

Biosphere Dose Assessment: Review of Dose Consequence of Radionuclides in the Uranium-238 Series Decay Chain

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Presentation Outline

- Approach
- Scoping calculation
- Confirmatory calculations
- Critical issues needing further examination
- Needs for complementary information and clarification
- Conclusions

Approach

- Familiarization review
 - Does the SKB documentation clearly describe ^{238}U dose calculations
 - Are adequate technical bases provided for ^{238}U dose calculations?
 - Identify important assumptions or conclusions that should be evaluated
 - Identify methods and assumptions that could underestimate ^{238}U dose
- Scoping calculations
 - Potential for disequilibrium of ^{238}U decay products ^{230}Th and ^{226}Ra during geosphere transport
- Confirmatory calculations
 - Indoor and outdoor effective doses from a single canister radon pulse release
 - ^{222}Rn dose conversion factor

CNWRA Scoping Calculation

- Constructed two compartment models for partial ^{238}U decay chain transport in the geosphere with continuous releases
 - Model 1: No Thorium Transport
 - Model 2: Thorium Transport Included
- Scoping calculation focused on two radionuclides (^{230}Th and ^{226}Ra) to investigate SKB assumption of complete ^{230}Th retention
- Calculated and compared ^{226}Ra fluxes into the biosphere for long simulation times
- Simplification made
 - *Constant production rate* of ^{230}Th used as input in lieu of time-dependent production
 - Acceptable for comparing two models

Long-Term (Steady-State) Results: Insights from ^{226}Ra Biosphere Flux Ratio

- ^{230}Th sorption and decay in far field can contribute significantly to ^{226}Ra biosphere flux
- Release of ^{230}Th from the near field over long timeframes can result in larger ^{226}Ra fluxes to the biosphere, compared to a model assuming no thorium transport
- ^{226}Ra biosphere flux ratio
 - Increases as $g_{\text{Th}} / g_{\text{Ra}}$ increases
 - Decreases to 1 as h_{Ra} increases
 - Ratios of $g_{\text{Th}} / g_{\text{Ra}} < 1$ still yield biosphere flux ratios > 1
 - Ratios of $g_{\text{Th}} / g_{\text{Ra}} \ll 1$ result in biosphere flux ratio = 1

Long-Term (Steady-State) Results: Treatment of Near Field and Far Field

- Calculation assumes release rate of ^{226}Ra from the near field is 10 times greater than release rate of ^{230}Th

$$g_{\text{Th}} / g_{\text{Ra}} = 0.00001 \text{ ka}^{-1} / 0.0001 \text{ ka}^{-1} = 0.1$$

- Larger $g_{\text{Th}} / g_{\text{Ra}}$ values would increase ^{226}Ra biosphere flux ratio
- Results for the three cases investigated are:
 - Low thorium retention in far field: ^{226}Ra biosphere flux is 1.7 times greater when ^{230}Th transport from near field is considered
 - Moderate thorium retention in far field: ^{226}Ra biosphere flux is 3.8 times greater when ^{230}Th transport from near field is considered
 - High thorium retention in far field: ^{226}Ra biosphere flux is 5.5 times greater when ^{230}Th transport from near field is considered

CNWRA Confirmatory Calculations: Radon Pulse Release from a Single Canister

- Short-lived decay products excluded from transport calculations (TR-10-50, Appendix D)
- Biosphere synthesis analyzes then excludes ^{222}Rn (TR-10-09, Section 4.2; TR-11-01, Section 13.8 citing R-06-81 and R-06-82)
- Conducted confirmatory calculations to evaluate the technical bases for excluding ^{222}Rn from biosphere calculations
- Confirmatory results compare well with SKB results for indoor and outdoor doses; reporting discrepancies among documents noted
- SKB values for ^{222}Rn dose coefficient and other factors are reasonable
- The calculation provides insights into the radon hazard from a canister release at a point in time but does not provide a strong basis for excluding radon from biosphere modeling

Critical Issues Needing Further Examination

- Potential enhanced release of radon and its decay products, such as ^{210}Pb , from the waste form (*refer to "Independent Radionuclide Transport Modeling: Reproducing Results for Main Scenarios" for details*)
- The radionuclide ^{230}Th , parent of ^{226}Ra , is assumed to be confined to the near field (TR-11-01, page 658). Given the high degree of sorption expected for thorium following its release from the waste canister, reasons for the lack of appreciable thorium buildup in the far field should be examined further.
- Radon is not explicitly modeled in groundwater contamination scenarios. Due to different sorption behaviors between radium and its noble gas decay product (radon), groundwater concentrations of radon and its decay progeny can be significantly enhanced compared to the calculated groundwater plume concentration of radium. Implications of this enhancement should be assessed with respect to ^{222}Rn and ^{210}Pb concentrations in the biosphere.

