFPA Standard 664 Explanatory Material Annex A describes some variations from these definitions and criteria. It states that the ratio of particle surface area to volume is a key factor in the deflagrability of wood dust, and that particles with a minimum dimension greater than 500 microns generally have a surface-to-volume ratio that is too small to pose a deflagration hazard. Some platelet-shaped particles and fibers with lengths that are large compared with their diameters may not pass through a 500-micron sieve but could still pose a deflagration hazard.

Another NFPA Standard 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids* has the following definitions:

- *3.3.4 - Combustible Dust.* A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, *regardless* of particle size or shape.
- *3.3.5 - Combustible Particulate Solid.* Any combustible solid material composed of distinct particles or pieces, *regardless* of size, shape, or chemical composition.

A recent article from a prominent dust-testing laboratory[1] summarized experiments involving wood dusts with a mean particle diameter of approximately 840 microns, considered non-deflagrable according to the NFPA Standard 664. These experiments found that even this larger wood dust is an explosion hazard. In addition, adding even a small amount of fine wood particles together with these larger particles will increase the violence of the explosion.

NFPA Standard 664 advises that a hazard exists where this deflagrable wood dust has accumulated on surface areas in depths of ⅛ inch over 5% of the area of the facility. The photographs taken in November 2011, two months before the incident (Figures 17 to 24), and reports and statements from workers to investigators confirm that there were considerable accumulations of wood dust in the sawmill.

The deflagration hazard of wood dust is evaluated in a laboratory according to the American Society for Testing and Materials (ASTM) Standard Testing Methods. These tests determine the following:

- Minimum explosive concentration (MEC) (ASTM E1515)
- Minimum ignition energy (MIE) (ASTM E2019)
- Moisture content
- Full Dust Explosion Severity: P_{max}, $(dP/dt)_{max}$, K_{st} (ASTM E1226)
- Minimum Ignition Temperature – Cloud (MIT) (ASTM A1491)
- Hot-Surface Ignition Temperature of Dust Layer (LIT) (ASTM E2021)

Dust deflagration severity is measured as a K_{st} value. The higher the value, the more energy is released during the deflagration, and therefore the more severe the explosion. The K_{st} value is expressed as bar-metres per second. Bar is a pressure unit of measurement, with 1 bar being equal to 14.5 pounds per square inch (psi). K_{st} is the maximum rate of pressure rise in a given explosion over a range of dust concentrations and then normalized to one cubic metre.

The P_{max} value is also expressed in bars, and is the determination, through testing, of the maximum pressure that the dust cloud material can reach while exploding.

Dust is classified into dust explosion classes based on the K_{st} value (Figure 26):

Dust explosion class	Kst (bar.m/s)	Characteristic
St 0	0	No explosion
St 1	>0 and <=200	Weak explosion
St 2	>200 and <=300	Strong explosion
St 3	>300	Very strong explosion

Figure 26: *Dust explosion classes.*
Source: OSHA CPL 03-00-008, Combustible Dust National Emphasis Program

Coal dust explosions are well known for their catastrophic effects and loss of life, yet coal dust has a relatively low violence and explosivity or K_{st} value (80-130 bar-metres per second). Methane also has a relatively low K_{st} value of 55 bar-metres per second, but the ability of gas explosions to destroy buildings and facilities is well known.

2.5.2 The wood dust samples from Babine sawmill

After the incident, dust samples were taken from various areas in the destroyed sawmill and were tested for explosivity (Figure 27). These tests were conducted by a laboratory specializing in dust sample explosivity testing, using the ASTM Standard Test Methods. The amount and availability of wood dust samples that were representative of the conditions prior to the explosion was limited at the Babine sawmill. This was due to the explosion and subsequent fire; the finer dusts ignited and created the primary deflagration, and much of the remaining wood dust and debris in the general areas that were affected by the explosion was consumed either by the secondary explosions or by the fire that destroyed the entire mill. Appendix 10 shows the locations where the samples were taken.

The samples were sieved before the testing was conducted. All of these test samples were greater than 500 microns in particle size, with the exception of one Exhibit 546 sample that was ground prior to testing. The samples did not contain either the actual wood dust that was dispersed in the air or the actual wood "fines" that would have been present on the equipment and building structure near the origin of the explosion, as these fuelled the explosions and were consumed. The ground sample would be more representative of the dusts that were consumed at the time of the explosion.

	Exhibit #515	Exhibit #514	Exhibit #468	Exhibit #546	Exhibit #546
Location	Babine: Area 14 Sorter	Babine: Area 13 Sorter	Babine: 8R25 motor reducer	Babine: 8R25 motor reducer	Babine: 8R25 motor reducer
Moisture (wt. %)	1.2%	12.6%	1.1%	66%	2.2%
Particle Size	>500 microns	>500 microns	>500 microns	>500 microns	Mean 14 microns; 100% < 75 microns
MEC	40 < MEC < 50 g/m³	100 < MEC < 125 g/m³	150 < MEC < 200 g/m³	MEC > 2,000 g/m³	50 < MEC < 60 g/m³
MIT	460°C	480°C	> 600°C	Undetermined	430°C
MIE	100 < MIE < 300 mJ	MIE > 1000 mJ	MIE > 1000 mJ	Undetermined	10 < MIE < 30 mJ
P_{max}	7.4 ± 10% bar	6.9 ± 10% bar	5.4 ± 10% bar	Undetermined	8.0 ± 10% bar
LIT	320°C	320°C	310°C	370°C	310°C
K_{st}	112 ± 12% bar-m/s	59 ± 20% bar-m/s	9 ± 30% bar-m/s	Undetermined	163 ± 12% bar-m/s

***Figure 27:** Summary of the dust sample results based on data from the external laboratory. The second #546 sample above was ground to this particle size distribution prior to testing.*

The wood dust samples collected from the Babine mill show a maximum deflagration hazard or K_{st} value potentially as high as 163, which places them in the Class 1 category. These values clearly indicate that some of the wood dust was capable of exploding.

The layered ignition test (LIT) indicates that the layered dust could ignite at temperatures as low as 310°C. The minimum ignition temperature test (MIT) is a determination of the temperature required to ignite a cloud of wood dust; one of the samples tested as low as 430°C for ignition. Typical flame temperatures for a cigarette are between 400 and 700°C, and the temperature for a candle is approximately 1,000°C.

The minimum ignition energy (MIE) was tested and found to be as low as 10–30 millijoules (mJ). Typically the lower the MIE, the more easily ignited the dust/air mixture is, and is expressed as the energy conveyed by an electrical spark. The MIE for some coal dust ranges from 30 to 60 millijoules, and a typical static spark can discharge approximately 22 millijoules of energy. This low test result indicates that the dust samples could have been ignited by a static discharge within the sawmill.

The minimum explosive concentration (MEC) is the minimum required concentration of combustible dust suspended in air for an explosion to occur. The MEC for the Babine sawmill samples to sustain deflagration was determined to be as low as 40 to 50 grams of wood dust per cubic metre.

Beetle-killed pine is known to have low moisture content and the log supply to the mill contained this type of wood. Some of the samples tested were examined in an "as received" condition. They were very wet, having been exposed to the elements for many weeks before being collected. Their condition immediately prior to the incident would have been significantly different. The wood dusts were inside the mill structure, in a dry environment and protected from the elements. Dusts that had settled on equipment that generated heat, such as electric motors, would have been heated and further dried. Because of the initial low moisture content, protection from outside weather conditions, and the heating and drying of this dust, it is assumed that dust with very low moisture content would have been present at the time of the explosion. These dusts would have been largely consumed in the explosion and subsequent fire.

All evidence and sample testing support the hypothesis that this was a wood dust explosion – that it was present in sufficient concentration to enable deflagration and that there was a sufficient quantity throughout the mill to support the initial and subsequent explosions. Wood dust was the dominant fuel in the Babine sawmill explosion. However, there is some possibility that other gases may have been present in small pockets in some areas throughout the sawmill, and that such gases may have provided additional fuel for the explosion to expand and propagate. For example, the severity of the breach at E-24 (roof level) may indicate that the venting oxygen/acetylene cart located in the basement level (D-21, Appendix 4) supplied both oxygen and fuel in this area when these tanks vented, increasing the violence of the explosion so that it breached the roof and north wall.

2.6 What occurred in the dust explosion at Babine sawmill

Appendices 8 and 9 contain blast vector indication arrows to show the direction of the explosion pressure when it damaged or disturbed specific physical objects or structures. These vector arrows are presented in different colours to indicate direction and to show the path of the dust collection ducting in the basement level:

- The red arrows indicate a near-horizontal direction out from the point of origin. Each red arrow corresponds to a physical item (written inside the arrow).
- The green arrows represent explosion pressure damage in the vertical plane, going upward from the basement level into the structure above, or from the operating floor through the roof level.

- The yellow arrows represent general outer debris such as wall panels and siding. Unlike the red arrows, each yellow arrow does not necessarily correspond to a physical item but rather encompasses the debris area.

2.6.1 The area where the primary explosion occurred

In the immediate area of the primary explosion (H-25, Appendix 4), waste conveyor 8R-25 carried wood dust and debris from the edger saws and dumped them onto the vibrating infeed conveyor for the #2 chipper. Slightly southwest of this location, the outfeed conveyor from vibrating screens 1 and 2 carried the dust and debris to the main wood conveyor 9-22, which ran along the north-south wall that divided the full basement and half-basement levels. To the southwest and west of the 8R-25 motor-reducer assembly were vibrating screens 1, 2, and 3, where the wood debris was shaken and screened to separate chips, sawdust "fines", and larger debris. The screens were approximately 20 to 40 feet away from the ignition point.

Approximately 50 feet to the southwest, the baghouse emptied the very fine collected wood dust onto the basement-level waste conveyor. All of this activity disturbed and dispersed the fine wood dust into the air. Millwright 3 and other workers described the conditions in the mill like a light fog. Others stated that you couldn't see across the mill. Another worker described this basement area as inaccessible due to the dust.

The area where the explosion originated was quite small, and was indicated by many obvious facts and physical evidence. The return belt for conveyor 8R-25 was found hanging immediately behind the 8R-25 motor drive. The heavy rubber reinforced belt was molded into a shape that went back and away from the motor drive. This could have occurred only with significant heat and pressure which molded the belt into this form which is opposite its design condition (Figure 28).

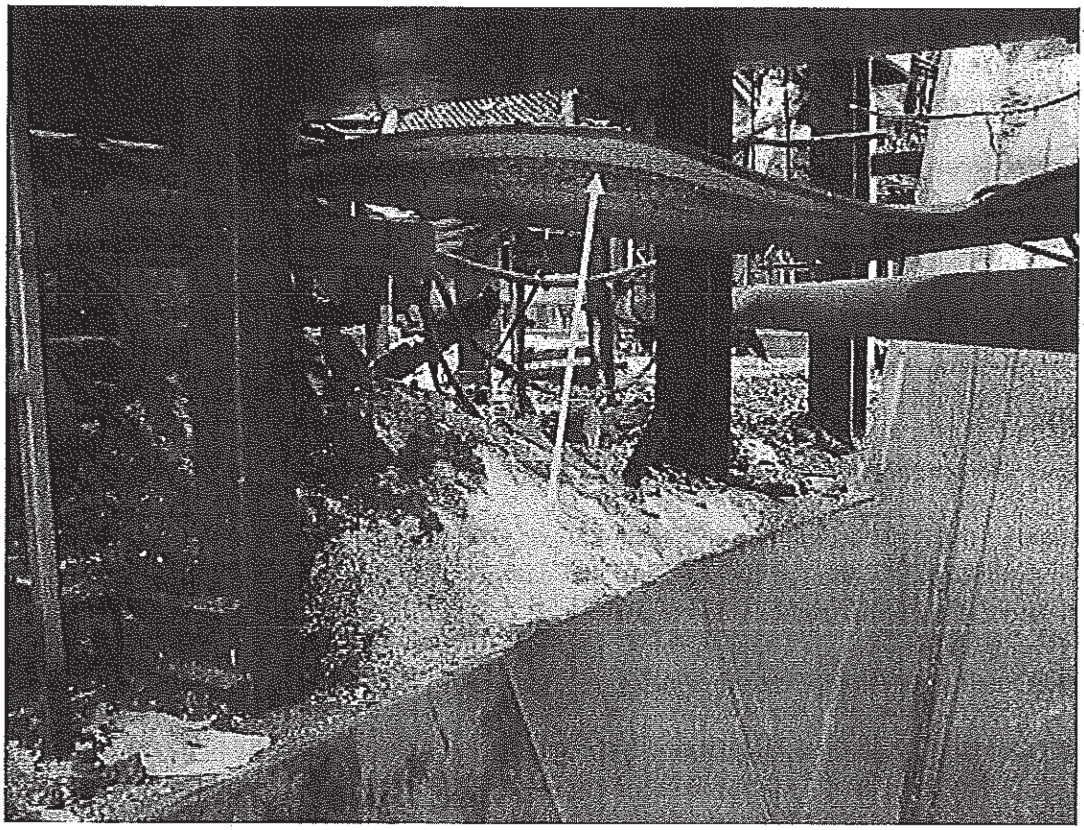


Figure 28: *The conveyor belting behind the 8R-25 motor-reducer assembly. The yellow arrow indicates the pressure and heat forming of the belt.*

The 8R-22 chipper outfeed conveyor was immediately in front of the 8R-25 motor drive. The flanges on the south side (the blast side) of the conveyor structure were clean of all wood dust and debris. On the north side, the flanges and floor were covered with wood dust and debris, which had been protected from the primary explosion by the 8R-22 conveyor structure. The electrical disconnect box for the conveyor was on the south side of the 8R-22 conveyor, between the point of origin and the conveyor. The metal labeling on the disconnect box was peeled away and folded to the east as a result of the explosion pressure.

The guards for chipper outfeed conveyor 13-24 had been found knocked off and scattered to the northeast of their original position, away from the point of origin. Within the conveyor itself, all of the chips were piled against the west side of the conveyor walls, the side closest to the point of origin. This could have occurred only if the explosion pressure struck the conveyor from the west and the pressure wave was broken by the conveyor. As the pressure wave flowed over the western edge of the conveyor, it descended and struck the east-side conveyor wall, which created a swirl or undercurrent effect that moved all the chips to the protected west side.

The exterior walls near the #2 chipper (H-27, Appendix 4) were blown outward and the large framed 9-feet-by-9-feet exhaust fan was thrown out and over the green chain, approximately 60 feet to the east, by the explosion (see Appendix 9). Along this same blast vector from the motor drive, an angle towards the east wall, the floor trapdoor for the chipper and the access door in the floor grating to the level above were both thrown open and away from the point of origin. The exhaust fan and doors are very heavy objects that could have been displaced only by the explosion pressures. The lumber travelling on the green chain outside the mill was also disturbed where the lumber was not protected by the chipper building. The explosion pressure pushed this unprotected lumber eastward.

The point of origin was contained above by the lumber transfer tables from both the #1 and #2 eliminators. These tables consist of heavy steel plating and the transfer return chains run in channels below the tables. In many areas, the steel plates were pushed and buckled upward due to the explosion pressure, and the heavy transfer chains were pushed eastward and out of their return channels.

The half-basement floor beneath the eliminator outfeed lumber transfer tables was found clean of debris and uncluttered. This area was where the lumber transfer chain outfalls typically dropped significant amounts of wood debris every shift. There was no wood waste at all in this area and there were no fire suppression activities near this area. The area appeared to have been swept clean of all wood debris when found by investigators. This was likely due to the explosion pressure travelling out from the point of origin and lofting and consuming all of the wood dusts and waste that had previously been on the floor in this area.

The #2 chipper vibrating infeed conveyor 8R-23 ran straight east and away from the 8R-25 motor drive. The north side of this conveyor where the explosion occurred was clean of wood dust and debris. The wood dust and debris remained untouched on the south side, and accumulations were present on the floor and on all the structural flanges and beams. The conveyor structure made a significant wall separating the area of origin of the explosion from the southern packaging areas of the sawmill; it protected the latter areas by preventing the explosion pressure and deflagration from expanding in their direction (Figure 29). The heavy damage seen in the sorter areas following the explosion was due to the 40-minute period when natural gas flowed freely after the natural gas supply line to the mill at the east wall of the sorter wing was severed (see section 2.3.2). The damage was due to fire fuelled by the natural gas supply, not from the explosion.

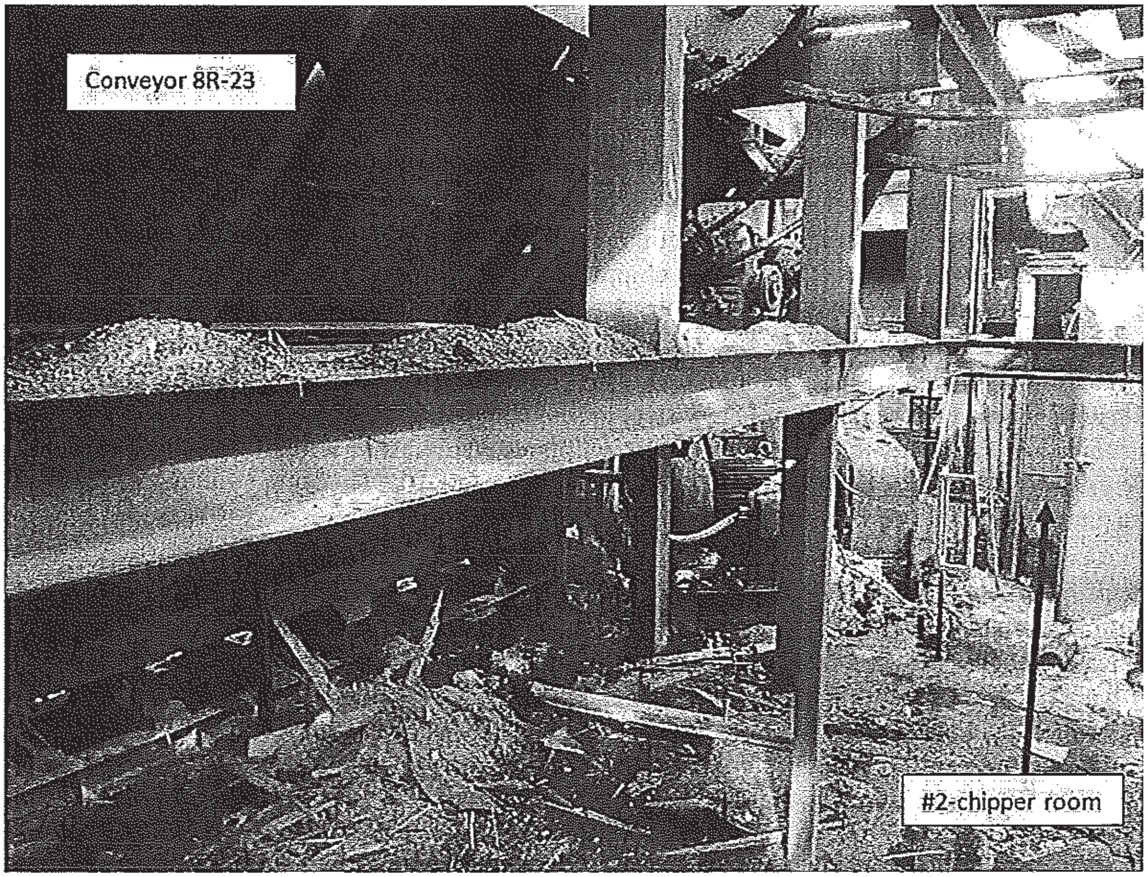


Figure 29: South side of the #2 chipper in-feed conveyor 8R-23. The wood waste on the structural flanges and floor were protected by the conveyor structure and were not disturbed by the explosion.

To the west of the 8R-25 motor drive were the vibrating screens and conveyors, oriented both north to south and east to west. The #3 screen skirting was buckled as a result of the explosion pressure travelling west from the motor drive. However, the area west of the origin was crowded with conveyor and screen structures that restricted the explosion's expansion in this direction; instead, much of the pressure was directed northward into the areas beneath the gang-saws (Figure 30). Compared with the rest of the mill, the basement layout was very open all along the north wall, running east to west. The gear oil room structure and equipment were pushed northwestward, and firefighting equipment in the vicinity of the gear oil room had been displaced in the same direction. The primary explosion was directed by the nearby structures and equipment and by the available fuel into the general area of E-24 (Appendix 3). It also expanded southwestward, into part of the area where the screens and edger conveyors were located (Figure 30).

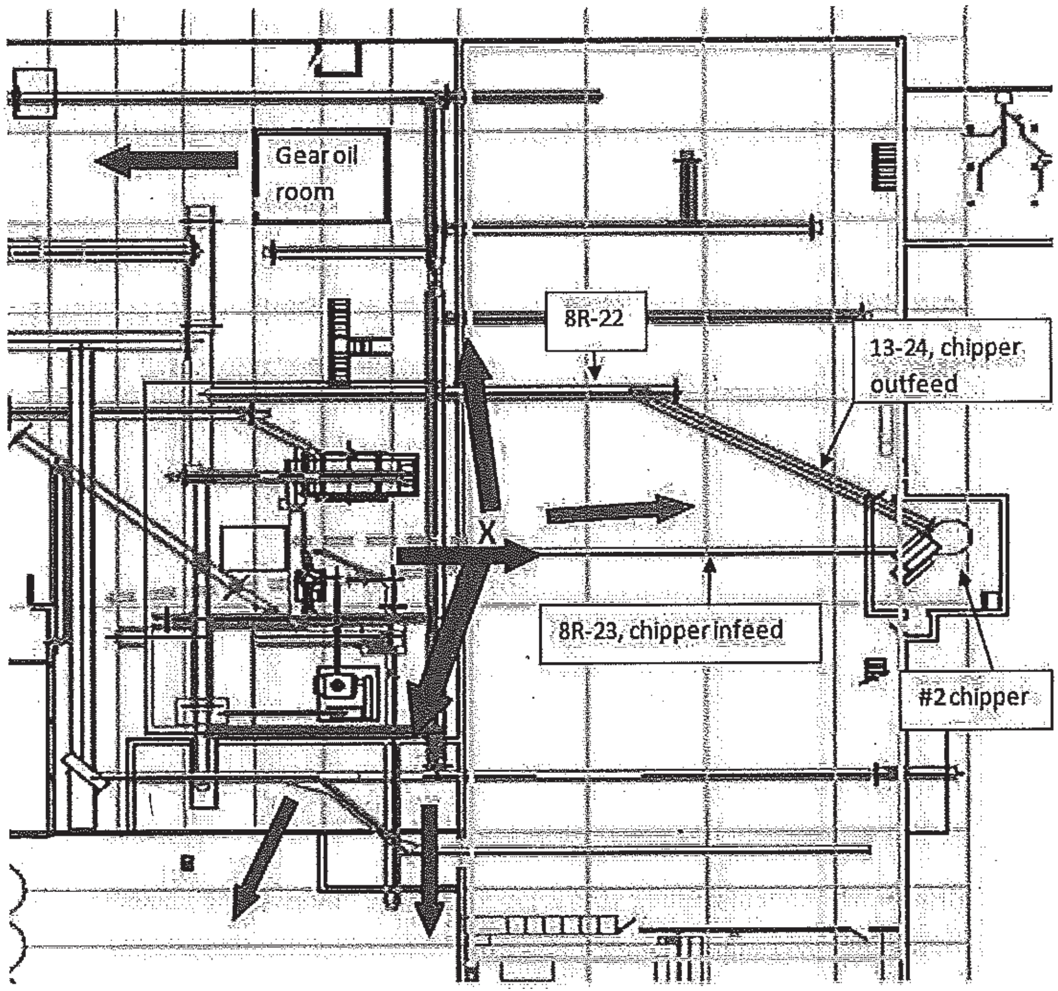


Figure 30: *Note the following in this enlarged diagram of the basement level near H-25 (Appendix 4): The blue arrow represents conveyor 8R-25. The red rectangle outlines the area where various screens and structures restricted the explosion pressure's expansion westward. The yellow rectangle outlines the half-basement area; everything to the left of it is full basement. The green arrows indicate the paths travelled by the explosion pressure.*

Witness statements following the incident indicate that the fireball rose through the gratings and floor throughout this area and engulfed the operating floor. This basement area under the edgers and beside all the vibrating screens was approximately 20–30 feet southwest of the point of origin and had large dust accumulations. The abundant fuel resulted in a catastrophic secondary explosion in that part of the basement. The #2 Edger Operator and the Saw-filer were on the operating level, slightly to the west of the primary explosion and generally above the conveyors and screens. The #2 Edger Operator was facing west at the time. He stated that the floor rose up behind him and that he was engulfed in the fireball; he suffered serious burns. The Saw-filer was jogging the bandsaw to set the newly installed saw blade when the floor rose below him, and he also suffered serious burns.

The #2 Eliminator Operator stated that he felt a strong rush of air and heat from behind and saw flames after feeling the shock wave. The explosion pressure beneath the eliminator tables vented through the walkway grating directly into the #2 Eliminator Operator's work area, approximately 30 feet to the northeast on the operating level (Figure 31). The bent grating is shown in Figure 32 and the path of the explosion in Figure 33. The floor under the eliminator tables was clean of all debris and wood waste due to this explosion pressure as discussed previously.

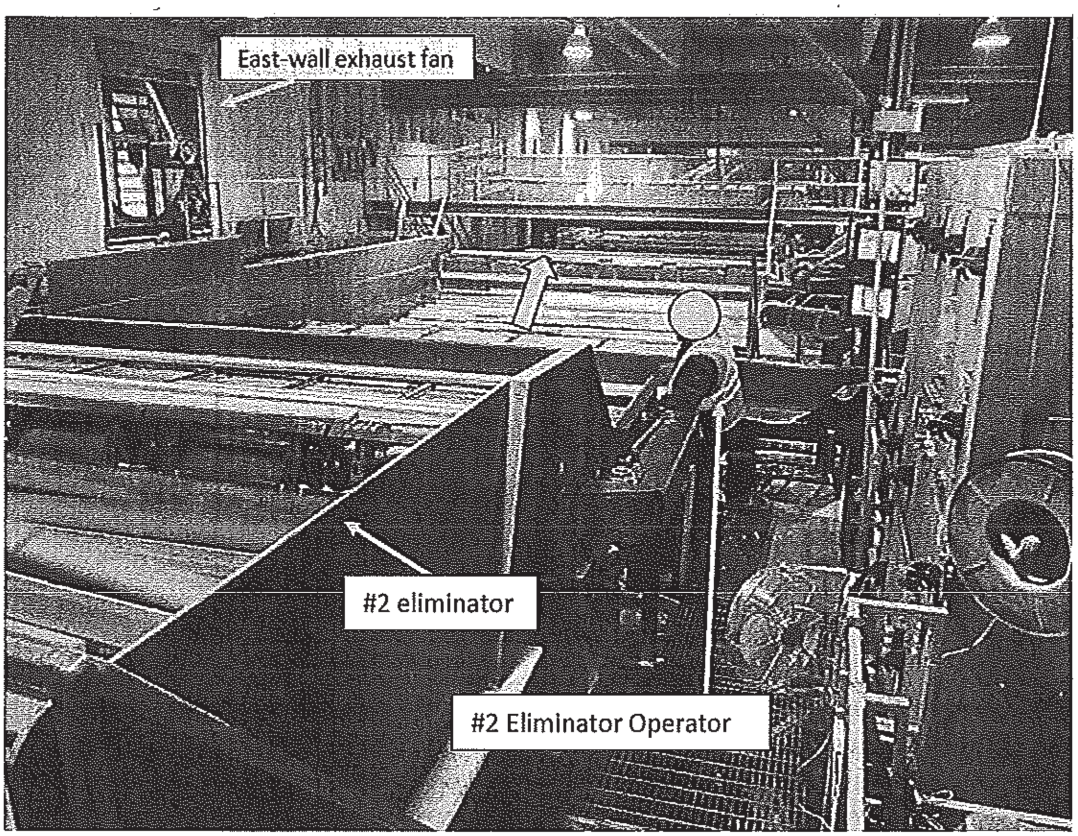


Figure 31: *The #2 eliminator position prior to the explosion. The large yellow arrow points south. (Photograph by WorkSafeBC, November 22, 2011.)*

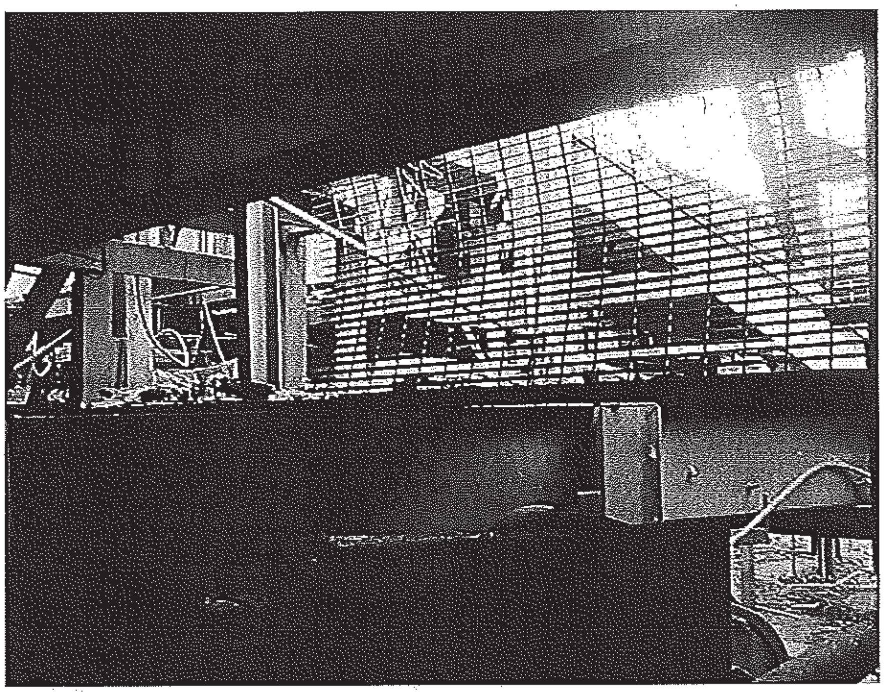


Figure 32: View from between the ignition point at the 8R-25 motor-reducer assembly and the #2 eliminator position. The grating was bent by the force of the explosion pressure.

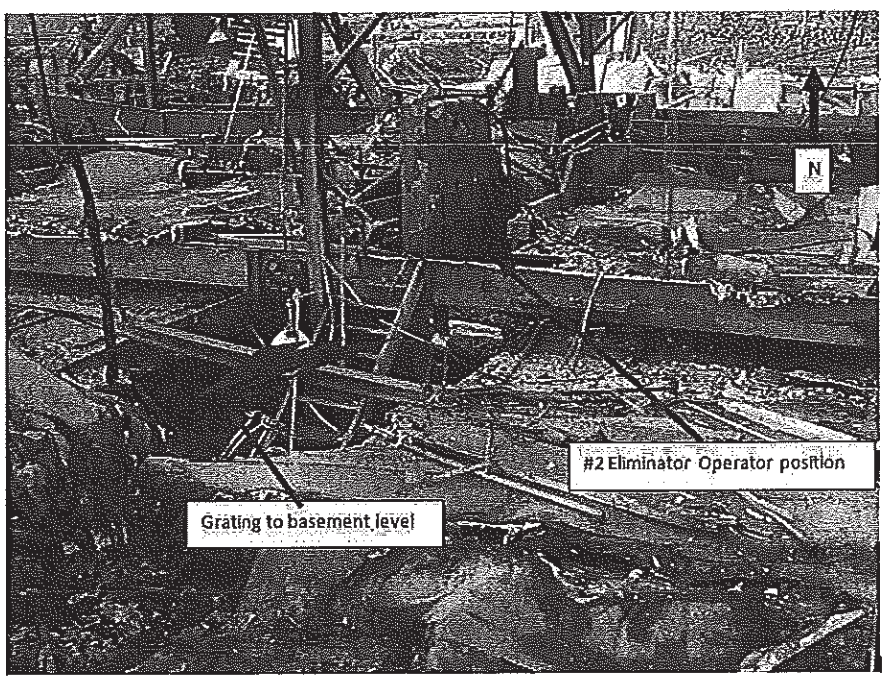


Figure 33: Photograph showing #2 Eliminator Operator's position and the path of the explosion.

2.6.2 Accumulation of wood dust in the mill

In the Babine explosion, it is believed that an open flame from the motor-reducer's V-belt guard, located in the basement level of the mill, likely ignited the dust mixture suspended in the air above the motor (Figure 34). Several large wood waste conveyors as well as the chipper and vibrating screens were in this general area, with the 8R-25 conveyor dumping into the chipper vibrating infeed conveyor directly above this location. All of these caused the dispersal of the fine wood dust into the air. A contained space of approximately 15,000 cubic feet (425 cubic metres) in this general area was bounded by the high conveyor wall sheeting and an exterior wall.

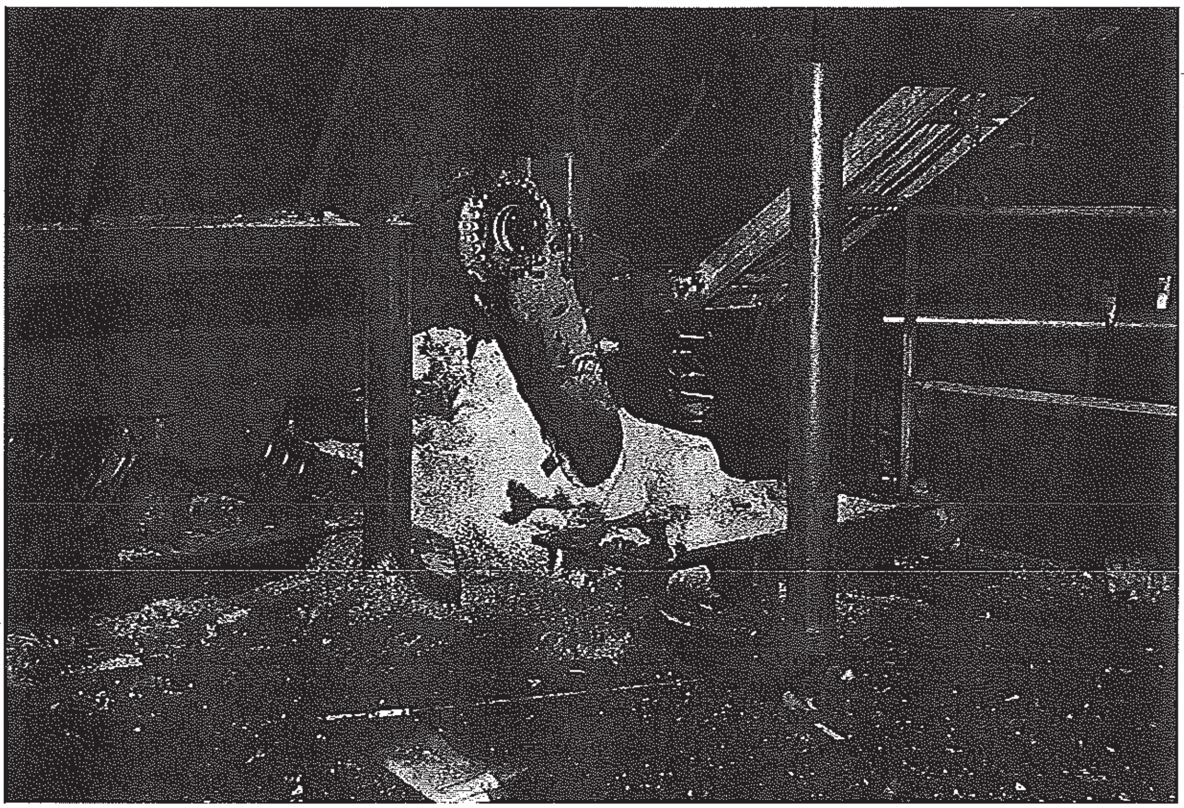


Figure 34: *The 8R-25 motor mounting plate after removal of the motor-gear reducer assembly and guard. Note the amount of wood dust that was protected from the explosion.*

Above this area on the operating level were the eliminators and transfer tables, where lumber was moved on chains. The lumber was ejected from the various trim and edger saws onto the transfer chains and moved south to the stacking and packaging areas. The fine wood dust from all sawing activities settled on top of the lumber, and was dislodged and dispersed by the vibrations and movement along the transfer chains.

The floor space under the eliminator tables where the chain runs terminated was reported to be covered with significant piles of wood waste following each shift. There was no evidence of these piles after the incident, and there had been no clean-up activity in this area during the shift. They were likely to have been consumed by the explosion. After the incident, accumulations of fine wood dust were present throughout the sorting and packaging areas. These areas were protected from the blast and fireball by the chipper infeed conveyor 8R-23, giving an indication the conditions that likely prevailed throughout the mill and under the transfer tables before the explosion. Accumulations present at the end of the lumber travel path, would mean accumulations would have been present along the entire travel route.

Some areas of the operating level floor had steel grating and were open to the basement level. Dust fell through these openings and settled in the basement level, where the operation of the conveyors and other equipment kept the finer particles moving and dispersed above the basement level floor. Thus, dust coming from above mixed with dust suspended in the basement, and this zone reached a density sufficient to support an explosion.

2.6.3 Progression of the explosion

The smouldering and subsequent burning within the guard at the 8R-25 motor-reducer assembly most likely ignited the dust concentrations in the air. The primary deflagrating explosion was initiated, and the pressure and thermal fronts expanded equally in all directions. However, the 8R-23 conveyor (#2 chipper infeed) prevented the pressure from expanding southward, redirecting it in all other directions. Overpressure built up in the small area and damaged the underside of the eliminator tables, which were found after the incident to be deformed and bent upward, before venting upward through the floor grating, directly at the #1 and #2 Eliminator Operators.

To the east, the sawmill wall was displaced and blown out into the log yard. The large exhaust fan was ripped from its attachment on that wall and thrown 60 feet out into yard along with the main sawmill structural members (Figure 35). The fan was 9 feet by 9 feet and very heavy. Even the lumber on the green chain outside the sawmill was displaced on this side of the mill as the overpressure escaped (Figure 36).

Figure 35: *The large exhaust fan, indicated by the yellow arrow, was blown out approximately 60 feet from where it had been mounted on the mill's east wall.*

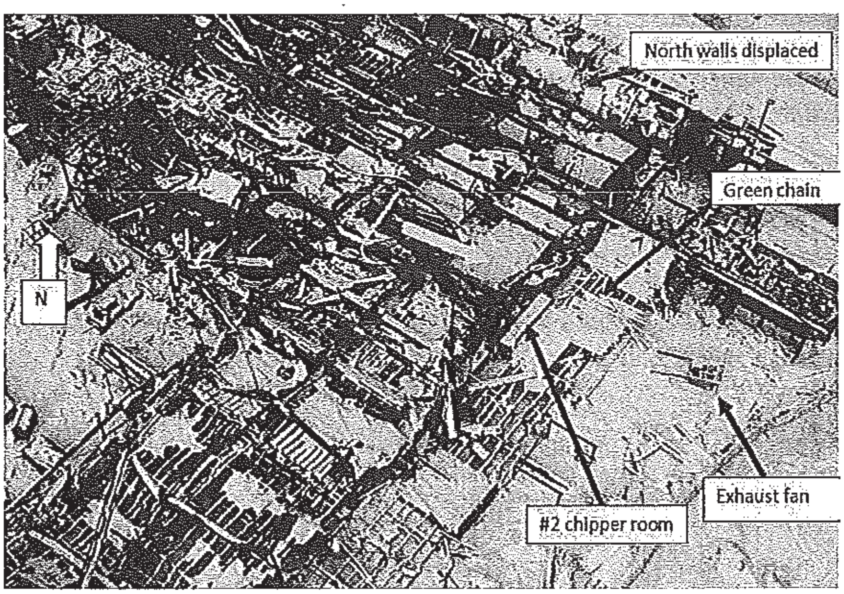


Figure 36: *Aerial photograph of the east side of the sawmill. The large yellow arrow indicates the easterly direction of the explosion's expansion from the point of origin. Note that the lumber on the green chain is disturbed only where it was not protected by the #2 chipper building.*

As the primary explosion expanded from the motor-reducer assembly, it descended and expanded into the full basement immediately to the west. The dispersion of fine wood dust fuelled the explosion's immediate expansion throughout this new area. The many conveyor and screen structures as well as the sawmill walls prevented or restricted much of the explosion pressure from entering the west side of the basement level in this area; instead, the overpressure vented through the southern wall (J-21, Appendix 4), displacing the wall stairs and structure in the process. It also expanded as much as the equipment structures permitted to the north and west. Where it was restricted it went under or over if there was available expansion space. This is how the explosion pressure, albeit very reduced in strength, entered the centre basement areas.

Between this ignition area and the north side of the basement level, the area was separated by some vibrating screens and waste conveyors that dumped into conveyor 9-32. This equipment prevented the explosion pressure from travelling unrestricted through these areas within the full basement, but it did not impede the northwesterly pressure and thermal expansion in the half-basement level where the explosion had originated. Within milliseconds, the deflagrating explosion expanded in this direction, consuming the wood dust fuels on this half-basement level. The full basement opened up at the location of the gear oil room, and the explosion pressure expanded into this space, knocking down the gear oil room walls to the west and quickly expanding into this space, which had plentiful available fuel.

The heat generated by the incoming thermal front likely caused the oxygen/acetylene bottles located there (D-21, Appendix 4) to vent, which added fuel and oxygen to the explosion, thereby increasing the violence and pressure. The temperatures generated by a dust explosion are reported to be in a range of 1,725 to 3,225°C. The pressure vented through the roof near the HDA gang-saw operator booth. In the process, it displaced the thermal oil line located on the roof southward and also pushed the baghouse southward and off its original support structure (Figures 37–38).

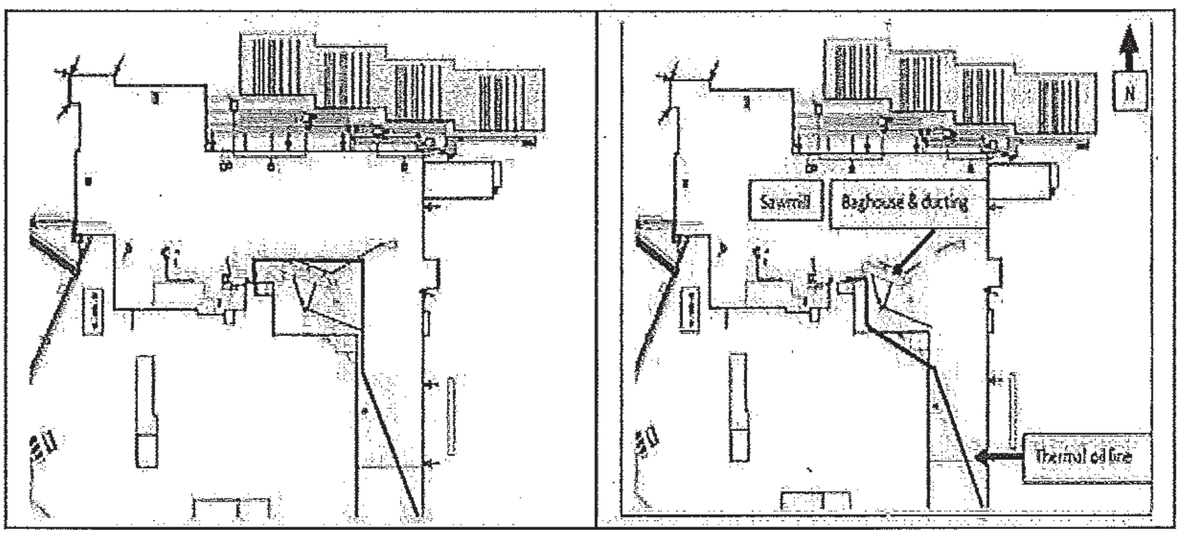


Figure 37: *The diagrams show the layout of the sawmill roof. The thermal oil line is shown in red. The left diagram shows the way the oil line was designed to cross the roof; the right diagram shows the oil line's location after the explosion.*

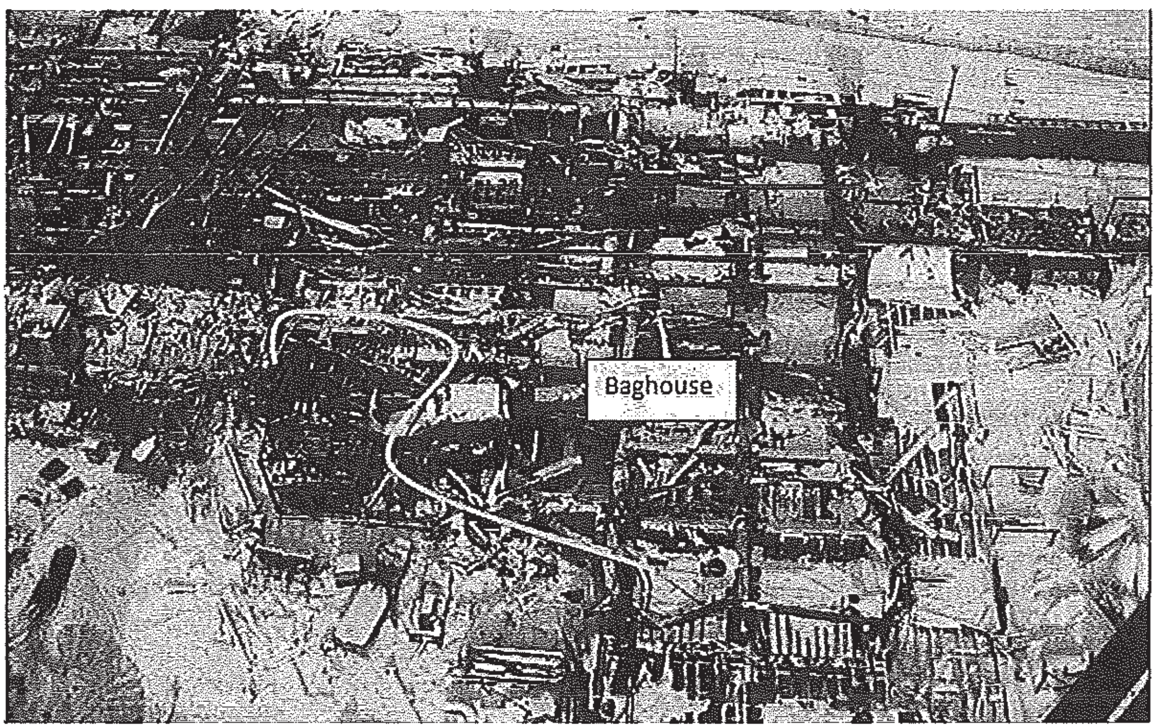


Figure 38: *Aerial photograph showing the baghouse location and the thermal oil line (traced in yellow). The vented area in the roof is north of the baghouse.*

Along the south wall of the sawmill in the basement level, running along grid line G, is a corridor defined by the conveyors below line 3. There was little or no blast damage throughout this area, except to the walls of the power distribution centre (PDC) room (G-10, Appendix 4), which appear to have been pushed westward by the explosion pressure. The line 3 hydraulic room is near the PDC room (F-11, Appendix 4). There was evidence that it had been pushed westward, but the major damage that destroyed the room and walls is the post-incident fire (Figure 39). There is little violence associated with this damage, simply overpressure.

