



Investigation Report



Lakeland Mills Ltd. – Explosion and Fire – April 23, 2012

BC Safety Authority – Incident Investigation – Jurisdiction and Role

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*. 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 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 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.

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

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Incident Synopsis

On April 23, 2012 at approximately 9:38pm, an explosion and fire occurred in the Lakeland Mills Ltd. sawmill located at 1385 River Road in Prince George, BC.

The explosion and fire caused two fatalities and injured an additional 22 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 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.

SAMAC Engineering Ltd., contracted by BC Safety Authority to provide fire and explosion expertise, identified a likely area of explosion origin in the basement below the headrigs. It was determined that gas, boiler and pressure vessel equipment subject to the *Safety Standards Act* did not supply a combustible fuel or ignition source to the area of explosion origin. Electrical equipment was identified as possible sources for ignition.

Wood dust was the only other fuel source known to be within the 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. Electrical light assemblies installed within or near the area of origin were identified as possible ignition sources. Other electrical equipment and wiring in use within the basement area 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 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, this other equipment was not the focus of the BC Safety Authority investigation.

The electrical (and gas) code 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 area within the basement where the explosion originated was a *hazardous location* as defined by the electrical (and gas) code 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, electrical equipment installed and in use within the area was not certified for use or configured for *hazardous locations* containing combustible wood dust.

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:

- history of fires at the site;
- history of wood dust related fire safety inspection deficiencies;
- evidence of wood dust found during the investigation;
- statements regarding the presence of wood dust at the facility by employees;
- standards establishing the combustibility of wood dust and methods to control the associated hazards;
- conclusion that wood dust fueled the explosion, demonstrating the existence of *hazardous locations*; and
- identification of electrical equipment not approved for hazardous locations within and near the area of explosion origin.

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 these investigation findings and those from previous incidents, 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*.

BC Safety Authority therefore reiterates the following recommendations, recently made as a result of a similar investigation into the Babine Forest Products Explosion and Fire of January 20, 2012. These recommendations aim 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.

Site Information

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

Photograph 1 shows an aerial view of the Lakeland Mills Ltd. site, which consisted of numerous buildings and structures including the sawmill. On April 23, 2012, the sawmill at the Lakeland Mills Ltd. site in Prince George utilized equipment that was subject to the *Safety Standards Act*.

Portable propane cylinders and propane appliances were in use at the site and are subject to the *Gas Safety Regulation*.

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*. These items are referred to as 'electrical equipment' for the remainder of this report.



Photograph 1: Google satellite view of the Lakeland Mills Ltd. site after the explosion and fire.

History of Fires and Fire Safety Oversight at the Site

Employees stated that two wood dust fires occurred in the headrig area of the sawmill in January of 2012. Descriptions of these fires suggest that wood dust dispersed in these areas exploded. Employees communicated that one was ignited by an electric motor failure and the other was ignited by a spark from metal friction.

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

- electrical motor overheating due to dust build-up on cooling surfaces,
- electrical motor igniting hydraulic oil,
- small electrical sparks or arcs igniting wood dust,
- hot electrical lights igniting wood dust,
- fires within the dust collection system.

During the investigation, the Prince George Fire Rescue Service provided BC Safety Authority with documentation of past fire safety inspections conducted at the Lakeland Mills Ltd. site. The following deficiencies that have relevance to this investigation and to the identification of hazardous locations, as required by the electrical and gas codes.

Inspection Date	Documented Deficiencies (relevant to <i>Safety Standards Act</i>)
September 24, 2008	- Fire Safety Plan ² required for mill
September 13, 2010	- Fire Safety Plan Required for mill/site
November 29, 2011	- Building and machinery surfaces shall be kept clean of accumulations of combustible dusts.
March 7, 2012	

Table 1: Deficiencies relevant to the *Safety Standards Act* documented by Prince George Fire Rescue Service during inspections prior to the incident.

The Prince George Fire Rescue Service provided the following photographs that document combustible dust accumulations from their November 29, 2011 inspection.



² The *British Columbia Fire Code* identifies that a *Fire Safety Plan* documents (but is not limited to) the facility plan to control fire hazards in the building, and the inspection and maintenance activities of building facilities provided for the safety of occupants.

Photograph 2: Combustible dust accumulations on high bay (metal halide or high pressure sodium bulb) light assembly, ceiling mounted piping and other horizontal surfaces.



Photograph 3: Combustible dust accumulations around electrical motor.



Photograph 4: Combustible dust accumulations around stairwell horizontal surfaces.

Photograph 5: Combustible dust accumulations on machinery horizontal surfaces.

While the March 7, 2012 inspection documented a combustible dust accumulation deficiency, the inspection letter also contained the following statements:

Your efforts to reduce the amount of accumulated fine wood dust on the building and machinery surfaces did not go unnoticed. The unacceptable amount of dust that was present during the Fire Inspection on November 29, 2011 has been significantly reduced.

Given the above statements, photographs 2 through 5 may not reflect the condition of combustible dust accumulation at the mill just prior to the incident however do reflect conditions that were previously permitted to exist. During interviews, employees stated having initiated a mill clean-up following the January incidents and management statements indicate efforts were being oriented towards improving dust clean-up; however, a hazardous accumulation of combustible wood dust was concluded to have existed in the mill on April 23, 2012.

Operating Environment at the Time of the Incident

In the days leading up to the incident, the outside temperatures and relative humidity at the facility were considered typical for the time of year.

Table 2: Average Temperature and Humidity for Prince George

	Apr 19	Apr 20	Apr 21	Apr 22	Apr 23
Temperature* (°C)	5	6	3	5	6
Relative Humidity* (%)	66	46	48	80	93

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

There was speculation that severe cold and dry weather conditions could increase the risk of dust explosions at sawmills. Those weather conditions were not present in the days leading up to this incident and employees did not report any operational challenges presented by the external weather environment.

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 (CFEI³) was contracted to assist BC Safety Authority with the interpretation of explosion and fire damage and to assist with the investigation.

Explosion Area of Origin

SAMAC Engineering Ltd. was contracted by BC Safety Authority to provide fire and explosion investigation expertise. A likely area of explosion origin was identified in the basement below the large headrig. This area's determination is discussed in the appended fire and explosion investigation report.

BC Safety Authority's investigation focused on equipment subject to the *Safety Standards Act* that:

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

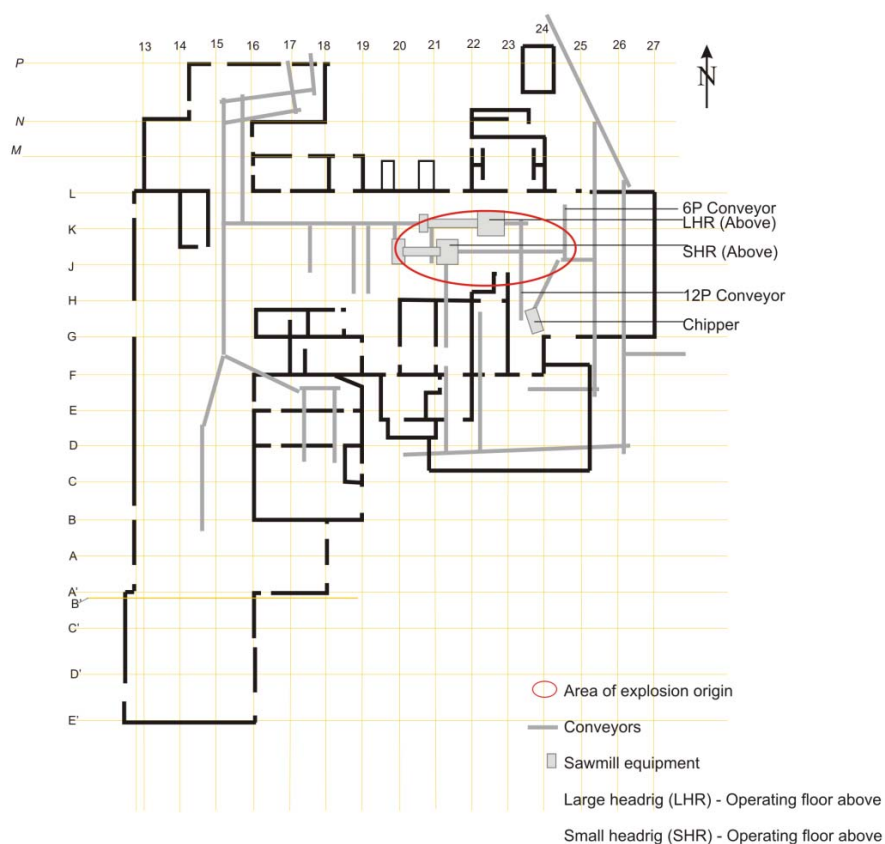


Figure 1: General arrangement drawing (plan view) of the sawmill basement. The possible area within the basement where the explosion originated is indicated in red.

Note: Figure 1 was produced from field observations and drawings provided by Lakeland Mills Ltd. and is intended for illustrative purposes only.

³ CFEI is a professional designation granted to qualified persons by the (US) National Association of Fire Investigators (NAFI)

Fuel for the Explosion

The site utilized a waste wood system for energy production. Natural gas supply was disconnected from the site and all natural gas fired equipment was removed from the site in 1995. Natural gas could not have been present in the area of origin and could not have contributed to the incident.

Lakeland Mills Ltd. identified that portable propane cylinders were used to supply propane to forklifts, pressure washers and torches. The cylinders were supplied by a vendor and stored in a cage outside the mobile shop, as per the requirements of the *Gas Safety Regulation*. Employees did not indicate that propane cylinders were in use within the sawmill and no evidence of propane cylinders was found within the mill during the investigation. The use or storage of propane did not contribute to the incident.

The energy system heats and circulates thermal fluid and ethylene glycol to various parts of the mill as well as locations outside the mill to transfer heat energy. Equipment that would have contained these combustible fluids was not located within the area of origin. It was also reported by Lakeland Mills Ltd. that the energy system was shut down three days prior to the incident for maintenance purposes and was not operating at the time of the incident. It is very unlikely that the energy system equipment or associated combustible fluids contributed to the incident.

Pressurized air system components would not normally be considered to possibly contribute fuel to an explosion. However, their failure in close proximity to accumulations of wood dust, could lead to a combustible wood dust atmosphere being unintentionally generated by the release of pressurized air. There was no pressurized air equipment located in the basement area of origin. There was no evidence that suggests a failure of pressurized air equipment contributed to the incident.

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 were found in the area of origin as well as throughout the sawmill. In accordance with the conclusion of SAMAC Engineering Ltd (Appendix), BC Safety Authority concludes 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.

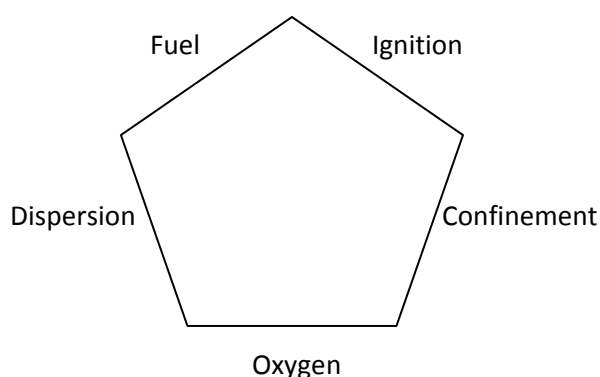


Figure 2: Dust explosion pentagon

Fuel

As discussed in the previous section, it was determined that wood dust fuelled the explosion at the sawmill.