Needs for Complementary Information and Clarification

- Radiological dose was calculated due to gas phase transport of radon for a pulse release from a single canister (TR-11-01, Section 13.8, Table 13-11), and corrosion rate was mentioned to influence gas releases after the pulse. The production rate of ^{222}Rn will be continuous from the radioactive decay of ^{226}Ra . Continuous ^{222}Rn release following the initial pulse release of ^{222}Rn may be significant. Provide additional information on the continuous ^{222}Rn release or justify why its further consideration is unnecessary.
- The magnitude of ^{222}Rn effective dose results from the same pulse release calculation do not match in various reports (Table 13-11 in TR-11-01, Table 8-10 in R-06-82, and Tables 7-2 and 7-3 in R-06-81). Please explain the differences.

Needs for Complementary Information and Clarification

- The caption of Table 8-11 (R-06-82) indicates that the annual lifetime risk was estimated by “dividing the dose with 50 years.” Clarify if the ^{222}Rn effective doses in Tables 8-10 and 8-11 in R-06-82 included division by 50 years.
- SKB reports a smaller landscape dose factor for ^{226}Ra than the value for ^{238}U (e.g., mean values in Figure 5-40 and Table 5-5 of TR-10-06). Because the ingestion dose coefficient used to calculate the landscape dose factor is higher for ^{226}Ra than ^{238}U (TR-10-07, Table 6-2) these results should be checked or explained further.
- Clarify if radionuclide buildup in groundwater during glacial periods was considered. Include discussion of access to any built-up radionuclide concentrations at the end of the glacial period and brought into the biosphere.

Needs for Complementary Information and Clarification

- After a wetland is drained, further contamination of the soil through groundwater is not modeled, because irrigation with surface water is assumed to be the dominant pathway (TR-11-01, page 635). Discuss how this biosphere feature (no ground water contributions for wetlands, reliance on surface water) affects ^{226}Ra deposition, ^{222}Rn transport, and the overall potential for radon concentrations in the biosphere.
- TR-10-06 states that under conditions where repository radon could be important it would be “outset” by higher doses from natural radon but provides no citation to a technical basis. SKB should cite the technical bases for any conclusory statements in their documentation.

Needs for Complementary Information and Clarification

- Inconsistent /imprecise statements identified in various documents regarding the treatment of decay products in calculations should be clarified. For example,
 - Transport analysis documentation (TR-10-50, Appx D) states short-lived daughters were excluded from transport calculations but included in LDF's. LDF documentation in TR-10-06 shows no LDFs for Rn or decay products and no explicit or implicit inclusion in Rn in LDFs.
 - TR-10-06 states dose coefficients used to calculate LDF's included short lived daughters citing an EU directive as the source, however, the EU directive suggests that ^{222}Rn and decay products were not included in ^{226}Ra dose coefficient.
 - TR-10-06 acknowledges potential for ^{222}Rn to affect ^{226}Ra LDF but states ^{222}Rn is not included in LDF's.

Conclusions

- Completeness of safety assessment
 - ^{238}U dose calculations are generally complete although additional supplemental analyses would clarify the technical basis for excluding specific decay products
- Scientific soundness and quality
 - Overall, the transport and biosphere analyses are based on sound and familiar scientific methods although in specific areas noted the documentation did not always provide technical bases for methods, assumptions, and conclusions
- Data and model adequacy
 - Specific data and models reviewed under this initial review phase appeared generally adequate for their intended purpose
- Treatment of uncertainties
 - Supplemental sensitivity analyses provided useful insights, however, the performance assessment model included limited propagation of uncertainties

