APPLICATION OF A LOSS CAUSATION MODEL TO THE WESTRAY MINE EXPLOSION

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On 9 May 1992 an underground explosion destroyed the Westray coal mine located in Plymouth, Nova Scotia, Canada. Twenty-six miners were killed. This paper attempts to resolve the multiple layers of accident causation by systematic application of a loss causation model. Immediate and basic causes having their origin in lack of management control are identified. The analysis helps to identify the lessons to be learned from this disaster, the two most important of which are the need for a rigorous loss management system and an appropriate attitude toward industrial safety.

Keywords: loss causation; domino model; explosion; process safety management.

FOREWORD

This paper is a case study developed using public domain resources. The work was undertaken for the sole purpose of identifying the lessons to be learned from the Westray coal mine explosion. As reported by Crowl and Louvar, the study of case histories provides valuable information that can be used to improve procedures to prevent similar accidents in the future. In industry, one can learn from case histories, or ignore them and be involved in potentially life threatening accidents. Case histories find wide use in the CPI (Chemical Process Industries) in a variety of applications, such as the example recently reported by Mahnken of incorporating them into process hazard analyses.

INTRODUCTION

A loss causation model is a tool that can be used in accident investigation to assist in determining the root causes of an accident in the workplace. There are many different variations of loss causation models. (See, for example, the Bellamy and Geyer model as reported by Lees, and Kletz’s ‘layered’ model as reported by Lees, and also Crowl and Louvar.) The loss causation model applied in the current work is commonly known as the domino model (Figure 1). This is a structured method of identifying and categorizing the multiple events that cause an accident.

First, the loss that occurred is described in terms of the following:

- damage to the process and/or equipment involved, taking into account revenue lost due to inactivity of the process.
- environmental damage caused by the accident.

Second, the incident that occurred is described in detail, in terms of the substances (e.g., methane) and events that transpired (e.g., fire, explosion) and resulted in physiological and/or structural threshold limits being exceeded. Then, the immediate causes of the accident are identified. Substandard practices could include failure to use personal protective equipment, removing safety devices, and the failure to follow procedures. Substandard conditions include inadequate ventilation, excessive exposure to harmful materials, defective equipment, and inadequate personal protective equipment.

After the immediate causes of the accident are analysed, the basic causes are investigated. Some personal factors that could bear responsibility are inadequate employee capability, lack of knowledge by the employee about possible dangers, a high stress level in the work environment, and improper job motivation imposed by management. Job-related factors could also be responsible, such as inadequate leadership, inadequate maintenance, inadequate work standards, and the abuse or misuse of equipment.

Lack of control of the workplace by management leads to most of the basic causes previously mentioned. An inadequate loss management programme can lead to potential accidents and shows a fundamental lack of management control. Inadequate programme standards or inadequate compliance with existing standards also illustrate a need for changes that should be incorporated by management.

The basic premise of the domino loss causation model is thus one of multiple causes—accidents are seldom, if ever, the result of a single event. On the contrary, there are typically several layers or levels of causation. Immediate
 causes (essentially symptoms) exist because of deeper, more systemic basic causes, which in turn find their origin in factors that lie primarily within the control of management.

A case study using the domino loss causation model was developed for the Westray coal mine explosion, which occurred in Plymouth, Nova Scotia (Pictou County), Canada, on 9 May 1992, killing 26 miners. The methane levels in the mine were consistently higher than regulations permitted, which was caused by inadequate ventilation in the mine. Flammable dust concentrations were also higher than permissible levels due to inadequate clean-up of coal dust and the fact that there was no crew in charge of rock dusting (inerting the coal dust with limestone or dolomite). These and many other factors contributed to the poor work conditions that continually existed in the Westray mine and made it an accident waiting to happen. All of these substandard conditions and practices could be attributed to the lack of concern that management had towards safety issues in the mine, which was one of the primary root causes of the problem at Westray.

Other authors, such as Munro, have commented on the roles of the inspectorate and other government officials in the Westray disaster (roles which, for the most part, outside the scope of the current paper). The analysis that follows relies exclusively upon public domain references such as the book by Jobb and, primarily, the Report of the Westray Mine Public Inquiry (Justice K. Peter Richard, Commissioner). Significant contributing factors are given for each level of causation, with the objective of avoiding such costly incidents in the future. Again, this is the primary purpose of case studies of industrial accidents.

![Diagram of domino loss causation model]

**LOSS**

Losses resulting from the Westray explosion include:

- Deaths of 26 human beings.
- Extensive damage to the mining equipment and the mine itself.
- Bankruptcy of the parent company, Curragh Resources. The mine had to be closed because it was rendered inoperable, thus removing a source of additional revenue for the company.
- Default of millions of dollars in provincial and federal government loans.
- Millions of dollars of severance, workers' compensation, pension plan, and unemployment insurance payments.
- Cost of running an extensive criminal investigation and trial involving the mine and underground managers.
- Loss to Nova Scotia Power (electrical utility company) of approximately 700,000 tonnes of Westray coal.
- Future wages of the 26 miners killed in the explosion.
- Future income of other residents of Pictou County as a result of the mine becoming inoperable.
- Enormous personal losses faced by the 26 miners' families and friends, on which it is impossible to put a price tag.

**INCIDENT**

There was an explosion in the Westray mine on the morning of 9 May 1992. This incontrovertible fact means that the fire triangle criteria (fuel, oxidant and ignition source) were satisfied. The Inquiry Report gives the fuel source as initially an accumulation of methane (due to methane layering at the mine roof) which, once ignited, triggered a full-blown coal dust explosion. The oxidant was the oxygen in the mine atmosphere. The methane ignition source is postulated to have been sparks from the continuous miner striking pyrites or sandstone at the coal face being worked in the Southwest section of the mine. The existence of other potential ignition sources has been recognized by the Inquiry Report and several other authors (for example, Munro).

This sequence of a primary gas explosion leading to a secondary coal dust explosion is well-documented in the literature (e.g., Hertzberg et al.). The term secondary explosion is somewhat misleading, however, because of the devastating effects of a coal dust explosion due to the overpressures and rates of pressure rise generated. Figure 2 shows representative data from laboratory-scale, closed-vessel (261) testing of a coal dust having a mass mean diameter of 19 μm and a volatile content of 34 weight %. The phenomena displayed in Figure 2 (e.g., a relatively rapid rise and then plateau in both overpressure and rate of pressure rise) are well established.