Dispersion

A system of conveyors within the basement transported wood dust generated by the sawmill machinery and activity on the operating floor above to storage or disposal locations outside of the mill. Waste dust and material produced at the large headrig was transported via waste conveyors to the basement through openings in the operating floor near the headrig. Employees stated that accumulations of wood dust in the area near the large and small headrigs was common as well as suspensions of dust in the atmosphere. Employees also stated that the basement was often contaminated with wood dust.

A dust blow-down operation was reported to have been completed several times daily on the headrigs at the beginning of production break periods, such as for lunch or coffee. The explosion occurred approximately five to ten minutes into a production break period at the mill. The blow-down operation removes wood dust by blowing compressed air over the machinery parts intended to be cleaned. This operation produces a dispersion of wood dust on the operating floor that would have been directed to or migrated to the basement area below the large and small headrigs, where the explosion originated.

Oxygen

The basement contained breathable air.

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

Confinement

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

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. Different types of installed light assemblies were identified as possible ignition sources. Electrical equipment, including the installed lighting, operated 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, 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 around flammable materials or within *hazardous locations*.

Electrical equipment that is certified for use within *hazardous locations*, including combustible dust 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, if not 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.

There were no indications that any of the electrical equipment found was certified for use in a hazardous environment containing combustible dusts.

Electrical Equipment Found Within the Area of Origin

The following electrical equipment and associated wiring was found within or near the area of origin as illustrated in Figure 3.

- P6 Conveyor Motor
- Light Assemblies
 - High Bay
 - Fluorescent
 - Wall Pack
- Wiring supplying power to other electrical equipment was routed through the area of origin.

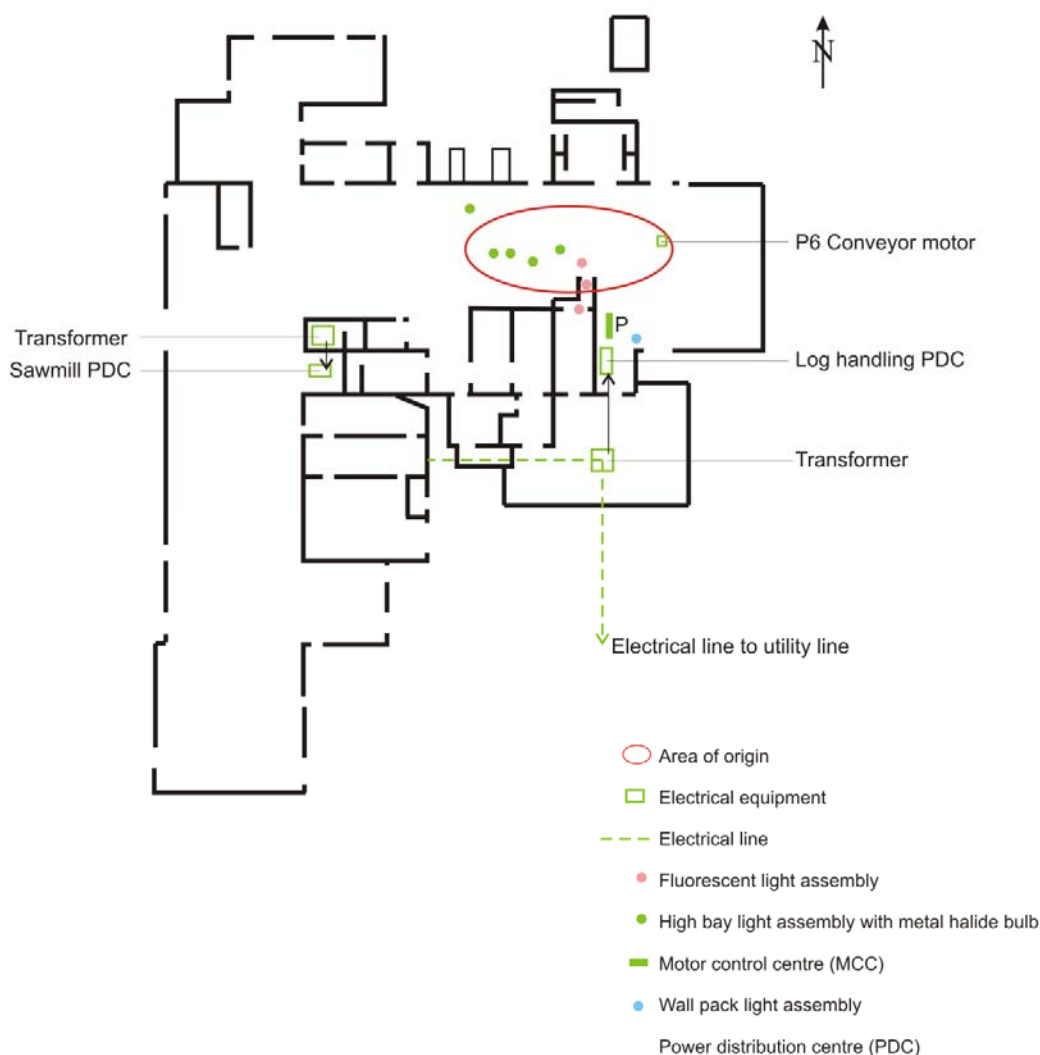


Figure 3: Plan view of mill - electrical equipment within or near the area of origin - from supplied diagrams and investigation findings.

Note: Figure 3 was produced from field observations and drawings provided by Lakeland Mills Ltd. and the Prince George Fire Rescue Service. Figures are intended for illustrative purposes only.

P6 Conveyor Motor

A detailed evaluation of the P6 conveyor motor was commissioned by WorkSafeBC. BC Safety Authority investigators witnessed that the motor functioned with no indications of an appliance failure or overheating prior to the incident. Wiring to the motor and spliced connections was found intact with no signs of electrical failure.

Hazardous accumulations of wood dust were found packed within the junction box and cooling fins of the motor as shown in Photographs 6 through 11. Although this contamination presents ignition hazards and would have impeded proper cooling of the motor, there were no signs of the motor having ignited the packed dust or having overheated during operation. It is therefore considered unlikely that failure or overheating of the motor during operation provided the ignition source for the incident.



Photograph 6: P6 motor assembly, shaft and guard, gear reducer and chain guard as found. Note that the yellow shaft guard was installed over the shaft connecting the motor and reducer.



Photograph 7: P6 motor found with wire sheath not connected to the motor junction box.



Photograph 8: P6 motor – wood dust found within junction box.



Photograph 9: P6 motor – end view top quarter – wood dust found contaminating cooling fins.



Photograph 10: P6 motor – view of side cooling fins -wood dust contamination.



Photograph 11: P6 motor – top view showing depth of cooling fin contamination on scraped portion.

Light Assemblies

Light assemblies found within or near the area of origin were of the high bay, fluorescent or wall pack types as shown in photographs 12 through 16. These assemblies comprised of a ballast, a bulb (or tube) and a reflector. The high bay assemblies did not incorporate a cover; the wall pack assemblies included a clear bulb cover while the fluorescent assemblies utilized a metal cage protection cover for the tube.



Photograph 12: Wall pack light assembly with missing cover found near the area of origin. The installed bulb is possibly a metal halide or high pressure sodium type.



Photograph 13: High bay light assembly found within the area of origin with metal halide bulb.



Photograph 14: Fluorescent light assembly found within the area of origin.



Photograph 15: Fluorescent light assembly found within the area of origin.



Photograph 16: Open style high bay light assembly found near the area of origin with possible metal halide or high pressure sodium bulb.

Metal halide and high pressure sodium bulbs are often used in high bay and wall pack light assemblies (as shown in photographs 12, 13 and 16) and can have maximum surface temperature ratings of 450-500°C, depending upon the output rating of the bulb. Ballast maximum surface temperature ratings can be as high as 250°C.

Fluorescent light assemblies have much lower tube and ballast temperature ratings. The tubes rely on spring contact pressure at the exposed electrodes to maintain electrical contact, which can result with sparking under certain conditions, such as vibration.

WorkSafeBC commissioned testing for dust cloud and dust layer ignition temperature as well as minimum ignition energy values of wood dust samples from the sawmill. These tests identified a possible dust cloud ignition temperature of 430°C and a wood dust layer ignition temperature of 310°C. Minimum ignition energy (without inductance in the test circuit) was identified at 440 milli-Joules, which demonstrated that spark energy was able to directly ignite a dust cloud sample.

The metal halide light bulb and ballast of the high bay light assemblies were in direct contact with the basement atmosphere, exposing dust clouds in the mill to possible bulb surface temperatures of 450°C - 500°C, which is above the identified sample dust cloud ignition temperature.

Settled dust on upward facing surfaces of high bay light assemblies (as shown in photograph 2), wall pack light assemblies and fluorescent light assemblies would have been exposed to a constant high heat source from the ballast and reflectors. As discussed in the appended report, it is possible that wood dust accumulations on these surfaces developed reduced ignition temperatures and energies due to pyrolysis in addition to interfering with proper cooling of the light assembly. There would be an increased risk of combustion should this dust have become dispersed.

The tubes of the fluorescent light assemblies were in direct contact with the basement atmosphere, exposing dust clouds in the mill to possible sparking at the tube contacts as well as heat generated at the ends of the tubes. It was demonstrated that spark energy, similar to what could occur at a fluorescent tube contact, could ignite a wood dust cloud.

The light assemblies found within or near the area of origin are therefore considered possible ignition sources for the explosion.

Electrical Wiring or Other Electrical Equipment - Found Within or Near the Area of Origin

No evidence of arcing or electrical failure prior to the explosion was observed on any wiring or other electrical equipment found within or near the area of origin.

In non-combustible environments, electrical equipment and wiring 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 (or installed wiring) 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.

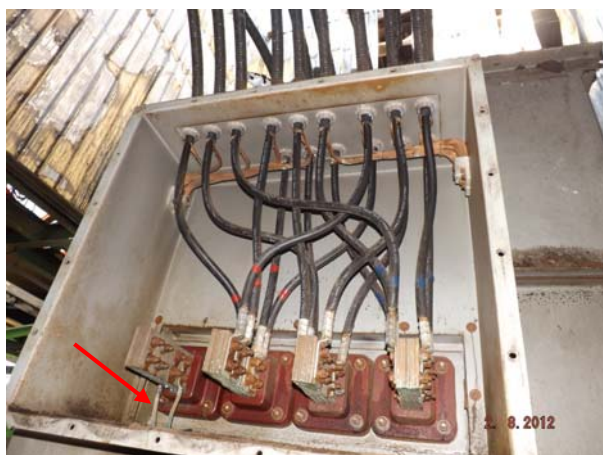
The absence of failure of such equipment is therefore not sufficient to rule out the possibility of it being an ignition source.

Electrical equipment found within or near the area of origin consisted of disconnects, push buttons, control panels, 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 or near the area of origin in the basement provided an ignition source for wood dust.