Conclusions

- Safety significance
 - Potential safety significant issues were identified for further consideration in the main review phase
- Transparency and traceability
 - Information could generally be traced to source but with some effort
 - Effective use of graphics to convey complex information
 - Several instances of incomplete referencing of related/supporting analyses
 - Frequent use of indirect, passive, and/or ambiguous language affected transparency in all documents reviewed

Backup Slides

Objectives

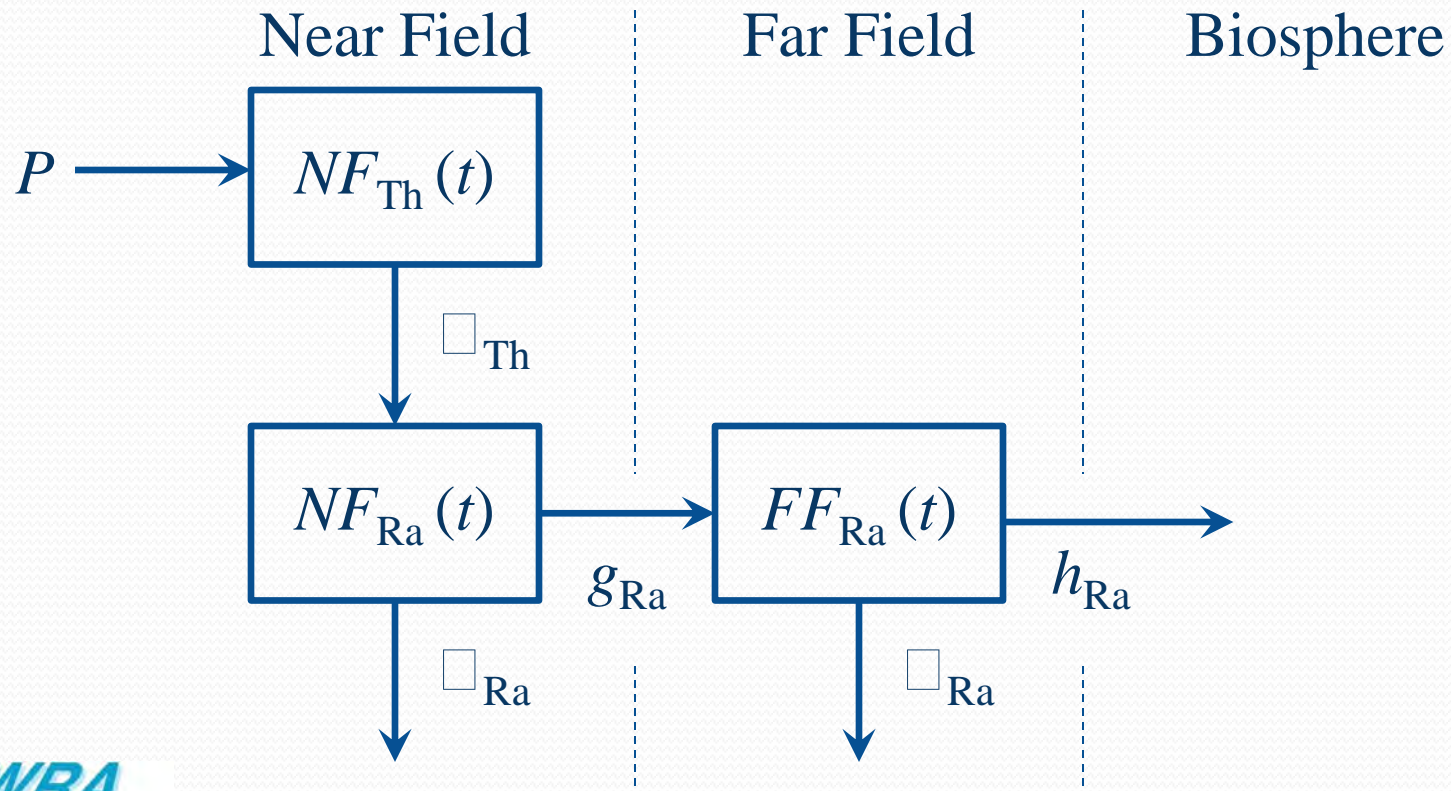
- Perform scoping calculations to evaluate the potential for significant dose from the ^{238}U chain; make comparisons with SKB results
- Review relevant portions of:
 - TR-01-11 SR-Site Safety Assessment Report
 - TR-10-09 Biosphere Synthesis Report
 - TR-10-50 Radionuclide Transport Report
 - Supporting References
- Technical note shall identify
 - Information needs
 - Clarifications
 - Critical issues requiring further examination

