

Construction-related Nosocomial Infections in Patients in Health Care Facilities

Decreasing the Risk of *Aspergillus*,
Legionella and Other Infections



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Construction-related Nosocomial Infections in Patients in Health Care Facilities

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Introductory Statement

This document, *Construction-related Nosocomial Infections in Patients in Health Care Facilities: Decreasing the Risk of **Aspergillus**, **Legionella** and Other Infections*, has been developed under the direction of the Health Canada Infection Control Guidelines Steering Committee. It is intended to aid health care professionals to improve the quality of health care. The information in this document is designed to assist in developing policies, procedures and evaluative mechanisms to ensure an optimal level of care.

The information in this document was current at the time of publication. It should be emphasized that areas of knowledge and aspects of technology advance with time.

The Health Canada Infection Control Guidelines Steering Committee acknowledges, with sincere appreciation, the many professionals who contributed advice and information to this endeavour.

Professionals using this document are encouraged to refer to the Health Canada *Infection Control Guidelines* series for further information and recommendations related to infection prevention and control. The series includes the following:

- *Routine Practices and Additional Precautions for Preventing Transmission of Infection in Health Care* (1999)
- *Infection Prevention and Control Practices for Personal Services: Tattooing, Ear/Body Piercing and Electrolysis* (1999)
- *Hand Washing, Cleaning, Disinfection and Sterilization in Health Care* (1998)
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- *Canadian Contingency Plan for Viral Hemorrhagic Fevers and Other Related Diseases* (1997)

- *Preventing the Transmission of Tuberculosis in Canadian Health Care Facilities and Other Institutional Settings* (1996)
- *Long Term Care Facilities* (1994)
- *Occupational Health Prevention and Management of Infectious Diseases in Health Care Workers* (2001)
- *Prevention of Nosocomial Pneumonia* (1990) (under revision)
- *Antimicrobial Utilization in Health Care Facilities* (1990)
- *Prevention of Surgical Wound Infections* (1990)
- *Prevention of Urinary Tract Infections* (1990)
- *Organization of Infection Control Programs in Health Care Facilities* (1990)
- *Perinatal Care* (1988)

For information regarding the above Health Canada publications, contact:

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Acknowledgements

The Division of Nosocomial and Occupational Infections gratefully acknowledges the assistance of the following people, who have provided intellectual input on sections of this paper.

Mr. Donald Ardiel, Architect; Mr. Allan Brogden, Engineer; Dr. Elizabeth Bryce; Ms. Siu Mee Cheng; Dr. John Conly; Ms. Brenda Dyck; Mr. Gerry Granek, Engineer; Mr. Grant Gillis, Engineer; Ms. Linda Kingsbury; Ms. Terry Kirkland; Ms. Barbara Lyons; Ms. Susan MacMillan; Ms. Judy McLeod; Dr. Dorothy Moore; Ms. Barbara Neabel; Dr. Lindsay Nicolle; Mr. Andrew Norris, Architect; Ms. Shirley Paton; and Ms. Diane Phippen.

The Scientific Publication and Multimedia Services unit, Management Planning and Operations Directorate, Health Canada, was responsible for the actual production of this document.

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Introduction and Rationale

Health care facilities are undergoing construction and renovations to address restructuring in the health care system. If dust particles contaminated with bacteria and fungi are dispersed during construction, there may be health risks for patients, staff, and visitors⁽¹⁾. Early planning in construction and renovation projects must integrate infection prevention and control, engineering services, and building design to prevent nosocomial (hospital-acquired) infections, and minimize allergen load and other workplace hazards^(1,2).

Several reports document incidents of construction-related nosocomial infections caused by *Aspergillus* species (spp)⁽³⁻²⁹⁾ and *Legionella* spp⁽³⁰⁻³⁴⁾. Nosocomial aspergillosis is a cause of severe illness and mortality in immunocompromised patients^(8,19,35). The primary route of acquiring *Aspergillus* infection is by inhalation of fungal spores. Pneumonia results from local lung tissue invasion. The fungus may disseminate via the bloodstream to involve multiple other deep organs⁽³⁶⁾. The mortality rate is high for both nosocomial aspergillosis (65%-100%)^(24,37-43) and legionnaires' disease (24%-80%)^(41,44-46) in hospitalized populations, even when infections are recognized and treated.

Section A.3 discusses the risk factors for acquisition and death from nosocomial construction-related infections. Construction and renovation projects in health care facilities pose a threat to patients and may, occasionally, also be a health risk to staff and visitors.

As nosocomial aspergillosis is difficult to diagnose and treat⁽⁴⁷⁾, emphasis must be placed on prevention and surveillance to improve detection^(48,49). Legionnaires' disease is one of the few preventable nosocomial pneumonias, and so vigilant surveillance is recommended to identify nosocomial, laboratory-confirmed cases of legionellosis, taking into account the type of patient population served by the facility^(36,50). Appropriate infection prevention and control measures must be employed throughout construction and renovation projects in health care facilities to reduce health risks^(1,13,16,51). A multidisciplinary team of architects, engineers, infection prevention and control professionals (ICPs), and representatives from environmental services, administration, medicine, and nursing is necessary for appropriate risk management planning for construction projects^(1,2,13,16,19,25,47,52-58). As an integral part of prevention, clear lines of communication among all

personnel involved must be established in the planning phase of the project, and guidelines should be developed and followed to ensure that an effective communication plan is used throughout the project^(52,59,60). The protection of susceptible patients and residents will depend on the acceptance and effectiveness of implementing infection prevention measures. Successful risk management will require a high level of commitment, understanding and cooperation from all personnel involved in the construction or renovation project (G. Granek, P. Eng., Toronto: personal communication, 1998).

Currently, Canadian guidelines to address construction-related nosocomial infections and preventive measures to protect patients, health care facility staff, and visitors at the time of construction and renovation do not exist. This paper summarizes the evidence for construction-related nosocomial infections in the literature and identifies measures necessary to prevent disease transmission. The focus is on architects, engineers, infection prevention and control professionals (ICPs), and administrators who are involved in any aspect of health care facility construction and renovation. For the purposes of this document, construction and renovation activities refer to major and minor building activities that occur in established health care facilities but not to new, freestanding health care facilities being built.

– A – Summary of Construction-related Nosocomial Infections ---

A review of the literature of nosocomial infections related to construction or renovation projects in health care facilities is provided. The review spans a 20-year period (1978-1998). It reveals numerous construction-related nosocomial outbreaks, mainly in acute care facilities, and documents the importance of rigorous infection prevention and control practices. As noted in Tables 1 and 2, the majority of infections were related to construction or renovation projects within or adjacent to the health care facility^(3-5,7,8,11-15,17-22,24,25,27,29,30,32-34,42,61). Others were associated with ventilation systems that were malfunctioning or improperly maintained when the health care facility was undergoing construction or renovation^(9-11,16,26,62,63). Two documented outbreaks of pseudofungemia^(64,65) and one outbreak of pseudobacteremia⁽⁵⁵⁾ occurred when dust particles from construction or renovation projects contaminated laboratory specimens⁽⁶⁴⁾, bronchoscopy material⁽⁶⁵⁾, and blood culture bottles⁽⁵⁵⁾.

Table 1. Summary of the Documented Reports on Construction-related Nosocomial Outbreaks due to Fungus

Etiologic Agent	Underlying Medical Condition of Patients	Number of Patients		Circumstances	Reference/ Year
		Infected/ Colonized	Number of Patients who Died		
<i>A. fumigatus</i> ⁽³⁾ <i>A. niger</i> ⁽¹⁾ <i>A. terreus</i>	Burn ⁽²⁾ Trauma ⁽¹⁾ Perforated viscus and wound dehiscence ⁽¹⁾	4	Not available	Renovations in the central inventory control department resulted in <i>Aspergillus</i> spores being dispersed and settling on the supply boxes. The packages inside became contaminated when the box was opened. Patients then became infected when the packages were opened during dressing changes.	Bryce et al., 1996 ⁽²⁷⁾
<i>A. flavus</i> ⁽³⁾ <i>A. fumigatus</i> ⁽²⁾ <i>A. niger</i> ⁽¹⁾	Leukemia ⁽⁶⁾	6	2 (related to underlying illness)	Repair of false ceiling due to a water leak in a store room housing intravenous (IV) supplies. Adhesive tape and arm boards were contaminated.	Grossman et al., 1985 ⁽²⁵⁾
<i>A. fumigatus</i> ⁽¹⁸⁾	Leukemia ⁽¹⁵⁾ Myeloma ⁽¹⁾ Lymphoma ⁽¹⁾ Paramyeloidosis secondary to breast cancer	22	18	Spores were dispersed during demolition of ducts and false ceilings, removal of fibrous thermal insulating material (glass fibre), and work on roller-blind casings.	Perraud et al., 1987 ⁽²⁴⁾
<i>A. fumigatus</i> ⁽³⁾	Heart transplant ⁽³⁾	3	2	Connecting bridge between the old and new unit allowed dust to circulate from a nearby construction project. In addition, one air vent was not properly closed.	Hospital Infection Control, 1990 ⁽⁶⁶⁾
<i>A. fumigatus</i> <i>A. flavus</i>	Hematologic malignancy ⁽²⁾ Advanced age ⁽¹⁾ Renal transplant ⁽⁷⁾	10 (retrospective review of autopsy reports)	10 (4 due to invasive aspergillosis)	Window air conditioners in the renal transplant unit were heavily contaminated with <i>Aspergillus</i> spp. The unit was close to adjacent road construction.	Lentino et al., 1982 ⁽⁹⁾
<i>A. niger</i> <i>A. flavus</i> <i>A. fumigatus</i>	Diagnosis not provided (hospital admits patients with leukemia, lymphoma, myeloma, brain tumours, sarcomas, and metastatic carcinomas)	8	3	Believed <i>Aspergillus</i> spores settled on wet fireproofing material when it was installed during construction. Spores were dispersed when the dry fireproofing material was disturbed above false ceilings during renovation or maintenance.	Aisner et al., 1976 ⁽¹⁸⁾
<i>A. fumigatus</i> ⁽³⁾	Patients on an oncology unit	3	1 (had BMT)	Remodelling of adjacent radiology department. Dust barriers had not been installed.	Berg, 1995 ⁽⁷⁾