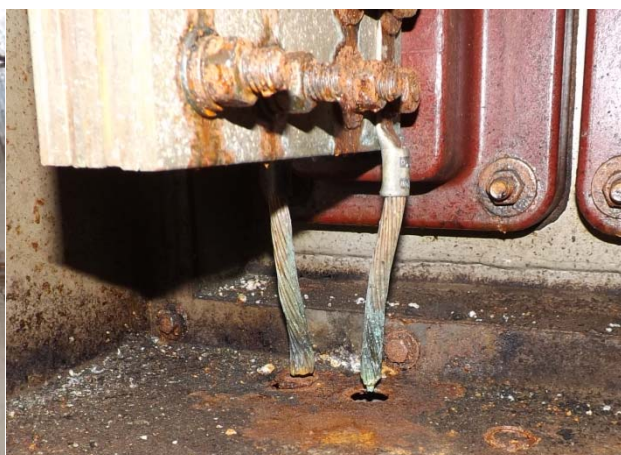
Transformer Neutral Connection

Two three-phase transformers supplied power to the sawmill, one located toward the west of the building feeding the sawmill Power Distribution Center (PDC) and the other located south of the area of origin feeding the log handling PDC as shown in figure 3. The log handling PDC distributed and controlled electrical power to the lighting circuits and other equipment within or near the area of origin. Wiring distributing power from the log handling PDC was routed within or near the area of origin.

The neutral connection of the transformer supplying the log handling PDC was found severed, leaving the transformer neutral floating as shown in photographs 17 through 20. Arc damage was observed at cable ends as well as on the transformer enclosure. WorkSafeBC commissioned an evaluation of the severed transformer neutral cables which confirmed the presence of arc damage as well as mechanical overload and cutting. The evaluation also concluded that the damage appeared relatively old (months or years) and had likely been present for a considerable period of time preceding the explosion.



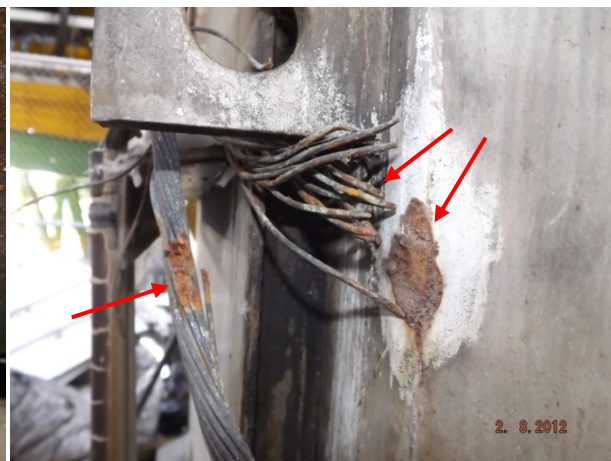
Photograph 17: Three-phase transformer feeding the log handling PDC. Neutral terminal and severed cables are identified by the red arrow.



Photograph 18: Severed neutral connections of transformer. Location is within the transformer enclosure at the external feed-through.



Photograph 19: Damaged neutral cables at the under-side of the transformer enclosure - external feed-through location.



Photograph 20: Arc damage between transformer neutral cables and exterior of the transformer enclosure.

It was observed that the transformer circuit did not incorporate ground fault protection. The arc damage to the neutral cables was likely caused by ground faults within the circuit some time prior to the explosion, leading to the failure or disconnection of the neutral connection. The floating neutral condition would have left the electrical system vulnerable to overvoltage conditions, increasing the risk of electrical equipment failure while inhibiting the distribution system from safely detecting and responding to such failures. The floating neutral condition increased the risk of generating possible electrical ignition sources within a potentially combustible environment.

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 wood dust:

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

Details of these non-compliance findings are as follows:

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*. 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 noted that the transformer feeding the log handling PDC was manufactured in 1980 and it is estimated that its installation and much of the system would have likely been accomplished after this manufactured date. In 1986, the *Canadian Electrical Code, Part I, Fifteenth Edition, Safety Standard for Electrical Installations, Canadian Standards Association C22.1-02* and subsequent editions were utilized as the *BC Electrical Code*. Referenced sections of the 1986 and subsequent editions of the Code are similar in technical content and intent. For ease of reference and relevance to current practices, only the specific content of the 2012 edition of the Code is referenced.

Combustible Dust Migration into Electrical Equipment Enclosures

Technical Requirement:

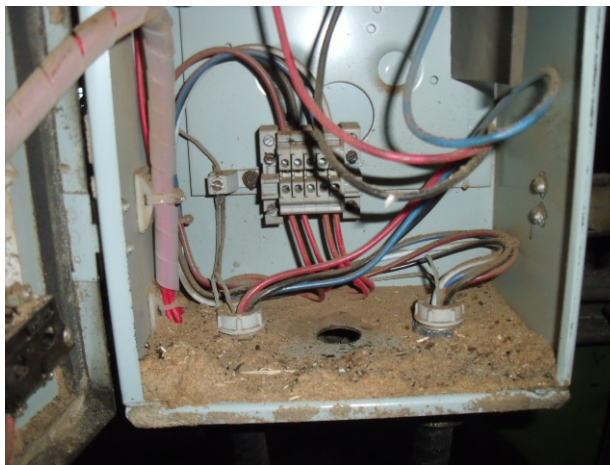
12-3024 Unused openings in boxes, cabinets, and fittings

Unused openings in boxes, cabinets, and fittings shall be effectively closed by plugs or plates affording protection substantially equivalent to that of the wall of the box, cabinet or fitting.

Condition Found:

Unused openings in boxes were found open, permitting combustible wood dust migration into the box as shown in photograph 21.

Photograph 21: Unfilled opening in lower center of enclosure contaminated with combustible wood dust.



Discussion:

As shown in photograph 21 above, unfilled electrical enclosure holes allowed for combustible dust to contaminate the enclosure, exposing the combustible dust to possible ignition sources. Ignition of combustible dust within an enclosure could lead to the ignition of a combustible environment outside of an enclosure. Unfilled electrical enclosure holes increased the risk of combustible dust ignition within or near the area of origin.

Hazardous Use of Electrical Equipment Within a Combustible Dust Environment

Technical Requirement:

Section 18 of the Canadian Electrical Code, Part 1, requires that certain precautions be taken to reduce ignition hazards when electrical equipment and wiring are operated in the presence of combustible dusts. As discussed later in this report, this section applies to accumulation of wood dust.

Condition Found:

Accumulations of deflagrable wood dust were found on electrical equipment, wiring, within MCC cabinets and control panels as well as on upward facing surfaces throughout the facility. At the time of the incident, the area of origin within the basement should have been considered a *hazardous location* as described by section 18 of the *Canadian Electrical Code*. At the time of the incident, electrical equipment such as control boxes, electrical motors, motor control centres, lights and wiring installed and in use within or near the area of origin was not compliant to section 18 of the *Canadian Electrical Code* for *hazardous locations*. The use of this equipment was therefore not compliant to the Code and presented ignition hazards in the presence of combustible dust.

This topic is further discussed in the section titled Hazardous Locations.

Inadequate Ground Fault Protection

Technical Requirement:

14-102 Ground fault protection (see Appendix B)

(1) Ground fault protection shall be provided to de-energize all normally ungrounded conductors of a faulted circuit that are downstream from the point or points marked with an asterisk in

Diagram 3 in the event of a ground fault in those conductors as follows:

(a) for circuits of solidly grounded systems rated more than 150 volts-to-ground, less than 750 V phase-to-phase and 1000 A or more; and

(b) for circuits of solidly grounded systems rated 150 V or less to ground and 2000 A or more.

Condition Found:

The circuit feeding the log-handling PDC from the transformer was solidly grounded and rated at 480 V and 2500 A, requiring ground fault protection per 14-102(a) and (b).

Discussion:

Ground fault currents may have caused the arc damage observed on the transformer neutral cables and led to the floating neutral condition of the circuit found during the investigation. Operation of the system in a floating neutral condition increased the risk of generating possible electrical ignition sources within a potentially combustible environment.

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

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

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;*

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.

- (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)

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 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 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. Similar results from other combustion test completed by WorkSafeBC are 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 dust⁹ 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 93m² (1000ft²), 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* and other industry standards.

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

- history of wood dust fires at the facility,
- history of wood dust related fire safety inspection deficiencies,
- 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 or near the area of origin was not compliant to section 18 of the *Canadian Electrical Code* for *hazardous locations* and therefore presented ignition hazards.

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.

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*.

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* 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*.

Conclusions and Recommendations

Root and Contributing Causes of the Incident

The investigation determined that wood dust was the fuel for the explosion at Lakeland Mills Ltd. on April 23, 2012. All necessary conditions for a wood dust explosion existed in the sawmill. A single 'most likely' ignition source was not apparent at the scene and 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.

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:

- history of fires at the site;
- history of wood dust related fire safety inspection deficiencies;
- evidence of wood dust found during the investigation;
- statements regarding the presence of wood dust at the facility by employees;
- standards establishing the combustibility of wood dust and methods to control the associated hazards;
- conclusion that wood dust fueled the explosion, demonstrating the existence of *hazardous locations*; and
- identification of electrical equipment not approved for hazardous locations within and near the area of explosion origin.

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 these investigation findings and those from previous incidents, 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*.

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*.

BC Safety Authority therefore reiterates the following recently made 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.

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).

Appendix

SAMAC Engineering Ltd. Fire Investigation Report



[REDACTED]

[REDACTED]

[REDACTED]

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

Dear [REDACTED]:

Re: Lakeland Sawmill – Explosion & Fire
Incident Date: 23 April 2012

[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 Lakeland Sawmill located at 1385 River Road, Prince George, BC. It is understood that on 23 April 2012 at approximately 21:30h an explosion and fire occurred in the sawmill.

The Prince George Fire Department responded to the incident and contained the fire to the stud mill. However, the fire was deemed too dangerous for an interior attack and was therefore fought from the exterior. There were 24 casualties including two fatalities and the mill was a total loss.

The scene was initially under the control of the Police and BC Coroner's Service but was later 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.