SKB Documents Reviewed

- TR-11-01, Long-term safety for the final repository for spent nuclear fuel
- TR-10-09, Biosphere analyses for the safety assessment SR-Site — synthesis and summary of results
- TR-10-50, Radionuclide transport report for the safety assessment SR-Site
- TR-10-06, Landscape dose conversion factors used in the safety assessment SR-Site
- TR-10-07 Element-specific and constant parameters used for dose calculations in SR-Site
- R-06-82, The biosphere at Forsmark Data, assumptions and models used in the SR-Can assessment
- R-06-81, The ecosystem models used for dose assessments in SR-Can

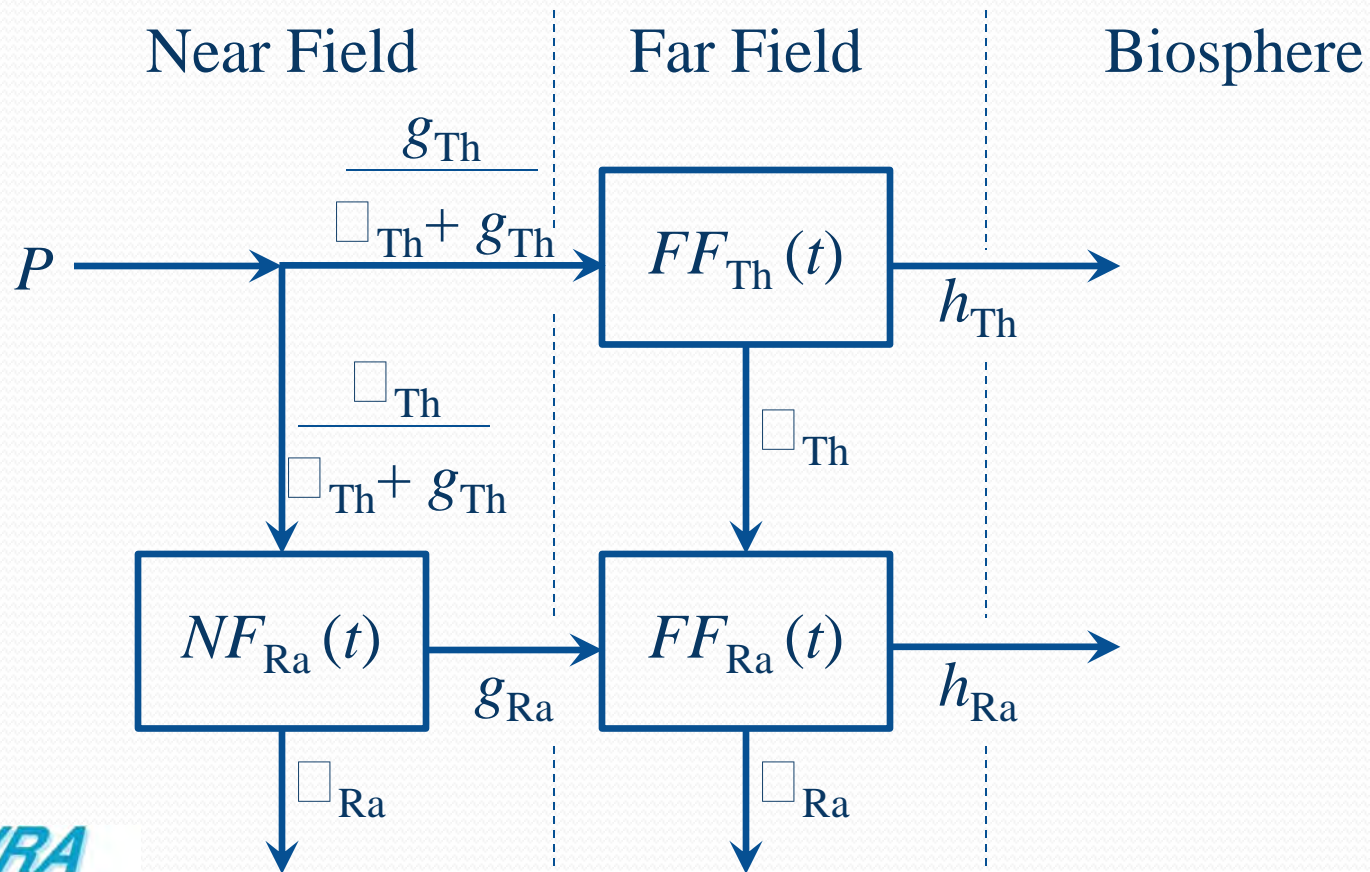
^{238}U Decay Chain Transport in the Geosphere: Comparison of Two Models

