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CONSTRUCTION

Summary Report: Understanding the Rationale for Spatial Separation and Exposure Protection Requirements in the NBC

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Bwalya

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Executive summary

Three fire protection engineering firms were commissioned by the National Research Council (NRC) to conduct three tasks related to the spatial separation and exposure protection provisions in the National Building Code of Canada (NBC). This work was conducted as part of the "Construction Sector Digitalization and Productivity Challenge program", an initiative aimed at transitioning the National Building Code of Canada (NBC/NBCC) towards performance-based compliance options to foster innovation and productivity. The NRC staff provided background materials from previous NRC reports and meeting minutes from Codes Canada archives. The consultants' work was guided by the NRC staff through meetings and feedback on draft reports. Each firm delivered a report containing the details of the review exercise. These tasks are:

1. Review and document current provisions related to spatial separations.

- Review and document the historical changes for spatial separation provisions in the NBC, specifically provisions 3.2.3.1 and 3.2.3.2. in Part 3 and provisions 9.10.15.1 to 9.10.15.4 in Part 9 of Division B.
- Identify current performance target for the aforementioned provision.
- Describe calculation methods and assumptions used to develop tables 3.2.3.1-A to 3.2.3.1-E [1].
- Provide critical analysis and identify possible research gaps. Compile the findings of this review in a report.

2. Review and document current provisions related to exposure protection.

- Review and document the historical changes for exposure protection provisions in the NBC, specifically provisions 3.2.3.3 to 3.2.3.22, in Part 3 and provision 9.10.15.5 in Part 9 of Division B. Identify current performance target for each provision.
- Describe calculation methods and assumptions used to develop table 3.2.3.7.
- Discuss reasoning behind exposure protection measures, such as opening sizes, distances, construction materials constraints and fire resistance requirements in the aforementioned provisions.
- Provide critical analysis and identify possible research gaps. Compile the findings of this analysis in a report.

3. Perform a review of international approaches to addressing spatial separation between buildings and measures for limiting fire spread between buildings

- Review the different objectives of Spatial Separation in international approaches
- Discuss the prescriptive and performance-based design approaches in the international codes
- Discuss the Impact of Sprinkler Systems: reduced limiting distances to boundaries or increased areas of unprotected openings

The first report provided a historical analysis of the spatial separation requirements, focusing on the significant influence of the 1958 St. Lawrence Burn Tests, which provided foundational data for radiant heat exposure and incident heat flux that informed the development of regulations concerning limiting distance and the percentage of unprotected openings. This report also discusses subsequent changes related to factors like fire department arrival time and the concentration of openings.

The second report specifically reviews the historical evolution of a wider range of exposure protection provisions in both Part 3 (Articles 3.2.3.3 to 3.2.3.22) and Part 9 (Article 9.10.15.5), documenting their development primarily based on code committee meeting minutes and noting that many requirements originated from committee discussions rather than specific scientific data or quantitative performance metrics.

While the code prescribes performance levels such as fire resistance ratings or physical separation distances, the reports often found a lack of quantitative metrics to substantiate the rationale behind many specific requirements, such as the provisions for “Walls Enclosing Attic or Roof Spaces”, “Party Walls” provisions and the allowance of “Unlimited Unprotected Openings” in certain low fire load occupancies. Both reports identify areas for potential further study to better quantify performance targets and gain a deeper understanding of the underlying rationale behind specific requirements within the NBC's prescriptive provisions Such as: 1. Revisiting flame front factor and fire department arrival time assumptions, 2. quantifying fire load and heat flux for specific occupancies ,3. quantifying the benefit of sprinklers and heat flux reduction. 4. Assessing fire Hazard from skylights and 5. studying exterior fire dynamics for outdoor storage.

The third report compares and contrasts the approach to spatial separation in the National Building Code of Canada (NBC) with selected international codes, including the International Building Code (IBC), the National Construction Code (NCC) of Australia, the New Zealand Building Code (NZBC), Swedish Regulations (BBR), and UK Building Regulations. Comparing the NBC's spatial separation provisions with these international codes reveals that many jurisdictions utilize prescriptive approaches, often involving tables, to control fire spread between buildings, similar to the NBC. However, in contrast to the NBC, most international codes reviewed explicitly include or permit performance-based design options that allow for calculations of thermal radiation for spatial separation.