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<i>A. fumigatus</i> ⁽⁶⁾	Patients in intensive therapy unit for respiratory failure, Crohn's disease, chronic bronchitis, emphysema, asthma, multiple trauma, septic shock, abdominal aneurysm	6	3 (related to underlying disease)	It was suggested that spores in fibrous insulation material above perforated metal ceilings were dispersed during minor building in adjacent offices and stores areas.	Humphreys et al., 1991 ⁽¹⁴⁾
<i>A. fumigatus</i> ⁽⁶⁾	Bone marrow transplantation (BMT)	6	6	Heavy fungal spore contamination resulted from construction of an adjacent BMT unit.	Barnes & Rogers, 1989 ⁽¹²⁾
<i>A. fumigatus</i> ⁽³⁾	Renal transplantation	3	1	Renovation activity on the floor above caused dust to be dispersed from false ceilings in the renal transplant ward.	Arnow et al., 1978 ⁽⁵⁾
<i>A. fumigatus</i> ⁽³⁾	Renal disease – chronic renal failure ⁽²⁾ – Wegener granulomatosis	3	2	The outbreak coincided with hospital renovation on a unit near the renal unit on which the patients were being housed.	Sessa et al., 1996 ⁽¹⁵⁾
<i>A. flavus</i> ⁽⁴⁾ <i>A. fumigatus</i> ⁽¹⁾ <i>A. niger</i> ⁽¹⁾ Other <i>Aspergillus</i> spp	Immunosuppression from – lymphoreticular malignancy ⁽⁷⁾ – high-dose corticosteroid therapy ⁽⁶⁾ – disseminated carcinoma ⁽¹⁾	11	11	Not provided. Patients were either located on the same floor as or one floor below the construction area.	Opal et al., 1986 ⁽⁴⁾
<i>A. flavus</i> ⁽⁵⁾ <i>A. fumigatus</i> ⁽⁶⁾	Patients on a BMT/leukemia unit	13	5	Fire in an old building close to the hospital and repeated window opening by a patient shortly afterwards suggest fungal spores dispersed during the fire were the source. The hall carpet then became contaminated and was an ongoing source of the infection.	Gerson et al., 1994 ⁽³⁾

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<i>A. terreus</i> ⁽⁴⁾	BMT ⁽²⁾ Acute myelogenous leukemia (AML) ⁽¹⁾ Disseminated choriocarcinoma ⁽¹⁾ Diagnosis not provided in the remaining 2 patients	6	4	Renovations were taking place two floors below the intensive care unit (ICU). Air pressure in ICU was negative to hallway and nearby elevator shafts. This was thought to have occurred when a wall was built during earlier renovations. In addition, patient room ventilation was conventional rather than unidirectional.	Flynn et al., 1993 ⁽¹⁰⁾
<i>Aspergillus</i>	Patients on burn unit, dialysis unit and oncology	5	not available	Air intake vents had not been covered during demolition on the nursing units where the patients were housed.	American Health Care Consultants, 1995 ⁽²⁶⁾
<i>Airborne fungi</i> ⁽³⁾ <i>Candida tropicalis</i> ⁽²⁾ <i>Fusarium</i> ⁽¹⁾	BMT	7	6	Several potential sources included loose wallpaper in a corridor; poorly sealed chase openings and direct opening from BMT rooms with floors above and below; inadequate air exchange and exhausts; negative pressure in 4 of the 16 BMT rooms; high-efficiency particulate-air (HEPA) filters not maintained or changed in 4 years.	American Health Care Consultants, 1995 ⁽⁶³⁾
<i>Aspergillus</i>	Patients on a hematology unit	5	5	Large-scale excavation work while hospital was being rebuilt. The isolation rooms that housed the patients overlooked the building site.	Shields et al., 1990 ⁽²⁹⁾
<i>Zygomycetes</i> <i>Aspergillus</i> <i>Rhizopus indicus</i>	Premature infant with respiratory distress syndrome Premature infant with ligation of a patent ductus arteriosus	2	2	Major source of mould was dust above the false ceiling.	Krasinski et al., 1985 ⁽²¹⁾

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Etiologic Agent	Underlying Medical Condition of Patients	Number of Patients Infected/Colonized	Number of Patients who Died	Circumstances	Reference/Year
<i>Aspergillus</i>	AML ⁽²⁵⁾ Acute lymphoblastic leukemia (ALL) ⁽⁷⁾ Chronic lymphocytic leukemia (CLL) ⁽¹⁾ Chronic myelogenous leukemia (CML) ⁽¹⁾ BMT ⁽²⁾	36 (over 69 months)	17	Not provided, however, four cases were identified prior to hospital construction compared with 28 cases during construction and four cases after control measures had been initiated, suggesting hospital construction was related to the outbreak.	Loo et al., 1996 ⁽¹³⁾
<i>A. flavus</i> ⁽³⁴⁾	Old cavitary tuberculosis (TB) Diabetes Idiopathic thrombocytopenic purpura (ITP) Leukemia Lung cancer Chronic obstructive pulmonary disease (COPD) Bacterial pneumonia	32	1	Construction activity adjacent to the hospital and a defective ventilation system in old wing of hospital (e.g. prefilters heavily soiled, gaps between the individual filters and framework). Unfiltered air was allowed to enter patient care areas.	Sarubbi et al., 1982 ⁽¹¹⁾
<i>Aspergillus</i>	Immunosuppressive treatment for vasculitis	3	3	Construction work and demolition of hospital buildings adjacent to the medical unit the patients were on. Contributing factors: no special ventilation system and windows could not be completely closed.	Dewhurst et al., 1990 ⁽²⁰⁾
<i>A. flavus</i> ⁽⁶⁾ <i>A. fumigatus</i> ⁽¹⁾ <i>Mucoraceae rhizopus</i> ⁽¹⁾	AML ⁽³⁾ ALL ⁽³⁾ Aplastic anaemia ⁽¹⁾ Metastatic Wilm's tumour ⁽¹⁾	8	5	Directly related to increased spore counts from soil excavation that occurred during hospital construction in a pre-existing facility.	Lueg et al., 1996 ⁽¹⁷⁾
<i>Aspergillus</i> ⁽³⁾ <i>Zygomycetes</i> ⁽²⁾	Burkitt's lymphoma ⁽¹⁾ AML ⁽¹⁾ ALL ⁽³⁾	5	5	Exposure to construction activity was independently associated. Extensive renovation was taking place as well as new construction. Windows could be opened on the unit the children were on, and the "reversible pressure" system did not provide the indicated pressure relationships.	Weems et al., 1987 ⁽¹⁶⁾

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<i>A. fumigatus</i> ⁽²⁾ <i>A. flavus</i> ⁽¹⁾ Unknown ⁽²⁾	Neutropenia as a result of high-dose chemotherapy	5	not provided	There was a significant increase of mould in the air in the patient rooms and corridors after construction was started. Sealing windows and other areas suspected of causing leaks decreased the amount of mould in the air. Therefore, leaks around windows were suspected to be the major source.	Iwen et al., 1994 ⁽⁸⁾
<i>Scedosporium proliferans</i> (inflatum) ⁽⁴⁾	AML ⁽³⁾ ALL ⁽¹⁾	4	4	Source is unknown. The patients were housed in two isolation rooms at the entry to the unit, which was opposite to the construction zone.	Alvarez et al., 1995 ⁽⁴²⁾
<i>Sporothrix cyaneus</i> *	Pneumonia with abnormal chest x-rays that required bronchoscopy with biopsy ⁽⁴⁾	4	0	Dust from renovation activity within and adjacent to a bronchoscopy unit contaminated the specimens or specimen containers stored in the bronchoscopy suite.	Jackson et al., 1990 ⁽⁶⁵⁾
<i>Aspergillus penicillium</i> *	Diabetes, hyaline membrane disease, asthma, meconium aspiration, cerebral palsy, Wilms' tumour, ALL, bronchiolitis	13	0	Agar plates were left open to air and were not processed under laminar hood. Spores entered the laboratory through a false ceiling that was connected to the renovation area. In addition, air was drawn in because of the negative pressure within the laboratory.	Hruszkewycz et al., 1992 ⁽⁶⁴⁾

Note. * These examples represent cases of pseudoinfection.

