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Loss of collections in museums can be significant during a fire. It is important that museums put control measures in place to prevent a fire, to detect a fire, and to respond quickly if a fire does occur. To evaluate potential collection losses due to fire over a certain period of time, substantial information is required and there is little quantitative data for fires in museums. It was decided to obtain this data by collecting fire museum records from Canadian fire authorities as well as from fire authorities in other countries and by consulting with experts. This project has resulted in establishing fire Control Levels for museums and in creating a set of reference materials to help risk assessors evaluate the potential collection losses due to a fire. According to experts consulted in this study, having an active fire safety committee composed of staff and management is one of the key elements in fire prevention. Such a committee helps promote awareness and identify problems, as well as propose solutions and ensure that these solutions are applied to minimize risk of fire in an institution. For optimal protection, museums are encouraged to have a fire alarm system that is monitored continuously as well as an automatic fire suppression system.

Les pertes de valeurs des collections reliées aux incendies peuvent être très considérables. Il est important que les musées soient bien préparés à l'aide de mesures préventives adéquates. Pour évaluer les pertes de valeur des collections sur une période de temps donnée, des données précises sont requises. En raison d'un manque de données pertinentes, il a été décidé de compiler des données provenant des agences canadiennes de prévention des incendies et d'autres pays, ainsi que de consulter des experts en incendie dans les musées. Le fruit de ce travail a permis d'établir des niveaux typiques de contrôles contre les incendies dans les musées ainsi que de récolter des informations de référence pour permettre aux évaluateurs d'estimer les pertes de valeurs des collections dues aux incendies. Selon les experts consultés dans cette étude, la présence d'un comité actif sur la prévention des incendies dans le musée est un élément clé de la prévention car il permet de bien sensibiliser les gestionnaires et le personnel aux risques des incendies, d'identifier les lacunes, de proposer des solutions et de vérifier leur mise en place dans le but de minimiser les risques d'incendies. Les musées sont encouragés à utiliser un système de détection sous surveillance continue ainsi qu'un système de suppression automatique car ils ont démontrés une très grande efficacité dans la réduction des dommages.

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Introduction

Several important fires in Canadian cultural heritage institutions have been recorded since 1980. Six fires have each caused more than CDN$1 million damage (as shown in **Table I**).[1-10] Of those six fire events, some institutions were totally burned, causing the loss of unique or significant objects, while others were substantially damaged by smoke and water. **Figure 1** shows direct and indirect possible effects related to a fire event. Many different agents of deterioration, shown in bold in **Figure 1**, can be involved due to the effects of a fire. Unfortunately, often after an incident, not all damaged objects will be treated to recover their value. In addition, after a fire some museums may remain closed for periods of a few months to a few years during reconstruction of the building and recovery of the collection, limiting a community's access to its cultural heritage. The five institutions that were significantly damaged have now all installed fire suppression systems.

Reports on recent significant fires in cultural institutions in the United States and in Europe can be found in the literature.[11-15] A recent major fire, highly reported in the media, occurred on April 30, 2007, at the Georgetown Branch Library in Washington, D.C.[16,17] while this article was under development. The fire destroyed the roof of the 72-year-old building and much of the second floor, which housed historical documents and artwork. Firefighters rescued what items they could, but much of the library and its contents suffered fire, smoke and water damage. The damage was estimated at more than US$20 million. The fire was caused by the unsafe use of a heat gun during renovations on the roof. Below is the summary of the weaknesses in the control strategy and what went wrong during this incident.

The two weaknesses were:
1) No direct phone line to the fire department or other emergency authorities.
2) No automatic fire suppression system in the building (US buildings built before 1974 are not required to have suppression systems).

What went wrong included:
1) A 10 to 15 minute delay before calling 911 while the workers themselves tried to suppress the fire before a library staff member called the fire department. Luckily someone passing by had already called 911.
2) Two nearby fire hydrants were not working and the water pressure was low in the other nearby hydrants.

Table I: Some Important Fires in Canadian Cultural Heritage Institutions since 1980.

Year	Institution	Cause	Loss, Recovery and Comments*
1980	Miner's Museum, Glace Bay, Nova Scotia[1]	Smoking or arson	70-80% of the building and collection lost. Damage was estimated at more than $1 million. No monitored fire alarm and no fire suppression system was in place.
1985	Weldon Law Library, Dalhousie University, Halifax, Nova Scotia[2]	Lightning strike caused an electrical malfunction	Hundreds of books were lost and many more damaged. $0.25 million for the recovery efforts.
1988	Taras Shevchenko Museum, Oakville, Ontario[3]	Arson	No fire suppression system was in place. More than $1 million lost. Museum reopened in Toronto.
1990	Royal Saskatchewan Museum, Regina, Saskatchewan[4,5]	Unsafe use of products	Only smoke damage to the collection; $2 million for the recovery efforts. It took one hour to locate the fire in the building. No fire suppression system was in place.
1992	Billings Estate Museum, Ottawa, Ontario[1,3]	Arson	$0.125 million in damage. No fire suppression systems in place. During this fire, a melodeon (reed organ) was partly charred and damaged by water and soot. It was the second time that this musical instrument was damaged by a fire incident in a 7 year period.
1992	Four large commercial and residential heritage buildings near historic Notre Dame Basilica, Montreal, Quebec[6]	Not reported	The four buildings were totally destroyed and the Basilica had substantial smoke damage and broken windows. Damage for all buildings was estimated at more than $3 million.
1993	Canadian Warplane Heritage Museum, Hamilton, Ontario[3,7]	Undetermined	$3 million (does not include cost of replacing five historic planes at around $1 million each). No fire suppression system was in place.
1997	Green Gables, Cavendish, Prince Edward Island[8]	Electrical fire	$2.3 million for the recovery efforts.
2003	Guy House, Oshawa Community Museum & Archives, Oshawa, Ontario[9,10]	Arson	Less than 2% of the collection lost. The entire collection suffered smoke damage. It cost $0.25 million to repair the building. From the insurance, the museum received $80,000 to reinstall the collection and remove the soot deposits on the collection. As of May 2007, cleaning of the collection was not yet completed. The house remains without a sprinkler system.

* Loss and cost expressed in dollars are not adjusted to inflation.

Three weeks later in the United Kingdom, the historic tea clipper Cutty Sark, one of the most famous sailing ships in the world, was ravaged by fire under suspicious circumstances.[18]

During the final stage of the revision of this paper, a fire damaged Quebec City's historic drill hall, the Manège Militaire, during the night of April 4, 2008. Built between 1885 and 1888, it housed the oldest French-speaking unit of the Canadian army, the Voltigeurs de Québec. Fortunately, 90% of the collection was retrieved after the fire. The cause of the fire remains unknown at this time.[19,20]

Until recently, no systematic research has been done in Canada to assess the risk of fire in cultural heritage institutions by examining the major causes of fires and the effectiveness of fire protection measures. The goals of this project were: to obtain quantitative data related to museum fires in Canada; to analyze the data in the light of risk management; and, to transform this analysis into reference materials that others can use to help prevent and reduce the impact of fire incidents as well as to predict the risk of fire for an institution.

This paper focuses primarily on the impact of heat and combustion as the main direct effects of fire, but it will also provide some guidelines to consider for assessing the consequences of water damage and soot deposition. The paper will conclude with a discussion on the issue of water-based suppression systems and the risks of water damage.

