CODES CANADA

# Impact Analysis of Installing Passive Radon Stacks in Part 9 Residential Occupancies

Submitted to Task Group on Radon and Soil Gas Mitigation
May 2022

This document is a working paper dealing with the National Model Codes. Work on these Codes is carried out under the authority of the Canadian Board for Harmonized Construction Codes.

National Research Council Canada Conseil national de recherches Canada

Canada

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## Executive Summary

This report summarizes the impact analysis for PCF 1713 on installing passive radon stacks in Part 9 residential occupancies that are in contact with the ground, which is being recommended by the Task Group on Radon and Soil Gas Mitigation.

The benefits of reducing radon by installing passive radon stacks followed a pattern typical of preventive interventions, with the direct costs incurred up front and a delay before the benefits are experienced. The direct benefits included the number of lung cancer deaths that would be prevented and the associated lung cancer treatment costs avoided following the reduction in residential radon exposures. The results of the analysis were presented in two parts:

I. Example case: passive radon stacks installed in relevant Part 9 units built in 1 year
II. Full analysis: passive radon stacks installed in relevant Part 9 units built over 100 years

The methodology used to estimate the benefits of installing passive radon stacks was defined as follows:

- Two estimates of current radon exposure (lower and upper)
- Effectiveness of passive radon stacks at reducing indoor radon based on recent field studies
- 75 year service life of passive radon stacks
- Excess relative risk of lung cancer from radon modelled using cumulative radon exposure resulting from the duration and concentration of radon exposure over time (BEIR VI model)
- Lung cancer incidence and survival defined by type and stage at diagnosis
- Lifetable approach based on lung cancer incidence, all-cause mortality and smoking prevalence

In 2021, the annual cost of installing passive radon stacks in the 117,742 units of Part 9 residential occupancies in contact with the ground built in that one-year period was estimated to be $112,897,401 ($93,633,327 - $131,261,476). The annual lung cancer cases prevented – and therefore the annual lung cancer treatment costs prevented – increased over the 75 year service life of the passive radon stacks because there was a greater reduction in the relative annual risk of lung cancer for residents who lived for a longer period with reduced radon exposure. The total lung cancer treatment costs prevented over the 75-year lifespan of the 117,742 units of new housing built in 2021 with passive radon stacks installed ranged from 10 to 16 million dollars, at $10,231,105 ($8,443,980 – $12,047,540) and $16,050,125 ($14,278,700 – $17,554,105) for the lower and upper radon estimates, respectively. A total of 141 (117 – 167) and 222 (197 – 242) lung cancer deaths were estimated to be prevented for the lower and upper radon estimates, respectively, in the residents of the 117,742 units over 75 years following the installation of passive radon stacks.

The impact analysis for PCF 1713 on installing passive radon stacks in Part 9 residential occupancies demonstrated that the main benefit would be preventing 10,000 to 16,000 radon-associated lung cancer deaths in Canada over 100 years should the proposed change be adopted. The cumulative number of lung cancer deaths prevented over 100 years was estimated to be 10,356 (8,601 – 12,208) for the lower residential radon exposure and 16,132 (14,402 – 17,586) for the upper estimate of current residential radon exposure. Although the costs incurred for installing passive radon stacks in new housing construction always exceeded the savings from lung cancer treatment for cases prevented, the cumulative cost per lung cancer death prevented decreased steeply after implementation and dropped below the Treasury Board of Canada Secretariat reference value after 30 – 40 years.

## Scope

This report summarizes the impact analysis for PCF 1713 on installing passive radon stacks in Part 9 residential occupancies. The Task Group on Radon and Soil Gas Mitigation (TG) is recommending that the National Building Code mandate the addition of a passive radon stack system to all Part 9 dwelling units containing residential occupancies that are in contact with the ground.

## Method

Lung cancer is the most common cause of cancer death in Canada, causing about 20,000 deaths annually [1]. Radon is the second most important cause of lung cancer after smoking and is the main cause of lung cancer for people living in non-smoking households.

The benefits of reducing radon from installing passive radon stacks follow a pattern typical of preventive interventions, where the costs are incurred up front while there is a delay before the benefits are experienced. The direct benefits include the number of lung cancer deaths that would be prevented and the associated lung cancer treatment costs avoided by the reduction in radon resulting from the installation of passive radon stack systems in relevant housing. A likely range of values is provided for the costs and benefits by conducting a Monte Carlo analysis using 10,000 simulations to sample from a range of values for residential radon exposure, the installation costs and effectiveness of passive radon stacks, the lung cancer treatment costs, and the smoking prevalence by age and sex.

The TG agreed to first evaluate the costs and benefits of installing a passive radon stack in relevant Part 9 dwelling units built in a single year, as an example case, to demonstrate that the benefits from preventing radon-attributed lung cancer deaths increase over time and are experienced over the lifespan of the housing. The full analysis is then presented, wherein the costs and benefits are determined by aggregating the effects of implementing passive radon stacks in relevant Part 9 dwelling units built each year over a 100-year period.

This approach was chosen to clarify the costs and benefits resulting from the addition of the passive radon stack to the installation of a capped radon rough-in, which was added as a requirement to the NBC 2010:

I. Example case: passive radon stacks installed in relevant Part 9 units built in 1 year
II. Full analysis: passive radon stacks installed in relevant Part 9 units built over 100 years

The average and range of values for residential radon concentration expected in new housing construction, the effectiveness of the passive radon stack systems proposed and their effective service life, and the method used to calculate the number of lung cancer deaths attributable to radon used in the analysis are presented below.

## Main Data Sources

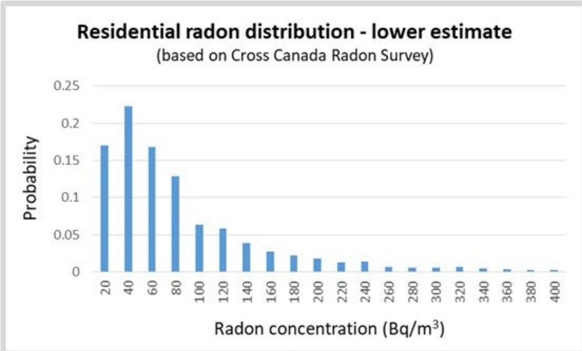
- **Health-related data** (by sex and age group)
  - Canadian cancer statistics 2018 [2] – lung cancer incidence rate
  - Death database 2018 [3] – mortality rate
  - Canadian Community Health Survey 2018 [4] – smoking prevalence
- **Population and new housing construction data**
  - Statistics Canada 2021 [5]
  - Canadian Mortgage and Housing Corporation (CMHC) 2021 [6]
- **Costing data**
  - Passive radon stack systems – RSMeans January 2022 [7]
  - Lung cancer treatment – indexed to 2021 dollars [8,9]

## Residential Radon Exposures

The Cross Canada Survey of Radon (CCRS) was conducted between 2009 and 2011 using a stratified random sampling strategy based on Health Regions by the Radiation Protection Bureau at Health Canada [10]. A second radon survey of 33 Census Metropolitan Areas (CMAs) in Canada was conducted between 2012 and 2013 [11]. Both of these surveys provided residents with an alpha-track detector for radon measurement over a 3-month period. This data was combined to yield an estimate of arithmetic average residential radon of 79 Bq/m$^3$ (uncertainty interval: 62 – 99), which represented a lower estimate of radon in current new housing construction.

A trend of increasing indoor radon in housing built over the last seven decades was reported recently [12], based on data contributed by residents who paid privately for an alpha-track detector to measure radon over a 3-month period. The geometric mean residential radon was reported to have generally increased in housing surveyed in the three regions of Canada presented over the last three decades. Over the most recent decade, there has been a small decrease in the geometric mean residential radon for the central and Atlantic region, a small increase for the North and Pacific region, and a larger increase for the Prairies. An upper estimate of radon in current new housing construction was, therefore, conservatively estimated to be about 100 Bq/m$^3$, and assuming a geometric standard deviation of 2, was represented by an arithmetic average residential radon of 126 Bq/m$^3$ (uncertainty interval: 109 – 146 Bq/m$^3$).

The residential radon exposures were characterized by lognormal distributions, which tend to have many lower values and fewer higher values resulting in a long right tail as shown in the plots in Figure 1. The estimates and ranges for the geometric mean and standard deviation for the upper and lower radon estimates are presented in Table 1. It is important to characterize the distribution of residential radon exposures: radon preventive measures in new housing construction result in significant benefits because every radon exposure is reduced. By contrast, the total benefit is much smaller when retrofitting radon mitigation in existing housing because only the highest radon exposures in a population are reduced.



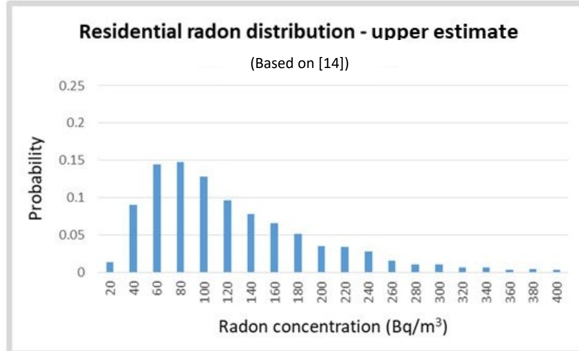



*Figure 1. Plots of lower and upper radon estimates for radon exposures in new housing*

*Table 1. Lower and upper residential radon estimates for current new housing*

| Residential Radon | Lower Estimate ($Bq/m^3$) | Upper Estimate ($Bq/m^3$) |
|---|---|---|
| **Arithmetic mean** (uncertainty interval) | **79** (62-99) | **126** (109-146) |
| Geometric mean (uncertainty interval) | 50.4 (45-55) | 100 (90-110) |
| Geometric standard deviation (uncertainty interval) | 2.64 (2.4-2.9) | 2.0 (1.8-2.2) |

## Effectiveness of Passive Radon Stacks

The effectiveness of passive radon stack systems has been evaluated in several recent field studies conducted by the NRC's radon research team, led by Dr. Liang Grace Zhou. Initial field studies of passive radon stacks installed in new and existing housing identified several design factors that affected the performance of the systems [13]. While well-designed passive radon stacks were reported to be more effective during the winter, those that lacked stack insulation in unconditioned spaces experienced a reduction in effectiveness during the winter months. A reduction in the effectiveness of passive radon stacks in new housing during the winter season was reported for those with a bathroom on the floor in contact with the ground, which may have resulted from unsealed ground-contact floor cut outs left to accommodate plumbing.

According to a recent field study [14], well-designed passive radon stacks installed in new housing construction were demonstrated to be very effective at reducing radon and were not found to be affected by the factors identified in the previous study [13]. The effectiveness of the passive radon stacks was found to be related to the initial radon concentration and varied slightly by season (Figure 2): a greater percentage reduction of radon was reported in homes with a high initial radon concentration and the passive radon stacks were usually more effective during the winter season. The arithmetic mean effectiveness was 82±2% for homes with an initial radon concentration above 70 $Bq/m^3$ and 39±2% for homes with an initial radon concentration below 70 $Bq/m^3$. The range in effectiveness of passive radon stacks was plotted in Figure 3 for homes with initial radon concentrations above and below 70 $Bq/m^3$.

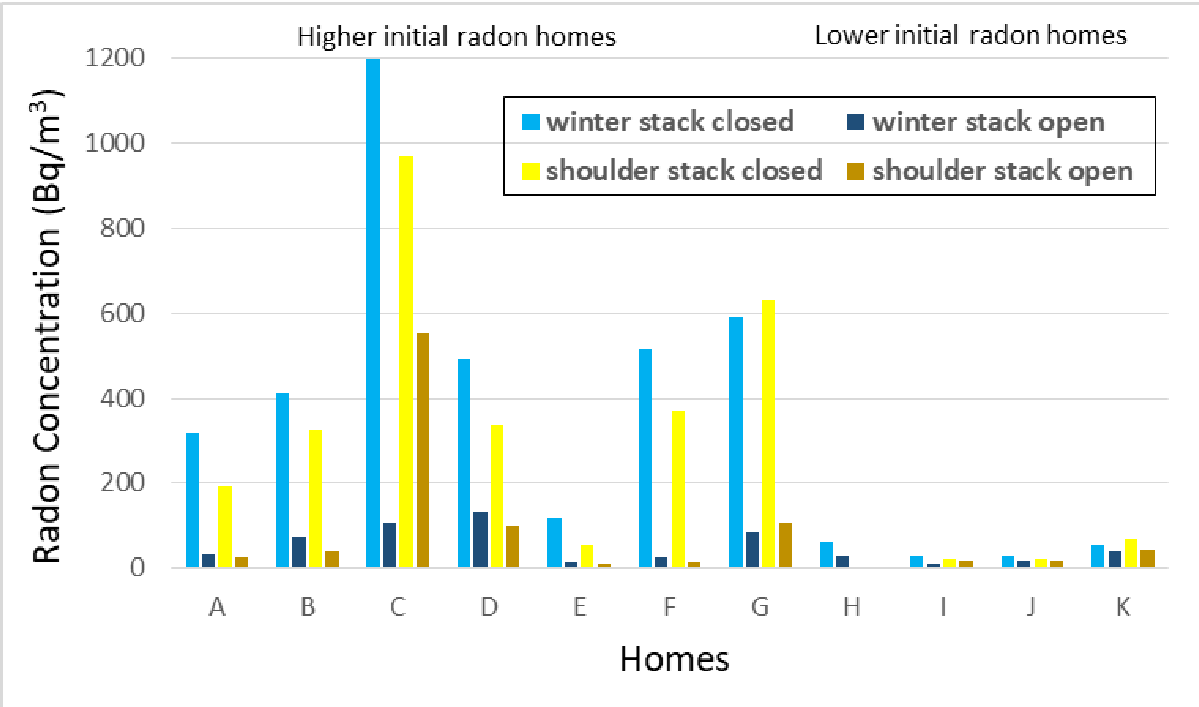



*Figure 2. Seasonal indoor radon concentrations in homes with open and closed passive radon stacks*