**IMMEDIATE CAUSES**

Substandard practices are behaviours that could permit the occurrence of an accident. Substandard practices that contributed to the Westray explosion include:

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Improper use of the ventilation system (e.g., re-rerouting without provision for personnel). Munro\textsuperscript{5} also refers to the use of contaminated air to ventilate working areas and the practice of allowing intake air to pass by unventilated abandoned workings.

- Poor housekeeping with respect to clean-up and removal of coal dust.
- Continuation of mining in spite of inoperable methane detection devices.
- Storage of fuel and re-fueling of vehicles in non-flameproof areas underground.
- Inadequate rock dusting procedures.

Figure 3 shows representative data\textsuperscript{10} for the rock dust requirements of coal dust and methane/coal dust mixtures, as determined via laboratory-scale, closed-vessel (261) testing. (This is the same coal dust for which basic explosibility data are given in Figure 2.) The rock dust (dolomite) in Figure 3 has a mass mean diameter of 37 $\mu$m and a calcium/magnesium analysis of 55 weight % CaCO$_3$ and 35 weight % MgCO$_3$. Significant amounts of rock dust, a thermal explosion inhibitor, are required to reduce the explosion pressure and rate of pressure rise to acceptable levels. The co-presence of methane results in an increase in the amount of rock dust required for explosion suppression. Again, these are well-established phenomena.

**Substandard conditions** are circumstances that could permit the occurrence of an accident\textsuperscript{4}. Substandard conditions that contributed to the Westray explosion include:

- Inadequate ventilation system design and capacity. Munro\textsuperscript{5} includes the following points in his list of ventilation system deficiencies: inadequate airflow for clearing methane from the working face during mining, inadequate airflow to prevent the layering of methane at the roof, and inadequately constructed airflow devices for controlling airflow underground.
- Poor state of the mine roof, with attendant frequent roof-falls.
- Inadequate system to warn of high methane concentrations.
- Thick layers of coal dust having an unacceptably high level of combustible matter.

With reference to the final point above, the Coal Mines Regulation Act\textsuperscript{11} of the province of Nova Scotia (which applied to the Westray mine) stipulates an upper limit of 35 weight % combustible matter in mine dust. Alternatively, this limit may be expressed as a minimum of 65 weight % incombustible matter (taken to be the inherent ash and moisture in the coal dust plus admixed rock dust). The Act\textsuperscript{11} further specifies that the percentage of incombustible dust is to be increased by 10% for each 1% of methane present in the mine atmosphere. In terms of the scientific phenomena involved, the basis for these regulations is clearly demonstrated by the data in Figure 3.

**BASIC CAUSES**

Basic causes are the underlying or root causes for the existence of immediate causes\textsuperscript{4}. As with the immediate level
of causation (substandard practices and substandard conditions), it is helpful to separate basic causes into two broad categories (personal factors and job factors).

**Personal factors** that contributed to the Westray explosion include:
- Lack of mining experience of personnel working in the mine.
- Lack of knowledge of safe underground work practices.
- Physiological stress caused by methane overexposure and fatigue due to 12-hour shifts.
- Psychological stress caused by fear of reprisal for reporting safety concerns.
- Improper motivation by which production proceeded at the expense of safety.

**Job factors** that contributed to the Westray explosion include:
- Lack of proper orientation and training for new employees.
- Inadequate follow-through on recommendations from mine inspectorate personnel.
- Poor communication of standards (e.g., concerning the roles and responsibilities of occupational health and safety committees).
- Inadequate purchasing and maintenance of rock dust inventory.
- Inadequate leadership in terms of assignment of responsibility (e.g., mine examiner and production supervisor responsibilities undertaken by the same person).
- Lack of safe work practices and procedures.
- Inadequate engineering during mine design and planning with respect to potential loss exposures (e.g., intersecting geological fault lines leading to frequent roof-falls).

### LACK OF MANAGEMENT CONTROL

Lack of control in managing loss is generally due to deficiencies in one or more of three areas—the loss management programme or system itself, the standards identified and set for the loss management programme, and the degree of compliance with such standards.

**Inadequate programme elements** that contributed to the Westray explosion include:
- Management commitment and accountability to safety matters.
- Management of change procedures.
- Incident investigation (including near miss reporting and investigation).
- Training (orientation, safety, task-related, etc.).
- Task definition and safe work practices and procedures.
- Workplace inspections and more detailed hazard identification methodologies.
- Programme evaluation and audit.

**Inadequate programme standards** that contributed to the Westray explosion include standards relating to virtually all the programme elements listed above, including inadequate:
- Concern expressed by management toward safety matters.
- Follow-through on inspections for substandard practices and conditions.
- Action on hazard reports submitted by employees.
- Job instructions for employees.
- Equipment maintenance.
- Scheduling of management/employee meetings to discuss safety concerns.

**Inadequate compliance factors** that contributed to the Westray explosion include:
- Poor correlation between management actions and official company policy concerning the relationship between safety and production.
- Compliance to industry practice and legislated standards concerning numerous aspects of coal mining: methane concentrations, rock dusting, control of ignition sources underground, etc. The previously mentioned Coal Mines Regulation Act of the province of Nova Scotia represented the primary external standard for Westray.

### LESSONS LEARNED

The previous sections highlight several important lessons to be learned from this costly tragedy. When viewed in a proactive manner, it becomes obvious that the domino model shown in Figure 1 offers multiple opportunities for loss control. These opportunities occur at the pre-contact (lack of management control, basic causes and immediate causes) stages, contact (incident) stage, and post-contact (loss) stage. In pre-contact control, the main objectives are to reduce risk and prevent accidents from happening in the first place. If an incident were to occur, pre-contact control also involves planning ways to reduce the severity of the loss. The second level of control (contact control) involves measures taken to reduce the degree of damage at the time of the incident. Post-contact control seeks to contain the extent of loss after the accident occurs.

There are lessons to be heeded from Westray for the coal mining industry—reminders of the importance of, for example, rock dusting and underground ventilation. These reminders are technical in nature, and would seem to find little application in the CPI, other than perhaps by extension into the realm of explosion suppression and mitigation techniques such as relief venting. The most critical lessons from Westray, however, are the ones that transcend industrial boundaries and are related to the basic principles of loss management.

In the field of loss management, it is ultimately desired to eliminate risks, hazards and accidents altogether; therefore pre-contact control should be emphasized. This requires attention to both system and **attitude** perspectives. A loss management system—implemented, supported and enforced by management personnel—is absolutely critical. An approach used widely in the Canadian chemical industries is Process Safety Management, or PSM. This management system incorporates such key features as incident investigation, training, and hazard identification. The complete suite of PSM elements is given in Table 1; the MIACC handbook provides details on the various components of each PSM element.

