Radiation Safety of Natural Stone and Building Materials

天然石材與建材之輻射安全

(Prepared for Taiwan Marble Association / 為台灣區石礦製品工業同業公會編製)

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Date / 日期

[16th, September, 2025]

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1. Executive Summary / 摘要

English

This document provides a bilingual overview of radiation in natural stone and building materials, comparing levels to international safety standards and everyday exposures. Key findings show:

- Natural stone (e.g., granite countertops) emits low levels of natural radiation, **well below the 1 mSv/year public safety limit** set by ICRP, IAEA, EU, Taiwan, and Japan.
- Other daily items such as bananas, drinking water, bricks, and cement also emit natural radiation, often at similar or higher levels than stone.
- By contrast, common medical imaging (X-rays, CT scans) and long-haul flights deliver doses **hundreds of times higher** than natural stone.

The conclusion is clear: **natural stone is safe for public use, and fears about radiation are based on misunderstanding or misinformation.**

中文

本文件提供天然石材與建材輻射之雙語概述，並與國際安全標準及日常生活暴露進行比較。主要發現如下：

- 天然石材（如花崗石檯面）確實含有微量天然輻射，但其劑量遠低於 ICRP、IAEA、歐盟、台灣與日本制定的 **每年 1 mSv 公眾安全限值**。
- 其他日常項目如香蕉、飲用水、磚頭、水泥也含有天然輻射，且常與石材相當甚至更高。
- 相比之下，常見醫療檢查（X 光、電腦斷層）及長途飛行的輻射劑量，**比天然石材高出數百倍**。

結論非常明確：**天然石材安全可用，關於其輻射的恐慌多源於誤解或錯誤資訊**。

2. ■ International Basis / 國際基準

2.1 ICRP / IAEA

(International Commission on Radiological Protection / 國際放射防護委員會; International Atomic Energy Agency / 國際原子能總署)

- **Public exposure limit / 公眾暴露上限**: ≤ 1 mSv/year / 每年 ≤ 1 mSv
- **Measurement / 測量方式**: Activity concentration in Bq/kg / 以 Bq/kg 測量核素濃度
- **Activity Concentration Index (I) / 放射性濃度指標 (I)**

$I = C_{Ra}/300 + C_{Th}/200 + C_{K}/3000$

- **Rule / 規範**: If I ≤ 1 → Safe for construction indoors / 若 I ≤ 1 → 室內建材可安全使用

2.2. European Union (EU) / 歐盟

- **Directive 2013/59/Euratom (Basic Safety Standards / 基本安全標準指令)**
- Requires testing of **natural building materials / 天然建材需檢測**
- Uses **Activity Concentration Index (I) / 使用指標 I**
- **If I > 1 → Needs restriction or further assessment / 若 I > 1 → 需限制或進一步評估**

2.3. United States (US) / 美國

- No single nationwide regulation / 沒有統一全國性法規
- **EPA (Environmental Protection Agency / 環境保護署)** and **NCRP (National Council on Radiation Protection / 全國輻射防護委員會)** provide guidance
- Building materials should not cause exposure > **1 mSv/year above background / 建材額外輻射不應超過每年 1 mSv**
- Granite, tiles, concrete sometimes tested in **Bq/kg and µSv/h / 以 Bq/kg 與 µSv/h 檢測**

2.4. Taiwan / 台灣

- Authority: **AEC (Atomic Energy Council / 原子能委員會)**
- Background: strict regulation after Co-60 rebar incident in 1980s / 1980 年代鈷-60 污染鋼筋事件後規範嚴格
- **Annual effective dose limit = 1 mSv/year / 公眾有效劑量上限 = 每年 1 mSv**
- Testing uses **Bq/kg (activity concentration) and μSv/h (dose rate) / 同時使用 Bq/kg 與 μSv/h 檢測**

2.5. Japan / 日本

- Authority: **NRA (Nuclear Regulation Authority / 原子能規制廳)**
- Follows **ICRP & IAEA guidance / 採用 ICRP 與 IAEA 指引**
- Building materials should not give > **1 mSv/year additional exposure / 建材不得導致額外超過每年 1 mSv**
- Uses **Bq/kg and Index I / 使用 Bq/kg 與指標 I**