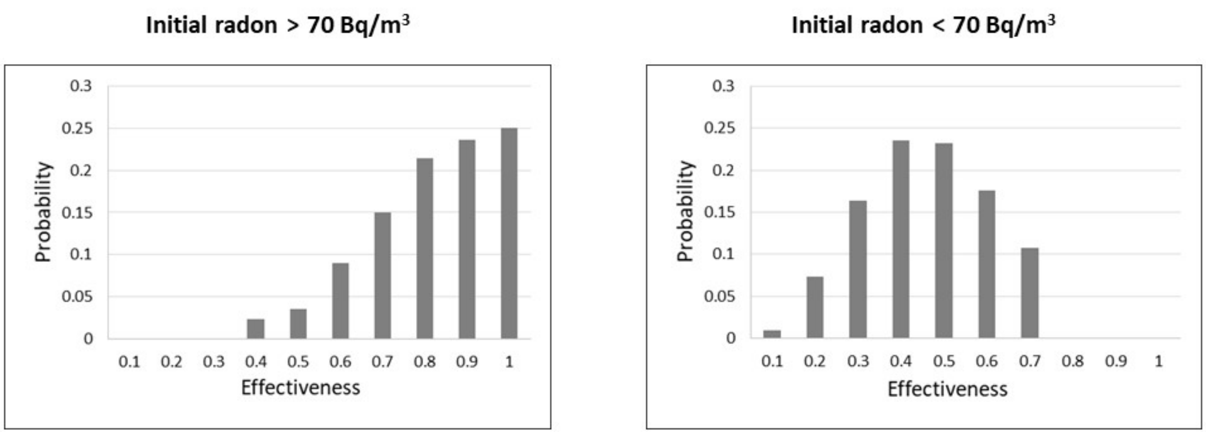



*Figure 3. Range in effectiveness of passive radon stacks*

The effectiveness of passive radon stacks was estimated by comparing the month-long average concentration of indoor radon with and without the passive stack operating in each home, and was defined as follows:

$$Eff(\%) = 100(1 - Co/Cc)$$

where $Cc$ represents the radon concentration with the stack closed, and $Co$ represents the radon concentration with the stack open. Hourly indoor radon concentrations were measured using a continuous radon monitor for a duration of 1 month for each of four test scenarios: stack open and stack closed during both the shoulder and winter seasons.

## Service Life of Passive Radon Stack System

The service life of a passive radon stack was estimated to be the lifespan of the dwelling unit. For this analysis, the service life represents the time during which the passive radon stack is functioning as intended without maintenance, inspection or replacement. The Canadian Housing and Mortgage Corporation (CMHC) provided data on dwelling conditions by period of construction for Canada in 2016 [15]. For example, the percentage of homes in need of major repairs was 0.9%, 5.3% and 10% for homes built between the years 2011-2016, 1981-1990 and 1946-1960, respectively. All homes built earlier than 1945 were grouped into a single category, of which 14% were in need of major repairs. A major repair was defined as a building requiring either major remedial work or demolition, both of which would be expected to adversely affect the performance of a passive radon stack system. It was conservatively assumed that any building built before 1945 might be in need of major repairs and, therefore, 75 years was assumed to be the lifespan of the dwelling unit and the service life of a passive radon stack for this analysis.

## Lung Cancer Attributable to Radon

The excess relative risk of lung cancer from radon was modelled to estimate the reduction in lung cancer risk that would result from a reduction in residential radon exposure occurring at any point during a person's lifetime. There is no safe level of radon, and the excess relative risk of radon increases linearly with the cumulative radon exposure. There is a health benefit from reducing any concentration of indoor radon, lowering the risk of lung cancer for both smokers and non-smokers, which is proportional to the reduction in cumulative or long-term radon exposure.

The excess relative risk of lung cancer attributable to radon was calculated using the BEIR VI exposure-age-concentration (EAC) model [16,17], based on the exposure duration, exposure intensity, attained age and smoking status (Eq 1):

$$\varepsilon_t = \beta \times \delta \times K \times \omega \times \eta_t \times \gamma_\omega \times \varphi_t \qquad (1)$$

where $\varepsilon_t$ = excess relative risk at age $t$, $\beta$ = potency of radon, $\delta$ = smoking factor, $K$ = dosimetric factor, $\omega$ = radon exposure rate, $\eta_t$ = exposure duration, $\gamma_\omega$ = dose rate factor, and $\varphi_t$ = attained age factor.

All previous radon exposure contributes to a person's excess relative risk of lung cancer, and due to the time lag between exposure to radiation and a diagnosis of lung cancer, recent exposure (i.e., within 5 years) is excluded. The cumulative exposure to radon is calculated using three weighted periods, with a greater effect from exposure occurring 5 – 15 years prior and a decreased effect from exposure further in the past (Eq 2):

$$\eta_t = \Delta_{[5,14]}(t) + 0.77\Delta_{[15,24]}(t) + 0.57\Delta_{[25+]}(t) \qquad (2)$$

Lung cancer morbidity and mortality was represented using a Markov cohort model consisting of the eight states shown in Figure 4: dead, alive without lung cancer, and alive with one of six possible categories for the diagnosis of lung cancer [18]. Recently published Canadian data was available for lung cancer incidence by type and stage at diagnosis, with 12% being small cell lung cancer (SCLC) and 88% being non-small cell lung cancer (NSCLC) [19]. Lung cancer stage at diagnosis was characterized in this analysis as local, regional or distant (Figure 5). Lung cancer has high mortality because it is typically diagnosed at later stages.

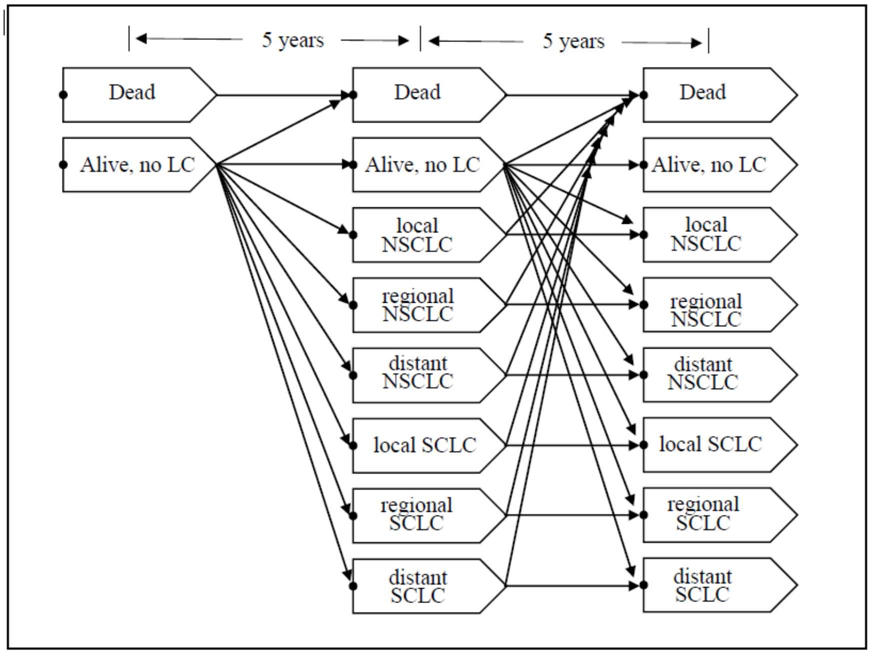



*Figure 4. Lung cancer morbidity and mortality model [18]*

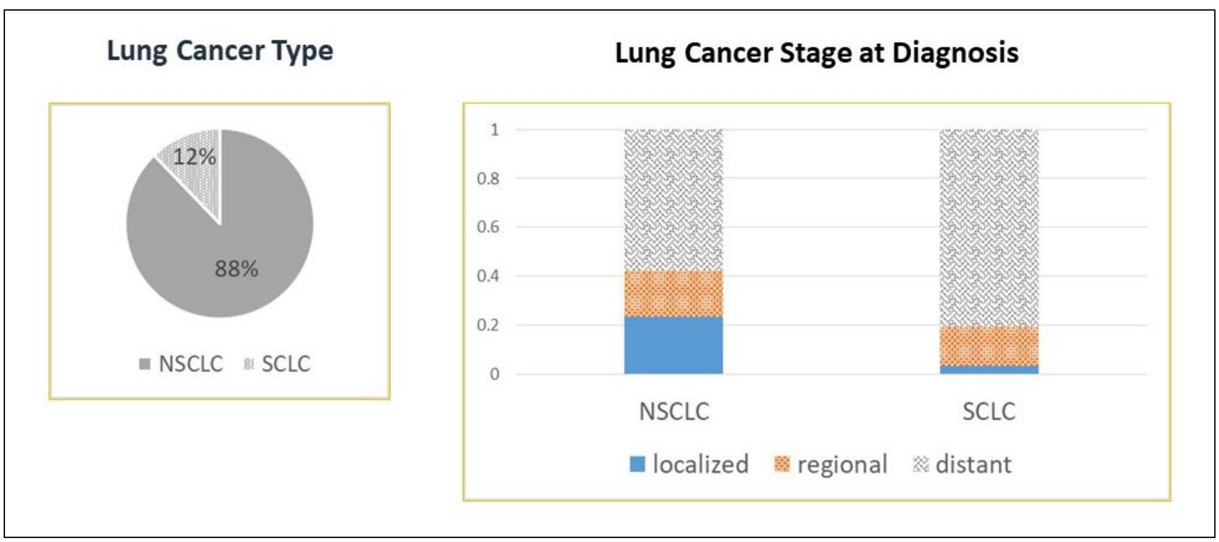



*Figure 5. Lung cancer type and stage at diagnosis in Canada [18]*

An abridged period life-table approach with 5-year age intervals was used to determine the probability of being diagnosed with lung cancer, based on age- and sex-specific all-cause mortality rates, lung cancer incidence rates, the modelled excess relative risk of lung cancer from radon, and smoking prevalence. The 5-year relative survival rates reported in the US Surveillance, Epidemiology, and End Results Program (SEER) for lung cancer by type and stage at diagnosis [20] were used for the Canadian analysis due to similar patterns of all-cause mortality rates and low life expectancy after lung cancer diagnosis in both countries. The probability of surviving with lung cancer for each 5-year interval was approximately double for NSCLC compared to SCLC and slightly higher for women than for men. For example, 5-year survival was 65% for women and 53% for men for a localized stage of NSCLC at diagnosis but only 3.6% for women and 2.2% for men for a distant stage of SCLC at diagnosis. The risk of lung cancer will be reduced in all current and future residents when passive radon stacks are installed in new homes because radon exposures will be decreased over the lifespan of the home. The number of lung cancer deaths and total treatment costs avoided were determined using the proportion of the population that will be residing in the new housing construction in which the passive radon stacks will be installed.

## Results I – Passive radon stacks installed in 1 year of new housing construction

### I - Quantitative Direct Costs

The most recent data available was used to determine the quantitative direct costs for this analysis: based on the late 2021 and January 2022 cost estimates for the installation of passive radon stacks [7] and the 2021 CMHC data on new housing completions [6].

The following three archetypes were agreed upon for calculating detailed cost estimates (Appendix 1):

1) Bungalow with basement
2) 2-storey with basement
3) 3-storey with basement

Several assumptions were agreed upon when comparing costs of these archetypes:

1) The average height of each storey, including the basement, would be 2.44 m (8 ft). The minimum ceiling height found in Table 9.5.3.1. of the NBC 2015 is 2.1 m. In 2018, Codes Canada performed an online survey for the TG on Stairs, Ramps, Handrails, and Guards to collect data from Canadian home builders. It showed that
    a. 89% of ceiling heights in basements were 2.44 m or more, and
    b. 79% of ceiling heights on the first floor were more than 2.44 m.

   As the actual ceiling heights are in excess of the Code minimum, it was agreed to compromise and use 2.44 m.

2) Each floor of the house would have a horizontal run of 600 mm (2 ft) with two 90° angles to allow for the shifting of walls where the vertical radon stack would be encapsulated.

3) 2.1 m would be used as the length of radon pipe in the unconditioned attic space, and for the extension above the roof line.

4) Costs for a vent cap, pipe flashing collar and R13 insulation were added to the passive radon stack in the unconditioned space.

5) To simulate a 3-storey stacked townhome (one dwelling unit above the other), a firestop was added to the passive radon stack system of the 3-storey archetype, but the costs of the passive stack were split between the 2 units.

*Construction Cost per Dwelling Unit*

The average costs per dwelling unit were calculated using RSMeans Online with data for January 2022 [7]. The expected range or uncertainty in the mean cost per dwelling unit, and the standard error of the mean cost, was derived from cost estimates supplied in late 2021 by two radon mitigators who are members of the Canadian Association of Radon Scientists and Technologists (CARST). A third cost estimate was supplied in early 2022 from a plumber in the Winnipeg area who had experience in radon mitigation; the average radon concentration in Winnipeg is much higher than the national average. Table 2 shows the Canadian national average costs per dwelling unit calculated for each archetype. Appendix 1 contains the individual items included in the US national average costing estimates, which were adjusted to provide the slightly lower Canadian national average estimates listed in Table 2.

*Table 2. Costs for installation of passive radon stack system per dwelling unit*

| Cost Estimator | Bungalow | 2 Storey | 3 Storey | 3-Storey Stacked Townhome |
|---|---|---|---|---|
| RSMeans (CDN national average) | $712 | $999 | $1,273 | $673 |
| Winnipeg plumbing and heating contractor | $954 | $1,182 | $1,321 | $712 |
| CARST mitigator #1 | $779 | $875 | $982 | $446 |
| CARST mitigator #2 | $883 | $997 | $1,020 | $555 |

*National Annual Construction of Archetypes*

National new housing construction completions for the four house types summarized in Table 3 were obtained from the CMHC quarterly data reports for 2021 [6].