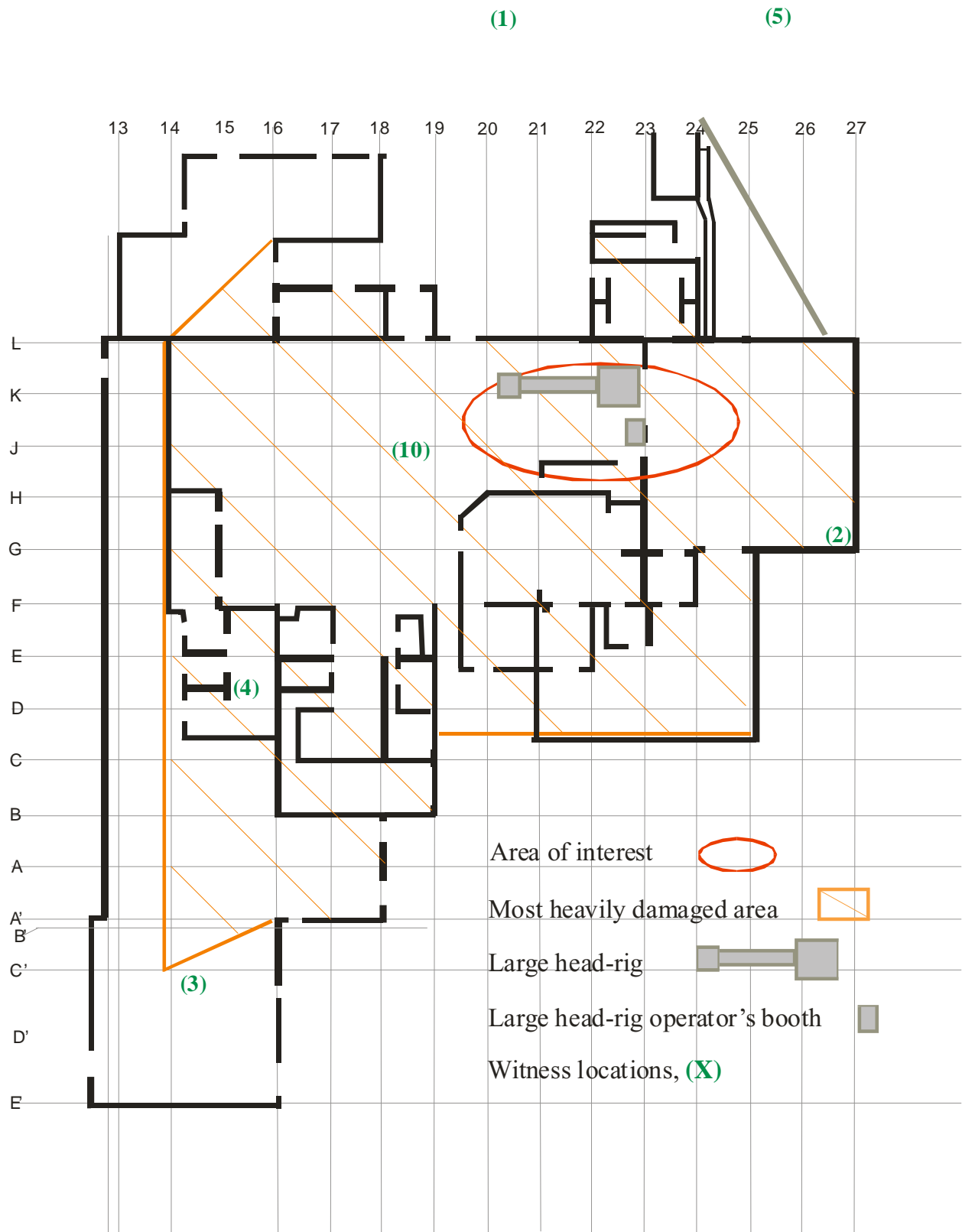


Figure 1:
Stud Mill Operating Floor plan
(not to scale)

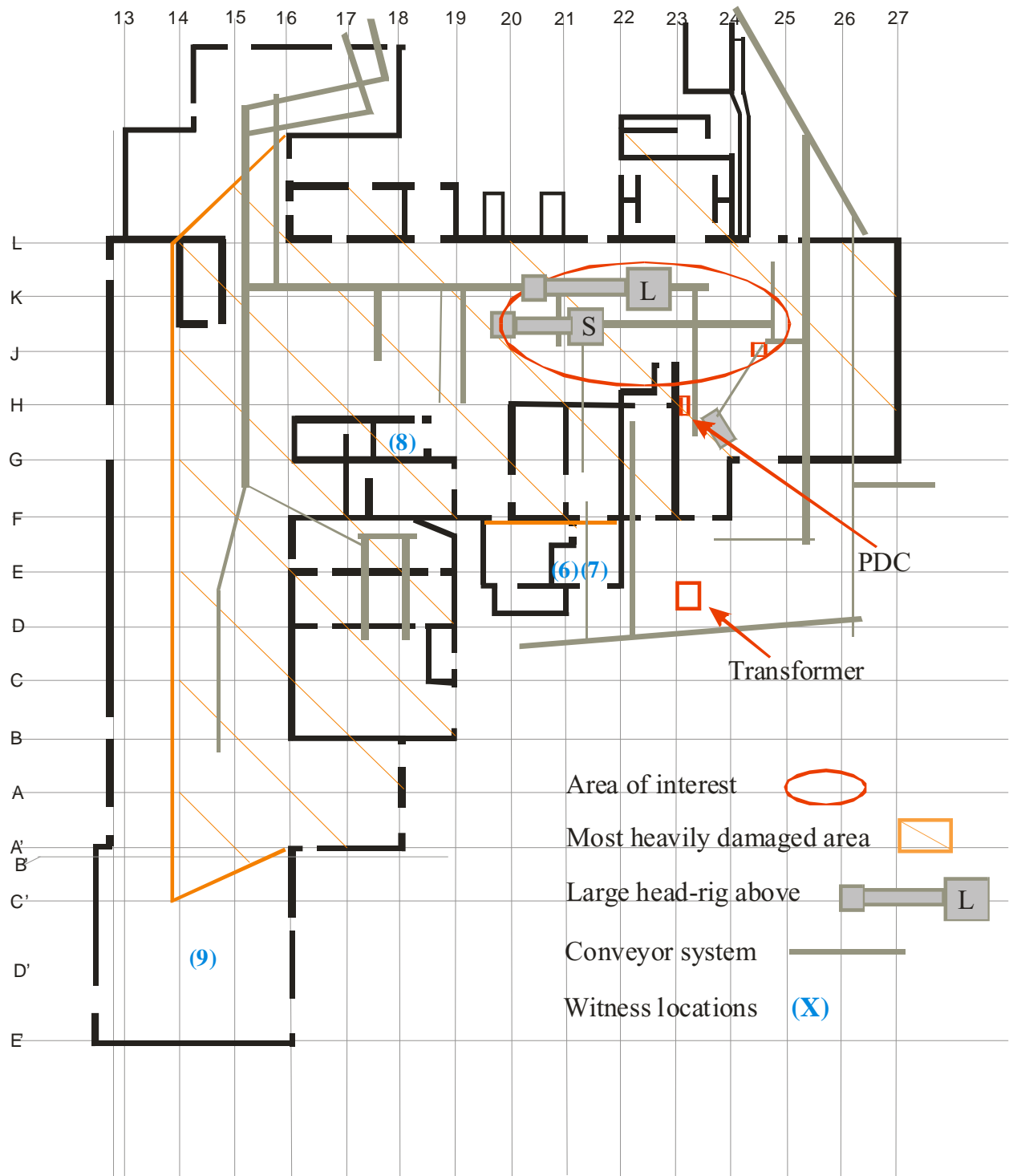


Figure 2:
Basement floor plan showing the footprint of the mill (blue outline)
(not to scale)

3.0 INFORMATION AVAILABLE

The following activities were performed during our investigation:

- reviewed information provided,
- examined and photographed the fire scene from 01 to 16 May 2012 and again from 25 to 26 August 2012,
- reviewed 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
- reviewed the reports on laboratory examinations of retained exhibits.

4.0 REVIEW OF INFORMATION

4.1 Description of the Mill

The mill was a steel frame structure approximately 13.71m high occupying approximately 4185m². The exterior walls were framed with 2 inch by 6 inch wooden studs clad on both sides with plywood with fibreglass insulation between the walls and metal exterior siding. The roof was bitumen on metal and the interior partitions were wood frame clad with plywood. The volume of wood used in the walls and partitions served as a significant "class A" fuel load once the fire started.

The various processes took place on three levels within the mill building. There were enclosed shops, store rooms and lunch rooms on the levels as well. The basement of the mill was at ground level.

There was a large amount of heavy electrical machinery in the mill including but not limited to saws, conveyers, fans and pumps. The electrical machinery in the mill was controlled from large electrical panels known as Motor Control Centres (MCCs). The MCCs were situated in various locations throughout the mill.

4.2 Explosion Potential

The mill contained a number of materials that, under the right conditions could have caused, or contributed to the cause, of the explosion. To the extent possible all of these materials had to be examined and either ruled in or ruled out as the possible cause. Potential explosive sources that were investigated included:

- 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, (Note: *in the case of dust explosions there is frequently a primary explosion or event that throws dust into suspension where it mixes with air. The dust cloud may then be ignited by either heat from the primary explosion or by another ignition source causing a more violent secondary explosion.*) 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 that were investigated included:

- electrical appliances, panels, wiring and fittings,
- heat generated by lighting equipment,
- portable propane and acetylene appliances,
- sparks from saws and machinery, and
- heat generated by machinery due to friction.

4.3 Fire Scene Observations

4.3.1 Origin Observations

Fire scene observations key to determination of the origin are listed below (Figure 3 and Photographs 1 to 50). For the purpose of this report, damage has been categorized as either blast damage or burn damage. All observed blast damage was recorded and plotted in the diagram shown in Figure 3. Red vector arrows were used to indicate horizontal blast direction and circular red swirl patterns were used to indicate vertical blast direction. Unless otherwise specified, equipment referred to was located in the basement of the mill.

Origin observations were:

- the building sustained both blast and burn damage,
- debris from the explosion was found in a 360° pattern around the mill,
- most of the horizontal blast damage was observed in the basement,
- all vertical blast damage observed occurred in an area bounded by grids H to L and 20 to 23 (Figures 1, 2 and 3),
- except on the extreme west side and areas of the south side of the mill (Figure 3), approximately 99% of the combustible mill structure was consumed by the fire,
- before the explosion there were a number of wood frame equipment rooms, store rooms, work shops, lunch rooms and other rooms throughout the mill. Except between grids G to H and 16 to 18, whatever had remained of the rooms after the explosion was destroyed by the fire,
- on the operating level, the blade covers for the large head-rig band saws in grid K-20/21 were lifted vertically out of position,
- on the operating level, the area bounded by grids G to H and 20 to 21 was collapsed into the basement with the remains of a number of band saw blades on top of the rubble,

- a band saw blade was hanging over a steel roof I beam at grid J-20/21,
- on the operating floor, in an area open to the basement at grid J-22, a number of wall mounted electrical cabinets were blown open,
- on the operating floor, in front of the small head-rig operator's booth at grid J-22, the steel deck plates were separated and bowed upwards.
- on the operating floor, a steel stand at grid K-22 was displaced approximately 2.5m east of its original position,
- a wooden door approximately 3.5m by 3.5m and a 12m steel I beam were blown from the exterior of the mill at grid L-25 approximately 150m in a north-easterly direction from the building,
- there was extensive collapse in the area of grid G-19/20,
- the general trajectory of blast debris tended to be outward 360° from grid J/K-21,
- The Log Handling PDC feeders from the Log Handling Transformer had two of three phases arced and separated at grid G-23,
- the main ground was arced and separated at the Log Handling Transformer grid E-23, and
- the Log Handling Transformer was shifted to the south approximately 15 Cm.

4.3.2 Cause Observations

Fire scene observations key to determination of the cause were as follows (Photographs 1 to 22 and Figure 3):

- the explosion occurred within 8 minutes of the 21:30h break,
- at break time the large head-rig operator routinely blew wood dust from the rig with compressed air,
- when the large head-rig operator blew down the rig, he would blow the wood dust down into the 12P conveyor.
- 12P conveyor opened out in the basement at grid J-23/24,
- many of the light fixtures and electrical connection boxes and cabinets in the mill were not rated for use in explosive atmospheres,
- when examined, electrical connection boxes and cabinets were found to contain fine wood dust, and
- most of the equipment and horizontal surfaces in the basement that were not burned were heavily coated with wood dust.