Table 2. Summary of the Documented Reports on Construction-related Nosocomial Outbreaks due to Bacteria

Etiologic Agent	Underlying Medical Condition of Patients	Number of Patients Infected/Colonized	Number of Patients who Died	Circumstances	Reference/Year
<i>Nocardia asteroides</i> ⁽⁷⁾	Chronic liver disease ⁽⁴⁾ Liver transplant ⁽⁹⁾	7	6	Considerable amounts of dust were visible on ward surfaces and equipment. Renovations were being done on the unit at the time. Environmental screening was negative for <i>Nocardia</i> spp.	Sahathevan et al., 1991 ⁽⁶¹⁾
<i>Legionella pneumophila</i>	One patient had myelodysplasia and neutropenia and was admitted for dental extraction. The other was admitted for gastrointestinal bleed.	2	2	A water valve in the potable water supply was turned off near the area of soil excavation. Authors believe repressurization of the water supply after the valve was reopened may have caused massive descalement inside the pipe and led to the outbreak.	Mermel et al., 1995 ⁽³⁴⁾
<i>Legionella bozemanii</i> ⁽⁴⁾	Lymphoma ⁽²⁾ Uremia ⁽¹⁾ Rheumatoid arthritis ⁽¹⁾ ITP ⁽¹⁾	5	0	Soil entered the water supply during construction and installation of new plumbing.	Parry et al., 1985 ⁽³²⁾
<i>Legionella</i> spp	20 of the patients were immunocompromised	49 (3 employees)	15	Aerosols from soil excavation or water-cooling towers were considered to be the source.	Haley et al., 1979 ⁽³⁰⁾
Not reported (CDC found serologic evidence of legionnaires' disease)	Psychiatric illnesses	81	14	Source was suspected to have been derived from soil excavation on hospital grounds of a pre-existing facility.	Thacker et al., 1978 ⁽³³⁾

1. Etiologic Agents

As shown in Tables 1 and 2, construction-related nosocomial infections are primarily due to fungi and, to a lesser extent, bacteria. The predominant etiologic agent is *Aspergillus*. In particular, *Aspergillus fumigatus*^(3-5,7-9,13-15,17,23-25,27,41,62,67), *A. flavus*^(3,4,8,9,11,13,17,25), *A. niger*^(3,4,8,9,13,17,27), and *A. terreus*^(10,27) have been repeatedly documented. Other fungi implicated include *Candida tropicalis*⁽⁶³⁾, *Candida parapsilosis*⁽²¹⁾, *Fusarium*⁽⁶³⁾, *Zygomycetes*^(16,21), *Rhizopus indicus*⁽²¹⁾, *Mucoraceae rhizopus*⁽¹⁷⁾, and *Scedosporium prolificans*⁽⁴²⁾. The major bacteria were *Legionella* spp^(30,32-34), including *L. pneumophila*⁽³⁴⁾ and *L. bozemanii*⁽³²⁾. *Nocardia asteroides*⁽⁶¹⁾ is another bacterium reported to have caused outbreaks. There were also two identified cases of pseudofungemia, one caused by *Sporothrix cyanescens*⁽⁶⁵⁾ and the other by *Penicillium*⁽⁶⁴⁾, as well as one case of pseudobacteremia caused by *Bacillus* spp⁽⁵⁵⁾. Since *Aspergillus* and *Legionella* species are the most frequent causes of construction-related nosocomial infection, they will be described in more detail. Understanding the relation between these organisms and construction and renovation activities leads to a better understanding of the need for preventive measures.

Aspergillus organisms are fungi found ubiquitously in soil, water, and decaying vegetation^(36,40). The fungal spores (conidia) proliferate on dead organic debris⁽⁶⁸⁾ and can remain viable for months in dry locations⁽⁶⁹⁾. During construction and renovation activities, spores can be dispersed on dust or dirt particles when floors, walls, or ceilings are penetrated⁽¹⁾. Since *Aspergillus* spores are small (2.5 μm-3.5 μm) and settle very slowly (0.03 cm per second), they can remain suspended in air for prolonged periods⁽⁶⁹⁾. This increases the likelihood that they will be inhaled or will contaminate environmental surfaces.

Normally, *Aspergillus* species are transient colonizers in humans⁽⁷⁰⁾. The small size of the conidia allows the organisms to bypass the host defences of the upper airway and to reach the pulmonary alveolar spaces⁽⁷⁰⁾. Three main processes may occur when *Aspergillus* spores reach the lungs: colonization, hypersensitivity, or invasive infection⁽⁷¹⁾. The host's response determines the manifestations of disease⁽⁷¹⁾. Healthy individuals, such as health care workers, may become sensitized to *Aspergillus* but have only a minute risk of infection if exposed⁽⁷²⁾, whereas exposure to *Aspergillus* can be life-threatening and often fatal for patients who are severely immunosuppressed^(36,37,73). Assigning a clinical diagnosis of invasive pulmonary aspergillosis may be difficult, as early signs are nonspecific and the rate of isolation of the organism in sputum cultures is low⁽⁷⁴⁾. It is essential that preventive measures to decrease patients' or residents' exposure to dust particles contaminated with aspergillus spores be undertaken. This is especially important for patients who are granulocytopenic⁽⁷⁵⁾.

Legionella is also a ubiquitous organism⁽⁴⁵⁾. This gram-negative, aerobic, rod-shaped bacterium is found in natural aquatic environments⁽⁴⁵⁾ as well as in soil and dust⁽⁷⁶⁾. Reservoirs in hospitals have included cooling towers, evaporative condensers, locally produced distilled water, heated potable water systems, and heating and air-conditioning systems^(36,45,77,78). During construction and renovation projects, water systems are often disrupted and the potable water can become contaminated with *Legionella* when the water supply is restored⁽¹⁾. Contamination may be related to massive descaling in the water pipes as they are repressurized⁽³⁴⁾ or to the introduction of contaminated soil into the plumbing system⁽³²⁾. *Legionella* can then proliferate in the facility's water supply if certain conditions

exist, such as sediment in hot water tanks⁽⁷⁹⁾, low hot-water temperatures at faucets⁽⁷⁸⁾, and water systems that are prone to stagnation^(77,78,80,81). In addition, soil and dust containing dormant forms of *Legionella* can become airborne during soil excavation and can subsequently contaminate cooling towers⁽⁷⁶⁾ or be inhaled by susceptible patients^(30,32,33). The occurrence of a nosocomial infection caused by *Legionella* depends on the resistance of the host, exposure of the host to a contaminated source, and the degree of contamination of the source^(44,46,82,83). Patients receiving high dose steroids are at particular risk. Legionnaires' disease is thought to be acquired by inhalation of aerosols contaminated with *Legionella* from the water supply⁽⁸³⁻⁸⁵⁾. Legionnaires' disease can be difficult to diagnose if not suspected^(80,84) because specialized laboratory methods and culture media are required⁽⁸²⁾. Thus, preventive measures to decrease the transmission of *Legionella* should be implemented when construction or renovation activities that disrupt some of the health care facility's water supply are planned.

2. Source of the Microorganism Causing Infection in Construction Settings

Biological sources causing infection in construction settings include mould, dust, or soil contaminated with fungal spores or bacteria. Contaminated mould or dust particles have been reported to come from above false ceilings^(5,21,24,25,64,86), fibrous insulating material^(14,24), roller-blind casings⁽²⁴⁾, and fire-proofing material⁽¹⁸⁾. An outbreak of aspergillosis occurred after a fire demolished an old building adjacent to a hospital's bone marrow transplantation unit. The outbreak was believed to be caused by fungal spores, dispersed during the fire, entering the hospital through an open window and contaminating the hall carpet⁽³⁾. Other outbreaks have been reported when contaminated dust particles infiltrated adjacent patient care areas where no impermeable barrier had been erected⁽⁷⁾ or windows had not been properly sealed^(8,16). Cutaneous aspergillosis developed in four patients when dressing supplies were used that had been contaminated during construction activities in a central inventory area⁽²⁷⁾. Soil excavation was also suspected of dispersing fungal spores^(9,17,22,29) or bacteria^(30,32,33) into the air, which were then inhaled by susceptible patients.

Outbreaks have been related to the hospital's plumbing or ventilation system. Leaking water pipes caused water damage to the false ceiling in an IV supply storeroom⁽²⁵⁾. During renovations to repair the ceiling, dust and mould particles were dispersed and contaminated the IV supplies. The contaminated supplies were used in treating children with leukemia, some of whom developed cutaneous aspergillosis⁽²⁵⁾. An outbreak of legionellosis was reported following the installation of new water pipes⁽³²⁾. It is possible that soil contaminated with *Legionella* entered the water supply at the time the new pipes were connected to the existing hospital plumbing system⁽³²⁾. In another example, legionnaires' disease occurred after the repressurization of the water supply when a valve near the area of soil excavation was reopened after being closed⁽³⁴⁾. The sudden surge of water was thought to have caused a massive descalement inside the water pipes, which led to the outbreak⁽³⁴⁾.

A construction-related nosocomial outbreak of *A. flavus* occurred when a defective ventilation system allowed unfiltered air from an adjacent construction zone to circulate into patient care areas. Prefilters were heavily soiled, and gaps were found between the individual filters and framework⁽¹¹⁾.

Hospital ventilation systems have been implicated in the development of nosocomial fungal outbreaks during periods of construction or renovation when 1) vents were not closed properly^(26,62); 2) incorrect air pressurization in patient care areas allowed airflow to move from dirty areas to clean areas^(10,16,63); 3) air exchange and exhaust were inadequate⁽⁶³⁾; or 4) HEPA filters were not properly maintained⁽⁶³⁾. Finally, an outbreak of aspergillosis was related to a heavily contaminated window-mounted air conditioner that was adjacent to a road construction project⁽⁹⁾.

As this review illustrates, a variety of sources of infection exist in health care facilities during construction and renovation activities. When such activities are being planned, health care personnel and other professionals involved must consider potential sources of highly concentrated microorganisms that may cause nosocomial infections.

3. Risk Factors for Construction-Related Nosocomial Infections

A. Exposure to Construction

Any patients exposed to health care facility construction activities or soil excavation may be at increased risk of acquiring a construction-related nosocomial infection. Weber and colleagues found that hospitalization during construction was an independent risk factor for development of invasive nosocomial fungal infection ($p = 0.09$)⁽²³⁾. Similarly, Weems and associates demonstrated that the incidence of invasive aspergillosis or zygomycosis was significantly higher during construction periods ($p = 0.001$ Fisher's Exact Test)⁽¹⁶⁾. Klimowski and colleagues reported an increased incidence of aspergillosis over 20 years that coincided with the increasing number of internal hospital renovation projects and, to a lesser extent, external construction projects⁽¹⁹⁾. Soil excavation and construction have also been identified as risk factors in an outbreak of *L. bozemanii*⁽³²⁾. Thacker and associates showed a relation between patients who were allowed access to the hospital grounds at the time of soil excavation and risk of acquiring legionnaires' disease ($p < 0.0001$)⁽³³⁾. Thus, the importance of decreasing patients' exposure to construction activities or soil excavation is well documented.