*Table 3. National building construction completions for 2021*

| Province/Territory | Total | Single Detached | Semi-detached | Rowhouse | Duplex |
|---|---|---|---|---|---|
| Canada | 117,742 | 69,076 (59%) | 12,197 (10%) | 24,039 (20%) | 12430 (10%) |

To convert the CMHC building construction completions from 2021 to the archetypes that were used for the passive radon stack costing calculations, the survey data collected for the TG Stairs (based on an unpublished Codes Canada survey from 2018), regarding the number of floors by building type, was applied (Table 4). The percentages of each home type built by the responding home builders in the TG Stairs survey (56%, 14%, 22% and 8% for single-detached, semi-detached, rowhouse and duplex, respectively) were similar to those reported for new home construction in 2021.

*Table 4. Number of storeys per home type*

| House Type and Number of Storeys | Detached (%) | Semi-detached (%) | Rowhouse (%) | Duplex (%) |
|---|---|---|---|---|
| Bungalow (w/wo basement) | 21 | - | - | - |
| 2-storey | 68 | 86 | 86 | - |
| 3-storey (detached/attached) | 11 | 14 | 14 | - |
| 3-storey stacked | - | - | - | 100 |

The StatsCan definition of a duplex is equivalent to that of a stacked townhome as defined by the TG. The CMHC new construction completions by dwelling type were converted using Table 4 to determine the total number of dwelling units by archetype used by the TG, which are presented in Table 5.

*Table 5. National building construction completions by TG archetype for 2021*

| Province/Territory | Total | Bungalow | 2-Storey | 3-Storey | 3-Storey Stacked Townhome |
|---|---|---|---|---|---|
| Canada | 117,742 | 14,506 | 78,162 | 12,644 | 12,430 |

The total mean cost for the 117,742 units of new housing built in 2021 was estimated to be $109,850,789, having a standard error of ±8.8% and a 95% confidence interval of $90,517,050 – $129,184,528. The annual costs for passive radon stacks for Part 9 dwelling units in Canada in 2021 (Table 6) were derived by combining the values from Table 2 with those from Table 5.

*Table 6. Annual national passive radon stack costs by TG archetype for 2021*

| Cost Estimator | Bungalow | 2-Storey | 3-Storey | 3-Storey Stacked Townhome | Total |
|---|---|---|---|---|---|
| RSMeans (CDN national average) | $10,324,056 | $78,120,975 | $16,091,254 | $8,361,116 | **$112,897,401** |
| Winnipeg plumbing and heating contractor | $13,836,800 | $92,397,835 | $16,696,495 | $8,845,064 | **$131,776,194** |
| CARST mitigator #1 | $11,305,800 | $68,375,477 | $12,418,565 | $5,545,893 | **$97,645,735** |
| CARST mitigator #2 | $12,814,420 | $77,911,260 | $12,899,032 | $6,900,763 | **$110,525,475** |

## I - Quantitative Indirect Costs

The TG agreed that there are no quantifiable indirect costs to be considered. Energy loss is expected to be negligible during the operation of a passive radon stack. The net effect is expected to be zero annually because the soil temperature underground remains relatively stable throughout the year. Minimal energy loss is expected for a passive stack during the winter, because the typical airflow (95% UI: 3-12 cfm) is a fraction of the airflow in an active stack, and this would be balanced by a small reduction in the cooling required during the summer.

## I - Qualitative Indirect Costs

The TG agreed that there are no qualitative indirect costs to be considered.

I - Quantitative Direct Monetary Benefits

The direct monetary benefit was represented by the reduction in medical costs from reducing residential radon exposures, which was determined using the average cost of lung cancer treatment avoided for each case of lung cancer prevented by the installation of passive radon stacks in the new housing construction described above.

Lung cancer treatment costs reported in 2013 Canadian dollars were characterized using two categories, curative lung cancer surgery or advanced lung cancer treatment, which included any use or combination of chemotherapy, radiotherapy and/or supportive care [21]. Curative lung cancer surgery was assumed to be limited to localized stages of non-small cell lung cancer, while an advanced lung cancer treatment approach was assumed for regional and distant stages of non-small cell lung cancer and all stages of small cell lung cancer.

The most recent estimate of the average lung cancer treatment cost in Canada was reported for advanced lung cancer treatment in 2019 dollars [8]. This estimate was updated using data from cases between 2013 and 2016 that reflected changing patterns for small cell lung cancer treatment and was restricted to costs associated with lung cancer treatment, rather than the total healthcare costs after receiving a lung cancer diagnosis estimated for non-small cell lung cancer in 2013 dollars in Ontario between 2010 and 2015 [9]. The 2019 cost of curative lung cancer surgery was estimated to have increased by the same percentage as that of the cost of advanced lung cancer treatment from the values reported in 2013 dollars [9]. The mean and range (based on the standard error) for lung cancer treatment costs in 2021 dollars are presented in Table 7, indexed using a factor of 1.04 based on the most recent Consumer Price Index values from the 2019 treatments costs [22].

*Table 7. Lung cancer treatment costs per person for Canada in 2021*

| Treatment per Person | Average Cost ($) | Range ($) |
|---|---|---|
| **Curative lung cancer surgery** | 48,753 | 46,134 – 51,080 |
| **Advanced lung cancer treatment** | 69,878 | 63,243 – 76,323 |

The total lung cancer treatment costs prevented over the 75 year building lifespan of the 117,742 units of new housing built in 2021 ranged from $10,231,105 ($8,443,980 – $12,047,540) to $16,050,125 ($14,278,700 – $17,554,105) for the lower and upper radon estimates, respectively. The annual lung cancer treatment costs prevented for the residents of the 117,742 units of new housing built in 2021 over the 75 year building lifespan are presented in Table 8. The annual lung cancer treatment costs prevented (Figures 6 and 7) increased steadily over the time horizon from a mean of $12,914 and $19,437 after 5 – 9 years to a mean of $255,188 and $407,215 after 70 – 74 years for the lower and upper radon estimates, respectively, resulting from the increase in the annual number of lung cancer cases prevented over time. A greater reduction in cumulative radon exposure occurred over time following the installation of the passive stack in new housing because the cumulative radon exposure depends on both the radon concentration and the duration of exposure. A greater reduction in lung cancer treatment costs was estimated for the higher radon exposure scenario, because there is a greater radon reduction (in $Bq/m^3$) for each passive radon stack effectiveness modelled when the initial radon concentration is higher.

*Table 8. Annual lung cancer treatment costs prevented over 75 years following the installation of passive radon stacks in 1 year of new housing construction*

| Time Horizon (Years) | Annual Lung Cancer Treatment Costs Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean ($) | Range ($) | Mean ($) | Range ($) |
| 5 – 9 | 12,914 | 10,997 – 14,795 | 19,437 | 17,724 – 21,013 |
| 10 – 14 | 39,188 | 33,299 – 45,064 | 59,305 | 53,952 – 64,142 |
| 15 – 19 | 62,821 | 53,273 – 72,492 | 95,548 | 86,781 – 103,483 |
| 20 – 24 | 83,893 | 71,001 – 97,106 | 128,185 | 116,128 – 139,014 |
| 25 – 29 | 102,941 | 86,842 – 119,516 | 158,000 | 142,766 – 171,571 |
| 30 – 34 | 119,811 | 100,682 – 139,503 | 184,674 | 166,441 – 200,791 |
| 35 – 39 | 137,855 | 115,312 – 161,028 | 213,520 | 191,840 – 232,459 |
| 40 – 44 | 157,002 | 130,651 – 184,037 | 244,451 | 218,845 – 266,534 |
| 45 – 49 | 176,972 | 146,463 – 208,184 | 277,029 | 247,071 – 302,646 |
| 50 – 54 | 197,625 | 162,613 – 233,322 | 311,047 | 276,264 – 340,766 |
| 55 – 59 | 217,588 | 178,065 – 257,668 | 344,191 | 304,471 – 378,029 |
| 60 – 64 | 235,125 | 191,509 – 279,145 | 373,497 | 329,248 – 411,108 |
| 65 – 69 | 247,298 | 200,864 – 293,995 | 393,928 | 346,575 – 434,157 |
| 70 – 74 | 255,188 | 207,056 – 303,653 | 407,215 | 357,900 – 449,207 |

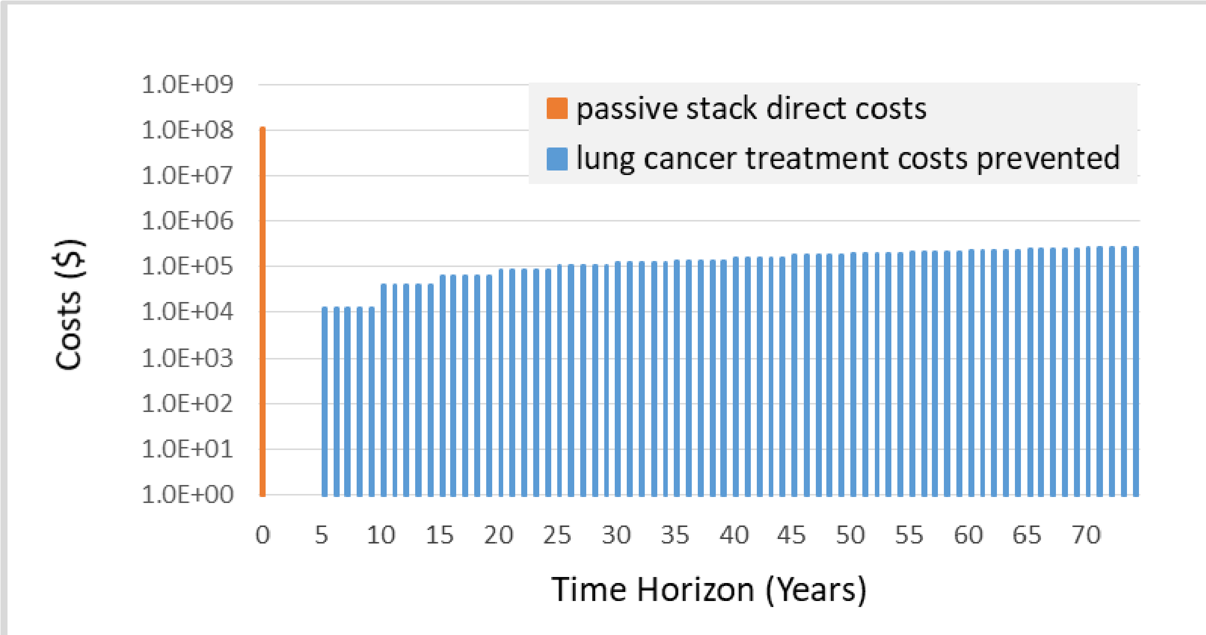



*Figure 6. Annual direct costs and lung cancer treatment costs prevented for passive radon stacks installed in 1 year of new housing construction using the lower radon estimate*

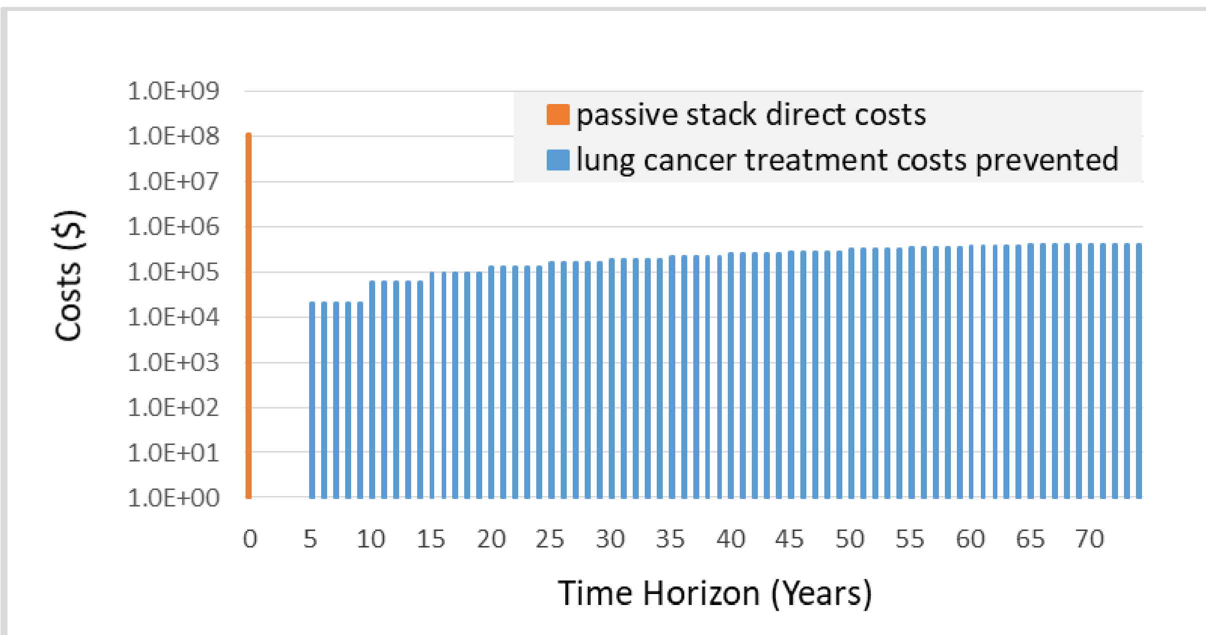



*Figure 7. Annual direct costs and lung cancer treatment costs prevented for passive radon stacks installed in 1 year of new housing construction using the upper radon estimate*

## I - Quantitative Number of Lung Cancer Deaths Prevented

The Canadian demographic data from 2018 used in the analysis—lung cancer incidence and all-cause mortality per 100,000 population, and the prevalence of daily smoking by sex and age-group—are presented in Table 9 [2–4]. Lung cancer is a disease that tends to develop later in life, with lung cancer incidence being low at ages below 60 but increasing steeply at ages above 70. Lung cancer incidence in Canada is slightly lower for women than for men. All-cause mortality per 100,000 population increases with age, while daily smoking prevalence peaks around ages 50 – 64 and is also slightly lower for women than for men.