1 Report 1 Summary: Historical Basis for Spatial Separation Tables

The first report [1] details how the NBC's core spatial separation requirements, particularly those related to the permitted area of unprotected openings and limiting distance, are largely founded on the 1958 St. Lawrence Burn Tests. These full-scale fire tests were conducted in eight buildings in Aultsville, Ontario. The Fire Section of the Division of Building Research of the National Research Council (NRC) conducted these tests, with participation from the Joint Fire Research Organization (JFRO) of the UK.

A primary objective of the St. Lawrence Burn Tests was to examine the spread of fire by radiant heat, including aspects like radiation intensity at a distance, the radiant temperature of openings, and the flame front distance from openings. The spatial separation regulations of the NBC were almost exclusively based on the results from Buildings # 4 and 5 of these tests. These were both two-storey residential buildings with similar areas.

The process of converting the test results into the NBC regulations involved several key technical concepts and assumptions:

Radiant Heat Exposure Equations: The general approach involved understanding the radiant emissive power of the fire (the hazard), the relationship between this power and the incident heat flux at a distance, and the critical incident heat flux below which ignition is unlikely.

Incident Heat Flux and Source Radiant Emissive Power: Radiometers were used to measure the incident heat flux at distances of 6.1 m (20 ft) and 12.1 m (40 ft) from the buildings. To determine the source radiant emissive power (the hazard), these measurements were normalized back to the building face. This normalisation was initially challenging due to varying flame size and extension; so it was simplified by assuming the measured heat flux originated only from the openings (windows and doors) in the building face. This simplification, while making geometrical representation easier, resulted in artificially high calculated radiant emissive powers and associated temperatures for the openings. This has caused regulatory guides referencing unrealistic peak temperatures.

Fire Department Arrival Assumption: To make the regulations practical, a significant assumption was made that a fire department is expected to arrive and control an exposure fire within 10 to 11 minutes. This time frame, allowed for a reduced, more practical source radiant emissive power value of $8.5 \text{ cal./cm}^2\cdot\text{s}$ (356 kW/m^2) to be used for the 'high hazard' exposure condition. Buildings with non-combustible lining and lower

heat flux, were used to derive a 'low hazard' value (half of the 'high hazard' peak) of 4.25 cal./cm²·s (178 kW/m²).

Exposed Source Criteria (Critical Incident Heat Flux): The criterion for 'acceptable' exposure was based on the ignition of building materials, specifically wood, considered at the time to have the lowest ignition temperature. The pilot ignition of wood at 0.3 cal./cm²·s (12.5 kW/m²) was selected as the critical heat flux. Pilot ignition was chosen over spontaneous ignition (0.8 cal./cm²·s) due to observations of sparks and flying brands from actual fires that could act as pilot ignition sources.

Relationship Between Source and Exposed: Quantifying this relationship involved simplifying geometrical calculations. This included:

- A basic planar configuration factor equation.
- **A flame front factor** derived from observed flame extension in the St. Lawrence tests (1.5 m for low hazard, 2.1 m for high hazard), which was later simplified to a single 1.8288 m (6 ft) value. This factor is applied by reducing the distance in the configuration factor calculation.
- **The limiting distance** concept, introduced earlier in the NBC, which measures the distance to a property boundary and uses a 'mirror boundary condition' assumption to represent the distance to a notional identical adjacent building. The report notes that this assumption breaks down when adjacent buildings differ significantly.
- **The grey radiator concept**, which simplifies configuration factor calculations by treating the entire plane containing openings as the emitting source and expressing the openings as a percentage. This underlies the structure of the NBC tables which regulate the permitted percentage of unprotected openings.

The developed methodology led to the creation of tables showing the permitted percentage of unprotected openings based on factors like limiting distance, area of exposing building face, and occupancy (low/high hazard). Special tables were developed for sprinklered buildings in the 1995 NBC, based on assumptions like a reduced emissive power or higher critical configuration factor.

Modifications documented since the initial development include

Fire Department Arrival Time: While the 10 – 11 minutes assumption was used in the table development, an explicit requirement referencing fire service intervention was added in the 1970 NBC, stating that required limiting distances should be doubled if

properly equipped fire-fighting services are not available within 10 minutes of alarm receipt.