The only acceptable **attitude** toward industrial safety—both morally and, in the case of present-day Nova Scotia,
Table 1. Elements of Process Safety Management (PSM)\textsuperscript{12}.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Accountability: objectives and goals</td>
</tr>
<tr>
<td>2.</td>
<td>Process knowledge and documentation</td>
</tr>
<tr>
<td>3.</td>
<td>Capital project review and design procedures</td>
</tr>
<tr>
<td>4.</td>
<td>Process risk management</td>
</tr>
<tr>
<td>5.</td>
<td>Management of change</td>
</tr>
<tr>
<td>6.</td>
<td>Process and equipment integrity</td>
</tr>
<tr>
<td>7.</td>
<td>Human factors</td>
</tr>
<tr>
<td>8.</td>
<td>Training and performance</td>
</tr>
<tr>
<td>9.</td>
<td>Incident investigation</td>
</tr>
<tr>
<td>10.</td>
<td>Company standards, codes and regulations</td>
</tr>
<tr>
<td>11.</td>
<td>Audits and corrective actions</td>
</tr>
<tr>
<td>12.</td>
<td>Enhancement of process safety knowledge</td>
</tr>
</tbody>
</table>

legally\textsuperscript{13,14}—is expressed by the Internal Responsibility System, or IRS. This concept, which is the foundation of occupational health and safety legislation in Canada, states that every individual in an organization is responsible for health and safety. Primary responsibility lies with each person (manager, supervisor, employee, contractor, etc.) to the extent of their authority and ability to ensure a safe and healthy workplace. In this manner one hopefully avoids the unfortunate occurrence of people in lower levels of management being asked to do jobs for which they are not properly equipped.

While the Internal Responsibility System is in one sense a management system for preventing accidents, it is perhaps more appropriately viewed as a system of personal beliefs shared universally.\textsuperscript{15} Expressed in this way, it becomes clear that attitude toward industrial safety at all levels in a company hierarchy is at least as important as the actual safety management system itself.

**CONCLUDING REMARKS**

Disasters such as the Westray coal mine explosion can be prevented with proper leadership by management on safety issues. Loss causation models (e.g., the domino model used in the current work) are useful tools that aid in the identification of root causes of specific incidents. Pre-contact accident causation levels afford the greatest opportunities for preventing repeat occurrences in the same or different companies and industries. The importance of implementing a loss management programme in industrial organizations cannot be overstated.

**REFERENCES**


**ADDRESS**

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INTRODUCTION

The enclosed video tape runs for about 29 minutes. It is a recreation of an oil rig fire that occurred in the North Sea in 1988. 167 men were killed. Many messages are available including the root cause being traced back to management. The video tape is ideal for a process safety or design course where proper hazard analysis is discussed, or management of change is explained, or permitting systems are discussed (e.g.: lock-tag-try). Another place in the curriculum where the video can be shown are Freshman introductory courses where decision making may be discussed.

This is a very easy SACHE product to use. Simply arrange for a VCR playback machine and a television monitor. Place the tape in the machine. Press play. The message; however, is not so simple. The information that students gain in 29 minutes cannot be covered in any more efficient manner. Paraphrasing Dr. Tony Barrell’s last statements near the end, the outcome from viewing this tape is the prevention of future events like this.

Table 1. Summary of Critical Actions that Led to the Disaster

| Date: July 6, 1988 |
|-------------------|------------------|
| 1. A day maintenance crew begins minor repair work on Pump “A” that is located in Module C the Gas Compression Room. A blank flange is inserted onto a relief line. The flange is not tightened to leak tight. This repair job was to take one shift to complete. Stand-by pump “B” is used to operate the process. |
| 2. Day crew “packs it up” and leaves the Pump “A” minor repair unfinished. |
| 3. Permit to Work (PTW) order for the day repair job is not passed onto the night crew. |
| 4. Pump “B” trips. Night crew is unable to restart. Without this pump or Pump “A”, the platform would have to shutdown production. |
| 5. Member of night crew pulls a PTW for a major repair on Pump “A”. This PTW differs from the one for the minor repair done that day, indicating a different long term repair that hadn’t been started with the exception of electrical isolation. |
| 8. Ignition occurs. An explosion occurs. Many fires follow. |
| 10. Emergency fire water deluge system fails. Automatic start had been turned to manual start. Crew could not reach the manual start button. |
Table 1. Continued:

11. Fires grow in intensity fueled by additional material that back flows into platform from surrounding oil platforms who continued pumping oil to the mainland even when they were aware of Piper Alpha’s dilemma.

12. High pressure gas lines fail. A fire “virtually impossible to fight” results. Energy released within minutes equal to 1.5 times the annual Great Britain energy demand.

13. Portions of the platform slides into the sea. As the event unfolded, 61 men escaped by jumping into the North Sea. 167 men lost their life through smoke inhalation or exposure to fire.

14. Lord Cullen report follows two years later. Root cause traced back to poor management from top to bottom. Failure in communication cited. PTW’s were disregarded and improperly utilized by the crews. Upper management failed to institute emergency response exercises. They did not properly analyze what could happen in the event of an emergency. Emphasis placed on maintaining production no matter what.