Figure 39: *The line 3 hydraulic room looking south, the double doors pushed open westward. Some of the PDC electrical components are on the wall in the background.*

Many workers reported the explosion coming from the basement area, behind the bandsaw, behind the #2 Edger Operators location or in the area of the trimmer saws. This puts the initial explosion on the eastern side of the sawmill and travelling outward from there. For example, the Watchman was located at the far western side of the basement at approximately F-1 (Appendix 4) when he saw the lights flicker and was then hit by the force of the explosion. There are different accounts of when the lights went out or flickered before the workers felt the explosion or fireball, and the differences are explained by their location at the time. The initial flickering that the Watchman observed was likely a result of the primary explosion hitting the electrical system and causing some disturbance in the lighting circuits as it travelled towards him. As the explosion grew, in milliseconds it travelled through the basement levels and affected additional MCC panels and the PDC room which resulted in the power-out situation.

The structure and materials between the conveyors under production lines 2 and 3 were relatively undamaged except where affected by the sawmill fire. Figure 40 shows the corridor east of the PDC room, between the south wall and line 3. Note the large accumulations of wood waste remaining beneath conveyor 9-92. This indicates that the explosion did not originate here, and that it had little strength as the explosion pressure travelled from east to west through this area.

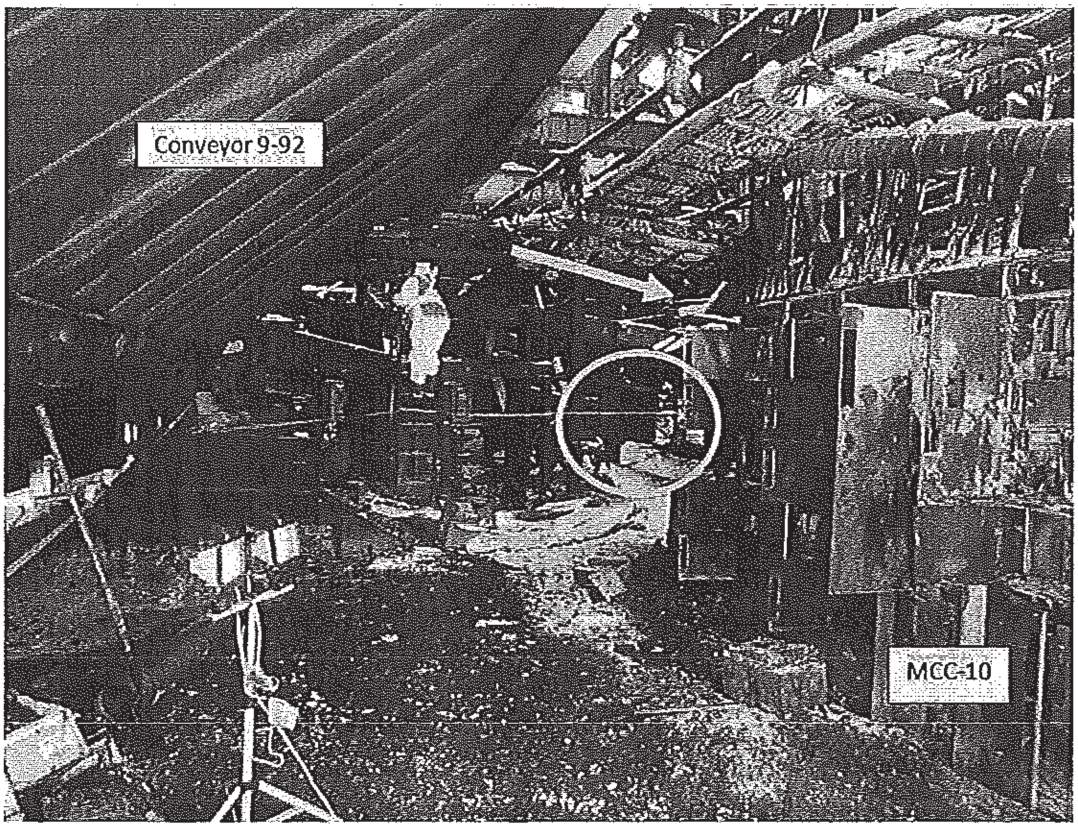


Figure 40: *This view is looking east from in front of the boiler room. The explosion pressure and thermal front likely took a path travelling towards the reader from the east, under the conveyors and screens in the area outlined by the yellow circle. Other access was restricted by the conveyor structures. The yellow arrow indicates the location of the #1 chipper.*

North of the line 2 conveyors and west of the gear oil room (E-23, Appendix 4), the full basement level was wide open. With little to restrict its expansion, the deflagration grew significantly and vented through the operating floor and the roof above as well the north wall into the location of the #1 cut-off saw (A-13, Appendix 3).

In the basement level, the equipment and conveyors uniformly show thermal damage at approximately 5–6 feet above the floor. The pressure wave is believed to have lofted the wood dust in front of its travel path; the dust was exposed to high temperatures and pressures and it ignited once airborne. This phenomenon did not occur at lower levels, below 5–6 feet, as the dust was being lofted, and it did not deflagrate at ground level.

2.7 What happened to the Lead Hand and #1 Cut-off Saw Operator?

This section looks at what happened to the two workers who died in the incident.

2.7.1 Lead Hand

Just minutes before the explosion, the Saw-filer saw the Lead Hand going down into the basement level in the area of G-23 (Appendix 4), where a stairway accessed the basement level just north of the vibrating screens and the 8R-25 motor-reducer assembly ignition point. During the week of January 16–20 the mill had experienced breakdowns and numerous other problems associated with the extreme cold, such as freezing water lines and frozen conveyors. It is likely that the Lead Hand was investigating and performing routine checks on these systems to ensure that the shift ran as smoothly as possible under those conditions. The Lead Hand was found inside the sawmill at a doorway near the round saw filing room (D-27, Appendix 3). It was not determined whether he had succumbed to the explosion and fire or was overcome by the falling roof and other sawmill debris while attempting to leave the burning sawmill.

2.7.2 #1 Cut-off Saw Operator

The #1 Cut-off Saw Operator was in his wooden operator's booth (B-13, Appendix 3) when the explosion occurred. The booth was a simple wooden structure. As the deflagrating explosion entered the full basement near the gear oil room (E-23, Appendix 4), it was growing and expanding northward and westward. With the available fuel beneath and in the operating level near the VDA and HDA gang-saw centres, the explosion pressures peaked in the available space. The sawmill structure failed as the explosion pressures vented skyward through the weaker roof section and also through the north wall between the equipment and structures located there. The direction of initiation as the explosion rolled into the full basement meant that the area where the #1 Cut-off Saw Operator's booth was located was in the path of the expanding explosion and pressure wave. This overpressure breached the north wall and vented outward into this location. The operator's booth was destroyed and the #1 Cut-off Saw Operator died while still in the booth.

2.8 Changing conditions that may have influenced the explosion

British Columbia sawmills have operated for many decades without a significant explosion incident similar to the one that occurred at the Babine sawmill in Burns Lake on January 2012. The investigation looked at changing conditions that may have increased the risk of explosions.

2.8.1 The effect of humidity on the wood dust

Statistics from studies conducted in the United States show that humidity and explosion frequency are closely related. Most explosions occurred during the winter months in high-latitude states and inland areas 160 kilometres or more from a coastline.[2] These studies conclude that the humidity of the ambient air directly affects the moisture content of the dust.

In the incident at Babine Forest Products, the mill had closed doors, windows, and other openings as much as possible throughout the winter months and these were still in this condition in January 2012 as the weather remained bitterly cold. The ambient air through the winter months is very dry and did not add to the moisture content of the dusts, which were extremely dry to begin with. The low humidity probably contributed to the severity of the explosion at the Babine sawmill. This is similar to the finding of the British Columbia Safety Authority with regard to a February 23, 2011 fire at the mill (see section 2.9).

2.8.2 The mountain pine beetle

British Columbia has an estimated 10 million hectares of lodgepole pine forest. As of 2005, approximately 8.7 million hectares had been affected by the mountain pine beetle outbreak. The annual allowable harvest was increased in these affected areas. The increase was to allow harvest before the wood lost its commercial value.

One significant development in some B.C. sawmills has been the high percentage of beetle-killed pine that is being processed. Salvage harvesting and subsequent processing of this dead wood have increased over the past decade. A number of studies commissioned under the Mountain Pine Beetle Initiative have examined the challenges of milling this dead wood and the marketability of the wood. In response to a provincial request in October 2002, the federal government announced the Mountain Pine Beetle Initiative (MPBI). The Initiative was included within a suite of federal programs targeted at the forest sector. The MPBI is administered by Natural Resources Canada, Canadian Forest Service (CFS). One study comments on the large increase in the amount of fine particles resulting from processing of this type of wood compared with processing green wood. [3]

Another study found that the shelf life of mountain pine beetle-killed pine may be greater than five years, but that the decreasing moisture content of the dead pine adds challenges to industrial use.[4]

Dry logs delivered to a sawmill also present difficulties in the processing stage. Debarkers tend to become less efficient when handling dry logs because the dry fibre is easily damaged. These machines are adjusted so as to minimize fibre damage as well as remove as much bark as possible – a balance that is especially critical with dry logs.[5] Frequent switching between live logs and dead ones is likely to be problematic. Modification of debarkers is required, and log ponds or spray washing of logs have been recommended;[6] for environmental reasons pertaining to run-off water, modern sawmills are reluctant to use these. Dry wood also requires more energy to saw. Saws and chipper and planer blades become dull faster due to the dryness of the wood. Checks and splits in logs open up and reduce board width and length. When checked lumber breaks during processing, pieces can jam sawmill and planer machinery, which leads to downtime and reduced productivity.[7]

The various statements from the Babine mill workers certainly indicate that beetle-killed wood was producing more and finer dusts and waste than typical green wood. The mill's production rates fluctuate but averaged approximately 65,000 board feet per hour during normal production days. For several days leading up to incident, production was reduced due to the extreme weather conditions.

Studies under the Mountain Pine Beetle Initiative found that extractive content, particularly resin acids, can be much higher in beetle-killed pine[8]. The tree uses the extractives to kill or push out the pest, and this increases the normal amount of extractive development. When these trees are harvested, their higher resin acid content may cause the dust produced through processing to be more combustible than normal green pine.

The Babine sawmill processed a large amount of beetle-killed wood that was harvested locally. This wood had been standing dead for a number of years and, as pointed out repeatedly by the Mountain Pine Beetle Initiative studies, the wood would have had a moisture content of less than the fibre saturation point (generally regarded as 30% in lodgepole pine)[4]. This very low moisture content means that the wood will break up and generate significantly more debris and dust than typical green logs.

Cutting beetle-killed pine produces a considerably greater volume of wood dust and much finer dust than the dust produced from cutting green wood. In some cases, this dust can resemble flour. This condition was never a consideration when designing sawmills 30 and 40 years ago, as all the wood was green and sawmill conditions were almost damp due to the fresh wood. Today, in mills processing beetle-killed pine, this fine dust, if permitted to disperse into the air from the saw equipment, will settle in fine layers throughout the mill. The workers at the Babine mill stated that when they were processing beetle-killed pine and the dust collection system was not operating normally, the mill was unbearable in some areas because of the levels of dust in the air. Consequently, the mill management implemented a policy mandating that all workers wear dust masks.

A sawdust sample collected from the destroyed Babine mill and a separate sample from a sawmill cutting only green wood were sent to an expert in wood fibres for comparison testing. The purpose was to determine any differences in the characteristics of the Babine sample compared with a green wood sawdust sample that had not been affected by the mountain pine beetle. The Babine mill was at the end of its second day of processing green wood and the wood waste is likely to have been mixed with the beetle-killed wood from earlier in the week.

The fibre analysis indicated the following:

- On average, the Babine sample had three times as much extractive content as the green wood sample.
- The percentage of "fines" within the macerated sawdust samples is also noteworthy. The percentage of "fines" in the sample from Babine was two times higher than for the green wood mill.
- The wood sample from Babine was considerably drier than the green wood sample. Its moisture content was below the fibre saturation point.

Wood extractives are typically chemical compounds which include organic compounds such as terpenes, resin, and fatty acids. They are key components of a tree's defense mechanism against an attack by an organism – in this case, the mountain pine beetle. The total extractive levels increase significantly in beetle-killed wood, as shown in the fibre analysis report that was completed on the wood dust samples (Figure 41). The values represent averages of the sample taken from each mill. It is unknown whether these extractives increased the combustibility or explosibility of the wood dust.

	Acid Insoluble Lignin (%)	Acid Soluble Lignin (%)	Total Lignin (%)	Moisture Content (% water)	Extractives Content (%)	Isolated Extractives (%)	Fibre Length (mm)	Fibre Width (um)	Coarseness (mg/m)	Fines (%)	Average Particle Size (mm2)	Particles per gram (#/gram)
Babine EXH 543	34.00	0.43	34.43	26.07	4.28	3.67	0.92	31.50	0.13	9.70	0.10	71,301
Green Wood EXH 169	28.03	0.65	28.68	49.99	1.26	2.11	1.10	34.27	0.19	5.16	0.11	86,721

Note: 1. Extractive content was measured two ways: 1) quantifying loss after extractions (Labelled Extractives Content), 2) quantification by isolating the extractives (Labelled Isolated Extractives)
2. Values represent averages of three tests per sample.

Figure 41: *Comparison between wood dust samples taken from the Babine sawmill and a green wood sawmill.*

Particle size is a key component in the explosibility of wood dust. The smaller the particles and the greater the number of them, the more violent the explosion is likely to be. Additionally, these particles travel and disperse farther away than do coarser dusts. The number of particles by weight is not much different in the Babine sawmill when compared to the green wood mill. The Babine sample included green wood mixed with beetle-killed pine wood, as the mill was completing the second day of processing green timber.

The percentage of "fines" as shown in Figure 41 is not a reference to small particles but rather the number of "fines" produced when the sample was chemically macerated. The Babine sample is twice the percentage when compared to the green wood sample. This is likely a consequence of the extremely low moisture content of the Babine sawdust sample which when being processed resulted in sawdust that was significantly finer and of smaller particle sizes.

Historically, wood waste overflow and spillage was easily identified and was shovelled or pushed into collection areas and conveyors. Now the dusts (beetle-killed pine) migrate farther away and cannot be easily shovelled or disturbed as this disperses them back into the air.

The Babine sawmill had no wood dust collection system in either of the chipper locations, under or around the edger saws, or in the eliminator areas, yet these were some of the dustiest locations in the mill. The original design of the mill included a dust collection system in the edger area that also serviced the trim-saws near the eliminators, indicating that the mill owners at the time recognized that these areas were significant dust producers. Under the current owners, however, the dust collection system was redirected to serve other areas of the mill, and the original trim-saw and eliminator areas were no longer covered by the system. Over the years, the wood available for processing changed, until beetle-killed pine accounted for a large share of the mill's production. The mill's reliance on natural ventilation in the trim-saw and eliminator areas as well as its use of clean-up workers to blow down, sweep, and control wood dust accumulations throughout the premises proved to be ineffective for the volume and type of wood dust resulting from the extremely dry beetle-killed wood.

The B.C. Ministry of Forests, Lands and Natural Resource Operations sets the stumpage rate for salvage-harvest pine very low, at 25 cents per cubic metre, which is significantly lower than for other species types. This is the cost that the logging company must pay the government to harvest the timber. The very low stumpage rate has given sawmills incentive to harvest the dead timber and process it into saleable lumber products. Even with the problems of low moisture content, breakage, and greater volumes of dust being produced, there is still profit to be made due to the low stumpage rate. The more lumber processed, the greater the profit. At the Babine sawmill, much effort was devoted to tweaking feed-speeds, shift arrangements, assignments of workers, and other production-related activities to attain higher production levels of lumber per shift. A similar effort was not put into controlling the potentially explosive levels of dust created by these increased production levels.

The challenges facing the sawmill industry in connection with processing beetle-killed pine have been well researched and published. These publications are available through the B.C. Ministry of Forests, Lands and Natural Resource Operations website. They address the difficulty that the industry would face with the additional breakage of the wood, the increase in wood waste, and the lower moisture content.

The industry has adapted to the increased processing of beetle-killed pine in most areas, with the exception of effective waste control and removal. The wood dust at the Babine mill was excessive and created a hazardous situation for all workers.

2.9 Previous incidents

On February 23, 2011, a dust explosion and significant fire occurred at the Babine sawmill when an operator attempted to start the bandsaw. The explosion occurred within and in front of the MCC panel but did not escalate into a full-scale secondary explosion. The British Columbia Safety Authority (BCSA) investigated and concluded that beetle-killed wood dust in the panel was ignited by hot gases from a fuse. The BCSA report noted sawdust accumulation in and on equipment in the vicinity of the switch. According to the BCSA, the sawdust appeared to be unusually dry due to the wood source (beetle-killed wood) and the preceding weather conditions, and ignition of the sawdust was explosive and resulted in other fires.

Hampton Affiliates also investigated. The Hampton report contains an entry that states: "This mill has a tremendous amount of dry wood fibre dust, resulting in a very large fuel load."

[redacted] reported to investigators that there had been a previous significant fire on or about December 6, 2011, that he believes the mill did not investigate. This fire started in the walls of the machine and carpenter shops in the vicinity of T-26 (Appendix 3). The fire was blamed on sparks igniting the sawdust in the wall. There was significant damage done to the wall and electrical wiring.

There had also been a number of smaller fires in the sawmill in the months leading up to the incident. Many of these were blamed on friction fires (hot bearings) and on contractors doing work around the sawmill.

2.10 WorkSafeBC involvement with Babine Forest Products

The inspectional and contact history between WorkSafeBC and Babine was reviewed for the five years prior to the explosion. There were numerous contacts, meetings, and inspections during this time period. Many of the interactions involved the logging operation side of the business as well as the sawmill.

Of note are the following records:

- Inspection Report 2009161980306, dated September 17, 2009. This report summarizes a September 9 inspection of the planer mill by a WorkSafeBC officer who noted that the mill was clean of dust and debris. Two orders were issued to the mill regarding proper identification of working load limits and for unprotected access to low voltage electrical equipment.
- On February 25, 2011, Babine notified WorkSafeBC of the February 23, 2011 fire. WorkSafeBC did not attend to investigate but asked the mill to forward a copy of the mill's investigation report once completed.
- Inspection Report 2011161980116, dated April 8, 2011. This report summarizes a partial inspection of the sawmill that was conducted on March 29. It was noted that a new management team was in place. One order regarding ineffective safeguarding was issued to

the mill, and the fire of February 23, 2011 was discussed. The mill was reminded to submit an incident investigation report regarding this fire to the WorkSafeBC officer.

- On May 13, 2011, Babine forwarded to WorkSafeBC a copy of the BC Safety Authority report with regard to the February 23, 2011 fire.
- On May 27, 2011, Babine forwarded to WorkSafeBC a copy of Hampton's investigation report with regard to the February 23, 2011 fire.
- Inspection Report 2011161980248, dated July 13, 2011. This report was generated to record a July 6, 2011 follow-up inspection conducted to confirm compliance with the April 8 order regarding safeguarding. No additional violation orders were written. This report records the information that the sawmill had been approved the sum of $20,000 monthly to upgrade guarding and that efforts were ongoing.
- Inspection Report 2011166350202, dated November 24, 2011. This report was generated to record that, on November 22 and 23, ten air samples were collected by a WorkSafeBC officer to assess workers' exposure to softwood dust as part of WorkSafeBC's Interior/North Wood Dust Sampling Pilot Project to which Babine had volunteered participation. No orders were written.
- Inspection Report 2011161980432, dated November 30, 2011. This report summarizes a co-inspection that occurred on November 23 when the air samples were collected. The WorkSafeBC officer reviewed the mill's ongoing work relating to safeguarding of the sawmill equipment, infrared testing for electrical hot-spots, and improvements to the mill's electrical system including the MCC pressurization efforts. Photographs taken during the inspection show dusty conditions and accumulations of sawdust in the mill. No orders were issued.
- On December 6, 2011, Babine emailed WorkSafeBC a summary of the mill's recent safety improvements, one of which was pressurizing all main MCC banks to prevent dust entry.
- Inspection Report 2011161980459, dated December 23, 2011. This report records a WorkSafeBC inspection that was conducted on December 15 following an inquiry related to the mill's emergency eyewash equipment and procedures. No orders were issued.
- Inspection Report 2011166350224, dated December 28, 2011. No inspection occurred. This report was issued to communicate the air sample testing results to Babine. Two of the samples had exceeded the allowable exposure limits which, according to the report, suggested that the mill's current ventilation systems and water misters were not adequately protecting some workers. The Inspection Report cited Babine with a violation of Part 5.48 of the Occupational Health and Safety Regulation for exceeding wood dust respiratory exposure limits and imposed a deadline of January 31, 2012 for notifying WorkSafeBC of the steps taken to achieve compliance. The WorkSafeBC officer emailed this Inspection Report to the mill manager advising him that, "...Until the ventilation system is upgraded, there will need to be some positions in the mill where respiratory protection is mandatory (e.g. clean-up)...".
- Consultation Report 2012161980059, dated January 3, 2012. This report was generated to record an e-mail stream from the mill regarding their compliance efforts arising from the order cited in the December 28, 2011 Inspection Report. The Maintenance Superintendent

advised the WorkSafeBC officer that they were looking into test fitting dust masks to protect workers from dust exposure.

Prior to the incident, WorkSafeBC did not enforce the combustible dust provisions of the Occupational Health and Safety Regulation at the Babine sawmill. However, as set out above, a violation order for excessive levels of airborne dust was issued, with the expectation that Babine would improve its ventilation system.

As the employer, Babine was ultimately responsible to ensure that its operations complied with occupational health and safety legislation.

2.11 Was this a preventable incident?

The investigation shows that the explosion and fire that destroyed the sawmill constituted a preventable incident. The sawmill management had known for some time that the dust collection system was undersized for this type of operation, and in fact had made a down payment on replacement or additional baghouse systems in 2011. It was determined at the time that these improvements could not be made as the mill's power system was already working at maximum capacity and could not handle additional electrical loading. The electrical upgrade was planned and preliminary work had commenced before the incident occurred. While the electrical upgrade was being done, there was no reduction in production; in fact, production levels increased. As well, Babine had moved the collection ducting from the trim saws and edgers to the bandsaw and debarkers. These areas now had no dust collection.

Preventing a wood dust explosion involves removing one of the five components that need to be available for the explosion to occur: oxygen, containment, ignition, dust as fuel, and dispersion of the dust. Oxygen is available in the air, but the other four components can be controlled.

In the Babine sawmill, high-walled conveyor systems and other equipment and structures contributed to containment in the half-basement level. If containment cannot be avoided, then the hazard assessment should focus on controlling the other components required for an explosion.

There are numerous ignition sources throughout a sawmill. Effective inspection and maintenance programs and the time to perform this work would reduce the likelihood of ignition, particularly if extraction and clean-up of wood dust is also improved.

Sawmills have various control measures for dispersion of the airborne dusts, including natural ventilation, mechanical ventilation, and misting systems. These have been generally successful to date in keeping the dust concentrations below a deflagration level. However, mills "button up" during the winter months to preserve heat, which makes these systems less effective. Misting systems are typically turned off during the winter because of freezing and baghouse concerns regarding frozen filter elements. The dust management systems will need to be improved to capture all of the fine dusts produced that are now currently migrating through the sawmills. The sawmills also contribute to the dispersal of dust into the air with various clean-up activities and normal production by using blow-down, sweeping dust through floor openings to the basement levels below, and by vibrating screens and conveyors.

Wood dust was the major fuel for the explosion and fires. The Babine sawmill was spending considerable amounts of money on upgrading the sawmill's production capabilities and improving the dust management system by opening up floors, pressurizing the MCC panels, and improving the waste conveyors systems. There had been a little work done on the sawmill dust collection system, and extra clean-up efforts were made following the February 23, 2011, explosion and fire, the Hampton investigation report of which identified a "very large fuel load" of dry dust. However, no adequate actions were taken to reduce or control the levels of airborne wood dust within the mill even though this was the root cause of the Occupational Health and Safety Regulation violation cited in December 2011. Effective actions should have been taken to control both the airborne dispersal of wood dust as well as the excessive accumulations on floors and surfaces. Such actions might have prevented this incident.

3 Conclusions

3.1 Findings as to causes

All the components for a wood dust explosion existed. Wood dust – the fuel – was dispersed in air. Near the ignition source was a containment zone. Oxygen was present in the air.

3.1.1 Concentration of dispersed wood dust in the air

The wood dust that was dispersed in the air within the Babine sawmill was of sufficient concentration to explode.

3.1.2 Friction within the motor-reducer V-belt guard provided ignition source

Wood dust from beneath the 8R-25 conveyor migrated into the confined area within the motor-reducer V-belt guard. The dust was compacted and subjected to near-constant friction from the rotating belts and sheaves. This dust caught fire and ignited the airborne wood dust that was dispersed in the area. An explosion and subsequent fire travelled through the mill, disturbing and dispersing the accumulated wood dusts and setting off secondary deflagrating explosions that totally destroyed the mill, killing two workers and injuring 20, many seriously.

3.2 Findings as to underlying factors

3.2.1 Ineffective wood dust control measures

The dust collection system was ineffective in controlling airborne dusts and the accumulation of other fine dusts in the sawmill. The collection ducting serviced only the bandsaw and debarker areas and not the east side of the sawmill where the trim-saws and eliminators were or the other areas where these dusts were being produced. Lumber-processing equipment generates large amounts of wood dust by abrasive or cutting actions. It is important to provide an effective dust collection system to capture the dust at the point of release and transport the material through ducting into collection equipment.

The mill produced large volumes of wood waste that was not adequately removed from the mill during production shifts. This provided abundant fuels for the explosion and subsequent fires.

3.2.2 Ineffective inspection and maintenance system

The application of a nearly solid guard at the 8R-25 motor-reducer assembly's location required increased inspection and maintenance to ensure that the containment that it presented was adequately monitored and controlled. This was not being done.

3.2.3 Conditions of the wood and weather

The cold weather conditions resulted in a very dry environment with low humidity. This condition was compounded by the very dry beetle-killed wood. The dusts produced were drier and finer and they migrated throughout the mill. These dusts were mixed with green wood dusts as green wood was being processed at the time. Many of the sawmill workers agreed that the dust from processing the beetle-killed pine was finer and more noticeable. The dry humidity, environment and dust conditions contributed to this incident.

3.2.4 Waste conveyor configurations increased airborne wood dust

The waste conveyors in the basement level did not adequately capture the fine dust generated during lumber processing. These conveyors were open to the operating floor above and there were large open areas along the conveyor sidewalls. Wood waste was dropped from one conveyor to another, accompanied by vibration in some cases. The conveyors were not equipped with an effective dust collection system. Fine wood dust stirred up by the constant action of the conveyors was free to disperse into the air.

Babine installed dust collection ducting for some of the conveyors but not for others. Even where such ducting was installed, the fine dust was not effectively captured. This fine dust should have been removed independent of the waste conveyor system.

The volume of the coarser wood dust and debris exceeded the capacity of the conveyor system.

3.2.5 Inadequate supervision of clean-up and maintenance staff

The accumulations of wood waste before the explosion and the poor condition of some of the electrical equipment that was inspected after the incident indicate that supervisors were not effectively or adequately monitoring the work that was being done.

4 Health and Safety Action Taken

After a second explosion at a mill, at Lakeland Mills in Prince George in April 2012, health and safety initiatives were taken by WorkSafeBC and industry. These are available on worksafebc.com:
http://www.worksafebc.com/news_room/features/2012/sawmills/default.asp

4.1 WorkSafeBC

WorkSafeBC's actions include the following:

- A directive order to every sawmill in B.C. to undertake a comprehensive risk assessment with respect to hazards created by combustible dusts and develop and implement an effective combustible dust control program
- Follow-up inspections of sawmills by WorkSafeBC prevention officers
- Inspections expanded to similar wood-processing operations where dust accumulation could be a hazard
- Hazard alert on the increased risk in winter of combustible dust:
  http://www2.worksafebc.com/publications/posters.asp?reportID=36940

4.2 Industry resources

Wood products manufacturers and WorkSafeBC provided a number of resources on testing and control measures for wood dust, including a compilation of best practices. Available online:
http://www.worksafebc.com/news_room/features/2012/Sawmills/IndustryResources.asp

Appendix 1, How the Investigation Was Conducted

WorkSafeBC's Investigations Department conducts health and safety investigations using a methodology that involves collecting information from various sources to understand the facts and circumstances of the incident and analyzing that information to identify causal and underlying factors that led to the incident.

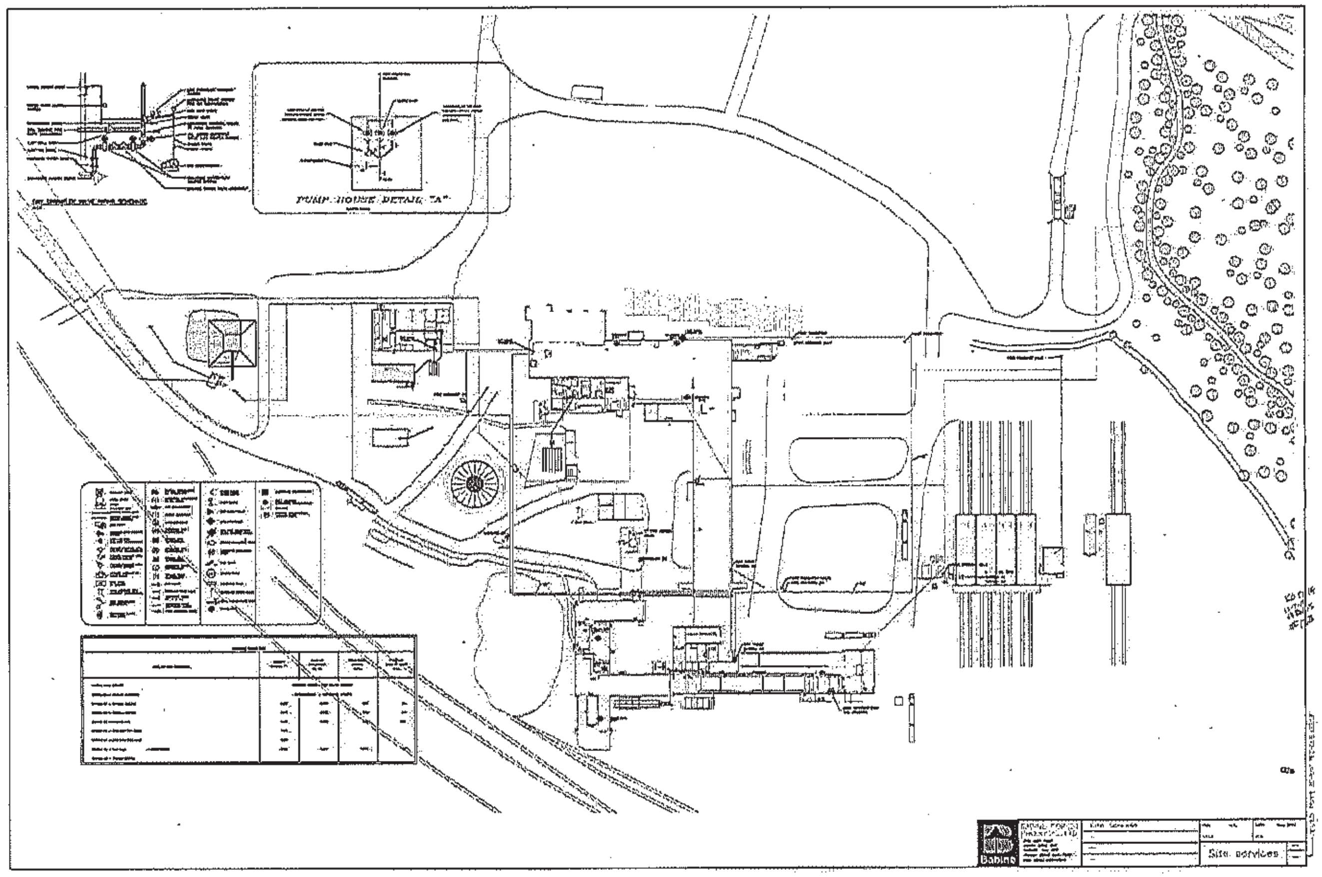
The field investigation generally applied the principles set out in NFPA 921, *Guide for Fire and Explosion Investigations,* including:

- Securing and examining the incident site, including any equipment involved
- Taking notes and photographs
- Interviewing the mill workers and management and other persons with relevant information
- Collecting documentation
- Establishing the origin of the explosion and the ignition source
- Identifying blast and thermal damage
- Developing different hypotheses to explain the explosion
- Testing these hypotheses to eliminate them or confirm their validity
- Conducting tests of materials or equipment that may have contributed to the incident

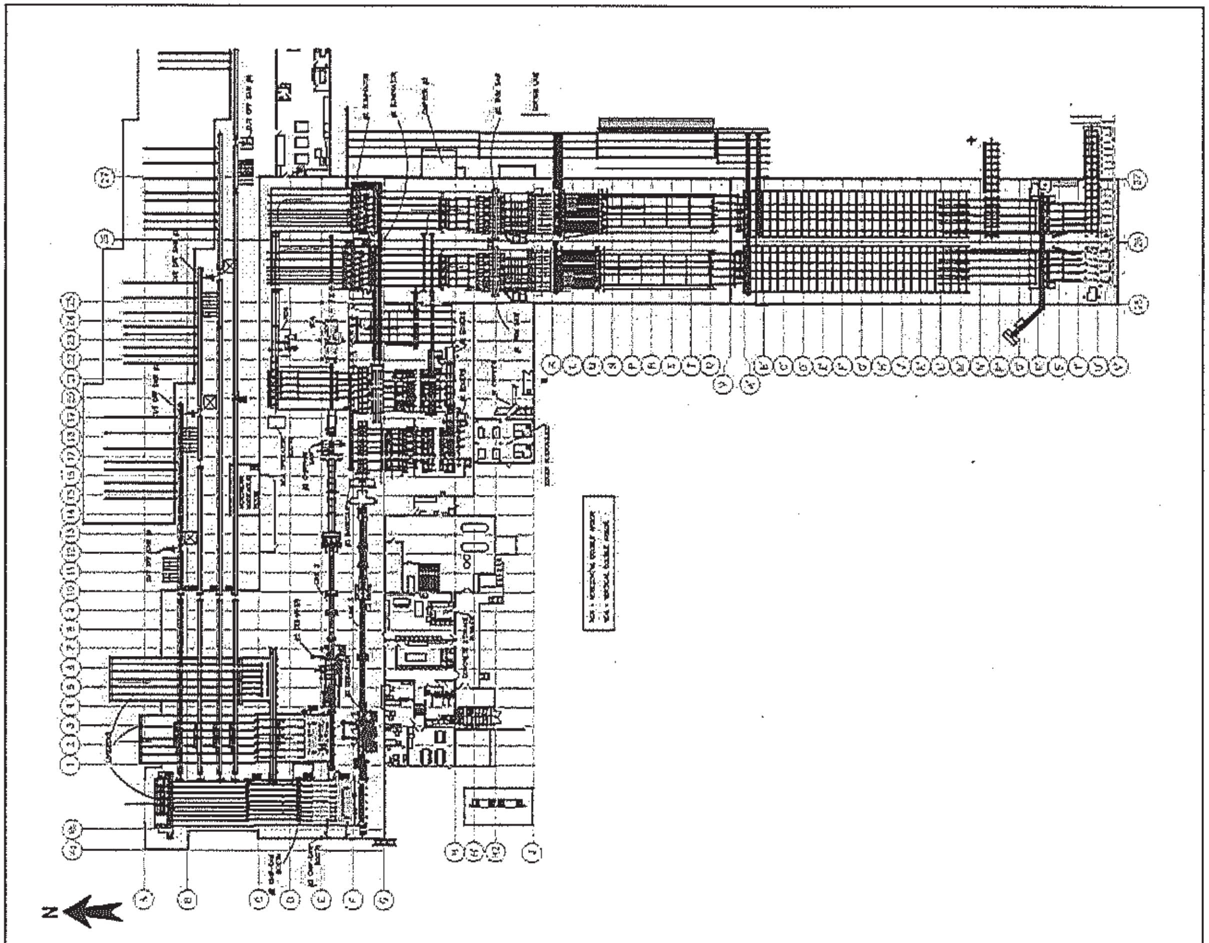
Analysis of the data included:

- Determining a sequence of events that led to the explosion
- Examining the contributory events for unsafe acts and conditions
- Exploring the underlying factors that made the unsafe acts or conditions possible
- Identifying health and safety deficiencies

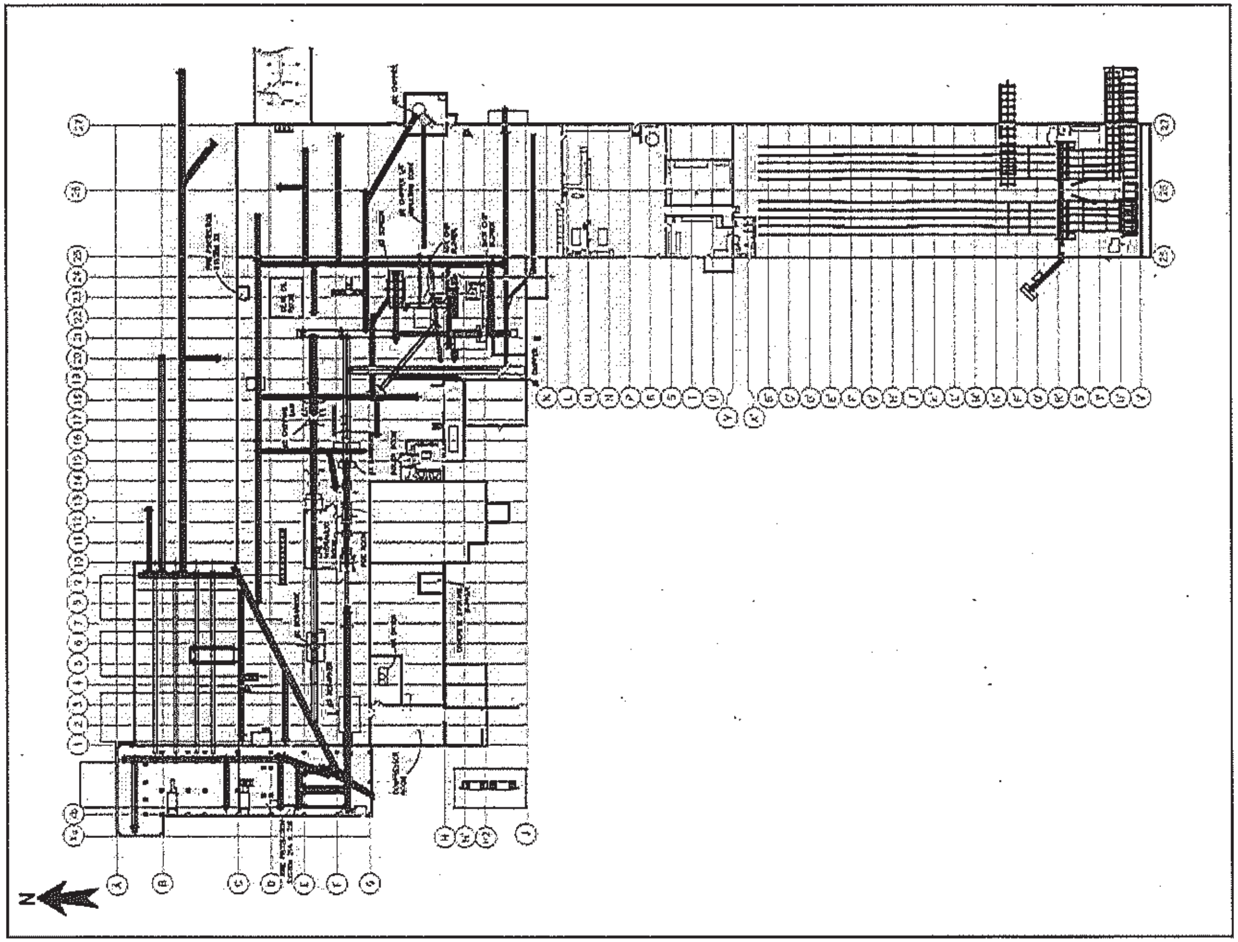
Appendix 2, Plan View Drawing



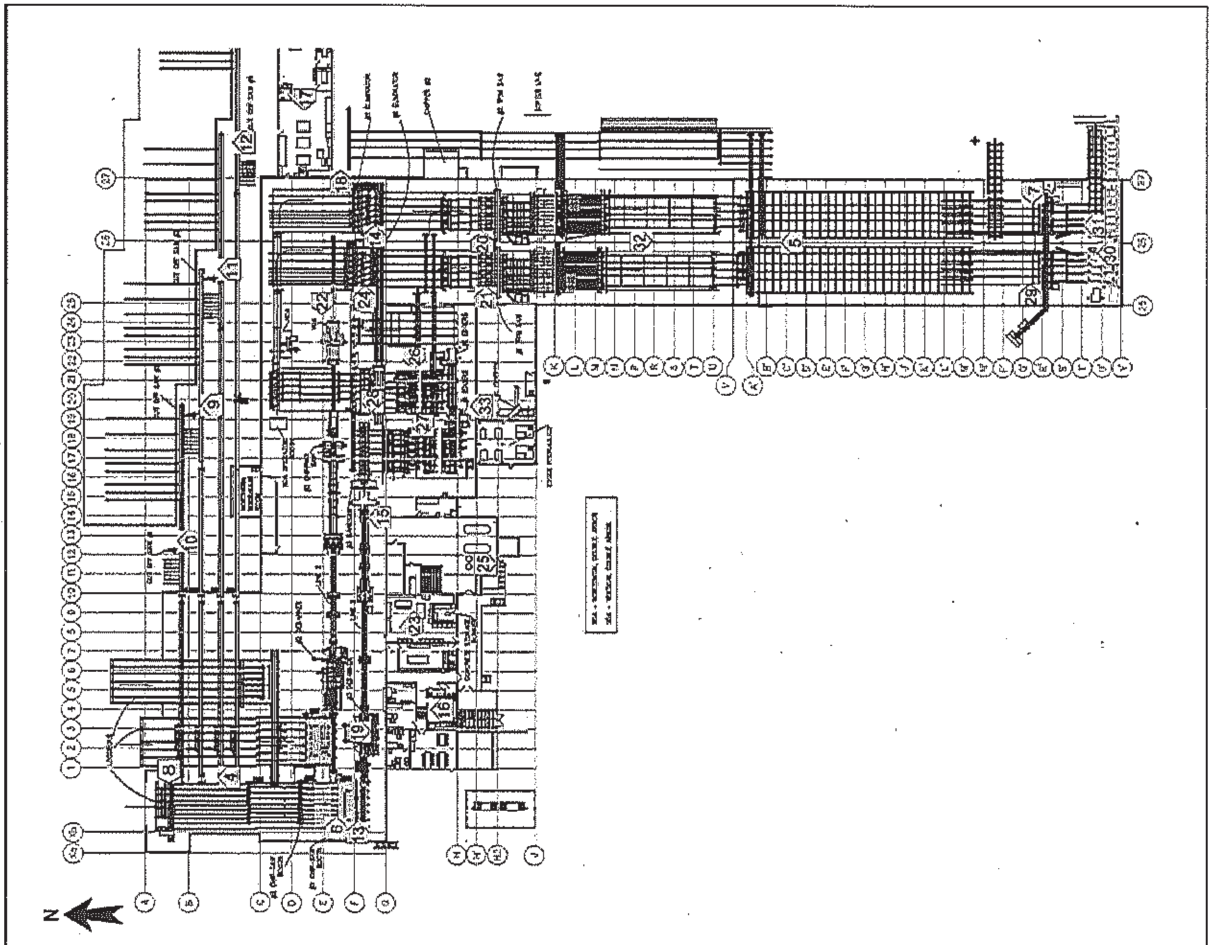
Appendix 3, Operating Floor Drawing with Grid References and Equipment Labelling