Concentration of Openings: Introduced in the 2005 NBC to better align with the 'grey radiator concept', regulating the maximum concentrated area of unprotected openings. This included rules for adjacent or stacked spaces considered as a single room based on separating wall openings.

Staggered or Skewed Exposing Building Faces: Provisions were added, particularly in Part 9, allowing calculation of unprotected openings for individual portions of exposing faces based on their respective limiting distances and the total face area.

Recommendations for future analysis

The report identifies recommendations for future analysis, such as reviewing the flame front factor, reassessing the 10-minute fire department arrival assumption, considering alternative approaches for concentrated openings, and extending the method for staggered faces from Part 9 to Part 3 buildings.

2 Report 2 Summary: Historical Basis for Exposure Protection Provisions

The second report [2] provides a historical review of exposure protection provisions in NBC Parts 3 (Articles 3.2.3.3 to 3.2.3.22) and 9 (Article 9.10.15.5). Unlike the spatial separation tables which have a clear technical basis from the St. Lawrence tests, this report found that the historical basis for many of these other requirements is more often attributed to significant **discussion at the committee** level than to specific testing. While specific performance levels requirements (e.g., fire resistance ratings, separation distances) are prescribed, **quantitative performance metrics to substantiate “why” these specific levels were chosen are often not found** in the reviewed documentations.

The report reviewed a wide **array of provisions**, noting the chronology of changes and, where possible, identifying the reasoning or performance targets:

Walls Enclosing Attic or Roof Spaces: Requirement introduced to regulate gable ended walls and ensure consistency with exposing building face standards above the exposed area.

Party Walls: Intent is to limit fire spread between adjacent buildings, potentially leading to damage. Generally, no quantitative performance metrics identified.

Combustible Projections (e.g., balconies, canopies, soffits): Requirements were introduced to prevent fire spread between buildings via these projections. Initially introduced in the 1985 NBC with an exception for houses due to public comment and to permit existing practices. Distances to property lines and between projections on the same property were established, with rationale often based on committee consensus to ensure a minimum separation. Changes in the 2010 NBC related to roof soffit projections were supported by analysis following an apartment fire in Fort MacMurray, which provided some heat flux data at various distances. Part 9 significantly relaxes requirements for projections between houses and detached garages/accessory buildings on the same property.

Construction of Exposing Building Faces: These requirements, dating back to the 1941 NBC, specify fire resistance ratings, construction type, and cladding materials based on limiting distance, occupancy, and fire load. The intent is to provide sufficient fire resistance to limit spread until emergency responders arrive at the fire scene. The performance criterion is related to the percentage of permitted unprotected openings (governed by Article 3.2.3.1). The report notes that the required fire resistance in Article 3.2.3.7 may sometimes exceed structural fire protection requirements and suggests evaluating this against expected fuel loads.

Protection of Exterior Structural Members: Introduced in the 1960 NBC to protect structural members from fires originating on adjacent properties, and preventing collapse. Requirements specify fire resistance ratings, generally not less than 1 hour, unless sufficiently far from the property line. The report identifies a gap, noting that if exposed to a fire from an adjacent building with a higher fuel load than assumed for the structural member's internal fire protection, the level of performance might be inadequate.

Unlimited Unprotected Openings: Allowed for low fire load occupancies like storage garages at certain distances. The rationale was based on the perceived low fire load. However, the report notes that no specific fire load quantification was presented to substantiate this claim. Study could be conducted to quantify fuel loads and expected heat fluxes. Similar provisions exist for “**Low Fire Load Buildings**”, **Article 3.2.3.11**, / one-storey buildings of low-hazard industrial occupancy.

Area Increase for Unprotected Openings (e.g., wired glass, glass block): Allows increasing the permitted area of openings when using these materials, or when sprinklered. The report states no quantifiable performance metrics are identified for these increases and suggests studying the heat flux reduction provided by sprinklers, noting the current relaxation (doubling) appears anecdotal.

Protection of Exit Facilities: Requirements to protect exterior exit doors, stairs, or ramps from nearby openings (both within the same building and from other fire

compartments). Distances and angles (e.g., less than 135° intersecting walls) are specified for when protection is needed. The 135° angle was noted as somewhat arbitrary.