Table 2. Video Tape Event Log with Potential Discussion Topics

<table>
<thead>
<tr>
<th>Video Running Time</th>
<th>Event</th>
<th>Discussion Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00:00</td>
<td>Very beginning of tape</td>
<td></td>
</tr>
<tr>
<td>0:00:20</td>
<td>Start</td>
<td>Title Spiral to Disaster – (CD) Why did the film maker select this title?</td>
</tr>
<tr>
<td>0:00:38</td>
<td>A Survivor testimony</td>
<td></td>
</tr>
<tr>
<td>0:00:57</td>
<td>North Sea</td>
<td>Piper Oil Field – Production rate 30,000 tons per day, Revenue- 5.6 million dollars per day</td>
</tr>
<tr>
<td>0:01:23</td>
<td>Date and time</td>
<td>Night of July 6, 1988, 226 men aboard the platform</td>
</tr>
<tr>
<td>0:01:36</td>
<td>Burning Platform</td>
<td>Built by Occidental Petroleum in 1976 for oil recovery only. Adapted to extract gas later</td>
</tr>
<tr>
<td>0:02:37</td>
<td>Cross section of platform</td>
<td>Note the location of the gas works.</td>
</tr>
<tr>
<td>0:03:14</td>
<td>Men working on platform</td>
<td>Note that the major process of oil recovery continued to operate while maintenance work was in progress. (CD) When should a process be totally shut down? At what level should this decision be arrived at?</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Details</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>0:03:42</td>
<td>Men working on the pumps</td>
<td>Pump A taken out of service. A pressure safety valve (relief valve) was being serviced.</td>
</tr>
<tr>
<td>0:04:02</td>
<td>Metal pipe with metal blank flange attached.</td>
<td>Common for pipes taken out of service to be blanked off by a blank flange. Note that this installed blank flange was not leak tight. Normally, these are intended to be leak tight.</td>
</tr>
<tr>
<td>0:04:22</td>
<td>Two permits to work (PTW) filled out</td>
<td>One permit for the valve repair. One permit for a long term pump maintenance of 2 weeks.</td>
</tr>
<tr>
<td>0:04:52</td>
<td>Control Room not notified about work permit 1</td>
<td>Communication/Shift change/ (CD) How should shift change communications be handled?</td>
</tr>
<tr>
<td>0:05:15</td>
<td>Dr. Tony Barrell, Former Chief Executive, North Sea Safety</td>
<td>Dr. Barrell offers analysis throughout this tape. (CD) Work permits were treated as a “formality”. How do you get employees and contractors to understand the serious of work permits and related items?</td>
</tr>
<tr>
<td>0:05:50</td>
<td>Automatic Fire Deluge switched to manual</td>
<td>(CD) When should safety systems be over-ridden. How do you assess when it is proper to override a safety system? Murphy’s law? Is it always true?</td>
</tr>
<tr>
<td>0:06:26</td>
<td>9:26 PM Pump B trips</td>
<td>If gas supply stops, all power is lost. (CD) What can be done when the power is lost? (Fail safe, emergency backup)</td>
</tr>
<tr>
<td>0:07:12</td>
<td>9:52 PM Engineer notices that Pump A may be available</td>
<td>PTW checked by engineer appears to only be isolated electrically. He is unaware of the 2nd permit. (CD) Would you override a PTW if you thought it might keep production going?</td>
</tr>
<tr>
<td>0:08:53</td>
<td>9:57 PM Pump A restarted</td>
<td></td>
</tr>
<tr>
<td>0:09:36</td>
<td>Metal plate leaks</td>
<td>70 kg in 30 seconds of gas enters into the room.</td>
</tr>
<tr>
<td>0:09:51</td>
<td>Emergency shut down button pressed</td>
<td></td>
</tr>
<tr>
<td>0:10:23</td>
<td>Oil fire</td>
<td>Weakness of fire walls vs blast walls (CD) Think of the unthinkable. How can we do this in hazard analysis? (HAZOPS and methods)</td>
</tr>
<tr>
<td>0:11:00</td>
<td>10:04 PM Emergency procedures collapse</td>
<td>“May Day” is issued. No public announcements on board.</td>
</tr>
<tr>
<td>0:12:13</td>
<td>Men were not told to abandon the platform. Life boat is isolated from the men</td>
<td>(CD) Emergency preparedness. Is it important to practice emergency situations with all personnel involved?</td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td>Notes</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>0:12:44</td>
<td>100 men move to the accommodation block below the helideck</td>
<td></td>
</tr>
<tr>
<td>0:13:28</td>
<td>Two men attempt to go to the fire deluge pumps</td>
<td></td>
</tr>
<tr>
<td>0:13:41</td>
<td>Oil Fire continues</td>
<td></td>
</tr>
<tr>
<td>0:14:00</td>
<td>Back pressure from other oil rigs noted</td>
<td></td>
</tr>
<tr>
<td>0:14:24</td>
<td>Operators at Claymore rig shown. Manager decides to continue to pump.</td>
<td><em>(CD)</em> A neighboring plant is under deress. What actions should you be thinking about? How close does the neighbor need to be 50 ft, 20 miles? What links needed to be known about in this case to assess this situation properly?</td>
</tr>
<tr>
<td>0:15:10</td>
<td>“Don’t shut down”</td>
<td>Tartan Rig manager received approval to continue pumping from a supervisor in Aberdeen. <em>(CD)</em> Home offices can be a nuisance. How do you deal with managers and supervisors who are not physically close to a situation?</td>
</tr>
<tr>
<td>0:15:40</td>
<td>Dr. Barrell</td>
<td>Shut down is not a decision one is likely to make if there is a fear of being blamed and penalized. <em>(CD)</em> How do we overcome this barrier?</td>
</tr>
<tr>
<td>0:16:40</td>
<td>Report about high pressure gas lines</td>
<td>A previous report mentions the danger of high pressure gas lines. A fire virtually impossible to fight. Nothing was done to change or improve the situation. <em>(CD)</em> when should outside professional advice be ignored?</td>
</tr>
<tr>
<td>0:17:22</td>
<td>10:20 PM Explosion of gas lines</td>
<td>3 tons per second of gas exits the pipeline. Equal to 1.5 times the consumption of all of Great Britain.</td>
</tr>
<tr>
<td>0:18:07</td>
<td>Some took manners into their own hands</td>
<td></td>
</tr>
<tr>
<td>0:18:24</td>
<td>Claymore telephone link knocked out. “Can we shut down now?”</td>
<td><em>(CD)</em> “We should shut down” – What do you think? See next item also.</td>
</tr>
<tr>
<td>0:19:16</td>
<td>“We can see the fire, can we shut down?”</td>
<td><em>(CD)</em> discuss the emotions and thoughts that these two men experiencing during this period.</td>
</tr>
<tr>
<td>0:19:51</td>
<td>Rescue Boat Feris</td>
<td>Too long to react. <em>(CD)</em> Discuss importance of emergency preparedness drills (see above).</td>
</tr>
<tr>
<td>0:20:25</td>
<td>10:50 PM 2nd gas lines bursts. Intense melting.</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>Event</td>
<td></td>
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<td>--------</td>
<td>--------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>0:21:07</td>
<td>Claymore shuts down</td>
<td></td>
</tr>
<tr>
<td>0:21:34</td>
<td>Comment-if the shut-down had occurred at the time of the initial incident at Piper Alpha, things may have been different</td>
<td></td>
</tr>
<tr>
<td>0:22:00</td>
<td><strong>11:20 PM</strong> Accom.. block and most of the rig slides into the sea.</td>
<td></td>
</tr>
<tr>
<td>0:22:32</td>
<td>167 men died, 61 survived</td>
<td></td>
</tr>
<tr>
<td>0:22:35</td>
<td>Testimony of a survivor</td>
<td></td>
</tr>
<tr>
<td>0:24:52</td>
<td>Only the drilling deck remained. Temperatures reached 1,000 C</td>
<td></td>
</tr>
<tr>
<td>0:26:10</td>
<td>Lord Cullen Report</td>
<td></td>
</tr>
<tr>
<td>0:26:11</td>
<td>Dr. Barrell</td>
<td></td>
</tr>
<tr>
<td>0:27:00</td>
<td>Corrective Actions taken</td>
<td></td>
</tr>
<tr>
<td>0:27:30</td>
<td>Dr. Barrell on the positive that should be taken from this accident.</td>
<td></td>
</tr>
<tr>
<td>0:28:04</td>
<td>Remaining rig is blown up.</td>
<td></td>
</tr>
<tr>
<td>0:28:41</td>
<td>Will you go back [to an oil rig]?</td>
<td></td>
</tr>
<tr>
<td>0:29:48</td>
<td>END</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Simplified Cross Sectional View of Piper Alpha Platform (adapted from Reference 4)