3.📊 Summary Table / 總結表

Region / 區域	Main Rule / 主要規範	Key Unit / 核心單位	Safety Limit / 安全標準
ICRP / IAEA 國際基準	Activity Concentration Index (I) / 放射性濃度指標 (I)	Bq/kg, Index I / Bq/kg、指標 I	I ≤ 1 → ≤ 1 mSv/year / I ≤ 1 → 每年 ≤ 1 mSv
EU 歐盟	Directive 2013/59/Euratom / 歐盟基本安全標準指令	Bq/kg, Index I / Bq/kg、指標 I	Same as ICRP / 與 ICRP 相同
US 美國	EPA & NCRP guidance / 環保署與全國輻防委員會指引	Bq/kg, μSv/h, mSv/year / Bq/kg、μSv/h、mSv/年	≤ 1 mSv/year above background / 額外 ≤ 每年 1 mSv 註 1.
Taiwan 台灣	AEC regulation / 原能會規範	Bq/kg, μSv/h, mSv/year / Bq/kg、μSv/h、mSv/年	≤ 1 mSv/year / ≤ 每年 1 mSv
Japan 日本	NRA guidance / 原子能規制廳指引	Bq/kg, Index I / Bq/kg、指標 I	≤ 1 mSv/year / ≤ 每年 1 mSv

- 註 1. **在自然背景輻射之上，每年額外不得超過 1 mSv**

✅ Key Point / 關鍵重點

- **Bq/kg** = laboratory testing of radioactivity in materials / 實驗室檢測建材放射性
- **Index I** = combined evaluation of Ra, Th, K radionuclides / 將鐳、釷、鉀放射性綜合為一個指標
- **mSv/year** = final effective dose limit to public indoors (≤ 1 mSv/year) / 公眾室內年劑量上限（≤ 每年 1 mSv

4.📖 Explanation / 解釋

Background radiation (背景輻射)

- The natural radiation that everyone is exposed to every year, coming from soil, air, cosmic rays, and food.
- 每個人每年都會接觸到的自然輻射，來源包括土壤、空氣、宇宙射線、食物等。
- Typical level / 常見數值: 約 **2 – 3 mSv/年**

Above background (在背景之上 / 額外)

- Means the **additional radiation** caused by man-made sources or specific building materials, on top of the natural baseline.
- 指的是 **在自然背景之外**，由人造來源或特定建材帶來的 **額外輻射劑量**。

In rare cases, radon may also emanate from certain building materials; however, large-scale testing of federal buildings across Canada has shown that such materials are *not* significant contributors to indoor radon levels. The main source of radon remains the soil beneath buildings.
（Source: Health Canada, *Guide for Radon Measurements in Public Buildings*, 2023, https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radon.html）

在極少數情況下，氡氣可能來自某些建築材料；然而，加拿大聯邦建築物的廣泛測試結果顯示，這些材料對室內氡濃度的貢獻並不顯著。氡的主要來源仍然是建築物下方的土壤。
（資料來源：加拿大衛生部，《公共建築氡測量指南》，2023 年，https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radon.html）

✅ Example / 例子

- Natural background in Taiwan: **~2.4 mSv/year**
- 臺灣的自然背景輻射：約 **每年 2.4 mSv**

If someone lives in a house with granite countertops and concrete walls:
若有人住在有花崗石檯面和混凝土牆壁的房屋：

- Natural background: **2.4 mSv/year**
  - 自然背景輻射：**每年 2.4 mSv**
- Extra from building materials: **≤ 1.0 mSv/year** (regulation limit)
  - 建材所增加的額外輻射：**每年 ≤ 1.0 mSv**（規範上限）
- **Total exposure should stay ≤ 3.4 mSv/year**
  - **總暴露劑量應保持在 ≤ 每年 3.4 mSv**

- **≤ 1 mSv/year above background**
  = 在自然背景輻射之上，每年額外不得超過 1 mSv

5. 📎 Summary of References / 參考文獻總結

- EU-OSHA – Directive 2013/59/Euratom (Annex VIII)

📎 https://osha.europa.eu

EU basic safety standards, defining the Activity Concentration Index and the 1 mSv/year dose limit for building materials.

👉 歐盟基本輻射安全標準，明定建材的活度濃度指數與 1 mSv/年劑量上限。

- European Commission – Radiation Protection Report No. 112

📎 https://energy.ec.europa.eu

Guidelines for applying activity concentration and dose criteria for building materials across EU member states.