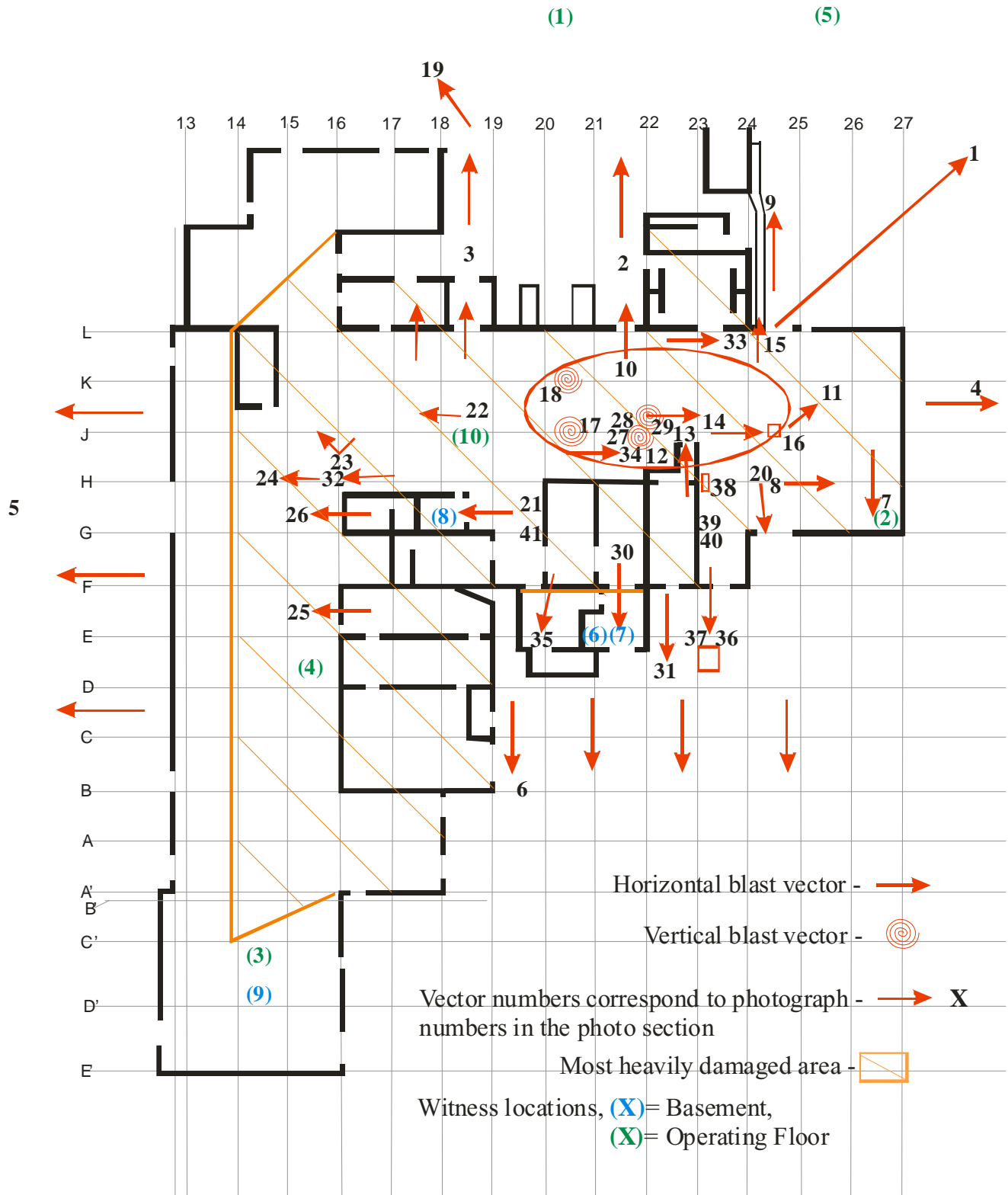


Figure 3:
Blast vector and witness location plan (not to scale)

Note: the bold numbers in the plan correspond to photograph numbers in the photograph section; the red arrows show the blast direction indicated by the post-blast positions of the objects shown in the various photographs. The bracketed numbers indicate the locations of witness discussed in Section 4.4.

4.4 Witness Information

4.4.1 Witness #1

Witness #1 provided the following information:

- he was on security and safety patrols – 6 months,
- he was in the security shack at time of explosion; 25 to 30 minutes after 9pm,
- he did not hear the break alarm,
- he was looking at the NE wall at the time of the blast and saw a wall coming out, heard a boom; then felt a concussion,
- he called 911, then saw bag houses go – both at the same time,
- he rushed to the mill from the security shack and saw first burn victim come out,
- he saw the top of the exterior wall come out,
- he didn't see flames until the bag houses went, and
- the explosions seemed to be in the building's upper area between the hydraulics and the hogs.

4.4.2 Witness #2

Witness #2 provided the following information:

- he was with Lakeland for 37 years, and a debarker operator 2 years,
- they were cutting a mix of pine and spruce,
- he doesn't think the misters were on,
- he would spray the logs down with a hose if the logs got too dusty,
- he noticed the mill was dustier the past year, more dust on beams and crane,
- maintenance staff had been cut back to two clean up personnel as opposed to one/shift,
- the incident day was normal, nothing unusual,
- he was in his shack at the time of the blast,
- something knocked him off his feet and he may have heard a “whoosh”,
- his hands were burning,
- he escaped through his shack door,
- he saw fire by the slasher,
- there was debris in the exit stairway,
- he made his way downstairs by the debarker then to the cut-off saws, and
- he got out by the millwright shop and went over to the energy plant.

4.4.3 Witness #3

Witness #3 provided the following information:

- he was on weekend shift clean-up,

- his clean-up assignment was to blow down the centre part of the mill,
- the air was quite dusty during blow down,
- dust was blown into the conveyors or onto the floor,
- when dust got on the floor it was squeegeed into piles then swept up,
- there was more dust lately; when the other cleaning shift didn't clean up,
- he was often put on the stacker so did not have time to do a complete clean-up,
- there was lots of sawdust and piles of chips in the basement,
- the weekday clean-up often did not clean the basement,
- some motors under the head-rigs had large volumes of sawdust on them,
- 2 minutes after the lunch horn blew he heard a "kaboom",
- he looked behind and saw a fire ball coming at him; he was near the bins for the stacker facing west,
- Worker 1, an electrician was with him and another electrician, Worker 2, was near them,
- he saw "black gas" followed by an orange fireball coming from the north end,
- Worker 1 pushed him to the floor,
- he curled up in a ball and the heat blew over them,
- they stood up and saw that the walls were gone,
- he grabbed his stuff and went out the door; it took about 3 minutes,
- he was outside by the planer when he heard another bang and the lights went out, and
- Worker 3 was cleaning up by the eliminator; he was badly burned – arms, face and neck.

4.4.4 Witness #4

Witness #4 provided the following information:

- on the night of the fire he started at 16:30h and noted nothing out of the ordinary,
- the foreman asked him to work through his break at 19:00,
- the edger, eliminator and sorter usually run through break,
- the head-rigs, barker, slasher, and horizontal and vertical saws, shut down at break,
- the foreman asked him to work through his lunch break at 21:00h,
- he was across from the scanner, 3rd floor, farther south, same floor as lunch room,
- he heard a "big boom" and turned his head and saw sawdust; it covered him,
- he looked north when he heard the boom but saw no flame until after the smoke cleared; at that time the lights were still on,
- he ran to the lunch room and met 2 people coming out; they all ran downstairs to ground level; he saw a large door opening and ran outside,
- they usually blow down some of the equipment at lunch time,
- there may have been an acetylene kit on the other side of the scanner,

- contractors were working on a conveyor in his area, and
- he hadn't seen any propane cylinders in the mill.

4.4.5 Witness #5

Witness #5 provided the following information:

- he was a large forklift operator in the planer,
- the planer was very dusty; it was a very powdery dust,
- it was a normal day until lunch break,
- he was in the mobile shop when the explosion hit,
- there was a bright light and the building shook when the explosion hit,
- he jumped up and saw a mushroom cloud through the roof in the area of the large head-rig, then an explosion went outwards, and
- he was not sure if he saw one or two explosions.

4.4.6 Witness #6

Witness #6 provided the following information:

- he was with Lakeland Mills for 21 years,
- his job was working with a journeyman making repairs,
- he came in at 15:30h and all was normal,
- at lunch break he was in the millwright lunch room,
- he heard a muffled explosion, then the walls blew out,
- the blast came through the door,
- he went out and tried to use a fire hose but there was no water,
- lockers were all over the place,
- he went to maintenance shop but couldn't get out; the lights were out,
- it was too smoky and fire was increasing,
- south wall of maintenance lunch room was blown out,
- the sequence of events was a muffled explosion, a fireball, he felt heat, then heard a whoosh; he was knocked down but not burned,
- the west lockers were still standing but the east lockers were blown over, and
- the blast came from the north or northeast.

4.4.7 Witness #7

Witness #7 provided the following information:

- he was in his position since 1972,
- at the time of the explosion he was in the basement in the millwrights room,

- he heard a big “kaboom” around 21:30 and found himself laying outside on a wall,
- flame, heat and blast came from the north, and
- fire came through the door, he saw flames, then heat, then an explosion.

4.4.8 Witness #8

Witness #8 provided the following information:

- he was a slasher operator,
- at the time of the explosion he was in the basement washroom,
- he heard a “whoof” sound and then a shock wave hit,
- the lights in the washroom stayed on,
- he looked out of the washroom and saw blackness and smoke so he closed the door,
- he exited the washroom and turned right toward the millwrights shop,
- it was pitch black but he could see light in the area of the edger line,
- he could not get through on the basement level so he went up to the operation floor then over and down at the south end, and
- he thought Worker 4 would be the only person blowing down at break time.

4.4.9 Witness #9

Witness #9 provided the following information:

- he was an electrician,
- at the time of the explosion he was slightly south of the stacker at the dunnage re-entry deck,
- he heard beams rattling and cross members clanging like thunder, then smoke coming along the top, then it lit up,
- there were spot fires everywhere,
- there was lots of dust in the MCC panels, and
- after the explosion Worker 4 told him that he had been blowing down at break.

4.4.10 Witness #10

Witness #10 provided the following information:

- he was a saw filer,
- he was changing saws at break,
- at the time of the explosion he was at the horizontal saw large VAG, facing south,
- he heard a whoosh and looked to his left (east) toward the large and small head-rigs,
- he saw a wall of black and deep red coming toward him,
- as a wall of fire hit him he closed his eyes and held his breath, and
- after the blast the lights were out and he could see outside.

4.5 Safety Officer's Assessments

The assessments of the safety officers will be expanded on as required in the final BCSA report. However, to date based on information from the team's safety officers:

- 1) no evidence was found that boilers or pressure vessels contributed to the cause of the fire,
- 2) no evidence was found that natural gas or propane contributed to the cause of the fire, and
- 3) electrical equipment remains a possible ignition source of the fire; items of interest include MCC panels, lighting equipment and the motors.