Walls Exposed to Another Wall: Regulates unprotected openings in walls of different fire compartments that face each other or intersect at an angle less than 135°. A formula is specified in Article XXXXX to determine the required separation distance between the openings. The formula does not apply to sprinklered buildings unless across a firewall or from an un-sprinklered compartment.

Walls Exposed to Adjoining Roof: Requirements for windows in walls adjacent to roofs (within 3 storeys vertically and 5 m horizontally) and for skylights in such roofs. Introduced to address potential fire spread, based partly on experience with adding a non-combustible building to a combustible one.

Protection of Soffits: Provisions to limit fire spread into attic/roof spaces via unprotected soffits, particularly near windows and doors. Requires protection or separation for projections within a certain distance of property lines or imaginary lines between buildings. Allows projection to the property line when facing a public way. While materials and distances are specified, no specific performance criteria (e.g., required heat flux reduction) were found to substantiate the protection level. Part 9 requirements are generally harmonized with Part 3, with additional relaxations for small buildings and houses.

Canopy Protection for Vertically Separated Openings: Requires a fire-rated canopy (or sufficient recess) between vertically aligned openings in certain occupancies to prevent fire spread up the building facade. Waived if the building is sprinklered throughout.

Covered Vehicular Passageways: Requires separation with fire resistance ratings from adjoining buildings, particularly for shipping/receiving areas. Below-grade passageways must be non-combustible. The report notes the fire resistance rating aligns with storage garages but questions if the fuel load is truly equivalent, suggesting a potential gap.

Walkways Between Buildings: Requires fire separation from connecting buildings for walkways at or above grade. Also specifies construction type based on the connected building. No quantifiable performance metrics identified.

Underground Walkways: Limits fire spread between buildings via underground walkways, with requirements for fire separation, maximum width, and limitations on use. An ambiguity regarding smoke barrier doors is noted.

Storage and Process Equipment Located Outdoors: Refers to the National Fire Code for location requirements relative to buildings. The report notes that outdoor fire dynamics differ from compartment fires and suggests study on commodity storage and horizontal fire spread to buildings.

Installation of Service Lines under Buildings: Requires service lines under buildings to conform to relevant standards. No quantifiable performance metrics identified.

The second report concluded that while specific performance levels are prescribed, the historical basis is largely based on committee discussion rather than testing, and **quantitative performance metrics are typically not available to substantiate the requirements**. Numerous areas for further study are identified, primarily focused on quantifying the performance targets set by the acceptable solutions. Examples of areas recommended for further study are:

- Quantifying Fire Load and Heat Flux for Specific Occupancies
- Understanding the Benefit of Sprinklers and quantify the overall reduction in heat flux
- Substantiating Assumed Flame Size for Combustible Projections
- Evaluating Risk from Exposed Structural Members
- Reviewing the Basis for Increasing Fire Resistance with Limiting Distance
- Evaluating Vertical Fire Spread and Canopy Protection
- Assessing Fire Hazard from Skylights
- Studying Exterior Fire Dynamics for Outdoor Storage

3 Report 3 Summary: Building Fire Safety Review of International Approaches Provisions on Construction Type, Materials, Spatial Separation, and Maximum Travel Distance

The objective of the third report [3] is to compare and contrast the NBC's provisions, particularly those in Part 3 of Division B, with selected international codes (IBC, NCC, NZBC, Swedish and UK) across key areas, focusing on spatial separation and exposure protection provisions.

National Building Code of Canada (NBC)

The National Building Code of Canada (NBC) includes acceptable solutions in Part 3 that address the concept of spatial separation between buildings as a key strategy for

limiting the spread of fire. The NBC regulates potential fire spread by using the distance from a building to a property line as the primary controlling dimension. This regulatory approach treats each building independently, without directly considering the characteristics of buildings located on neighbouring properties. Importantly, the NBC's requirements also aim to ensure adequate spatial separation between multiple buildings that may be situated on the same property. Furthermore, the NBC's spatial separation provisions may mandate that specific components of a building's construction, such as its exterior cladding materials and the assemblies of its exterior walls, be constructed using non-combustible materials to further mitigate the risk of fire spread.