Additional Readings:

PEAS 4773
INDUSTRIAL SAFETY AND LOSS MANAGEMENT

Exercise

Bhopal was a primary driving force behind the development of the Responsible Care® initiative in Canada and then worldwide. To better understand this significant impact, consider Bhopal from the following perspectives:

- the engineering lessons,
- the management lessons, and
- the legacy lessons we have learned from the incident.

To seed your discussion of engineering and management lessons you have the incident description in the class notebook as well as the attached article from Process Safety Progress by Willey et al.

In your consideration of legacy lessons, I want you to discuss the specific issue of the environmental, health and safety responsibilities of North-American based companies operating in developing countries. You might want to consult the attached article from the Journal of Loss Prevention in the Process Industries by J.P. Gupta (first two pages only).
The Accident in Bhopal: Observations 20 Years Later

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The most influential process safety accident passed its 20th anniversary on December 3, 2004. At an international symposium to mark the event in Kanpur, India, during the week of this anniversary, process safety practitioners from around the world assembled to discuss progress in resolving the Bhopal tragedy and in advancing the practice of process safety worldwide. This paper provides insight into the Bhopal site as attendees found it in December 2004. Since 1984, many positive steps worldwide have been made in regard to improvements in process safety and protection of personnel within chemical plants and of people in the surrounding communities. However, little visible progress has been made in decommissioning and decontaminating the Bhopal plant site, now under control of the Indian state of Madhya Pradesh. Many plant chemicals, abandoned there in 1985, were still at the site in 2004, mostly in substandard storage conditions. Mitigation recently commenced, but unconfirmed reports of the mitigation methods are concerning. The lesson learned: we all have a responsibility to ensure that events which follow a chemical accident reach a proper conclusion; and that no further undue suffering results to the general public and our fellow employees. © 2007 American Institute of Chemical Engineers Process Saf Prog 26: 180–184, 2007

Keywords: chemical accidents, case histories, process safety

INTRODUCTION

Background About the Original Accident

The Pesticide Plant and the Methyl Isocyanate Release

Much information about the original Bhopal accident is available through books [1–5], journal reports [4] case histories [5], documentaries [6,7], proceedings from international conferences [8,9], and the internet [10–12]. In essence, about 41 metric tons of methyl isocyanate (MIC) was released from the Union Carbide India Limited (UCIL) pesticide plant in Bhopal just after midnight on December 3, 1984. This gas spread slowly southward from the plant site during the early morning hours with very stable weather conditions. Of the 900,000 population within the city, over 200,000 people were exposed to MIC-tainted air. Documented death counts are listed at 3,787 [13]. The number of undocumented deaths will never be known, but estimates are over 10,000. Chaos surrounded the city afterwards. Thousands panicked. As the story of the disaster circled the globe, international aid began to flow into the city. Union Carbide, USA, was the majority owner of the plant (50.9%), with Indian investors owning the rest [14]. Warren Anderson, then chairman, made a personal trip to India to reach out, only to be placed under arrest. Several years later Union Carbide settled with the Indian Government for over $470 million dollars [15]. The event that caused the release was traced to a runaway reaction created by the contamination of a storage tank of MIC with a substantial amount of water. Although the safety relief valve opened at design pressure, all downstream measures to mitigate an external release of MIC to the surroundings were on standby (a caustic scrubbing tower) or out-of-service (a flare tower). MIC exited at an elevation from ground level of ∼35 m for a significant period of time. The cloud then descended to ground level (MIC gas is ∼2 times as dense as air), infiltrating the surrounding residential areas (illegal shanty towns), and flowing slowly toward the center of Bhopal, located about 2 km to the south.

The UCIL plant manufactured Sevin®, a Union Carbide trade name for a pesticide, whose active ingredient is 1-naphthyl-N-methylcarbamate, or the generic name carbaryl. The reaction involved two
reactants, MIC and α-naphthol. MIC is reactive, toxic, volatile, and flammable. The maximum exposure (TLV-TWA) during an 8-h period is 0.02 ppm (20 parts per billion). By comparison, phosgene, another extremely toxic gas, has a TLV-TWA of 0.1 ppm (100 parts per billion). Individuals begin to experience severe irritation of the nose and throat at exposures to MIC above 21 ppm. The LC50 for rats exposed to MIC vapors in air for 4 h is 5 ppm. In humans, exposure to high concentrations can cause enough fluid accumulation in the lungs to cause drowning. At lower levels of exposure, the gas affects the eyes and lungs. Long-term effects also exist. MIC has a boiling point of 39.1°C and a vapor pressure of 348 mm Hg at 20°C. As such, it is quite volatile and it will easily enter into the surroundings at very high concentrations. With a molecular weight of 57, about two times that of air, MIC has a higher vapor density compared to air. Further details related to process safety and the plant layout can be found in Willey’s Case History [5].

The 20th Anniversary of the Bhopal Gas Tragedy

On December 1–3, 2004, Prof. J. Gupta of the Indian Institute of Technology, Kanpur organized the “International Conference on the 20th Anniversary of the Bhopal Gas Tragedy,” in Kanpur, India [16]. The focus of the conference was the Bhopal tragedy and its effects on process safety. Process safety representatives from around the world attended. Papers from this conference are available in print [9] and on the internet [17]. Perhaps, the most memorable presentations were the first-hand witness stories from Bhopal residents and UCIL workers. For example, Swaraj Puri, the chief of police of Bhopal described how exposed to MIC vapors, he risked his life seeking answers in the dark night to manage the chaos of evacuation, obtain medical help for the victims, and eventually oversee the removal and disposal of bodies. Poor communications (less than 10,000 telephones for 900,000 residents at the time) hampered the discovery of what was affecting the multitudes.