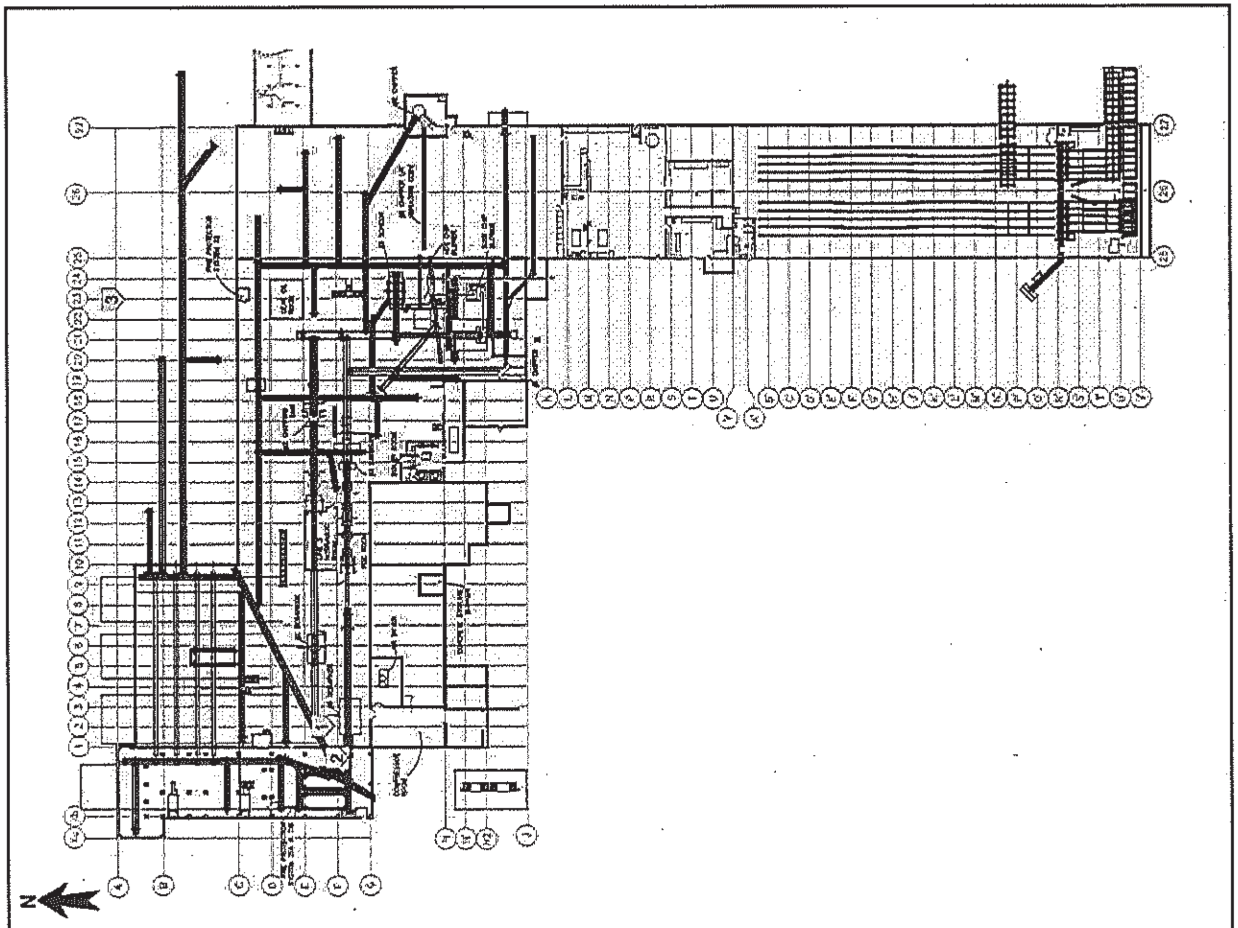
Appendix 4, Basement Level Drawing with Grid References and Equipment Labelling



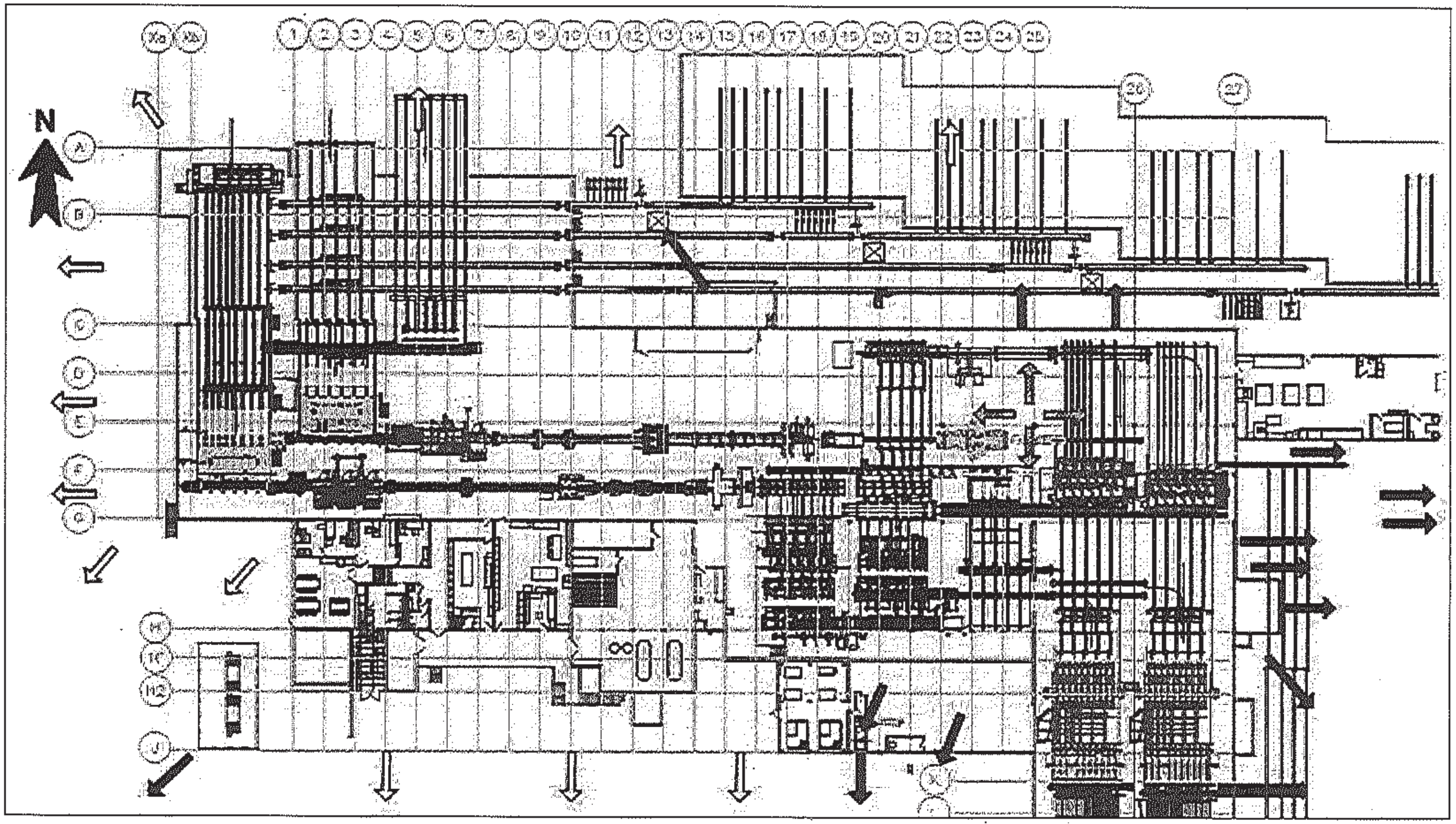
Appendix 5, Operating Level Drawing with Worker Locations



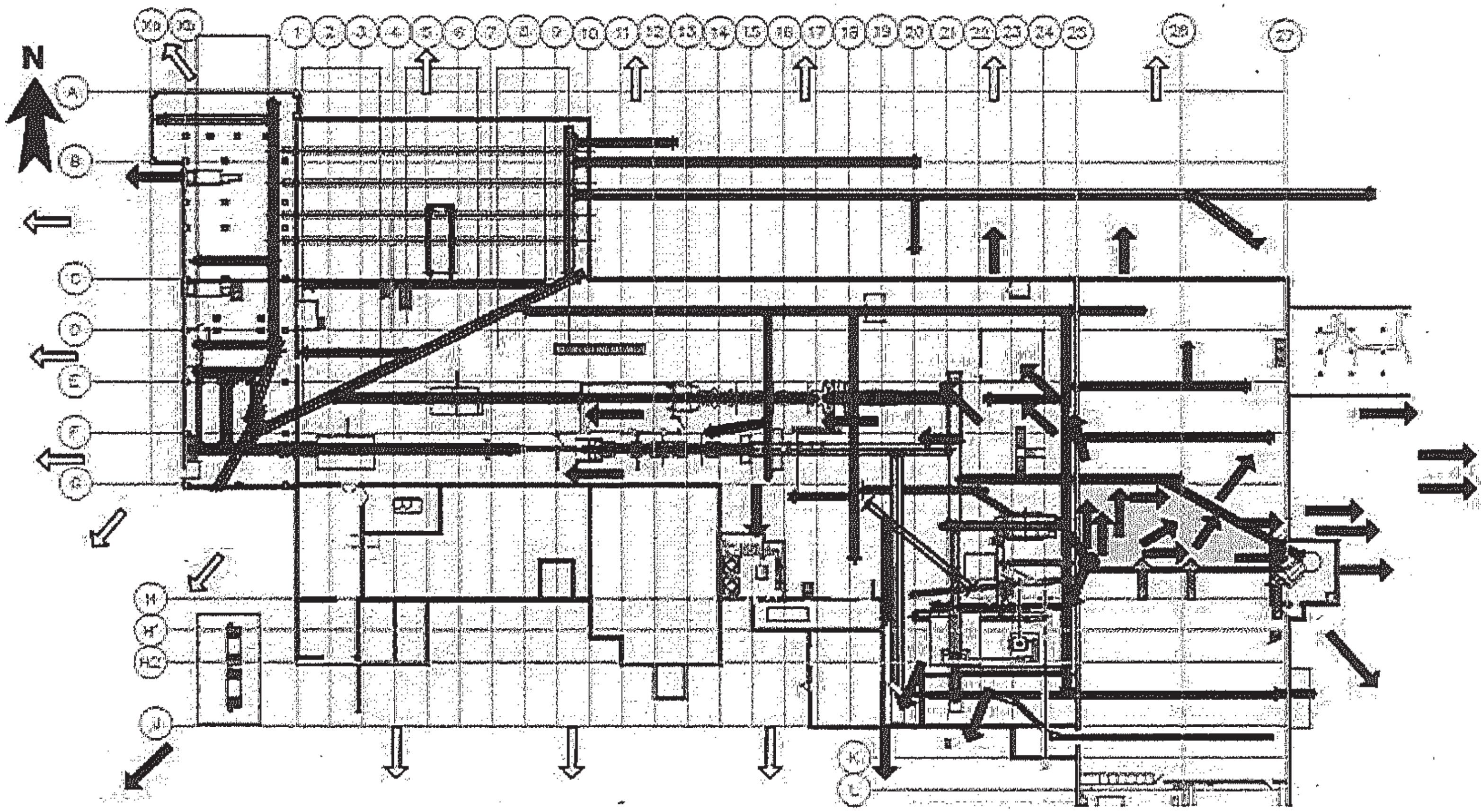
Appendix 6, Basement Level Drawing with Worker Locations



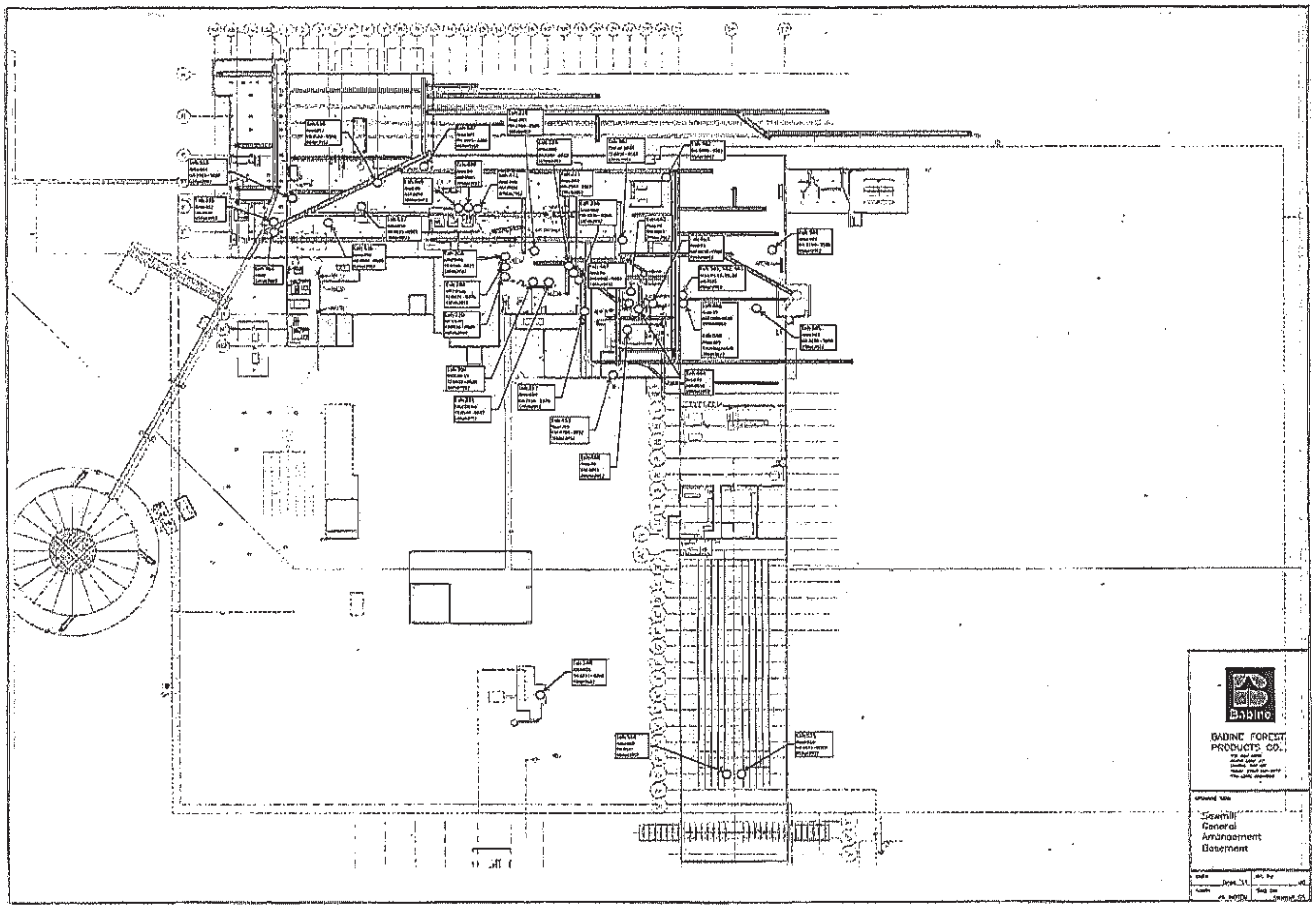
Appendix 8, Operating Floor Drawing with Blast Vectors



Appendix 9, Basement Level Drawing with Blast Vectors



Appendix 10, Plan Drawing with Grid Reference Showing Evidence Sample Locations



Notes

[1] Ashok Ghose Dastidar, "This is not 'dust' so I don't have a problem," *Process Safety News* 19, 3 (2012): 1, 4-5. Available online at:
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[3] Martin Feng and Robert Knudson, *Improving Value Recovery of OSB from Post-Mountain Pine Beetle Wood*, Mountain Pine Beetle Initiative Working Paper 2005–13 (Victoria: Pacific Forestry Centre, 2005), pp. 11–12. Available online at:
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[4] Tennessee Trent, Val Lawrence, and Kathy Woo, *A Wood and Fibre Quality-Deterioration Model for Mountain Pine Beetle-Killed Trees by Biogeoclimatic Subzone,* Mountain Pine Beetle Initiative Working Paper 2006-10 (Victoria: Pacific Forestry Centre, 2006), p. 18. Available online at:
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[5] A.J. Mancini, "Manufacturing and marketing older dead lodgepole pine," in *The Dead Softwood Lumber Resource: Proceedings of Symposium Held May 22–24, 1978, Spokane, WA* (Pullman: Washington State University, 1978), pp. 193-96.

[6] Ibid.

[7] Anthony Byrne, Cameron Stonestreet, and Brian Peter, *Current Knowledge of Characteristics and Utilization of Post-Mountain Pine Beetle Wood in Solid Wood Products,* Mountain Pine Beetle Initiative Working Paper 2005-8 (Victoria: Pacific Forestry Research Centre, 2005). Available online at:
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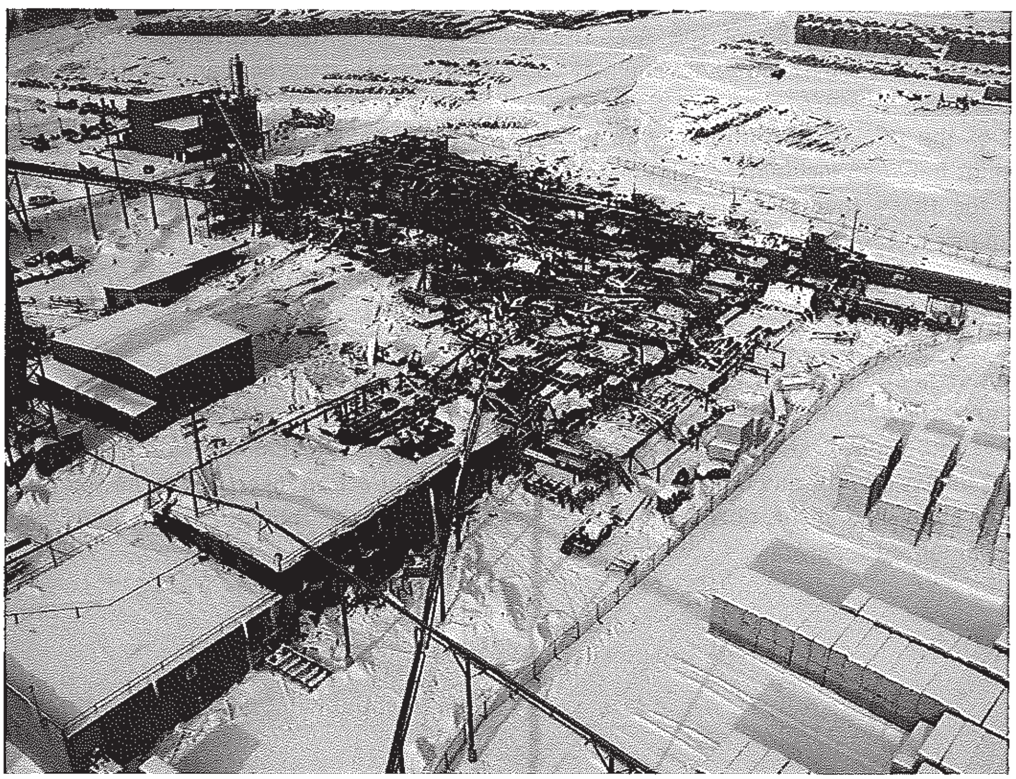
[8] Larry Allen and Vic Uloth, *Operational Extractives Management from Mountain Pine Beetle-Attacked Lodgepole Pine for Pulp and Papermaking,* Mountain Pine Beetle Initiative Working Paper 2007-15 (Victoria: Pacific Forestry Research Centre, 2007). Available at: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/28110.pdf

Safety Authority

Recommendations Report



Babine Forest Products – Explosion and Fire – January 20, 2012

BC Safety Authority – Incident Investigation – Jurisdiction and Role

The BC Safety Authority administers the *Safety Standards Act* on behalf of the Province of British Columbia.[1] The *Safety Standards Act* and associated *Regulations* apply to the following products and persons doing regulated work on these products:

i. amusement devices;
ii. passenger ropeways;
iii. boilers and boiler systems;
iv. electrical equipment;
v. elevating devices and passenger conveyors;
vi. gas systems and equipment;
vii. pressure vessels;
viii. pressure piping;
ix. refrigeration systems and equipment; and
x. any other regulated product specified in the regulations.

Incidents involving products or work subject to the *Safety Standards Act* are required to be reported in accordance with Section 36 of the *Act*. The BC Safety Authority investigates these incidents in accordance with Section 37 of the *Act* and may appoint persons to assist with an investigation.

The role of the BC Safety Authority with respect to the investigation of incidents is to understand relationships between incidents, equipment and work that are subject to the *Safety Standards Act*. It is our aim for these investigations to prevent the recurrence of similar incidents and to initiate improvements toward the management of safety risks with regulated equipment and work. Often, these investigations are conducted in cooperation with other agencies including the Fire Officials, WorksafeBC, the Police and the Coroners Service.

This recommendations report is not a final investigation report. The purpose of this document is to advance hazard awareness and promote safe practices. This document outlines nine recommendations to improve the identification and management of combustible dust *hazardous locations* by wood processing facility owners and operators. Issues of enforcement action taken under the *Safety Standards Act* are not addressed in this document. Any regulatory compliance activities arising from this incident will be documented separately.

[1] Some municipalities administer portions of the *Safety Standards Act*.

Incident Synopsis

On January 20, 2012 at approximately 8:07pm, an explosion and fire occurred in the Babine Forest Products sawmill located at 19479 Highway 16 East, approximately 20 kilometers East of the town of Burns Lake, British Columbia.

The explosion and fire caused two fatalities and injured 20 people. The sawmill was destroyed by the explosion and fire.

Site Information

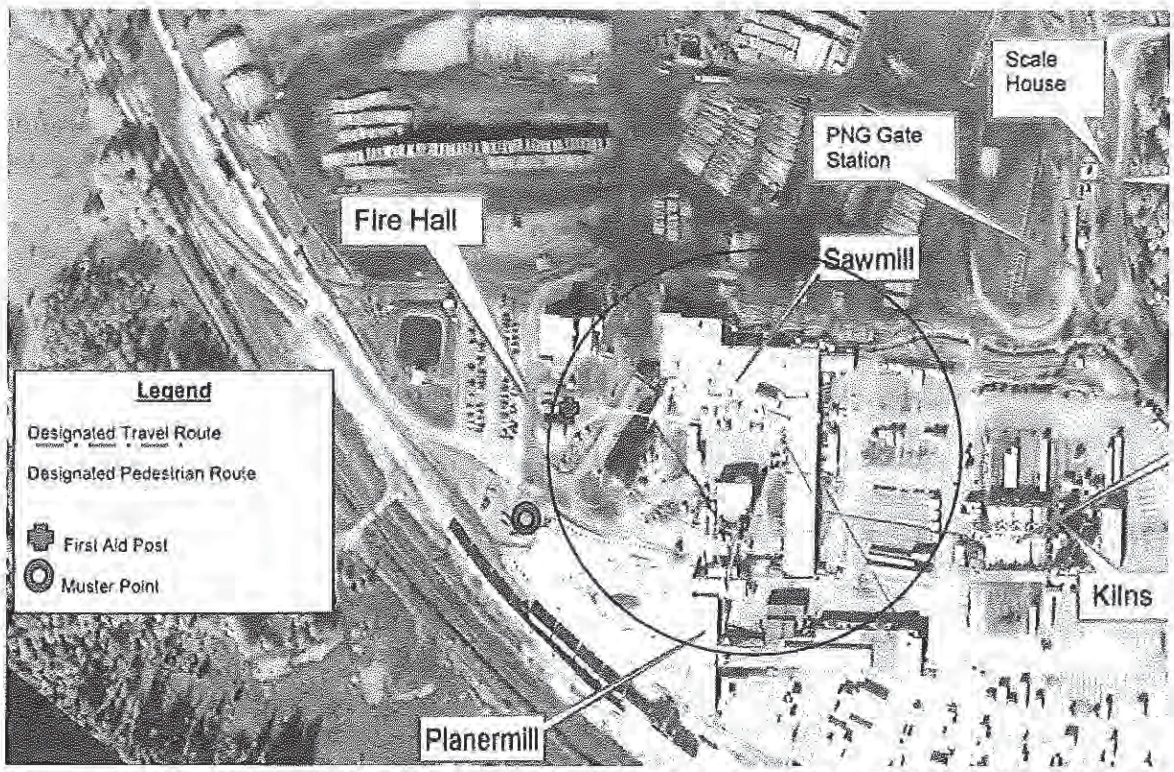
Safety Officers and a contracted certified fire and explosion investigator were dispatched by the BC Safety Authority to the sawmill site to identify equipment and systems subject to the *Safety Standards Act*, evaluate the role that this equipment, or its operation may have had regarding the incident and to identify non-compliances with the relevant *Regulations*. WorksafeBC assumed the role of lead investigating agency, responsible for overall control of the site and evidence removed for evaluation. While there was professional collaboration from all on-site investigating organizations, each organization was responsible for making findings and conclusions independently.

Photograph 1 shows an aerial view of the Babine Forest Products site, which consisted of numerous buildings and structures including the sawmill. On January 20, 2012, the sawmill at Babine Forest Products site near Burns Lake utilized equipment that was subject to the *Safety Standards Act*.

Natural gas fuelled appliances, natural gas distribution components, propane storage, propane dispensing, portable propane cylinders and propane appliances were in use at the sawmill and are subject to the *Gas Safety Regulation*.

Boilers, pressure vessels and pressure piping systems were in use at the sawmill and are subject to the *Power Engineers, Boilers, Pressure Vessel and Refrigeration Safety Regulation*.

Electrically powered appliances, electrical equipment, electrical signal and power distribution components were in use at the sawmill and are subject to the *Electrical Safety Regulation*.



Photograph 1: Aerial view of the Babine Forest Products site prior to the explosion and fire of January 20th, 2012.

Incident Investigation Recommendations

Owners and operators of wood processing facilities are responsible for the safe use of regulated electrical and gas equipment at their facilities, including the proper configuration of equipment used in *hazardous locations*. The safe use of equipment involves maintaining an environment that is suitable for regulated equipment. As a result of this incident, the BC Safety Authority intends to order wood processing facility owners and operators to document an assessment of their facilities, specifically for *hazardous locations* and effective hazard management. The assessment under consideration would be completed:

- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations*.

The BC Safety Authority therefore makes the following nine recommendations to improve the identification and management of combustible dust *hazardous locations* by wood processing facility owners and operators.

Safety Authority

Recommendations to Owners and Operators of Wood Processing Facilities:

Recommendation #1:
Document a facility assessment to identify *hazardous locations* that is completed:
- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations*.

Recommendation #2:
Where *hazardous locations* are identified and contain regulated equipment, document a plan to either:
- develop and implement auditable wood dust management practices for these locations that are accepted by a qualified person as an effective means to manage the combustion hazard, or
- configure the equipment for safe operation given the presence of the combustible dust hazard. Safe operating configurations include:
    a) obtaining approval for operation in the *hazardous location*, or
    b) permanent removal of the equipment from the *hazardous location*.

Recommendation #3:
Incorporate any identified *hazardous locations* and the chosen means to manage the combustion hazards into the facility's *Fire Safety Plan*, or other suitable facility document(s).

Recommendations to the BC Office of the Fire Commissioner:

Recommendation #4:
Publish a list of professional qualifications suitable for individuals who identify wood dust combustion and explosion *hazardous locations* in an industrial environment.

Recommendation #5:
Identify suitable fire and explosion prevention guidance material to be used in BC for the identification and classification of *hazardous locations* due to combustible wood dusts.

Recommendation #6:
Add details of a qualified person and accepted guidance material related to *hazardous location* classification and management into the *Fire Safety Plan* requirements of the *BC Fire Code*.

Recommendations to the Canadian Standards Association:

Recommendation #7:
Specifically identify wood dust as a combustible dust belonging to group G dusts in section 18 of the *Canadian Electrical Code, Part 1*.

Recommendation #8:
Improve coordination between section 18 of the *Canadian Electrical Code* and referenced fire and explosion prevention standards for *hazardous location* identification and classification.

Recommendation #9:
Improve the natural gas and propane code requirements and accompanying guidance material relating to *hazardous location* identification and alignment with fire prevention standards.

Hazardous Locations

Applicable safety codes require operators to identify and manage fire and explosion hazards. Special precautions are required at locations where fire and explosion hazards are likely to exist in order to control potential fuel or ignition sources.

Compliance with these codes require designers and operators to exercise a degree of foresight in respect of the actual operating conditions which may be encountered in the future: equipment which is code compliant at the time of installation or inspection may become non-compliant if hazardous environments are permitted to develop.

This discussion of *hazardous locations* and code material is being summarized to provide an understanding of the requirements in existence relative to combustible wood dust which is applicable to sawmill environments. This discussion also provides additional context for the recommendations made by the BC Safety Authority.

British Columbia Fire Code

The BC Safety Authority does not administer the *British Columbia Fire Code*; however, the code contains useful excerpts.

At the time of the incident, the 2006 edition of the *British Columbia Fire Code* was adopted by the Province of British Columbia. Division B, Part 5 – *Hazardous Processes and Operations* applies to "processes and operations that involve a risk from explosion, high flammability or related conditions that create a hazard to life safety". Section 5.3 – *Dust-Producing Processes* applies "…where *combustible dusts*[2] are produced in quantities or concentrations that create an explosion or fire hazard." The current 2012 edition contains similar requirements.

These sections of the *British Columbia Fire Code* require:

- Wiring or electrical equipment located in *hazardous locations*[3] to conform to the *British Columbia Safety Standards Act* and pursuant regulations for hazardous locations.
- The preparation of a *Fire Safety Plan* for hazardous processes or operations that includes (but not limited to) the control of fire hazards.
- Bonding and grounding of electrically conductive parts.
- Electrical interlocking of dust producing equipment to required dust removal equipment.

[2] Combustible dusts means dusts and particles that are ignitable and liable to produce an explosion. (British Columbia Fire Code – 2006 Edition)

[3] The British Columbia Fire Code (2006 edition) refers to hazardous locations as being areas in which flammable gases or vapours, combustible dusts or combustible fibres are present in quantities sufficient to create a hazard.

- Control or removal of equipment that may produce an ignition source and conformity to the hazardous locations requirements of the *British Columbia Safety Standards Act.*

Canadian Electrical Code

The *Electrical Safety Regulation* adopts the *Canadian Electrical Code* (with BC amendments) as the technical standard for most electrical equipment in the Province. BC Amendments to editions of the Code did not affect the requirements discussed below.

Section 18 of the Electrical Code applies to electrical equipment and wiring installed or used in *hazardous locations*. Rule 18-004 classifies *hazardous locations* according to the nature of the hazard, as follows:

(b) Class II locations are those that are hazardous because of the presence of combustible or electrically conductive combustible dusts;

(c) Class III locations are those that are hazardous because of the presence of easily ignitable fibres or flyings, but in which such fibres or flyings are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures.

Class II combustible dust atmospheres are divided into Groups E, F or G. Group G atmospheres are comprised of those *"containing flour, starch, or grain dust, and other dusts of similarly hazardous characteristics."* Appendix B guidance material relating to Rule 18-008 of the *Canadian Electrical Code,* although not a binding requirement, includes wood flour in a list of combustible dusts. The group G definition and associated guidance material suggests a combustion hazard be considered when operating in the presence of wood flour or dust.

Section 18 prescribes installation techniques to separate the combustion hazards from potential electrical ignition sources in Class II and III *hazardous locations*, including:

- Use of metal conduits and sealed enclosures for wiring (18-202, 204, 252, 254, 302 & 352)
- Sealing and use of dust tight enclosures for switches, motor controllers etc (18-206, 256, 304 & 354)
- Use of outside clean air for electrical component ventilation (18-212, 262, 310 & 360)
- Use of luminaires and other equipment that is certified for the hazardous environment (18-216, 220, 264 and others)

Propane and Natural Gas Codes

At the time of the incident, the 2010 editions of the *Propane storage and handling code* (CSA B149.2-10) and the *Natural gas and propane installation code* (CSA B149.1-10) were adopted by the *Gas Safety Regulation*. Each code contains a section titled *hazardous locations* with the following requirement:

> *An appliance, unless certified for installation in a hazardous location, shall not be installed in any location where a flammable vapour, combustible dust or fibres, or an explosive mixture is present.*

The 2005 edition of the *Natural Gas and Propane Code Handbook (B149HB-05)* contains the following 'note on hazardous environments':

> *Hazardous environments, in relation to gas appliance installations may be practically defined as any space containing concentrations of flammable vapours, combustible dust or fibres, or explosive mixtures which may be ignited by appliance operation. Technical information on hazardous environments is available from the National Fire Protection Agency (NFPA). Refer to NFPA 499: Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas....*

Fire and Explosion Prevention Standards

Several (US) National Fire Protection Agency (NFPA) and industry standards are publically available that illustrate the fire and explosion hazards presented by wood dust. Table 1 below compiles published combustion and explosion characteristics of wood dust as well as other combustible dusts that are expressly identified by the *Canadian Electrical Code* as Group G atmospheres. Test data describing explosion and fire hazard characteristics can be sample specific - values presented in Table 1 are for general reference only.

Table 1: Sample Explosion and Fire Hazard Characteristics – derived from referenced documents

Material	Deflagration Index, K_{st} (bar-m/s)		Explosion Pressure P_{max} (bar)	Dust Layer Ignition Temperature (°C)
	Value	Group[4]		
Aluminum	415[2]	3 (very strong explosion)	12.4[2]	320[1]
Coal (bituminous)	129[2]	1 (weak explosion)	9.2[2]	180[1]
Sugar	138[2]		8.5[2]	370[1]
Wheat flour	87[3]		8.3[3]	360[1]
Wheat starch	115[2]		9.9[2]	380[1]
Wheat grain dust	112[3]		9.3[3]	Not Available
Wood flour	205[2]	2 (strong explosion)	10.5[2]	260[1]
Wood bark (ground)	Not Available	Not Available	Not Available	250[1]

Notes:

[1] *NFPA 499 – Classification of Combustible Dusts and of Hazards (Classified) Locations for Electrical Installations – 2008 Edition* – Table 4.5.2.

[2] *NFPA 68 – Standard on Explosion Protection by Deflagration Venting – 2007 Edition* – Table E1(a)

[3] *NFPA 61 – Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities – 2008 Edition* – Table A.6.2.1

[4] Hazard Communication Guidance for Combustible Dusts – Occupational Safety and Health Administration – OSHA 3371-08 2009. Four dust explosion classes are communicated for corresponding Kst ranges – 0 is assigned a "no explosion" characteristic. Values between 0 and 200 is assigned a "weak explosion" characteristic. Values between 200 and 300 are assigned a "strong explosion" characteristic and values above 300 are assigned a "very strong explosion" characteristic.

Table 1 above illustrates that wood dust can have explosion and fire hazard characteristics similar to other known dusts that are identified as combustible dusts in the *Canadian Electrical Code*. NFPA 499 classifies wood flour as a group G combustible dust and NFPA 68 assigns wood flour a hazard class of "2", which is identified as having "strong explosion" characteristics by the US Occupational Safety and Health Administration. Given the above, wood dust and potential ignition sources exposed to wood dust are required to be managed. Locations where wood dust accumulates or is suspended in atmosphere are considered hazardous locations.

Testing of wood dust samples from BC sawmills was conducted by WorksafeBC and the results are described in WorksafeBC Industry Update dated August 16, 2012. This advisory confirms that wood dust types found in BC wood processing facilities present explosion and combustion hazards.

NFPA 664 - Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities identifies that "*portions of the facility where* [wood] *dust accumulations occur or where suspensions of wood dust in air could occur shall be equipped with electrical systems and equipment per Article 502 or 503 of NFPA 70, National Electrical Code*[4]". With respect to *hazardous locations* due to dust accumulation, the standard generally describes the presence of a deflagration hazard when deflagrable wood dust[5] is present as a layer on upward facing surfaces at a depth greater than 3.2mm (1/8 in) over five percent of the area or 93m^2 (1000ft^2), whichever is less.

[4] Article 502 or 503 of NFPA 70, National Electrical Code is similar to section 18 of the *Canadian Electrical Code* for *hazardous locations*. Article 500 is Hazardous (Classified) Locations while 502 is Class II [combustible dust] Locations and 503 is Class III [combustible dust] Locations.

[5] Deflagrable wood dust is generally referred to as wood dust that has explosive characteristics and is available to become suspended in atmosphere. NFPA 664 contains specific definitions for these terms.

Application of *Hazardous Location* Requirements

Areas of sawmills where accumulations of deflagrable wood dust may be present or areas where operations could generate a suspension of wood dust in the atmosphere should be considered as potential *hazardous locations* as described by the *Canadian Electrical Code*, propane and natural gas codes as well as other industry standards.

Industry professionals with the appropriate knowledge and experience necessary to evaluate the combustion risk of a potentially *hazardous location*, should be consulted to confirm the classification as hazardous, or not, and to evaluate the effectiveness of hazard management techniques. Classifications of *hazardous locations* and the evaluations of hazard management techniques should be conducted in accordance with accepted industry standards, such as NFPA 499 and NFPA 664.

Electrical and gas equipment installed within a classified *hazardous location* must comply with the applicable *hazardous location* requirements.

Compliance with the *Safety Standards Act*

The *Safety Standards Act* contains the following requirement:

> ***Operation and use of regulated products***
> *69 (3) A person must not use a regulated product in a manner that is unsafe or that creates a risk of personal injury or damage to property.*

During installation, assumptions are made to support the selection of appropriate configurations and use of electrical equipment. Any condition deemed necessary for a particular configuration to be compliant at the time of installation must be maintained during operation. If operational activity results in a drift away from assumed conditions necessary for the type of installation to remain safe, so that a residual byproduct of production creates or contributes to a hazardous environment or location, compliance should be re-evaluated.

If wood dust management activities fail to maintain a non-hazardous environment, equipment and installations in use at those locations that are not certified or configured for such a *hazardous location* fail to remain in a safe condition and are non-compliant to the *Safety Standards Act*.

Investigation Report

Babine Forest Products – Explosion and Fire – January 20, 2012

BC Safety Authority – Incident Investigation – Jurisdiction and Role

The BC Safety Authority administers the *Safety Standards Act* on behalf of the Province of British Columbia.[1] The *Safety Standards Act* and associated *Regulations* apply to the following products and persons doing regulated work on these products:

(i) amusement devices;
(ii) passenger ropeways;
(iii) boilers and boiler systems;
(iv) electrical equipment;
(v) elevating devices and passenger conveyors;
(vi) gas systems and equipment;
(vii) pressure vessels;
(viii) pressure piping;
(ix) refrigeration systems and equipment; and
(x) any other regulated product specified in the regulations.

Incidents involving products or work subject to the *Safety Standards Act* are required to be reported in accordance with Section 36 of the *Act*. The BC Safety Authority investigates these incidents in accordance with Section 37 of the *Act* and may appoint persons to assist with an investigation.

The role of the BC Safety Authority with respect to the investigation of incidents is to understand relationships between incidents, equipment and work that are subject to the *Safety Standards Act*. It is our aim for these investigations to prevent the recurrence of similar incidents and to initiate improvements toward the management of safety risks with regulated equipment and work. Often, these investigations are conducted in cooperation with other agencies including the Fire Officials, WorksafeBC, the Police and the Coroners Service.

This investigation report does not address issues of enforcement action taken under the *Safety Standards Act*. Any regulatory compliance activities arising from this incident will be documented separately.

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[1] Some municipalities administer portions of the *Safety Standards Act*. See reference 1 at the end of this report for more details.

Contents

Incident Synopsis

On January 20, 2012 at approximately 8:07pm, an explosion and fire occurred in the Babine Forest Products sawmill located at 19479 Highway 16 East, approximately 20 kilometers East of the town of Burns Lake, British Columbia.

The explosion and fire caused two fatalities and injured 20 people. The sawmill was destroyed by the explosion and fire.

Summary

Safety Officers and a certified fire and explosion investigator from SAMAC Engineering Ltd. were dispatched by the BC Safety Authority to the sawmill site to identify equipment and systems subject to the *Safety Standards Act*, evaluate the role that this equipment or its operation may have had regarding the incident and to identify non-compliances with the relevant *Regulations*. WorksafeBC assumed the role of lead investigating agency, responsible for overall control of the site and evidence removed for evaluation.

The investigation identified two possible areas of origin for the explosion in the basement of the sawmill structure. SAMAC Engineering Ltd., contracted by the BC Safety Authority to provide fire and explosion expertise, identified an area below the band saw near a motor control centre. WorkSafeBC identified a possible area of origin in the basement near a waste conveyor motor. The BC Safety Authority accepts that the explosion may have initiated from either basement location.

Gas, boiler and pressure vessel equipment that would have contained or used a combustible gas, vapour or liquid was evaluated. From these evaluations it is concluded that a leak or release of natural gas, propane, ethylene glycol or thermal fluid from this equipment did not contribute to the explosion.

Wood dust was the only other fuel source known to be within either basement area that was capable of producing the explosion. The damage produced and the witness descriptions of the explosions were consistent with combustible wood dust as the explosive fuel. It is therefore concluded that wood dust fueled the explosion.

A single most likely ignition source for the wood dust explosion was not found during the investigation. A motor control centre and light assembly were identified as possible ignition sources. It was also identified that a pre-existing fire could have ignited the explosion. Electrical equipment in operation within the identified basement areas was neither approved nor configured for safe operation within a combustible dust environment. Therefore the normal operation of this electrical equipment presented possible ignition sources for either a fire or the explosion and their possible contribution to the incident could not be ruled out. It is also possible that equipment not subject to the *Safety Standards Act* presented possible ignition sources, however, other equipment was not the focus of the BC Safety Authority investigation.

Electrical and Gas codes classify areas containing combustible dust as *hazardous locations,* requiring specific precautions to be taken in order to manage potential ignition sources. Facility owners and operators can manage combustible dust hazards by preventing the development of combustion hazards and/or by configuring equipment to safely operate in the presence of the hazard. Where facility operators elect to manage combustible dust instead of implementing *hazardous location* equipment configurations, these activities must be sustained such that a non-hazardous environment is always maintained.

At the time of the incident, the areas within the basement where the explosion originated were *hazardous locations* as defined by the electrical and gas codes due to the presence of combustible wood dust and operations that generated a suspension of wood dust in the atmosphere. At the time of the incident, equipment installed and in use within those areas was not certified for use or configured for *hazardous locations* containing combustible wood dust.

Configurations of electrical equipment were found that also did not comply with general installation code requirements. These configurations would have further increased the risk of electrical equipment acting as an ignition source for combustible wood dust.

The BC Safety Authority concludes the root cause of the incident to be the failure to effectively recognize and manage wood dust explosion hazards. This finding is based upon the:

- available wood dust explosion hazards, classifications and prevention standards material,
- history of fires at the site;
- evidence of wood dust found during the investigation;
- statements regarding the presence of wood dust at the facility by employees;
- conclusion that wood dust fueled the explosion, demonstrating the existence of *hazardous locations*; and
- configuration of electrical equipment for a 'non-hazardous' environment.

Owners and operators of wood processing facilities are responsible for the safe use of regulated electrical and gas equipment at their facilities, including the proper configuration of equipment used in *hazardous locations*. The safe use of equipment involves maintaining an environment that is suitable for regulated equipment. As a result of this incident and the investigation findings, the BC Safety Authority is considering ordering wood processing facility owners and operators to document an assessment of their facilities specifically for *hazardous locations* and effective hazard management. The assessment under consideration would be completed:

- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations*.

The BC Safety Authority therefore makes the following recommendations to improve the identification and management of combustible dust *hazardous locations* by wood processing facility owners and operators.

Recommendations to Owners and Operators of Wood Processing Facilities:

Recommendation #1:
Document a facility assessment to identify *hazardous locations* that is completed:

- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations*.

Recommendation #2:
Where *hazardous locations* are identified and contain regulated equipment, document a plan to either:

- develop and implement auditable wood dust management practices for these locations that are accepted by a qualified person as an effective means to manage the combustion hazard, or
- configure the equipment for safe operation given the presence of the combustible dust hazard. Safe operating configurations include:
    a) obtaining approval for operation in the *hazardous location,* or
    b) permanent removal of the equipment from the *hazardous location*.

Recommendation #3:
Incorporate any identified *hazardous locations* and the chosen means to manage the combustion hazards into the facility's *Fire Safety Plan*, or other suitable facility document(s).

Recommendations to the BC Office of the Fire Commissioner:

Recommendation #4:
Publish a list of professional qualifications suitable for individuals who identify wood dust combustion and explosion *hazardous locations* in an industrial environment.