B. Patient characteristics

Certain patients are at increased risk of construction-related nosocomial infections because of underlying medical conditions. Comorbidity is one of the best predictors of the development of invasive aspergillosis⁽⁸⁷⁾ or legionnaires' disease^(36,50).

A brief description of the immune response to fungal and bacterial organisms is provided to help the reader understand the relation between the underlying medical condition and development of infection. When a person with a healthy immune system is exposed to *Aspergillus*, macrophages kill the conidia (spores), and neutrophils provide a defence against the mycelia. When a host has granulocytopenia (very low numbers of neutrophils), an increased likelihood of invasion of tissue by *Aspergillus* can occur⁽¹⁵⁾. The duration of granulocytopenia is an independent risk factor for invasive nosocomial fungal infections ($p < 0.01$)⁽²³⁾. Neutrophils play a less important role in the

defence against *Legionella* that reach the lungs. Consequently, granulocytopenic patients are not at excessive risk for legionnaires' disease⁽⁸¹⁾.

Immunosuppressive conditions identified as risk factors for construction-related nosocomial fungal infections include graft-versus-host disease requiring treatment^(36,87-89); prolonged neutropenia or granulocytopenia because of cytotoxic chemotherapy^(3,15,17,22,23,42,87,88,90); prolonged use of antibiotics^(15,17,42,87,88); and steroid therapy^(87,89). Other risk factors for the development of aspergillosis include dialysis and mechanical ventilation⁽⁴³⁾, smoking⁽⁸⁷⁾, and patient age⁽⁸⁸⁾, the very young and very old being at greater risk^(21,87). Grauhan and colleagues reported that the risk of a fungal infection increases in patients who exhibit three or more risk factors ($p < 0.001$)⁽⁴³⁾.

Similarly, immunosuppressive therapy for organ transplantation, immunodeficiency diseases, steroid therapy^(32,44,46,54,77,81,84,85,91), and advanced age are risk factors for acquiring and dying from legionnaires' disease⁽³⁶⁾. Males may be at greater risk^(33,44,77,84,85,91), since more men than women are reported to have acquired legionnaires' disease. Additional risk factors for legionnaires' disease include smoking^(44,77,84,85,91), excessive use of alcohol^(77,84), surgery⁽⁸⁵⁾, diabetes^(84,91), and neoplastic, pulmonary, renal, or cardiac disease^(44,46,81,84,91).

In summary, patients with any of the risk factors listed in Table 3 may be at greater risk for nosocomial infections during construction and renovation activities. Immunosuppressed patients are at greatest risk of acquiring a nosocomial fungal infection or legionellosis^(3,7,15,32,42,81,84,89,91). This includes patients who have undergone bone marrow or solid organ transplantation, oncology patients who are receiving chemotherapy, patients receiving dialysis, and patients taking immunosuppressive medication, including steroids. Such high risk individuals may receive care in health care facilities across the continuum of care, e.g. oncology patients in ambulatory units; thus there is a need for a risk assessment prior to construction and renovation activities wherever health care is provided.

Table 3. Patient Risk Factors for Construction-related Nosocomial Infections

Risk Factors for Infections with Filamentous Fungi	Risk Factors for Legionnaires' Disease
<ol style="list-style-type: none"> 1. Exposure to construction activities 2. Immunosuppressive conditions (e.g. bone marrow or solid organ transplantation; graft-versus-host disease requiring treatment; prolonged neutropenia or granulocytopenia because of cytotoxic chemotherapy; prolonged use of antibiotics to treat fevers or previous infections; and steroid therapy or other immunosuppressive therapy) 3. AIDS, congenital immunodeficiencies 4. Dialysis, renal failure 5. Diabetic ketoacidosis 6. Mechanical ventilation 7. Smoking 8. Age of the patient (e.g. neonates and very old patients have a greater risk) 	<ol style="list-style-type: none"> 1. Exposure to soil excavation during construction and malfunction of plumbing systems 2. Immunosuppressive conditions (e.g. bone marrow or organ transplantation; graft-versus-host disease requiring treatment; and steroid therapy) 3. Advanced age 4. Chronic pulmonary disease 5. Smoking 6. Excessive use of alcohol 7. Surgery 8. Diabetes 9. Neoplastic disease 10. Renal failure 11. Cardiac failure

– B –

Risk Assessment and Infection Prevention Measures

A proactive approach is required to decrease the occurrence of construction-related nosocomial infections. The key to eliminating *Aspergillus* infections is to minimize the dust generated during the construction activity and to prevent dust infiltration into patient care areas adjacent to construction^(59,75,92,93). These activities will also eliminate other dust-borne fungi (e.g. *Rhizopus*) that may cause invasive fungal infections. Special attention should also be directed to the facility's plumbing system when disruptions occur during construction or renovation projects. Attention to infection prevention measures and ensuring that appropriate personnel are involved are necessary to protect susceptible patients^(56,57).

To provide this protection, preventive measures should be clearly outlined^(13,16) in the contract documents before any construction or renovation project is started, and should be maintained for the duration of the project. A multidisciplinary team, including administrative support, is needed to ensure that the preventive measures are effective^(19,58,94). The responsibilities of all personnel involved in the project need to be clearly outlined in the contract documents in order to identify the liability of all those involved⁽⁵¹⁾. The following section identifies the preventive measures needed to decrease the risk of construction-related nosocomial infections, and discusses strategies to improve communication between ICPs and other professionals.

1. Risk Assessment and Preventive Measures Checklist

The Risk Assessment and Preventive Measures Checklist is recommended during the design process to assist the multidisciplinary team to identify the patient population at risk and the preventive measures to be initiated. This tool was adapted with permission from the Infection Control Construction Permit developed by V. Kennedy, formerly from St. Luke's Episcopal Hospital, Houston, Texas. The

checklist describes four levels of construction activity that may occur within a health care facility and four risk groups, ranging from lowest to highest risk. The project planning committee can use the checklist to identify risk groups that may be affected by their proximity or exposure to the construction zone. With the use of the Construction Activity and Risk Group Matrix, appropriate infection prevention measures are identified by matching the construction activity with the risk group⁽⁹⁵⁾.

The Risk Assessment and Preventive Measures Checklist was adapted from the original source by listing the preventive measures under two categories: construction/renovation activities and plumbing activities. The preventive measures were then further subdivided into categories that represent the personnel responsible for the project (e.g. engineering/maintenance staff). Additional preventive measures suggested in the literature were included. The section on construction activity was expanded to provide more examples. The Infection Control Risk Group was renamed the Population and Geographical Risk Group, and changes were made to the four categories based on suggestions from the literature. Construction-related nosocomial infections should be decreased by the early identification of the population risk group and initiation of appropriate preventive measures.

Instructions on How to Complete

The Risk Assessment and Preventive Measures Checklist is to be completed *during the planning design phase* of the construction/renovation project by the multidisciplinary planning committee. Infection prevention and control professionals must be involved in each phase of the project to ensure that the appropriate preventive measures are initiated and followed. The type of construction activity is first identified by selecting the level of activity that best describes the project being planned for the health care facility. The types of construction activity are described in Part A. The second step (Part B) involves identifying the population and geographical risk group that may be affected by the project because of its physical proximity or exposure to the construction/renovation activity. There are four groups described in Part B that will help the planning committee to identify the risk group. The appropriate infection prevention measures are identified by matching the construction activity with the population risk group in Part C. As indicated by the shaded areas in the “Construction Activity and Risk Group Matrix”, the checklist must be completed and a copy sent to the infection control department to be filed for all Class III and IV categories. Adaptations to the prevention measures can be made only after approval has been provided by the ICP.

**Risk Assessment and Preventive Measures Checklist for Health Care Facility
Construction and Renovation**

Location of Construction:	Project Start Date:	Estimated Duration:
Project Manager (PM):	Contractor(s):	Infection Prevention and Control Professional (ICP):
PM's phone number:	Contractor's phone number:	ICP's phone number:

Yes	No	Construction Activity (see Part A)	Yes	No	Population Risk Group(see Part B)
		Type A: Inspection, non-invasive activities.			Group 1: Lowest Risk
		Type B: Small scale, short duration, minimal dust-generating activities.			Group 2: Medium Risk
		Type C: Activities that generate moderate to high levels of dust, require greater than one work shift to complete.			Group 3: Medium to High Risk
		Type D: Activities that generate high levels of dust, major demolition and construction activities requiring consecutive work shifts to complete.			Group 4: Highest Risk

Part A: Types of Construction Activity

Type A	Inspection and non-invasive activities: These include, but are not limited to, activities that require removal of ceiling tiles for visual inspection (limited to 1 tile per 50 square feet), painting (but not sanding), wall covering, electrical trim work, minor plumbing (disrupts water supply to a localized patient care area [e.g. 1 room] for less than 15 minutes), and other maintenance activities that <i>do not generate</i> dust <i>or</i> require cutting of walls <i>or</i> access to ceilings other than for visual inspection.
Type B	Small scale, short duration activities that create minimal dust. These include, but are not limited to, activities that require access to chase spaces, cutting of walls or ceilings where dust migration can be controlled for the installation/repairs of minor electrical work, ventilation components, telephone wires or computer cables, and sanding of walls for painting or wall covering to <i>only repair</i> small patches. It also includes plumbing that requires disruption to the water supply of more than one patient care area (e.g. > 2 rooms) for less than 30 minutes.
Type C	Any work that generates a moderate to high level of dust or requires demolition or removal of any fixed building components or assemblies (e.g. counter tops, cupboards, sinks). These include, but are not limited to, activities that require sanding of walls for painting or wall covering, removal of floor-coverings, ceiling tiles and casework, new wall construction, minor duct work or electrical work above ceilings, major cabling activities, and any activity that <i>cannot be completed</i> within a single work shift. It also includes plumbing that requires disruption to the water supply of more than one patient care area (e.g. > 2 rooms) for more than 30 minutes but less than 1 hour.