Other speakers discussed the long-term health effects, and epidemiology studies and monitoring of the long term health impacts of the disaster have unexpectedly ceased. Finally, there were many papers related to process safety and how this accident influenced process safety practice across the world.

THE SITE 20 YEARS LATER

Our most astonishing discovery was the current condition of the Bhopal plant site. As one approaches, it looks like a jungle. Plants and trees have taken over (Figure 1). Tank 610, the tank that overpressured and released the MIC, was removed from its underground vault, and is now above ground and totally surrounded by brush and overgrowth. Even more astonishing, sadly, bags of chemicals have been left behind, as shown in Figure 2. Figure 3 is a photograph very near the filter area where a water washing cycle was underway the night of the accident. One theory of the accident postulates that water from this washing operation backed up into the MIC storage tank [5]. We were able to identify the gate valve that fed the process vent header located above in the pipe rack. Its stem indicated full closure, although this provides no evidence of its condition more than 20 years earlier during the incident. Figure 4 is a photograph of the top entry to the concrete vault containing Tank 611, an identical storage tank.
to 610. Much of the piping is in place, undisturbed after 20 years. The rupture disk tag is still readable, and somewhat hidden. The spring relief valve leads to the relief vent system lines. Figure 5 shows the scrubber system. Manufactured of stainless steel, it is in reasonably good condition after more than 20 years. Some motors appear as if they could operate today. Pumps, however, show signs of corrosion after sitting in the elements for 20 years. Figure 6 is a photograph of the flare system. This flare system went out service several weeks earlier due to a corroded pipe replacement project [14]. It was not repaired. Figure 7 shows the control room. By early 1980s standards, this was a typical control room with state-of-the-art equipment. Much of the paper that litters the floor are the remains of operating instructions and safe work permits. Its location from the plant was about 100 m to the west, well isolated from the process area. We heard from the local engineers who served as our hosts that mercury was contaminating the ground. As Figure 8 shows, mercury droplets are quite prevalent near certain units. Figure 9 shows a
tank that has corroded completely, unknown contents lying below on the ground.

DISCUSSION
The consequences of Bhopal extend well beyond December 3, 1984 and the days immediately following. Thousands of people injured that day continue to suffer from symptoms caused by exposure to MIC, including respiratory distress. Twenty years later, chemicals remain on the site, with the potential for significant environmental and health impacts.

Bhopal has lead to improved process safety practices through leading companies, through AIChE’s Safety and Health Division and Center for Chemical Process Safety, and through many other organizations around the world. Fundamental principles, such as management of change, mechanical integrity, hazard analysis, and layers of protection, are now in the toolbox of most practicing chemical engineers around the world. As we work together to build a global culture of process safety, the use of the process safety tools—and the strength of process safety practices—will help prevent future Bhopals.

CONCLUSIONS
To keep our industry moving forward on this course and to prevent future tragedies like Bhopal, we as chemical engineers must all commit to never forgetting what happened on December 3, 1984. It is distressing how many chemical engineering students have never heard of Bhopal—we must be sure that this is one of their very first engineering lessons.

LITERATURE CITED
Application of DOW's fire and explosion index hazard classification guide to process plants in the developing countries

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DOW's Fire and Explosion Index Hazard Classification Guide (DOW Index) has become a standard document in many countries, including several developing countries. The DOW Index, first issued by the DOW Chemical Co. in 1984, was based upon the Factory Mutual's Chemical Occupancy Classification Guide. The latter as well as subsequent revisions of the DOW Index are based primarily on the experiences in the U.S. which, while applicable to other developed countries, will not be applicable to developing countries in toto, due to differences in costs, training, attitudes and regulations. (This is not intended as a criticism of the situation in the developing countries, since many of the developed countries had themselves passed through similar situations in previous years.) Application of the DOW Index as is, therefore, results in lower than realistic values, thus giving a false sense of security than is actually warranted by the situation in hand. Suggested below are changes that should be and can easily be made to take into account the ground realities. Mentioned in separate sections are also a few comments on the recently issued DOW Index, 7th edition, to make it more internationally user-friendly, as well as suggestions to include some more items to make the DOW Index more dynamic. © 1997 Published by Elsevier Science Ltd. All rights reserved

Keywords: DOW Index; fire; explosion; safety; hazard; loss control

Introduction
The DOW's Fire & Explosion Index Hazard Classification Guide [1] (hereafter called the DOW Index) has become a standard reference in numerous countries to evaluate the possible hazards due to fire and explosion in the chemical process industry. Its use is also spreading to the developing countries due to the international nature of large projects which involve multinational funding, as well as licensing of technology, design, fabrication, erection, commissioning and/or training by foreign companies because the DOW Index provides a common means of evaluation. Also inherent in its use is the underlying assumption that all such countries have similar ground realities. In the developing countries, the situation is, more often than not, very different due to various factors associated with the availability of resources, costs of imported items, training, management and staff attitudes, regulations, political and bureaucratic interventions, and the like as discussed below. Therefore, application of the DOW Index, as is, often leads to an unrealistically low degree of hazard values giving a false sense of security. This paper discusses it in detail and suggests ways out of it.

Situation in the developing countries
The major points related to the situation in most of the developing countries are discussed below. These will trigger one's thinking regarding other associated points. For some specific developing countries, there could also be additional points while a few of the ones mentioned below may not apply:

1. Major equipment is very costly due to foreign exchange conversion rate, cost of international transport, import duty and the like. Sometimes,
second-hand equipment or a whole used plant is purchased because of cost considerations. Its actual inside state vis-a-vis corrosion, erosion, etc., may not actually be known.

2. For the above reasons as well as due to a lack of experience mixed with improper planning, adequate spares may not be available in stock. Importing spares when the need has arisen may take weeks or months and it is also subject to availability and changes in export control regimes of the exporting countries. This results in continued use after repairs of a part which otherwise should have been replaced. A 'make do' mentality naturally sets in.

3. Shortage of replacement parts (e.g. gaskets), and the pressure of production results in postponement of preventive and scheduled maintenance that has its own repercussions. Pressure of production is always high, since in the developing countries the plant capacity is generally significantly less compared to the need. Thus, it is likely that only the breakdown maintenance is carried out in several cases.

4. Due to frequent power outages or frequency fluctuations, the major equipment is put to a lot of stress. Its NDT temperature also rises. Thus, its practical life gets reduced to less than the designed life, specially where low temperature operations are involved. However, for the reasons already mentioned, the units are kept in use far longer than they should safely be.

5. Fire protection equipment may not be adequate due to insufficient water/foam, etc. What is true even with many major and modern plants is their not testing these systems at the recommended frequency to save on material, cost and the 'nuisance value' of a fire drill.