*Table 9. Demographic data by age (mean [Mn], range) for the Canadian population (2018)*

| Age | Lung Cancer Incidence per 100,000 M | | Lung Cancer Incidence per 100,000 F | | All-Cause Mortality per 100,000 M | All-Cause Mortality per 100,000 F | Smoking Prevalence M (%) | | Smoking Prevalence F (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mn | Range | Mn | Range | | | Mn | Range | Mn | Range |
| 0 | 0 | 0-0 | 0 | 0-0 | 116 | 106 | 0 | 0-0 | 0 | 0-0 |
| 5 | 0 | 0-0 | 0 | 0-0 | 10 | 10 | 0 | 0-0 | 0 | 0-0 |
| 10 | 0 | 0-0 | 0 | 0-0 | 10 | 10 | 0 | 0-0 | 0 | 0-0 |
| 15 | 0 | 0-0 | 1 | 0-1 | 50 | 20 | 0 | 0-0 | 0 | 0-0 |
| 20 | 0 | 0-0 | 1 | 0-1 | 80 | 40 | 12.2 | 11-13.6 | 9.3 | 8.2-10.5 |
| 25 | 1 | 1-2 | 1 | 0-1 | 100 | 50 | 12.2 | 11-13.6 | 9.3 | 8.2-10.5 |
| 30 | 2 | 1-2 | 2 | 1-3 | 110 | 50 | 12.2 | 11-13.6 | 9.3 | 8.2-10.5 |
| 35 | 2 | 1-3 | 3 | 2-4 | 130 | 70 | 15.2 | 13.7-16.8 | 10.4 | 9.3-11.5 |
| 40 | 5 | 3-6 | 7 | 5-9 | 160 | 90 | 15.2 | 13.7-16.8 | 10.4 | 9.3-11.5 |
| 45 | 9 | 7-11 | 11 | 9-13 | 230 | 140 | 15.2 | 13.7-16.8 | 10.4 | 9.3-11.5 |
| 50 | 27 | 24-31 | 31 | 28-35 | 370 | 230 | 16.3 | 14.7-18 | 13.4 | 12.1-14.8 |
| 55 | 65 | 61-70 | 82 | 77-88 | 560 | 360 | 16.3 | 14.7-18 | 13.4 | 12.1-14.8 |
| 60 | 136 | 128-143 | 131 | 124-139 | 900 | 560 | 16.3 | 14.7-18 | 13.4 | 12.1-14.8 |
| 65 | 216 | 205-227 | 207 | 197-217 | 1,380 | 870 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 70 | 316 | 301-330 | 298 | 284-311 | 2,090 | 1,410 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 75 | 413 | 393-434 | 373 | 355-391 | 3,510 | 2,380 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 80 | 459 | 433-486 | 364 | 343-385 | 6,040 | 4,310 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 85 | 452 | 419-487 | 280 | 259-303 | 10,930 | 8,050 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 90 | 377 | 334-424 | 209 | 188-233 | 21,530 | 18,350 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |
| 95 | 377 | 334-424 | 209 | 188-233 | 21,530 | 18,350 | 8.5 | 7.4-9.7 | 6.6 | 5.7-7.5 |

A total of 300,532 people were estimated to be living in the 117,742 units of new housing construction in 2021, determined from the 2021 population [5] using the proportion of the occupied housing stock (14,978,941) represented by 1 year of new housing construction. The number of people by sex and age group are listed in Table 10.

*Table 10. Residents by sex and age group living in 1 year of new housing construction*

| Age | Male (Number) | Female (Number) |
|---|---|---|
| 0 | 7,588 | 7,210 |
| 5 | 8,223 | 7,846 |
| 10 | 8,379 | 8,060 |
| 15 | 8,249 | 7,924 |
| 20 | 10,057 | 9,222 |
| 25 | 10,749 | 10,003 |
| 30 | 10,778 | 10,428 |
| 35 | 10,534 | 10,427 |
| 40 | 9,783 | 9,944 |
| 45 | 9,284 | 9,460 |
| 50 | 9,485 | 9,619 |
| 55 | 10,553 | 10,671 |
| 60 | 10,087 | 10,405 |
| 65 | 8,510 | 9,051 |
| 70 | 6,963 | 7,607 |
| 75 | 4,714 | 5,352 |
| 80 | 2,936 | 3,685 |
| 85 | 1,675 | 2,453 |
| 90 | 690 | 1,327 |
| 95 | 154 | 450 |
| Total | 149,391 | 151,141 |

To estimate the number of lung cancer deaths that would be prevented by the installation of passive radon stacks in new housing, lung cancer morbidity was modelled using lung cancer incidence and survival, based on localized, regional and distant stages at diagnosis for both non-small cell and small cell lung cancer. The installation of a passive radon stack in any given year will affect residents of all ages and, therefore, the reduction in lung cancer risk was modelled over time starting at each of the twenty age groups used to describe the population. The reduction in lung cancer risk for each person increased over time following the installation of the passive radon stack in new housing because it is related to the cumulative radon exposure, which is affected by both the reduction in radon concentration and the duration of the reduced exposure. The number of attributable lung cancer deaths prevented was determined by applying the risk of radon-attributable lung cancer to the population for each age group, starting 5 years after the installation of the passive radon stack, and at each 5-year interval afterwards. The risk of lung cancer following the installation of passive radon stacks was compared to the baseline case of no passive stacks.

A total of 141 (117 – 167) and 222 (197 – 242) lung cancer deaths were estimated to be prevented for the lower and upper radon estimates, respectively, in the residents of the 117,742 units of new housing built in 2021 over 75 years following the installation of the passive radon stacks (Table 11). No reduction in lung cancer deaths were experienced in the first 5 years after installation of the passive radon stacks because of the delay in the effect of radon reduction on attributed lung cancer cases. There was an increase in the number of annual lung cancer deaths prevented over time, which resulted in the steeply increasing cumulative number of lung cancer deaths represented in Figures 8 and 9. Again, a greater number of lung cancer deaths were prevented for the upper radon estimate, because there is a greater radon reduction (in $Bq/m^3$) for each passive radon stack effectiveness modelled when the initial radon concentration is higher.

*Table 11. Cumulative lung cancer deaths prevented from passive radon stacks installed in 1 year of new housing construction*

| Time Horizon (Years) | Cumulative Number of Lung Cancer Deaths Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean | Range | Mean | Range |
| 5 – 9 | 1 | 1 – 1 | 1 | 1 – 1 |
| 10 – 14 | 3 | 3 – 4 | 5 | 4 – 5 |
| 15 – 19 | 7 | 6 – 8 | 11 | 10 – 12 |
| 20 – 24 | 13 | 11 – 15 | 20 | 18 – 21 |
| 25 – 29 | 20 | 17 – 23 | 31 | 28 – 33 |
| 30 – 34 | 28 | 24 – 33 | 43 | 39 – 47 |
| 35 – 39 | 38 | 32 – 44 | 58 | 52 – 63 |
| 40 – 44 | 49 | 41 – 57 | 75 | 67 – 81 |
| 45 – 49 | 61 | 51 – 71 | 94 | 84 – 102 |
| 50 – 54 | 75 | 62 – 88 | 116 | 103 – 126 |
| 55 – 59 | 90 | 75 – 105 | 139 | 125 – 152 |
| 60 – 64 | 106 | 88 – 125 | 165 | 147 – 180 |
| 65 – 69 | 123 | 102 – 146 | 193 | 172 – 210 |
| 70 – 74 | 141 | 117 – 167 | 222 | 197 – 242 |

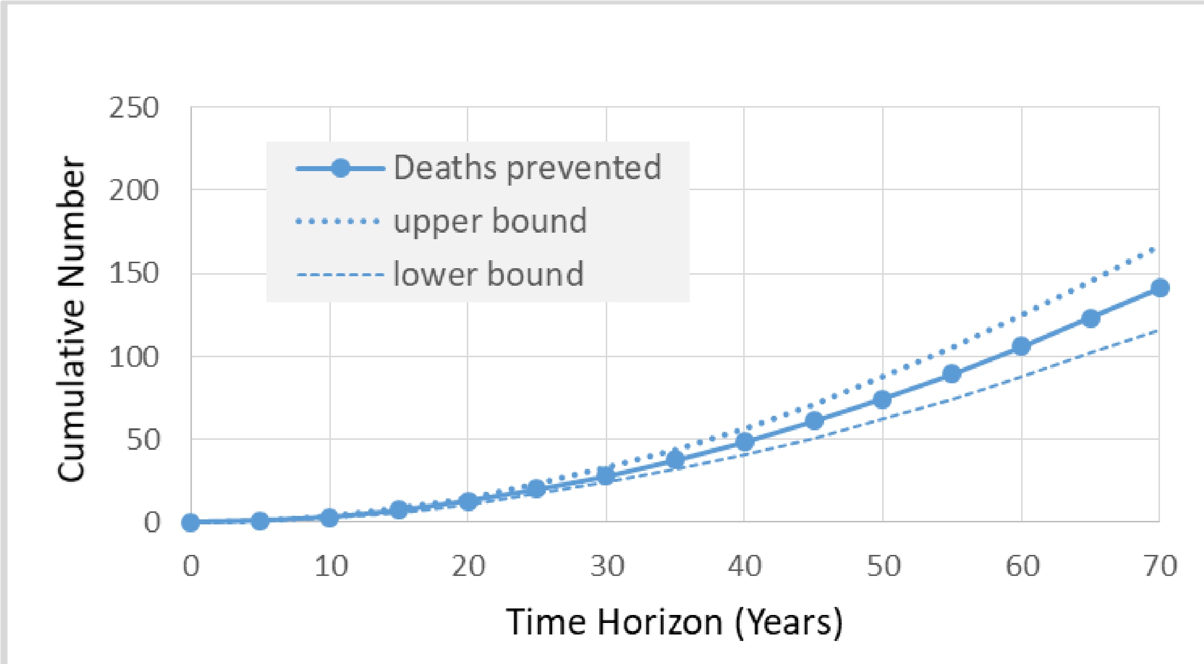



*Figure 8. Cumulative lung cancer deaths prevented from passive radon stacks installed in 1 year of new housing construction using the lower radon estimate*

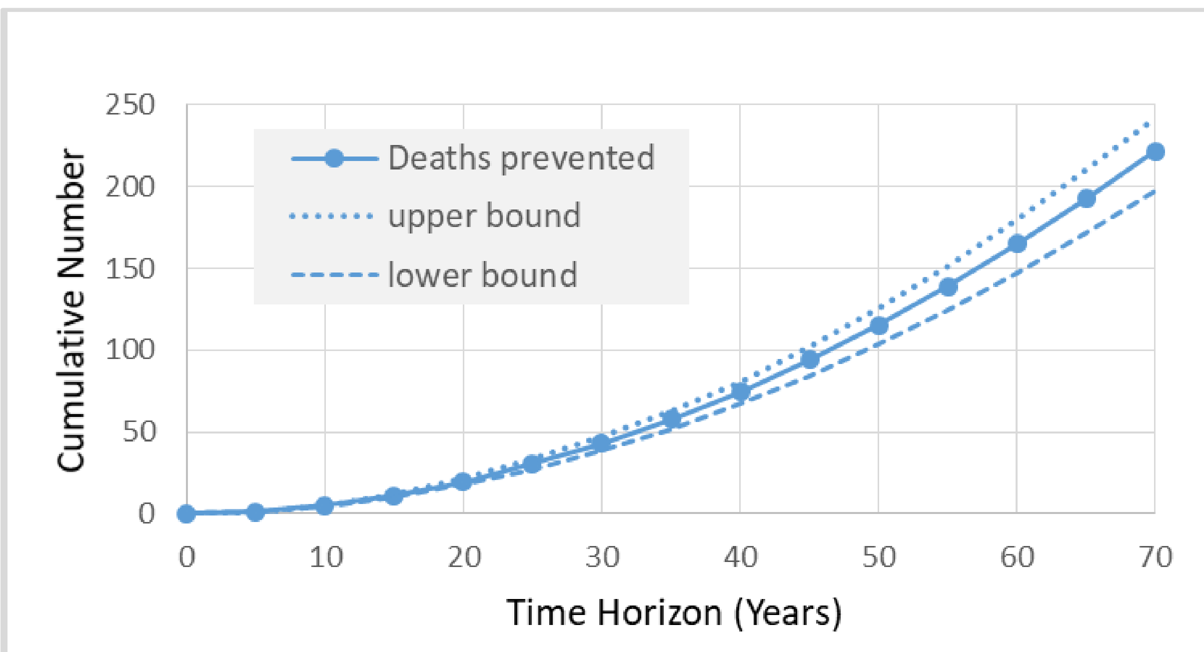



*Figure 9. Cumulative lung cancer deaths prevented for passive radon stacks installed in 1 year of new housing construction using the upper radon estimate*

The cumulative cost per lung cancer death prevented provides a useful comparison of the costs and the benefits of installing passive radon stacks in new housing construction. Table 12, Figure 10 and Figure 11 present the estimates for the example case of installing passive radon stacks in 1 year of new housing construction, for both the lower and upper radon estimates. The cumulative cost per lung cancer death prevented decreased rapidly and then stabilized. The cost dropped below the reference value recommended by the Treasury Board of Canada Secretariat (TBS) within 20 – 25 years after implementation. The TBS' cost-benefit analysis guide describes the value of statistical life (VSL) as the aggregation of the estimated willingness to pay for a small reduction in mortality risk across many individuals in an exposed population [23]. The VSL does not represent the value of an individual human life, but the marginal value of mortality risk reductions in a population. The TBS recommends interventions when the cost is lower than 8.3 million dollars (in 2021 dollars) per death prevented, labelled as the "TBS reference value for 2021" in Figures 10 and 11.