Type D	Major demolition, construction and renovation projects. These include, but are not limited to, activities that involve heavy demolition or removal of a complete cabling system and new construction requiring consecutive work shifts to complete. It also includes plumbing that results in disruption to the water supply of more than one patient care area (e.g. > 2 rooms) for more than 1 hour.
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Part B: Population and Geographic Risk Groups

Group 1 Lowest Risk	<ul style="list-style-type: none"> • Office areas • Unoccupied wards • Public areas
Group 2 Medium Risk	<ul style="list-style-type: none"> • All other patient care areas unless stated in Group 3 or 4 • Outpatient clinics (except for oncology & surgery) • Admission/discharge units
Group 3 Medium to High Risk	<ul style="list-style-type: none"> • Emergency room • Radiology/MRI • Post anesthesia care units • Labour and delivery (non operating room [OR]) • Normal newborn nurseries • Day surgery • Nuclear medicine • Physiotherapy tank areas • Echocardiography • Laboratories (specimens) • General med/surg wards other than those listed in Group 4 • Pediatrics • Geriatrics • Long-term care
Group 4 Highest Risk	<ul style="list-style-type: none"> • All ICUs • All ORs • Labour & delivery ORs • Anesthesia and pump areas • Oncology units and outpatient clinics for patients with cancer • Transplant units and outpatient clinics for patients who have received bone marrow or solid organ transplants • Wards and outpatient clinics for patients with AIDS or other immunodeficiency • Dialysis units • Tertiary care nurseries • All cardiac catheterization & angiography areas • Cardiovascular/cardiology patients • All endoscopy areas • Pharmacy admixture rooms • Sterile processing rooms • Central Processing Dept. • Central Inventory Dept.

Part C: Construction Activity and Risk Group Matrix

A copy of the Risk Assessment and Preventive Measures Checklist must be sent to the Infection Prevention and Control Department when the matrix indicates that Class III and/or Class IV preventive measures are required (see shaded areas). Adaptations to the prevention measures can be made only after approval has been provided by the ICP. The ICP should also be consulted when construction activities need to be done on hallways adjacent to Class III and Class IV areas.

Risk Group	Construction Activity			
	Type A	Type B	Type C	Type D
Group 1	I	II	II	III / IV
Group 2	I	II	III	IV
Group 3	I	III	III / IV	IV
Group 4	I–III Contact IC to ensure appropriate classification	III / IV	III / IV	IV

Part D: Specifications for Infection Prevention and Control Measures

Class I	Engineer/Maintenance Staff & Contractors
Date:	<i>a) Construction/Renovation Activities</i> Dust Control* <ul style="list-style-type: none"> • Immediately replace tiles displaced for visual inspection • Vacuum work area.
Initials:	<i>b) Plumbing Activities</i> <ul style="list-style-type: none"> • Schedule water interruptions during low activity (e.g. evenings if at all possible) • Flush water lines prior to reuse • Observe for discoloured water • Ensure water temperature meets the standards set by the health care facility • Ensure gaskets and items made of materials that support the growth of <i>Legionella</i> are not being used • Ensure faucet aerators are not installed or used • Maintain as dry an environment as possible and report any water leaks that occur to walls and substructures Environmental Services <i>a) Plumbing Activities</i> <ul style="list-style-type: none"> • Report discoloured water and water leaks to maintenance and ICP Medical/Nursing Staff <i>a) Construction/Renovation Activities</i> Risk Reduction <ul style="list-style-type: none"> • Minimize patients' exposure to construction/renovation area <i>b) Plumbing Activities</i> <ul style="list-style-type: none"> • Report discoloured water and water leaks to maintenance and ICP

* Note. Class II specifications must be followed if dust should be created during the Type A construction activity.

Class II	The following specifications are to be considered in addition to Class I
Date:	Engineer/Maintenance Staff & Contractors <i>a) Construction/Renovation Activities</i>
Initials:	<div> 1) Dust Control <ul style="list-style-type: none"> • Execute work by methods that minimize dust generation from construction or renovation activities <ul style="list-style-type: none"> – wet mop and/or vacuum as necessary • Provide active means to minimize dust generation and migration into the atmosphere <ul style="list-style-type: none"> – use drop sheets to control dust – control dust by water misting work surfaces while cutting – seal windows and unused doors with duct tape – seal air vents in construction/renovation area – place dust mat at entrance to and exit from work areas </div> <div> 2) Ventilation <ul style="list-style-type: none"> • Disable the ventilation system in the construction/renovation area until the project is complete • Monitor need to change and/or clean filters in construction or renovation area </div> <div> 3) Debris Removal & Cleanup <ul style="list-style-type: none"> • Contain debris in covered containers or cover with a moistened sheet before transporting for disposal </div> <div> <i>b) Plumbing Activities</i> <ul style="list-style-type: none"> • Avoid collection tanks and long pipes that allow water to stagnate • Consider hyperchlorinating or superheating stagnant potable water (especially if <i>Legionella</i> is already present in potable water supply) </div> <div> Environmental Services <i>a) Construction/Renovation Activities</i> Dust Control <ul style="list-style-type: none"> • Wet mop and vacuum area with a HEPA filtered vacuum as needed and when work is complete • Wipe horizontal work surfaces with a disinfectant </div> <div> Medical/Nursing Staff <i>a) Construction/Renovation Activities</i> Risk Reduction <ul style="list-style-type: none"> • Identify high risk patients who may need to be temporarily moved away from the construction zone • Ensure that patient care equipment and supplies are protected from dust exposure </div>

Note. The above specifications are to be considered in addition to those listed in Class I.

Class III	The following specifications are to be considered in addition to Class I and II
Date:	Engineer/Maintenance Staff & Contractors
Initials:	<p><i>a) Construction/Renovation Activities</i></p> <p>1) Risk Reduction</p> <ul style="list-style-type: none"> • Ensure that ICP consultation has been completed and infection prevention and control measures have been approved <p>2) Dust Control</p> <ul style="list-style-type: none"> • Erect an impermeable dust barrier from true ceiling (includes area above false ceilings) to the floor consisting of 2 layers of 6 mil polyethylene or Sheetrock • Ensure that windows, doors, plumbing penetrations, electrical outlets and intake and exhaust vents are properly sealed with plastic and duct taped within the construction/renovation area • Vacuum air ducts and spaces above ceilings if necessary • Ensure that construction workers wear protective clothing that is removed each time they leave the construction site before going into patient care areas • Do not remove dust barrier until the project is complete and the area has been cleaned thoroughly and inspected • Remove dust barrier carefully to minimize spreading dust and other debris particles associated with the construction project <p>3) Ventilation</p> <ul style="list-style-type: none"> • Maintain negative pressure within construction zone by using portable HEPA equipped air filtration units • Ensure air is exhausted directly outside and away from intake vents or filtered through a HEPA filter before being recirculated • Ensure ventilation system is functioning properly and is cleaned if contaminated by soil or dust after construction or renovation project is complete <p>4) Debris Removal & Cleanup</p> <ul style="list-style-type: none"> • Remove debris at the end of the work day • Erect an external chute if the construction is not taking place on ground level • Vacuum work area with HEPA filtered vacuums daily or more frequently if needed <p><i>b) Plumbing Activities</i></p> <ul style="list-style-type: none"> • Flush water lines at construction or renovation site and adjacent patient care areas before patients are readmitted <p>Environmental Services</p> <p><i>a) Construction/Renovation Activities</i></p> <ul style="list-style-type: none"> • Increase frequency of cleaning in areas adjacent to the construction zone while the project is under way • In collaboration with ICP ensure that construction zone is thoroughly cleaned when work is complete <p>Infection Prevention and Control Personnel</p> <p><i>a) Construction/Renovation Activities</i></p> <p>1) Risk Reduction</p> <ul style="list-style-type: none"> • Move high risk patients who are in or adjacent to the construction area • In collaboration with environmental services ensure that construction zone is thoroughly cleaned when work is complete • Inspect dust barriers <p>2) Traffic Control</p> <ul style="list-style-type: none"> • In collaboration with the facility project manager designate a traffic pattern for construction workers that avoids patient care areas and a traffic pattern for clean or sterile supplies and equipment that avoids the construction area

	<p><i>b) Plumbing Activities</i></p> <ul style="list-style-type: none"> Consider hyperchlorinating or superheating stagnant potable water (especially if <i>Legionella</i> is already present in potable water supply) <p>Medical/Nursing Staff</p> <p><i>a) Construction/Renovation Activities</i></p> <p>Risk Reduction</p> <ul style="list-style-type: none"> Move high risk patients who are in or adjacent to the construction area Ensure that patients do not go near the construction area In collaboration with environmental services and ICP ensure that construction zone is thoroughly cleaned when work is complete
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Note. The above specifications are to be considered in addition to those listed in Class I and II.