Recommendation #5:
Identify suitable fire and explosion prevention guidance material to be used in BC for the identification and classification of *hazardous locations* due to combustible wood dusts.

Recommendation #6:
Add details of a qualified person and accepted guidance material related to *hazardous location* classification and management into the *Fire Safety Plan* requirements of the *BC Fire Code*.

Recommendations to the Canadian Standards Association:

Recommendation #7:
Specifically identify wood dust as a combustible dust belonging to group G dusts in section 18 of the *Canadian Electrical Code, Part 1*.

Recommendation #8:
Improve coordination between section 18 of the *Canadian Electrical Code* and referenced fire and explosion prevention standards for *hazardous location* identification and classification.

Recommendation #9:
Improve the natural gas and propane code requirements and accompanying guidance material relating to *hazardous location* identification and alignment with fire prevention standards.

Site Information

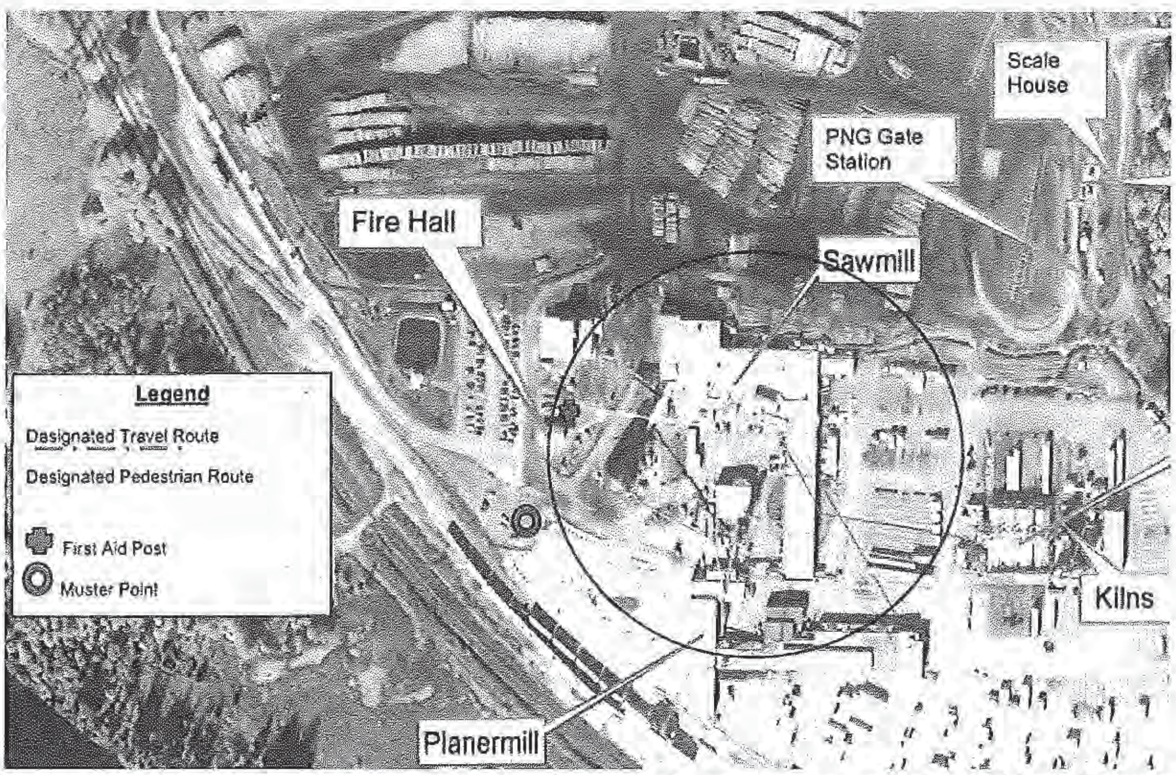
Overview of Site and Equipment Subject to the *Safety Standards Act*

Photograph 1 shows an aerial view of the Babine Forest Products site, which consisted of numerous buildings and structures including the sawmill. On January 20, 2012, the sawmill at Babine Forest Products site near Burns Lake utilized equipment that was subject to the *Safety Standards Act*.

Natural gas fuelled appliances, natural gas distribution components, propane storage, propane dispensing, portable propane cylinders and propane appliances were in use at the sawmill and are subject to the *Gas Safety Regulation*. These items are referred to as 'gas equipment' for the remainder of this report.

Boilers, pressure vessels and pressure piping systems were in use at the sawmill and are subject to the *Power Engineers, Boilers, Pressure Vessel and Refrigeration Safety Regulation*. These items are referred to as 'pressure equipment' for the remainder of this report.

Electrically powered appliances, electrical equipment, electrical signal and power distribution components were in use at the sawmill and are subject to the *Electrical Safety Regulation*. These items are referred to as 'electrical equipment' for the remainder of this report.



Photograph 1: Aerial view of the Babine Forest Products site prior to the explosion and fire of January 20th, 2012.

History of Fires at the Site

The BC Safety Authority investigated a fire that occurred at this site on February 23, 2011. It was concluded to have been fueled by wood dust within a motor control centre (MCC) cabinet and ignited by an electrical fuse failure.

Interview statements made by employees of Babine Forest Products indicate that a fire had occurred approximately two weeks prior to the explosion on January 20, 2012. It was stated that this fire was the result of hot work, such as welding, being conducted at the facility.

Employees stated that a fire, ignited by overheated roller bearings, had occurred within the sawmill on the day of the explosion (January 20, 2012). The fire was located in the Northwest section of the mill and was reported to be extinguished by approximately 5pm.

Employees stated that small fires at this mill were common. Reasons identified included:

- friction from moving parts combined with a dust buildup,
- electrical motor overheating due to dust build-up on cooling surfaces,
- small electrical sparks or arcs igniting wood dust,
- hot work, such as welding, within the building igniting wood dust.

Operating Environment at the Time of the Incident

In the days leading up to the incident, the outside temperatures at the facility were cold and dry. Average temperatures and humidity values for the Burns Lake region is summarized in Table 1 below.

Table 1: Average Temperature and Humidity

	Jan 16	Jan 17	Jan 18	Jan 19	Jan 20
Temperature* (°C)	-23	-31	-36	-34	-21
Relative Humidity* (%)	53	65	64	63	75

* Values stated are daily averages derived from hourly results obtained from the National Climate Data and Information Archive - www.climate.weatheroffice.gc.ca

The cold temperatures experienced in the days leading up to the incident resulted in the freezing of water and ethylene glycol within system pipes. Employees described activities that were being taken to thaw and repair burst pipes as well as to clean up leaked water while operations continued. Employees also stated that outside windows that were normally opened had been closed to improve internal heating.

Investigation

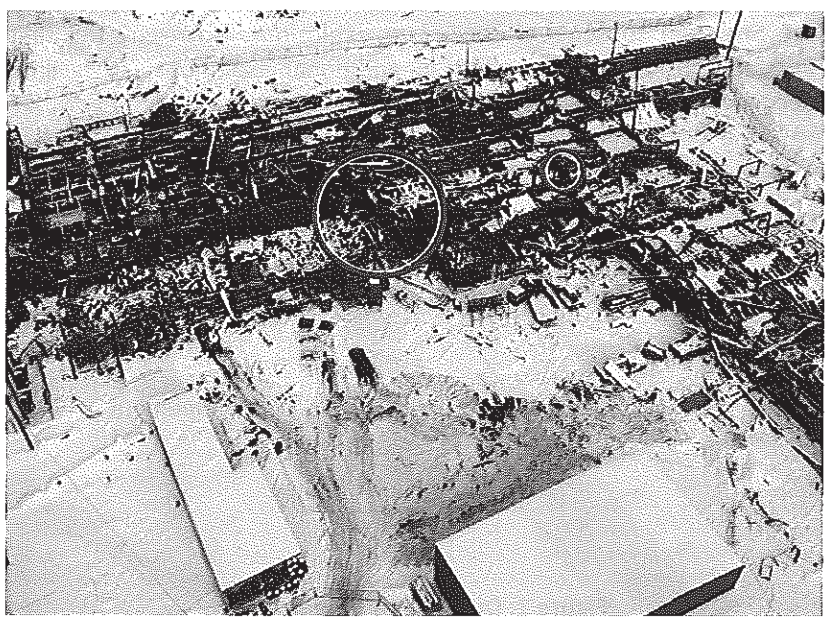
Safety Officers with expertise in gas, electrical and pressure equipment were dispatched to the sawmill site to identify equipment and systems subject to the *Safety Standards Act*, evaluate the role that this equipment or its operation may have had regarding the incident and to identify any non-compliances with the relevant regulations. An experienced and certified fire and explosion investigator (CFEI[2]) was contracted to assist the BC Safety Authority with the interpretation of explosion and fire damage and to assist with the investigation.

Explosion Areas of Origin

SAMAC Engineering Ltd. was contracted by the BC Safety Authority to provide fire and explosion investigation expertise. A possible area of explosion origin was identified in the basement below the band saw. This area's determination is discussed in the appended fire and explosion investigation report (Appendix A). WorkSafeBC identified a possible area of origin in the basement near a waste conveyor motor assembly labeled 8R-26[3]. On the evidence currently available, the BC Safety Authority accepts that the explosion could have originated from either of these areas. These areas are identified in Photograph 2.

BCSA investigation focused on equipment subject to the *Safety Standards Act* that:

1. could have supplied a fuel to the basement areas where the explosion originated, or
2. was located within the identified basement areas and could have ignited a fuel.



Photograph 2: Aerial view of the sawmill site after the explosion and fire of January 20, 2012. The circles indicate the possible areas within the basement where the explosion originated.

[2] CFEI is a professional designation granted to qualified persons by the (US) National Association of Fire Investigators (NAFI)

[3] This conveyor motor assembly was found labeled in the mill as 8R-26; however, mill drawings and documents identified it to be motor 8R-25. This report refers to this motor assembly as 8R-26 due to the mill labeling found. It is understood that this label could have been an error and the correct motor identification is 8R-25.

Fuel for the Explosion

Various combustible materials that could fuel an explosion were found within the basement area of the sawmill. Fuels that were found near the basement area under the band saw included natural gas, propane, thermal fluid, ethylene glycol and wood dust. Wood dust was found near the area of the conveyor motor assembly 8R-26.

Examination of appliances and associated piping using natural gas, propane, thermal fluid and ethylene glycol concluded that none of these fuels contributed to the initiating explosion. Detailed findings, discussion and conclusions relating to natural gas, propane and gas odor employee reports are contained in Appendix B. Findings, discussion and conclusions relating to thermal fluid and ethylene glycol system findings are detailed in Appendix C.

Wood dust samples from the sawmill were tested by WorkSafeBC to determine combustion and explosion characteristics. It was determined that wood dust accumulations at the facility presented a combustion and explosion hazard. Evidence of hazardous amounts of wood dust was found in both identified basement areas as well as throughout the sawmill. The cold and dry conditions listed in Table 1 may have increased the combustion and explosion risk of wood dust generated during the days preceding the incident. It is concluded that the explosion was fuelled by wood dust.

Wood Dust Explosions

"Dust explosions in industrial scenarios usually occur in a series. The initial ignition and explosion are most often less severe than subsequent secondary explosions. However, the first explosion puts additional dust into suspension, which results in additional explosions....In facilities such as grain elevators, these secondary explosions often progress from one area to another"[4]. Five conditions are generally required for a dust explosion to occur and these are represented as the dust explosion pentagon.

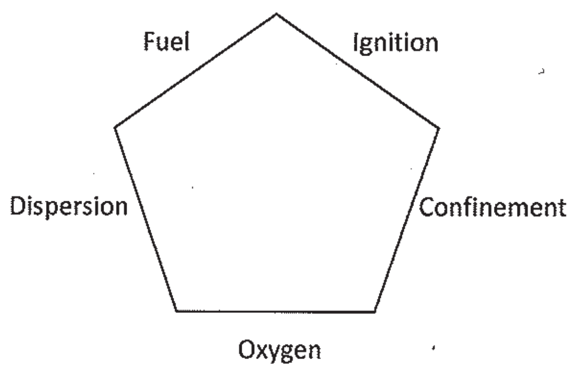


Figure 1: Dust explosion pentagon

<u>Fuel</u>
As discussed in the previous section, it was determined that wood dust fuelled the explosion at the sawmill.

[4] (US) National Fire Prevention Association (NFPA) 921 – Guide for Fire & Explosion Investigations – section 21.9.7

Dispersion
A system of waste conveyors within the basement transported wood dust generated by the sawmill machinery and activity on the operating floor above to a location southwest of the sawmill structure. Waste conveyor systems are common in sawmills in British Columbia. The conveyor system was reported by employees during interviews to have contributed to wood dust dispersion at many locations within the basement, including both possible areas of origin. This system also provided a source of settled, or layered, wood dust available for dispersion and possible ignition. Employee interview statements indicate that this presence of wood dust was typical at the facility.

A dust blow-down operation was reported to have been completed at the band saw just prior to 8pm on the day of the incident. The blow-down operation removes wood dust by blowing compressed air over the machinery parts intended to be cleaned. The operation, as described by the employee, produced a dispersion of wood dust. This operation possibly added to a dispersion of wood dust in the area of the basement below the band saw.

Oxygen
The basement contained breathable air.

Confinement
The foundation structure combined with the placement of interior walls, conveyors and motor control cabinets within the basement provided locations where suspended wood dust would have been confined.

Employees stated during interviews that outside windows that were normally open were closed due to the cold weather, which may have increased the general containment of wood dust within the sawmill structure.

Ignition
There were many possible wood dust ignition sources within the sawmill basement. A single most likely ignition source for the wood dust explosion was not found during the investigation. A motor control centre and light assembly were identified as possible ignition sources. It was also identified that a pre-existing fire could have ignited the explosion. Electrical equipment in operation within the identified basement areas was neither approved nor configured for safe operation within a combustible dust environment. Therefore the normal operation of this electrical equipment presented possible ignition sources for either a fire or the explosion and their possible contribution to the incident could not be ruled out. These possible ignition sources are discussed further in this report.

It is also possible that equipment not subject to the *Safety Standards Act* presented possible ignition sources. Given the presence and mandate of WorksafeBC at this incident site, the BC Safety Authority only investigated possible ignition sources from equipment subject to the *Safety Standards Act.*

Electrical Ignition Hazards

The sawmill used numerous pieces of industrial equipment for its operation that were electrically powered. Control circuits and wiring between controls and equipment were located and routed throughout the facility. The sawmill facility also incorporated numerous electrical circuits to support basic utility infrastructure, such as lighting and general power distribution circuits with outlet receptacles. Normal operation or failures (e.g., fuse failure) of electrical equipment can produce a source of ignition unless specific mitigating precautions are taken for use in *hazardous locations*.

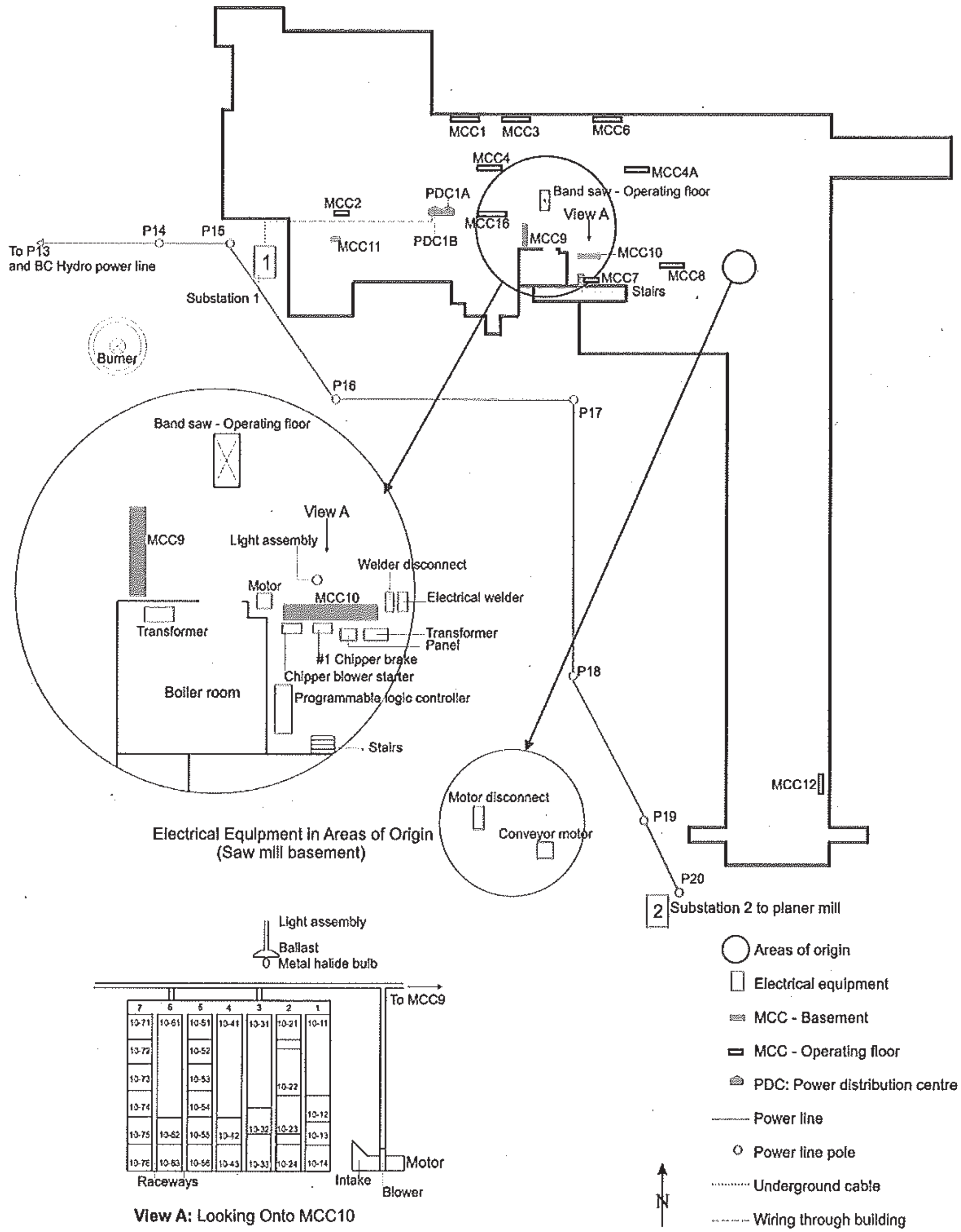


Figure 2: Plan view of mill - electrical equipment from supplied diagrams and investigation findings

Note: Figure 2 was produced from field observations and drawings provided by Babine Forest Products. Figures are intended for illustrative purposes only.

Electrical Equipment Found within the Possible Areas of Origin

The following electrical equipment was found within the possible areas of origin as illustrated in Figure 2:

- MCC #9
- MCC #10
- light assembly with metal halide bulb
- pressurization motor for MCC #9 and MCC #10
- electric welder and disconnect
- Programmable Logic Controller (PLC)
- lighting transformer
- panel
- chipper blower starter
- chipper #1 brake
- conveyor motor (8R-26)
- conveyor motor disconnect (8R-26)

Pressurization Motor for Motor Control Centre (MCC) #9 and MCC #10

Babine Forest Products employees stated that attempts were made to pressurize MCCs as a fire risk mitigation measure following a wood dust fire in February of 2011. The fire in February of 2011 started within an MCC in a different area of the sawmill. The intent was to keep dust out of the MCCs by maintaining a positive internal pressure, relative to the sawmill, from a supply of clean pressurized air from the blower motor. Employees stated that the pressurization system did not work as intended and was therefore not in use. The motor switch on the appliance was found in the ON position while the start/stop button on the motor disconnect switch was in the STOP position. The motor exhibited no evidence of arcing or electrical failure.

With the start/stop button in the STOP position, it is unlikely that the ventilation motor presented a source of ignition at the time of the incident.

Motor Control Centre (MCC) #9

MCC #9 was found to have all access doors in the closed and latched position. No evidence of arcing or electrical failure was observed internal to MCC #9 however cabinets closer to the ceiling exhibited evidence of internal fire. Wood dust was observed to be within the cabinets as shown in Photograph 3.

Clean pressurization air was not being supplied to MCC #9 and wood dust was found within the cabinets. Normal operation or failure of electrical equipment within MCC #9 are potential sources of ignition for a wood dust cloud or layer. MCC #9 was not identified as being a likely ignition source, however, wood dust found within MCC #9 presented a fire hazard.

Photograph 3: Example of wood dust accumulation in MCC #9

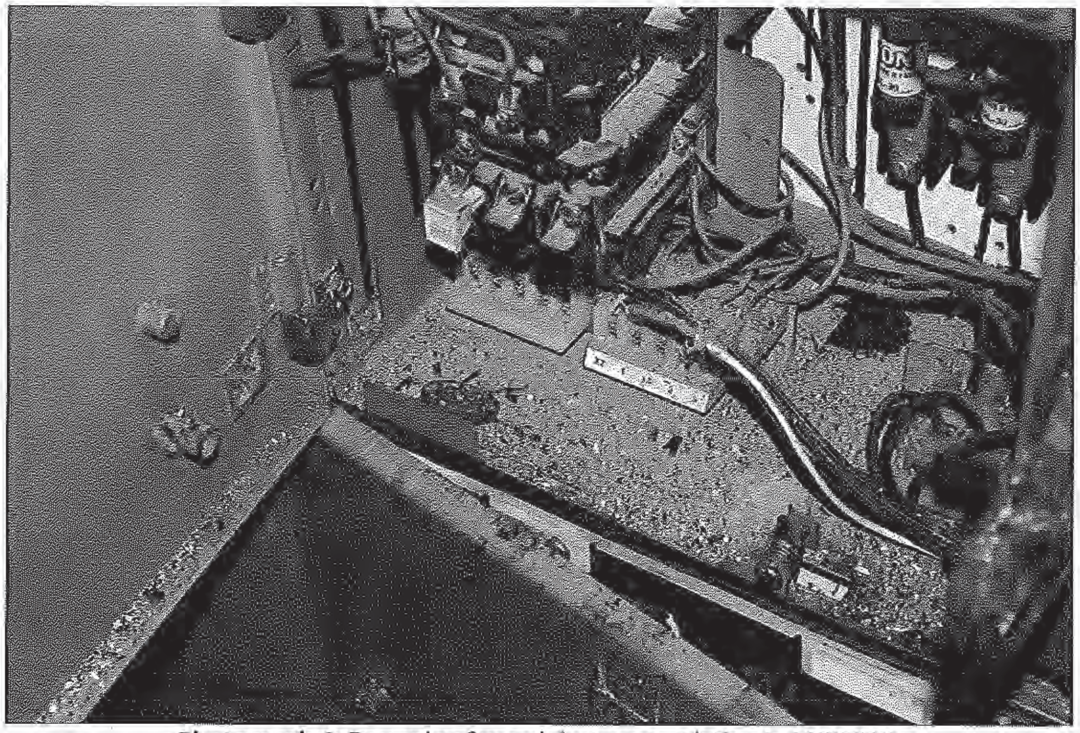
Motor Control Centre (MCC) #10

MCC #10 was found with cabinet access doors unlatched and doors to cabinets 10-11, 10-22, 10-61 and 10-71 in the open position. Wood dust was found within the cabinets as shown in Photograph 4. Electrical components within MCC #10 exhibited a greater amount and different pattern of fire damage than those within MCC #9. A possible fire or explosion from within MCC #10 was identified as a possible ignition source for the explosion (Appendix A).

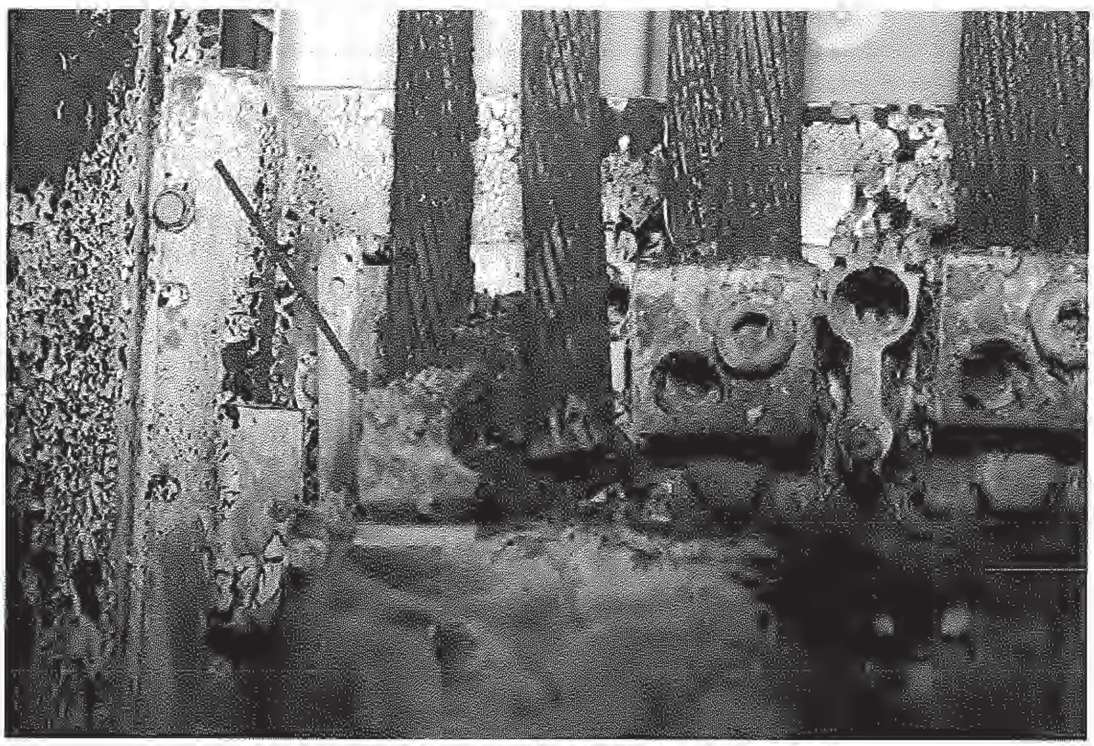
Cabinet 10-31 contained six 400 MCM tap conductors feeding a breaker with one of the breaker lugs fractured and molten metal near the lug fracture as shown in Photograph 5. An evaluation was commissioned by WorksafeBC to review the fractured lug and molten material within cabinet 10-31 of MCC #10. It was communicated to BC Safety Authority investigators during this evaluation that the distribution of molten material was more consistent with a material that had dripped onto the lug rather than the result of an arc flash. The molten metal was analyzed and found to not be of the same composition as the lug material. As stated in appendix A, the position of MCC #10 had been shifted approximately 15cm south and 15cm east. This shift in position may have applied a mechanical load to the lug. It is more likely that the broken electrical feeder lug and molten material found deposited on the lug were a result of the explosion and fire rather than a cause.

Electrical motor control components can generate sparks during normal operation. MCC #10 contained numerous motor control components within its cabinets. Electrical equipment can also generate significant amounts of heat during normal operation. Hot spots on components can develop if cooling is impaired due to a layer or build-up of wood dust.

Clean pressurization air was not being supplied to MCC #10 and wood dust was found within the cabinets. Unsecured cabinet doors may have exposed electrical equipment to a combustible atmosphere outside of MCC #10. It is also possible that the cabinet doors were opened as a result of an explosion from within MCC #10. On the evidence currently available to the BC Safety Authority, the operation of or a failure of the electrical equipment within MCC #10 could have ignited a combustible cloud of wood dust that came into contact with it.



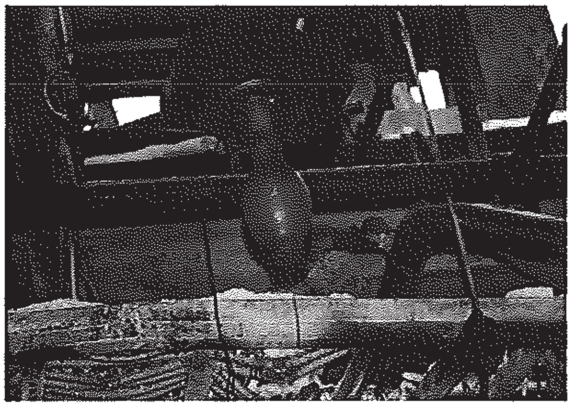
Photograph 4: Example of wood dust accumulation in MCC #10



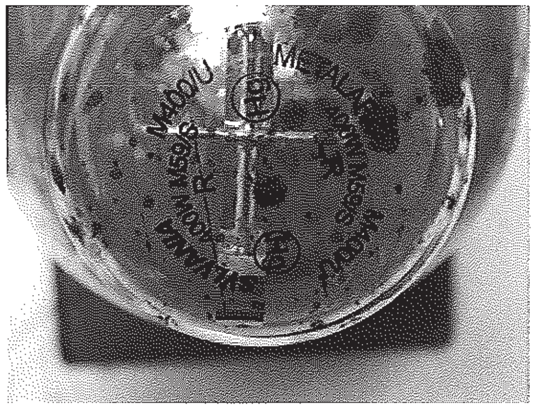
Photograph 5: Fractured feeder lug in cabinet 10-31

400 Watt Metal Halide Light Bulb and Light Assembly

The light assembly shown in photographs 6 and 7 comprised of a ballast, 400 Watt metal halide bulb and a reflector. The reflector was found on the floor in front of MCC #10 and appeared to be an 'open' design, and no evidence of a shield was found in the area. The ballast and metal halide bulb were found in their installed locations above and in front of MCC #10, as shown in Figure 2 and Photographs 6 and 7. The bulb was intact and there was no evidence of electrical failure of the ballast or the bulb.



Photograph 6: Light assembly and metal halide bulb in front and above MCC #10



Photograph 7: Metal halide bulb product markings

Manufacturer's specifications associated with the bulb part number depicted in photograph 7 indicate a maximum bulb temperature of 400°C and a maximum base temperature of 250°C.

WorksafeBC commissioned testing for dust cloud and dust layer ignition temperature values of wood dust samples from the sawmill and identified a possible dust cloud ignition temperature of 430°C and a wood dust layer ignition temperature of 310°C.

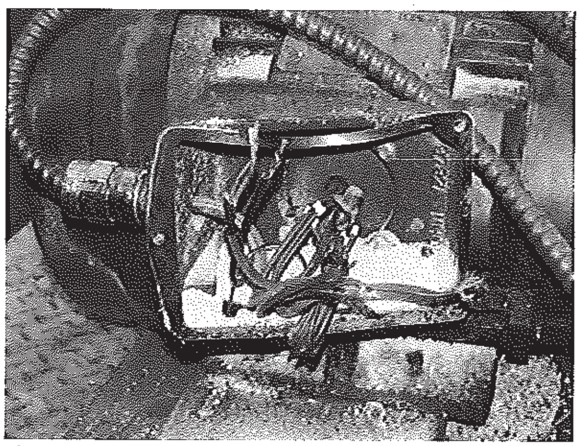
The light bulb and base were in direct contact with the basement atmosphere. As discussed in appendix A, it is possible that wood dust accumulations on the light assembly surfaces developed reduced ignition temperatures due to pyrolysis in addition to interfering with proper cooling of the light assembly. The light assembly is therefore considered a possible ignition source.

Other electrical equipment found within the areas of origin

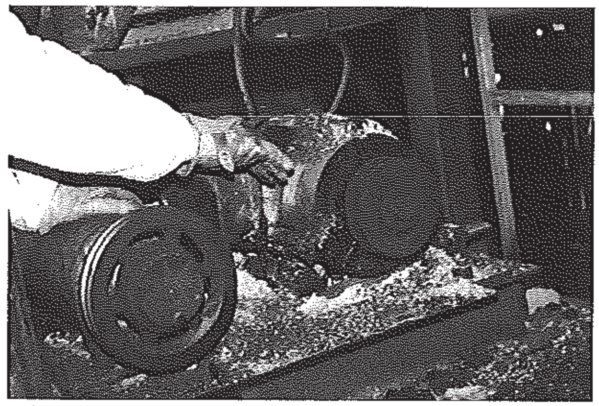
No evidence of arcing or electrical failure was observed on any other electrical equipment found within either area of origin. A detailed evaluation of conveyor motor labeled 8R-26 was commissioned by WorksafeBC and BC Safety Authority investigators witnessed that the motor functioned with no indications of an appliance failure prior to the incident. Hazardous accumulations of wood dust were found within the junction box and cooling fins of the motor as shown in Photographs 8 and 9.

In non-combustible environments, electrical equipment would typically only be considered a possible source of ignition under certain failure conditions. Electrical equipment can generate sparks and heat during normal operation with sufficient energy to present an ignition source for a combustible dust atmosphere or buildup of combustible dust on equipment surfaces. As such, electrical equipment that is certified for use within combustible environments will typically separate spark and heat generating components from the environment or limit the amount of electrical energy such that sparks and heat can not be generated during operation or failure. Electrical equipment operated within combustible atmospheres that is neither approved nor configured for safe operation within a combustible dust environment can present possible ignition sources during normal operation. The absence of failure of such equipment is therefore not sufficient to rule out the possibility of it being an ignition source.

Electrical equipment found within the areas of origin consisted of disconnects, push buttons, hydraulic oil tank heaters, switches, motors and lights. There were no indications that any of the electrical equipment found was certified for use in a hazardous environment containing combustible dusts. It is possible that electrical equipment located within either identified area of the basement provided an ignition source for wood dust.



Photograph 8: Wood dust deposits within conveyor motor junction box labeled 8R-26.



Photograph 9: Wood dust accumulation around conveyor motor labeled 8R-26.

Compliance with the *Electrical Safety Regulation*

This investigation found instances where electrical equipment was installed or used in a manner contrary to the *Canadian Electrical Code*[5]. Some non-compliant configurations found would have increased the risk of electrical equipment acting as an ignition source for a wood dust:

- cloud explosion or
- layer fire that could have become an explosion ignition source.

Details of these technical non-compliance findings are provided in Appendix D.

[5] The *Canadian Electrical Code*, Part 1 is adopted with amendments as the *BC Electrical Code* by the *Electrical Safety Regulation*. The BC amendments to the *Canadian Electrical Code* are not relevant to the discussions in this report. This report refers to *Canadian Electrical Code* in various locations which is intended to also include reference to the *BC Electrical Code*.

Hazardous Locations

Applicable safety codes require operators to identify and manage fire and explosion hazards. Special precautions are required at locations where fire and explosion hazards are likely to exist in order to control potential fuel or ignition sources.

Compliance with these codes require designers and operators to exercise a degree of foresight in respect of the actual operating conditions which may be encountered in the future: equipment which is code compliant at the time of installation or inspection may become non-compliant if hazardous environments are permitted to develop.

British Columbia Fire Code

The BC Safety Authority does not administer the *British Columbia Fire Code*; however, the code contains useful excerpts.

At the time of the incident, the 2006 edition of the *British Columbia Fire Code* was adopted by the Province of British Columbia. Division B, Part 5 – *Hazardous Processes and Operations* applies to "processes and operations that involve a risk from explosion, high flammability or related conditions that create a hazard to life safety". Section 5.3 – *Dust-Producing Processes* applies where *combustible dusts*[6] are produced in quantities or concentrations that create an explosion or fire hazard.

These sections of the *British Columbia Fire Code* require:

- Wiring or electrical equipment located in *hazardous locations*[7] to conform to the *British Columbia Safety Standards Act* and pursuant regulations for hazardous locations.
- The preparation of a *Fire Safety Plan* for hazardous processes or operations that includes (but not limited to) the control of fire hazards.
- Bonding and grounding of electrically conductive parts.
- Electrical interlocking of dust producing equipment to required dust removal equipment.
- Control or removal of equipment that may produce an ignition source and conformity to the hazardous locations requirements of the *British Columbia Safety Standards Act.*

Canadian Electrical Code

The *Electrical Safety Regulation* adopts the *Canadian Electrical Code* (with BC amendments) as the technical standard for most electrical equipment in the Province. For the purposes of compliance, electrical installations are compared to the edition of the *Canadian Electrical Code* that was in force at the time of the installation. It was reported that the sawmill completed a major electrical service and it was estimated that this work was completed around 2005. In 2005, the *Canadian Electrical Code, Part I, Nineteenth Edition, Safety Standard for Electrical Installations, Canadian Standards Association C22.1-02*

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[6] Combustible dusts means dusts and particles that are ignitable and liable to produce an explosion. (British Columbia Fire Code – 2006 Edition)

[7] The British Columbia Fire Code (2006 edition) refers to hazardous locations as being areas in which flammable gases or vapours, combustible dusts or combustible fibres are present in quantities sufficient to create a hazard.

was utilized as the BC Electrical Code. BC Amendments to the 2002 edition of the Code did not affect the requirements discussed below and the currently adopted standard is similar.

Section 18 of the Electrical Code applies to electrical equipment and wiring installed or used in *hazardous locations.* Rule 18-004 classifies *hazardous locations* according to the nature of the hazard, as follows:

(b) Class II locations are those which are hazardous because of the presence of combustible or electrically conductive combustible dusts;

(c) Class III locations are those which are hazardous because of the presence of easily ignitable fibres or flyings, but in which such fibres or flyings are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures.

Class II combustible dust atmospheres are divided into Groups E, F or G. Group G atmospheres are comprised of those *"containing flour, starch, or grain dust, and other dusts of similarly hazardous characteristics."* Appendix B guidance material relating to Rule 18-008 of the *Canadian Electrical Code,* although not a binding requirement, includes wood flour in a list of combustible dusts. The group G definition and associated guidance material suggests a combustion hazard be considered when operating in the presence of wood flour or dust.

Section 18 prescribes installation techniques to separate the combustion hazards from potential electrical ignition sources in Class II and III *hazardous locations,* including:

- Use of metal conduits and sealed enclosures for wiring (18-202, 204, 252, 254, 302 & 352)
- Sealing and use of dust tight enclosures for switches, motor controllers etc (18-206, 256, 304 & 354)
- Use of outside clean air for electrical component ventilation (18-212, 262, 310 & 360)
- Use of luminaires and other equipment that is certified for the hazardous environment (18-216, 220, 264 and others)

Propane and Natural Gas Codes

At the time of the incident, the 2010 editions of the *Propane storage and handling code* (CSA B149.2-10) and the *Natural gas and propane installation code* (CSA B149.1-10) were adopted by the *Gas Safety Regulation.* Each code contains a section titled *hazardous locations* with the following requirement:

> *An appliance, unless certified for installation in a hazardous location, shall not be installed in any location where a flammable vapour, combustible dust or fibres, or an explosive mixture is present.*

The 2005 edition of the *Natural Gas and Propane Code Handbook (B149HB-05)* contains the following 'note on hazardous environments':

> *Hazardous environments, in relation to gas appliance installations may be practically defined as any space containing concentrations of flammable vapours, combustible dust or fibres, or explosive mixtures which may be ignited by appliance operation. Technical information on hazardous environments is available from the National Fire Protection Agency (NFPA). Refer to NFPA 499: Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas....*

Fire and Explosion Prevention Standards

Several (US) National Fire Protection Agency (NFPA) and industry standards are publically available that illustrate the fire and explosion hazards presented by wood dust. Table 2 below compiles published combustion and explosion characteristics of wood dust as well as other combustible dusts that are expressly identified by the *Canadian Electrical Code* as Group G atmospheres. Test data describing explosion and fire hazard characteristics can be sample specific - values presented in Table 2 are for general reference only.

Table 2: Sample Explosion and Fire Hazard Characteristics – derived from referenced documents

Material	Deflagration Index, K_{st} (bar-m/s)		Explosion Pressure P_{max} (bar)	Dust Layer Ignition Temperature (°C)
	Value	Group[4]		
Aluminum	415[2]	3 (very strong explosion)	12.4[2]	320[1]
Coal (bituminous)	129[2]	1 (weak explosion)	9.2[2]	180[1]
Sugar	138[2]		8.5[2]	370[1]
Wheat flour	87[3]		8.3[3]	360[1]
Wheat starch	115[2]		9.9[2]	380[1]
Wheat grain dust	112[3]		9.3[3]	Not Available
Wood flour	205[2]	2 (strong explosion)	10.5[2]	260[1]
Wood bark (ground)	Not Available	Not Available	Not Available	250[1]

Notes:

[1] *NFPA 499 – Classification of Combustible Dusts and of Hazards (Classified) Locations for Electrical Installations – 2008 Edition* – Table 4.5.2.

[2] *NFPA 68 – Standard on Explosion Protection by Deflagration Venting – 2007 Edition* – Table E1(a)

[3] *NFPA 61 – Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities – 2008 Edition* – Table A.6.2.1

[4] Hazard Communication Guidance for Combustible Dusts – Occupational Safety and Health Administration - OSHA 3371-08 2009. Four dust explosion classes are communicated for corresponding Kst ranges – 0 is assisgned a "no explosion" characteristic. Values between 0 and 200 is assigned a "weak explosion" characteristic. Values between 200 and 300 are assigned a "strong explosion" characteristic and values above 300 are assigned a "very strong explosion" characteristic.

Table 2 above illustrates that wood dust can have explosion and fire hazard characteristics similar to other known dusts that are identified as combustible dusts in the *Canadian Electrical Code*. NFPA 499 classifies wood flour as a group G combustible dust and NFPA 68 assigns wood flour a hazard class of "2", which is identified as having "strong explosion" characteristics by the US Occupational Safety and Health Administration. Given the above, wood dust and potential ignition sources exposed to wood dust are required to be managed. Locations where wood dust accumulates or is suspended in atmosphere are considered hazardous locations.

Testing of wood dust samples from the sawmill was conducted by WorksafeBC and confirmed that the wood dust at the facility presented explosion and combustion hazards as described in WorksafeBC Advisory dated August 16, 2012.

NFPA 664 - Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities identifies that "*portions of the facility where* [wood] *dust accumulations occur or where suspensions of wood dust in air could occur shall be equipped with electrical systems and equipment per*

Article 502 or 503 of NFPA 70, National Electrical Code[8]". With respect to *hazardous locations* due to dust accumulation, the standard generally describes the presence of a deflagration hazard when deflagrable wood dust[9] is present as a layer on upward facing surfaces at a depth greater than 3.2mm (1/8 in) over five percent of the area or $93m^2$ ($1000ft^2$), whichever is less.

Application of *Hazardous Location* Requirements

At the time of the incident, the identified areas of the basement should have been considered *hazardous locations* as described by the *Canadian Electrical Code*, propane and natural gas codes as well as other industry standards.

Accumulations of deflagrable wood dust were found on electrical equipment, wiring, within MCC cabinets and on upward facing surfaces throughout the facility. Given the

- history of wood dust fires at the facility,
- evidence of accumulated wood dust found during investigation, and
- descriptions of wood dust at the facility made by employees during interviews;

it is concluded that *hazardous locations* existed at the facility prior to the incident.

At the time of the incident, electrical equipment installed and in use within either area of origin was not compliant to section 18 of the *Canadian Electrical Code* for *hazardous locations* and therefore presented ignition hazards.

Compliance with the *Safety Standards Act*

The *Safety Standards Act* contains the following requirement:

> ***Operation and use of regulated products***
> ***69** (3) A person must not use a regulated product in a manner that is unsafe or that creates a risk of personal injury or damage to property.*

During installation, assumptions are made to support the selection of appropriate configurations and use of electrical equipment. Any condition deemed necessary for a particular configuration to be compliant at the time of installation must be maintained during operation. If operational activity results in a drift away from assumed conditions necessary for the type of installation to remain safe, so that a residual byproduct of production creates or contributes to a hazardous environment or location, compliance should be re-evaluated.

If wood dust management activities fail to maintain a non-hazardous environment, equipment and installations in use at those locations that are not certified or configured for such a *hazardous location* fail to remain in a safe condition and are non-compliant to the *Safety Standards Act.*

[8] Article 502 or 503 of NFPA 70, National Electrical Code is similar to section 18 of the *Canadian Electrical Code* for *hazardous locations*. Article 500 is Hazardous (Classified) Locations while 502 is Class II [combustible dust] Locations and 503 is Class III [combustible dust] Locations.

[9] Deflagrable wood dust is generally referred to as wood dust that has explosive characteristics and is available to become suspended in atmosphere. NFPA 664 contains specific definitions for these terms.

As concluded previously, some areas of the sawmill that contained electrical equipment subject to the *Safety Standards Act*, were *hazardous locations* as described by the *Canadian Electrical Code.* Electrical equipment installed and in use within those areas was not approved for safe use within *hazardous locations (refer to appendix D)* and therefore presented ignition hazards within a combustible environment. The use of electrical equipment within certain areas of the sawmill was unsafe and not compliant with the *Safety Standards Act.*

Fuels Added to the Fire Following the Initial Explosion

The investigation examined appliances and associated piping that contained natural gas, propane, thermal fluid and ethylene glycol and concluded that none of these fuels contributed to the initiating explosion (refer to appendices B and C). It was determined that the initial explosion and fire damaged equipment carrying natural gas, propane and thermal fluid. These fuels were subsequently added to the fire.

Natural Gas

The natural gas supply line was found broken at the riser location, outside of the sawmill along the east wall. It was concluded that the explosion likely caused the break in the natural gas supply pipe at this location. Natural gas consumption by Babine Forest Products was recorded by the utility supplier on an hourly basis and the hourly consumption increased by a factor of five between 8pm and 9pm on the date of the incident, likely reflecting a leakage of fuel into the fire at the location of the break. The natural gas supply to the sawmill was turned off at 8:47pm on the date of the incident, approximately 40 minutes after the initial explosion.