6. Several items installed afresh with the new plant may not be maintained in the required top form throughout the operating life of the plant. The credits/penalties taken as per the DOW Index should be the ones applicable even on the last day of its operating life, bearing in mind the laxity that usually sets in maintaining systems that are infrequently used.

7. Adequately trained manpower may not be available in enough numbers. This sometimes puts pressure on the operators to operate plants and systems, including safety systems, that are beyond their capabilities. Due to the shortage of personnel and sometimes also to reduce the costs, the necessary training, the initial break-in period as well as the training upgrade may be compressed in time.

8. Due to trade unions and/or labour laws that generally deny the management 'Hire & Fire' freedom, the worker's job at least up to the operator's or sometimes up to the engineer's level is permanent or secure. Bonus, as decreed by the Government, is given even in the loss-making companies. Rewards/punishments are rare due to the problems these can create. Many workers therefore feel no stake in the company and are usually not excited about their jobs. The management also does not usually try to motivate the workers and explain to them the future plans and individual worker's prominent role in it.

9. Sometimes an inappropriate worker has to be hired due to pressures from politicians, bureaucrats, friends and relations. Because of the 'protection' such a worker thus enjoys, he has little interest in getting the requisite training or to do his best.

10. A lot of research has been done globally on the effects of stresses on one's attitudes and capability to work. In the developing countries, these stresses are further aggravated, amongst others, by poor pay, concerns about children's education and adequate health care, tensions within a joint family (three generations living together), inadequate housing, unable to satisfy the family's desires to be part of the exploding consumerism phenomenon, etc. Some workers start a part-time business or take up a second job which affects their alertness in their regular job.

11. Too many permitted holidays result in a worker doing a double shift even when physically tired or working in an unfamiliar area when the regular staff is on holiday and replacements are not easily available.

Thus, it is evident that the situation in the developing countries differs significantly from that in the developed countries, and this needs to be taken into account for a meaningful application of the DOW Index in such countries. We give below modifications in the various ranges and values for use in calculations using the DOW Index. This has been done in three parts:

- A. Fire and Explosion Index Calculations (F&EI)
- B. Loss Control Credit Factors
- C. Other Remaining Factors in the DOW Index

A. Suggested modifications in the entries in the DOW F&EI calculation form

It is imperative that all the conditions given in the DOW Index regarding choosing the penalty factors are well understood and the form is being filled by an expert experienced with the situation in the particular developing country. Foreign consultants entering for the first time may not be able to appreciate the ground situation unless helped by a senior local experienced person.

Material factor. It should be calculated for the worst case since the feedstock composition might vary significantly due to source of feed, impurities present, ageing in the warehouse, etc.

General process hazards. Base Factor: as given, 1.00

A. Exothermic Chemical Reactions: Range as well as the specific values suggested for different exotherms should be shifted by 0.2 to account for unknown impurities, worker’s inadequate training and less than full response to emergencies, etc.
Exercise

Several case studies are described in the class notebook, including (among others):
- Westray
- Piper Alpha
- Flixborough
- Bhopal
- Seveso

Analyze each of these incidents according to the Safety, Health, Environment and Sustainability categorization of Lemkowitz et al.:
- Type of exposure
- Time scale of exposure
- Biological scale of exposure
- Spatial scale of exposure
- Time scale of effects

This categorization scheme is found in the preface material in the class notebook under The Context For The Course.
Exercise

Case studies come in all sizes and the lessons they teach can be quite varied.

Answer questions 1 – 8 from the following final exam (2011).

Now, for each of the case studies given, identify a key lesson learned.

Finally, for each of the case studies given, prepare an alternate exam question.
Dalhousie University
Department of Process Engineering and Applied Science

CHEE 4773
Industrial Safety and Loss Management

CHEE 6701
Loss Prevention and Risk Assessment

Examiner: Dr. Paul Amyotte, P.Eng.

Final Exam

Read Carefully:
- This is an open-book exam.
- Any type of calculator is permitted.
- Attempt all questions.
- Questions are of equal value (10 marks each). Parts of a multipart question are weighted equally with respect to that question.
- All reference articles and other resource documentation required are either provided with this exam or have already been provided during the course. Answers of a general nature showing little or no relation to the reference article (if applicable) will receive minimal marks.
- When you are finished, hand in only your examination answer booklet. Do not hand in the exam paper or the provided readings. Only the work in the examination answer booklet will be marked.
- Do not ask any questions of a technical nature during the exam period. This includes questions on how to interpret a given exam question.

1. Reference (Provided With Exam):
OH&S Update, Gravel Pit Blast Injures Three, OHS Canada, 27 (8), 7-8 (December 2011).

Categorize and identify the losses related to the incident described in this article.

2. Reference (Provided With Exam):
OH&S Update, Charges Laid After Fall, OHS Canada, 27 (8), 12 (December 2011).

Having read this article and seen the magnitude of the fine levied against Cimco Refrigeration, you might have some questions about the company's commitment to safety. What items would you include in an analysis of the company's safety culture?
3. Reference (Provided With Exam):
OH&S Update, Refinery Blast Injures 36, OHS Canada, 27 (8), 10-11 (December 2011).

Identify the steps you would take to conduct an investigation for the incident described in this article. This is an incident investigation from start (i.e., the event itself) to finish (i.e., the point when you, as incident investigator, have completed the investigation).

4. Reference (Provided With Exam):
OH&S Update, Accidents Preventable: Blitz, OHS Canada, 27 (8), 14 (December 2011).

You have been given the opportunity to provide input to the campaign described in this article. In an effort to demonstrate that all accidents are indeed preventable, you decide to identify the three safety management system elements you consider to be most helpful in this regard. What are these elements and why would you choose them?

5. Reference (Provided With Exam):
OH&S Update (Stelmakowich, A.), Sawmill Adopts Safety Measures, OHS Canada, 27 (8), 8 (December 2011).

Provide an analysis of this article from the perspective of the hierarchy of controls.

6. Reference (Provided With Exam):
OH&S Update (Stelmakowich, A.), Sawmill Adopts Safety Measures, OHS Canada, 27 (8), 8 (December 2011).

Provide an analysis of this article from the perspectives of:

(a) the role of management, and

(b) the role of legislation.

7. Reference (Course Reading No. 4):

Explain how this article is an example of the concepts of risk assessment and risk management.
8. Reference (Provided With Exam):

Demonstrate how a thorough hazard analysis would have identified the design error referred to in this excerpt. You are required to use either a What-If? analysis or a HAZOP study.

9. For each case below, identify the more hazardous material on the basis of the given physical property. Also state the reason for your choice.