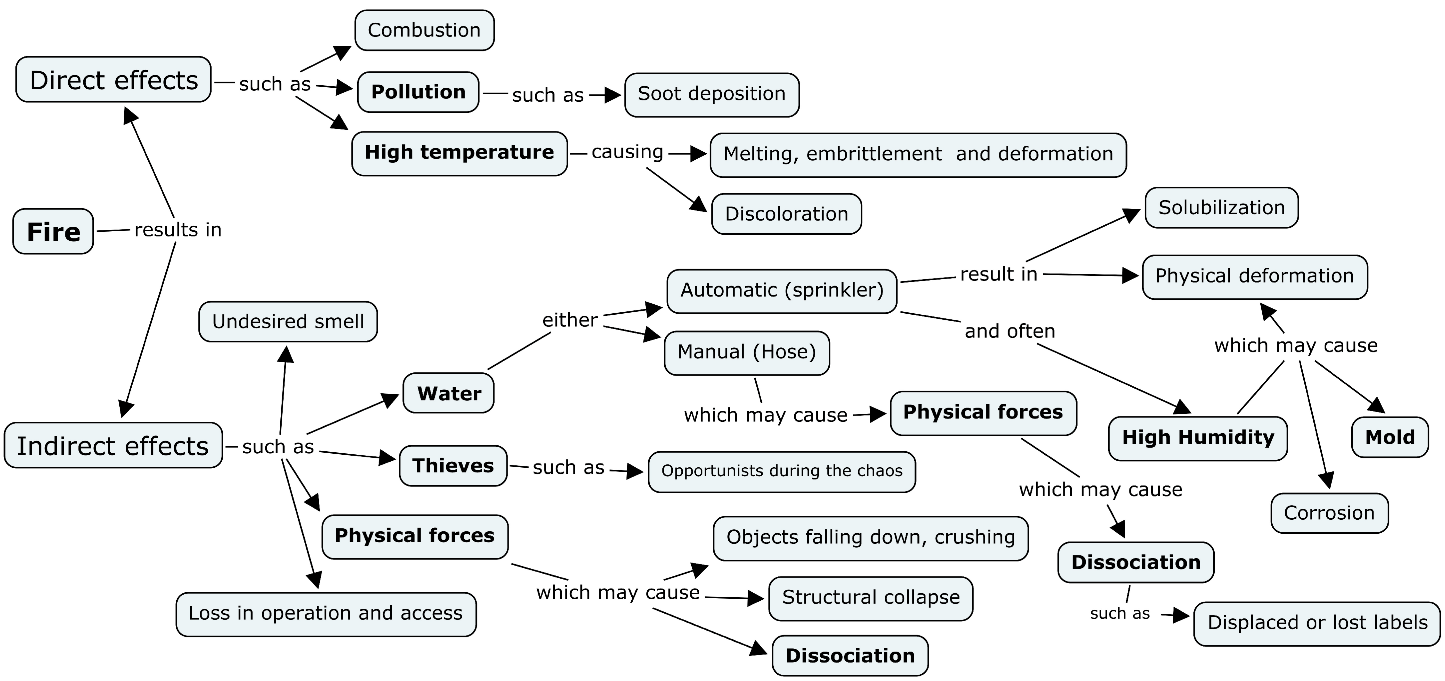

Figure 1. Chain of causes and effects due to a fire incident. Agents of deterioration are shown in bold.

It should be noted that the Tables included in this paper are not recognized by fire agencies or legal authorities; however, they can be used as guidelines to aid in the assessment of the risk of fire in museums.

Risk Assessment

The Australian and New Zealand Standard for risk management defines risk assessment as the overall process of risk identification, risk analysis and risk evaluation.[21] Risk assessment can help establish priorities for optimal preservation, and evaluate the overall preservation of a collection. During the past decade, many risk assessments of heritage collections have been carried out in Canada and in other countries using a method developed by Waller, which allows decision makers to predict the improvement in preservation of collections quantitatively by identifying and reducing the greatest hazards.[22] A single expression can summarize the risks for a specific hazard:

$$\text{Risk} = \text{Likelihood} \times \text{Consequence}.$$

Risk represents the chance of something happening that will have an impact on objectives (here, preserving cultural heritage); Likelihood is the general description of probability or frequency of an event; and Consequence is the impact of the event. **Figure 2** illustrates the parameters involved in determining risk of fire in museums. An important parameter for assessing the risk is the Control Level (CL) in place. Control Levels are the sets of measures in place in an institution to prevent fires, to detect a fire in its early stage, and to respond to a potential fire. These are ranked from Control Level 1 to Control Level 6 based on their efficiency. This paper will provide quantitative data that will help assess the risk of fire in a collection.

Collecting Data on Fire

To get a good idea of how Control Levels in museums correlate with the frequency of fires and their consequences, a large sample of systematically reported fire incidents is needed. Too small a sampling is not adequate, while too old a sampling may not reflect today's reality resulting from changing policies, as well as new building and fire codes, etc. Consequently, it was decided to collect data from 1994 to 2004 with the help of Canada's provincial fire commissioners and fire marshals.

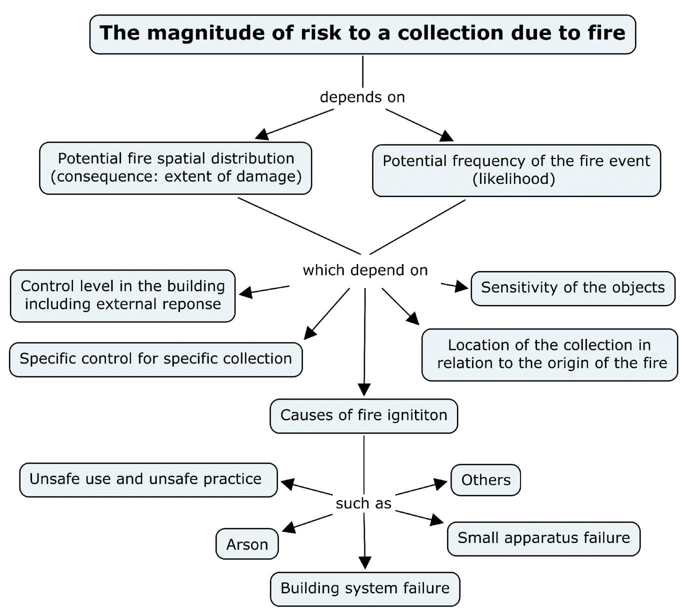

Figure 2. Factors that determine the magnitude of risk to a collection due to fire.

Fire marshals and fire commissioners in each province and territory collect data on fires from fire departments in their jurisdiction. Fires reported are grouped into different types of building occupancy including libraries, museums and art galleries. Data accumulated by fire authorities include only those events where the fire services were called and do not include false alarms. Information requested includes date, time of day, area of origin, ignition source, cause, fire protection system in place, total response time and loss. There are gaps in the data from 1994 to 2004 received from the fire marshals and commissioners. British Columbia, Saskatchewan, Quebec, Nunavut and New Brunswick provided data commencing in 1995, 1997, 1998, 1999 and 2002 respectively. The Government of Newfoundland and Labrador does not keep such records. Data for archives was more difficult to find because they were compiled under either museum or government buildings. Without the possibility of additional information, it was decided to exclude them. Data for fires in libraries were only available from Quebec and New Brunswick.

It was observed that the description of fire protection systems in place during a fire varied considerably. Because there is no standard fire reporting system established in Canada, it was decided to ask two fire experts, Paul Baril (currently a fire protection advisor and formerly a fire consultant at the Canadian Conservation Institute) and Robert Marchand (Manager, Protection Services at the Canada Science and Technology Museum) to list typical Control Levels that museums in Canada or in other developed countries may employ. The experts were asked to assess the typical likelihood and consequences of a fire event for each Control Level in light of the data from fires in Canada and in other countries, and based as well on their expert judgment.

Control Levels for Fire Risk

Through consultation with fire experts, generic progressive Control Levels found in museums have been developed. Six levels were established as shown in **Table II**. They represent typical levels of fire prevention and protection in museums in Canada. At each level, measures are grouped according to typical control strategies in conservation: Avoid, Block, Detect and Respond. Training and Procedures have also been included in separate columns due to their importance in fire prevention. Control Level 1 represents the least efficient protection against fire, while level 6 represents the ultimate reasonable protection for an institution. The Control Levels were developed after considering the different causes of fires, which are described below in detail. Improving the Control Level of an institution reduces the likelihood and consequences of a fire.

In order to fulfill a specific Control Level, all measures required in that level must be present as well as all measures required by lower levels. For example, the third level of control under the "Block" column contains all measures for Level 3 in addition to the items for Level 2.

Having a mixture of measures from Level 2 and Level 4 does not make an "average" Level 3. A "true" Level 3 is reached when all measures (with or without some measures from superior levels) of Level 3 and below are present in the museum. For example, in some cases, a substantial improvement of the response time will result in little reduction of risk of fire since the limiting factor might be a poor detection system such as a 9 volt smoke detector that is not connected to a central system.

In some situations, equivalencies are acceptable. For example, if there is no sprinkler system in an exhibition area, where the chances of a fire occurring are low and the rest of the building is protected, an equivalency could be used to achieve a level 5 for "Respond." An equivalent measure to an automatic sprinkler system in an exhibition area could be that trained staff must be in the space at all times and must be available to respond at the early stage of a fire. It is not expected that all museums can reach high Control Levels. For example, wooden buildings cannot achieve Level 4 since a non-combustible building is specified under "Block" in Level 4a.

Control Levels presented in **Table II** focus mainly on the building or room level and less on the enclosure level, i.e. display cases or storage cabinets. The measures for enclosures are mainly limited to "Block." Additional hazards can be present if the enclosure has complex electronic and mechanical components in it. To assess the risk of fire for a specific collection (micro-assessment), the features of the enclosure and the nature of the objects will need to be considered. In general, enclosures do not provide much protection during a large fire. Either the enclosure will burn and the fire will consume the collection within, or the collection will become damaged by the high temperature inside the enclosure. Fire experts concur that nothing is fireproof. In the best situation, materials can be fire resistant or non-combustible. Airtight enclosures offer good protection against different types of agents of deterioration during small, localized fires. Primarily, they block smoke and water infiltration into the enclosure and may help retard combustion and reduce temperature elevation.