*Table 12. Cumulative cost per lung cancer death prevented for passive radon stacks installed in 1 year of new housing construction (in 2021 dollars)*

| Time Horizon (Years) | Cumulative Cost per Lung Cancer Death Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean ($) | Range ($) | Mean ($) | Range ($) |
| 10 – 14 | 36,580,679 | 31,930,329 – 43,058,992 | 21,921,768 | 21,504,483 – 24,807,360 |
| 15 – 19 | 14,590,391 | 13,116,446 – 17,891,484 | 9,921,009 | 8,922,493 – 11,121,682 |
| 20 – 24 | 8,385,267 | 7,408,986 – 9,722,797 | 5,563,599 | 4,951,783 – 6,147,774 |
| 25 – 29 | 5,424,688 | 4,813,044 – 6,262,528 | 3,531,153 | 3,201,564 – 3,996,035 |
| 30 – 34 | 3,853,382 | 3,334,060 – 4,410,892 | 2,483,182 | 2,227,880 – 2,791,390 |
| 35 – 39 | 2,858,812 | 2,482,484 – 3,285,985 | 1,822,573 | 1,658,928 – 2,070,671 |
| 40 – 44 | 2,194,236 | 1,917,209 – 2,546,297 | 1,402,509 | 1,265,555 – 1,574,971 |
| 45 – 49 | 1,730,091 | 1,511,238 – 2,030,420 | 1,096,828 | 991,841 – 1,239,776 |
| 50 – 54 | 1,403,321 | 1,215,020 – 1,654,978 | 879,191 | 793,293 – 995,337 |
| 55 – 59 | 1,155,972 | 997,612 – 1,361,568 | 718,170 | 644,585 – 814,680 |
| 60 – 64 | 964,942 | 833,445 – 1,137,871 | 593,686 | 530,433 – 676,484 |
| 65 – 69 | 821,523 | 708,662 – 968,652 | 498,642 | 443,794 – 571,714 |
| 70 – 74 | 707,599 | 610,267 – 836,228 | 424,164 | 377,231 – 488,634 |

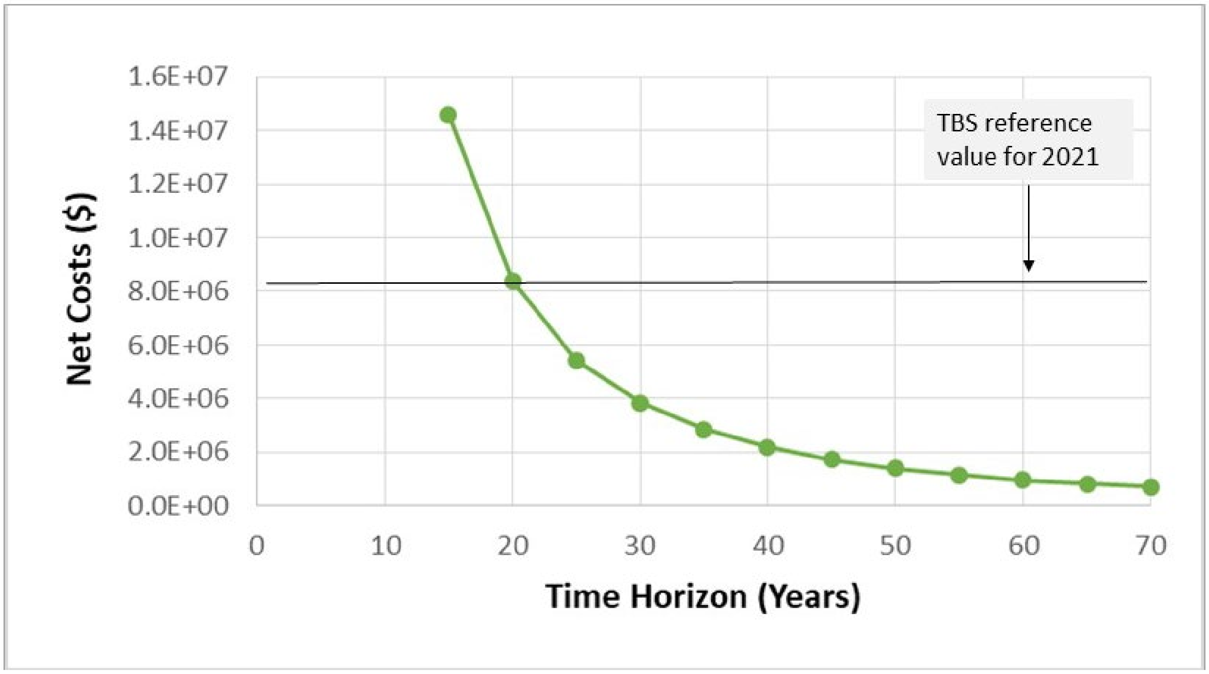



*Figure 10. Cumulative cost per lung cancer death prevented for passive radon stacks installed in 1 year of new housing construction using the lower radon estimate (in 2021 dollars)*

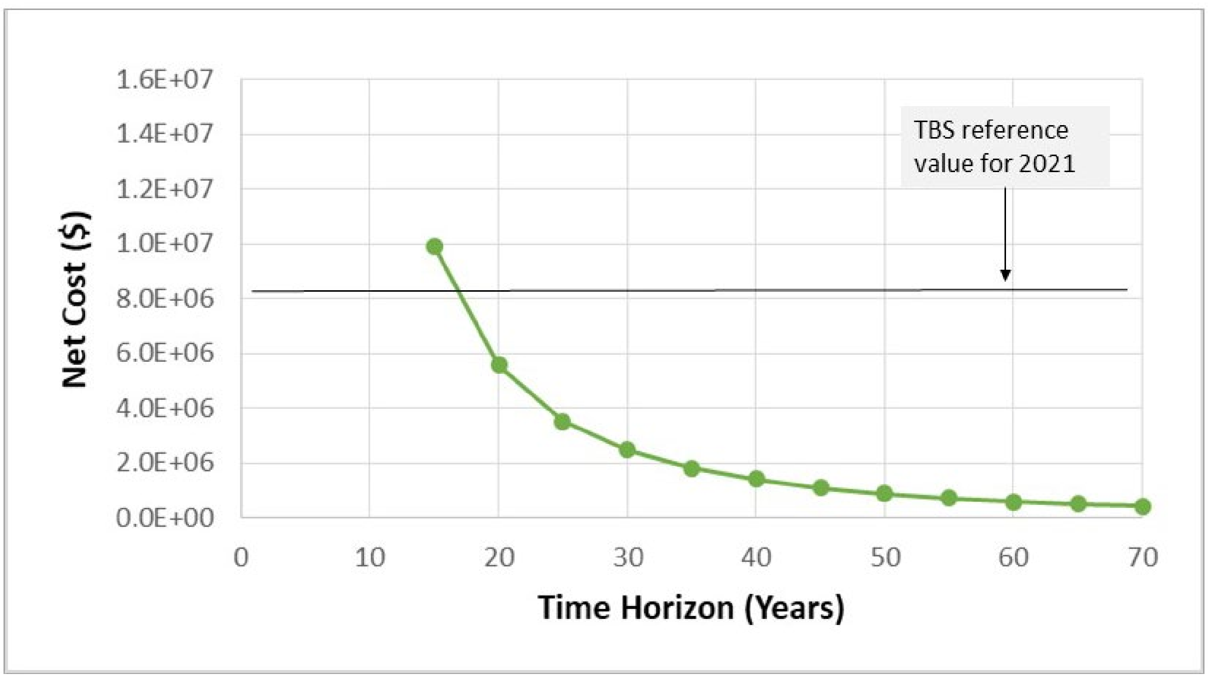



*Figure 11. Cumulative cost per lung cancer death prevented for passive radon stacks installed in 1 year of new housing construction using the upper radon estimate (in 2021 dollars)*

## Results II – Passive radon stacks installed over 100 years of new housing construction

The full analysis of the aggregated annual costs and benefits of passive radon stacks installed over 100 years of new housing construction is presented in this section. For example, the installation of passive radon stacks in new housing built in 2021 was represented in year 0 and the benefits from year 5 to year 74 in the time horizon, and the installation of passive radon stacks in new housing built in 2026 was represented in year 5 with the benefits from year 10 to year 79. A 100-year time horizon was selected because it was appropriate for the human lifespan and the benefits would be experienced by all current and future residents of housing with passive radon stacks installed (housing lifespan of 75 years). Population growth has been quite stable recently and was modelled using the 5-year average value of 5.7% determined from 2006 – 2021, with housing growth assumed to equal the population growth for this analysis. This analysis was based on the 2021 – 2022 cost estimates for both the direct costs for passive radon stack installation and the costs for lung cancer treatment described in the 1 year analysis, because it was not possible to predict future costs.

### II - Quantitative Direct Costs

The annual direct costs for installing passive radon stacks in new housing over 100 years are presented in Table 13, Figure 12 and Figure 13. The annual direct cost was determined in the 1-year analysis to be $112,897,401 ($93,633,327 – $131,261,476) in 2021 (year 0 in the time horizon). The increase in passive radon stack costs was determined every 5 years from the 2021 estimate by assuming an increase in the number of new constructing housing equal to the population growth, and reached an annual direct cost of $323,674,662 ($268,444,934 – $376,324,112) by year 95 in the time horizon.

*Table 13. Annual direct costs for passive radon stacks installed in new housing over 100 years*

| Time Horizon (Year) | Annual Costs for Passive Radon Stacks in New Housing | |
|---|---|---|
| | Mean ($) | Range ($) |
| 0 | 112,897,401 | 93,633,327 – 131,261,476 |
| 5 | 119,332,553 | 98,970,427 – 138,743,380 |
| 10 | 126,134,509 | 104,611,741 – 146,651,753 |
| 15 | 133,324,176 | 110,574,610 – 155,010,903 |
| 20 | 140,923,654 | 116,877,363 – 163,846,524 |
| 25 | 148,956,302 | 123,539,373 – 173,185,776 |
| 30 | 157,446,811 | 130,581,117 – 183,057,365 |
| 35 | 166,421,279 | 138,024,241 – 193,491,635 |
| 40 | 175,907,292 | 145,891,623 – 204,520,658 |
| 45 | 185,934,008 | 154,207,446 – 216,178,336 |
| 50 | 196,532,246 | 162,997,270 – 228,500,501 |
| 55 | 207,734,584 | 172,288,114 – 241,525,030 |
| 60 | 219,575,456 | 182,108,536 – 255,291,957 |
| 65 | 232,091,256 | 192,488,723 – 269,843,599 |
| 70 | 245,320,458 | 203,460,580 – 285,224,684 |
| 75 | 259,303,724 | 215,057,833 – 301,482,491 |
| 80 | 274,084,037 | 227,316,129 – 318,666,993 |
| 85 | 289,706,827 | 240,273,148 – 336,831,012 |
| 90 | 306,220,116 | 253,968,717 – 356,030,380 |
| 95 | 323,674,662 | 268,444,934 – 376,324,112 |

### II - Quantitative Direct Monetary Benefits

The annual lung cancer treatment costs prevented for the lower and upper radon estimates are presented in Table 14. The annual lung cancer treatment costs prevented increased over the time horizon for both lower and upper radon estimates, ranging from about 7 to 10 million annually 50 years after the implementation of passive radon stack installation in new housing, to about 18 to 28 million dollars annually after 100 years. Although the annual lung cancer treatment costs prevented were always lower than the direct annual cost of installing passive radon stacks in new housing, as shown in Figures 12 and 13, the cumulative lung cancer treatment costs prevented over 100 years was substantial at $749,854,270 ($623,124,755 – $879,143,440) and $1,168,392,250 ($1,044,471,820 – $1,274,042,655), for the lower and upper radon estimates, respectively.