5.0 ANALYSIS

5.1 Origin of the Explosion

Analysis of the origin of the explosion is based on the following information (Figures 1, 2 and 4 and Photographs 1 to 50):

- 1) debris from the explosion was found in a 360° pattern around the mill,
- 2) most of the horizontal blast damage was observed in the basement,
- 3) all vertical blast damage observed occurred in an area bounded by grids H to L and 20 to 23 (Figures 1 and 3),
- 4) on the operating level, the blade covers for the large head-rig band saws in grid K-20/21 were lifted vertically out of position,
- 5) on the operating level, the area bounded by grids G to H and 20 to 21 was collapsed into the basement and the remains of a number of band saw blades were present on top of the rubble,
- 6) a band saw blade was hanging over a steel roof I beam at grid H-20/21,
- 7) on the operating floor, in an area open to the basement at grid J-22 a number of wall mounted electrical cabinets were blown open,
- 8) on the operating floor, in front of the small head-rig operator's booth at grid J-22 the steel deck plates were separated and bowed upwards.
- 9) a steel stand on the operating floor at grid K-22, was displaced approximately 2.5m east of its original position,
- 10) a wooden door approximately 3.5m by 3.5m and a 12m steel I beam were blown from the exterior of the mill at grid L-25 approximately 150m in a north-easterly direction from the building,
- 11) the general trajectory of blast debris tended to be outward 360° from grid J/K-21,
- 12) The Log Handling PDC feeders from the Log Handling Transformer had two of three phases arced and separated at grid G-23,
- 13) the main ground was arced and separated at the Log Handling Transformer grid E-23,
- 14) the Log Handling Transformer was shifted to the south approximately 15 Cm,
- 15) Witness #1 stated the explosions seemed to be in the upper area of the building between the hydraulics and the hogs,
- 16) Witness #2 was in the debarker operators shack and after the explosion saw fire by the slasher,

- 17) Witness #3 was near the bins for the stacker facing west; he looked behind and saw a fire ball coming at him; he saw “black gas” followed by an orange fireball coming from the north end,
- 18) Witness #4 was across from the scanner, 3rd floor, farther south, the same floor as the lunch room; he heard a “big boom” and turned his head and saw sawdust, it covered him; he looked north when he heard the boom but saw no flame until after the smoke cleared,
- 19) Witness #5 was in the mobile shop when the explosion hit; he stated there was a bright light and the building shook; he jumped up and saw a mushroom cloud through the roof in the area of the large head-rig,
- 20) Witness #6 was in the millwright lunch room; he stated that he heard a muffled explosion then the walls blew out; the blast came through the door; the south wall of the maintenance lunch room was blown out; the blast came from the north or northeast,
- 21) Witness #7 was in the basement in the millwrights room; he stated he heard a big “kaboom” around 21:30h and found himself laying outside on a wall; flames, heat and the blast came from the north,
- 22) Witness #8 was in the basement washroom; he stated he heard a “whoof” sound and then a shock wave hit; he looked out of the washroom and saw blackness and smoke so he closed the door; he then exited the washroom and turned right toward the millwrights shop; he could not get through on the basement level so he went up to the operation floor then over and down at the south end,
- 23) Witness #9 was slightly south of the stacker at the dunnage re-entry deck; he heard beams rattling and cross members clanging like thunder, then smoke coming along the top then it lit up, and
- 24) Witness #10 was at the horizontal saw large VAG, facing south; he heard a whoosh and looked to his left (east) toward the large and small head-rigs and saw a wall of black and deep red coming toward him.

Analysis of the explosion damage (Figure 3) shows the blast damage expanding out from the area centred approximately on grid J-21. Most of the blast damage identified was in the basement. Blast damage observed above the basement level, primarily vertical blast damage, was mostly seen in the area bounded by the red oval in Figure 3. The band saw blade seen hanging over the roof beam at grid J-20/21, the collapse in the area of grid G-20 and the trajectory of the large wooden door, are strong indicators of a basement explosion.

Before the explosion, the beam on which the band saw blade was hanging at grid J-20/21 was flush with the ceiling. The band saw blade was somewhere on the operating floor. In order for the band saw blade to end up hanging on the beam it had to have been blown up by a blast from below. At the same time the roof had to have been blown up from the beam so that the band saw blade could land on it.

Most of the collapse observed in the mill could be attributed to the fire that followed the explosion. However, the collapse at grid G-20 was much more significant than in other areas and it was the only area where a large area of the operating level collapsed into the basement. This suggests that the area of the operating floor at grid G-20 was destabilized by an event other than the fire. Following the explosion, Witness #8 exited the basement washroom and turned right toward the millwrights shop; he intended to exit through grid G-20 but his escape route was blocked by debris. It is likely that the debris that blocked Witness #8’s route was the collapsed

material from the operating floor. Based on this information the collapse at grid G-20 was likely a direct effect of the explosion.

The large wooden door was located on the north wall of the mill at grid L-25 on the operating level. Rather than being blown directly out from the north wall, the door was propelled in a north-easterly direction in a line from grids G and J-20. If the door had been blown in a horizontal trajectory it would have struck the conveyor outside the building. However, the door was blown up over the conveyor suggesting the propelling force originated below the door in the basement.

Based on the preceding information a secondary explosion very likely occurred in the basement in the area of grids J-20/21.

Information from Witnesses 3, 4 and 8 indicate some lights were still on after the main explosion. Information from Witness #3 was that approximately three minutes after the main explosion there was a bang then the lights went out.

The Log Handling Transformer, which was directly south of the Log Handling PDC, was displaced to the south about 15 cm. This would suggest a blast front moving north to south. The combination of witness information and physical evidence, suggests at least one smaller blast occurred, after the secondary explosion, somewhere north of the PDC, possibly in the area of grids J-23 or J-24.

5.2 Cause of the Explosion

Analysis of the cause of the explosion is based on the following information:

- the explosion occurred within 8 minutes of the 21:30h break,
- at break time the large head-rig operator routinely blew wood dust from the rig with compressed air,
- when the large head-rig operator blew down the large head-rig, he would blow the wood dust down into the 12P conveyor.
- The 12P conveyor opened out in the basement at grid J-23/24,
- many of the light fixtures and electrical connection boxes and cabinets in the mill were not rated for use in explosive atmospheres,
- when examined, electrical connection boxes and cabinets were found to contain fine wood dust,
- most of the equipment and horizontal surfaces in the basement that were not burned were coated with wood dust,

The event occurred as an explosion followed by a fire.

5.2.1 Explosive Fuel Sources

The explosive fuel sources that were investigated and may have been present in the mill at the time of the explosion were:

- portable propane and acetylene cylinders,
- hydraulic systems,

- wood dust, and
- boilers and pressure vessels.

Of these fuels, only wood dust could have been present in the mill in a quantity sufficient to cause the observed blast damage.

In order for a dust explosion to occur, five conditions are required. These are an explosive fuel, dispersion of the fuel, air mixed with the fuel in the right proportions, an ignition source and confinement. These may be referred to as a dust explosion pentagon (Figure 4).

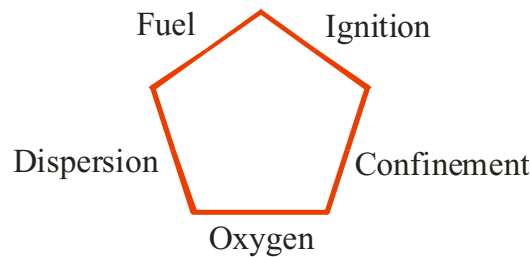


Figure 4: Dust Explosion Pentagon

In the case of dust explosions, there is frequently a primary explosion or event that throws dust into suspension where it mixes with air. The dust cloud may then be ignited by either heat from the primary explosion or by another ignition source causing a more violent secondary explosion.

Any of the explosive substances listed in Section 4.2, Explosive Potential, could have initiated the primary explosion. However, no evidence, such as ruptured containers, pressure vessels or piping, was found to indicate this occurred. As such, with the exception of wood dust, all of the explosive substances listed in Section 4.2 could be reasonably ruled out. Therefore, based on the available information, both the primary and secondary explosions were very likely¹ fuelled by wood dust.

The explosion occurred approximately eight minutes into the 21:30h break. Information from witnesses was that at the 21:30h break the large head-rig operator routinely blew down his machine with compressed air. Blowing down the large head-rig would have blown a significant amount of wood dust into suspension where it could then have been readily ignitable. There was no evidence or witness information of any other event that could have put a significant amount of dust into suspension at the time of the explosion. Additionally, witness information and blast damage place the origin of the explosion in the area where dust from the blow down would have been concentrated (Figure 3, red oval). Therefore, based on the available information, the blow-down of the large head-rig very likely contributed to the explosion by placing a quantity of wood dust into suspension before the blast.

5.2.2 Ignition Sources

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

- an electrical occurrence in a panel or other equipment (such as arc flash, other arcing, or normal sparking of contacts),
- sparks or heat from electrical appliances, panels, wiring and fittings,

- heat generated by lighting equipment,
- heat or flame from portable propane or acetylene equipment,
- sparks from saws and machinery,
- heat generated by machinery due to friction, and
- a pre-existing smouldering fire.

Examination of the numerous electrical panels, appliances, wiring and fittings in the area of origin showed no definitive evidence of an electrical occurrence, such as an arc flash, arcing, sparking or heat that could be directly related to the cause of either a primary or secondary explosions. Evidence of possible arcing was noted in some locations. However, it was determined that this arcing was a result rather than the cause of the explosion (eg: the main power feed from the Log Handling Transformer to the Log Handling PDC). In some locations, electrical components were too severely damaged to provide any useful information. Based on the foregoing, an electrical event can neither be confirmed nor ruled out as the ignition source of either the primary or secondary explosions.

The explosion occurred during the 21:30h break when the activity level in the mill was low. There was no evidence that any portable propane or acetylene appliances were being used and the saws and machinery in the area of origin were shut down. Based on this information, heat or flame from portable propane or acetylene appliances can reasonably be ruled out as the ignition source. Further, sparks from saws or machinery, can reasonably be ruled as unlikely to have ignited the primary or secondary explosions.

Within the area of origin, no definitive evidence was found that heat due to friction was the ignition source of the primary or secondary explosions. The heat of the fire could have obliterated evidence of overheating. However, the explosion occurred at break when the machinery was shut down and none of the witnesses reported noting any overheating or other problems suggestive of overheating of machinery. Based on the preceding information it is unlikely that heat due to friction was the ignition source of the primary or secondary explosions.

Sparks from saws or machinery and heat due to friction can cause smouldering fires in wood dust and wood waste which could ignite dust in suspension. For the purposes of this discussion these fires will be referred to as pre-existing smouldering fires. Smouldering fires produce heat, smoke and, in the later stages, light, all of which are detectable by the human senses. Witnesses were in and out of the area of origin throughout the day and none of them reported detecting a smouldering fire before the explosion. Nor was anything detected by the fire suppression/detection system. As such, it is unlikely a pre-existing smouldering fire was the ignition source of either the primary or secondary explosions. However, despite the low likelihood, this possibility cannot be ruled out absolutely.

Another possible ignition source of the explosion that must be considered is the lighting equipment. Many of the lighting fixtures in the mill were open bulb fixtures with metal halide bulbs. The operating temperature of metal halide light bulbs can range from 250⁰C to 500⁰C. The ignition temperature of pine dust is approximately 250⁰C. With open bulb fixtures, fine wood dust can collect on the light fixture and bulb. Over time the heat from the bulb and/or fixture can cause the dust to decompose due to pyrolysis. When pyrolysis occurs, the ignition temperature of the wood dust is gradually reduced. If the dust remains in contact with the heated surface long enough, ignition can occur, particularly if the dust is disturbed. It is possible that

airborne dust from a blow-down, or other occurrence, disturbed pyrolyzed dust on a light fixture or fixtures which then ignited a primary explosion. Due to the extent of the damage in the area of origin this potential ignition source could neither be confirmed nor ruled out.

Of the possible ignition sources discussed:

- 1) heat or flame from portable propane or acetylene equipment can be ruled out,
- 2) sparks from saws and machinery, heat generated by machinery due to friction, and a pre-existing smouldering fire can neither be confirmed nor ruled out but can be considered unlikely, and
- 3) an electrical occurrence in a panel or other equipment, and heat generated by lighting equipment can neither be confirmed nor ruled out.