Class IV	The following specifications are to be considered in addition to those in Class I, II and III
Date:	<p>Engineer/Maintenance Staff & Contractors</p> <p><i>a) Construction/Renovation Activities</i></p> <p>1) Dust Control</p> <ul style="list-style-type: none"> Before starting the construction project erect an impermeable dust barrier that also has an anteroom Place a walk-off mat outside the anteroom in patient care areas and inside the anteroom to trap dust from the workers' shoes, equipment and debris that leaves the construction zone Ensure that construction workers leave the construction zone through the anteroom so they can be vacuumed with a HEPA filtered vacuum cleaner before leaving the work site; or that they wear cloth or paper coveralls that are removed each time they leave the work site Direct all personnel entering the construction zone to wear shoe covers Ensure that construction workers change the shoe covers each time they leave the work site Repair holes in walls within 8 hours or seal them temporarily <p>2) Ventilation</p> <ul style="list-style-type: none"> Ensure negative pressure is maintained within the anteroom and construction zone Ensure ventilation systems are working properly in adjacent areas Review ventilation system requirements in the construction area with ICP to ensure system is appropriate and is functioning properly <p>3) Evaluation</p> <ul style="list-style-type: none"> Review infection control measures with other members of the planning team or delegate to evaluate their effectiveness and identify problems at the end of the construction project <p><i>b) Plumbing Activities</i></p> <ul style="list-style-type: none"> If there are concerns about <i>Legionella</i>, consider hyperchlorinating stagnant potable water or superheating and flushing all distal sites before restoring or repressurizing the water system <p>Environmental Services</p> <p><i>a) Construction/Renovation Activities</i></p> <p>Evaluation</p> <ul style="list-style-type: none"> Review infection prevention and control measures with other members of the planning team or delegate to evaluate their effectiveness and identify problems at the end of the construction project <p>Infection Prevention and Control Personnel</p> <p><i>a) Construction/Renovation Activities</i></p> <p>1) Risk Reduction</p> <ul style="list-style-type: none"> Regularly visit the construction site to ensure that preventive measures are being followed. Wear coveralls and shoe covers when visiting the site.
Initials:	

	<p>2) Evaluation</p> <ul style="list-style-type: none"> Review infection control measures with other members of the planning team or delegate to evaluate their effectiveness and identify problems at the end of the construction project <p>b) <i>Plumbing Activities</i></p> <ul style="list-style-type: none"> If there are concerns about <i>Legionella</i>, consider hyperchlorinating stagnant potable water or superheating and flushing all distal sites before restoring or repressurizing the water system <p>Medical/Nursing Staff</p> <p>Staff are not allowed to visit the construction site.</p> <p>a) <i>Construction/Renovation Activities</i></p> <p>Evaluation</p> <ul style="list-style-type: none"> Review infection control measures with other members of the planning team or delegate to evaluate their effectiveness and identify problems at the end of the construction project <p>b) <i>Plumbing Activities</i></p> <ul style="list-style-type: none"> Consider using another source of potable water for patients who are at greatest risk until potable water has been cleared for signs of <i>Legionella</i> after major plumbing installation/repairs
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Note. The above specifications are to be considered in addition to those listed in Class I, II and III.

Adapted from *Reduce dust and danger during construction*. Hosp Infect Control 1997;24:26-29⁽⁹⁵⁾ (with oral permission from Virginia Kennedy, creator of the tool, formerly from St. Luke's Episcopal Hospital, Houston, TX).

2. Preventive Measures

Preventive measures have been shown to be effective in health care facilities^(4,13,37,96) as well as in commercial and residential buildings⁽⁹⁷⁾ undergoing renovations. In three of these studies^(37,96,97), preventive measures were initiated before renovations began. After implementing the measures, Overberger and colleagues collected air samples from various locations both within and outside the construction zone before, during, and after the construction (30 weeks)⁽³⁷⁾. In the construction zone, total particulate concentrations and spore counts rose steadily and then declined at the end of the construction, whereas in adjacent patient care areas total particulate concentrations and spore counts did not change significantly from baseline levels. Thus, preventive measures were effective in protecting patient exposure to high levels of airborne particulates and fungal spores generated during construction⁽³⁷⁾. In a similar study, Streifel and colleagues demonstrated that preventive measures reduced infiltration of fungal spores when a building adjacent to the hospital was demolished⁽⁹⁶⁾. Concentrations of airborne microorganisms decreased during the testing of three commonly used methods to minimize dust and prevent migration of dust particles into adjacent areas⁽⁹⁷⁾. The three methods tested were as follows:

- a plastic barrier from the floor to the ceiling to isolate the construction zone plus negative pressurization;
- a plastic barrier and a high-efficiency exhaust fan with a HEPA filter; and
- a plastic barrier and a portable exhaust fan with a side-draft hood.

The second method was the most effective in reducing concentrations of airborne microorganisms in the construction zone and preventing migration of dust particles to adjacent office areas⁽⁹⁷⁾. Neither airflow rates nor the placement of plastic barriers in relation to the true or false ceiling were described in the study.

In two studies, the preventive measures were initiated after the outbreak of a nosocomial fungal infection^(4,13). Before implementation of the preventive measures, the incidence density for nosocomial aspergillosis during construction was 9.88 per 1,000 days at risk, as compared with baseline levels of 3.18 per 1,000 days at risk⁽¹³⁾. Following implementation of the control measures, the incidence density decreased to 2.91 per 1,000 days at risk during construction⁽¹³⁾. Opal and associates reported similar findings. There were no additional cases of disseminated aspergillosis after infection prevention measures had been started, as compared with 11 cases that had occurred before the measures were implemented⁽⁴⁾.

The evidence shows that preventive measures are effective in decreasing the incidence of construction-related fungal infections and that they are cost-effective, because the patients' safety was maintained and further cases were prevented.

Several other preventive measures have been reported:

- Superheating and hyperchlorinating the hospital's hot water system, thus preventing further cases of nosocomial pneumonia caused by *Legionella bozemanii*. It was believed that *L. bozemanii* entered the hospital's water supply during the installation of new plumbing at the construction site⁽³²⁾.
- During periods of excavation on hospital grounds or when the plumbing system has been shut down and is later repressurized:
 - 1) hyperchlorination of stagnant potable water, to be carried out before repressurization;
 - 2) reporting of persistent discoloured water to maintenance personnel and the infection control department;
 - 3) culture of the water supply for *Legionella* in areas housing immunocompromised patients⁽³⁴⁾.
- Ongoing routine *Legionella* surveillance to allow for comparison of results before, during, and after construction.
- Selection of plumbing materials that do not promote the growth of bacteria and are resistant to corrosion^(45,98,99).
- Removal of faucet aerators and other obstructing and stagnating features such as long pipe lines and dead-ends^(32,45,80,99).
- Assessment of hot water temperature to ensure that it meets the standards set by the health care facility⁽⁹⁹⁾.
- Establishment and implementation of a regular program of preventive maintenance^(32,54,80,99).

The following situation highlights the importance of vigilance with respect to the preventive measures. There was a sudden increase in the number of cases of legionnaires' disease reported in a hospital after its emergency water pump failed⁽³¹⁾. The water pressure dropped for only a few minutes, but

the water remained discoloured for up to 4 weeks. In an attempt to recreate the change in water colour, the water supply to one wing was turned off for 5 minutes and then turned back on. Compared with a sample taken before the water supply was turned off there was a 30-fold increase in the concentration of *Legionella pneumophila* in a second water sample taken after the water supply had been turned back on⁽³¹⁾.

Preventive measures are listed in Table 4, categorized according to phase: preconstruction, construction, and post construction. The multidisciplinary planning committee should select preventive measures according to the activity planned, its duration, and the patient population that may be affected by the construction or renovation project. The committee should understand the risks and respond with appropriate measures. When high risk populations are involved, the infection control department should be notified even for minor construction activity. For example, if the activity involves drilling holes in the walls of a bone marrow transplant unit, the ICP should be notified to ensure appropriate preventive measures are in place.

Table 4. Infection Prevention Measures for Health Care Facility Construction

Preconstruction Preventive Measures

1. The infection control department must be consulted to provide information on infection prevention measures and appropriate administrative/jurisdictional responsibilities delegated before construction begins^(1,53,56,100).
 2. Management must identify whose responsibility it is to stop construction projects if breaches in preventive measures arise. The ICP should be given the administrative authority to stop construction if there is significant breach in safety measures⁽²⁶⁾.
 3. The project manager must identify essential services (i.e. water supply, electricity, ventilation systems) that may be disrupted and measures to compensate for the disruption, and should communicate these to the personnel responsible^(53,101).
 4. The ICP in collaboration with nursing staff must identify patient population(s) that may be at risk and the appropriate preventive measures to ensure their safety^(53,102).
 5. The ICP should conduct routine *Legionella* surveillance to allow for comparison of results before, during, and after construction^(93,103).
 6. The plumbing materials selected should be durable and resistant to corrosion and bacterial growth^(45,98,99). Items made of degreased stainless steel, natural unpigmented polypropylene, polytetrafluoroethylene (PTFE), or polyvinylidene fluoride (PVDF) are examples of materials that are nonleaching and will not degrade the quality of the water⁽⁹⁹⁾.
 7. All personnel involved in the construction or renovation activity should be educated and trained in the infection prevention measures^(1,53,99,101), for example, the infection control personnel could educate the project managers and contractors, who then ensure that the construction workers receive the appropriate education.
 8. Methods for dust containment and removal of construction debris should be outlined⁽⁵³⁾.
 9. Traffic patterns for construction workers should be established that avoid patient care areas^(1,4,21,37,53,104).
 10. If possible, an elevator should be designated for the sole use of construction workers^(1,37). If possible, the ventilation of the elevator cab and shaft should not be recirculated in the facility.
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11. The integrity of the health care facility's exterior structure, spatial separations and ventilation, and water supply should be reviewed and assessed for any infection control problems^(48,49,51,53,102) (G. Granek, P. Eng., Toronto: personal communication, 1998). For example, it is important to ensure that the air pressure, airflow, and air exchange rates have been assessed by the HVAC personnel and that filtration systems are working appropriately. Any infection control problems identified should be corrected before the construction activity begins⁽¹⁰⁵⁾.
12. A regular program of preventive maintenance should be in place for the health care facility water and ventilation systems^(32,54,80,99,102). For example, Wallin recommends that every 7 months is the optimal cleaning frequency for HVAC systems⁽¹⁰⁶⁾. Frequency should be increased in high risk areas. (Refer to Part B: Population and Geographical Risk Groups in Risk Assessment and Preventive Measure Checklist in earlier section.) HVAC cleaning and maintenance protocols must conform with Canadian standards.