Measures missing in **Table II** are security and arson control, because arson is generally considered to be a security issue, even though the outcome is a fire. Thieves and vandals require their own Control Levels, but these have not yet been completed by the author. Analysis of Likelihood and Consequences of fire caused by arson in relation to the fire Control Levels is currently underway as part of a report on Security Control Levels.

Likelihood

From 1994 to 2004, 100 fires in museums and art galleries were reported in Canada. One large fire (more than $1 million in damage) occurred during this period at the Green Gables[8] (curiously, this event was not reported by the fire marshall of PEI). Eleven of the reported fires caused damage in the range of $100,000 to $400,000. As mentioned above, not all the provinces and territories reported data for the full period of 1994-2004. To determine the Likelihood of a fire in a museum in Canada, the

Table II: Control Levels (CL) for Fire Prevention and Response. (See also notes in Appendix 1.)

CL*	Avoid	Block	Detect	Respond	Training	Procedures
1			a) Local smoke alarms provided, tested monthly and batteries replaced annually. b) A telephone is available.	a) Fire station available full time. b) Portable fire extinguishers provided.		a) Open-flame fire safety procedures in place. b) Visual inspection of portable fire extinguishers is conducted quarterly.
2		a) Fire resistive construction. b) Collection storage rooms fire-rated for 1 to 2 hours. c) Enclosed emergency staircase provided in multi-level buildings.	Under "Detect", CL1b plus: a) Fire alarm system installed throughout the building, with an annual inspection.	All items under "Respond" in CL1 plus: a) Water supply available to firefighters.	a) A few staff members are trained in the use of portable fire extinguishers.	All items under "Procedures" in CL1 plus: a) Annual inspection of portable fire extinguishers.
3		All items under "Block" in CL2 plus: a) Exhibit rooms protected from other areas with a minimum 1 hr fire-rated separation. b) Fire doors equipped with automatic closing devices.	All items under "Detect" in CL2 plus: a) Fire alarm system monitored full time. b) Automatic smoke detection provided in collection-holding areas.	All items under "Respond" in CL1 plus a) Municipal or private fire hydrants provided. b) Standpipe system with fire department connections is provided.	a) Portable fire extinguisher training provided every 5 years.	All items under "Procedures" in CL2 plus a) Monthly testing of fire alarm system. b) Building's electrical system inspected every 10 years for building more than 40 years old.
4	a) Avoid high crime-rated areas. b) Avoid having the institution on properties attached to structures classified "industrial" or "storage", or containing high hazard contents. c) Avoid close proximity to wooded areas and fire-prone bush.	Items "Block" in CL2b,2c,3a and 3b plus: a) Noncombustible building. b) Automatic HVAC shutdown provided.	All items under "Detect" in CL3 plus: a) Dedicated and supervised telephone line provided for the fire alarm system.	All items under "Respond" in CL3 plus: a) Automatic fire suppression system provided in collection storage rooms with a high fuel load, with annual inspection of automatic fire suppression system(s).	a) Staff trained in fire prevention methods. b) Portable fire extinguisher training provided every 3 years.	All items under "Procedures" in CL3 plus: a) Monthly fire safety inspections conducted. b) Active fire safety committee and Emergency Response plan in place. c) Building's electrical system inspected every 10 years. d) Fire prevention procedures for facility rental and user groups in place. e) Hot work permit required. f) Building systems (mechanical/electrical) preventive maintenance program in place and reviewed every 3 years.
5	All items under "Avoid" in CL4 plus: a) Avoid sharing occupancy of your building (including attached building) with an unprotected occupant.	All items under "Block" in CL4 plus: a) Combustible / flammable liquids kept in approved storage cabinets.	All items under "Detect" in CL4 plus: a) Separate fire alarm zones provided for collection storage rooms. b) Trained security personnel provided full time.	All items under "Respond" in CL3 plus: a) Automatic fire suppression system provided in collection storage rooms and exhibit rooms, with annual inspection of automatic fire suppression system(s).	All items under "Training" in CL4 plus: a) Team trained in emergency response. b) Portable fire extinguisher training provided for new staff.	All items under "Procedures" in CL4.
6	All items under "Avoid" in CL5	All items under "Block" in CL5	All items under "Detect" in CL5	All items under "Respond" in CL3 plus: a) Automatic fire suppression system provided throughout the building, with annual inspection of automatic fire suppression system(s).	All items under "Training" in CL5 plus: a) Emergency measures exercise performed at least every 5 years.	All items under "Procedures" in CL4 plus: a) Electrical inspection conducted following renovations and/or new projects. b) Formal fire department site visits are conducted annually.

* Control Level 1 represents the least efficient protection against fire, while Control Level 6 represents the ultimate reasonable protection for an institution.

number of museums included in the study from 1994-2004 needed to be known. These numbers were obtained from the various provincial and territorial museum associations. For each year between 1994 and 2004, the average meantime between fires was calculated based on the data reported and by the number of museums identified by the museum associations. For example, in 1994, 6 provinces reported all together 7 fires. At that time, the 6 provinces also reported a total of about 800 museums. Therefore, in 1994, there was the possibility of one fire per museum every 114 years (800/7). The average meantime for the period studied is 160 years for any given heritage institution. The standard deviation based on frequency of fire for each year of the period covered is 70 years. Thus, it can be stated that the frequency of fire is one every 160 +/- 70 years. This is an average frequency for all types of museums in these six provinces. An unfortunate example, shown in Table I, is the Billings Estate Museum, which suffered 2 fires in 7 years. One ill-fated object, a melodeon, was affected by both fires. In general, the age and the size of museum and its activities will influence the frequency of fires.

With data provided by the US National Fire Protection Association (NFPA),[13] it was possible to determine that an individual American museum has a similar average frequency with a meantime between fires of just over 200 years. In both Canada and the United States, the number of fires in museums over the past 10 years has decreased by more than half compared to the previous decade.

For the period covered in this study, it is certain that more fires happened in museums than those on record, but these additional fires either were small and quickly controlled internally without fire department intervention, or were not reported by the firefighting authorities. In both cases, losses to the collections would be considered negligible. In 1985, Harmathy *et al*. estimated that 22% of all fires that occurred in the United States were either not reported or had been classed as "undetermined."[23] In 1984, the losses related to unreported fires for all types of buildings were estimated at less than US$100 per incident.[24] Many institutions will not report fires where the loss is less than the deductible on their insurance.

Between 1998 and 2002, the province of Quebec suffered 13 fires in libraries. With approximately 1000 libraries in Quebec, this indicates an average meantime between fires of 385 years per library (5 years x 1000 libraries / 13 fires). This frequency is in the same order of magnitude as for libraries in the United States, which was reported in 2006 as one fire every 600 years.[25]

The frequency of fire events in a museum depends on the control strategies in place to prevent (avoid) fires. With the help of a consultant's knowledge,[26] it was possible to estimate a reduction of the frequency of fire events based on the Control Levels (CL1 to CL5) as shown in **Table III**. This was done by assessing the reduction of the likelihood of different causes of fires for the different Control Levels. For each Control Level, the likelihood of a fire for one museum is the summation of the number of fires due to different causes for a period of time. The results are reported in number of years on average for a fire to occur in one museum. As the level of control increases, the probability of a fire will decrease. Based on different fire scenarios (causes) studied, there is no substantial reduction in the frequency of fire between Control Levels 1 and 2. From Level 2 to 3, there is a small reduction of 12%. Instead of a fire every 140 years, a fire will occur every 160 years with upgraded measures. Based on expert advice, it is estimated that most Canadian museums could achieve Control Level 3.[26] The frequency of a fire occurring is estimated to be reduced by 80% if the control is upgraded from CL3 to CL4. The improvement is mainly due to the greater awareness of museum management and staff in institutions that established a Fire Safety Committee and, as part of disaster preparedness, have a fire plan in place.[26] This committee can function as part of the responsibility of the Building Emergency Organization. More information on the role of this committee can be found in the document entitled "Fire Prevention Programs for Museums."[27] The reduction in frequency of fires from CL4 to CL5 is also based on the assumption of better security control of potential arson events.

Table III: Estimated Reduction of Fire Events Based on Control Levels.

Control Level	**Likelihood***([years x museums]/fires)
CL1	140
CL2	140
CL3	160
CL4	720
CL5	1500
CL6	2800

* Average meantime (in years) between fires, per museum.