Model 1: Thorium Retained in Near Field



^{238}U Decay Chain Transport in the Geosphere: Comparison of Two Models

Model 2: Thorium Transport Included



Scoping Calculation Parameter Description

Parameter	Description
P	Production rate of ^{230}Th in the near field (atoms ka^{-1})
$NF_{\text{Th}}(t)$	Time-dependent amount of ^{230}Th in the near field (atoms)
$FF_{\text{Th}}(t)$	Time-dependent amount of ^{230}Th in the far field (atoms)
g_{Th}	^{230}Th transfer constant from near field to far field (ka^{-1})
h_{Th}	^{230}Th transfer constant from far field to biosphere (ka^{-1})
λ_{Th}	^{230}Th radioactive decay constant (ka^{-1})
$NF_{\text{Ra}}(t)$	Time-dependent amount of ^{226}Ra in the near field (atoms)
$FF_{\text{Ra}}(t)$	Time-dependent amount of ^{226}Ra in the far field (atoms)
g_{Ra}	^{226}Ra transfer constant from near field to far field (ka^{-1})
h_{Ra}	^{226}Ra transfer constant from far field to biosphere (ka^{-1})
λ_{Ra}	^{226}Ra radioactive decay constant (ka^{-1})

Scoping Calculation: Long-Term (Steady-State) Results

$$\text{Model 1 } ^{226}\text{Ra Flux to Biosphere} = \frac{g_{Ra}}{\lambda_{Ra} + g_{Ra}} \frac{h_{Ra}}{\lambda_{Ra} + h_{Ra}} P$$

Model 2 ^{226}Ra Flux to Biosphere

$$= \frac{g_{Ra}}{\lambda_{Ra} + g_{Ra}} \frac{\lambda_{Th}}{\lambda_{Th} + g_{Th}} \frac{h_{Ra}}{\lambda_{Ra} + h_{Ra}} P + \frac{g_{Th}}{\lambda_{Th} + g_{Th}} \frac{\lambda_{Th}}{\lambda_{Th} + h_{Th}} \frac{h_{Ra}}{\lambda_{Ra} + h_{Ra}} P$$

$$\frac{\text{Model 2 } ^{226}\text{Ra Flux to Biosphere}}{\text{Model 1 } ^{226}\text{Ra Flux to Biosphere}} = \frac{\lambda_{Th}}{(\lambda_{Th} + g_{Th})} \left[1 + \frac{(\lambda_{Ra} + g_{Ra})g_{Th}}{g_{Ra}(\lambda_{Th} + h_{Th})} \right]$$

Long-Term (Steady-State) Results: Low ^{230}Th Retention in Far Field

- Low ^{230}Th retention in far field
 - $h_{\text{Th}} = 0.05 \text{ ka}^{-1}$
 - 85 percent of ^{230}Th in far field enters biosphere before decay
 - 15 percent decays to ^{226}Ra
- ^{226}Ra biosphere flux is 1.7 times greater when ^{230}Th transport from near field is considered

$$\frac{\text{Model 2 } ^{226}\text{Ra Flux to Biosphere}}{\text{Model 1 } ^{226}\text{Ra Flux to Biosphere}} = \frac{0.0087}{0.0087 + 0.00001} \left[1 + \frac{0.4331 + 0.0001}{0.0001} \frac{0.00001}{0.0087 + 0.05} \right] = 1.7$$

