# A Scoping Calculation of Radiological Impacts on the Generic Biosphere for LILW Disposal Safety Assessment

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The biosphere modeling is the portion of the analysis following the release of radionuclides into a well, surface water body, soil, or other potential locations where humans might be exposed to radionuclides. In order to undertake a safety assessment of a near-surface disposal facility for LILW, it requires a set of radionuclide-dependent biosphere factors which relate radionuclide fluxes to the geosphere-biosphere interface to effective dose rates to the critical group. For the calculation of such factor, considerable international effort has been conducted on analysis of the biosphere. In this paper, a Pathway Dose Conversion Factor (PDCF) approach was taken into consideration and implemented in Excel spreadsheets. The results of illustrative calculations undertaken using these spreadsheets were compared with the other dose factors estimated.

A large variety of exposure pathways can be envisioned, associated with the use of contaminated water. The contribution of each of these individual exposure pathways is summed for an appropriate media to which exposure is assumed to occur. Concentrations in the biosphere are treated as dynamic only to the extent of dynamic concentrations in groundwater, surface water, or ocean water. Depletion or accumulation in soil components is neglected. The underlying assumption when using this approach is that the dynamic behavior of the surface soil layers is much more rapid than that of the groundwater system. This conceptual approach leads to a constant multiplier to water concentrations, which converts those concentrations to doses. This approach is known as a Pathway Dose Conversion Factor (PDCF) approach. PDCFs represent the sum of all exposure pathways for a particular exposure situation. For terrestrial ingestion, exposures can be modeled as the sum of ingestion doses from consumption of contaminated crops and animals. PDCFs are defined such that for a given exposure medium (groundwater, river water, lake, or ocean), the equations are rearranged such that each exposure pathway (drinking water, terrestrial foods, fish) associated with the exposure medium are summed to form the PDCF. The dose for a particular exposure medium is $E_j = C_j PDCF_j$ ,where j refers to the exposure medium. To calculate total dose, this equation is summed over all exposure media.

The biosphere formulation was made to match the formulation given in NCRP[1]. The NCRP formulation uses lumped parameters rather than distributed parameters, with recommendations about uncertainties in their use. The use of these lumped parameters simplifies probabilistic sampling by reducing the number of parameters that may be sampled. Dose conversion factors are taken from IAEA Safety Series 115. Plant and animal uptake factors are consistent with NCRP. Exceptions are the values for H-3 and C-14. NCRP did not tabulate values for these radioelements. The parameters recommended by Yu et al. in RESRAD are used for these elements.

For the generic conceptual model considered in this paper, the results of sample spreadsheet calculations were tested against the other two approaches for the exposure situations. In each calculation, the same consumption rates and dilution factors are used to compare the approaches taken. Table 1 and 2 shows the comparison results of biosphere factor with the other two cases. In the Table 1, the Nirex study[2] considered abstraction from a well, which the well water can be used for irrigation. They used two stages of calculation to estimate the radionuclide concentrations in soils and plants, which considering water balance and radionuclide transport in the soil system, and then to estimate radiological impacts. Although the soil layer is not treated as a dynamic compartment in this study, the difference lies within the range of three orders of magnitude. In the Table 2, the KAERI developed compartment models for river and ocean release using AMBER code[3]. The results obtained from the spreadsheet are similar to those obtained from KAERI study, except for actinides. Key difference would come from the different mass transfer parameters such as soil to plant concentration factors, transfer coefficients etc. which is being incorporated. Nevertheless, it is thought that the NCRP formulation in this study could provide a defensible and traceable formulation. The simple and logical structure of the spreadsheet also facilitates the undertaking of sensitivity calculations and scoping analysis. It should be noted that the relationship of groundwater and surface water systems associated with real sites will have specific real characteristics. These characteristics cannot be adequately dealt with in a generic sense, since any generic assumption about dilution associated with transport to the surface water may be either underestimated or overestimated for a real site.