*Table 14. Annual lung cancer treatment costs prevented for passive radon stacks installed in new housing over 100 years*

| Time Horizon (Years) | Annual Lung Cancer Treatment Costs Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean ($) | Range ($) | Mean ($) | Range ($) |
| 5 – 9 | 66,412 | 56,550 – 76,084 | 99,954 | 91,145 – 108,061 |
| 10 – 14 | 271,722 | 231,012 – 312,160 | 410,625 | 373,786 – 444,071 |
| 15 – 19 | 610,267 | 518,134 – 702,743 | 925,387 | 841,442 – 1,001,541 |
| 20 – 24 | 1,076,469 | 912,788 – 1,242,169 | 1,637,324 | 1,487,239 – 1,773,509 |
| 25 – 29 | 1,667,204 | 1,411,980 – 1,927,584 | 2,543,164 | 2,306,188 – 2,756,900 |
| 30 – 34 | 2,378,363 | 2,012,043 – 2,754,851 | 3,637,809 | 3,293,562 – 3,946,610 |
| 35 – 39 | 3,222,849 | 2,719,891 – 3,739,964 | 4,943,188 | 4,467,831 – 5,366,987 |
| 40 – 44 | 4,213,932 | 3,546,796 – 4,899,553 | 6,482,038 | 5,847,906 – 7,043,557 |
| 45 – 49 | 5,364,203 | 4,502,149 – 6,249,415 | 8,276,136 | 7,451,796 – 9,000,692 |
| 50 – 54 | 6,686,250 | 5,595,007 – 7,805,488 | 10,347,432 | 9,297,236 – 11,262,994 |
| 55 – 59 | 8,186,311 | 6,829,620 – 9,575,455 | 12,707,239 | 11,392,920 – 13,843,030 |
| 60 – 64 | 9,862,063 | 8,203,743 – 11,556,758 | 15,352,256 | 13,735,471 – 16,737,197 |
| 65 – 69 | 11,695,929 | 9,704,138 – 13,727,360 | 18,253,107 | 16,300,110 – 19,912,591 |
| 70 – 74 | 13,674,898 | 11,320,983 – 16,071,353 | 21,387,637 | 19,068,260 – 23,355,501 |
| 75 – 79 | 14,454,368 | 11,966,279 – 16,987,420 | 22,606,732 | 20,155,151 – 24,686,765 |
| 80 – 84 | 15,278,266 | 12,648,356 – 17,955,702 | 23,895,316 | 21,303,995 – 26,093,910 |
| 85 – 89 | 16,149,127 | 13,369,312 – 18,979,177 | 25,257,348 | 22,518,322 – 27,581,262 |
| 90 – 94 | 17,069,627 | 14,131,362 – 20,060,989 | 26,697,016 | 23,801,865 – 29,153,393 |
| 95 – 99 | 18,042,594 | 14,936,849 – 21,204,463 | 28,218,743 | 25,158,569 – 30,815,133 |

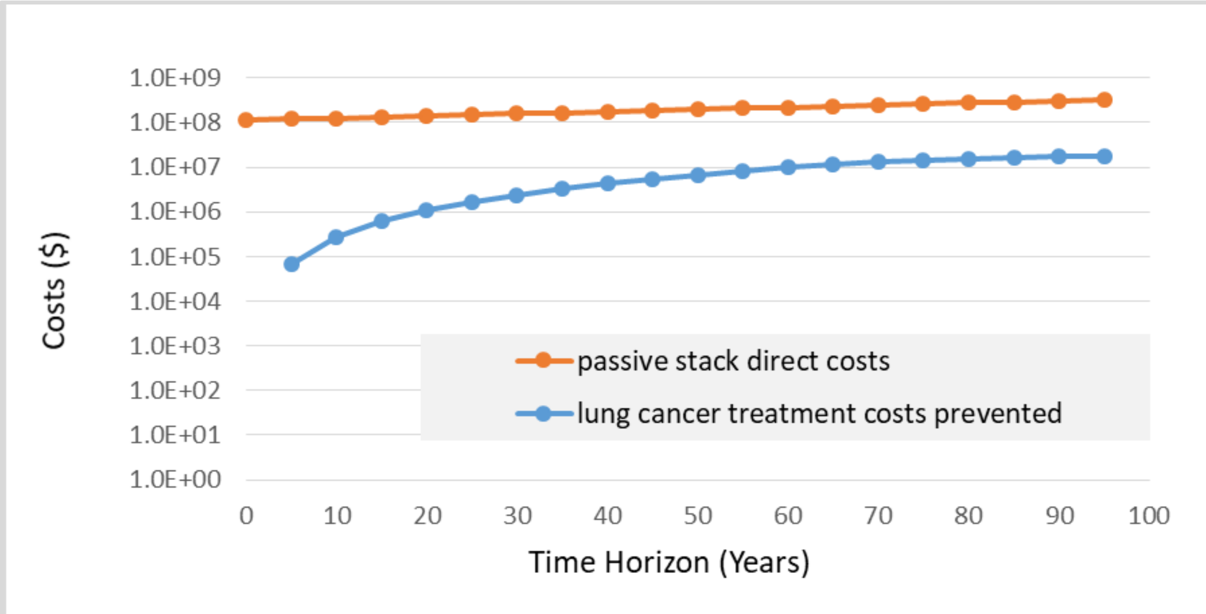



*Figure 12. Annual direct costs and lung cancer treatment costs prevented for passive radon stacks installed in new housing over 100 years using the lower radon estimate*

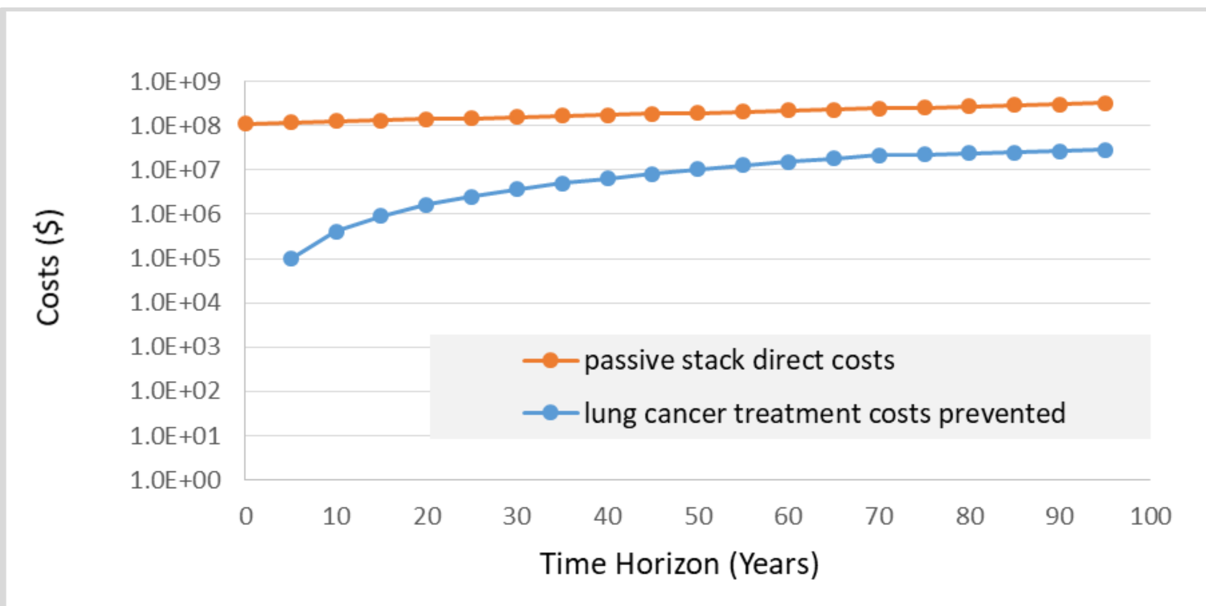



*Figure 13. Annual direct costs and lung cancer treatment costs prevented for passive radon stacks installed in new housing over 100 years using the upper radon estimate*

## II - Quantitative Number of Lung Cancer Deaths Prevented

It was estimated that 10,356 (8,601 – 12,208) to 16,132 (14,402 – 17,586) lung cancer deaths for the lower and upper radon estimates, respectively, would be prevented by installing passive radon stacks in new housing construction over 100 years. The cumulative number of lung cancer deaths prevented increased steeply over time, as shown in Table 15. Again, a greater number of lung cancer deaths were prevented for the upper radon estimate as shown in Figure 15 than for the lower radon estimate as shown in Figure 14.

*Table 15. Cumulative lung cancer deaths prevented for passive radon stacks installed in new housing over 100 years*

| Time Horizon (Years) | Cumulative Number of Lung Cancer Deaths Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean | Range | Mean | Range |
| 5 – 9 | 4 | 4 – 5 | 6 | 6 – 7 |
| 10 – 14 | 21 | 18 – 24 | 31 | 29 – 34 |
| 15 – 19 | 60 | 51 – 69 | 90 | 82 – 98 |
| 20 – 24 | 130 | 110 – 150 | 197 | 179 – 213 |
| 25 – 29 | 240 | 203 – 278 | 365 | 331 – 395 |
| 30 – 34 | 399 | 337 – 463 | 607 | 550 – 658 |
| 35 – 39 | 615 | 520 – 715 | 939 | 850 – 1,018 |
| 40 – 44 | 900 | 760 – 1,048 | 1,377 | 1,244 – 1,493 |
| 45 – 49 | 1,264 | 1,065 – 1,474 | 1,938 | 1,749 – 2,102 |
| 50 – 54 | 1,719 | 1,446 – 2,008 | 2,641 | 2,380 – 2,868 |
| 55 – 59 | 2,277 | 1,912 – 2,664 | 3,508 | 3,156 – 3,811 |
| 60 – 64 | 2,952 | 2,473 – 3,459 | 4,557 | 4,094 – 4,954 |
| 65 – 69 | 3,754 | 3,138 – 4,406 | 5,808 | 5,210 – 6,318 |
| 70 – 74 | 4,694 | 3,916 – 5,516 | 7,277 | 6,518 – 7,921 |
| 75 – 79 | 5,702 | 4,750 – 6,708 | 8,853 | 7,922 – 9,642 |
| 80 – 84 | 6,770 | 5,634 – 7,971 | 10,525 | 9,410 – 11,466 |
| 85 – 89 | 7,900 | 6,569 – 9,306 | 12,291 | 10,982 – 13,394 |
| 90 – 94 | 9,094 | 7,557 – 10,717 | 14,158 | 12,645 – 15,432 |
| 95 – 99 | 10,356 | 8,601 – 12,208 | 16,132 | 14,402 – 17,586 |

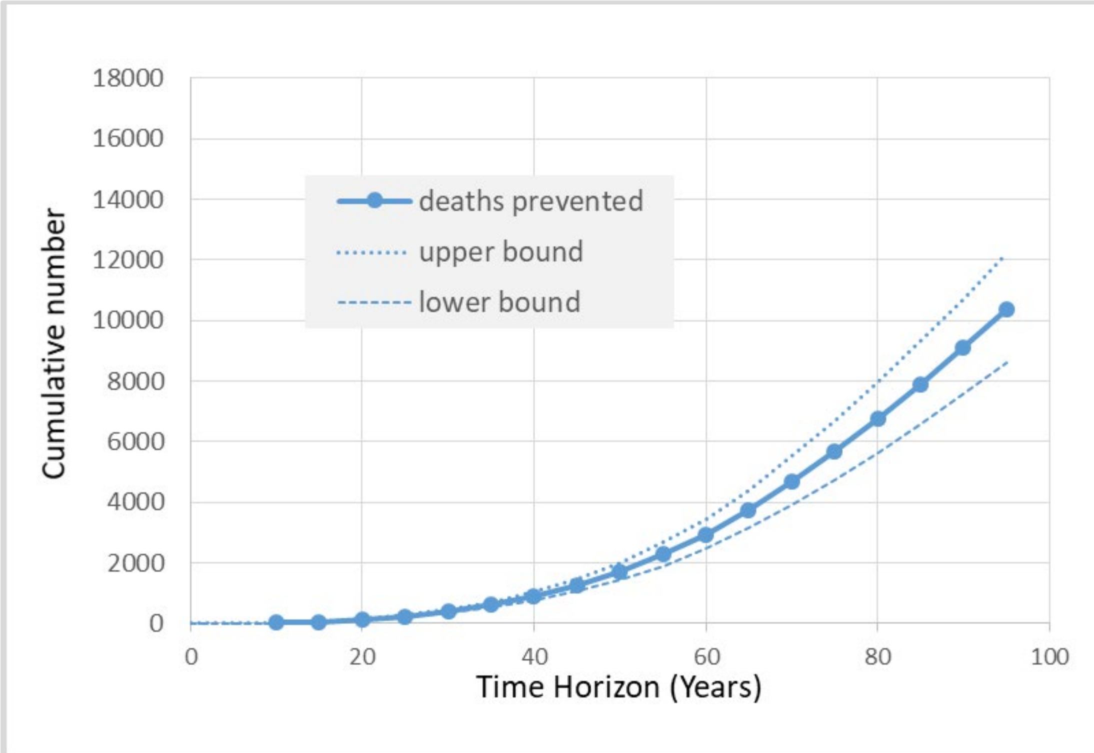



*Figure 14. Cumulative lung cancer deaths prevented for passive radon stacks installed in new housing over 100 years using the lower radon estimate*

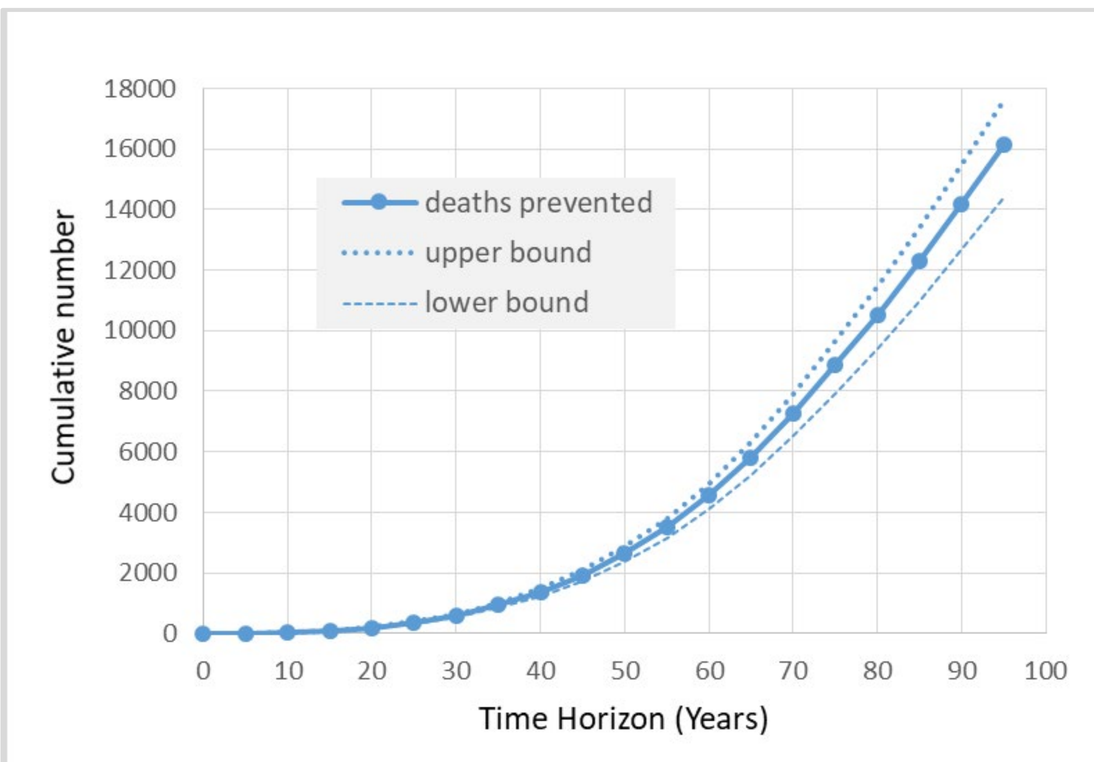



*Figure 15. Cumulative lung cancer deaths prevented for passive radon stacks installed in new housing over 100 years using the upper radon estimate*

The cumulative cost per lung cancer death prevented for passive radon stacks installed in new housing over 100 years is presented in Table 16, Figure 16 and Figure 17, providing a useful comparison between the costs and benefits of installed passive radon stacks in new housing. Again, the cumulative cost per lung cancer death prevented decreased rapidly and then stabilized. Figures 16 and 17 show that the cost dropped below the TBS reference value for preventing a death 30 – 40 years after implementation for the upper and lower radon estimates, respectively. The TBS' cost-benefit analysis guide describes the value of statistical life (VSL) as the aggregation of the estimated willingness to pay for a small reduction in mortality risk across many individuals in an exposed population [23]. The VSL does not represent the value of an individual human life, but the marginal value of mortality risk reductions in a population. The TBS recommends interventions when the cost is below 8.3 million dollars (in 2021 dollars) per death prevented, labelled as the "TBS reference value for 2021" in Figures 16 and 17.