Causes

Various causes of fires have been reported. For simplicity, these causes have been grouped into 5 categories as shown in **Table IV**. This Table illustrates the distribution of the 5 categories of causes of fire in museums in Canada, the United States and Europe.[13,28] Unsafe practice/unsafe use and arson are the two dominant causes of fires in museums in Canada. The distribution of causes in Canada compared with the United States and Europe must be interpreted with caution because the way fire events were reported differs. This is the case for the key word "malfunction" sometimes reported by firefighters. In this study, "malfunction" was divided between building systems and small apparatus. Two fires caused by lightning strikes were reported under "Others." Otherwise, no further details were provided by fire authorities under the cause "Others." Further discussion of the causes of fire in Europe can be found in the literature.[15]

Table IV: Causes of Museum Fires.

Causes	Description	Canada (1994-2004)	USA (1994-1998)	Europe (1980-1988)
Unsafe Use and Unsafe Practice	Unsafe activities include smoking, using an open flame, melting, cooking, etc. Renovations expose museums to a greater risk.	32%	12%	18%
Arson	Fire originated by malicious intent.	30%	7%	26%
Building System Failure	Malfunction of mechanical, electrical or heating system, HVAC system, etc. Includes electrical panel boxes; old, defective, damaged and/or inadequate wiring (including wires chewed by rodents); etc.	20%	41%	33%
Small Apparatus Failure	Small cooking or heating apparatus, small boilers, etc.	8%	31%	18%
Others	Includes natural causes such as lightning but excludes undetermined.	10%	9%	5%

Because unsafe practice/unsafe use is a major cause of fire (according to data in **Table IV**), efforts should be made to minimize this risk by increasing the awareness of staff and contractors when heat or open-flame activities are taking place. These activities are the most common unsafe use and unsafe practice. One solution is to require staff or contractors to fill out a form for a hot work permit before working with a flame or a source of high temperature. A hot work permit will specify the extra precautions required for these activities in a museum or gallery. By this means, authorities will be aware of the kind of hot work activity that is happening and, thus, they can be more proactive in taking precautions. Examples of hot work permit forms and specifications can be found in the literature or on the Internet.[29,30]

The possibility of fire by arson may be higher than the average if the museum has a controversial temporary exhibition or a controversial permanent collection. As mentioned before, the most efficient way to avoid or deter arsonists is by establishing preventive security measures. Based on limited data for libraries (in Quebec and New Brunswick), arson was found to be the cause of 36% of fires compared to 40% in American libraries.[25] In Canada, after arson, electrical failures in the building system were responsible for 20% of fires.

For assessing the likelihood of fire due to a specific cause in a museum, **Tables II, III and IV** should be used. For example, to know the frequency of fire due to unsafe use/unsafe practice in a museum, first, the Control Level of that museum has to be assessed by using **Table II**. Assuming the Control Level is 3, **Table III** indicates that the frequency is about one fire every 160 years for any possible cause. Because unsafe use is, in general, responsible for 32% of fires in a museum as shown in **Table IV**, the frequency for unsafe use is about one fire every 500 years (160 yrs/0.32).

Consequences

The consequences of a fire depend on many factors such as the cause, area of origin, time of ignition, response time and multiple parameters associated with fire spread.

Flashover: A Question of Time

One critical aspect for the potential consequence of a fire is the time that it takes for the fire to reach the flashover stage. Flashover is the transition from a fire that is dominated by the first material ignited to a fire that is dominated by burning material throughout all of the room. Flashover typically occurs between 4 and 10 minutes after ignition.[31,32] Pre-flashover refers to a small-size fire that is relatively easy to suppress. Post-flashover usually results in the total loss of that room and perhaps the entire building. Determining the time to reach a flashover stage depends on various factors such as the degree of combustibility of the material ignited, the density and the arrangement of the materials in the room (including both collection and non-collection items) and the size of the room. Museums must consider how they can best minimize the possibility that a fire reaches the flashover stage, and that it stays contained in that room. In the event of fire, a rapid response will minimize the amount of damage caused by combustion/heat, smoke, water and other agents of deterioration, as shown in **Figure 1**. More information on the science of fire can be found in the literature.[32]

Area of Origin

Based on the data from 100 fires in Canadian museums obtained for this project, most fires start in a non-collection area (**Figure 3**). Only 3 fires started in an exhibition area or a collection storage room. This gives a 3% possibility that a fire will start in

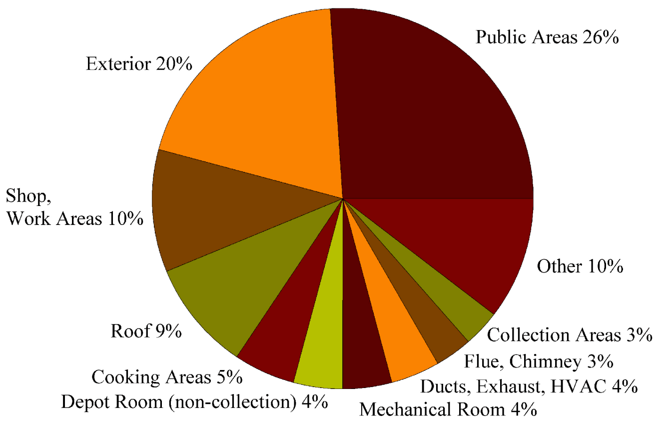

Figure 3. Distribution of fires based on area of origin. Based on 100 fires reported in Canada from 1994-2004.

a room housing collections. The cause of 2 of these 3 fires was due to a malfunction in the building system or in a small apparatus. **Figure 3** shows the overall distribution of the area of origin of fire. In 46% of the cases, the fire started in a public area or outside the museum.

Public spaces such as entrance areas, reception zones, auditoriums, toilets, etc. generally do not contain collections. By examining the data on the causes of fire in public areas and outside museums, it was noted that most fires were caused by intentional or unintentional human actions. Unsafe use and unsafe practices are responsible for 25% of fires outside and 41% in public areas. Arson was responsible for 33% of fires outside around the museum and for 45% in the interior public zone.

Time of the Ignition

It is useful to be aware of when a fire is most likely to happen during the year and also during a 24-hour period. **Figure 4** shows the number of fires that occurred throughout the year including the distribution of the causes. April, May and December appear to be the more risky months, with more than 10 fires reported per month. Arson reaches a peak in May. Building systems malfunctions, such as incorrect design or maintenance deficiencies, are the major causes of fire in December.

42% of museum fires occur during open hours (9:00 to 17:00). Roughly one third of fires caused by arson occurred during open hours. Because most museums are open a third of the day (8 hours/24 hours), this means that the possibility of fire by arson remains constant through the full day. The data from Quebec and New Brunswick indicate that 21% of fires in libraries start between 9:00 and 17:00. The NFPA reports 53% for American libraries for the same period.[30] The fact that an ignition occurs during closed hours has an impact on the fire spread if there is no monitored fire detection system, no automatic suppression system or if no one is on site to report the fire quickly.

Total Response Time

The total response time is the measure of time from receiving a call by the emergency communications centre to the arrival of the first fire vehicle at the site. Time includes dispatch, turnout and the drive to the fire scene. The NFPA has established the standard for total response time as within 6 minutes, 90% of the time.[33,34] **Figure 5** shows the response time distribution from the data collected. The average total response time for Canadian museums is 5 minutes and 33 seconds. Firefighters arrive at the scene within 6 minutes, 66% of the time, which is somewhat less than the 90% of time specified as the NFPA's objective. The total response time for 15 of the fires was 8 minutes and more. Most of these happened at rural museums or in small centres where distance and the lack of permanent professional fire responders is a problem. In order to minimize fires reaching the flashover stage, the need for automatic fire suppression becomes more obvious for museums where the response time is expected to be longer than 6 minutes. In Quebec, all building fires reported from 1998 to 2000 also had the similar performance of a 6 minute response time for 66% of the time.[35] Also in Quebec, by the time the first firefighters arrived, 81% of the time the fire was still contained in the room where the fire began; 16% of the time it was still limited to the building; and 3% of the time it already had spread to other buildings. This data indicates that if the response time cannot be improved, early detection and rapid transmission of the incident to emergency authorities should be reinforced.