Construction Preventive Measures

1. Patients who are immunosuppressed should be moved to an area away from the construction zone if the air quality cannot be ensured during construction^(13,107). These patients should wear a high efficiency mask if it is necessary to transport them through a construction area^(75,102,108).
 2. All windows, doors, air intake and exhaust vents should be sealed in areas of the health care facility adjacent to buildings that are going to be demolished plus areas housing patients who are most susceptible⁽⁹⁶⁾, to prevent air leaks into patient care areas.
 3. A dust barrier should be created from the floor to the true ceiling and edges sealed^(1,4,21,37,101,104). Plastic sheeting or Sheetrock are examples of materials that could be used to create dust barriers for short-term and long-term projects respectively⁽¹⁾.
 4. An impermeable dust barrier with an anteroom must be constructed in high risk areas if the project will take consecutive work shifts to complete⁽³⁷⁾. Refer to Part B: Population and Geographical Risk Groups in the Risk Assessment and Preventive Measure Checklist described earlier.
 5. All windows, doors, vents, plumbing penetrations, electrical outlets and any other sources of potential air leak should be sealed in the construction zone^(8,11,37,109).
 6. Air pressure within the construction zone should be negative compared with adjacent areas^(1,37,102,104). A fan may be used for this purpose^(21,37).
 7. Air in the construction zone should be exhausted directly outside. If this is not possible, then the air should be filtered through a HEPA filter before being recirculated in the health care facility⁽¹¹⁰⁾. The integrity of the HEPA filter should be assessed to ensure that it is not punctured.
 8. Open ends of exhaust vents should be capped to prevent air, exhausted from the construction zone, from being drawn back into patient care areas or released to outdoor streets around the health care facility⁽³⁷⁾.
 9. Air ducts and spaces above ceilings should be vacuumed with a HEPA filtered vacuum before the construction project is started if it involves these areas^(1,21).
 10. A walk-off mat should be placed outside the entrance to the construction zone to trap dust from the equipment and shoes of personnel leaving the construction zone. The mat should be vacuumed daily⁽³⁷⁾ (with HEPA filtered vacuum) or when visibly soiled.
 11. If the construction zone is adjacent to high risk patient areas (Refer to Part B: Population and Geographical Risk Groups in the Risk Assessment and Preventive Measure Checklist described earlier), construction workers should wear protective clothing⁽¹⁾ because of the high concentration of dust. To limit dust dispersion, construction workers must remove the protective clothing and vacuum themselves with a HEPA filtered vacuum to remove dust from their clothing before leaving the construction zone if there is no external nonpatient area exit⁽¹⁾.
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12. Areas adjacent to high risk patient areas should be vacuumed daily or more frequently if needed with HEPA filtered vacuums⁽¹⁾. Refer to Part B: Population and Geographical Risk Groups in the Risk Assessment and Preventive Measure Checklist described earlier.
13. The provision of the HEPA filtered vacuum should be part of the contract⁽⁷⁵⁾.
14. To reduce the risk of contamination, clean or sterile supplies and equipment should not be transported through a construction zone⁽¹⁾.
15. Used supplies and equipment should be enclosed in covered containers when being transported to prevent unnecessary contamination in other areas⁽¹⁾.
16. Consideration should be given to construction workers removing the debris in the evening, when patients are in their rooms and visitors have left. If this is not possible, debris should be removed at the end of the work day by construction workers. Debris should be in covered containers or covered with moistened sheets before it is removed from the construction area^(1,37). Exposure of patients to debris should be minimized as much as possible.
17. An external chute may be another option for removal of debris if construction is not taking place on ground level^(1,4,102).
18. When the potable water supply will be disrupted, alternative water sources should be provided for patient use. Discoloured potable water should be reported to maintenance personnel and the infection control department⁽³⁴⁾.
19. An effective surveillance system for *Legionella* in patients should be ensured during soil excavation on health care facility grounds or when the water supply has been disrupted and then repressurized⁽³⁴⁾.
20. Faucet aerators and other obstructing and stagnating features (e.g. long pipes and plumbing dead-ends) should be removed if possible^(32,45,80,99).
21. The ICP should visit the construction site regularly with the project manager until the project is done, to ensure that preventive measures are being adhered to or that appropriate modifications are made if there are any onsite design changes. If any concerns are identified, they should be brought to the attention of the program manager.

Post Construction Preventive Measures

1. The construction zone should be thoroughly cleaned, including all horizontal surfaces, before the barrier is removed, and again after the barrier is removed and before patients are readmitted to the area^(1,5,7,21). Time should be allowed for all dust to settle before final cleaning is carried out.
 2. The ICP should check the area before patients are readmitted to the finished area.
 3. The multidisciplinary project committee or designate should conduct a final walk through to ensure that the ventilation system is functioning properly in the construction zone and adjacent areas^(16,51,53,102).
 4. Water lines should be flushed prior to use if they were disrupted^(1,34).
 5. If the surveillance data suggest the presence of *Legionella*, measures to prevent further occurrences should be reviewed and instituted^(32,34).
 6. Unused cooling towers and the water supply in unoccupied portions of buildings should be disinfected before they are put in use⁽⁴⁵⁾.
 7. The hot water temperature should be assessed to determine whether it meets the standards set by the facility⁽⁹⁹⁾.
 8. The multidisciplinary project committee or designate should evaluate the preventive measures and review their effectiveness for any problems and positive outcomes^(53,102).
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3. Personnel Involved

The need to understand the responsibilities of the personnel involved in the project and to establish and maintain clear lines of communication between them and ICP is important in the prevention of construction-related nosocomial infections^(52,59,60). Infection control professional participation during the planning stage is key to the prevention of nosocomial infections.

Familiarity and involvement with the capital planning process will help ICPs become equal partners in construction or renovation projects in health care facilities. The ministries of health for most of the provinces and territories have developed a capital planning document that health care facilities must follow, based on the total cost of the construction and renovation project. This planning document ensures that 1) resources are used efficiently and effectively; 2) the approval process is streamlined; and 3) the key participants' roles and responsibilities are identified⁽¹¹¹⁾. Although the documents are different for each of the provinces and territories, the principles are the same. After a needs assessment, health care facilities submit a proposal to the Ministry of Health, outlining the need for the project and how it will fit into the general long-term plans of the facility and the region. If the proposal is accepted, schematic plans are developed and revised as the project advances. Approval of the final contract documents are sought from the Ministry of Health before bids from the documents are tendered. Construction begins after approval of the contract award by the province's or territory's Ministry of Health. Commissioning is the final phase. This involves ensuring that the construction or renovation activity was completed according to the plan and all systems are functioning properly⁽¹¹¹⁻¹¹⁵⁾.

ICPs will be more successful in their efforts if they know who are the key players and what are their roles, and if they educate those players about the need for preventive measures to decrease construction-related infections. The ICP should be aware of the roles of the following personnel involved in the project: 1) facility owners and their agents and employees; 2) architects, engineers, constructors, contractors, subcontractors, building trades and suppliers (D. Ardiel, Architect, London, ON: personal communication, 1998). Additional personnel have legal rather than contractual rights and responsibilities. These include building, fire and zoning officials, and provincial ministry officials.

The following section briefly describes the responsibilities of some of the key professionals involved in construction and renovation projects in health care facilities and how collaboration with the infection control professional can decrease the risk of construction-related nosocomial infections.

1. Facility Owners, Their Agents and Employees

a. Administration

Administrative support is essential for the successful completion of the construction project. Administrators should ensure that there are policies and procedures within the health care facility that clearly outline the responsibilities of participants in the construction project and the necessary infection control preventive measures. ICP can provide administrators with information on

infection control concerns and the importance of preventive measures to assist in the development of the policies and procedures.

b. Facility Project Managers

The facility project manager is the representative of the health care facility that is undergoing the construction or renovation⁽⁹⁴⁾. His or her responsibilities include overseeing and coordinating the activities of all personnel involved in the construction project and managing information flow among them (D. Ardiel, Architect, London, ON: personal communication, 1998). Facility project managers are also responsible for deciding who should be represented at the planning and design development meetings⁽⁹⁴⁾. They have a key role in construction or renovation projects in health care facilities.

The ICP should develop close working relationships with the facility project managers in their health care facility, who could be educated about infection control concerns and the importance of preventive measures in decreasing construction-related nosocomial infections. The infection control department should be involved during the planning and design development phase of the capital planning process. In addition, the person whose responsibility it is to stop the construction project if there is a significant breach in the preventive measures should be established and incorporated into the contract documents at the time the construction project is planned. Infection control has a role in making sure the project managers have adequate information on which to make a decision.

c. Environmental Services

Environmental service staff, either facility or contract, are responsible for keeping areas adjacent to the construction zone clean and clear of debris and for thoroughly cleaning the construction or renovation area before the patients are readmitted into these areas^(1,5,7,21). In some circumstances, the contractor is responsible for cleaning adjacent areas. Before the construction project is started, it should be clear who is responsible for cleaning adjacent areas — either the contractor or environmental services. The ICP can collaborate with environmental service staff during the construction phase of the capital planning process by making recommendations on the appropriate cleaning procedures that they should be using in areas adjacent to the construction site.

d. Medical and Nursing Staff

Medical and nursing staff are responsible for maintaining the patients' health and safety during the construction or renovation project. They should be aware of patient populations at risk, potential hazards that construction/renovation activities pose to patients, and the relevant preventive measures. The ICP can collaborate with the medical and nursing staff to identify patients considered at risk of acquiring construction-related nosocomial infections⁽⁵⁴⁾, such as those who are immunosuppressed because of their underlying medical condition or medical treatment^(3,7,15,32,42,81,84,89,91). Examples of these patients include oncology patients undergoing cytotoxic chemotherapy, bone marrow and solid organ transplantation patients, dialysis patients, and patients in intensive care units. (Refer to Table 3 for patient risk factors and to Part B: Population and Geographical Risk Groups of the Risk Assessment and Preventive Measures Checklist.) The increased awareness of medical and

nursing staff may enhance the initiation of timely investigations for patients suspected of having nosocomial pneumonia⁽⁵⁴⁾ and the identification of deficiencies in dust containment in the facility.