Propane

Two propane cylinders were found within the sawmill structure. The cylinder found within the basement in the area under the band saw was examined in a laboratory and it was observed that the valve was in the closed position. The cylinder exhibited, what was described to BC Safety Authority investigators as, local heat and burn damage to the area near the overpressure relief valve. It is likely that this valve had opened to relieve the pressure of expanding propane as a result of the heat from the surrounding fire. The vented propane had likely ignited.

Thermal Fluid

Thermal fluid was supplied from a low pressure thermal fluid plant, or energy plant, outside of the sawmill structure to a heat exchanger located within the sawmill structure. The heat exchanger was found to have fallen off its support structure and a flange bolt was found to be fractured. Evidence of thermal fluid leaking from this location was found and it was concluded that this leak was likely caused by the explosion.

A witness described seeing intense burning at the area of the sawmill that contained the heat exchanger and presumed that thermal fluid was leaking into the fire. The valve that isolates the system supply of thermal fluid to the sawmill was closed by an employee that had returned to the mill and was not present during the explosion. It is estimated that between one and two hours may have passed between the explosion and when the thermal fluid supply to the sawmill was removed. It was later estimated that approximately 3400 US gallons of thermal fluid leaked from the system during the incident.

The investigation found that employees responsible for supervising the energy plant did not have the required qualifications to manage the equipment at this low pressure thermal fluid plant. A qualified person with suitable emergency procedures and training may have isolated the sawmill from the supply of thermal fluid earlier than what occurred. This non-compliance with the *Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation* may have influenced the amount of thermal fluid that was added to the existing fire; however, it did not contribute to the initial explosion.

Conclusions and Recommendations

Root and Contributing Causes of the Incident

The investigation determined that wood dust was the fuel for the explosion at Babine Forest Products on January 20, 2012. All necessary conditions for a wood dust explosion existed in the sawmill. A single 'most likely' ignition source could not be concluded. However, multiple possible ignition sources resulting from operating electrical equipment not being designed or installed for safe use in a hazardous wood dust environment were identified. Other possible ignition sources, not subject to the *Safety Standards Act,* may have been identified by other investigating organizations.

The BC Safety Authority identifies the root cause of the incident to be the failure to effectively recognize and manage wood dust explosion hazards. This finding is based upon the:

- available wood dust explosion hazards, classifications and prevention standards material;
- history of fires at the site;
- evidence of wood dust found during the investigation;
- statements regarding the presence of wood dust at the facility by employees;
- conclusion that wood dust fueled the explosion, demonstrating the existence of *hazardous locations;* and
- configuration of electrical equipment for a 'non-hazardous' environment.

The cold, dry environment in the days leading up to the incident and the non-compliant configurations of the electrical system likely increased the risk of explosion and fire at the site and are considered contributing causes.

Propane cylinders left within the sawmill structure and a failure to quickly isolate the supply of thermal fluid to the sawmill contributed to propane and thermal fluid fuels being added to the fire, following the explosion. A failure to ensure the energy plant was supervised by employees with required qualifications and emergency procedures may have contributed to the amount of thermal fluid added to the fire.

Recommendations

Owners and operators of wood processing facilities are responsible for the safe use of regulated electrical and gas equipment at their facilities, including the proper configuration of equipment used in *hazardous locations*. The safe use of equipment involves maintaining an environment that is suitable for regulated equipment. As a result of this incident and the investigation findings, the BC Safety Authority is considering ordering wood processing facility owners and operators to document an assessment of their facilities specifically for *hazardous locations*. The assessment under consideration would be completed:

- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations*.

The BC Safety Authority may also consider ordering wood processing facility owners and operators that have identified *hazardous locations* containing regulated equipment to document a plan to either:

- develop and implement auditable wood dust management practices for these locations that are accepted by a qualified person as an effective means to manage the combustion hazard, or

- configure electrical and gas equipment for safe operation within the presence of the hazard. Safe configuration includes:
    a) obtaining approval for operation in the *hazardous location,* or
    b) permanent removal of the equipment from the *hazardous location.*

The BC Safety Authority therefore makes the following recommendations to improve the identification and management of combustible dust *hazardous locations* by wood processing facility owners and operators.

Recommendations to Wood Processing Facility Owners and Operators:
The following recommendations are made to wood processing facility owners and operators to ensure that *hazardous locations* are suitably identified and managed.

Recommendation #1:
Document a facility assessment to identify *hazardous locations* that is completed:

- by a professional that is qualified to identify combustible dust *hazardous locations*, and
- in accordance with a recognized industry standard for combustible dust *hazardous locations.*

Recommendation #2:
Where *hazardous locations* are identified and contain regulated equipment, document a plan to either:

- develop and implement auditable wood dust management practices for these locations that are accepted by a qualified person as an effective means to manage the combustion hazard, or
- configure the equipment for safe operation given the presence of the combustible dust hazard. Safe operating configurations include:
    a) obtaining approval for operation in the *hazardous location,* or
    b) permanent removal of the equipment from the *hazardous location.*

Recommendation #3:
Incorporate any identified *hazardous locations* and the chosen means to manage the combustion hazards into the facility's *Fire Safety Plan*, or other suitable facility document(s).

Recommendations to the BC Office of the Fire Commissioner:
Hazardous location identification, as described by the *Canadian Electrical Code*, natural gas and propane codes, requires specific explosion and fire prevention knowledge in order to apply fire prevention standards to an industrial environment. The following recommendations are made to the BC Office of the Fire Commissioner to assist owners and operators of wood processing facilities with their responsibilities to identify and manage *hazardous locations.*

Recommendation #4:
Publish a list of professional qualifications suitable for individuals who identify wood dust combustion and explosion *hazardous locations* in an industrial environment.

Recommendation #5:
Identify suitable fire and explosion prevention guidance material to be used in BC for the identification and classification of *hazardous locations* due to combustible wood dusts.

Recommendation #6:
Add details of a qualified person and accepted guidance material related to *hazardous location* classification and management into the *Fire Safety Plan* requirements of the *BC Fire Code.*

Recommendations to the Canadian Standards Association:
The *Canadian Electrical Code*, natural gas and propane codes are published by the Canadian Standards Association. Each of these codes contains sections titled *hazardous locations* that identify specific equipment requirements when operating in the presence of combustible dusts. The following recommendations are made to the Canadian Standards Association to improve the recognition of wood dust being a combustible dust and to improve alignment with fire prevention standards.

Recommendation #7:
Specifically identify wood dust as a combustible dust belonging to group G dusts in section 18 of the Canadian Electrical Code, Part 1.

Additional supporting discussion:
Section 18 of the 2012 Edition of the Canadian Electrical Code defines Group G dusts atmospheres as "comprising atmospheres containing flour, starch, or grain dust, and other dusts of similarly hazardous characteristics". This investigation identified that sufficient fire and explosion information is available in published standards to classify wood dust as having "similarly hazardous characteristics as flour, starch, or grain dusts". It is recommended that Section 18 of the Canadian Electrical Code be updated to specifically identify wood dust atmospheres as hazardous rather than its implied inclusion due to similarly hazardous characteristics.

Recommendation #8:
Improve coordination between section 18 of the *Canadian Electrical Code* and referenced fire and explosion prevention standards for *hazardous location* identification and classification.

Additional supporting discussion:
The *Canadian Electrical Code* adopts similar wording to the US National Electrical Code for *hazardous location* identification and classification. *NFPA 664 (Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities)* and *NFPA 499 (Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas)* contain hazard identification and classification language that mirrors the electrical codes however, these standards are not referenced by the *Canadian Electrical Code*. NFPA standards are also referenced by the National Fire Code of Canada and the BC Fire Code.

In the 2012 edition of the *Canadian Electrical Code*, the first edition of *IEC 60079-10-2 – Explosive atmospheres – Part 10-2: Classification of areas* was added as guidance for section 18 (appendix B of the *Code*). This international standard for area classification uses different classification terminology and structure than section 18 of the *Code*. The mismatch between code classification and guidance classification should be addressed as the code requirements are specific to area classification.

Recommendation #9:
Improve the natural gas and propane code requirements and accompanying guidance material relating to *hazardous location* identification and alignment with fire prevention standards.

Additional supporting discussion:
Gas codes CSA B149.1-10 and CSA B149.2-10 – *hazardous locations* are defined as being rooms that contain vapours corrosive to equipment or where a flammable vapour, combustible dust or fibres, or an explosive mixture is present. It is recommended that improved guidance be developed to interpret the term "present" and include the context of changing industrial operating environments. It is recommended that *hazardous location* identification be required in the Gas Codes and that recognized fire and explosion prevention standards be incorporated in the code rather than the handbook only.

References

1. The Province of British Columbia has entered into agreements with certain local governments to administer portions of the *Safety Standards Act*.

   Local governments that administer the *Electrical Safety Regulation*
   - City of Burnaby
   - City of North Vancouver
   - City of Surrey
   - City of Vancouver
   - City of Victoria
   - Corporation of the District of Maple Ridge
   - District of North Vancouver
   - Municipality of West Vancouver

   Local governments that administer a portion of the *Gas Safety Regulation*
   - City of Burnaby
   - City of Kelowna
   - City of North Vancouver
   - City of Richmond
   - City of Vancouver
   - Corporation of the District of Maple Ridge
   - District of North Vancouver

   The above local governments administer gas assessment programs for detached dwellings with gas services at a pressure of 14.0 kPa gauge or less as well as other buildings with gas services at a pressure of 14.0 kPa gauge or less with a total connected load for the meter of 120 kW or less.

2. Certified Fire and Explosion Investigator (CFEI) is a professional designation granted to qualified persons by the National Association of Fire Investigators (NAFI).

3. Natural gas odorization – see Canadian Standards Association (CSA) *Z662-07 Oil and gas pipeline systems*

   Propane odorization – see *CSA B149.1-10 Natural Gas and Propane Installation Code*, CSA *B149.2-10 Propane storage and handling code and* Standards Council of Canada (SCC) *CAN/CGSB 3.14-2006 Liquefied Petroleum Gas (Propane) for Fuel Purposes*

Appendix A

SAMAC Engineering Ltd. Fire Investigation Report

SAMAC
ENGINEERING LTD.

19 December 2012 [redacted]

Our File: [redacted]

[redacted]
British Columbia Safety Authority
200 – 505 Sixth Street,
New Westminster, BC. V3L 0E1

Dear [redacted]

Re: Babine Forest Products – Explosion & Fire
Incident Date: 20 January 2012
Your File [redacted]

1.0 INTRODUCTION

In accordance with your instructions, we have examined the available information in order to determine, if possible, the cause of the above noted explosion and fire.

2.0 INCIDENT AS UNDERSTOOD

The incident occurred at the Babine Forest Products sawmill located at 19479 Highway 16 East, approximately 20 kilometres east of Burns Lake BC. It is understood that on 20 January 2012 at approximately 20:07h an explosion and fire occurred in the sawmill.

Fire fighting operations were hampered by cold weather and water availability. The bulk of the fire was extinguished or had burned out within five days. However, spot fires continued to burn until 06 February 2012. There were 22 casualties including two fatalities and the mill was a total loss.

The scene remained under the control of the Police and BC Coroner's Service until about 01 February 2012 when it was released to WorkSafe BC. Worksafe BC assumed the role of lead investigating agency, responsible for overall control of the site and evidence removed for evaluation. WorkSafe BC and the BC Safety Authority (BCSA) each investigated the incident. The BCSA investigation team consisted of a gas, a boiler and an electrical safety officer as these disciplines are regulated by BCSA. In addition, SAMAC Engineering was contracted by BCSA to provide fire and explosion investigation expertise.

3.0 INFORMATION AVAILABLE

The following activities were performed during our investigation:

- examined and photographed the fire scene from 06 February 2012 to 23 February 2012 and again from 27 March 2012 to 05 April 2012,
- reviewed information provided including recorded and/or transcribed witnesses interviews,
- examined various pieces of sawmill equipment with the investigation team's safety officers,
- discussed the assessments of the investigation team's safety officers, and
- observed laboratory examinations of retained exhibits, 9 and 10 July 2012.

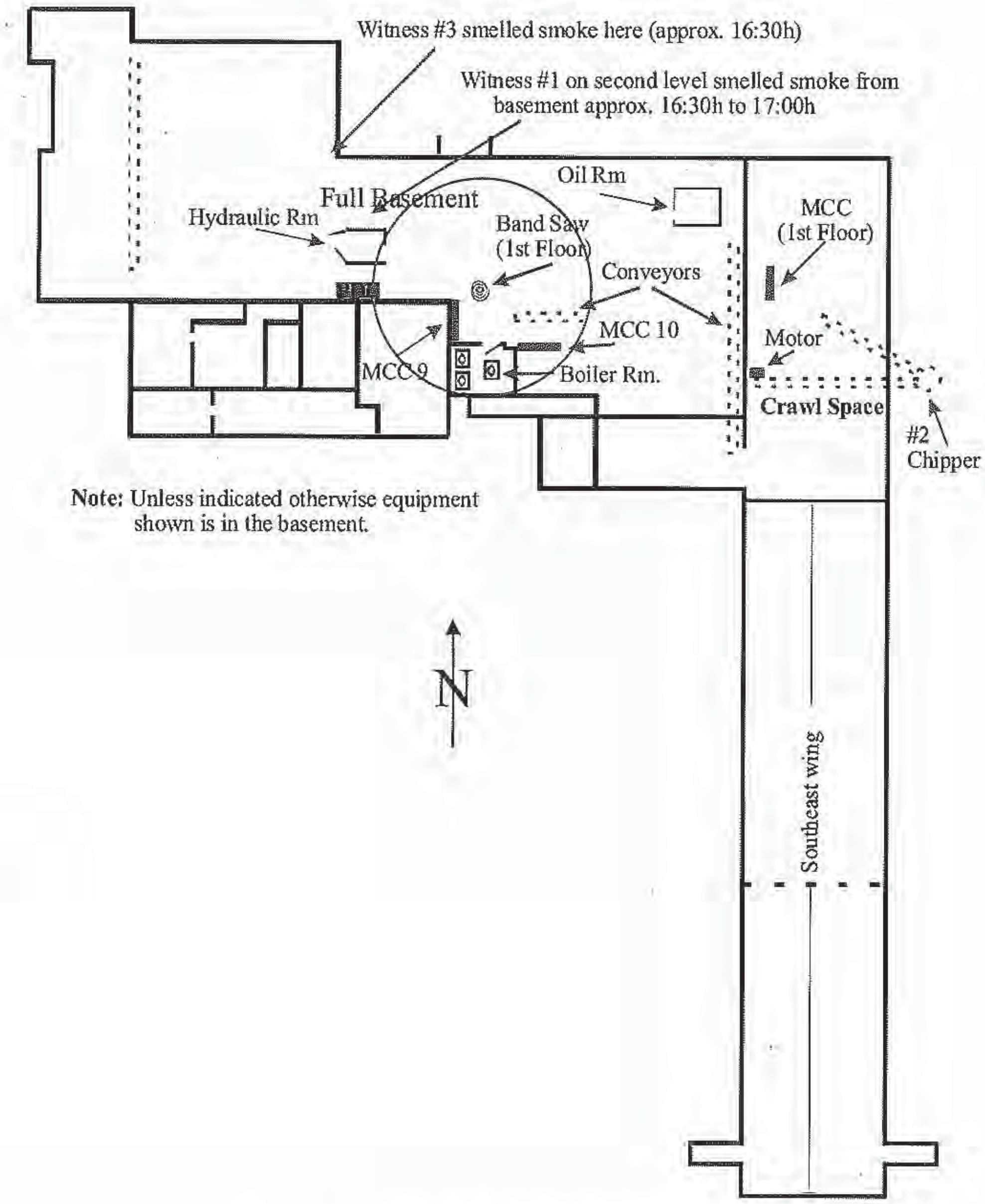


Figure 1: Basic footprint of the sawmill
(not to scale)

4.0 REVIEW OF INFORMATION

4.1 Description of the Mill

The mill was a two story steel frame structure with plywood walls and heavy timber floors and roof. The volume of wood used in the walls, floors and roof served as a large fuel load once the fire started.

There was a large amount of heavy electrical machinery in the mill including saws, conveyers, fans and pumps. The electrical machinery in the mill was controlled from large electrical panels known as Motor Control Centres (MCCs) (Figure 4 and Photograph 5). Each MCC had a number of cabinets containing electrical fittings of various kinds. MCCs were situated in various locations throughout the mill.

4.2 Explosion Potential

In order for an explosion to occur, five conditions are required. These are: an explosive fuel source, dispersion of the fuel, air mixed with the fuel in the right proportions, an ignition source and confinement. These are referred to as the Explosion Pentagon (Figure 2).

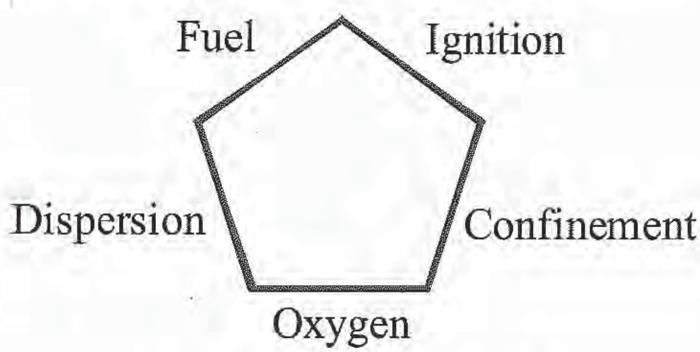


Figure 2: Explosion Pentagon

Potential explosive fuel sources in the mill included:

- natural gas for the boilers, hot oil heating system and other gas appliances,
- portable propane and acetylene cylinders,
- hydraulic systems,
- a substantial amount of fine wood dust on horizontal surfaces in the mill as well as inside some of the electrical panels and MCCs, and
- boilers and pressure vessels would not normally be considered fuel or ignition sources. However, the failure of a boiler or pressure vessel could cause the release of explosive fuels from the sources listed above.

There are three general types of explosions; Mechanical, Chemical, and Nuclear. An explosion fuelled by the types of fuels noted above, including dust, would be included in the Chemical Explosions classification. These could also be referred to as Combustion Explosions. Combustion explosions generate a high-pressure-gas blast-front as the result of an exothermic reaction from the ignition of the fuel. As the blast-front moves out from the origin of the explosion it increases in speed and resultant damage. As such, it is normal to see less blast damage in the area of origin where the velocity of the blast-front was lowest.

Potential ignition sources in the mill included:

- natural gas boilers, hot oil heating system and other gas appliances,
- electrical appliances, panels, wiring and fittings,
- portable propane and acetylene appliances,
- sparks from saws and machinery, and
- heat generated by machinery due to friction.

4.3 Fire Scene Observations

Fire scene observations key to determination of the origin were as follows (Photographs V1 to V20 and Figure 3):

Note: unless specified otherwise equipment referred to in the points below were located in the basement of the mill.

- the building was almost completely burned except for the south end of the southeast wing and the extreme west end of the main wing,
- before the explosion there had been a number of equipment rooms in the basement that housed electrical and mechanical equipment; most of these rooms were destroyed except in the west side and southeast end of the mill,
- debris from the explosion was found in a 360° pattern around the mill,
- the blade cover for the band saw, centrally located on the first floor, was lifted vertically out of position,
- heavy roof timbers in the building were normally oriented with their ends north and south; the south ends of the heavy timbers above the band saw area were shifted to the west while the north ends of the timbers were still in place,
- the metal door of the boiler room, which would normally have swung out from the boiler room to the north, was pushed in to the south,
- in the boiler room, makeup air ducts and boiler exhaust ducts were displaced to the south,
- the west end of MCC-10 was pushed to the south approximately 15cm and the entire panel was pushed approximately 15cm to the east,
- with the exception of areas noted previously there was less blast damage to the immediate area of MCC-10 than to some other areas of the basement,
- the wire cable trays in most of the basement were coated with charred wood dust on the upper side (Photograph 8); however, there was minimal charred wood dust on the cable trays above MCC-10 (Photographs 9 and 10),
- the charred framing of the east wall of the Power Distribution Centre (PDC) room was found on the floor to the west of its normal location,
- the double doors of the hydraulic room next to the PDC were blown open to the west,
- large pieces of equipment in the west end of the basement were pushed to the west and north,

- in the east side of the building where the basement transitioned from a full basement to a crawl space, the transition wall and a safety railing were scorched on the west side and a heater in that area was displaced to the east,
- in the east side of the first floor MCC-8R was pushed over to the west, and
- there was a large hole in the floor in front of MCC-8R.

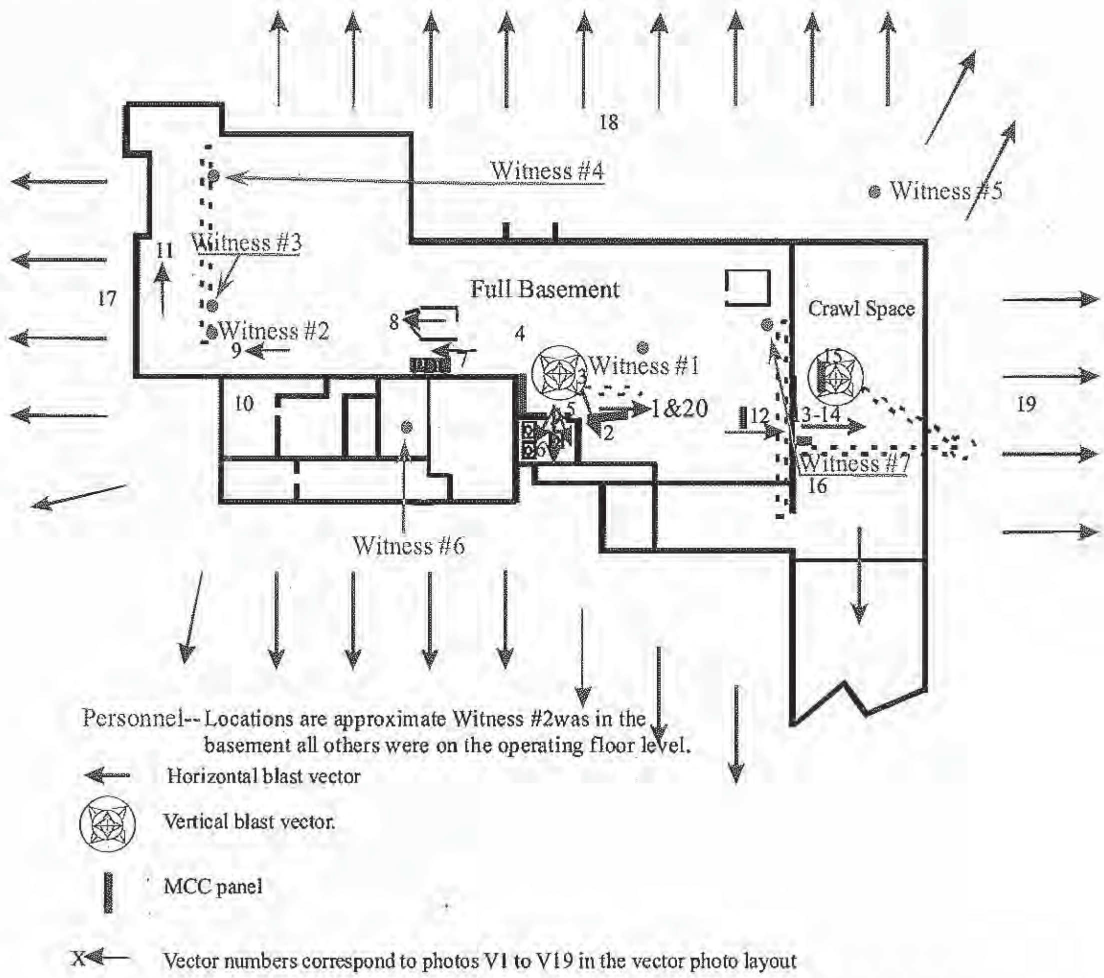


Figure 3 Partial building footprint showing blast vectors and witness locations (Photographs V1 to V20) (not to scale)

Fire scene observations (primarily of MCC 10) key to determination of the cause were as follows (Photographs 1 to 22, Figure 4 and Photographs M1 to M2:

- there was a burn pattern on the front of MCC-10 that was irregularly shaped and tended to follow the shapes of the individual cabinets,
- there was a relatively uniform horizontal burn pattern on the front of MCC-9,
- the doors of cabinets 10-11, 10-22, 10-61 and 10-71 were found in the open position and the door latches were in the open position,
- in MCC-10 the latches on the cabinets were V shaped,

- in MCC-10, the interiors of cabinets 10-31, 10-32, 10-41, 10-42, 10-51 to 10-55, 10-62, the lower part of 10-61 and 10-71 to 10-74 were extensively burned while the remaining cabinets were significantly less burned,
- in MCC-10, cabinet 10-41 was completely gutted,
- most of the equipment and horizontal surfaces in the basement were heavily coated with wood dust,
- there was a layer of wood dust inside MCC-9; MCC-9 was in the same area as MCC-10,
- the intake for the air pressurizing system for MCCs 9 and 10 was located on the floor next to MCC-10,
- there were carbon deposits inside the pressurizing system ducting for MCC-10,
- there was an open bulb 400 watt metal halide light fixture suspended above MCC-10; the bulb was intact but the shade was found on the floor in front of MCC-10, several of these metal halide lights were located in the basement of the mill, and
- of the potential explosive fuel sources known to have been present in the mill, no evidence was found to indicate that natural gas for the boilers, hot oil heating system or other gas appliances, portable propane and acetylene cylinders, hydraulic systems or boilers and pressure vessels caused or contributed to a primary or secondary explosion.

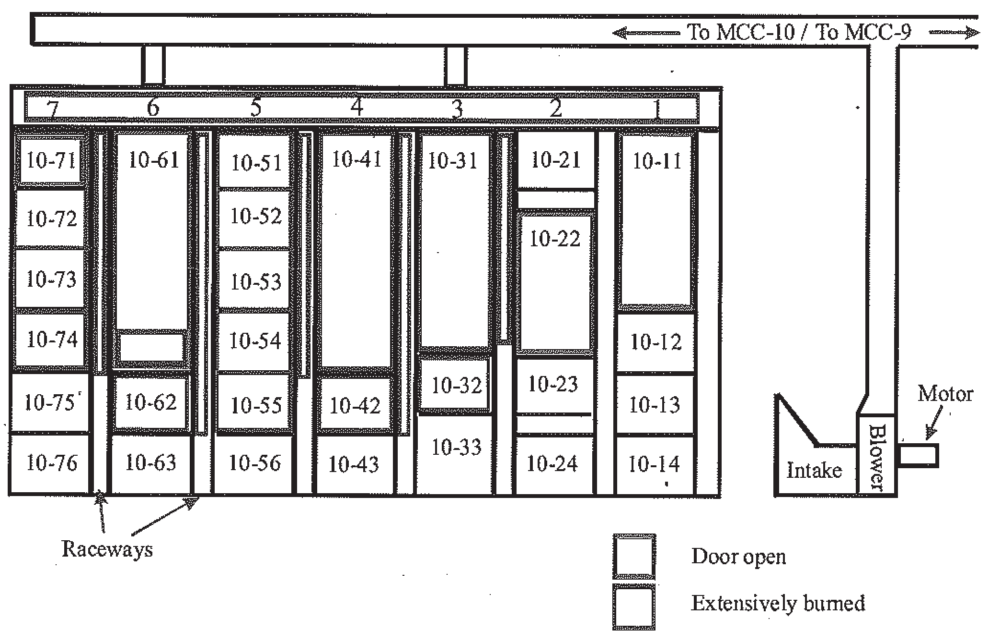


Figure 4: MCC-10
(not to scale)

4.4 Witness Information

Provided information from witnesses was as follows:

4.4.1 Witness #1

- he was the band saw filer,
- he came in to work at approximately 14:30h,

- there was no dust extraction and no cooling water for the saw blades,
- sometime around 16:30h to 17:00h while on the second level in the area of the band saws he smelled an odour like "a jack pine camp fire" from the level below,
- he mentioned the smoke smell to Employee #1 who told him Employee #2 had also smelled it and reported it to Employee #3; Witness #1 took no further action.
- he was in the area of the band saws when the explosion occurred,
- in the first event the floor came up beneath him and the roof went up, and
- in the second event, approximately 20 seconds after the first event, the walls were blown out. .

4.4.2 Witness #2

- he was a security watchman,
- at approximately 20:00h the fire alarm went off so he went to investigate,
- he went into the mill, underneath #3 chipping saw operating booth, checked dry valves 21, 21a and 21b; the valves were ok,
- he thought he saw smoke coming from the Butt Reducer hydraulic pack but it turned out to be steam,
- he then went to #2 Step Feeder,
- he was in the southwest end of the basement when the explosion occurred,
- the lights flickered then the blast hit him,
- he made his way out through the compressor room, and
- he did not smell gas in the basement before the explosion.

4.4.3 Witness #3

- he operated a canter/barker (DBA),
- *early in his shift (approximately 16:30h) he smelled smoke "like something* smouldering", and
- he heard another employee state "yeah, I'm over here by the cut-off saw belts. Where they come out of the mill. Putting out a fire or smouldering".

4.4.4 Witness #4

- he was at a control panel between cut-off saws 1 and 2 facing west,
- the explosion came from behind him, and
- he did not smell anything prior to the explosion.

4.4.5 Witness #5

- he was operating number 4 cut-off saw,
- when the explosion happened the booth door blew open and the shack shook, and
- he smelled nothing unusual.

4.4.6 Witness #6

- he was in the millwright room by the electrical shop, and
- the floor came up and he was blown out into the yard.

4.4.7 Witness #7

- at the time of the incident he was (*on the operating floor*) at a saw sharpening station between Eliminator 1 and Edger 2 facing west,
- he turned toward the band mills and saw a fireball coming toward him,
- it came up, just about hit the roof, and then came toward him, and
- "It sure looked like it came from the band mills".

4.5 Sawmill Equipment

Sawmill equipment non-destructively examined at the scene with the investigation team's safety officers included gas, electrical and pressure vessel equipment regulated by the British Columbia Safety Authority (BCSA). The following equipment exhibited conditions warranting more detailed examination: remains of cabinet 10-31 from MCC-10, an electric conveyer motor, a light bulb and fixture from above MCC-10 and a gas valve and piping. All of the noted items were retained by WorkSafe BC for future examination.

4.6 Safety Officer's Assessments

Based on assessments of the team's safety officers:

1) No evidence was found that boilers or pressure vessels contributed to the cause of the fire.
2) A minor underground gas leak was found outside approximately 130 feet (40m) from the mill; no evidence was found to link the leak to the cause of the explosion. To date, no evidence has been found to link any of the regulated gas equipment to the cause of the explosion.
3) Electrical equipment remains a possible ignition source of the fire; items of interest include all electrical equipment in the identified area of origin.

5.0 ANALYSIS

5.1 Origin of the Explosion

Analysis of the origin of the explosion was based on the following information (Figure 3 and Photographs V1 to V20):

- the building was almost completely burned except for the south end of the southeast wing and the extreme west end of the main wing,
- before the explosion there were a number of equipment rooms in the basement that housed electrical and mechanical equipment; most of these rooms were destroyed except in the west side and southeast end of the mill,
- debris from the explosion was found in a 360° pattern around the mill,

- the blade cover for the band saw, centrally located on the first floor, was lifted vertically out of position,
- heavy roof timbers in the building were normally oriented with their ends north and south, the south ends of the heavy timbers above the band saw area were shifted to the west while the north ends of the timbers were still in place,
- the metal door of the boiler room, which would normally have swung out from the boiler room to the north, was pushed in to the south,
- in the boiler room makeup air ducts and boiler exhaust ducts were displaced to the south,
- the west end of MCC-10 was pushed to the south approximately 15cm and the entire panel was pushed approximately 15cm to the east,
- in MCC-10, cabinet 10-31 contained six high voltage lines connected in pairs to three metal lugs; two of the lugs were found in normal condition while the third was extensively damaged,
- with the exception of areas noted previously there was less blast damage to the immediate area of MCC-10 than to some other areas of the basement,
- the charred framing of the east wall of the PDC room was found on the floor to the west of its normal location,
- the double doors of the hydraulic room next to the PDC were blown open to the west,
- large pieces of equipment in the west end of the basement were pushed to the west and north,
- in the east end of the building where the basement transitioned from full basement to a crawl space, the transition wall and a safety railing were scorched on the west side and a heater was displaced to the east,
- in the east end of the first floor MCC-8R panel was pushed over to the west,
- there was a large hole in the floor in front of MCC-8R,
- in the first event the floor came up beneath Witness #1, the band saw operator, and the roof went up,
- Witness #2 was in the southwest end of the basement when the explosion occurred, he made his way out through the compressor room,
- Witness #4 was at a control panel between cut-off saws 1 and 2 facing west, the explosion came from behind him,
- Witness #6 was in the millwright room by the electrical shop, the floor came up and he was blown out into the yard, and
- Witness #7 was on the operating floor at a saw sharpening station between Eliminator 1 and Edger 2 facing west; he stated "It (*the fireball*) sure looked like it came from the band mills".

Analysis of the explosion damage (Figure 3) showed the blast expanding out from the area of the basement below the band saw near where the boiler room, MCC-9 and MCC-10 were located (Figure 1, circled area). This area was below the band saw operated by Witness #1. Evidence from Witness #1 was that the floor came up from below him and the roof went up. The blade cover for the band saw being lifted vertically out of position, and the south ends of the heavy roof timbers being shifted to the west, also place the origin of the blast in the basement as noted above. Information from Witness #6 that the floor in the millwright room came up also places the origin of the blast in the basement. According to Witness #7 the fireball looked like it came from the band mills (*band saws*), which was where Witness #1 was. As such, Witness #7's information also places the origin at or below the band saws.

The band saw was in the same vertical plane as the south ends of the roof timbers. After the explosion, the south ends of the heavy roof timbers were shifted to the west while the north ends were still in place. This is very likely a result of the explosion lifting the roof above the band saw and at the same time blowing through the roof thus forcing the south ends of the timbers to the west.

The lower level of blast damage in the immediate area of MCC-10 in comparison to other areas of the mill is also an indicator that the explosion very likely originated in that area.

One of the cabinets in MCC-10 exhibited unusual conditions. Cabinet 10-31 contained six high voltage lines connected in pairs to three metal lugs. Two of the lugs were found in fair condition while the third was extensively damaged. A laboratory examination of the lugs on 09 July 2012 revealed that the damage to the extensively damaged lug was very likely mechanical damage. This damage very likely occurred as a result of lateral force on the lug when MCC 10 was pushed out of position by the explosion (Photographs V1 and V2). Based on this, failure of the lug in cabinet 10-31 can reasonably be ruled out as the cause of the explosion. However, the mechanical damage to the lug is a further indication that MCC-10 was moved to the east by an explosion in the basement in the area below the band-saw.

Based on the preceding information the explosion very likely originated in the area of the basement below the band saw.

MCC-8R, the MCC panel for the eliminator, was an anomaly because it was in the east end of the first floor but it was pushed over in a westerly direction. This very likely occurred when the blast-front from the explosion in the basement pushed through the floor, on the east side of MCC-8R, and the expanding gases blew the panel to the west.

5.2 Cause of the Explosion

Analysis of the cause of the explosion is based on the following information (Figures 3, 4, Photographs 1 to 22 and Photographs M1 to M21):

- the wire cable trays in most of the basement were coated with charred wood dust on the upper side; however, there was minimal charred wood dust on the cable trays above MCC-10,
- there was a burn pattern on the front of MCC-10 that was irregularly shaped and tended to follow the shapes of the individual cabinets,
- there was a relatively uniform horizontal burn pattern on the front of MCC-9,
- the doors of MCC-10 cabinets 10-11, 10-22, 10-61 and 10-71 were found in the open position and the door latches were in the open position,
- in MCC-10 the latches on the cabinets were V shaped,
- in MCC-10, the interiors of cabinets 10-31, 10-32, 10-41, 10-42, 10-51 to 10-55, the lower part of 10-61, 10-62 and 10-71 to 10-74 were extensively burned while the remaining cabinets were significantly less burned,

- in MCC-10, cabinet 10-41 was completely gutted,
- the west end of MCC-10 was pushed to the south approximately 15cm and the entire panel was pushed approximately 15cm to the east,
- most of the equipment and horizontal surfaces in the basement were heavily coated with wood dust,
- there was a layer of wood dust inside MCC-9 which was in the same area as MCC-10,
- the motor switch for the pressurizing system for MCC-10 was on at the time of the explosion but the start/stop switch was in the stop position,
- the intake for the air pressurizing system for MCC-10 was located on the floor next to MCC-10.
- there were carbon deposits inside the pressurizing system ducting for MCC-10,
- there was an open metal halide light fixture suspended above MCC-10; the bulb was intact but the shade was found on the floor in front of MCC-10,
- at about 16:30h Witness #1 and Witness #3 smelled smoke; sometime around 16:30h to 15:00h while on the second level in the area of the band saws Witness #1 smelled an odour like "a jack pine camp fire" from the level below,
- at approximately 20:00h the fire alarm went off so Witness #2 went to investigate,
- of the potential explosive fuel sources known to have been present in the mill, no evidence was found to indicate that natural gas for the boilers, hot oil heating system or other gas appliances, portable propane and acetylene cylinders, hydraulic systems or boilers and pressure vessels caused or contributed to a primary or secondary explosion, and
- there was a substantial amount of fine wood dust on horizontal surfaces in the mill as well as inside some of the electrical panels.

The event occurred as an explosion followed by a fire. As discussed in section 4.2, in order for an explosion to occur an explosive fuel source, dispersed and mixed with air in the right proportions, in a confined area in the presence of an ignition source would be required. The explosive fuel sources that would have been present in the mill at the time of the explosion were also listed in section 4.2. Of those fuels, no evidence was found that any of them except wood dust could have caused or contributed to either a primary or secondary explosion in the area identified as the origin. As such, all fuels except wood dust can reasonably be ruled as very unlikely. Of the explosive fuels noted, to date the only one proven to have been present in the identified area of origin is wood dust. Based on the evidence to date, wood dust very likely fuelled the explosion.

Reference C states: "Dust explosions frequently occur in two stages. A primary explosion of limited volume throws into suspension dust, which has accumulated in machines, on beams, ledges or other surfaces. Ignition of this dust cloud by the heat of the primary explosion or by a secondary ignition source results in a more violent secondary explosion."

Possible ignition sources of a primary explosion in the area of origin include:

- an electrical event in a panel such as an arc flash or other arcing or sparking of electrical contacts,
- flame from the natural gas boilers,

- spark or heat from electrical appliances, panels, wiring and fittings,
- heat or flame from portable propane or acetylene appliances,
- sparks from saws and machinery,
- heat generated by machinery due to friction, and
- a fire in the area of origin.

Flame from the natural gas boilers can be ruled out because the boilers were shut down at the time of the explosion. None of the propane or acetylene appliances examined exhibited conditions consistent with their being the cause of the explosion. As such they can be ruled as unlikely.

In the area of origin a large electrical panel identified as MCC-10 stood out as a possible source of the primary explosion. In a major fire such as this it would be normal to see a relatively uniform horizontal burn pattern on the front of MCC-10, had it been a result of the main fire. However, the burn pattern on the front of MCC-10 (Photograph 5) was irregularly shaped and tended to follow the shapes of individual cabinets. MCC-9 was in the same general area as MCC-10 (Figure 1) yet, in contrast to MCC-10 there was a relatively uniform horizontal burn pattern on the front of MCC-9. This suggests the burn pattern on MCC-10 was the result of an internal fire. All of the cabinets were interconnected via raceways for wiring (Figure 4). It is likely that an internal fire or explosion occurred inside MCC-10 and only became established in certain cabinets, possibly those that contained more wood dust, and the internal burning produced the burn pattern observed on the outside.

When MCC-10 was first examined, the doors of cabinets 10-11, 10-22, 10-61 and 10-71 which normally would have been closed and latched were found in the open position as were the latches. This could indicate that prior to the explosion the doors of these cabinets were not closed and latched properly. However, the latch bars for the cabinet doors were V shaped (Photograph M20). When latched panel doors with V shaped latch bars are forced open the V shape can cause the latch to rotate to the open position. As such, the position of the latches on the open cabinets is not a reliable indicator of whether or not they were left unlatched.

Most of the wood dust inside MCC-10 was burned away. However, wood dust accumulations were present in the less damaged cabinets of MCC-10 (Photograph 11) and wood dust deposits were observed in MCC-9 and MCC-12 which were less damaged. The intake for the air pressurizing system for MCCs 9 and 10 was on the floor next to MCC-10. Because the intake was in the dust contaminated environment, the pressurizing system could have introduced wood dust into the MCCs had it been used prior to the explosion without conducting a cleaning of the cabinets.

The carbon deposits inside the MCC pressurizing system ducting indicate that there was a combustible fuel (very likely wood dust) in the ducting prior to the explosion. The motor switch for the pressurizing system was on at the time of the explosion but the start/stop switch was in the stop position indicating the motor was off. Therefore, the combustion inside the ducting would have been due to fire burning back from the MCC-10 panel rather than fire being drawn in through the intake by the fan.

A possible explanation for the cabinet doors in MCC-10 being open, the combustion inside the pressurization system ducting and the irregular burn pattern on the front of MCC-10, is that a primary explosion occurred inside MCC-10 blowing the doors open. This could have caused wood dust outside MCC-10 to become suspended and ignited causing the second dust explosion which destroyed the mill. In order for this to occur dust would have had to be in suspension inside MCC-10 in the presence of an ignition source (the cabinet itself would have provided the confinement and the normal air in the cabinet would have provided the oxygen supply). There would have been on-going vibration in the mill due to the large machines and in some cases there can be a large jolt when a machine is started. Even with the air pressurizing for MCCs 9 and 10 off, dust inside MCC-10 could have been in suspension at a critical time due to on-going vibration and the starting of machinery. No evidence was found of arc flash inside MCC-10 so it can reasonably be ruled out. However, MCC-10 contained a large number of electrical switches, breakers and connections which could have provided an ignition spark for an interior explosion. No clear evidence was found that any of the cabinets ignited an explosion. However, as depicted in Photographs M1 to M24, some of the cabinets were so badly damaged that they could neither be confirmed nor ruled out as the ignition source of the explosion.

A primary explosion violent enough to blow open the doors of the cabinets would also have blown the wood dust off the cable trays above MCC-10. This would explain why there was no charred wood dust in the cable trays above MCC-10 in contrast to large amounts on the cable trays in all other areas of the basement. The airborne wood dust from the cable trays above MCC-10 could then have been ignited, by either the primary explosion or by an ignition source outside of MCC-10, causing the secondary explosion. The mill structure would have provided confinement for the second explosion and the normal air supply in the mill would have furnished the necessary oxygen.

The metal halide light above MCC-10 is another possible ignition source of dust in suspension. The maximum bulb temperature of the metal halide light bulb above MCC-10 was rated at 400^{0}C and 250^{0}C at the base. Tests by WorkSafe BC of dust samples from the mill indicated a possible dust cloud ignition temperature of 430^{0}C and a possible dust layer ignition temperature of 310^{0}C. Based on this, under conditions where the surface of the bulb could be maintained wood dust free, a halide light like the one above MCC-10 would be an unlikely ignition source. However, if part of the unprotected halide bulb became coated in wood dust, over time the heat from the bulb would have caused the ignition temperature of the wood dust to become reduced through pyrolysis. Over time the ignition temperature of dust on the halide bulb could have become reduced enough to be ignited by the bulb either in layer or in suspension. Due to the post-fire condition of the bulb the possibility that it was the ignition source could neither be confirmed nor ruled out.

Another possible ignition source of the explosion that must be considered is that there may have been a fire in the basement. At about 16:30h Witnesses #1 and #3 smelled smoke. Witness #1, who was on the second level in the area of the band saws, stated he smelled an odour like "a jack pine camp fire" from the level below. One level below the band saws was very near to MCC-10. Both individuals understood that the cause of the smoke that they each smelled had been dealt with. However, it is possible that there was still something smouldering in the mill which could have ignited wood dust in suspension.

Witness #2 reported that the fire alarm activated at approximately 20:00h, approximately seven minutes before the explosion. The fire alarm is activated by a drop in pressure in the sprinkler system. A drop in pressure in a sprinkler system can be due to a leak in the system or by the opening of a sprinkler head due to a fire. Witness #2 investigated and found nothing. However, by the time of the explosion Witness #2 was still in the process of checking the mill and had not yet found the cause of the alarm activation or reached the area of origin. As such the possibility that the explosion was caused by a pre existing fire in the area of origin cannot be ruled out.

Based on the forgoing information, the five elements required for an explosion to occur were all present in the mill in the area of origin.

6.0 CONCLUSIONS

6.1) The explosion very likely originated in the area of the basement below the band saw where the MCC-9 and MCC-10 were located.

6.2) The five elements required for an explosion to occur were all present in the mill in the area of origin.

6.3) Several possible ignition sources were identified including: the cabinets in MCC-10, an unprotected metal halide light, electrical appliances, panels, wiring and fittings, sparks from saws and machinery and heat generated by machinery due to friction.

We trust that the contents of this report are consistent with your current needs. Inspection notes and file material have been retained for future use as required.