Long-Term (Steady-State) Results: Moderate ^{230}Th Retention in Far Field

- Moderate retention in far field
 - $h_{\text{Th}} = 0.007 \text{ ka}^{-1}$
 - 45 percent of ^{230}Th in far field enters biosphere before decay
 - 55 percent decays to ^{226}Ra
- ^{226}Ra biosphere flux is 3.8 times greater when ^{230}Th transport from near field is considered

$$\frac{\text{Model 2 } ^{226}\text{Ra Flux to Biosphere}}{\text{Model 1 } ^{226}\text{Ra Flux to Biosphere}} = \frac{0.0087}{0.0087 + 0.00001} \left[1 + \frac{0.4331 + 0.0001}{0.0001} \frac{0.00001}{0.0087 + 0.007} \right] = 3.8$$

Long-Term (Steady-State) Results: High ^{230}Th Retention in Far Field

- High ^{230}Th retention in far field
 - $h_{\text{Th}} = 0.001 \text{ ka}^{-1}$
 - 10 percent of ^{230}Th in far field enters biosphere before decay
 - 90 percent decays to ^{226}Ra
- ^{226}Ra biosphere flux is 5.5 times greater when ^{230}Th transport from near field is considered

$$\frac{\text{Model 2 } ^{226}\text{Ra Flux to Biosphere}}{\text{Model 1 } ^{226}\text{Ra Flux to Biosphere}} = \frac{0.0087}{0.0087 + 0.00001} \left[1 + \frac{0.4331 + 0.0001}{0.0001} \frac{0.00001}{0.0087 + 0.001} \right] = 5.5$$

Confirmatory Calculations: Outdoor Effective Dose Radon Pulse Release from a Single Canister

- 2.5×10^{10} Bq ^{222}Rn released with no delay from geosphere transport
- 10,000-m² release area, 20-m mixing height, 2-m/s wind speed
- ICRP average daily breathing rate of 0.925 m³/hr
- Above corresponds to air concentration of 1.25×10^5 Bq/m³, 50-second exposure, and total 1600 Bq ^{222}Rn inhaled
- Derived radon dose coefficient for the confirmatory calculation from ratio of U.S. NRC worker dose limit and annual intake limit from 10 CFR Part 20, Appendix B Table 1, Column 1 (1.35×10^{-8} Sv/Bq)
- Calculated radon dose of 0.022 mSv for decay progeny equilibrium or 0.013 mSv when the SKB equilibrium factor of 0.6 was applied
- Confirmatory result compares well with SKB value of 0.011 mSv (R-06-82, Table 8-10); clarification needed because different results presented in other reports (see slide 12)

Confirmatory Calculations: Indoor Effective Dose Radon Pulse Release from a Single Canister

- Indoor effective dose calculation:

$$C = \frac{E * A}{V * v} \quad D = C * DC * F$$

- 2.5×10^{10} Bq ^{222}Rn released (E); no delay from geosphere transport
- 10,000 m² release area (A), 100 m² house platform, 1,000 m³ house volume (V), 2 hr⁻¹ house ventilation rate (v)
- UNSCEAR dose coefficient (DC) of 32 uSv/yr per Bq/m³
- Occupancy factor (F) of 0.5
- Confirmatory result (D) of 228 uSv compares well with SKB value of 230 uSv (R-06-82, Table 8-11; R-06-81, Table 7-3); clarification needed as different results are presented in other reports (slide 12)
- Calculation provides insights into radon hazard from a canister but does not provide a strong basis for excluding radon from biosphere modeling

Confirmatory Calculations: ^{222}Rn Dose Conversion Factor

- SKB value of 32 $\mu\text{Sv}/\text{yr}$ per Bq/m^3 for indoor radon exposure falls within Health Physics Society “best estimate” range of 20–47 $\mu\text{Sv}/\text{yr}$ per Bq/m^3 for indoor radon (converted from 3 to 7 mSv/yr per 4 pCi/L of indoor radon)
- SKB value of 47 $\mu\text{Sv}/\text{yr}$ per Bq/m^3 for outdoor radon exposure arises from a greater degree of radon decay progeny equilibrium
- SKB values are reasonable
 - SKB adopted commonly used equilibrium factor of 0.4 for indoor radon exposure
 - SKB used increased equilibrium factor to 0.6 for outdoor radon exposure