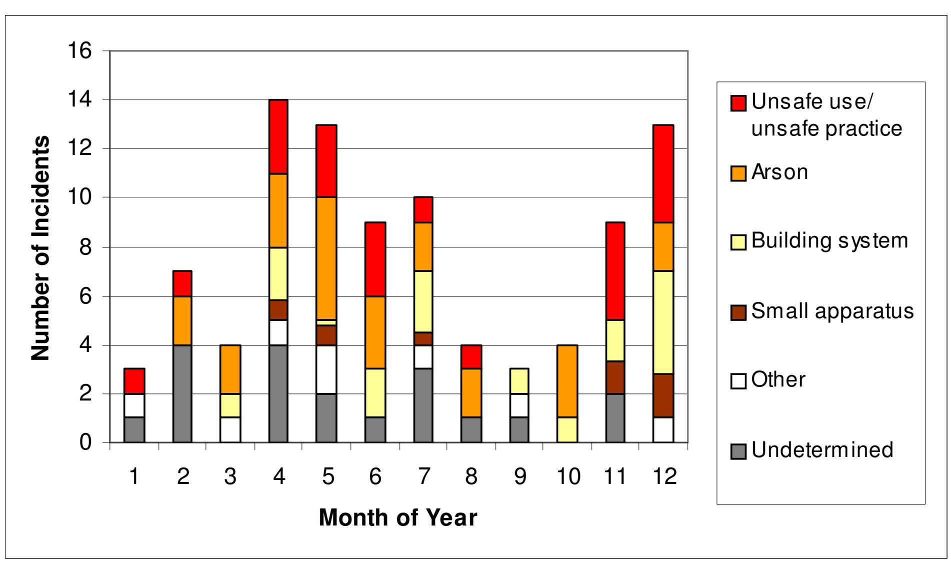

Figure 4. Fires by month for different categories of causes, based on 100 fires reported in Canada from 1994-2004.

Fire Spread

Most data on losses caused by fire tends to specify building damage, but is less precise about damage to collections due to combustion, smoke and water damage. This information is probably clarified later by the insurance company. The author had no success obtaining this information and the related recovery costs from the Insurance Bureau of Canada. As a result, the consequences or extent of damage had to be estimated with the collaboration of experts, with data collected from fire authorities and with other published data from the museum field and the fire protection field. The following are some observations extracted from various sources:

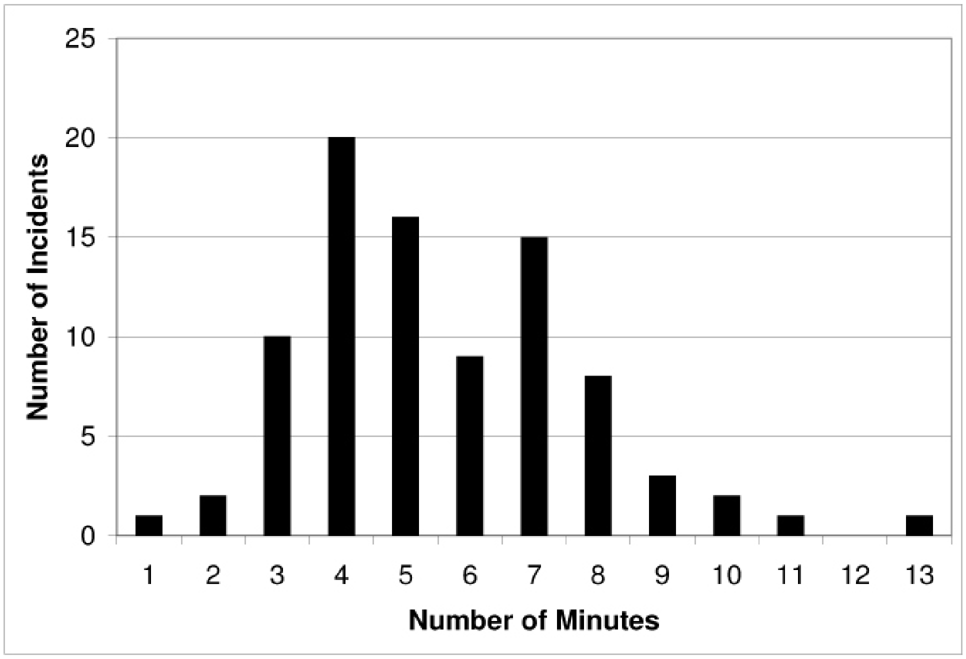

Figure 5. Response times, based on 100 fires reported in Canada from 1994-2004.

- The average damage per fire for Canadian museums is approximately $32,000, with a standard deviation of $2,000. There is a small trend of increased loss per fire from 1994 to 2004.

- Most material that ignited at the origin of a fire is not a museum object. Fires caused by arson can be speeded up with an accelerant and may ignite at multiple points within the available combustible materials.[25,26] It can be assumed that only 5% of the time, the first material ignited is, in fact, a museum object.

- Additional protection against fire, such as fire-resistant vaults or cabinets, can be provided for very sensitive objects or very significant objects.

- There is the possibility of failure with any fire protection technology or procedure. A probability of failure of up to 25% should be considered.[36,37] Some examples of failures include: a smoke detector is disabled, removed or covered with dust covers during renovation; a fire-resistant door is kept open (the opposite also happens when there are too many locked doors slowing down firefighters' access to the fire); inadequate clearance around sprinkler heads; blocked access to the central alarm system control panels; insufficient numbers of fire hydrants and low water pressure available (as shown by the defective hydrants around the Georgetown Library at the time of the 2007 fire); firefighters already busy with another fire; and failure of the central ventilation system (HVAC) to act as designed during a fire. Four of the failures mentioned here were encountered during the fire at The Royal Saskatchewan Museum in 1990 (**Table I**).

- There is a relationship between the fire spread and the Control Level in place. **Table V** shows the estimated distribution of the extent of fire in museums, based on the experts consulted in this study. The data in **Table V** results from discussions with consultants and the study of fires in Canadian museums and was created by compiling all potential scenarios based on the possible causes of fires with their respective frequency, for institutions having different Control Levels. **Table V** shows that at a low Control Level, the fire distribution is relatively uniform throughout the building. This means the probability of a fire is roughly the same for each confined space. As the level of protection is improved, fires tended to remain confined in a smaller space. From CL2 to CL3, a very significant reduction of fire spread is observed. This is due to the rapid reporting of the fire by an automatic fire alarm system to emergency authorities.

Table V: Distribution of Extent of Fire*

Museums with Control Level	Distribution (%) of Fires Confined to:			
	Material	Room	Floor	Building
CL1	28	29	17	26
CL2	28	34	19	19
CL3	42	56	2	0.07
CL4	53	46	1	0.01
CL5	68	31	1	0.006
CL6	99	1	0.02	0.001

*Based on Canadian data (1994-2004) and fire experts.

Table VI: US Fires in Museums and Art Galleries in Relation to the Type of Protection Systems Employed and the Extent of Fire Damage for the Period 1988 to 1998.[a] (Estimated damages ($/Fire) are direct property damage, expressed in US dollars.)

	Extent of Fire Damage						Total Number of Fires
	Confined to Material of Origin		Confined to Room of Origin		Beyond Room of Origin		
	% Fires	$/Fire	% Fires	$/Fire	% Fires	$/Fire	
No Fire Protection Systems	48%	500	28%	2100	24%	170000	267
Automatic Suppression System Only[b]	38%	300	41%	2200	21%	140000	35
Fire Detection Equipment Only[c]	58%	400	28%	7700	14%	92000	303
Both Fire Detection and Automatic Suppression Systems	62%	600	35%	13000	2%	28000	195

[a] Data adapted from the National Fire Protection Assocation.[38]
[b] Not a common set up.
[c] In the data collected, there was no distinction between local detection and detection system monitored full time.

- Fire data from US museums and art galleries, compiled by the NFPA for this study, shows, in **Table VI**,[38] that if the institution is without fire detection, as compared to having automatic detection equipment, there is roughly twice the fire spread beyond the room of fire origin. However, there is also nearly 10 times less fire spread beyond the room when both fire detection and fire suppression systems are in place. Not only is the probability of fire spread beyond the room reduced by fire protection systems, but the amount of damage per fire will also be reduced by a factor of 2 with the presence of smoke detection, and by a factor of 6 with both fire detection and suppression systems in place. Extent of damage expected for institutions having only fire detection equipment, and having both detection and suppression systems, are often similar to the results of the fire expert consultation shown in **Table V**. However, the Canadian data shows greater fire spread in the room compared with the data in **Table VI**.

- For a fire confined to the material of origin, some will be completely burned, some partly and others will remain almost intact. The same logic can be applied on larger scale such as to the floor and the whole building. Assuming that all materials are somehow vulnerable to heat and combustion, **Table VII** shows what the expected loss per surface area due to heat and combustion is for each Control Level. One (1) means complete loss and zero (0) means intact materials. A fractional loss of 0.5 in a room means that either all materials are half burned or half of the materials are completely burned. In both cases, the equivalent loss is 0.5. A high Control Level tends to control the fire faster and the consequences are reduced in each confined space. **Table VII**, established by consultation with fire experts, took into account several issues such as how much damage is typical during open and closed hours, and how fast the fire is detected and suppressed according to each Control Level. For each confined space, the minimum fractional loss is limited by the building design; if there are 4 rooms per floor, when the fire becomes larger than a confined room, damage at the floor level must be more than a 25% loss because the fire has already spread beyond one room. **Table VII** can be adjusted based on the design of the building and fire loading of the materials in it.