None of the witnesses reported any conditions that would indicate or suggest that an electrical occurrence in a panel or other equipment or heat generated by lighting equipment could have ignited either the primary or secondary explosions. However, compared to other types of equipment, there were all kinds of electrical equipment in the area of origin available to fail and a greater likelihood of a problem or pending failure being undetected. Therefore, it is likely the ignition source of the primary explosion was an electrical occurrence in a panel or other equipment, or heat generated by lighting equipment. The ignition source of the secondary explosion could have been any of the forgoing possibilities or heat from the primary explosion. The normal air supply in the mill would have provided the oxygen necessary for an explosion and the mill structure would have provided the confinement.

6.0 CONCLUSIONS

The following conclusions are based on our examination and analysis of the information available to date. Conclusions may change if or when more information becomes available.

- 6.1) An explosion very likely originated in the basement in the area of grids J-20/21.
- 6.2) There was likely a blast after the main blast, somewhere north of the PDC, possibly in the area of grid J-24/25.
- 6.3) The five elements required for a dust explosion to occur were all present in the mill in the area of origin.
- 6.4) Several possible ignition sources were investigated including: lights, 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): 50 Photographs
Annex A: References

Notes:

1. Likely and very likely are terms used by SAMAC Engineering Ltd. to indicate probabilities of about 75% and 95% respectively.

Annex A. List of References

- A. National Fire Protection Association (NFPA) Fire Protection Handbook
- B. NFPA 921, Guide For Fire and Explosion Investigations
- C. NFPA Inspection Manual
- D. CSA Guide for the Design, Testing, Construction, and Installation of Equipment in Explosive Atmospheres
- E. Metal Halide Lamps, Harvard University Health and Safety Group

SAMAC Photographs



Photograph 1

Facing southwest looking at the door (green arrow) and steel track (yellow arrow) from north side of the operating floor.

Note: the explosion carried the door up and over the conveyor (blue arrow).

Note: the red arrows in this and following photographs correspond with red “vector” arrows in Figure 4 indicating blast direction.



Photograph 2

Blast debris on the north side of the mill.

Note: the origin of door (green arrow) and final location (yellow arrow).

SAMAC Photographs



Photograph 3

Blast debris north side.

Note: the location of the large head rig (green arrow).



Photograph 4

Blast debris east side.

SAMAC Photographs



Photograph 5

Blast debris west side.



Photograph 6

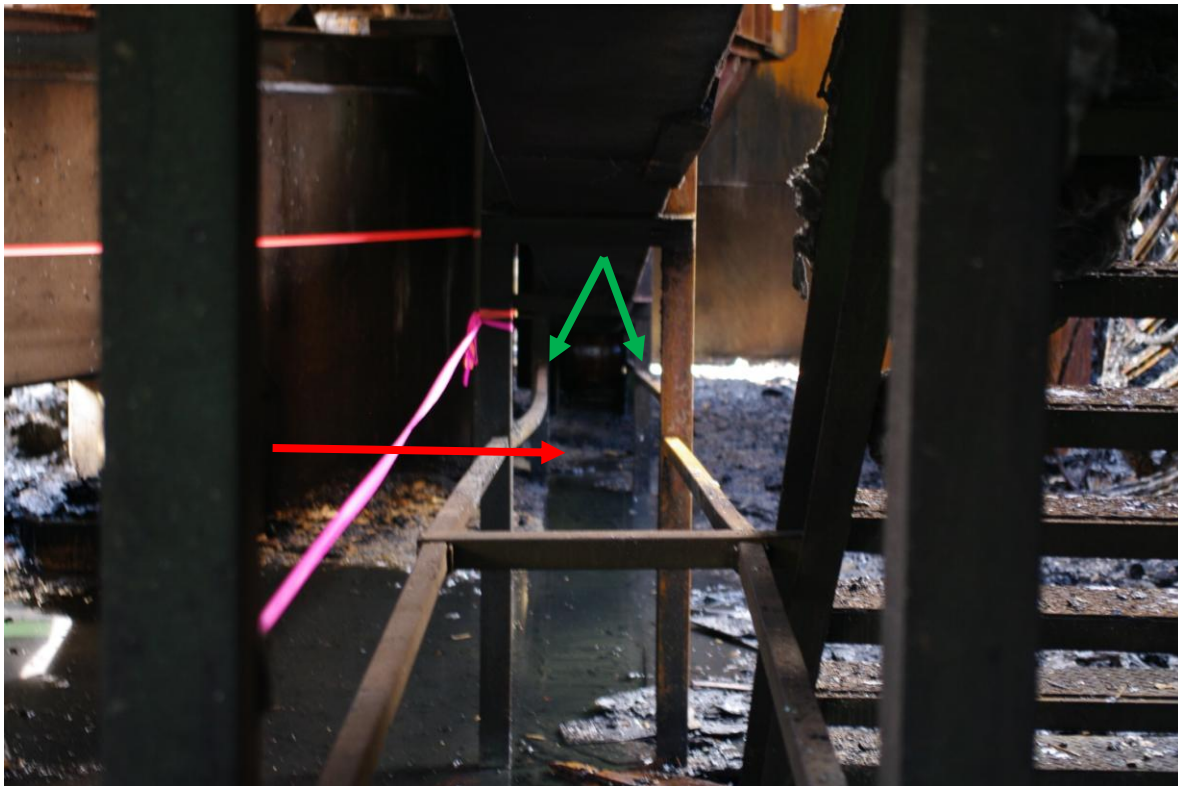
Blast debris south side.

SAMAC Photographs



Photograph 7

Facing SE looking at broken weld and separation of floor plates, grid G-27.



Photograph 8

Facing north looking at bowed railings (green arrows), grid H-24/25.

SAMAC Photographs



Photograph 9

Facing south
damage to vent
trunking, north grid
24/25.



Photograph 10

Facing south, grid
L-21/22.

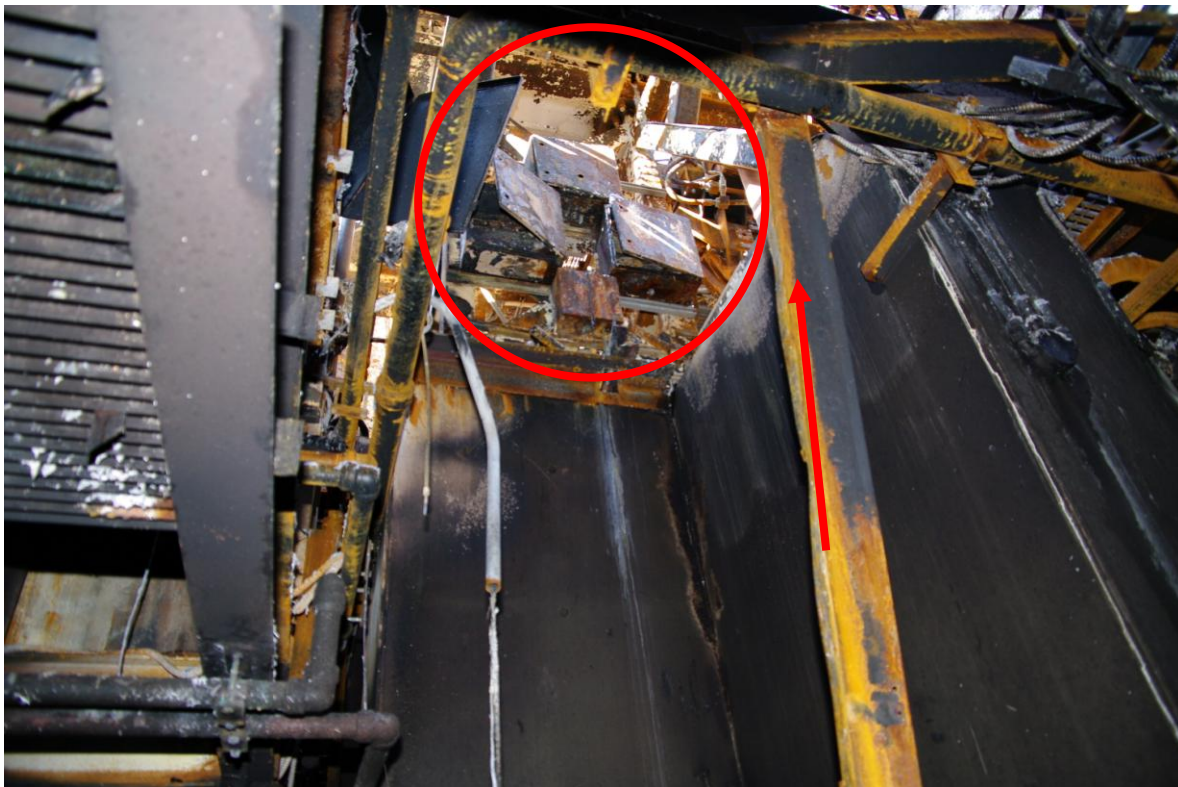
Note: the door
displaced outwards
(green arrow).

SAMAC Photographs



Photograph 11

Looking at a protective screen on basement floor displaced east of its original position, grid J-25/26.



Photograph 12

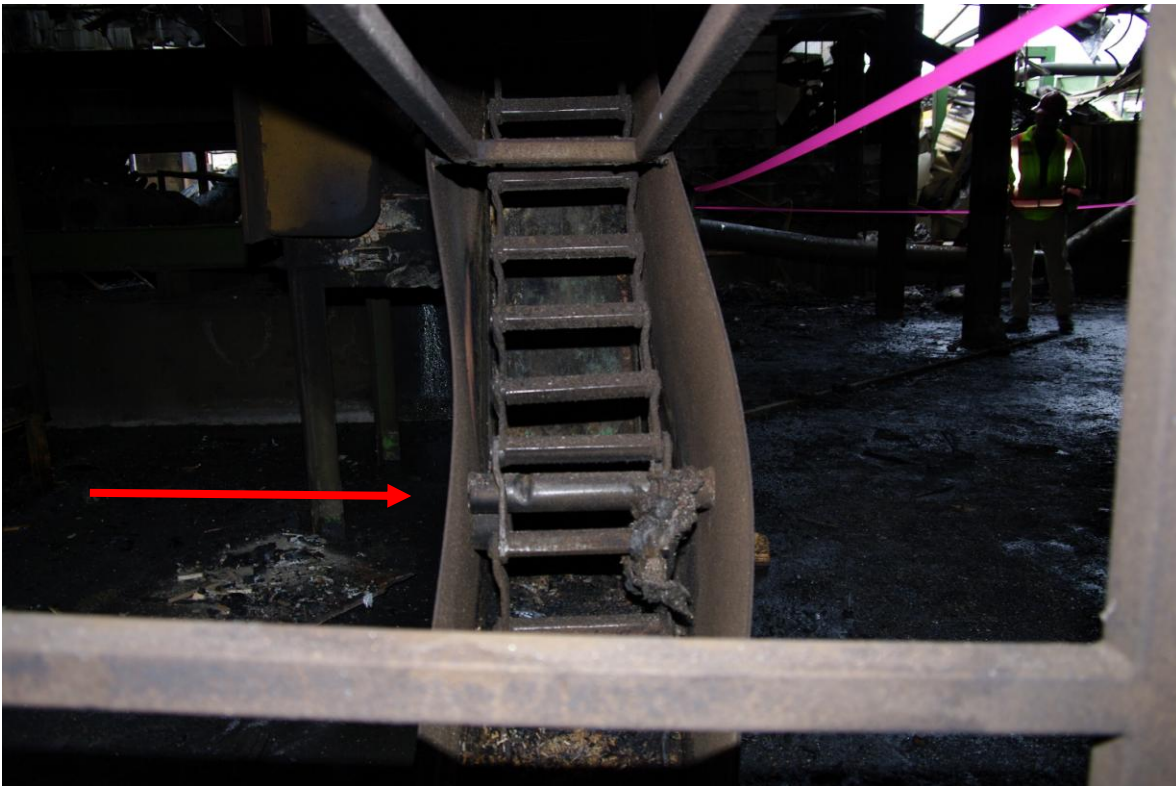
Looking up from basement to operating floor; cabinets blown open (circle), grid H/J-22.