3.2 International Building Code (IBC)

The fundamental objective of the International Building Code (IBC) spatial separation provisions is to limit the potential for fire to spread from within a building to adjacent properties by mandating the use of fire-rated exterior walls and by placing limitations on the percentage of unprotected openings permitted in those walls. The IBC addresses spatial separation as a means of limiting fire spread between buildings through the concept of Fire Separation Distance (FSD). To comply with the IBC's requirements, the primary approach involves specifying a fire-resistance rating for the exterior walls of a building, with the required rating being directly related to the calculated FSD. Notably, the IBC permits an increase in the allowable unprotected area (e.g., windows and doors) in exterior walls as the Fire Separation Distance increases or when greater fire protection measures are incorporated into the openings themselves. It is important to recognize that while the IBC provides prescriptive values for FSD and associated requirements, these values are often acknowledged as originating from established traditional practices rather than being solely derived from rigorous scientific calculations or comprehensive fire testing.

Australia Building Code (NCC)

The primary objective of the National Construction Code of Australia (NCC) is to limit the spread of fire between buildings. Its prescriptive, or Deemed-To-Satisfy, approach utilizes Fire Resistance Levels (FRLs) for external walls, with these FRLs being determined based on the separation distance between buildings. Notably, FRLs indicate a material or assembly's resistance to three critical fire performance criteria: structural adequacy, integrity (resistance to the passage of flames and hot gases), and insulation (ability to limit temperature rise on the unexposed side). The code offers prescriptive guidance and provides concessions that take into account various factors such as building classification, type of construction, exposure conditions, and the building's

height. Furthermore, the NCC includes specific provisions for protecting openings in external walls, as well as for separating walls and openings located in different fire compartments within a building, often requiring these openings to possess a prescribed FRL. In addition to the prescriptive path, the NCC also permits *performance-based assessments* through the use of a Verification Method. This method allows for the evaluation of potential fire spread to adjacent property using engineering principles. It is worth noting that both the NCC and the NBC (National Building Code of Canada) employ a prescriptive, table-based approach that considers factors like building classification, height, construction type, and separation distance. However, a key difference lies in the NCC's *performance-based approach*, which is specifically based on calculating the amount of radiation that would be transmitted to the property boundary in a fire scenario.

3.4 New Zealand Building Code (NZBC)

New Zealand Building Code (NZBC) Clause, for spatial separation, focuses on the necessity of limiting fire spread to safeguard both adjacent properties and designated escape routes. The specific performance requirements related to this objective are detailed in Clauses 3.6 and 3.7 of the code. The prescriptive approach outlined in Acceptable Solution C/AS2 evaluates the required spatial separation based on the building's designated *risk group* and its overall configuration. Compliance with these prescriptive requirements can be achieved through various methods, including adhering to distance separation tables, limiting unprotected areas in external walls as per specified tables, or by utilizing fire-resistant glazing that complies with defined size and separation restrictions. It's important to note that the required fire rating of the external wall is ultimately determined by property protection requirements that are specified elsewhere within the Acceptable Solutions. The NZBC provides tables that define the maximum allowable areas for both fire-resistant glazing and unprotected areas in external walls. These maximum areas are dependent on factors such as the building's risk group, the width of the fire compartment within the building, and the distance of the wall to the relevant property boundary. Similar to the NCC (National Construction Code of Australia), the NZBC also permits the use of *performance-based assessments*. This approach typically involves calculating the potential thermal radiation that could be emitted towards the property boundary in a fire scenario to demonstrate compliance.

Swedish Regulations (BBR)

In the Building Regulations for Building Works (BBR) Section 5:61, limiting the spread of fire is established as a fundamental performance objective. The Simplified Design

(Prescriptive) approach within the BBR considers adequate protection against fire spread to be achieved automatically if the distance separating two buildings is 8 meters or more. However, for situations where the separation distance is less than this 8-meter threshold, the exterior walls of the buildings are required to function as effective fire separations. In such cases, the highest fire resistance rating required for either of the adjacent buildings will govern the necessary fire resistance of the intervening exterior walls. It is noteworthy that, in contrast to the National Building Code of Canada (NBC), the BBR does not provide extensive tables detailing spatial separation requirements for prescriptive design solutions. Instead, for more detailed design considerations, particularly when the separation distance falls within the 8-meter range, a performance-based approach utilizing the BBRAD (Building Regulations Assessment Document) can be employed. This performance-based assessment typically involves evaluating the potential thermal radiation that could be transmitted to adjacent buildings in the event of a fire.