- One factor that can influence fire spread through the building is the rapidity with which materials (including objects) can burn and reach the flashover stage. If the materials in a room are slow to combust, there will be less possibility that a fire grows and spreads quickly. **Table VIII**, compiled from information provided by consultation with experts, provides a classification of materials based on

Table VII: Estimated Faction Loss of Material by Heat and Combustion.*

Control Level	Fraction Loss for Fire Confined to:			
	Material	Room	Floor	Building
CL1	0.8	0.7	0.8	0.8
CL2	0.8	0.5	0.7	0.5
CL3	0.5	0.4	0.4	0.4
CL4	0.3	0.3	0.3	0.4
CL5	0.1	0.2	0.3	0.4
CL6	0.1	0.2	0.3	0.4

*Fraction loss based on a building having 3 floors (including basement), and 4 rooms per floor; and based on the institution having, on average, a mixed collection of medium sensitivity to fire. One (1) means complete loss and zero (0) means intact materials.

Table VIII: Classification of Materials Based on Sensitivity to Heat and Combustion.

Sensitivity	Description	Examples of Materials	Relative Sensitivity of Materials to Heat and Combustion
Very low	Non-combustible and non-deformable materials: important fire can cause embrittlement or cracks.	Plaster, gypsum, ceramics, brick, stone	0.1
Low	Non combustible materials; deform at high temperature (post-flashover).	Glass, thin metal under stress	0.5
Medium	Thick organic materials; melt or deform or burn slowly with small flame and moderate temperature (pre-flashover).	Wood panel, thick books	1
High	Thin organic materials; melt or deform or burn rapidly with small flame and moderate temperature (pre-flashover).	Papers, textiles, palm leaf baskets, paintings	10
Very high	Very fast burning or explosive materials; material easily self-ignites in moderate temperature (pre-flashover) or combusts drastically in contact with the small flame.	Cellulose nitrate, combustible solvents, munitions, gun powder, fireworks	1000

their relative vulnerability to heat and combustion. If the museum has a lot of high and very high sensitivity objects in its collection, it will have to adjust the fire spread in **Table VII** by increasing the loss for each confined space. The building industry has developed classes of fire resistance for materials based on different tests, such as the Tunnel Flame Spread, but the focus has been on modern building products. Unfortunately, many museum objects are more vulnerable than modern materials in the minimum-resistant class.[30,39]

- The loss related to unreported fires for buildings in general are estimated today at about $200.[24]

- The main reasons why most fires spread beyond the room limit is due to a lack of, or a deficiency of, detection and suppression measures.

Fire Risk Assessment Scenario for a Typical Museum

What is the risk of fire for a museum? How can an estimate be calculated? For example, consider a museum with 3 floors, 4 rooms per floor, which contains a mixed collection in storage and exhibit spaces spread throughout the building. This fictional building might also have spaces for offices, mechanical systems, custodial storage, a gift shop, or a restaurant. For the sake of simplicity, let us assume that all objects have similar value and have medium sensitivity to heat and combustion. After assessing the building, hardware and procedures, it was determined that the museum fulfilled the criteria for Control Level 2. Thus, a frequency of fire can be estimated in Canada at one fire every 140 years (**Table III**). The assessment of the Consequences must consider more parameters; **Table IX** shows how 5 parameters were used to assess the Consequence of a fire incident for this example. The list of parameters can be more elaborate for a micro-assessment by considering more closely the parameters influencing the Likelihood and Consequences described above. For this example, the 5 parameters in **Table IX** are sufficient. For each size of a confined fire, from only the material itself to the overall building structure, a fraction is established for each parameter as explained below:

1) The first parameter is the fire-spread distribution based on the Control Level (**Table V**); for this example, the parameter was set as Control Level 2.

2) The second parameter is the maximum fraction of material (collection and non-collection) that can be damaged by different sizes of fire. All materials are vulnerable to heat or combustion. If the fire affects the whole building, 100% of the material is at risk. With 3 floors, 33% of the materials are at risk per floor. Assuming that there are 4 rooms per floor and that each room contains an equal portion of the collection, then the fraction is 0.083 (0.33/4). One material or a limited surface was estimated as 10% of the surface of the room (0.1 x 0.083 = 0.0083).

3) The third parameter is the expected fractional loss of the maximum fraction of material that could be damaged. That is, after the fire has been controlled by suppression (manual or automatic), what fraction of those materials are expected to be lost due to combustion and heat? **Table VII** provides this information for each Control Level. At Control Level 2, this fraction is given as 0.8 for a fire confined to a single material. The typical response times for the different Control Levels have also been considered.

4) The fourth parameter is the possibility that when the fire starts, there is a collection in the room, on that floor, or in the building. Because the building is a museum containing objects, the fraction is 1. If all 3 floors contain part of

Table IX: Example for the Assessment of the Potential Consequence of a Fire in Terms of Heat and Combustion.

Parameters of the Consequence	Fractions Parameters for Fire Confined to:			
	Material	Room	Floor	Building
1. Fire Spread Distribution (based on CL2)	0.28	0.34	0.19	0.19
2. Maximum Fraction of Material that can be Damaged by Heat and Combustion	0.0083	0.083	0.33	1.0
3. Fraction Loss of Materials Expected	0.8	0.5	0.7	0.5
4. Possible Presence of Collection	0.0015	0.03	1.0	1.0
5. Fraction of Loss of Collection Value	1.0	1.0	1.0	1.0
Fraction Loss of Value for Each Fire Size	0.0000028	0.00042	0.044	0.095
Consequences (Total Fraction Loss of Value)	0.14			

the collection, then the floor is also rated at 1. Canadian data shows that only 3% of fires start in a room that contains collections (collection storage or exhibition rooms). The possibility that the material first ignited is an object or that a few objects are close to the fire is estimated at 5% based on expert judgment.[26] Because there is already a 3% chance that an object is in the room, the fraction of collection possibly affected by fire at the material scale is 0.03 x 0.05 = 0.0015.

5) The fifth and last parameter deals with the fraction of loss of value for burned objects. The process for assessing the loss of value based on the damage expected can be quite complex. Since the nature of the collection is known only to those that work with it, it is the responsibility of those individuals to assess the loss of value based on their particular value criteria. To simplify this assessment, a direct correlation is applied for the fraction of damage and its respective loss. Thus, the maximum fraction for loss of value from fire is 1, with 0 defined as no loss. With a maximum fraction of loss of value of 1, the collection is completely combusted, and there is no more value associated to that collection.

The overall fraction loss of value for each confined fire will be the product of all these 5 fractions (example: fire confined to a material: 0.28 x 0.0083 x 0.8 x 0.0015 x 1.0 = 0.0000028). Thus, the Consequence is the summation of Loss for each confined space (0.0000028 + 0.00042 + 0.044 + 0.095 = 0.14). In this example, the potential consequence is a loss of value of 14% of the collection in that museum.

The Risk, as the product of the Likelihood and the Consequence, is:

Risk = (1 fire / 140 yrs) x (14% value loss/fire)
= 14%/140 yrs
= 0.10% loss of value per year.

If this museum can improve the fire protection strategy by upgrading the Control Level to CL3 or even to CL4, the risk becomes:

Risk at CL3 = (1 fire / 160 yrs) x (0.35% value loss/fire)
= 0.0018% loss of value per year.
Risk at CL4 = (1 fire / 720 yrs) x (0.14% value loss/fire)
= 0.00016% loss of value per year.

Each of these improvements, between CL2 and CL3 and between CL3 and CL4 are very significant and deserve serious consideration. An example of how to improve the fire protection of a historic site has been published by Weiger.[40]

Institutions can obtain a better idea of the relative risk of fire compared with other agents of deterioration by conducting a risk assessment. An extended risk assessment that includes all agents will help determine what the priority actions should be or what the overall risk for the institution is.

Indirect Effects: Water and Soot

Up to now, only damages directly associated with heat and combustion were considered. However, as shown in **Figure 1**, other agents of deterioration contribute to the damage of a collection during a fire. Soot deposition and water damage are expected to contribute significantly to the overall loss of a collection. If pollution and water are not covered in a large-scale risk assessment, their contribution during a potential fire event can be included in a fire damage assessment. A similar approach for assessing damage by combustion can be used for the loss of value due to soot deposition and water damage. The likelihood is the same since it is the same event but some elements of the consequences will be different and have to be considered such as:

- Avoid double counting when considering multiple agents. Combusted objects do not experience further losses if they become wet or covered by soot, but unburned objects do.
- Even a very small fire is likely to generate smoke throughout

a room and sometimes even beyond.

- Most objects in airtight enclosures will be protected against water and soot as long the enclosures are not damaged by direct and indirect effects of the fire (**Figure 1**). One weak point of display cases is the glass. Glass does not withstand sudden temperature changes well, neither will it withstand the impact from water ejected by a fire hose.
- During suppression of a small fire, half a room will easily become wet. Water can penetrate to lower floors during the suppression of a more significant fire.
- Damage caused by soot and water is often at least partly reversible, so the loss of an object's value is usually less than that for objects that are charred or severely combusted.