Yours truly,
SAMAC Engineering Ltd.

Chris deRosenroll C.D., CCFI, CFII, CFEI

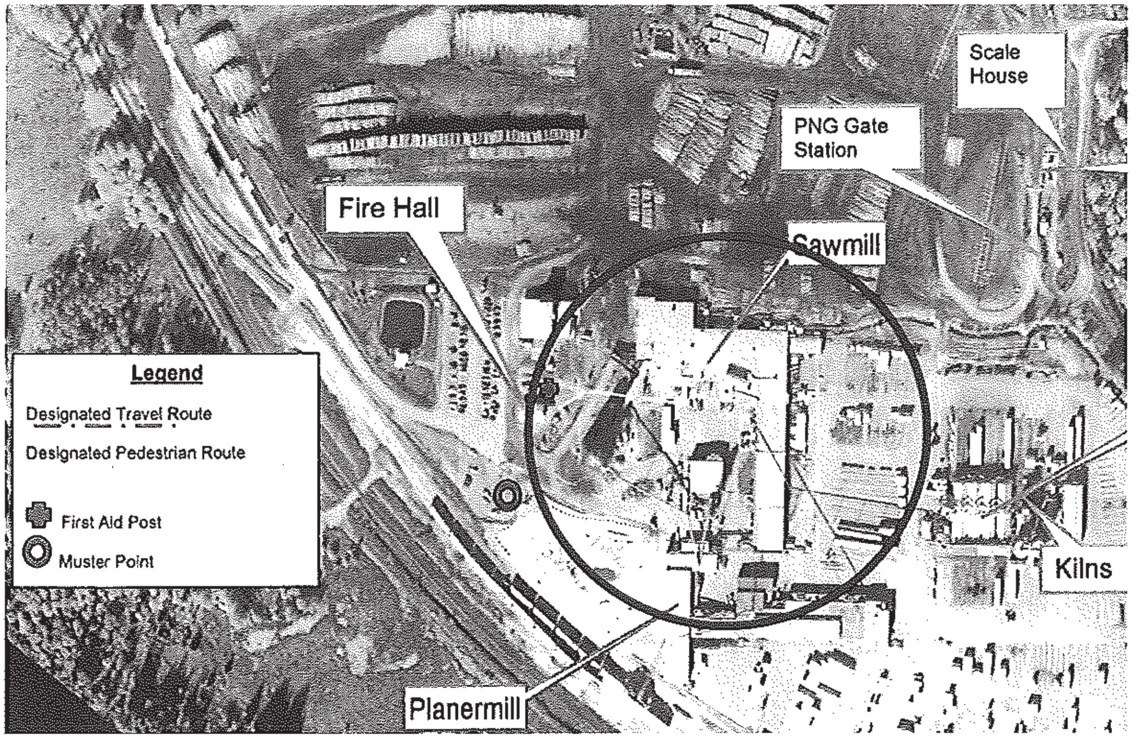
Reviewed by:
Steve MacInnis, P.Eng.

Attachment(s): 63 Photographs
Annex A: References

Annex A: References

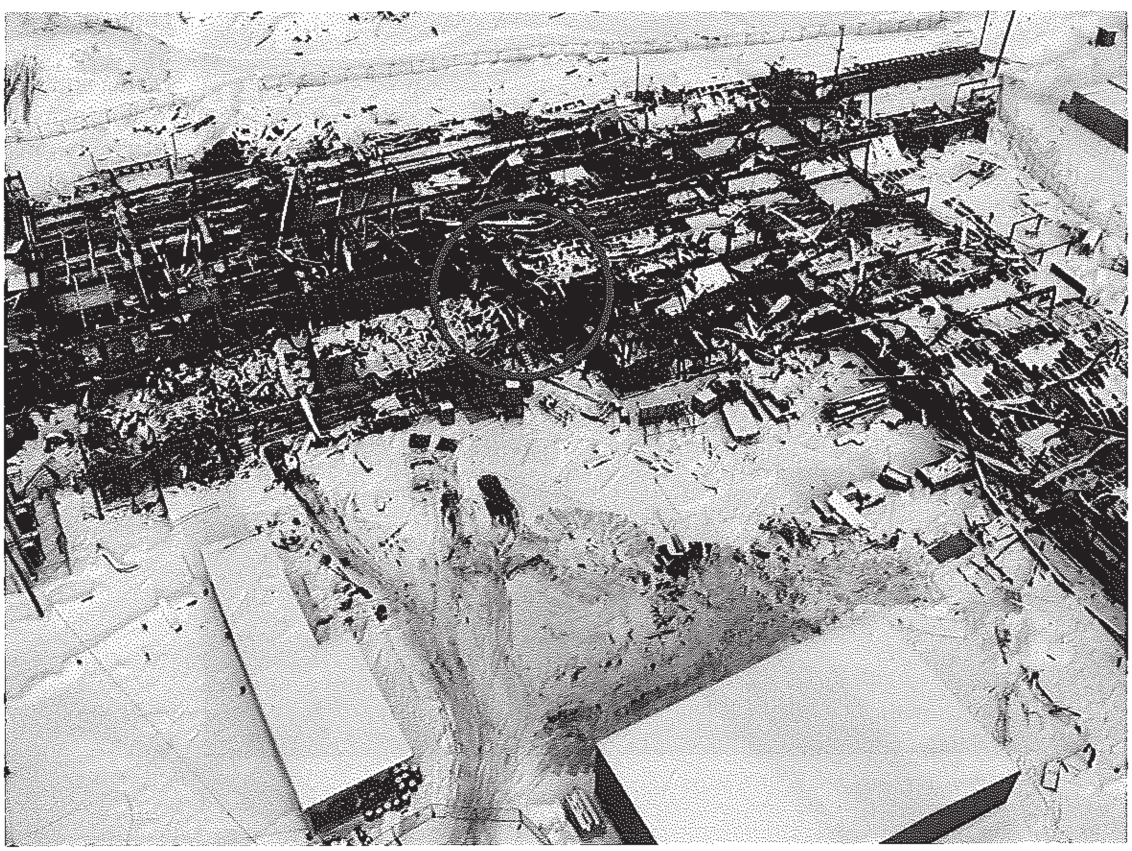
1) National Fire Protection Association (NFPA) Fire Protection Handbook
2) NFPA 921, Guide For Fire and Explosion Investigations
3) NFPA Inspection Manual
4) CSA Guide for the Design, Testing, Construction, and Installation of Equipment in Explosive Atmospheres
5) Metal Halide Lamps, Harvard University Health and Safety Group

SAMAC Location Photographs



Photograph 1

Looking at a pre-fire aerial view of the sawmill sight.



Photograph 2

Looking at a post-fire view of the sawmill.

Note: the circled area corresponds to the circled area in Figure 1 of the attached report.

Photograph 3

Facing north looking at the area indicated by the red circle in Photograph 2.

Note: the location of the band saw (red arrow).

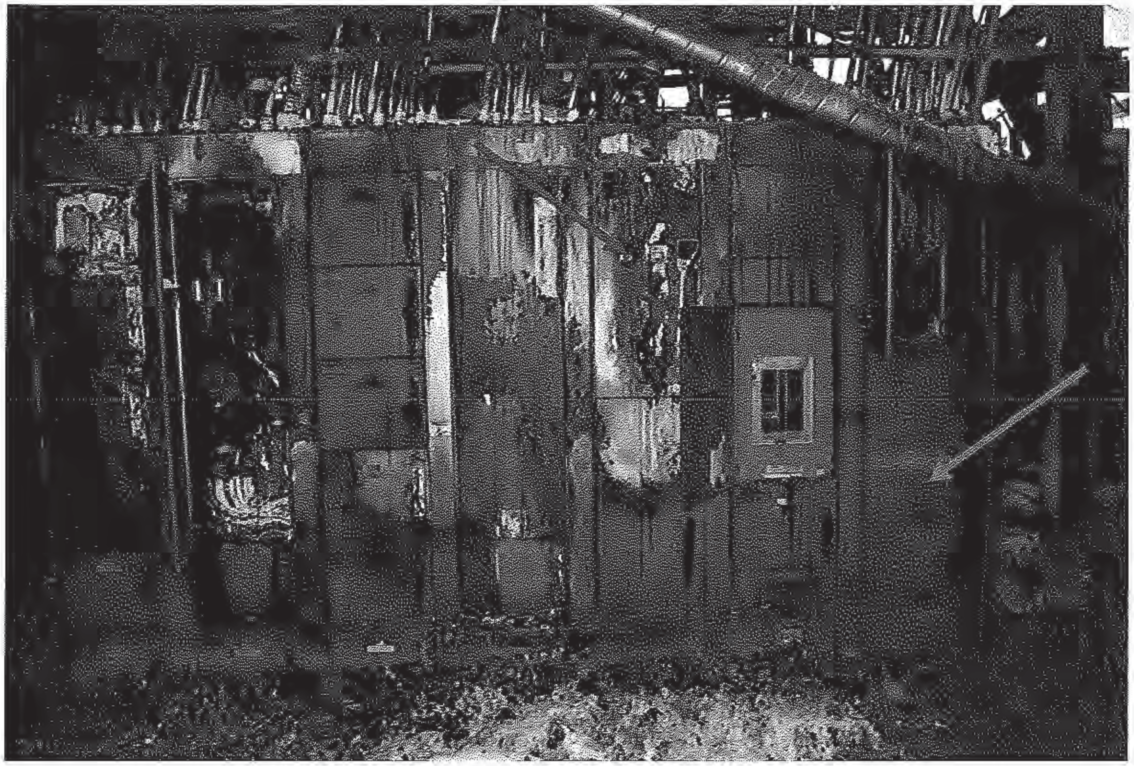
Note also: the boiler and MCC-10 are located in the basement (green arrow).

Photograph 4

Facing northeast looking at a closer view of the areas referred to in Photograph 3.

Note: the band saw (red arrow) and the boiler room and MCC-10 located in the basement (green arrow).

SAMAC Location Photographs



Photograph 5

Looking at the front of MCC-10.

Note: rather than being a uniform V pattern the burn pattern on the front of the panel follows the shapes of individual cabinets.

Note also: the locations of sub panels 10-31 (red arrow) and 10-13 (green arrow). Cabinet 10-13 is further referred to in Photograph 11.

Photograph 6

Looking from above at the location of the band saw (red arrow) in relation to MCC-10 (green arrow) and the boiler room (yellow arrow).

Photograph 7

Looking at the band saw (arrow) from MCC-10.

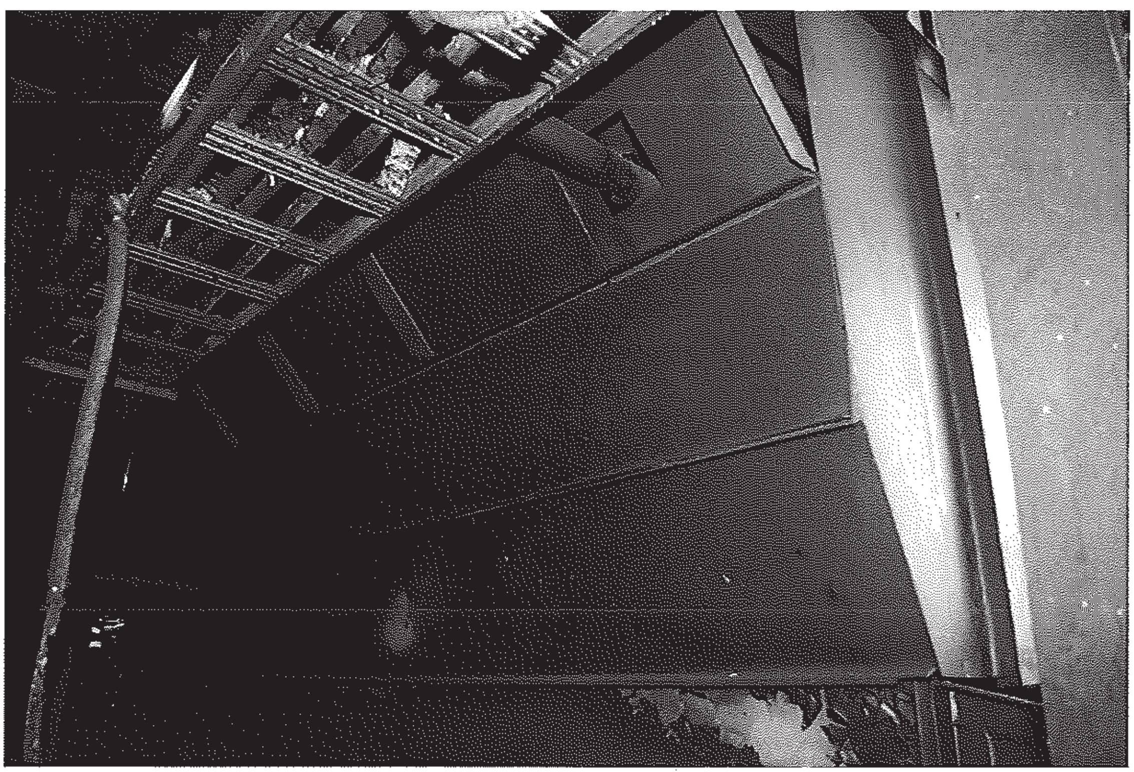
Photograph 8

Looking at an example of charred sawdust on wire cable trays. This is typical of the condition of cable trays in the basement of the mill.

Photograph 9

Looking at the cable trays above MCC-10.

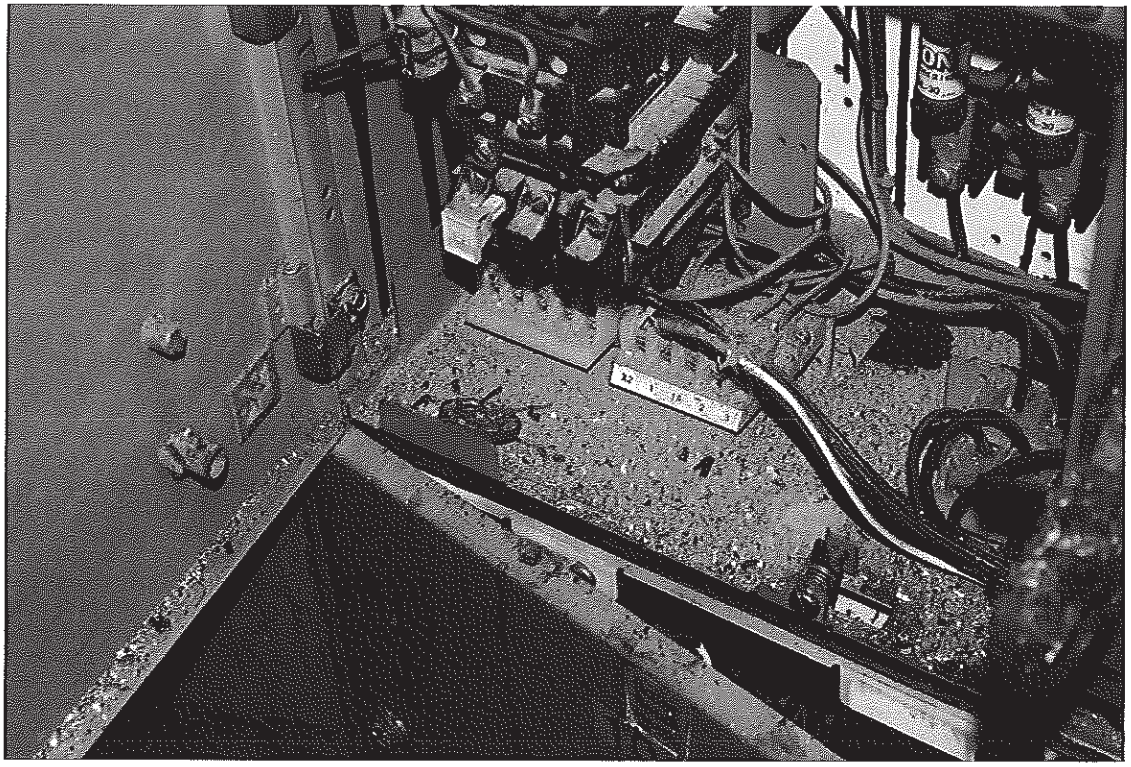
Note: the absence of charred sawdust.



Photograph 10

Looking at the cable trays by the conveyer next to MCC-10.

Note: the absence of charred sawdust.

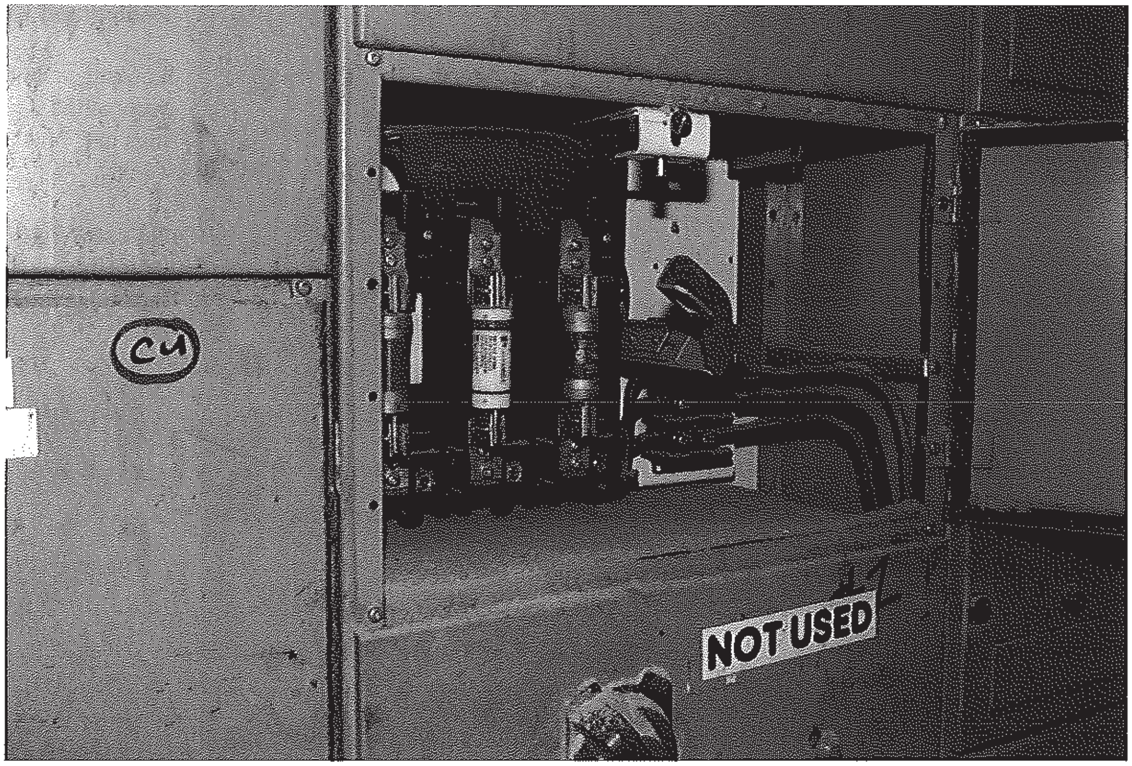


Photograph 11

Looking at the accumulation of sawdust inside MCC-10, sub panel 10-13.

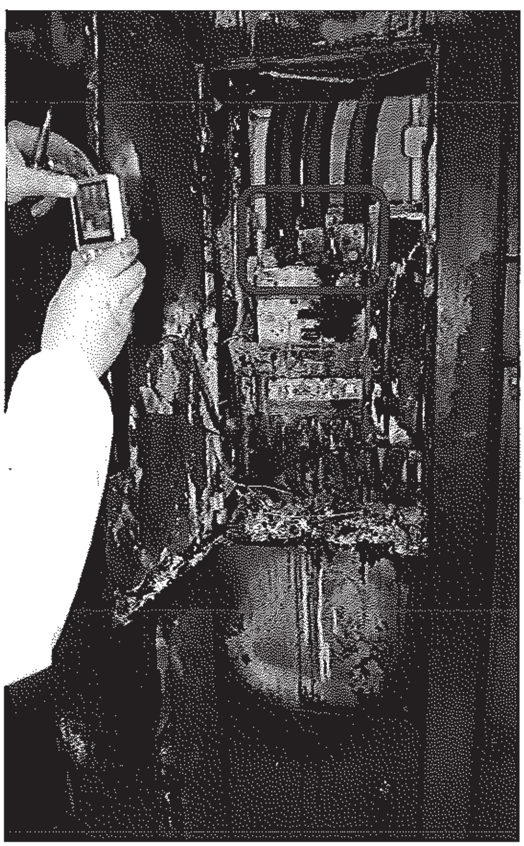
Photograph 12

Looking at the accumulation of sawdust inside MCC-9 (arrows).



Photograph 13

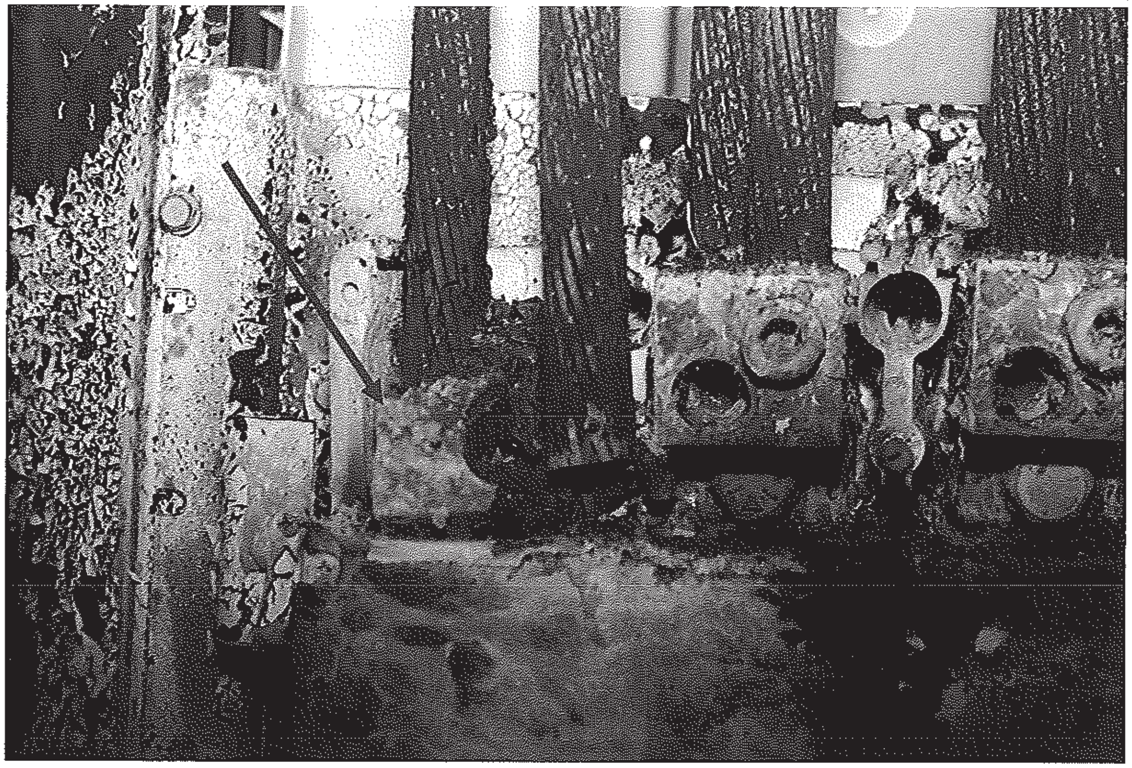
Looking at the accumulation of sawdust inside MCC-12.



Photograph 14

Looking at the interior of MCC-10, subpanel 10-31.

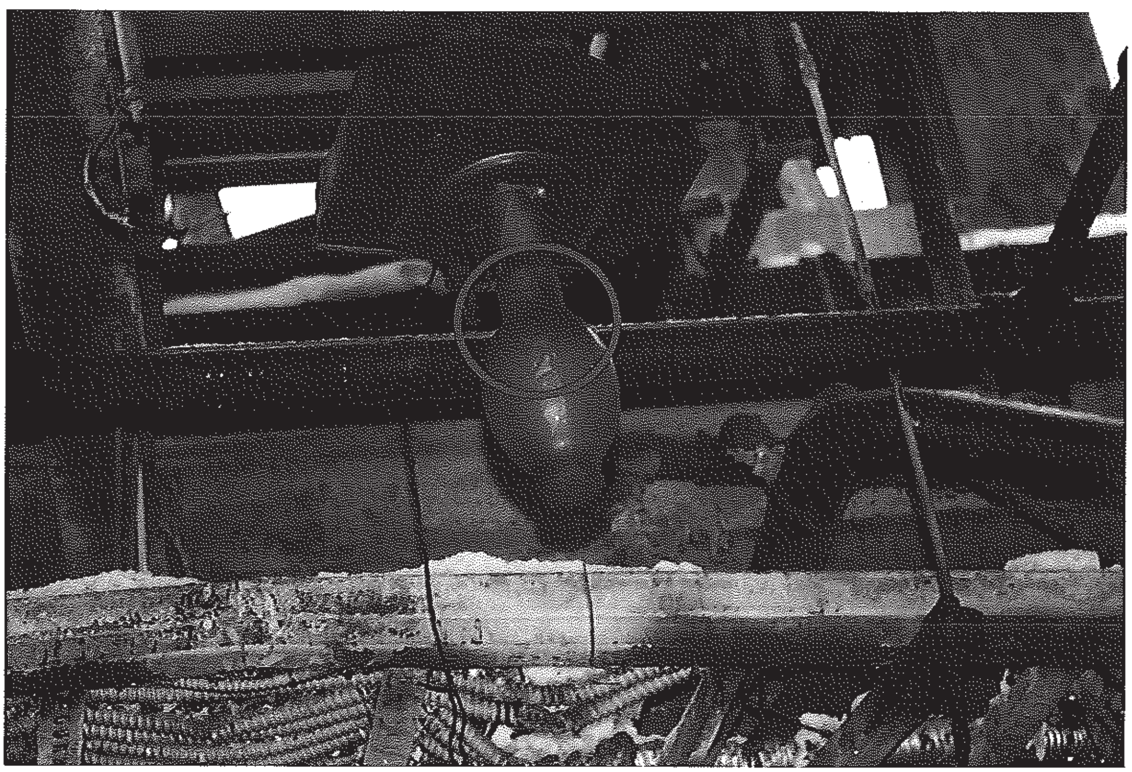
Note: the location of the three lugs (red outline).



Photograph 15

Looking at a closer view of the three lugs in subpanel 10-31.

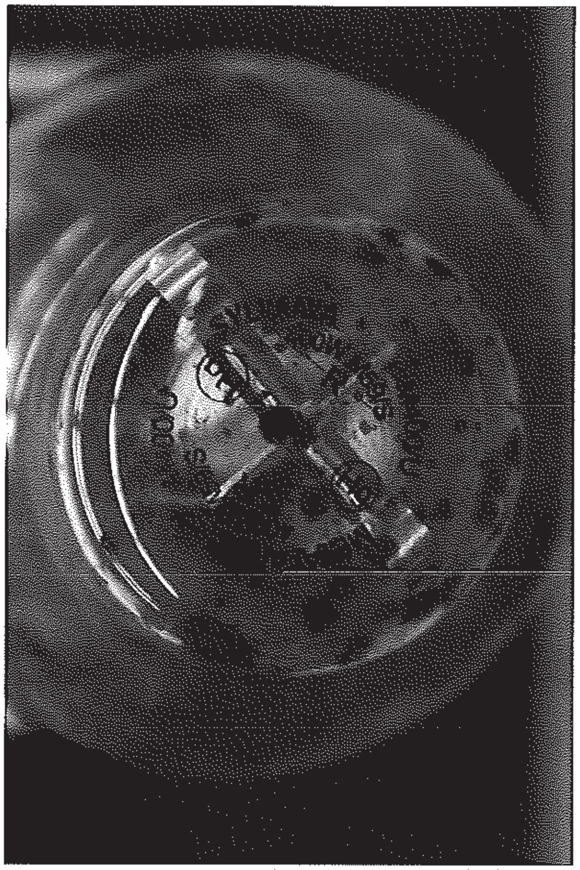
Note: two lugs are intact but the third (arrow) is broken up.



Photograph 16

Looking at the metal halide light above MCC-10.

Note: residue on the upper bulb surface (circle).



Photograph 17

Looking at the information on a metal halide light bulb identical to the one shown in photograph 16.

Photograph 18

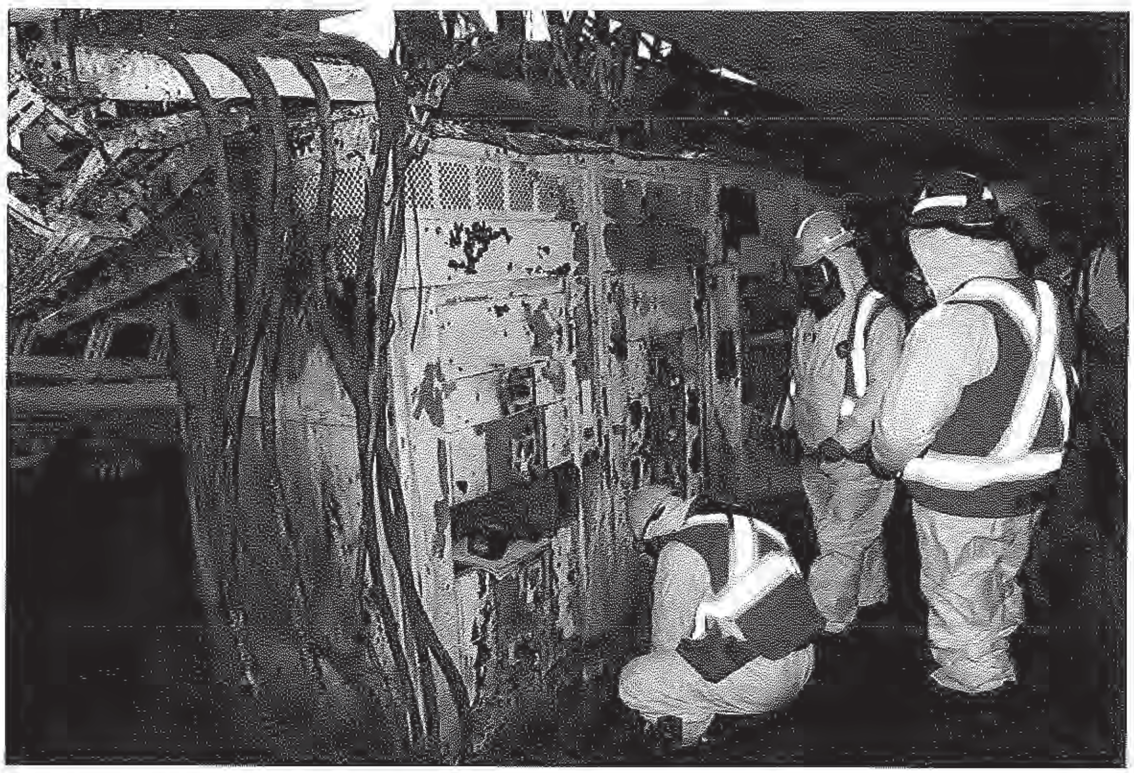
Looking at the interior of the ventilation ducting for MCC-10.

Note: the charred deposits on the inner surface.

Photograph 19

Looking at the interior of the transition on the blower for the ventilation system for MCC-10.

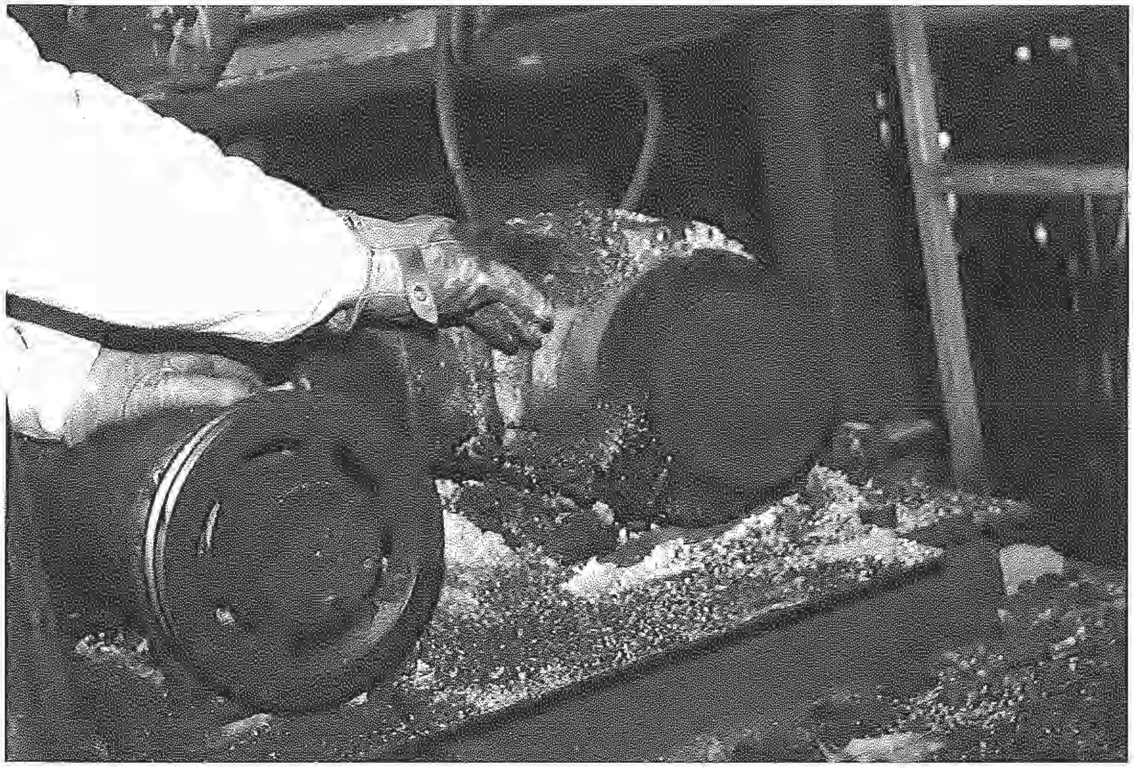
Note: the charred deposits on the inner surface (arrow).



Photograph 20

Looking at the PDC.

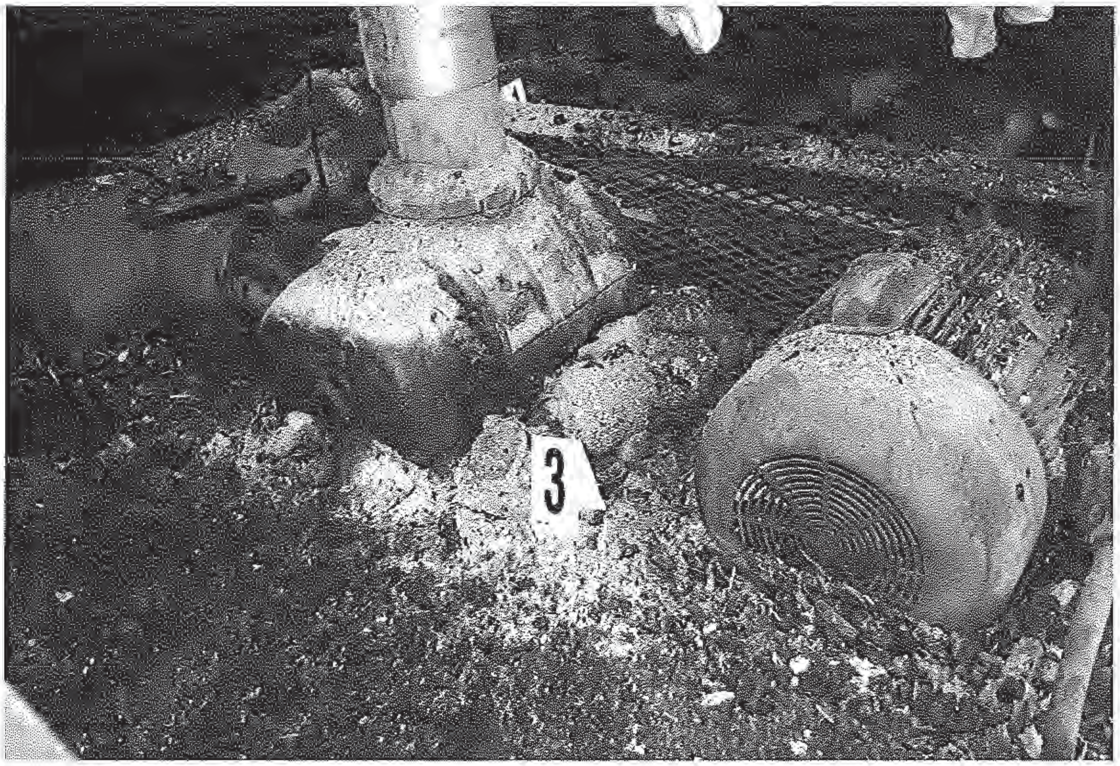
Note: before the explosion the PDC was in a fully enclosed room.



Photograph 21

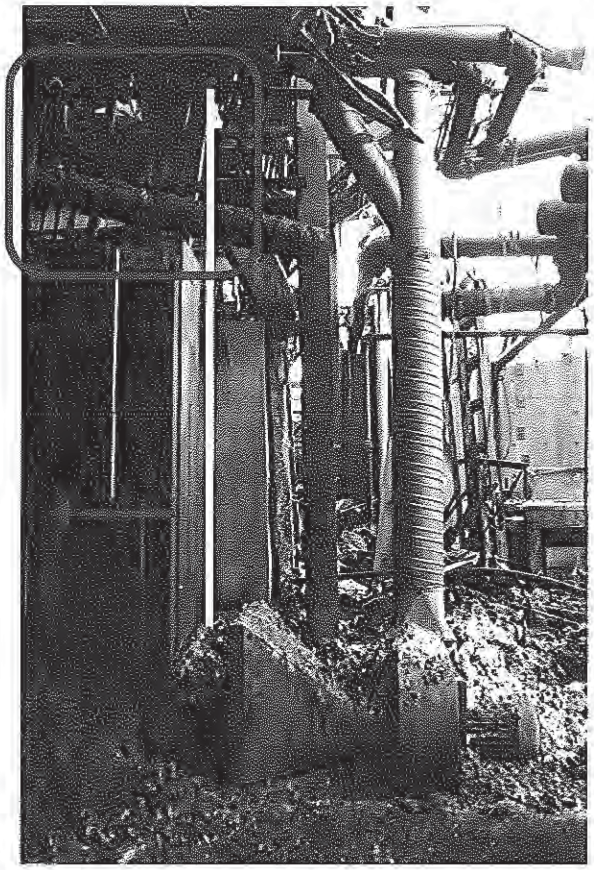
Looking at the motor taken into evidence by Worksafe BC from the east side of the mill basement.

Note: the sawdust on and around the motor.



Photograph 22

Looking at an example of the dust levels in the basement of the mill. This photograph was taken in the east side of the basement.

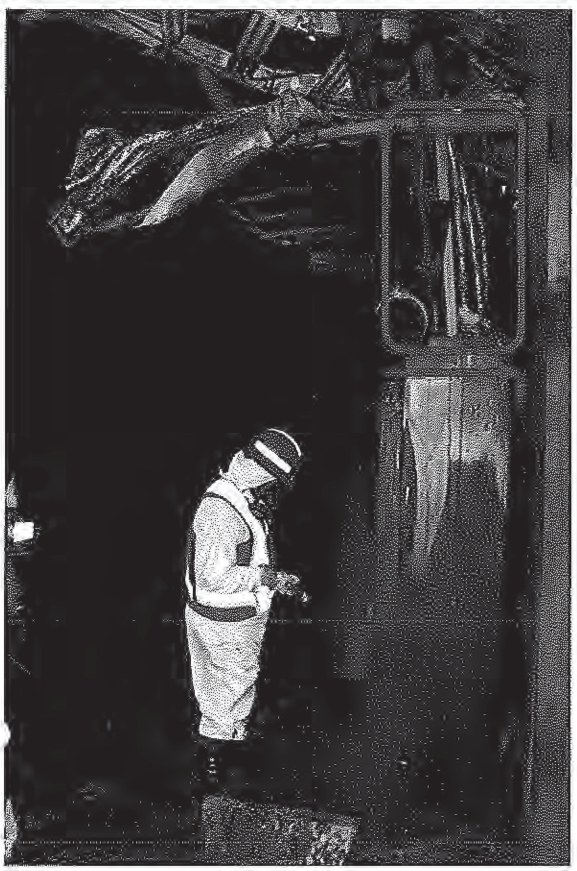


Photograph V1

Looking at the west end of MCC-10 from the front.

Note: the angle of the wires at the top of the panel (red outline) indicates an eastward movement of the panel.

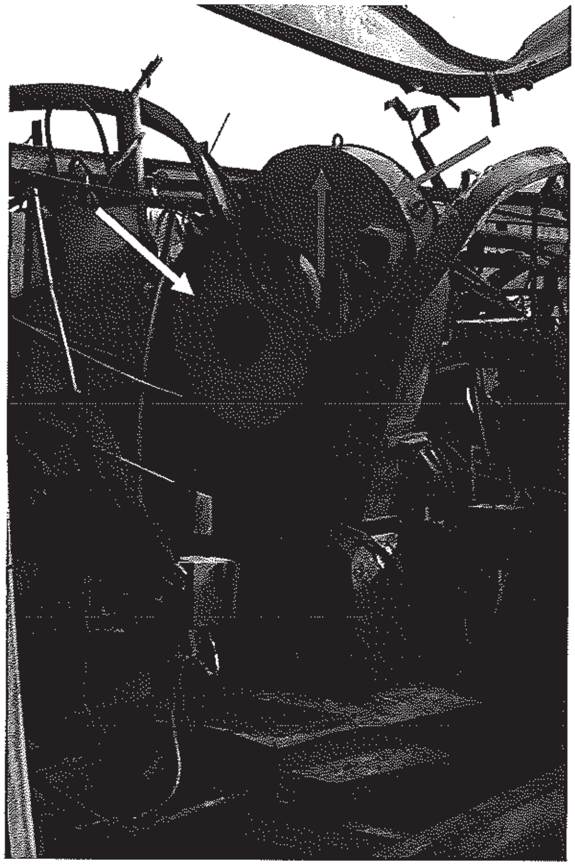
Note also: the red arrows in photographs V1 to V20 indicate the blast direction and correspond to the numbered arrows in Figure 4 of the report.



Photograph V2

Looking at the west end of MCC-10 from the end.

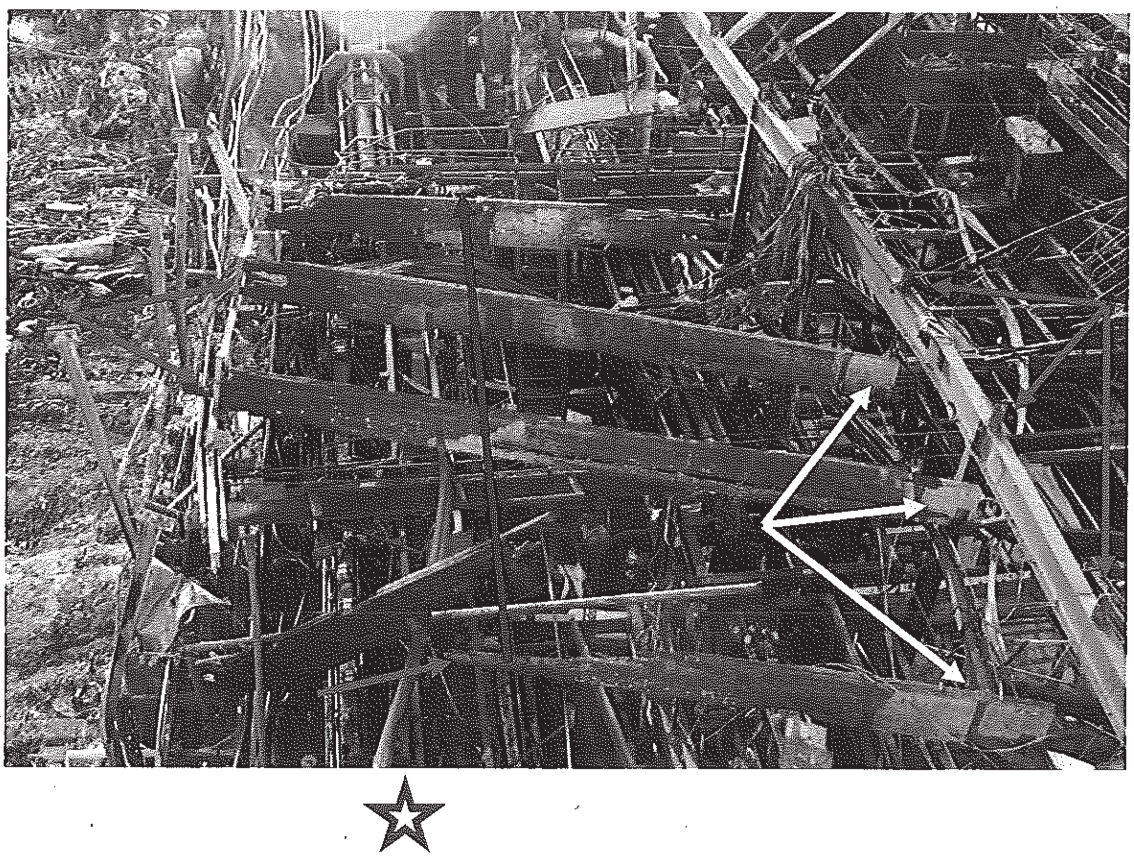
Note: the angle of the wires at the top of the panel (red outline) indicates a southward movement of the panel.