👉 歐盟委員會《輻射防護報告第 112 號》，提供建材活度濃度與劑量準則之應用指引。

- IAEA – Safety Reports Series No. 33: Radiation Protection and NORM Residues in Building Materials

📎 https://www.iaea.org/publications

International guidance on Naturally Occurring Radioactive Materials (NORM) in construction and building safety.

👉 國際原子能總署出版之報告，提供建築材料中天然放射性物質 (NORM) 的國際安全指引。

- WHO – Radon and Health

📎 https://www.who.int/health-topics/radon

Global health overview of radon exposure risks, mitigation strategies, and public health impacts.

👉 世界衛生組織對氡暴露風險、減緩措施與公共衛生影響的全球性說明。

- Health Canada – *Guide for Radon Measurements in Public Buildings (2023)*

📎 https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radon.html

Federal guidance confirming that, although radon can rarely emanate from certain building materials, large-scale testing across Canada has shown these materials are *not significant contributors* compared to soil.

👉 加拿大衛生部《公共建築氡測量指南》。官方指南指出，雖然少數建材可能釋放氡氣，但加拿大的廣泛測試顯示其貢獻可忽略不計，主要來源仍為地面土壤。

• UNSCEAR – 2000 Report to the General Assembly: Sources and Effects of Ionizing Radiation (Annex B)

📎 https://www.unscear.org

United Nations Scientific Committee report detailing radiation sources in the environment and exposure pathways.

👉 聯合國原子輻射影響科學委員會報告，詳述環境中輻射來源及暴露途徑。

• Radonorm – European Research Project

📎 https://www.radonorm.eu

EU-funded research initiative addressing radon and NORM risks in workplaces and dwellings.

👉 歐盟資助之研究計畫，專注於居家與工作環境中氡氣與天然放射性物質 (NORM) 的風險。

• ICRP – Publication 103: Recommendations of the International Commission on Radiological Protection

📎 https://www.icrp.org/publication.asp?id=ICRP%20Publication%20103

Core international recommendations on radiological protection, including dose limits and protection principles.

👉 國際放射防護委員會第 103 號出版物，闡述輻射防護的核心建議，包括劑量上限與防護原則。

• Taiwan Atomic Energy Council (AEC) – 建築材料天然放射性安全規範

📎 https://www.aec.gov.tw

Taiwan's official radiation safety guideline for building materials, aligned with EU and IAEA frameworks.

👉 台灣原子能委員會公布之建築材料輻射安全規範，與歐盟及國際原子能總署框架接軌。

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6.📊 Bilingual Table – Everyday Radiation Exposures in Sequence

📊 雙語對照表 – 按序排列的日常輻射劑量

Annual Natural Background Radiation (天然背景輻射, 2–3 mSv/year)

Item / 物品	Radiation Source / 輻射來源	Typical Dose / 劑量 (mSv/year or per time)	Notes / 說明
[1]Bananas / 香蕉	^40K (Potassium-40 / 鉀-40)	~0.036 mSv/year (1 per day / 每天一根)	Natural food radiation / 天然食物輻射
[2]Drinking water / 飲用水	Natural uranium, radium / 天然鈾、鐳	≤ 0.1 mSv/year	WHO guideline / 世界衛生組織建議上限
[3]Granite countertop / 花崗石檯面	^226Ra, ^232Th, ^40K	0.1 – 0.3 mSv/year	Below 1 mSv/year public safety limit / 低於 1 mSv/年 公眾安全標準
[4]Brazil nuts / 巴西堅果	^226Ra (naturally concentrated / 自然濃縮)	~0.2 – 0.4 mSv/year (regular eating / 經常食用)	Equation / 等式: ≈ 5 – 11 years of bananas ≈ 0.7 – 4 years of granite
[5]Brick / Clay tiles / 磚頭、陶瓷磚	Natural ^40K, ^226Ra / 天然鉀-40、鐳-226	0.2 – 0.6 mSv/year	Equation / 等式: ≈ 6 – 17 years of bananas ≈ 0.7 – 6 years of granite
[6]Cement / 水泥	Fly ash, natural radionuclides / 爐渣、天然核素	0.2 – 0.5 mSv/year	Equation / 等式: ≈ 6 – 14 years of bananas ≈ 0.7 – 5 years of granite
[7]Air travel / 搭乘飛機	Cosmic rays / 宇宙射線	0.05 mSv (Taipei – New York one way / 台北 – 紐約單程)	Equation / 等式: 1 flight ≈ 500 bananas ≈ 0.17 – 0.5 year of granite