With the museum described above (with CL2 and assuming that 30% of its collection is in airtight enclosures), the consequence of soot deposition and water damage are estimated respectively at 2.0% and 3.0% of total loss of value of the collection during a fire event. These losses are based on a maximum fraction for loss of collection value of 0.3 and 0.4. This brings the risk for the major effects of fire at:

$$\begin{aligned}\text{Risk} &= (1 \text{ fire} / 140 \text{ years}) \times \{(14\ \%\ \text{value lost/fire})_{\text{combustion}} + (2.0\%\ \text{value lost/fire})_{\text{soot}} + (3.0\%\ \text{value lost /fire})_{\text{water}}\} \\ &= 19\% / 140 \text{ years} \\ &= 0.14\% \text{ loss of value of the collection per year.}\end{aligned}$$

At CL3 and CL4, the loss of value due to the 3 major effects of fires is estimated at 0.0050% and 0.00060% respectively. As institutions become better protected against fire (maintain a better Control Level), the impact of water damage and soot deposition increases as the damage by heat and combustion become more limited.

Size of Fire

The possible size of a fire (whether confined to the original materials, or the room, floor, and building) will dominate the consequences (loss of value). Those sizes depend mainly on the Control Level in place. For museums having low Control Levels such as CL1 and CL2, the consequences of fire can be devastating due to lack of protection and the entire building can burn. In the example above (**Table IX**), fires that spread throughout the floor and the entire building are responsible for 0.044 and 0.095 of collection losses, respectively. Together they account for more than 99% of the value lost. At intermediate levels of protection (CL3 and CL4), most damage is due to the possibility that fires are deployed in the room and sometimes beyond. Some of the unexpected fire spread can be due to a failure in the control strategy. At levels CL5 and CL6, damage seems to be equally due to cumulative small fires up to one important fire at the building level. At these high levels of control, the main reason for the spread of fire beyond the room is probably due to failures in a control strategy or due to an exceptional cause such as an explosion or large earthquake.

The magnitude of loss for a museum protected at CL3 (0.0050%/yr above) is similar to what is observed in the 100 fires reported from 1994 to 2004 where none or very few fires spread beyond the room. If there are no further improvements in fire prevention, at this rate, the heritage community in Canada could lose up to 0.50% of the value of their collections due to the major effects of fires in 100 years.

Issues Related to Water-Based Suppression

There are some common concerns related to the water released by sprinkler systems either during a fire, or due to the accidental discharge of a sprinkler head, resulting in serious damage to the collection. Some common misunderstandings are:[41-44]

- “Sprinkler systems are prone to leakage or inadvertent operation.” The likelihood of failure is estimated at 1 head per 16 million sprinkler heads installed per year. Installation and maintenance must be well done. To avoid breaking the sensing elements, sprinklers that could be hit accidentally should be protected by a cage, or installed upright with a deflector. The probability is much higher that water damage will occur within an institution as result of a roof leak, bursting plumbing pipes, flooding, etc. However, dry pipe sprinkler systems are more susceptible to leaks than wet pipe systems. Dry pipe sprinkler systems have other issues and should not be used to protect collections.[44]
- “Sprinklers operate in the presence of smoke.” Only the fire detection system will activate the sprinkler head, not smoke.
- “All sprinklers operate at once during fire.” On the contrary, each head is triggered independently. Most fires are controlled by 3 sprinkler heads or less.
- “A sprinkler will release too much water.” **Table X** shows typical quantities of water released by water-based suppression systems. Fire can be controlled easily in a few minutes by a sprinkler system. However, because a sprinkler valve can only be turned off by a firefighter, water may easily run for 10 minutes. Still, sprinkler activation does far less damage than fire department hoses. During a fire event, if plastic sheets are available on site, museum staff can ask firefighters to cover items at risk of water damage. This happened at the Georgetown Library[16,17] and at the Petit séminaire de Québec.[26] However, these are exceptional cases because firefighters are under no obligation to rescue collections nor to prevent water damage.

In addition to the fear of water damage, common excuses to avoid automatic suppression systems are the trust in a rapid fire department response and the concern for the historic or aesthetic integrity of the building. To address aesthetic integrity concerns, sprinkler heads can be either concealed or can be integrated in a way that minimizes the visual impact. Fire department response time, as seen above (**Figure 5**), is usually fast in a city. However, the detection and communication of a fire incident must be done quickly. Otherwise, significant damage to a collection is expected, especially in non-fire resistive buildings. Also, during an unlikely situation of multiple simultaneous fires in the city, a fire department's priority is the rescue of institutions in which there are vulnerable citizens, such the hospitals or schools.

Table X: Typical Amount of Water Released by Different Fire Suppression Methods.

Suppression Method	Liters/min per Device	Volume of Water Released
Firefighter Hose	1000	Minimum of 2000 liters for a small fire
Sprinkler Heads (dry or wet pipe)	100	2000 liters for 10 min
Sprinkler Heads with Water Mist System	10	200 liters for 10 min
Portable Fire Extinguishers (10 liters)	10	20 liters for about 1 minute

The risk of water damage can be reduced by using a water mist system.[41,42,45] When activated, the system releases a mist of water under high pressure delivering approximately only 10% of the amount of water delivered by a conventional sprinkler system. The mist does not conduct electricity, and so it can be used on live electrical equipment.

Some institutions cover storage shelving with polyethylene sheeting or cotton sheeting to protect collections from potential water leaks, or from dust. Such materials are not forbidden by the NFPA, but are not encouraged.[30] Polyethylene sheeting does not contribute significantly to the fire load and protects a collection from water leakages, which happen much more often than a fire. However, under fire conditions, it should be noted that the plastic sheet can melt onto the collection and will be difficult to remove. Fire experts recommend that cotton sheeting should be treated with flame retardant, but direct contact of the retardant-treated sheeting with objects is usually not recommended. Bear in mind that a minimum of 46 cm (18 inches) clearance is required below the sprinkler and the top of any shelf or other obstruction.[46]

For institutions located in seismic zones, there are specific requirements for sprinkler systems in order to minimize the risk of a sprinkler being damaged and becoming inoperable during an earthquake. Further information is available in the literature.[46]

Conclusion

Strategies to prevent fires, to limit fire spread and to minimize the risk of a fire reaching flashover are key elements in reducing damage to a collection from combustion, charring, water, soot and all the other effects of a fire. Equipment and systems must not only be in place, but must be inspected regularly to ensure that they are working properly. In addition, an active fire safety committee composed of staff and management is one of the key elements in fire prevention. These committees help promote awareness, identify problems, and propose and ensure that solutions are applied to minimize the risk of fire. The tangible benefit is better preserved collections for future generations.

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Appendix 1: Notes for Table II.

Avoid.CL4b
Examples of hazardous occupancies include: firework plants, propane dispensing facilities, chemical plants, and storage facilities with large quantities of combustible and flammable liquids.

Avoid.CL5a
Shared and adjacent occupancies flanked by museum spaces have a fire separation of at least two hours. The fire alarm annunciator panel clearly shows which building is under alarm. Other occupancies are identified separately when shared fire alarm systems are provided. Shared Occupancy: Cafeterias, boutiques, parking garages and other co-occupants in the same building that do not answer to the museum. Adjacent Occupancy: Other occupancies linked to the museum (side by side or above & below) that do not answer to the museum.

Block.CL2a
Buildings designed to resist the spread of fire. Exterior finish may include brick, stone, glass, stucco, and metal sheeting or other non-combustible material. Roof covered with tar and gravel, asphalt shingles, clay tiles or other non-combustible product. Walls and ceilings may be wood frame but covered with low flame spread rating materials such as drywall or plaster. Noncombustible ceiling tiles are acceptable if designed not to lift during a fire. This can be obtained by installing ceiling clips.

Block.CL2b
Wall and ceiling surface would typically have a layer of fire rated drywall, Underwriters' Laboratories of Canada (ULC) 1 or 2

hours rated fire doors, doorframes and hardware.

Block.CL2c
Staircases used to evacuate occupants and to facilitate firefighting operations are enclosed and finished with non-combustible materials from floor to ceiling, between each floor, and provided with ULC listed fire doors that block smoke, heat and hot gases. ULC listed glass enclosures are also acceptable.

Block.CL3a
Exhibit holding areas are closed-off from adjoining rooms with ULC 1 hour rated doors, doorframes and hardware. Walls and ceiling surfaces are of non-combustible materials such as concrete, masonry blocks, drywall, plaster and/or other non-combustible material.