SAMAC Photographs



Photograph 13

Facing west looking at door and frame to the store room at grid J-23 (green arrow).



Photograph 14

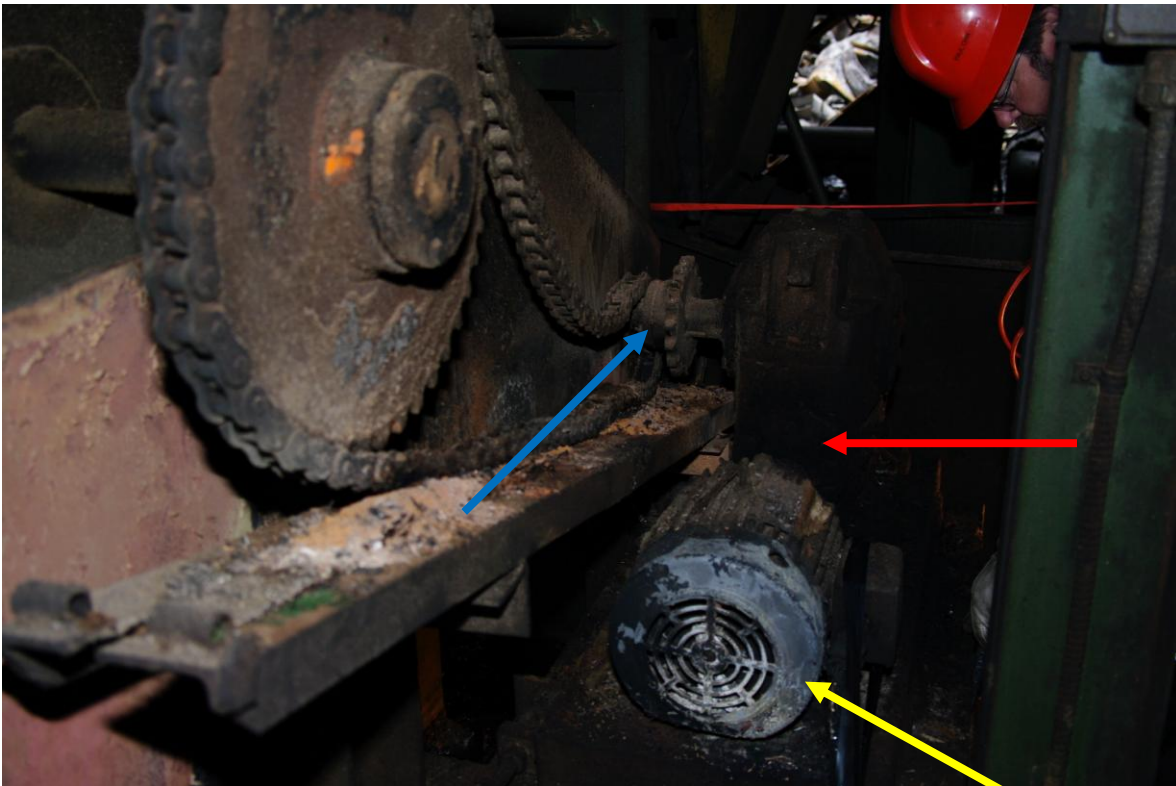
Facing north looking at conveyor 12P below the LHR, grid J-23/24.

SAMAC Photographs



Photograph 15

Facing north at vent trunking grid L-24/25.



Photograph 16

Facing south looking at the motor to conveyor 6P, J-24.

Note: chain off to east (blue arrow) and burn on west side of motor end cover (yellow arrow).

SAMAC Photographs



Photograph 17

Facing south looking at the area where an extensive amount of collapse occurred (green arrow) at grid J-20.

Note: a band saw blade (yellow arrow) hanging over a steel beam that was flush with the ceiling before the explosion.

Note also: the pile of band saw blades on top of the rubble below the hanging blade (blue arrow).



Photograph 18

Facing west looking at the band saws on the operation floor at grid K-20/21.

Note: the blade covers (green arrows) are out of their normal positions.

SAMAC Photographs



Photograph 19

Facing west looking at the southeast corner of the bag house filtration system (green arrow), north-grid 17/18.

Note: impact damage to the southeast corner of the unit.



Photograph 20

Light fixture over conveyor 12P grid G-24.

Note: the bottom of the frame is missing (oval).

SAMAC Photographs



Photograph 21

Facing south looking at the area in the basement where the greatest amount of collapse from above occurred, grid G - 19/20.



Photograph 22

Facing east looking at a protective screen displaced out to the west, grid J - 17.

SAMAC Photographs



Photograph 23

Facing west looking at damage to the dust extraction trunking, grid H-16.



Photograph 24

Facing north looking at a filing cabinet displaced to east to west, grid H-15.

SAMAC Photographs



Photograph 25

Facing south looking at the contents of a store room (green arrow) displaced east to west, grid E/F-15/16.



Photograph 26

Facing east looking at doors of an electrical vault displaced open east to west, grid G/H-16.

SAMAC Photographs



Photograph 27

Facing east looking at the small head-rig operator's booth, grid J-22.



Photograph 28

Facing east looking at the decking in front of the small head-rig operators booth, grid J-22.

Note: the deck plates are separated and bowed upwards (arrow).

SAMAC Photographs



Photograph 29

Facing north looking at the underside of the decking in front of the small head-rig operators booth shown in photograph 28, grid J-22.



Photograph 30

Facing south looking at the door of the maintenance lunch room (green arrow) displaced north to south, grid F-21/22

SAMAC Photographs



Photograph 31

Facing south looking at the outside door to the parts storage room, displaced north to south, grid D-22/23.

Note: the impact damage to the bottom of the door (circle).



Photograph 32

Facing north looking at a filing cabinet displaced east to west, grid H-15.

SAMAC Photographs



Photograph 33

Facing north looking at bent steel framing below the basement ceiling (circle) displaced west to east, grid L-24.



Photograph 34

Facing east looking at a steel stand on the operating floor, displaced approximately 2.5m east of its original position, grid J-22/23.

SAMAC Photographs



Photograph 35

Facing south looking at the maintenance shop.

Note: the lathe (circle) was displaced north to south and tipped on its side, grid E-20.



Photograph 36

Looking at the sawmill transformer. Grid D-23.

Note: the ground wire (green arrow) was found arced and separated.

SAMAC Photographs



Photograph 37

Looking at the log handling transformer.

Note: the right side of the transformer was shifted approximately 10cm to the south, grid D-23.



Photograph 38

Looking at a lighting panel, grid H-23.

SAMAC Photographs



Photograph 39

Looking at the Power Distribution Centre (PDC), grid G-23.

Note: the spatial relationship between the sawmill transformer (Photograph 37), the lighting panel (Photograph 38), and the PDC.



Photograph 40

Looking at a hole burned through a sprinkler pipe and cable tray (arrows) above the PDC, grid G-23.

SAMAC Photographs



Photograph 41

Facing north looking at the south side of the major collapse shown in Photographs 17 and 21, grid G-20.



Photograph 42

Looking at examples of unprotected lighting in the west side of mill (this and 6 following photographs).

SAMAC Photographs



Photograph 43
West side of mill.



Photograph 44
Looking at examples of unprotected fluorescent lighting (arrow) (this and following photograph), grid J-23.

SAMAC Photographs



Photograph 45

Grid J-22.



Photograph 46

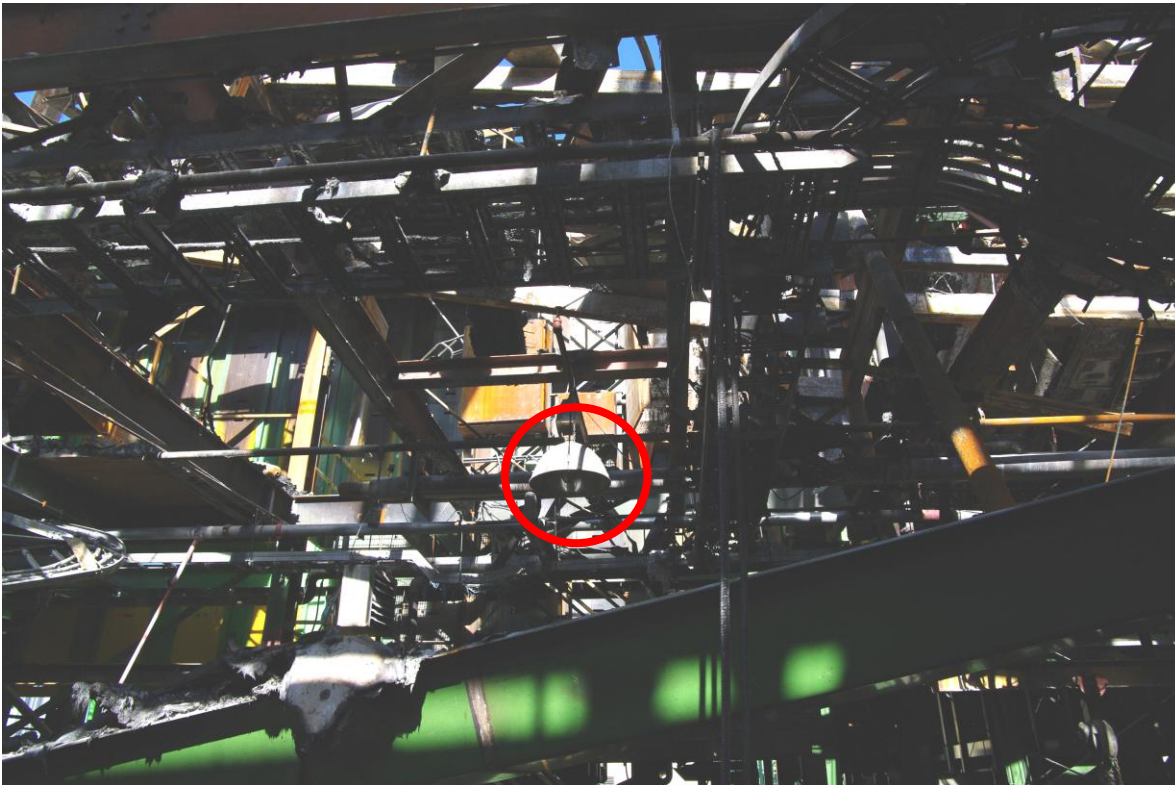
Looking at an example of unprotected lighting in the east side of mill.

SAMAC Photographs



Photograph 47

Southeast area of mill.



Photograph 48

West side, grid E/F-14/15.

SAMAC Photographs



Photograph 49

Motor 14P

Note: similar directional damage as motor 6P (Photograph 16).



Photograph 50

Looking at the door and steel beam shown in Photograph 1 (red outline).