(a) Flash point – heptane or nonane?
(b) Lower flammability limit – octane or propylene?
(c) Vapour pressure – diethylamine or isopropyl alcohol?
(d) Flammability range – hydrogen or methane?
(e) Autoignition temperature – butane or pentane?

10. Answer the following questions related to the Dow Fire & Explosion Index and the Dow Chemical Exposure Index.

(a) What is the penalty factor range for endothermic processes?
What does this tell you about endothermic processes compared to those involving exothermic chemical reactions?

(b) What is the fired equipment penalty for a distance of 120 ft from the source of a possible leak of material above its boiling point?
Which ISD principle would apply to the relocation of a furnace to minimize the fired equipment penalty?

(c) What is the material factor for oleic acid?
What does this tell you about oleic acid?

(d) What is the CEI for a hydrogen sulfide gas release from a 2-inch diameter hole?
Approximately what fraction is this of the CEI for the same scenario but with hydrogen sulfide as a liquid?

(e) What is the ERPG-3 value (in units of PPM) for methanol?
What does this tell you about methanol?
CHARGES LAID AFTER Fall

WHITBY — An Ontario company that makes and maintains refrigeration systems and a grocery distribution centre have been levied $125,000 in fines.

In early September, Cimco Refrigeration was fined $92,000 for pleading guilty to failing to ensure a power supply to a control panel was disconnected, locked out or tagged before work began on or near live exposed parts. In addition, Sobeys Capital Inc. pleaded guilty to failing to ensure no one interfered with or altered anything at the scene until permission to do so was received from a provincial inspector.

Under Ontario’s OH&S Act, until permission is obtained, “no person shall, except for the purpose of (a) saving life or relieving human suffering; (b) maintaining an essential public utility service or a public transportation system; or (c) preventing unnecessary damage to equipment or other property, interfere with, disturb, destroy, alter or carry away any wreckage, article or thing at the scene of or connected with the occurrence.”

Charges were laid following the injury of a worker at Sobeys’ Whitby Retail Support Centre in August of 2009. A Cimco Refrigeration worker was standing on a ladder while servicing an electrically powered door, Ontario’s Ministry of Labour (MOL) in Toronto reports. The worker made contact with the door’s energized control panel and fell, sustaining severe head injuries and electrical burns.
ACCIDENTS PREVENTABLE: BLITZ

MONTREAL — Quebec has launched a new campaign in a bid to reduce work-related injuries and fatalities.

On average, a worker in Quebec dies every four days and thousands of workers are injured, notes a statement from the Commission de la santé et de la sécurité du travail (CSST) in Montreal.

The same campaign was held in the spring and returned this fall, running between September 19 and October 16. In addition, the public is invited to help educate family and friends by taking part in a Facebook discussion at www.facebook.com/lacsst.

The thrust of the web-based initiative is to cultivate job safety not just as a company value, but a societal standard. “We want job safety to become a value shared by all Quebeckers and [ensure] that everyone is taking action to make workplaces safer,” Luke Meunier, president and CEO of the CSST, says in the statement.

“Everyone should be concerned because accidents can happen in all walks of life, not just in construction or in factories, but also in shops, restaurants, hospitals, etc.,” Meunier adds.

Although work-related incidents have dropped 37 per cent in Quebec over the past decade, he reiterates that all accidents are preventable.

SAWMILL ADOPTS SAFETY MEASURES

GLASLYN — L & M Wood Products Limited Partnership has been ordered to pay $10,000 following the serious injury of a worker at a sawmill near Glaslyn, Saskatchewan.

In July of 2009, a worker for Thunder Employment was operating a chain conveyor when he was caught, says Jennifer Fabian, director of safety services for the Occupational Health and Safety Division within Saskatchewan’s Ministry of Labour Relations and Workplace Safety in Regina.

L & M Wood Products pleaded guilty, as a contractor, to failing to ensure a stopping device for a trim saw was within an operator’s direct view and easy reach, contrary to the province’s Occupational Health and Safety Regulations.

Three additional counts were stayed. These charges cited the following failures: ensure there was an effective safeguard on a trim saw feed chain to prevent a worker from contacting a dangerous moving part; ensure workers do not wear loose-fitting clothing where it is possible clothing may contact a moving part; and ensure work at a place of employment was sufficiently and competently supervised.

Thunder Employment faces the same four charges as an employer. That case was adjourned until October 26.

Zane Delainey, general manager of L & M Wood Products, reports that the immediate issues around guarding and the stopping device were addressed within 48 hours of the incident. Company officials reviewed training and inspection programs, as well as adopted changes related to what types of companies are contracted for work on site, Delainey says.

While L & M Wood Products previously used its employee safety manual for incoming contractors, the company now has a safety book and orientation specific to contractors, which must be completed before starting work. If there is any breach of the rules, the contract is cancelled, Delainey adds.

Fabian emphasizes that communication is critically important in situations where an owner or contractor brings people on site. They must be “made aware of things they need to know related to the safety of the site” and that any related workers “are afforded the same standard of care as they would give their own workers.”

Employers, contractors and others should not wait for regulators to tell them what they need to do, Fabian says. “That’s everybody’s responsibility, to pay attention to safety, not just when officers show up and not just when somebody gets hurt, but beforehand,” she adds.

— By Angela Stelmakowich
THE SELLAFIELD LEAK

A *cause célèbre* in 1984 was a leak of radioactive material into the sea from the British Nuclear Fuels Limited (BNFL) plant at Sellafield, Cumbria. It was the subject of two official reports\(^5,10\) which agreed that the discharge was due to human error, though it is not entirely clear whether the error was due to a lack of communication between shifts, poor training or wrong judgment. However, both official reports failed to point out that the leak was the result of a simple design error, that would have been detected by a hazard and operability study\(^1\), if one had been carried out.

As a result of the human error some material which was not suitable for discharge to sea was moved to the sea tanks (Figure 8.3). This should not have mattered as BNFL thought they had "second chance" design, the ability to pump material back from the sea tanks to the plant. Unfortunately the return route used part of the discharge line to sea. The return line was 2 inches diameter, the sea line was 10 inches diameter, so solids settled out in the sea line where the linear flow rate was low and were later washed out to sea. The design looks as if it might have been the result of a modification. Whether it was or not, it is the sort of design error that would be picked up by a hazard and operability study.

The authors of the official reports seem to have made the common mistake of looking for culprits instead of looking for ways of changing the work situation, in this case by improving the design process.

![Figure 8.3 Simplified line diagram of the waste disposal system at Sellafield](image-url)