*Table 16. Cumulative cost per lung cancer death prevented for passive radon stacks installed in new housing over 100 years (in 2021 dollars)*

| Time Horizon (Years) | Cumulative Cost per Lung Cancer Death Prevented | | | |
|---|---|---|---|---|
| | Lower Radon Estimate | | Upper Radon Estimate | |
| | Mean | Range | Mean | Range |
| 10 – 14 | 87,509,475 | 73,317,979 – 104,367,854 | 57,841,356 | 51,730,067 – 64,057,543 |
| 15 – 19 | 41,326,592 | 35,211,273 – 49,581,794 | 27,294,382 | 24,714,689 – 30,507,731 |
| 20 – 24 | 24,398,976 | 20,662,993 – 29,255,568 | 16,053,055 | 14,562,455 – 18,001,657 |
| 25 – 29 | 16,274,312 | 13,753,969 – 19,560,688 | 10,666,874 | 9,669,342 – 11,987,905 |
| 30 – 34 | 11,730,778 | 9,915,934 – 14,136,004 | 7,675,117 | 6,952,311 – 8,635,059 |
| 35 – 39 | 8,930,858 | 7,536,714 – 10,767,431 | 5,823,170 | 5,273,393 – 6,564,694 |
| 40 – 44 | 7,062,608 | 5,950,668 – 8,524,355 | 4,589,142 | 4,153,132 – 5,181,590 |
| 45 – 49 | 5,744,078 | 4,833,226 – 6,952,361 | 3,719,857 | 3,363,705 – 4,206,065 |
| 50 – 54 | 4,776,819 | 4,012,981 – 5,793,673 | 3,082,256 | 2,784,241 – 3,488,768 |
| 55 – 59 | 4,044,319 | 3,391,960 – 4,913,156 | 2,599,454 | 2,346,638 – 2,945,620 |
| 60 – 64 | 3,476,137 | 2,910,054 – 4,230,197 | 2,225,375 | 2,008,020 – 2,524,497 |
| 65 – 69 | 3,027,645 | 2,530,410 – 3,690,926 | 1,930,561 | 1,741,080 – 2,192,535 |
| 70 – 74 | 2,668,606 | 2,227,554 – 3,258,246 | 1,695,062 | 1,527,824 – 1,926,799 |
| 75 – 79 | 2,412,016 | 2,011,467 – 2,948,132 | 1,527,303 | 1,376,069 – 1,737,113 |
| 80 – 84 | 2,222,903 | 1,852,380 – 2,718,776 | 1,403,874 | 1,264,600 – 1,597,397 |
| 85 – 89 | 2,078,471 | 1,731,374 – 2,543,654 | 1,309,934 | 1,179,781 – 1,490,918 |
| 90 – 94 | 1,964,915 | 1,636,169 – 2,405,564 | 1,236,140 | 1,113,073 – 1,407,122 |
| 95 – 99 | 1,873,362 | 1,559,454 – 2,294,178 | 1,176,704 | 1,059,221 – 1,339,605 |

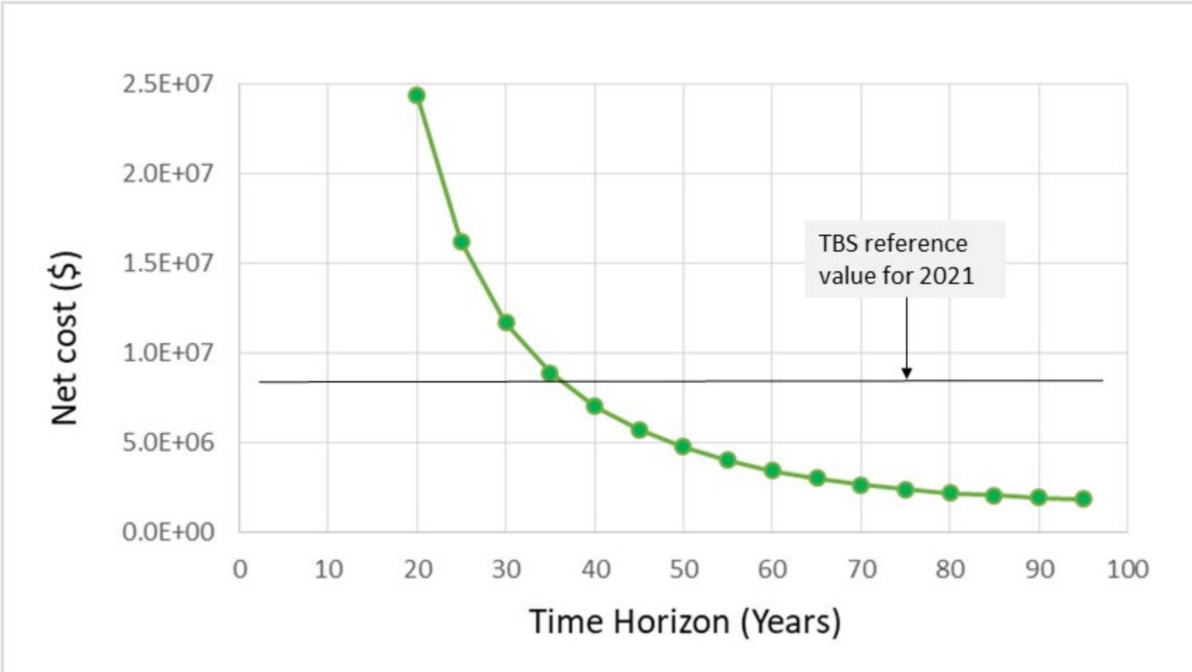



*Figure 16. Cumulative cost per lung cancer death prevented for passive radon stacks installed in new housing over 100 years using the lower radon estimate (in 2021 dollars)*

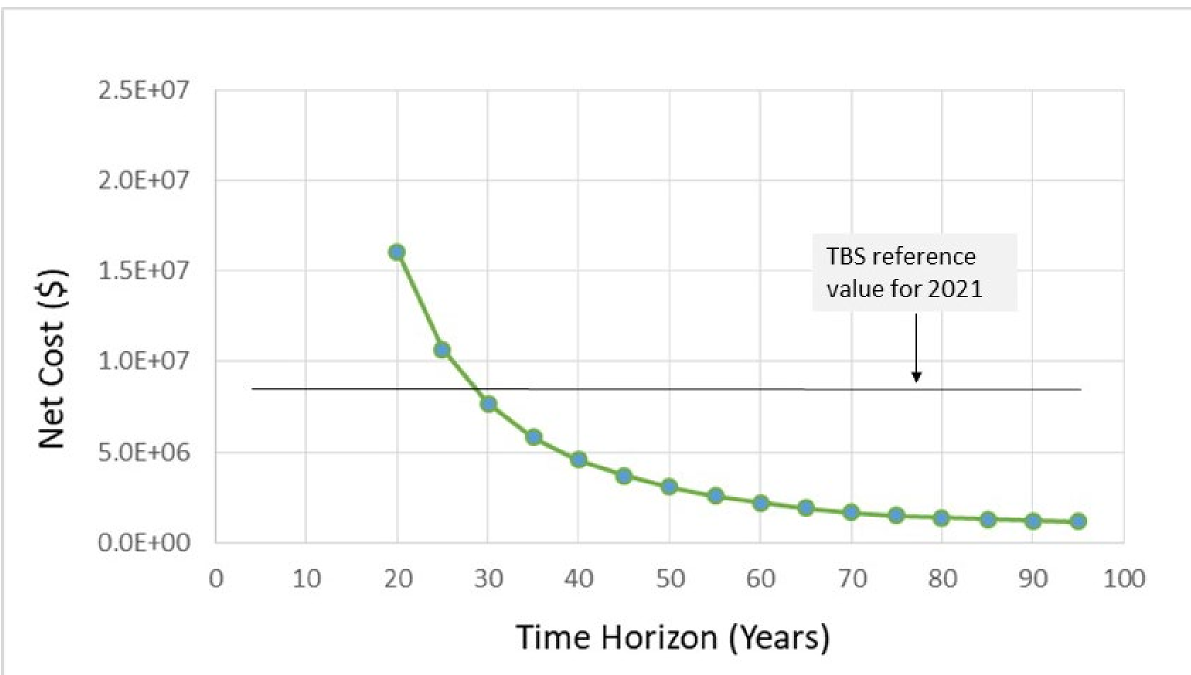



*Figure 17. Cumulative cost per lung cancer death prevented for passive radon stacks installed in new housing over 100 years using the upper radon estimate (in 2021 dollars)*

## Conclusions

The annual cost in 2021 of installing passive radon stacks in the 117,742 units of Part 9 residential occupancies in contact with the ground built in that 1-year period was estimated to be $112,897,401 ($93,633,327 - $131,261,476). The annual lung cancer cases prevented – and therefore the annual lung cancer treatment costs prevented – increased over the 75 year service life of the passive radon stacks because there was a greater reduction in the relative annual risk of lung cancer for residents who lived for a longer period with reduced radon exposure. The total lung cancer treatment costs prevented over the 75-year lifespan of the 117,742 units of new housing built in 2021 ranged from 10 to 16 million dollars: $10,231,105 ($8,443,980 – $12,047,540) to $16,050,125 ($14,278,700 – $17,554,105) for the lower and upper radon estimates, respectively. The cumulative number of lung cancer deaths prevented was estimated to be 141 (117 – 167) and 222 (197 – 242) for the lower and upper radon estimates, respectively, in the residents of the 117,742 units over 75 years following the installation of passive radon stacks.

The impact analysis for PCF 1713 on installing passive radon stacks in Part 9 residential occupancies demonstrates that the main benefit would be preventing 10,000 to 16,000 radon-associated lung cancer deaths in Canada over 100 years should the proposed change be adopted. The cumulative number of lung cancer deaths prevented over 100 years was estimated to be 10,356 (8,601 – 12,208) for the lower residential radon exposure and 16,132 (14,402 – 17,586) for the upper residential radon exposure. Although the costs incurred for installing passive radon stacks in new housing construction always exceeded the savings from lung cancer treatment for cases prevented, the cumulative cost per lung cancer death prevented decreased steeply after implementation and dropped below the Treasury Board of Canada Secretariat reference value after 30 – 40 years.

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## Appendix

*Table A-1. Summary of CDN and US national average costs using RSMeans*

| | Bungalow | 2-Storey | 3-Storey | 3-Storey Stacked Townhome |
|---|---|---|---|---|
| **RSMeans (US National Average)** | 756 | 1,058 | 1,347 | 712 |
| **RSMeans (CDN National Average)** | 712 | 999 | 1,273 | 673 |

Note: RSMeans CDN national average = 0.944503 × US national average.