Table 1. Comparison of PDCFs (Sv/Bq) for well pathway

| Radionuclide | This Study | Nirex Study[2] |
|---|---|---|
| H-3 | 1.86E-14 | 4.40E-17 |
| C-14 | 1.46E-11 | 5.80E-13 |
| Co-60 | 1.92E-10 | 7.23E-14 |
| Ni-59 | 3.53E-11 | 5.23E-16 |
| Ni-63 | 8.39E-11 | 1.15E-15 |
| Se-79 | 1.08E-10 | 2.77E-12 |
| Sr-90 | 5.03E-10 | 7.20E-14 |
| Zr-93 | 1.17E-14 | 3.43E-15 |
| Nb-94 | 6.49E-14 | 4.07E-13 |
| Tc-99 | 8.72E-13 | 2.40E-15 |
| I-129 | 8.32E-11 | 5.23E-13 |
| Cs-134 | 1.46E-09 | 1.01E-12 |
| Cs-135 | 1.54E-10 | 1.64E-13 |
| Cs-137 | 9.99E-10 | 7.07E-13 |
| Sm-151 | 3.67E-14 | 3.47E-16 |
| Pb-210 | 4.95E-09 | 2.35E-11 |
| Ra-226 | 1.68E-08 | 9.90E-12 |
| Ra-228 | 4.14E-08 | 3.13E-12 |
| Ac-227 | 1.36E-11 | 5.47E-12 |
| Th-228 | 1.74E-11 | 7.43E-12 |
| Th-229 | 7.59E-11 | 3.23E-11 |
| Th-230 | 2.61E-11 | 1.93E-11 |
| Th-232 | 2.86E-11 | 1.68E-11 |
| Pa-231 | 2.16E-11 | 3.73E-12 |
| U-233 | 2.21E-11 | 1.29E-13 |
| U-234 | 2.13E-11 | 1.27E-13 |
| U-235 | 2.04E-11 | 1.20E-13 |
| U-236 | 2.04E-11 | 1.18E-13 |
| U-238 | 2.08E-11 | 1.22E-13 |
| Np-237 | 6.33E-13 | 2.81E-13 |
| Pu-238 | 1.69E-12 | 8.10E-13 |
| Pu-239 | 1.84E-12 | 9.03E-13 |
| Pu-240 | 1.84E-12 | 9.00E-13 |
| Pu-241 | 3.53E-14 | 1.71E-14 |
| Pu-242 | 1.77E-12 | 8.70E-13 |
| Am-241 | 3.66E-12 | 9.10E-13 |
| Am-243 | 3.66E-12 | 9.83E-13 |
| Ru-106 | 5.46E-12 | 1.84E-14 |
| Eu-154 | 7.48E-13 | 1.75E-14 |
| Cm-244 | 9.56E-12 | 5.40E-13 |