Photograph V3

Looking at the band saw.

Note: the blade shield (green arrow) would normally cover the wheel (yellow arrow).



Photograph V4

Looking at the roof beams above and to the west of the band saw (star).

Note: the south ends of the beams (green arrows) have shifted to the west while the north ends (yellow arrows) are close to their normal locations but have dropped out of the brackets (blue arrows) that secured them to the steel I beam.

Photograph V5

Looking at the door to the boiler room.

Note: the door which would normally have opened out, was found open into the boiler room as indicated by the red vector arrow.

Note also: before the explosion the boiler room was completely enclosed.

Photograph V6

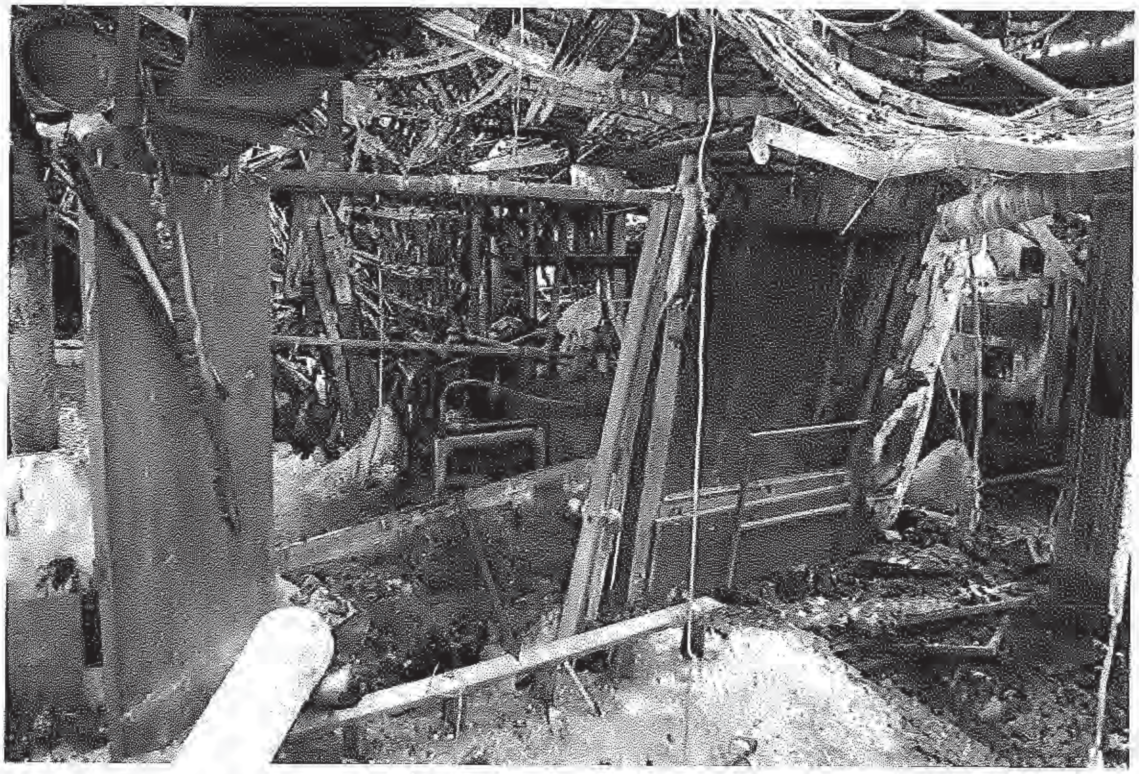
Looking at the boiler room from the south side.

Note: the makeup air duct (green arrow) and the boiler exhaust ducts (yellow arrows) were pushed to the south of their normal positions.

Photograph V7

Looking at the framing of the east wall of the PDC room (green arrow).

Note: the base of the framing (yellow arrow) is in its normal location however, the top has been pushed over to the west.



Photograph V8

Looking at the doors to the hydraulic room by the PDC room blown open to the west.

Photograph V9

Looking at the hard hat of Witness #2 photographed in the southwest end of the basement.

Photograph V10

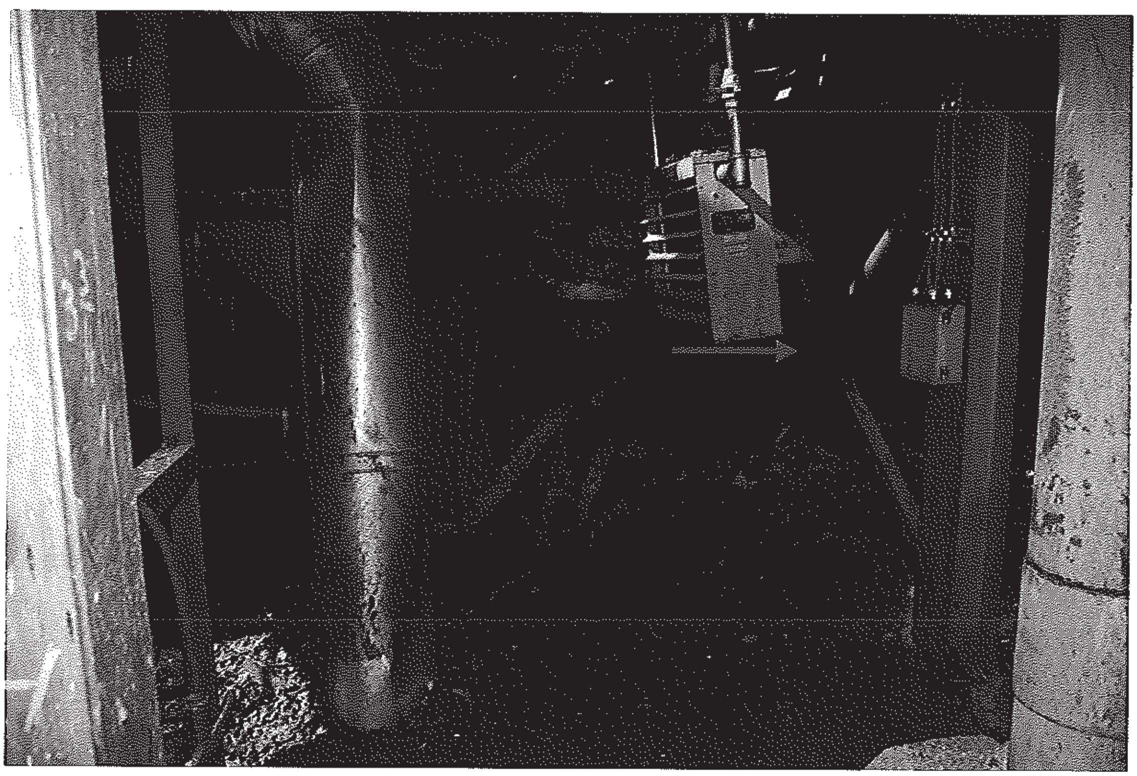
Looking at the compressor room through which Witness #2 escaped.

Note: before the explosion this room was completely enclosed with no exit to the outside.

Photograph V11

Looking at a heating unit in the west end of the basement.

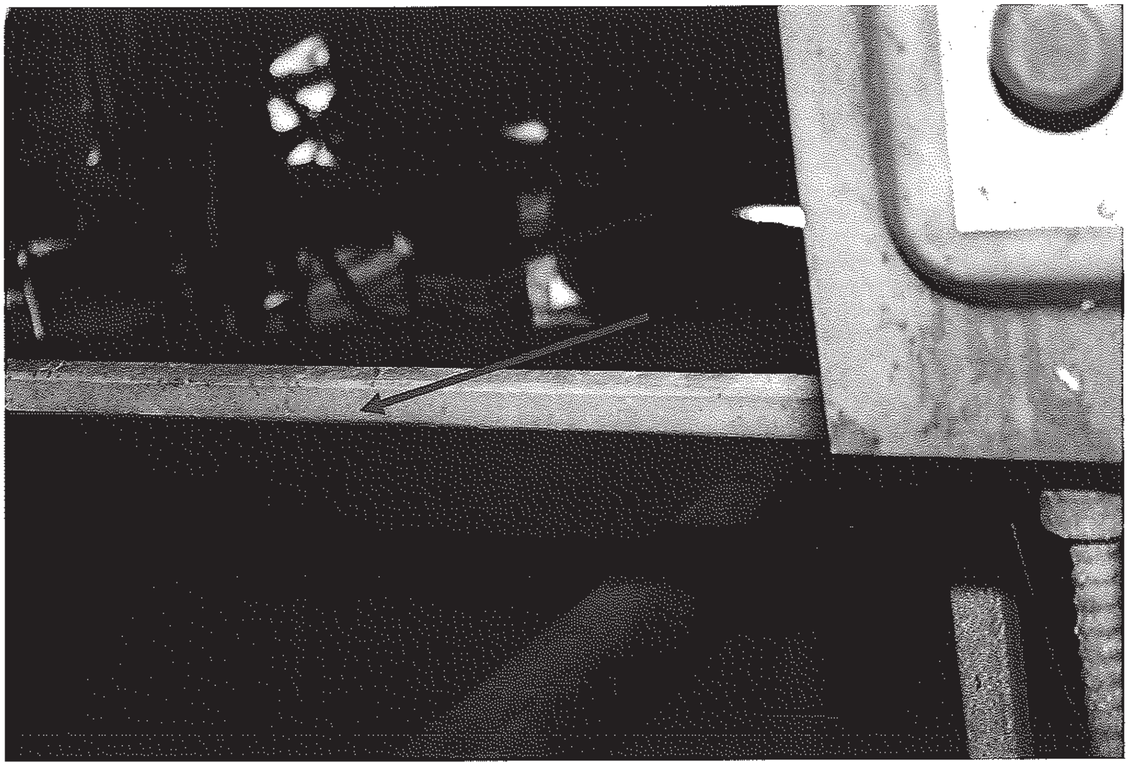
Note: the unit was blown in a northerly direction and turned over on its side exposing the bottom (green arrow).



Photograph V12

Looking at a heater in the east end of the basement.

Note: the bottom of the heater was pushed to the east.



Photograph V13

Looking at the east side of the guardrail used to prevent personnel from falling from the crawl space, in the east side of the mill into the basement.

Note: this side of the rail is relatively clean compared to the opposite side (Photograph V14).

Photograph V14

Looking at the west side of the railing shown in photograph V13.

Note: the condition of this side of the rail in comparison to the other side.

Photograph V15

Looking at the MCC panel for the eliminator.

Note: this panel was in the east side of the building and the top of the panel was pushed toward the west (arrow).

Note also: this photograph was taken through the opening through which a blast from the basement would have travelled striking the MCC panel .

Photograph V16

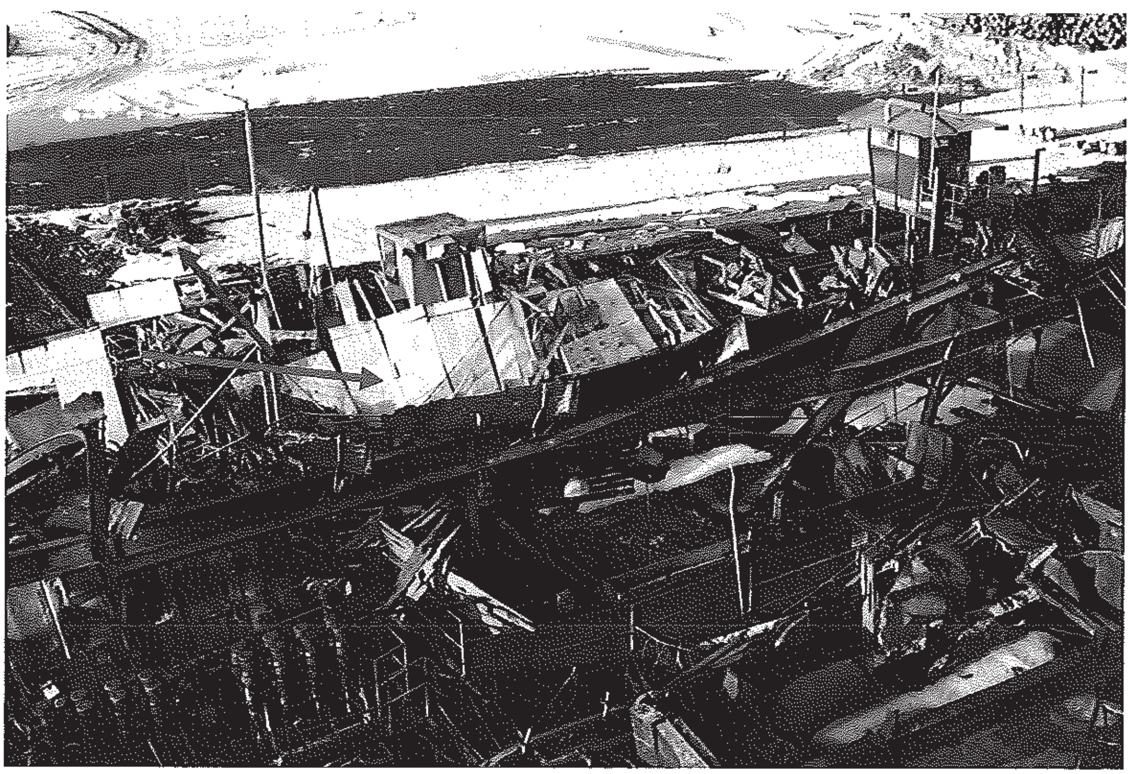
Looking at a machine guard on a conveyor in the southeast wing of the mill.

Note: the direction of the blast was from north to south (arrow).

Photograph V17

Looking at the west end of the mill.

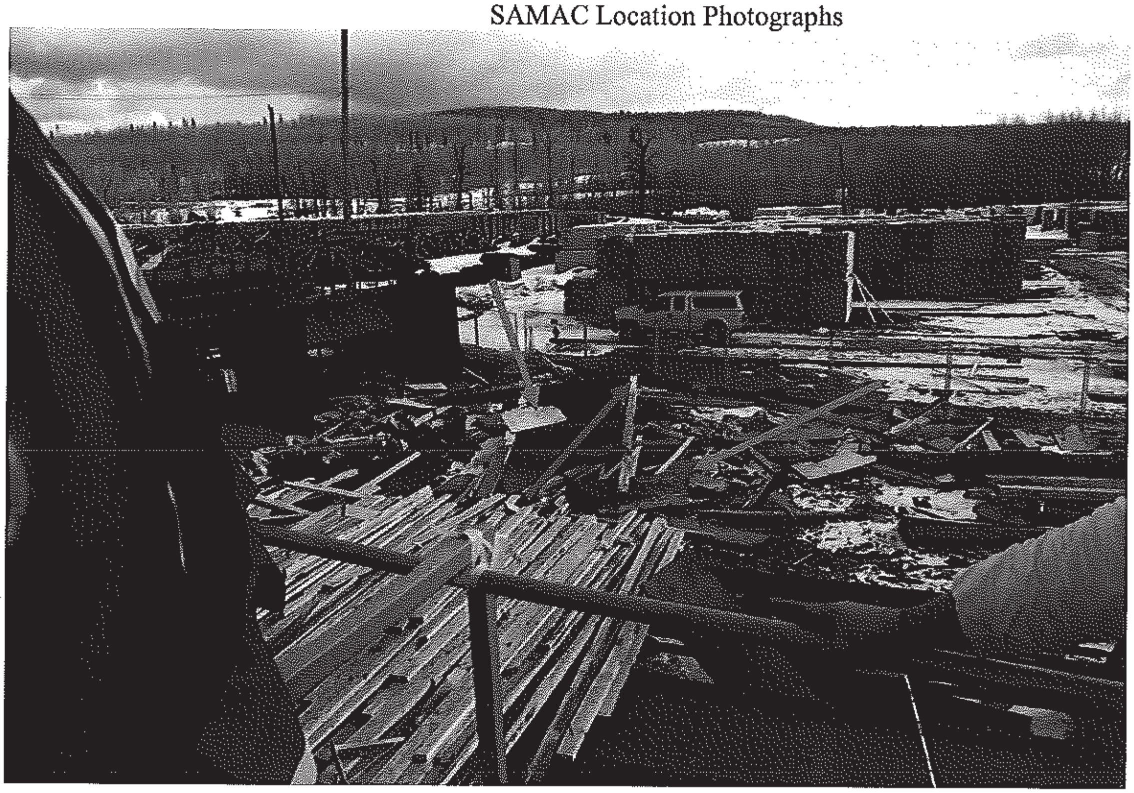
Note: the debris on the ground is the west exterior wall which was blown out to the west.



Photograph V18

Looking north from above the mill.

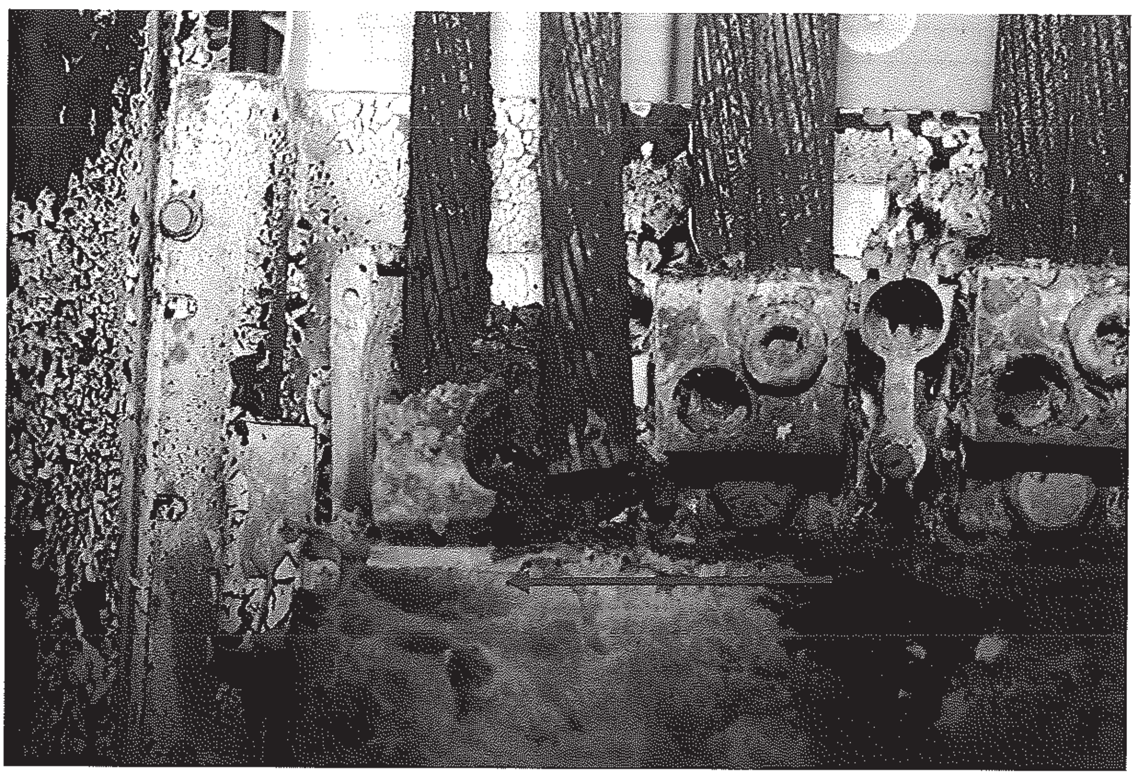
Note: the north walls (green arrow) were blown out to the north.



Photograph V19

Looking east from the east end of the mill.

Note: the east walls (green arrows) were blown out to the east.



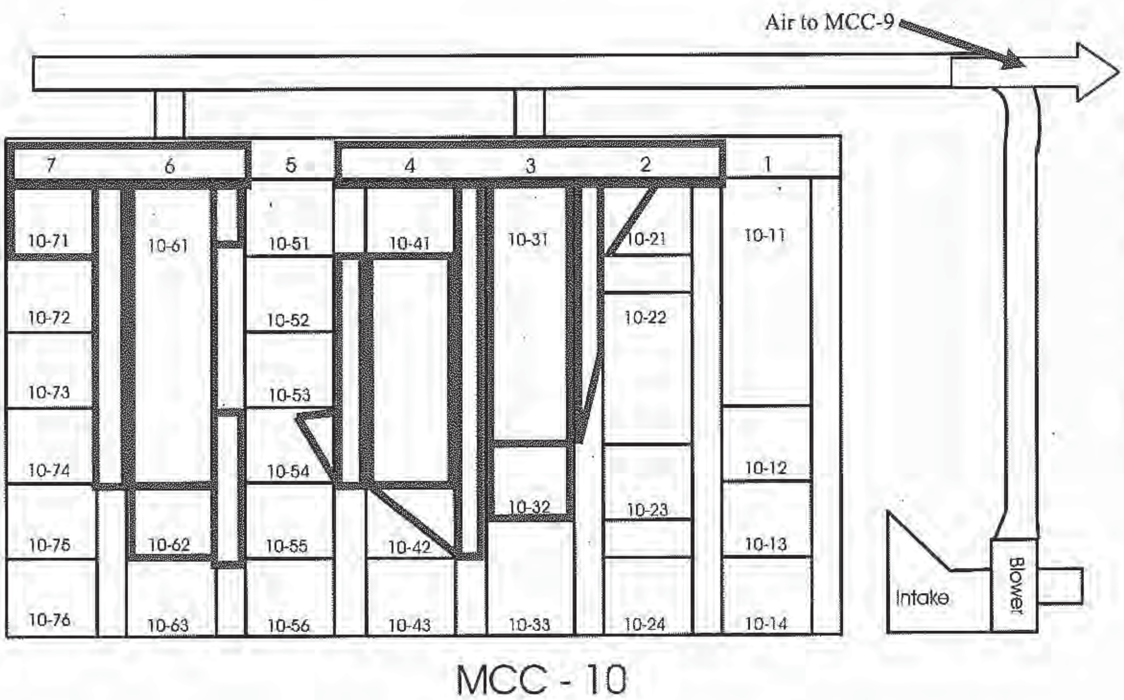
Photograph V20

Looking at the damaged lug in cabinet 10-31.

Photograph M1

Looking at the front of MCC-10.

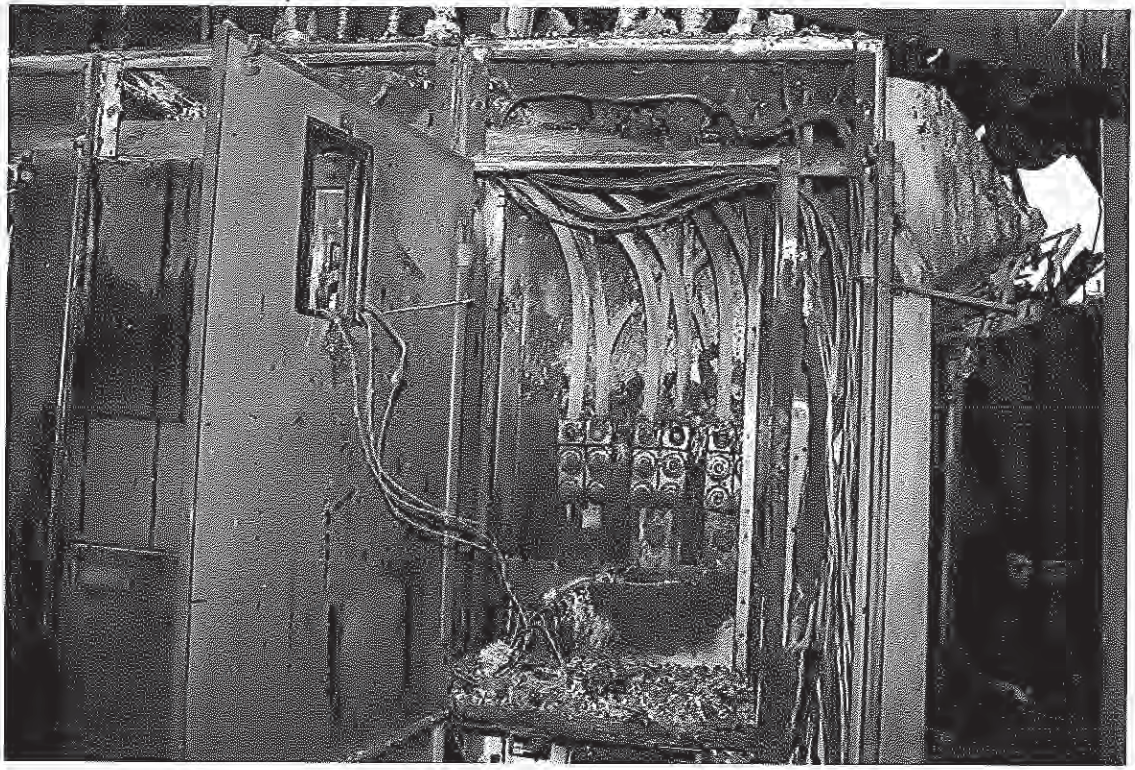
Note: the burn pattern on the front of the MCC.



Photograph M2

Looking at a line drawing of MCC-10.

Note: the red outlines are intended to duplicate the burn pattern on the MCC as shown in Photograph M1.



Photograph M3

Looking at cabinet 10-11.

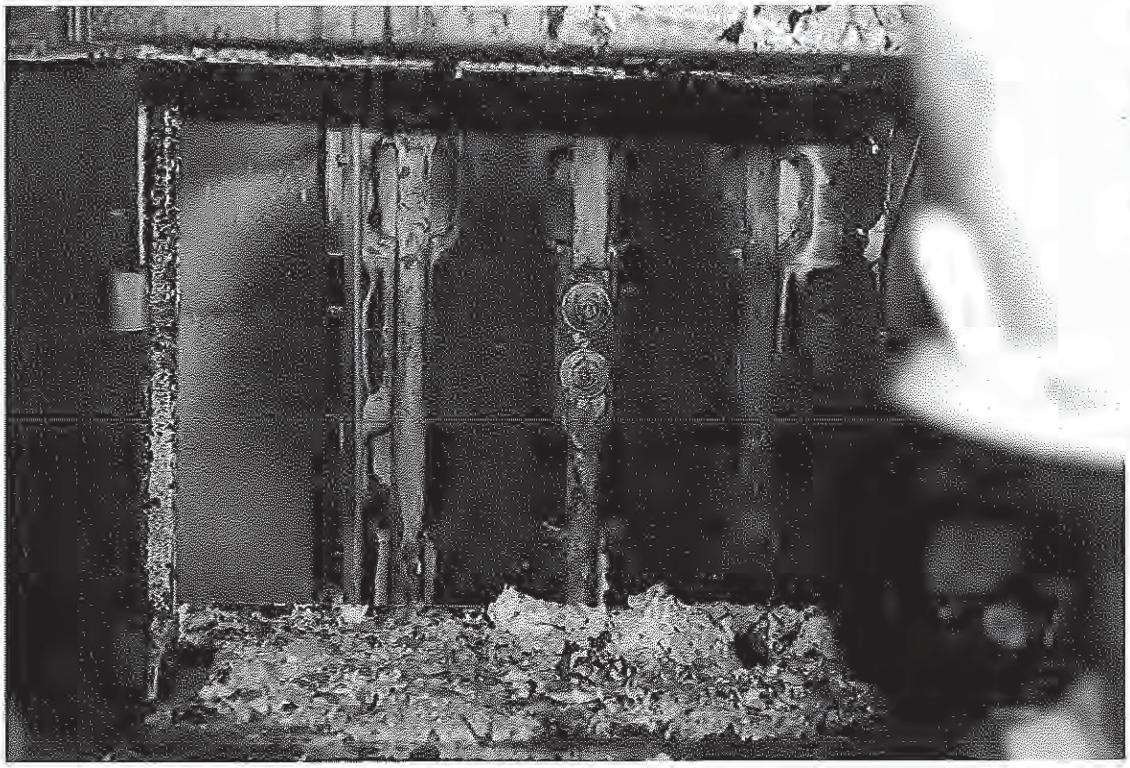
Note: the interior of this cabinet was extensively burned.

Photograph M4

Looking at cabinets 10-11 (top) to 10-14 (Bottom).

Note: the condition of cabinets 10-12 to 10-14 as compared to 10-11.

Note also: wood dust can be seen in the bottom two cabinets (arrows).



Photograph M5

Looking at the interior of cabinet 10-32.

Note: the extensive burn damage.

Photograph M6

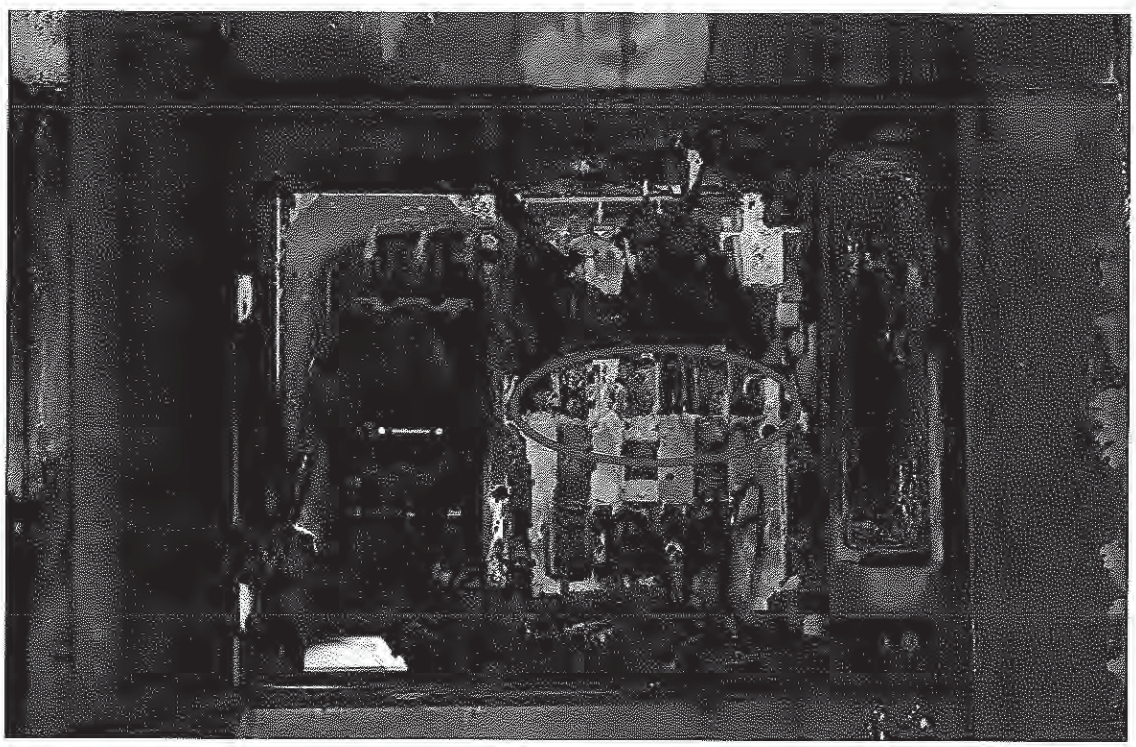
Looking at cabinet 10-41

Note: when the door of this cabinet was opened the contents fell out.

Photograph M7

Looking at cabinet 10-42.

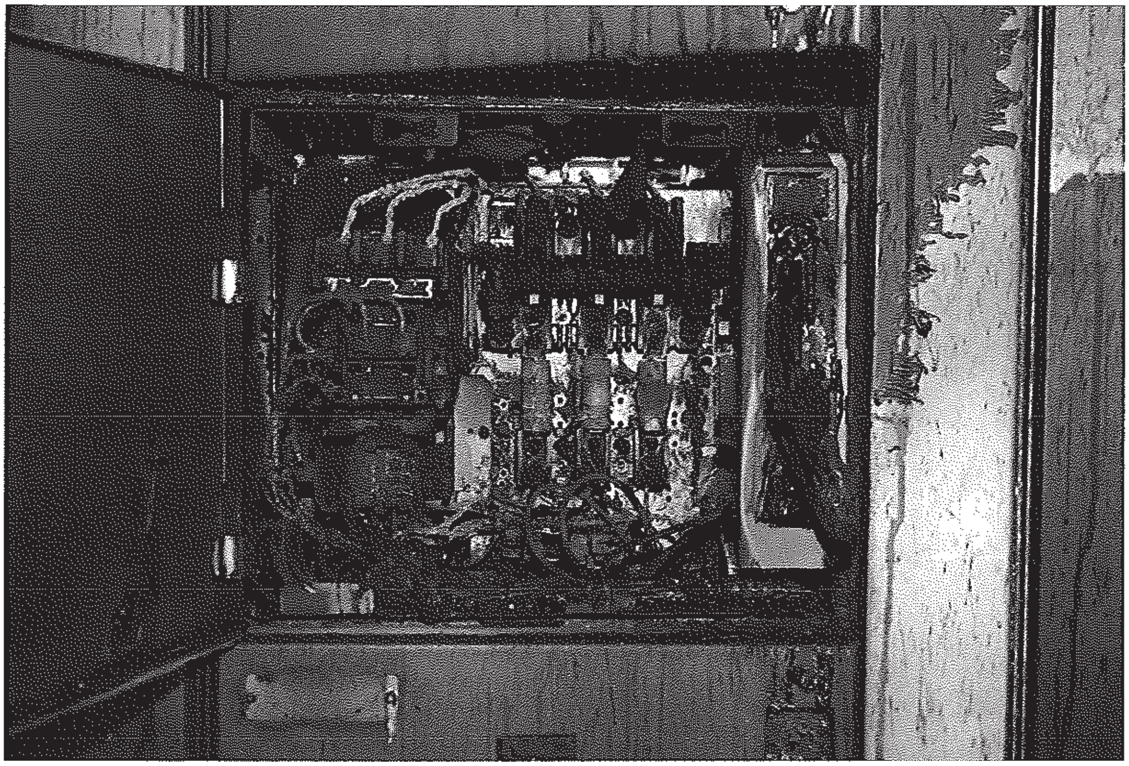
Note: the interior of the cabinet was completely burned and the tops of the fuse holders were pushed out toward the front of the panel (circle).



Photograph M8

Looking at cabinet 10-51.

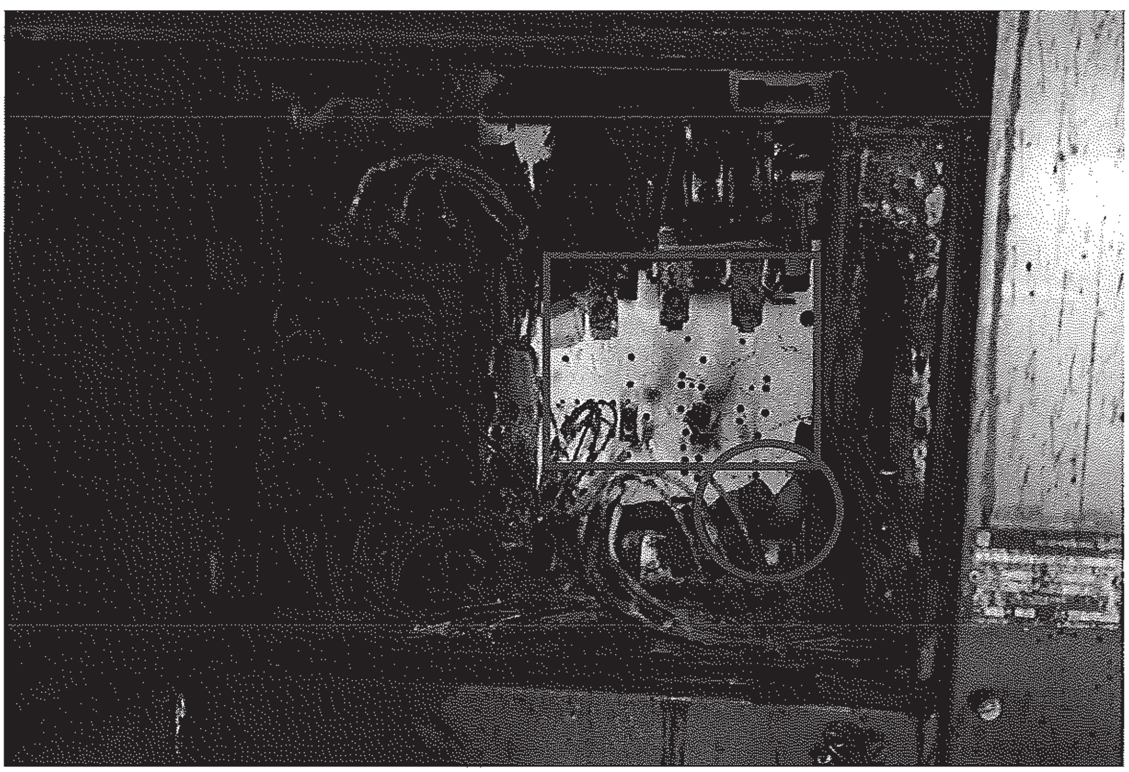
Note: the interior of the cabinet was completely burned however all components were present; also the fuse holders (circle) were separated from the base.



Photograph M9

Looking at cabinet 10-52.

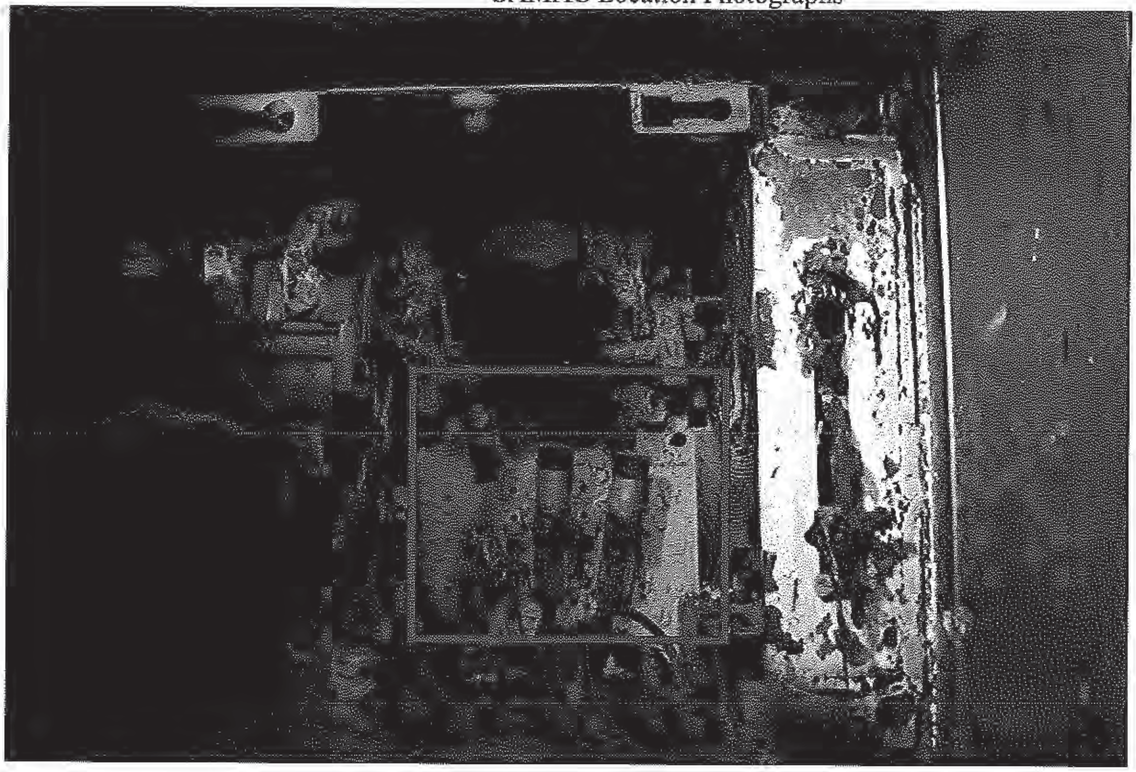
Note: the condition of this panel was slightly less damaged than cabinet 10-51.



Photograph M10

Looking at cabinet 10-53.

Note: in this cabinet the fuse mountings were destroyed (rectangle), two fuses were present (circle) and one fuse was missing.



Photograph M11

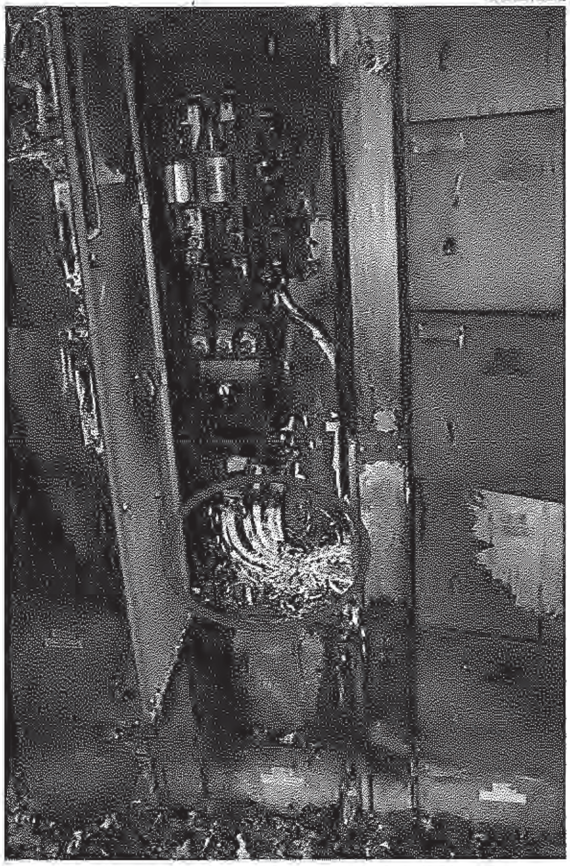
Looking at cabinet 10-54.

Note: the interior of the cabinet is heavily damage and the fuse holders are disrupted (rectangle).

Photograph M12

Looking at cabinet 10-55.

Note: as with the previously shown cabinets the interior of this one was heavily damaged.



Photograph M13

Looking at cabinet 10-61.

Note: damage to this cabinet was primarily at the bottom (circle).

Photograph M14

Looking at cabinet 10-62.

Note: damage to this cabinet coincides with the damage to the bottom of cabinet 10-61.

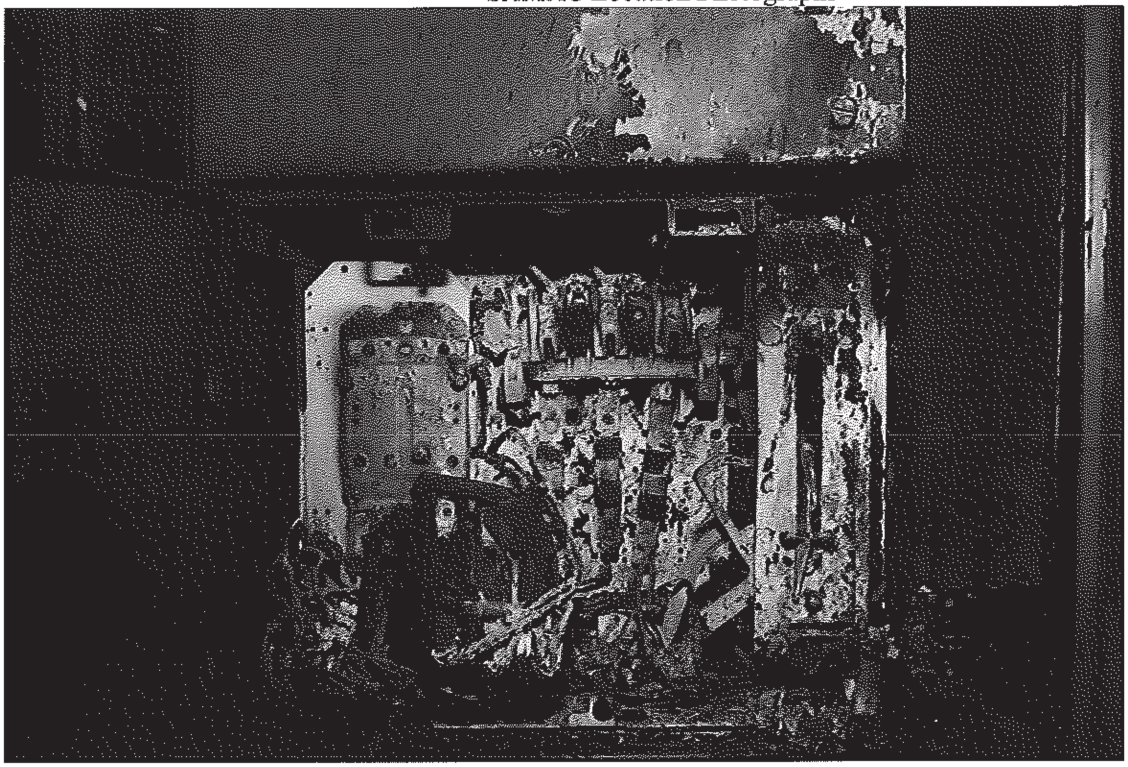
Photograph M15

Looking at cabinet 10-71.

Photograph M16

Looking at cabinet 10-72.

Note: the extensive damage and destruction of the fuse mounts (circle).