Item / 物品	Radiation Source / 輻射來源	Typical Dose / 劑量 (mSv/year or per time)	Notes / 說明
[8]Chest X-ray / 胸腔 X 光	Medical X-ray / 醫療 X 光	~0.1 mSv (once / 每次)	Equation / 等式: ≈ 3 years of bananas ≈ 0.3 – 1 year of granite
[9]CT scan (abdomen) / 腹部電腦斷層	Medical CT / 醫療斷層	5 – 10 mSv (once / 每次)	Equation / 等式: ≈ 140 – 280 years of bananas ≈ 17 – 100 years of granite

7. ✓ Key Messages / 關鍵訊息

1. Bananas, water, nuts, bricks, and cement all have natural radiation.
   香蕉、飲水、堅果、磚頭、水泥都含天然輻射。
2. Granite (0.1 – 0.3 mSv/year) is safe and below the 1 mSv/year limit.
   花崗石（0.1 – 0.3 mSv/年）安全且低於 1 mSv/年 標準。
3. Brazil nuts, bricks, and cement can be higher than granite.
   巴西堅果、磚頭、水泥可能比花崗石更高。
4. Flights and medical scans are orders of magnitude higher.
   飛行與醫療檢查的劑量高出數倍甚至數百倍。

8. Conclusion / 結論

English

Natural stone is a safe and sustainable building material. Its radiation levels are low, well-regulated, and comparable to or lower than many ordinary sources in daily life. Public fears often result from incomplete information or fake news.

By presenting scientific comparisons and referencing international standards, this document demonstrates that natural stone fully complies with safety requirements, and can be confidently used in construction, architecture, and interior design.

中文

天然石材是一種安全且永續的建材，其輻射劑量低、受嚴格規範，並與許多日常來源相當或更低。公眾恐慌往往源自不完整的資訊或假消息。

透過科學比較與國際標準之引用，本文件清楚顯示天然石材完全符合安全要求，可安心應用於建築、設計與室內裝修。

9. Acknowledgement / 致謝

The author wishes to sincerely thank the Taiwan Marble Association and all members for their commitment to promoting accurate scientific understanding of natural stone. Their dedication to safeguarding both industry reputation and public trust has made this document meaningful and useful for future reference.

作者謹此誠摯感謝台灣區石礦製品工業同業公會與全體會員，長期致力於推廣天然石材的正確科學認知。公會對於維護產業聲譽與社會信任的用心，使本文件更具意義並能作為未來參考之用。

📎 Appendix A – References for Everyday Radiation Exposures Table

📎 附錄 A – 日常輻射劑量對照表參考文獻

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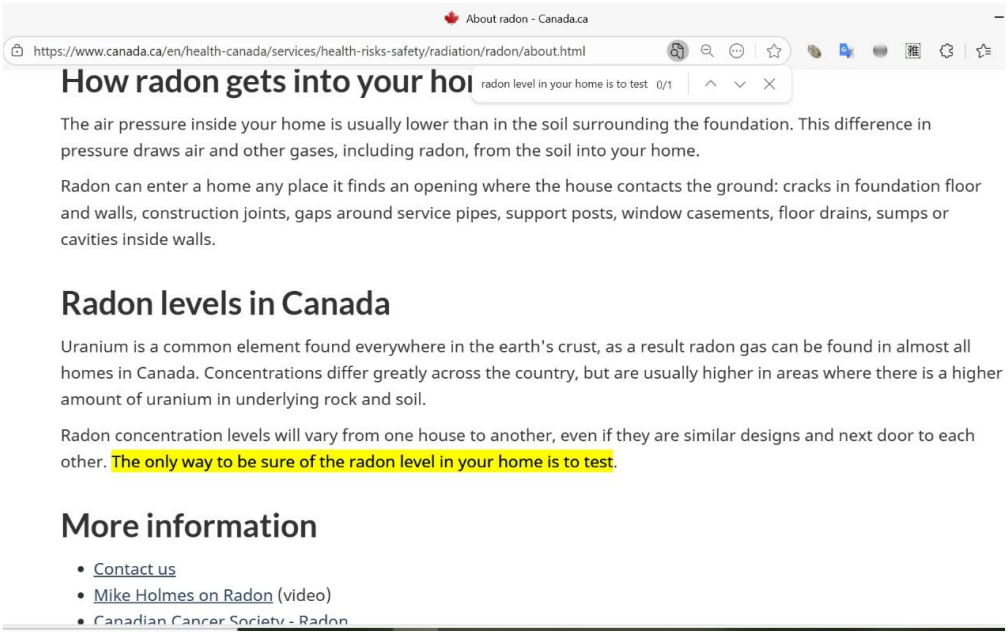
- **English:** IAEA. *Patient Radiation Exposure in Diagnostic Radiology*. 2014.
- **中文:** 國際原子能總署（IAEA），《診斷放射學中的病人輻射曝露》，2014 年。