Table 2. Comparison of PDCFs (Sv/Bq) for river and ocean exposures

| Radionuclide | This Study | | | KAERI Study[3] | | |
|---|---|---|---|---|---|---|
| | River-Farming | River-Freshwater fishing | Ocean-Marine fishing | River-Farming | River-Freshwater fishing | Ocean-Marine fishing |
| H-3 | 9.32E-20 | 3.14E-24 | 9.00E-25 | 4.06E-20 | 3.14E-24 | 9.44E-23 |
| C-14 | 1.75E-17 | 5.06E-18 | 1.48E-18 | 3.79E-19 | 9.05E-19 | 5.22E-19 |
| Co-60 | 2.22E-16 | 6.10E-19 | 1.75E-19 | 1.71E-18 | 8.24E-19 | 4.99E-19 |
| Ni-59 | 3.58E-17 | 1.10E-21 | 3.15E-22 | 2.39E-20 | 7.32E-22 | 2.57E-21 |
| Ni-63 | 8.52E-17 | 2.61E-21 | 7.50E-22 | 5.64E-20 | 1.74E-21 | 6.12E-21 |
| Sr-90 | 6.08E-16 | 5.40E-19 | 1.55E-19 | 1.01E-17 | 3.36E-19 | 6.06E-21 |
| Nb-94 | 1.88E-18 | 2.96E-20 | 8.50E-21 | 7.38E-19 | 2.64E-18 | 6.23E-19 |
| Tc-99 | 1.46E-18 | 3.35E-21 | 9.60E-22 | 2.68E-19 | 2.07E-21 | 1.21E-20 |
| I-129 | 5.55E-16 | 9.59E-19 | 2.75E-19 | 5.23E-17 | 8.68E-19 | 6.23E-19 |
| Cs-135 | 1.84E-16 | 3.49E-18 | 1.00E-18 | 9.92E-19 | 6.05E-19 | 7.63E-21 |
| Cs-137 | 1.19E-15 | 2.27E-17 | 6.50E-18 | 6.43E-18 | 4.01E-18 | 4.05E-20 |
| Ra-226 | 2.40E-14 | 2.44E-18 | 7.00E-19 | 2.90E-25 | 1.34E-30 | 1.03E-34 |
| Ra-228 | 5.93E-14 | 6.01E-18 | 1.73E-18 | 1.78E-30 | 5.42E-36 | 4.09E-39 |
| Ac-227 | 2.99E-16 | 0.00E+00 | 0.00E+00 | 3.61E-27 | 1.52E-31 | 8.70E-36 |
| Th-229 | 5.83E-16 | 1.06E-17 | 3.05E-18 | 2.53E-28 | 7.52E-36 | 3.82E-37 |
| Th-230 | 2.01E-16 | 3.66E-18 | 1.05E-18 | 3.60E-25 | 3.60E-33 | 3.99E-31 |
| Th-232 | 2.20E-16 | 4.01E-18 | 1.15E-18 | 2.60E-31 | 2.99E-39 | 2.53E-38 |
| Pa-231 | 4.93E-16 | 1.24E-18 | 3.55E-19 | 4.95E-27 | 5.31E-35 | 1.35E-34 |
| Pa-233 | 6.04E-19 | 1.52E-21 | 4.35E-22 | 5.07E-26 | 3.25E-32 | 1.93E-29 |
| U-233 | 5.07E-17 | 1.78E-19 | 5.10E-20 | 6.31E-30 | 1.70E-33 | 4.06E-34 |
| U-234 | 4.87E-17 | 1.71E-19 | 4.90E-20 | 9.35E-25 | 3.72E-29 | 1.24E-26 |
| U-235 | 4.68E-17 | 1.64E-19 | 4.70E-20 | 2.01E-27 | 2.11E-31 | 4.19E-30 |
| U-236 | 4.68E-17 | 1.64E-19 | 4.70E-20 | 3.48E-26 | 4.87E-30 | 1.25E-28 |
| Np-237 | 1.77E-17 | 1.92E-18 | 5.50E-19 | 3.16E-25 | 9.54E-29 | 1.23E-26 |
| Pu-238 | 4.99E-17 | 2.00E-18 | 5.75E-19 | 4.60E-17 | 8.51E-20 | 1.86E-18 |
| Pu-239 | 5.43E-17 | 2.18E-18 | 6.25E-19 | 1.96E-16 | 3.62E-19 | 7.91E-18 |
| Pu-240 | 5.43E-17 | 2.18E-18 | 6.25E-19 | 5.05E-17 | 9.25E-20 | 2.02E-18 |
| Pu-241 | 1.04E-17 | 4.18E-20 | 1.20E-20 | 9.58E-19 | 1.78E-21 | 3.85E-20 |
| Am-241 | 7.27E-17 | 3.49E-18 | 1.00E-18 | 3.97E-17 | 5.81E-18 | 7.96E-18 |
| Cm-244 | 1.64E-16 | 2.09E-18 | 6.00E-19 | 4.23E-17 | 4.12E-19 | 6.18E-18 |

## References


[1] NCRP, Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-Specific Studies, NCRP Report 129 (1999).

[2] M. C. Thorne, A Guide to the Spreadsheet Calculations for the Generic Performance Assessment, UK Nirex Limited (2003).

[3] Development of ACBIO: A Biosphere Template Using AMBER for a Potential Radioactive Waste Repository, J. Korean Radioactive Waste Society, Vol.3(3), p.213-229 (2005).