2. Architects, Engineers, Constructors, Contractors, Subcontractors, Maintenance Staff, Building Trades and Suppliers

ICP should be aware of existing building codes and professional guidelines or standards that address infection control issues⁽¹⁾. A list of standards/codes that may help the ICP is provided in the Appendix. By being knowledgeable of the codes and standards, the ICP can discuss the design of the project with the design team during the planning phase of the capital planning process. To ensure that preventive measures are incorporated into the construction project, the ICP can explain to the architect and other professionals involved in the construction the reasons for and importance of following such measures^(1,109).

The architect is responsible for ensuring that the construction or renovation building design meets the health care facility's building objectives. The architect must comply with professional standards and building and fire codes in the development and design of the construction or renovation project⁽¹¹⁶⁾ (D. Ardiel, Architect, London, ON: personal communication, 1998).

Maintenance staff may be the personnel who perform the work, depending on the type of construction activity that is undertaken. Likewise, engineers may be the personnel who design the project.

Engineers, maintenance staff, and contractors must follow building and fire codes and professional standards when planning and completing construction projects, carrying out construction or renovation projects and repairing structures, equipment and utilities within the health care facility^(54,101). As well, their responsibilities include monitoring and evaluating the ventilation system within the construction zone and adjacent areas to ensure that it is functioning properly, not only before the project starts but also throughout its duration and at completion^(48,101). This includes assessing the airflow, air pressure, and air exchange rate as well as assessing, cleaning, and evaluating the integrity of filters and ducts⁽¹⁰¹⁾. The maintenance staff and contractors are responsible for creating the dust barrier and helping prevent dust infiltration into adjacent areas during the construction project⁽¹⁰¹⁾. The contractors are also responsible for keeping the construction area clean and clear of debris. If the facility's plumbing system is affected by the construction, the contractors are responsible for monitoring the integrity of the system, assessing it for leaks, or minimizing dead-end reservoirs⁽¹⁰¹⁾. Engineers and maintenance staff can help train contractors in safe construction practices while they are working in health care facilities⁽¹⁰¹⁾.

Since these professionals conduct the construction activity, the ICP should communicate with them throughout the construction phase of the capital planning process. In collaboration with the project managers they are responsible for ensuring that infection prevention measures are initiated and followed for the duration of the project⁽¹⁾. Thus, the ICP can advise the engineers, maintenance staff, and contractors on appropriate preventive measures for a particular activity. When the project is complete, the ICP should review and evaluate the effectiveness of the preventive measures with other members of the construction planning committee to identify positive outcomes and any problems that may have occurred⁽⁵³⁾.

Summary

Construction and renovation projects in health care facilities are a risk for certain patients, particularly those who are immunocompromised. A proactive approach must be taken to limit construction-related nosocomial infections. This requires having a multidisciplinary team, supported by administration, to plan and implement preventive measures throughout the duration of the construction project. The ICP should be an active team member in all phases of the project. The ICP plays a major role by providing education to personnel; ensuring that preventive measures are identified, initiated, and maintained; and carrying out surveillance for infections in patients. By ensuring that the appropriate preventive measures are in place and clear lines of communication exist among the personnel, patient safety will be enhanced.

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 112. Nova Scotia Department of Health. *Health care capital construction guidelines*. Halifax, NS: Nova Scotia Department of Health, 1998.
 113. Saskatchewan Health. *Planning guide for Saskatchewan health districts part III: facilities planning*. Regina, SK: Capital and Special Operating Policy Unit, Saskatchewan Health (currently under revision).
 114. Yukon Government Services. *Building development projects procedures manual*. Whitehorse, Yukon: Yukon Health and Social Services, 1992.
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– Appendix –

Published Standards/ Codes Related to Construction

The following list is not exhaustive. It should be noted that each province or territory may incorporate the National Building Codes in a slightly different manner since these codes represent the minimum requirements. As well, each municipality or region may incorporate the provincial or territorial building codes in a slightly different manner for the same reason.

National Resources

- *Canadian Construction Documents Committee (CCDC)
- Canadian Standards Association
 - 1) CSA Standard CAN/CSA-Z317.1-99. *Special requirements for plumbing installations in health care facilities*. Toronto: Canadian Standards Association, 1999.
 - 2) CSA Standard CAN/CSA-Z317.2-01. *Special requirements for heating, ventilation, and air conditioning (HVAC) systems in health care facilities*. Toronto: Canadian Standards Association, 2001.
 - 3) CSA Standard CAN/CSA-Z317.10-01. *Handling of waste materials in health care facilities and veterinary health care facilities*. Toronto: Canadian Standards Association, 2001.
- *Canadian Contractors Association
- Health and Welfare Canada. *Interior finishes in hospital design*. 1st ed. Ottawa: Ministry of Supply and Services Canada, 1988.
- Health Canada. *Laboratory biosafety guidelines*. 2nd ed. Ottawa: Supply and Services Canada, Catalogue Number MR21-1/1996E, 1996.

- National Building Code of Canada (NCR-BLDG CODE) (copies can be obtained from CSA on behalf of the National Research Council)
- National Plumbing Code of Canada (NCR-PLUMB CODE) (copies can be obtained from CSA on behalf of the National Research Council)
- *National Fire Protection Association Standards
- Health Canada. *Fungal contamination in public buildings: a guide to recognition and management.*

Provincial Resources

Readers are advised to check their province or territory for the following:

- *Provincial Building Code
- *Provincial Fire Code
- *Provincial Hydro Electrical Safety Code
- *Provincial Bid Depository Council
- *Provincial Association of Architects
- *Provincial Engineers Association
- *Provincial General Contractors Association
- *Public Health Act
- *Ministry of Health Act
- *Public Hospitals Act
- *Homes for the Aged and Rest Homes Act
- *Charitable Institutions Act
- *Nursing Homes Act
- *Elderly Persons Centres Act
- *Tobacco Control Act
- *Environmental Protection Act
- *Occupational Health and Safety Act
- *Construction Lien Act

In addition, some provinces and territories have developed a manual that provides information on the capital planning process. Health care facilities must follow this process when they embark on construction or renovation projects to ensure that 1) resources are used efficiently and effectively; 2) the approval process is streamlined; and 3) the key participants' roles and responsibilities are

identified⁽¹¹⁾. A list of the available manuals is provided below. At the time of writing, there were no capital planning process manuals available for the Northwest Territories, British Columbia, Quebec, Prince Edward Island, or Newfoundland and Labrador. The reader is advised to contact the provincial Ministry of Health to obtain further information on the manuals or for specific information on the process that should be followed if no manual is available.

Saskatchewan: Saskatchewan Health. *Planning guide for Saskatchewan health districts part III: facilities planning*. Regina, SK: Capital and Special Operating Policy Unit, Saskatchewan Health (currently being revised).

Ontario: Ontario Ministry of Health. *Capital planning manual: a guide to the capital planning process*. Toronto, ON: Queen's Printer for Ontario, 1996.

Nova Scotia: Nova Scotia Department of Health. *Health care capital construction guidelines*. Halifax, NS: Nova Scotia Department of Health, 1998

Yukon: Yukon Government Services. *Building development projects procedures manual*. Whitehorse, YK: Yukon Health and Social Services, 1992.

Municipal/Regional Resources

- *Local construction association
- *Local planning and zoning by-laws

Other Resources

- APIC: *Infection control tool kit series: construction and renovation*.1999;1-242.
- APIC: *Text of infection control and epidemiology*.2000; CD-ROM.
- Guidelines/Practice Parameters Committee of the American College -of Critical Care Medicine, Society of Critical Care Medicine. *Guidelines for intensive care unit design*. Crit Care Med 1995;23:582-88.
- American Institute of Architects Academy of Architecture for Health. *Guidelines for design and construction of hospital and health care facilities*. Washington: American Institute of Architects Press, 1997.
- <http://www.e-architect.com>
- *American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) handbooks
- Lavoie J, Lazure L. *Guide for the prevention of microbial growth in ventilation systems*. Montreal, Quebec: Institut de recherche en santé et en sécurité du travail du Québec.

- Lelièvre M, Ouellette JM, Thibault B et al. Hôpital général de courte durée : programme type détaillé. Quebec: ministère de la Santé et des Services sociaux, 1997.
- Van Vliet J, Drerup O, Feigin J et al. *Building materials for the environmentally hypersensitive*. Ottawa: Canada Mortgage and Housing Corporation, 1995.
- Healthcare facility construction management: indoor air quality
<http://www.dehs.umn.edu/iaqconf.html>
- Saskatchewan Research Council's air quality section
<http://www.src.sk.ca/air.html>
<http://www.ncbi.nlm.nih.gov/PubMed>

Note. *Represents resources that were listed in Ontario Ministry of Health. *Capital planning manual: a guide to the capital planning process*. Toronto, ON: Queen's Printer for Ontario, 1996.