UK Building Regulations (Approved Document B)

Schedule 1, Part B4 of the UK Building Regulations mandates that the external walls of a building must be constructed to adequately resist the spread of fire to other buildings, with the specific requirements varying based on the building's height, its intended use, and its position relative to site boundaries. Approved Document B of the Building Regulations provides prescriptive guidance on limiting the extent of unprotected openings (such as windows and doors) in external walls. These limitations are determined by several factors, including the building's Purpose Group (occupancy type), the distance of the wall from a relevant boundary (referred to as the limiting distance), and whether or not the building is equipped with a sprinkler system. For external wall within 1,000 mm of the relevant boundary, the wall should be fire resisting from both sides and only small unprotected areas should be allowed. For external walls located 1,000 mm or more from the relevant boundary, the wall must provide a specified level of fire resistance when assessed from the inside of the building. The total allowable area of unprotected openings in such walls is determined using methods outlined in guidance documents like BR 187 or through the use of specific diagrams and tables provided in Approved Document B. A significant concession is made for buildings equipped with sprinkler systems: in such cases, the required boundary distance can be halved (with a minimum of 1 meter), or alternatively, the permitted total area of unprotected openings can be doubled compared to un-sprinklered buildings. British Standard BS 9999 also offers risk-based guidance on limiting unprotected openings in external walls. Overall, the approach used in Approved Document B regarding the limitation of unprotected openings shares similarities with that of the NBC (National Building Code of Canada),

as both consider factors such as occupancy type, distance to the boundary, and the presence of sprinklers. However, Approved Document B incorporates simplified tables and diagrams for ease of application and employs a straightforward doubling of the permitted unprotected area for sprinklered buildings.

4 Conclusion

The first two reports highlight a distinction in the technical basis for different types of exposure protection requirements in the NBC. The spatial separation tables (Articles 3.2.3.1, 3.2.3.2, etc.) have a relatively clear and well-documented technical lineage rooted in the 1958 St. Lawrence Burn Tests and the conversion of those results through specific engineering calculations and assumptions (radiant heat transfer, critical heat flux, configuration factors, flame front, grey radiator concept).

In contrast, the historical basis for many other exposure protection provisions (Articles 3.2.3.3 to 3.2.3.22, 9.10.15.5), covering aspects from combustible projections and soffits to walkways and structural member protection, appears to be less rigorously quantified in terms of performance metrics. The rationale for these provisions is often described as being based on committee discussions and consensus, aiming to prevent fire spread via specific pathways or building elements.

Both reports identify research gaps and areas for potential further study. Such as: 1. Revisiting flame front factor and fire department arrival time assumptions, 2. Quantifying fire load and heat flux for specific occupancies, 3. quantifying the benefit of sprinklers and heat flux reduction. 4. Assessing fire Hazard from skylights and 5. Studying exterior fire dynamics for outdoor storage. These often involve a need to quantify the performance of existing provisions, review underlying assumptions (like the flame front factor or fire department arrival time), and develop more robust technical bases for requirements currently lacking them, particularly in understanding and quantifying heat flux exposures and the effectiveness of various protection provisions.

The third report compares and contrasts the approach to spatial separation in the National Building Code of Canada (NBC) with selected international codes including the International Building Code (IBC), the National Construction Code (NCC) of Australia, the New Zealand Building Code (NZBC), Swedish regulations (BBR), and UK Building Regulations. While the NBC uses a prescriptive approach based on fire tests and calculation methods derived from them, focusing on distance to property lines and required wall/opening protection, the international codes reviewed employ a mix of *prescriptive tables* (similar in concept to NBC or based on FRLs/fire-resistant glazing) and *performance-based calculation methods* (often based on thermal radiation), with

varying levels of detail and specific requirements regarding wall ratings, opening protection, and the impact of sprinkler systems.

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