Block.CL3b
Fire doors held open for convenience or for operational reasons must be provided with ULC listed door holding devices that automatically release upon a fire alarm signal or when smoke is detected. Fire doors are not held open with wedges and/or with other means.

Block.CL4a
The building's structural members (load bearing walls, floors, columns, beams and roofs) are of approved non-combustible or limited combustible materials such as reinforced concrete, prefabricated masonry slabs, masonry blocks or steel for example. Interior finishes are all non-combustible and interior walls constructed with reinforced concrete, masonry blocks and/or metal studs.

Block.CL4b
The building's main air circulation system shuts down automatically when smoke is detected. Automatic fire dampers are provided to close-off sections and prevent fire spread between rooms and/or floors.

Block.CL5a
ULC listed and/or Canadian Standards Association approved metal cabinets are provided and used. They have one vent opening on each side, one at the top and the other at the bottom to prevent the accumulation of fumes. These vents are always kept clear and never blocked. Approved dispensing containers are provided and used.

Detect.CL1a
Smoke alarms (battery operated and/or hard wired) are provided in public areas, evacuation routes, and in areas such as kitchens and workshops. Stand-alone battery operated and 120 VAC smoke detectors are tested by pressing the detector button. This is done monthly to ensure they function as intended.

Detect.CL1b
Standard telephone or cellular telephone available at all times for emergency calls to 911, the fire department and/or the police department.

Detect.CL2a
A well maintained ULC listed fire alarm system comprised of manual fire alarm pull stations, fire detectors (heat or/and smoke detectors), fire alarm bells, battery backup, and an annunciator panel. The fire alarm system and its peripheral equipment (fire detectors, manual fire alarm pull stations, door holding devices, alarm bells, etc.) are tested at least once a year by a professional firm. Records are kept and deficiencies corrected.

Detect.CL3a
The fire alarm system is monitored twenty-four hours a day, seven days a week: in house, by a monitoring agency, by the fire department, or by the police department.

Detect.CL3b
Automatic smoke detection is provided in exhibit and storage rooms. Detectors are wired to fire alarm system.

Detect.CL4a
A telephone line is provided solely for the purpose of the fire alarm system. The monitoring agency, the fire department or the police department is automatically notified of faults in this line. A supervised line ensures line quality by notifying the fire alarm monitoring agency, the fire department or the police of problems (i.e. line breaks, grounds, short circuits, tampering).

Detect.CL5a
The fire alarm panel clearly indicates when fire is detected in a storage or exhibit room. The fire alarm system (panel) should have a separate zone for this purpose. Collection room fires need to be identified as quickly as possible. The fire department must not waste time finding the location of this alarm.

Detect.CL5b
Trained guards are in place twenty-four hours a day, seven days a week. Guards conduct tours every hour and they are ready to take action by containing fires, by limiting its spread (by closing doors for example) or by assisting firefighters in locating the fire.

Respond.CL1a
Trained firefighters and firefighting equipment is available twenty-four hours, seven days a week. This can be career personnel, auxiliary personnel, volunteers or a combination. Volunteers provide an acceptable level of service according to the NFPA. Training, equipment and the ability to accomplish fire department objectives is the key to performance.

Respond.CL1b
Portable fire extinguishers are installed in a visible and accessible location.

Respond.CL2a
Water supplies such as fixed water tanks should be provided and/or natural water sources such as rivers and lakes should be available when fire hydrants are not available; and be easily accessible to firefighters 24/7 throughout the year. The building will most likely be a total loss if the water supply is inadequate. Water trucks may not be adequate in most cases.

Respond.CL3a
Fire hydrants installed in accordance with approved standards are within 300 meters (1,000 feet), functioning and accessible at all times.

Respond.CL3b
A standpipe system should be provided for each floor. Hose connections must fit local fire department hoses. The system has 6.35 cm diameter (2.5") fire hose connections and is functioning. When hose connections or couplings do not conform, it complicates firefighting operations and precious time is wasted. Private fire hoses normally provided with standpipe systems are rarely used by staff for lack of training or fear of causing undue water damage to collections. These fire hoses are often in poor condition and unreliable. Firefighters prefer to use fire department hose lines.

Respond.CL4a
An approved, well-maintained automatic fire suppression system (water-based, gaseous, or other) is provided and functioning. A professional firm inspects automatic fire suppression systems annually. Records are kept and deficiencies corrected. High fuel load storage is applied to collection storage rooms: (1) when it has a size greater than 46.5 m^2 (500 ft^2); (2) when storing cellulose nitrate negatives not kept in cabinets designed for this purpose; (3) when storing more than 23 kg (10 standard rolls) of cellulose nitrate motion picture film; (4) when it has compact storage systems; or (5) when storing collections preserved in combustible or flammable solutions (some natural history collections).

Respond.CL5a
An approved, well-maintained automatic fire suppression system (water-based, gaseous, or other) is provided in storage rooms and exhibit rooms.

Respond.CL6a
This Control Level refers to an automatic sprinkler system (wet-pipe, dry-pipe, pre-action, water mist or other). Areas holding collections may be protected with a gaseous system.

Training.CL2a
Some staff and/or volunteers are trained in the use of portable fire extinguishers. Proper use and immediate action at the moment a fire is discovered can prevent serious collection losses. Training must include theory as well as actual use of equipment. Training should include selecting the correct type of extinguisher and hands-on exercises. To minimize cost, some facilities schedule practical training when fire extinguishers need to be replenished.

Training.CL3a
Professional portable fire extinguisher hands-on training and theory is provided to staff and/or volunteers.

Training.CL4a
Fire prevention training provided, for example in the safe use of chemical / flammable liquids, open flame apparatus such as a Bunsen burner, propane torch, welding equipment and other heat producing tools.

Training.CL4b
The institution ensures that courses are available every three years to previously trained staff/volunteers and to new employees/volunteers.

Training.CL5a
Sufficient staff trained in emergency collection salvage operations.

Training.CL5b
The institution ensures that courses are available yearly to previously trained staff/volunteers and to new employees/volunteers.

Training.CL6a
Disaster simulation exercises involving the fire and police departments, service providers prepared to provide water pumps, temporary collection storage, freeze/dry services etc. are performed every five years minimum.

Procedures.CL1a
Fire safety procedures are in place to prevent fires from candles, wood burning fireplaces, wood stoves, etc. This applies mostly to historic museums conducting cooking demonstrations, blacksmithing and glass blowing demonstrations, to name a few. It applies to open-pit fires, wood stoves, candles and lanterns used in demonstrations and to recreate the past. It also applies to work practices used in conservation laboratories and workshops.

Procedures.CL1b
Visual inspections are conducted quarterly to ensure portable fire extinguishers are in their designated place, visible, accessible, seals not broken, and pressure is in the operating range.

Procedures.CL2a
Inspections and required testing is done by a professional firm on an annual basis. Tags are attached showing the name of the firm and the date of inspections. Extinguishers need to be tested and recharged at specific intervals depending on types.

Procedures.CL3a
Random testing of fire detectors and manual fire alarm pull stations is carried out at least once a month.

Procedures.CL3b
For a building over 40 years old, the building's main wiring and distribution panels are inspected for deficiencies, loose contacts, overheating, etc. Random duplex receptacles, electrical fixtures, switches, etc., are removed and inspected for signs of wear, overheat and loose connections for example. Inspections are recorded and kept on file. A qualified journeyman electrician does this work.

Procedures.CL4a
Staff assigned to inspect work and exhibit/storage areas to

identify fire hazards. A checklist and a reporting system are in place.

Procedures.CL4b
A fire safety committee composed of staff and management is in place at least quarterly. Meeting minutes are recorded, and responsibilities assigned. The committee is endorsed by senior staff.

Procedures.CL4c
The Procedure 3b is followed independently of building age or previous renovations.

Procedures.CL4d
Temporary users of building facilities such as exhibit rooms and meeting rooms follow fire safety procedures to ensure they do not create additional fire hazards. This includes: temporary exposed electrical wiring and extension cords inspected by a certified electrician prior to opening; temporary exhibit and display materials used inside the facility is non-combustible or treated with fire-retardant coating; cooking and food preparation is closely supervised; procedures are approved by senior staff and reviewed annually; and procedures are kept on file and available for review.

Procedures.CL4e
Welding, cutting, soldering, and other heat producing operations are performed inside the building only when the building authority provides permission. Permits are granted if contractors follow strict fire prevention practices.

Procedures.CL4f
A building preventive maintenance program is in place and conducted at the minimum once a year. Major mechanical and electrical systems (motors, switchgear, distribution panels, HVAC systems, etc.) are maintained in good operating condition.

Procedures.CL6a
Electrical changes and modifications inspected by a journeyman electrician.

Procedures.CL6b
Firefighters are familiar with the premises; know where to respond during a fire alert and know where collections are located.