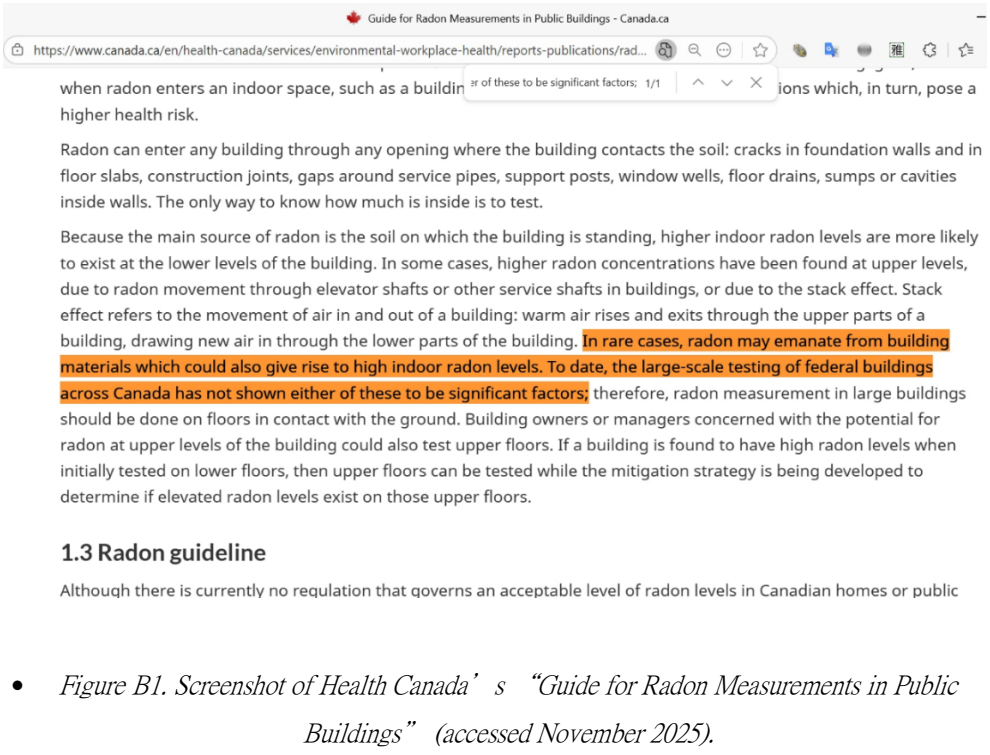
📎 Appendix B – Archived Reference Screenshots (For Record Only)

📎 附錄 B – 參考文獻截圖備份

- 🏛 Health Canada (加拿大衛生部)
- **Health Canada (2021, updated 2025).** *Radon – Health Canada.* Government of Canada.
  Available at: About radon - Canada.ca: https://www.canada.ca/en/health-canada/services/health-risks-safety/radiation/radon/about.html
-



- ***Title:*** *Guide for Radon Measurements in Public Buildings: Schools, Hospitals, Care Facilities, Detention Centres*
  Publisher: Government of Canada, 2010 (updated 2023)
  Official link:
  🔗 https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/radiation/guide-radon-measurements-public-buildings-schools-hospitals-care-facilities-detention-centres.html



- *Figure B1. Screenshot of Health Canada's "Guide for Radon Measurements in Public Buildings" (accessed November 2025).*