*Table A-2. Bungalow passive stack depressurization (PSD) unit costs[1]*

| Quantity | Line Number | Description | Crew[2] | Daily Output | Labor Hours | Unit[3] | Material ($) | Labor ($) | Total ($) | Ext. Mat. ($) | Ext. Labor ($) | Ext. Total ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **RSMeans data outputs** | | | | | | | | | | |
| 25 | 221113746600 | Pipe, plastic, residential installation, PVC, 4" diameter, schedule 40, includes couplings 10' OC, and hangers 3 per 10' | Q1 | 123 | 0.13 | L.F. | 8.95 | 4.90 | 13.85 | 223.75 | 122.50 | 346.25 |
| 2 | 221113762840 | Elbow, 90 Deg., plastic, PVC, white, socket joint, 4", schedule 40 | Q1 | 18.2 | 0.879 | Ea. | 26.50 | 33.00 | 59.50 | 53.00 | 66.00 | 119.00 |
| 1 | 221316803060 | Vent flashing, neoprene, one piece, 4" pipe | PLUM | 20 | 0.4 | Ea. | 10.55 | 16.75 | 27.30 | 10.55 | 16.75 | 27.30 |
| 7 | 072116200410 | Blanket insulation, for walls or ceilings, foil faced fiberglass, 3-1/2" thick, R13, 11" wide | CARP | 1150 | 0.007 | S.F. | 0.70 | 0.26 | 0.96 | 4.90 | 1.82 | 6.72 |
| | | RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | | | |
| -1 | 221113763460 | Coupling, plastic, PVC, white, socket joint, 4", schedule 40[4] | Q1 | 18.2 | 0.879 | Ea. | 14.05 | 33.00 | 47.05 | (14.05) | (33.00) | (47.05) |
| | | Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | | | |
| 1 | | Vent cap, PVC, 4" pipe | PLUM | N/A | 0.4 | Ea. | 15.00 | 16.75 | 31.75 | 15.00 | 16.75 | 31.75 |
| 2 | | Labels (1 set per level) | PLUM | N/A | 0.2 | Ea. | 8.00 | 8.40 | 16.40 | 16.00 | 16.80 | 32.80 |
| 1 | | Testing of system | | | | Ea. | | 60.00 | | | 60.00 | |
| **Total** | | | | | | | | | **180.41** | **293.15** | **190.82** | **483.97** |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-2. Bungalow PSD unit costs (continued)*

| Mat. O&P ($) | Labor O&P ($) | Total O&P ($) | Ext. Mat. O&P ($) | Ext. Labor O&P ($) | Ext. Total O&P ($) | Labor Type | Data Release (Year) | City Cost Index Location |
|---|---|---|---|---|---|---|---|---|
| **RSMeans data outputs** | | | | | | | | |
| 9.85 | 8.00 | 17.85 | 246.25 | 200.00 | 446.25 | RES | 2022 | National Average |
| 29.00 | 54.00 | 83.00 | 58.00 | 108.00 | 166.00 | RES | 2022 | National Average |
| 11.60 | 27.50 | 39.10 | 11.60 | 27.50 | 39.10 | RES | 2022 | National Average |
| 0.77 | 0.42 | 1.19 | 5.39 | 2.94 | 8.33 | RES | 2022 | National Average |
| RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | |
| 15.45 | 54.00 | 69.45 | (15.45) | (54.00) | (69.45) | RES | 2022 | National Average |
| Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | |
| 16.50 | 27.47 | 43.97 | 16.50 | 27.47 | 43.97 | RES | 2022 | National Average |
| 8.80 | 13.78 | 22.58 | 17.60 | 27.55 | 45.15 | RES | 2022 | National Average |
| | 60.00 | 60.00 | | | 60.00 | | | |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-3. 2-storey detached PSD unit costs[1]*

| Quantity | Line Number | Description | Crew[2] | Daily Output | Labor Hours | Unit[3] | Material ($) | Labor ($) | Total ($) | Ext. Mat. ($) | Ext. Labor ($) | Ext. Total ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 221113746600 | Pipe, plastic, residential installation, PVC, 4" diameter, schedule 40, includes couplings 10' OC, and hangers 3 per 10' | Q1 | 123 | 0.13 | L.F. | 8.95 | 4.90 | 13.85 | 313.25 | 171.50 | 484.75 |
| 4 | 221113762840 | Elbow, 90 Deg., plastic, PVC, white, socket joint, 4", schedule 40 | Q1 | 18.2 | 0.879 | Ea. | 26.50 | 33.00 | 59.50 | 106.00 | 132.00 | 238.00 |
| 1 | 221316803060 | Vent flashing, neoprene, one piece, 4" pipe | PLUM | 20 | 0.4 | Ea. | 10.55 | 16.75 | 27.30 | 10.55 | 16.75 | 27.30 |
| 1 | 072116200410 | Blanket insulation, for walls or ceilings, foil faced fiberglass, 3-1/2" thick, R13, 11" wide | CARP | 1,150 | 0.007 | S.F. | 0.70 | 0.26 | 0.96 | 0.70 | 0.26 | 0.96 |
| | | RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | | | |
| -2 | 221113763460 | Coupling, plastic, PVC, white, socket joint, 4", schedule 40[4] | Q1 | 18.2 | 0.879 | Ea. | 14.05 | 33.00 | 47.05 | (28.10) | (66.00) | (94.10) |
| | | Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | | | |
| 1 | | Vent cap, PVC, 4" pipe | PLUM | N/A | 0.4 | Ea. | 15.00 | 16.75 | 31.75 | 15.00 | 16.75 | 31.75 |
| 3 | | Labels (1 set per level) | PLUM | N/A | 0.2 | Ea. | 8.00 | 8.40 | 16.40 | 24.00 | 25.20 | 49.20 |
| 1 | | Testing of system | | | | Ea. | | 60.00 | | | 60.00 | |
| **Total** | | | | | | | | | **148.66** | **402.40** | **254.51** | **656.91** |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-3. 2-storey detached PSD unit costs (continued)*

| Mat. O&P ($) | Labor O&P ($) | Total O&P ($) | Ext. Mat. O&P ($) | Ext. Labor O&P ($) | Ext. Total O&P ($) | Labor Type | Data Release (Year) | City Cost Index Location |
|---|---|---|---|---|---|---|---|---|
| 9.85 | 8.00 | 17.85 | 344.75 | 280.00 | 624.75 | RES | 2022 | National Average |
| 29.00 | 54.00 | 83.00 | 116.00 | 216.00 | 332.00 | RES | 2022 | National Average |
| 11.60 | 27.50 | 39.10 | 11.60 | 27.50 | 39.10 | RES | 2022 | National Average |
| 0.77 | 0.42 | 1.19 | 0.77 | 0.42 | 1.19 | RES | 2022 | National Average |
| RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | |
| 15.45 | 54.00 | 69.45 | (30.90) | (108.00) | (138.90) | RES | 2022 | National Average |
| Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | |
| 16.50 | 27.47 | 43.97 | 16.50 | 27.47 | 43.97 | RES | 2022 | National Average |
| 8.80 | 13.78 | 22.58 | 26.40 | 41.33 | 67.73 | RES | 2022 | National Average |
| | 60.00 | 60.00 | | | 60.00 | | | |
| **Total** | | **210.59** | **442.22** | **415.92** | **1,029.84** | | | |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-4. 3-storey detached PSD unit costs[1]*

| Quantity | Line Number | Description | Crew[2] | Daily Output | Labor Hours | Unit[3] | Material ($) | Labor ($) | Total ($) | Ext. Mat. ($) | Ext. Labor ($) | Ext. Total ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 221113746600 | Pipe, plastic, residential installation, PVC, 4" diameter, schedule 40, includes couplings 10' OC, and hangers 3 per 10' | Q1 | 123 | 0.13 | L.F. | 8.95 | 4.90 | 13.85 | 402.75 | 220.50 | 623.25 |
| 6 | 221113762840 | Elbow, 90 Deg., plastic, PVC, white, socket joint, 4", schedule 40 | Q1 | 18.2 | 0.879 | Ea. | 26.50 | 33.00 | 59.50 | 159.00 | 198.00 | 357.00 |
| 1 | 221316803060 | Vent flashing, neoprene, one piece, 4" pipe | PLUM | 20 | 0.4 | Ea. | 10.55 | 16.75 | 27.30 | 10.55 | 16.75 | 27.30 |
| 1 | 072116200410 | Blanket insulation, for walls or ceilings, foil faced fiberglass, 3-1/2" thick, R13, 11" wide | CARP | 1,150 | 0.007 | S.F. | 0.70 | 0.26 | 0.96 | 0.70 | 0.26 | 0.96 |
| | | RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | | | |
| -3 | 221113763460 | Coupling, plastic, PVC, white, socket joint, 4", schedule 40[4] | Q1 | 18.2 | 0.879 | Ea. | 14.05 | 33.00 | 47.05 | (42.15) | (99.00) | (141.15) |
| | | Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | | | |
| 1 | | Vent cap, PVC, 4" pipe | PLUM | N/A | 0.4 | Ea. | 15.00 | 16.75 | 31.75 | 15.00 | 16.75 | 31.75 |
| 3 | | Labels (1 set per level) | PLUM | N/A | 0.2 | Ea. | 8.00 | 8.40 | 16.40 | 24.00 | 25.20 | 49.20 |
| 1 | | Testing of system | | | | Ea. | | 60.00 | | | 60.00 | |
| **Total** | | | | | | | | | **148.66** | **530.85** | **336.51** | **867.36** |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-4. 3-storey detached PSD unit costs (continued)*

| Mat. O&P | Labor O&P ($) | Total O&P ($) | Ext. Mat. O&P ($) | Ext. Labor O&P ($) | Ext. Total O&P ($) | Labor Type | Data Release (Year) | City Cost Index Location |
|---|---|---|---|---|---|---|---|---|
| 9.85 | 8.00 | 17.85 | 443.25 | 360.00 | 803.25 | RES | 2022 | National Average |
| 29.00 | 54.00 | 83.00 | 174.00 | 324.00 | 498.00 | RES | 2022 | National Average |
| 11.60 | 27.50 | 39.10 | 11.60 | 27.50 | 39.10 | RES | 2022 | National Average |
| 0.77 | 0.42 | 1.19 | 0.77 | 0.42 | 1.19 | RES | 2022 | National Average |
| RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | |
| 15.45 | 54.00 | 69.45 | (46.35) | (162.00) | (208.35) | RES | 2022 | National Average |
| Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs | | | | | | | | |
| 16.50 | 27.47 | 43.97 | 16.50 | 27.47 | 43.97 | RES | 2022 | National Average |
| 8.80 | 13.78 | 22.58 | 26.40 | 41.33 | 67.73 | RES | 2022 | National Average |
| | 60.00 | 60.00 | | | 60.00 | | | |
| **Total** | | **210.59** | **583.27** | **549.92** | **1,304.89** | | | |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-5. 3-storey duplex/stacked townhome PSD unit costs[1]*

| Quantity | Line Number | Description | Crew[2] | Daily Output | Labor Hours | Unit[3] | Material ($) | Labor ($) | Total ($) | Ext. Mat. ($) | Ext. Labor ($) | Ext. Total ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | 221113746600 | Pipe, plastic, residential installation, PVC, 4" diameter, schedule 40, includes couplings 10' OC, and hangers 3 per 10' | Q1 | 123 | 0.13 | L.F. | 8.95 | 4.90 | 13.85 | 402.75 | 220.50 | 623.25 |
| 6 | 221113762840 | Elbow, 90 Deg., plastic, PVC, white, socket joint, 4", schedule 40 | Q1 | 18.2 | 0.879 | Ea. | 26.50 | 33.00 | 59.50 | 159.00 | 198.00 | 357.00 |
| 1 | 221316803060 | Vent flashing, neoprene, one piece, 4" pipe | PLUM | 20 | 0.4 | Ea. | 10.55 | 16.75 | 27.30 | 10.55 | 16.75 | 27.30 |
| 1 | 072116200410 | Blanket insulation, for walls or ceilings, foil faced fiberglass, 3-1/2" thick, R13, 11" wide | CARP | 1,150 | 0.007 | S.F. | 0.70 | 0.26 | 0.96 | 0.70 | 0.26 | 0.96 |
| | | RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | | | |
| -3 | 221113763460 | Coupling, plastic, PVC, white, socket joint, 4", schedule 40[4] | Q1 | 18.2 | 0.879 | Ea. | 14.05 | 33.00 | 47.05 | (42.15) | (99.00) | (141.15) |
| | | Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs for cap and firestop | | | | | | | | | | |
| 1 | | Vent cap, PVC, 4" pipe | PLUM | N/A | 0.4 | Ea. | 15.00 | 16.75 | 31.75 | 15.00 | 16.75 | 31.75 |
| 1 | | Firestop between dwelling units | PLUM | N/A | 0.4 | Ea. | 45.00 | 16.75 | 61.75 | 45.00 | 16.75 | 61.75 |
| 3 | | Labels (1 set per level) | PLUM | N/A | 0.2 | Ea. | 8.00 | 8.40 | 16.40 | 24.00 | 25.20 | 49.20 |
| 1 | | Testing of system | | | | Ea. | | 60.00 | | | 60.00 | |
| **Total** | | | | | | | | | **148.66** | **530.85** | **336.51** | **867.36** |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-5. 3-storey duplex/stacked townhome PSD unit costs (continued)*

| Mat. O&P ($) | Labor O&P ($) | Total O&P ($) | Ext. Mat. O&P ($) | Ext. Labor O&P ($) | Ext. Total O&P ($) | Labor Type | Data Release (Year) | City Cost Index Location |
|---|---|---|---|---|---|---|---|---|
| 9.85 | 8.00 | 17.85 | 443.25 | 360.00 | 803.25 | RES | 2022 | National Average |
| 29.00 | 54.00 | 83.00 | 174.00 | 324.00 | 498.00 | RES | 2022 | National Average |
| 11.60 | 27.50 | 39.10 | 11.60 | 27.50 | 39.10 | RES | 2022 | National Average |
| 0.77 | 0.42 | 1.19 | 0.77 | 0.42 | 1.19 | RES | 2022 | National Average |
| RSMeans: Adjustment for extra coupler(s) that is/are not required | | | | | | | | |
| 15.45 | 54.00 | 69.45 | (46.35) | (162.00) | (208.35) | RES | 2022 | National Average |
| Material pricing from M. Brascoupe<br>Labour pricing adjusted from RSMeans vent flashing installation costs for cap and firestop | | | | | | | | |
| 16.50 | 27.47 | 43.97 | 16.50 | 27.47 | 43.97 | RES | 2022 | National Average |
| 49.50 | 27.47 | 76.97 | 49.50 | 27.47 | 76.97 | RES | 2022 | National Average |
| 8.80 | 13.78 | 22.58 | 26.40 | 41.33 | 67.73 | RES | 2022 | National Average |
| | 60.00 | 60.00 | | | 60.00 | | | |
| **Total** | | **210.59** | **583.27** | **549.92** | **1,381.86 (for both units)**<br>**690.93 (split between units)** | | | |

Notes: [1] additional costs for blocking are presented in Table A-6; [2] quantity 1 (Q1), plumber (PLUM), carpenter (CARP); [3] linear feet (L.F.), each (Ea.), square feet (S.F.); [4] material added to group costs for PVC that was replaced with 90 deg elbows.

*Table A-6. Additional costs associated with steel plates for protection of the radon stack at wall plates and blocking intersections*

| Bungalow ($) | 2-Storey ($) | 3-Storey ($) | 3-Storey Stacked Townhome ($) |
|---|---|---|---|
| 14.18 | 28.36 | 42.54 | 21.25 |

Note: These additional costs for blocking PSD have been added to the mitigators' cost estimates (Tables A-2 to A-5) and to the total costs presented in Table 6.