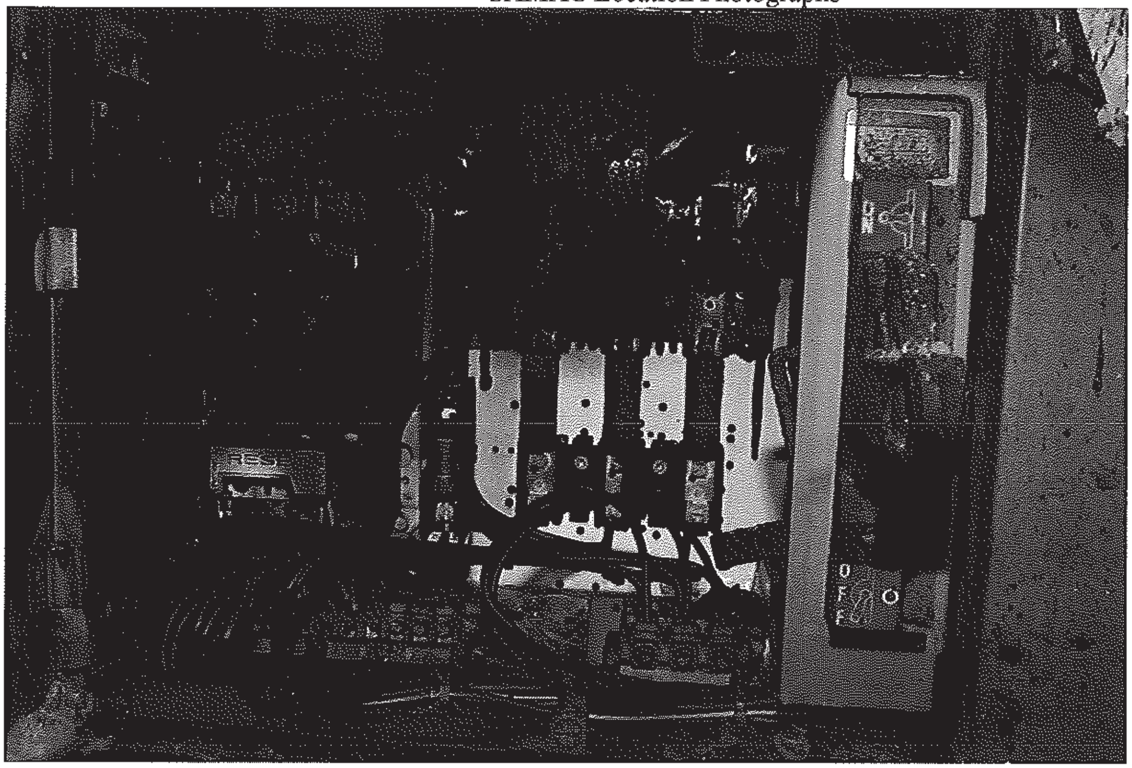


Photograph M17

Looking at cabinet 10-73.

Photograph M18

Looking at cabinet 10-74.



Photograph M19

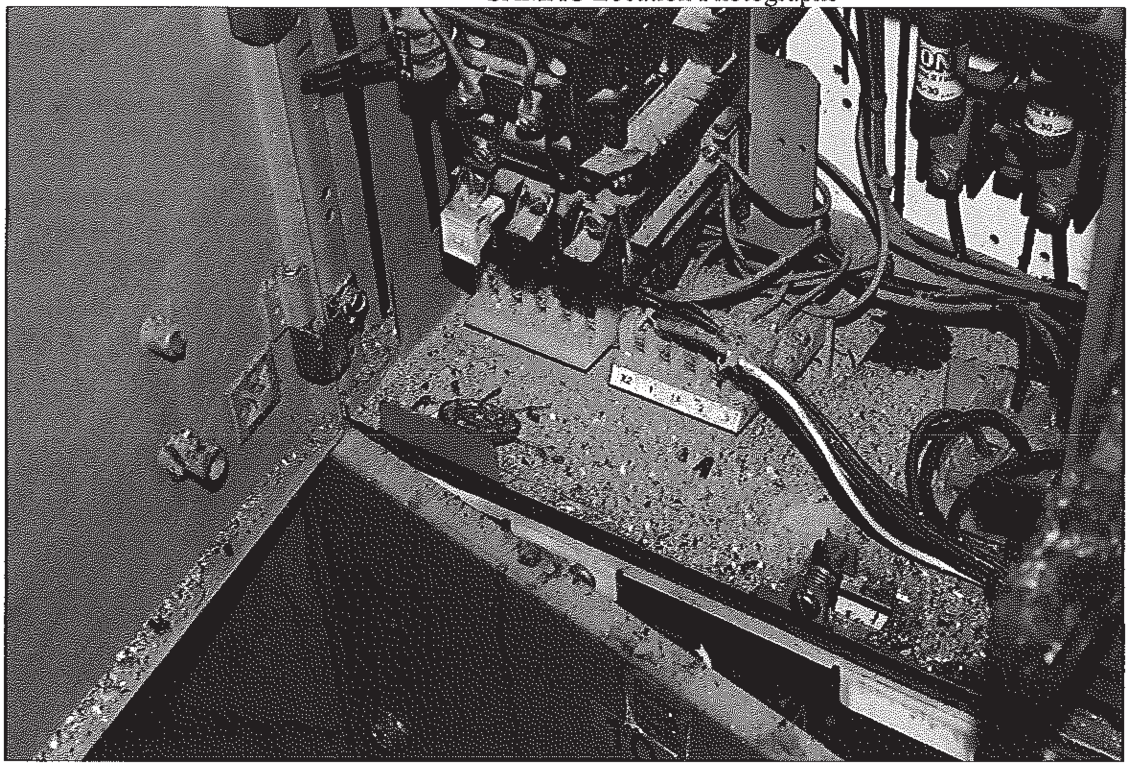
Looking at cabinet 10-75.

Note: the damage to this cabinet was primarily at the top.

Photograph M20

Looking at the door latch bars on cabinets 10-12 and10-13.

Note: the V shape of the latch bars (arrows).



Photograph M21

Looking at the bottom interior of cabinet 10-13.

Note: the layer of wood dust.

Appendix B

Natural Gas and Propane Equipment Findings

Gas Equipment Subject to the *Gas Safety Regulation*

Gas equipment discovered within the sawmill structure is listed in Table B1. Installed locations are identified in Figure B1. Gas equipment installation and use was evaluated as either a source of fuel or an ignition source within the areas of origin.

Equipment	Fuel	Model
Boiler #1	Natural Gas	Rudd CB200CC 2000 Mbtuh
Boiler #2	Natural Gas	Superhot AAE-2040-N-E-M 2000 Mbtuh
Boiler #3	Natural Gas	Superhot AAE-2040-N-E-M 2000 MBH
Direct Fired Make Up Air Heating Unit	Natural Gas	Roberts Gordon RDF50BIEN 500 MBH
Direct Fired Make Up Air Heating Unit	Natural Gas	Roberts Gordon RDF100CIEN 1000 MBH
Babbit Pot	Natural Gas	Unknown Approx 30-50,000 btuh
Roof-Top Office Heating Unit	Natural Gas	Undetermined
Regulator A	Natural Gas	Fisher 620 Inlet pressure 60 psi Outlet pressure 20-35 psi Body size 1"
Regulator B	Natural Gas	Unable to identify "CRANE 300 RAILROAD" was marked on the body mounting ring. Regulator destroyed. Inlet press 20-35 psi Outlet press 7"-5 psi
Regulator C	Natural Gas	Large diaphragm style, Unable to identify. Regulator, inlet pressure 60 psi, outlet pressure 7"wc Load 6000 Mbtuh
Various Gas Piping	Natural Gas	Underground – schedule 40 yellow jacket black iron - welded Aboveground – schedule 40 black iron - threaded
Catalytic Heater and portable 20lb fuel cylinder	Propane	Make and model not determined
Torch and portable 20lb fuel cylinder	Propane	Make and model not determined

Table B1: Gas equipment found within the sawmill structure

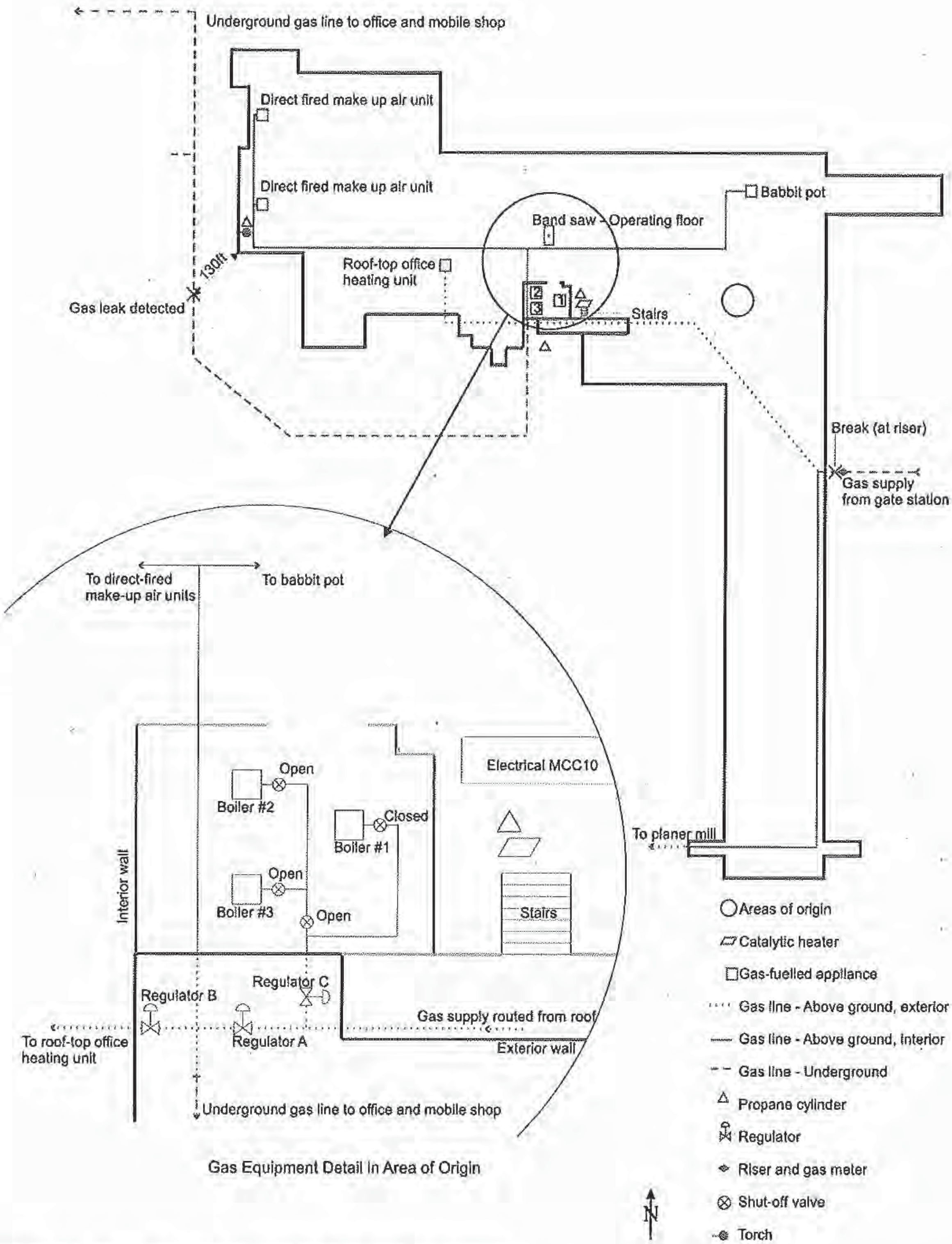


Figure B1: Plan view of mill - gas system and equipment

Note: Figure B1 was produced from field observations and drawings provided by Babine Forest Products. Figures are intended for illustrative purposes only.

Gas Equipment Field Investigation Findings

Natural Gas Supply

Natural gas piping and distribution components were examined to determine if a natural gas leak could have existed prior to the explosion and fire.

Natural gas leak outside of sawmill structure

Underground gas piping outside of the sawmill was pressurized and tested for leaks. One leak was detected west of the sawmill, approximately 40m (130ft) from the structure (and 150m (500ft) from the nearest potential area of origin) as indicated in Figure B1. The underground leak was found to be venting to the surface, next to a hydrant shed. The leakage rate was estimated in the field to have been approximately three cubic feet per hour. The investigation revealed no migration paths into the sawmill structure other than through atmosphere.

The distances of 40m between the leakage location and the nearest sawmill structure and approximately 150m to the nearest area of origin are significant when considering the migration of a low flow of natural gas through an unrestricted atmospheric environment.

Conclusion

This natural gas leak did not supply a combustible fuel mixture to the area of origin in the sawmill basement.

Potential leakage at boiler #1 shut-off valve

The shut-off valve supplying boiler #1 was found in the closed position. Leak tests conducted in the field suggested that gas may have leaked past the shut-off valve or at the valve seams prior to the incident. All other above ground gas piping and piping within the sawmill was pressure tested and no other leaks were found.

An analysis was commissioned by WorksafeBC to evaluate the natural gas supply shut-off valve to boiler #1. The evaluation was observed by BC Safety Authority investigators to not produce any readily identifiable leaks at the valve flange seals or the valve body seams. The evaluation did not produce a readily identifiable bypass condition within the valve.

Conclusion

The evaluation suggests that the shut-off valve for natural gas supply to boiler #1 was performing its function in the OFF position, preventing the flow of natural gas to boiler #1, which was undergoing maintenance.

Connection of boiler #1 to the natural gas supply union

The gas pipe supplying boiler #1 was found disconnected from the boiler manifold. The threads securing the union to the pipe were found damaged. It was reported that maintenance was being conducted on boiler #1. During an interview with the individual conducting this maintenance work, the person stated that the union connecting boiler #1 to the natural gas supply was left in a secured position.

An evaluation was commissioned by WorksafeBC to evaluate the thread damage to the union connecting boiler #1 to the natural gas supply. Thread damage was only found on the union and not on the mating thread of the nut. It was communicated to BC Safety Authority investigators that there was no relative hardness difference that would have explained damage to the union threads and not the nut threads. The damage to the threads was not consistent with what would be expected had the union been properly secured for usage and subsequently torn apart.

Conclusions

It is unlikely that the union connecting boiler #1 to the natural gas supply was properly secured at the time of the incident. However, given that:

- the pressure of the natural gas supply at the shut-off valve was low (approximately 7 inches of water column),
- the shut-off valve was in the off position and likely functioning as expected at the time of the incident, and
- an employee reported no detection of gas odor within the area of origin and the boiler room on the afternoon of the incident;

it is unlikely that natural gas was supplied to the area of origin from the connection of boiler #1 to the gas supply piping.

Regulator assemblies

Gas regulator assemblies installed on the outside wall of the sawmill, near the area of origin as shown in Figure B1, were found destroyed or severely damaged.

Although near the area of origin in the basement under the band saw, the regulators were installed outside of the sawmill structure. There was no evidence suggesting a possible leak from a regulator assembly prior to the incident. Any leakage from a regulator assembly prior to the incident would likely have been vented to outside atmosphere as there were no likely migration paths into the sawmill from this location. The location of the regulators against the outside wall of the area under the band saw exposed them to the effects of the explosion. The explosion probably caused the regulator assembly damage.

Conclusion

It is unlikely that natural gas was supplied to either identified basement area from the regulator assemblies.

Break in natural gas line at riser

The natural gas supply line was found broken at the riser location, outside of the sawmill along the east wall approximately four feet above ground as shown in Figure B1.

The sawmill gas supply riser travelled directly from the riser to the roof outside of the east wall of the sawmill. A leak at this location would be vented directly to atmosphere. During interviews, witnesses stated that the sawmill roof was lifted several feet in the air by the explosion which could have applied a vertical force to the natural gas supply pipe at the riser location.

Conclusions

It is unlikely that a natural gas leak at this location could have supplied a combustible fuel mixture to the areas of origin in the sawmill basement.

It is likely that the explosion caused the break in the natural gas supply pipe at this location.

Increased gas consumption at the time of the incident

Natural gas consumption by Babine Forest Products was recorded by the utility provider on an hourly basis. Reports indicate that hourly consumption increased by a factor of five between 8pm and 9pm on the date of the incident. The utility provider reported that the natural gas supply to the sawmill was turned off at 8:47pm on the date of the incident.

Approximately 40 minutes elapsed between the initial explosion and when the natural gas supply was removed from the sawmill. No evidence was found that suggests a significant breach of the natural gas supply system prior to the incident.

Conclusion

Damage to the natural gas supply system caused by the explosion and fire probably breached the system sufficiently to account for the five-fold increase in natural gas consumption between 8pm and 9pm on the date of the incident.

Gas Odor Reports

During interviews, twelve employees reported smelling a gas like odor at the sawmill before or on the date of the incident. A total of 46 employees stated they did not notice any gas odors prior to or on the day of the incident. Figure B2 represents the general areas associated with these odor reports.

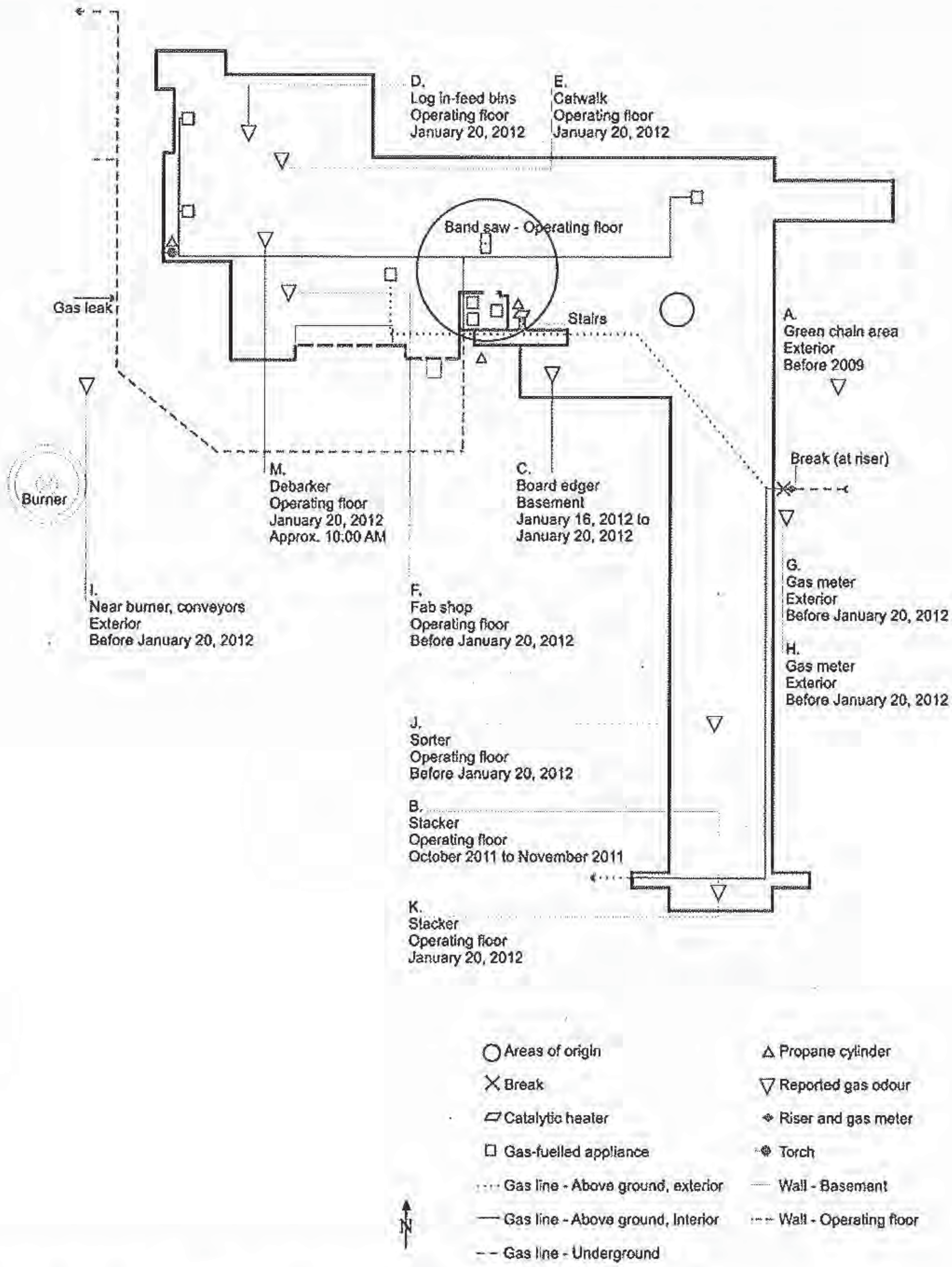


Figure B2: Plan view of mill - gas odor reports from interview statements

Note: Figure B2 was produced from employee interview statements and drawings provided by Babine Forest Products. Figures are intended for illustrative purposes only.

Odorants are added to natural gas and propane to provide a means to warn of the presence of gas. Odorant concentrations are intended to be readily detectable when the concentration of gas is at or above 20% of the explosive concentration limit[10]. Reports of odorant concentrations leading up to the date of the incident show that the odorant was consistently detectable.

Descriptions of gas odors from interviews were generally not indicative of a strong or steady gas presence in one location or near the area of origin. Gas odor near the board edger in the basement was reported to have been investigated by the employee of Babine Forest Products responsible for the natural gas supply system. This employee stated that the natural gas supply lines in the boiler room were checked during the afternoon of January 20, 2012 and no gas odors were detected at that time.

Conclusion
Gas odor reports at the sawmill are not consistent with an explosive level of natural gas (or propane) in the area of origin.

Gas Equipment Found within the Areas of Origin

The following gas equipment was found within the basement area under the band saw as illustrated in Figure B1:

- Boilers #1, #2 and #3
- Catalytic heater and associated 20lb portable propane cylinder

No gas equipment was found in the area near conveyor motor labeled 8R-26.

Boilers #1, #2 and #3
Boilers #1, #2 and #3 were not burning natural gas at the time of the incident. The natural gas supply to Boiler #1 was found to be shut-off and the unit was reported to be undergoing maintenance. Control switches for Boilers #1, #2 and #3 were reported to have been locked out at the electrical control panel and the natural gas supply valve positions found are represented in Figure B1. Some aluminum pilot lines within boilers #2 and #3 were found to be damaged or missing.

Natural gas supply piping and valves to boilers #1, #2 and #3 are discussed above as part of the natural gas supply. Controls for boilers #1, #2 and #3 were reported to be locked out at the electrical control panel.

Internal valve and control diagrams were reviewed for boilers #2 and #3 and there is no reported reason to suspect that these boilers would leak natural gas when in a locked out condition, provided that pilot lines upstream of internal controls were installed when gas was supplied to the boiler.

Boilers #2 and #3 were reported to have been test fired during December 2011 and operating properly. Proper operation would have required the aluminum pilot lines to have been installed at that time. It is likely that the missing pilot lines were a result of the explosion and fire.

Conclusion
It is unlikely that natural gas was supplied to either identified basement area from boiler #1, #2 or #3. It is unlikely that boiler #1, #2 or #3 could have provided an ignition source for a combustible atmosphere within the basement area under the band saw.

[10] See reference 3 at the end of this report for standards defining natural gas and propane odorant limits.

Propane fueled catalytic heater

The propane fueled catalytic heater was reported in an interview to have been in use on the morning of January 20. The appliance was located in the basement and was reported to be used to heat a glycol transfer pump and piping. The heater was reported to have been turned off prior to the incident.

An analysis was commissioned by WorksafeBC to evaluate the propane cylinder supplying fuel to the catalytic heater. The cylinder valve was observed to be in the closed position and it was communicated to BC Safety Authority investigators that approximately 1lb of propane was remaining in the cylinder.

Heat damage was observed on the cylinder in the area near the pressure relief valve.

There was no identifiable make or model number on the catalytic heater. The manufacturer and specifications for this heater were not determined.

Discussion

The findings related to the cylinder are consistent with the employee report that the heater was turned off and not in use at the time of the incident. It is possible that propane within the cylinder expanded as a result of the heat from a surrounding fire sufficiently to open the relief valve and vent propane to the surrounding area.

Paragraph 4.7.2 of *B149.2-10 Propane Storage and Handling Code* relates to the use of appliances in hazardous locations and states:

> *An appliance, unless certified for installation in a hazardous location, shall not be installed in any location where a flammable vapour, combustible dust or fibres, or an explosive mixture is present.*

During an interview, an employee stated that the catalytic heater replaced previously used heaters due to safety concerns related to the combustibility of the wood dust.

Catalytic heaters are often marketed as safe relative to other heaters because the use of a catalyst reduces the temperature of surfaces exposed to the atmosphere. Some are certified as explosion proof and certified for use in *hazardous locations.*

> Explosion proof typically means that the heater enclosure will withstand the effects of an internal explosion and prevent the release of gases at temperatures greater than that for which the unit is certified. Explosion proof does not mean that the heater will not cause an explosion if used in an environment for which it has not been specifically certified for safe use.
>
> Certified for use in hazardous areas means that the appliance has been certified to a specific category and type of environment. A temperature code is identified and relates to the maximum temperature of exposed surfaces. Certified for use in hazardous areas does not mean that the appliance is certified for use in all hazardous areas.

Proper installation and use of a catalytic heater in an area containing flammable vapours, combustible dust or combustible fibres requires the user/installer to identify the hazards and use an appliance rated specifically for that hazard.

Catalytic heaters certified for use in *hazardous locations* displaying temperature code "T1" can have surface temperatures up to 450°C.

WorksafeBC commissioned dust cloud and dust layer ignition temperature testing of wood dust samples from the sawmill and identified a possible dust cloud ignition temperature of 430°C and a wood dust layer ignition temperature of 310°C.

Conclusions

Although it was not determined if the catalytic heater in use was properly certified for the dust hazard present in the area of origin, it is possible that the surface temperatures were higher than what would be needed to ignite either a wood dust cloud or layer.

As indicated in the SAMAC Engineering Ltd. report (Appendix A), blast vectors and explosion damage suggest an explosive force originated in front of MCC #10. The catalytic heater was found behind MCC #10.

It is unlikely that the catalytic heater and associated propane cylinder supplied a fuel source to the area of origin prior to the existence of a fire.

It is unlikely that the catalytic heater provided an ignition source to the area of origin at the time of the incident.

The propane cylinder likely supplied fuel to the area during the fire.

Appendix C

Boiler and Pressure Vessel Equipment Findings

Pressure Equipment Subject to the *Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation*

Boiler and pressure vessel equipment discovered at the sawmill site is listed in Table C1. Installed locations are identified in Figure C1.

Pressure Equipment	Pressurized Contents	Unit Information
Boiler #1	Ethylene glycol	Rudd CB200CC Heating surface area: 16m^2
Boiler #2	Ethylene glycol	Superhot AAE-2040-N-E-M Heating Surface Area: 15m^2
Boiler #3	Ethylene glycol	Superhot AAE-2040-N-E-M Heating surface area: 15m^2
Sawmill Heating Pipes and Valves	Ethylene glycol	NPS 6 Piping
Thermal Fluid Heat Exchanger	Heat transfer fluid (shell side) Ethylene Glycol (tube side)	American Standard SN 84H43070-02 MAWP 150psig CRN# F3854.1
Thermal Fluid Distribution Piping and Valves	Thermal fluid	NPS 4 Piping
Sawmill Air Receiver	Air	Unit was not observed during field investigation
System Air Receiver	Air	Steel Fabricating & Welding Co Limited CRN # E529.1234567890T MAWP 137psi at 550°F SN 5657652
#2 Air Compressor	Air	Silvan Industries Inc CRN # L8095.567890134 MAWP 160psi at 250°F , MDMT 20°F at 160psi SN 679773, CUST PN 02250120-612 Pressure Relief Setting – 160psig
Sullair Air Compressor	Air	Silvan Industries Inc CRN # M5333.5678901234 MAWP 175psi at 250°F , MDMT 20°F at 175psi SN 674918, CUST PN 02250100-802 Pressure Relief Setting – 175psig
#1 Air Compressor	Air	Silvan Industries Inc CRN # C7021.610327 MAWP 150psi at 250°F , MDMT 20°F at 150psi SN 674918, CUST PN 02250100-802 Pressure Relief Setting – 150psig
Air Dryer and Filter	Air	Not Known
Air Dryer and Filter	Air	Not Known
Air System Piping	Air	N/A

Table C1: Boiler and Pressure Vessel Equipment Identified at Babine Forest Products

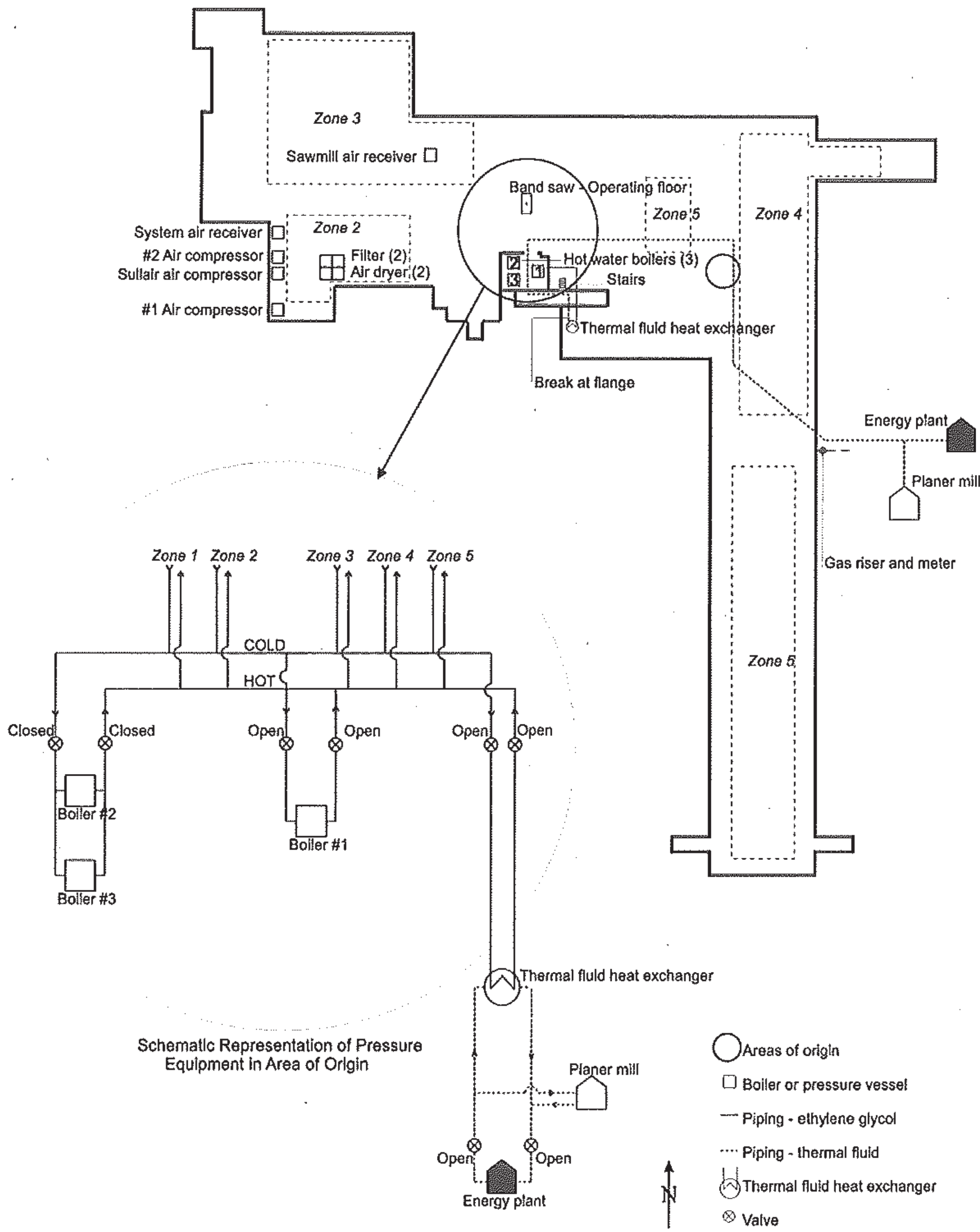


Figure C1: Plan view of mill - boiler and pressure vessel equipment

Note: Figure C1 was produced from field observations and drawings provided by Babine Forest Products. Figures are intended for illustrative purposes only.

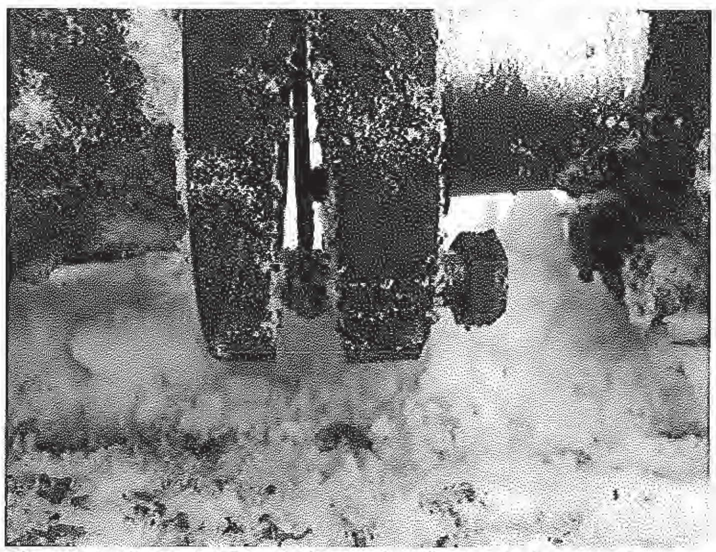
Pressure Equipment Field Investigation Findings

Ethylene Glycol System and Piping

Ethylene glycol was circulated within the sawmill and heated from three hot water boilers and/or a heat exchanger as shown in Figure C1. Valve positions found are indicated in Figure C1. Ethylene glycol fluid can present explosion and fire hazards under certain conditions. No evidence of ethylene glycol piping or piping component failures was found. It is unlikely that this equipment contributed to the incident.

Thermal Fluid Piping and Heat Exchanger

Thermal fluid was supplied from an energy plant outside of the sawmill structure to a heat exchanger located within the sawmill structure. The heat exchanger was found to have fallen off its support structure. A flange bolt that was part of the thermal fluid valve train assembly was found to be fractured as shown in Photograph C1. Thermal fluid residue was found in the area of the heat exchanger. There were no other findings that would indicate a failure of thermal fluid piping or thermal fluid leakage.



Photograph C1: Broken bolt at valve flange to heat exchanger

The location of the heat exchanger against the wall near the area of origin likely exposed it to the effects of the explosion. The explosion probably caused the heat exchanger to have fallen off its support structure and fractured the valve flange bolt, resulting in a leakage of thermal fluid estimated by Wellons Canada to be approximately 3400 US gallons. The mill thermal fluid isolation valves are shown in Figure 1 in the open position. These valves were open at the time of the incident and subsequently closed during fire fighting activities.

Conclusions

It is unlikely that thermal fluid was leaked at the heat exchanger prior to the explosion.

It is likely that following the explosion, the damage to the valve flange bolted connection produced a supply of thermal fluid to the then existing fire.

Boiler and Pressure Vessel Equipment Found within the Areas of Origin

Boilers #1, #2 and #3 and their associated piping and valves were found within the area of origin under the band saw as illustrated in Figure C1. Valve positions shown are as found during the investigation with the exception of the mill thermal fluid isolation valves from the energy plant: these valves were open at the time of the incident and subsequently closed during fire fighting activities. No boiler or pressure vessel equipment was found in the area near the conveyor motor labeled 8R-26.

Compliance with the Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation

This investigation found that pressure vessel supervision was conducted by unqualified individuals which may have contributed to the addition of thermal fluid to the fire, following the initial explosion.

Administrative Requirement

Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation
Definitions and Interpretations for this regulation
2 "fourth class plant" *means*

(c) a low pressure thermal fluid plant that exceeds 500 m^2 of boiler capacity but does not exceed 1 500 m^2 of boiler capacity,

"chief engineer" *means a power engineer who is designated by the owner to be responsible for the operation and maintenance of a plant and who is responsible for ensuring that all regulated work in the plant is performed by appropriately qualified persons;*
"shift engineer" *means a power engineer who is a person in charge of a plant under the supervision of a chief engineer or one who is in charge of a plant when the chief engineer is absent;*

Plant classifications
44 *(1) A plant classification referred to in this regulation requires a power engineer with a corresponding or higher class of certificate of qualification to be appointed as chief engineer of that plant.*

Continuous supervision status plant operation
45 *...the person in charge of the plant must be present at all times in the plant boiler room, refrigeration machinery room, engine turbine room or in the immediate vicinity within the plant premises while the plant is in operation.*

What a fifth class power engineer may do
24 *A fifth class power engineer's certificate of qualification entitles the holder to be*

(a) a shift engineer of a fourth class plant.

Condition Found

The total heating surface of the energy plant that supplied heated thermal fluid to the sawmill was 800 square meters. The energy plant was a fourth class plant requiring a chief engineer who holds a minimum Certificate of Qualification as a fourth class power engineer and shift engineers who hold a minimum Certificate of Qualification as a fifth class power engineer.

During interviews with employees of Babine Forest Products, it was determined that two dayshift kiln operators were in charge of the plant during their working shifts and that a nightshift attendant monitored the plant operation in their absence. Neither of the day shift kiln operators or the nightshift attendant held a Certificate of Qualification as a power engineer of any class.

Conclusion

The supervision of the energy plant was not in compliance with the *Power Engineers, Boiler, Pressure Vessel and Refrigeration Safety Regulation.* As discussed earlier in the report, an estimated 3400USG of thermal fluid was lost during the incident and qualified energy plant supervision with suitable emergency procedures and training may have isolated the sawmill from the system supply of thermal fluid prior to this loss. This non-compliance may have influenced the amount of thermal fluid that was lost by the system and was likely added to the fire.

Appendix D

Electrical Non-Compliances – Increased Risk of Electrical Ignition Sources

Compliance with the *Electrical Safety Regulation*

The *Electrical Safety Regulation* adopts the Canadian Electrical Code (with BC amendments) as the technical standard for most electrical equipment in the Province. For the purposes of compliance, electrical installations are compared to the edition of the *Canadian Electrical Code* that was in force at the time of the installation. It was reported that the sawmill completed a major electrical service upgrade and it was estimated that this work was completed around 2005. In 2005, the *Canadian Electrical Code, Part I, Nineteenth Edition, Safety Standard for Electrical Installations, Canadian Standards Association C22.1-02* was utilized as the BC Electrical Code. BC Amendments to the 2002 edition of the Code did not affect the non-compliances discussed below.

This investigation identified the following non-compliances to the *Electrical Safety Regulation* that increased the risk of electrical equipment in the areas of origin providing a source of ignition for a hazardous wood dust environment.

Safe Use of Electrical Equipment in Hazardous Locations

Technical Code Requirements
2-300 General requirements for maintenance and operation
(1) All operating electrical equipment shall be kept in safe and proper working condition.

Section 18 – Hazardous Locations
18-04 Classification
Hazardous locations shall be classified according to the nature of the hazard, as follows:
- *(d) Class II locations are those which are hazardous because of the presence of combustible or electrically conductive combustible dusts;*
- *(e) Class III locations are those which are hazardous because of the presence of easily ignitable fibres or flyings, but in which such fibres or flyings are not likely to be in suspension in air in quantities sufficient to produce ignitable mixtures.*

Section 18 prescribes installation techniques to separate the combustion hazards from potential electrical ignition sources in Class II and III hazardous locations, including:
- Use of metal conduits and sealed enclosures for wiring (18-202, 204, 252, 254, 302 & 352)
- Sealing and use of dust tight enclosures for switches, motor controllers etc (18-206, 256, 304 & 354)
- Use of outside clean air for electrical component ventilation (18-212, 262, 310 & 360)
- Use of luminaires and other equipment that is certified for the hazardous environment (18-216, 220, 264 and others)

Discussion
Electrical installations are generally configured for non-hazardous locations. These configurations assume that wood dust is managed in such a manner as to maintain the non-hazardous environment. When wood dust management fails to maintain a non-hazardous environment and electrical equipment is permitted to continue operation, techniques prescribed by Section 18 are required to keep equipment operating in a safe working condition.

Condition Found

Explosion and Fire Hazard Findings:

- Wood dust was found within cabinets of MCC #9 and MCC #10.
- Wood dust was found within the ventilation ducting for MCC #9 and MCC #10.
- Wood dust was found layered on top of cables and electrical components within the basement area of origin under the band saw and other locations that were observed.

Electrical Equipment Findings:

- Wiring was not routed within metal conduits and sealed enclosures.
- Motor Control Centres were not sealed to prevent the ingress of combustible dust.
- Ventilation system for MCC #9 and MCC #10 was not in use. When in use this system would have drawn air from beside MCC #10 and not clean air from outside of the building.
- Luminaires were of the open design and did not contain hazardous location certification indications.
- No electrical equipment within the areas of origin was observed to have been certified for use in a hazardous location.

Conclusion

At the time of the incident, the areas of origin were *hazardous locations* as classified by section 18 of the *Canadian Electrical Code*. At the time of the incident, electrical equipment installed and in use within the areas of origin was not compliant to section 18 of the *Canadian Electrical Code* for *hazardous locations* and therefore not compliant to rule 2-300. This non-compliance leads to a condition where potential ignition sources exist within a combustible *hazardous location*. At the time of the incident, electrical equipment within the areas of origin was not compliant with the *Electrical Safety Regulation*.

De-rating of Current Capacities of Conductors in Cable Trays

Technical Code Requirement

12-2210 Ampacities of conductors in cable trays

(3) in ventilated and ladder-type cable trays, where the air space between adjacent conductors, cables, or both is less than 25% of the diameter of the larger conductor or cable, and for any spacing in a non-ventilated cable tray, the ampacity of the conductors or cables shall be the value as specified in Table 2 or 4 multiplied by the correction factor specified in Table 5C for the total number of conductors in the cable trays.

Condition Found

MCC#9: Feeder cables to MCC #9 were protected by an 800 Amp circuit breaker. Two 400MCM conductors per phase were found installed for the motor load of 443 hp.

MCC#10: Feeder cables to MCC #10 were protected by a 1200 Amp circuit breaker. Two 350MCM conductors per phase were found installed for the motor load of 418 hp.

Discussion

MCC#9: The maximum allowable current for 400MCM conductors in Table 2 of the Code is 345 Amps yielding a maximum allowable current carrying capacity of 483 Amps, de-rated per Table 5C of the Code for compact routing in the cable tray.

MCC#10: The maximum allowable current for 350MCM conductors in Table 2 of the Code is 325 Amps yielding a maximum allowable current carrying capacity of 455 Amps, de-rated per Table 5C of the Code for compact routing in the cable tray.

Conclusion

The conductor size of the feeders supplying MCC #9 and MCC #10 have allowable currents of 483 and 455 Amps, respectively. The load for MCC #9 is shown to be 443 hp at 480 volts or 633 amps. The load for MCC #10 is shown to be 418 hp at 480 volts or 598 Amps. The feeder conductor size for MCC #9 and MCC #10 were not compliant to the *Electrical Safety Regulation*. This non-compliance may have contributed to overheating of feeder cables to MCCs #9 and #10, which were located in the basement area below the band saw.

Electrical Bonding

Technical Code Requirement

12-2208 Provisions for bonding

(1) *Where metal supports for metal cable trays are bolted to the tray and are in good electrical contact with the grounded structural metal frame of a building, the tray shall be deemed to be bonded to ground.*
(2) *Where the conditions of Subrule (1) do not apply, the metal cable tray shall be adequately bonded at intervals not exceeding 15 m and the size of bonding conductors shall be based on the ampacity of the largest ungrounded conductor...*

Condition Found

MCC bonding conductors were not connected to the cable tray between MCC#10 and the PDC. There was no evidence of a bonding conductor for MCC #9.

Discussion

A short circuit between a cable and the cable tray between MCC #10 and the PDC could have produced sparking or heating at mechanical connections of the tray.

Large fault currents in MCC #9 could have damaged small bond conductors in the motor and control cables as the fault utilized these small conductors with the building steel to return to the main system ground.

Conclusion

Provisions for electrical bonding of cable trays associated with MCC #9 and MCC #10 were not compliant to the *Electrical Safety Regulation*. This non-compliance could have increased the risk of ignition sources within the area.

Electrical Motor Ventilation

Technical Code Requirement

28-016 Ventilation

(1) *Adequate ventilation shall be provided to prevent the development around motors of ambient air temperatures exceeding 40°C for integral horsepower motors and 30°C for fractional horsepower motors.*

(3) *In locations where dust or flying material will collect in or on motors in quantities that interfere with the ventilation or cooling of motors, thereby causing dangerous temperatures, suitable types of enclosed motors that will not overheat under prevailing conditions shall be used.*

Condition Found

Some electric motors found in the facility had cooling fins and surface areas significantly contaminated with wood dust. Other motors were found to be completely covered with wood dust, impairing proper cooling of the equipment and providing heat insulation rather than dissipation.

Conclusion

Installation and use of electric motors were not compliant to the *Electrical Safety Regulation*. The sawdust and debris from the waste and chip conveyors was allowed to accumulate on the motors such that the motors were insulated, impairing motor cooling. Overheated motors could produce an ignition source for a wood dust cloud or layer.