Radioisotopes: Soil Concern Nuclear D&D Sites

Site-specific Soil Partition Coefficients (K_d)

Matthew Darois, CGWP
RSCS Director of Environmental & Engineering

Robert Wills, RRPT, MBA
GEL Nuclear Programs Manager

The POWER of our PLATFORM

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Agenda

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2022 Acquisition

About RSCS

Radiation Safety & Control Services, Inc. (RSCS), now part of Allied Power, specializes in radiation safety and measurement applications. Based in Seabrook, NH, RSCS provides health physics consulting, decommissioning support, environmental and engineering services, training, and instrument calibration.

The Allied Power Platform unites the expertise of RSCS and Dominion Engineering, offering engineering, asset management, and radiological protection services to support maintenance, modifications, and projects.

ALLIED POWER PLATFORM

About GEL

GEL Laboratories

GEL Delivers Analytical Services for:

- Radiochemistry D&D,
- Environmental Radiochemistry
- Radioactive Waste
- NORM
- TNORM
- Uranium Fuel Fabrication Support
- Site Kd Soil Studies
- Water Purification DF Studies
- Bioassay
- Medical Pharmaceuticals Production

Analytical Chemistry (to include radioactive samples)

- Metals
- Organics
- Inorganic
- General chemistry

With over 43 years of experience, GEL is a trusted provider of comprehensive analytical services and data solutions. GEL serves a diverse client base across various sectors, including Industrial, Department of Energy, Department of Defense, Nuclear Power, Waste Management, and States/Municipalities, both in the United States and internationally.

Key Definitions for Nuclear D&D

Soil Testing, Exposure Pathway Modeling, and Fate Transport Models

- **K_d, or the Soil Adsorption Coefficient** - Measurement of how much of a chemical substance or radioactive isotope “sticks” to soil compared to the amount dissolved in soil pore water
- **Pore Water** - The water that is found in the small spaces between sediment particle
- **$DCGL_{soil}$** - Derived concentration guideline limit is a measurement in pCi/gm in soil used to ensure that residual radioactivity from decommissioned sites doesn't exceed acceptable exposure limits. DCGLs are used to calculate the allowable levels of residual radioactivity to meet site specific license termination criteria

K_d Introduction

Key Points

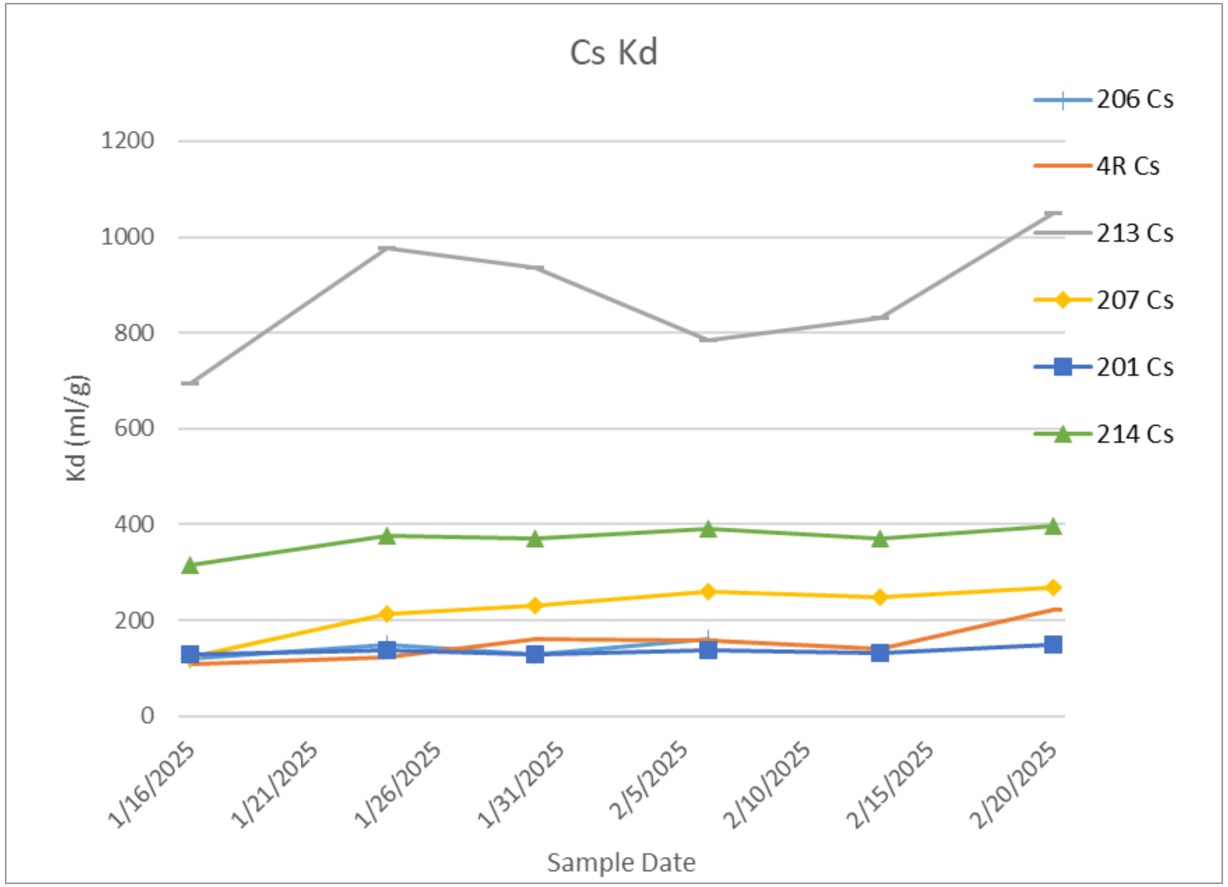
Soil partitioning coefficients (Kd) measures how much of a chemical substance or radioactive isotope adheres to soil compared to the amount dissolved in soil pore water. K_d can predict/estimate contaminant mobility through soil and their transport via pore water hydraulics.

- K_d values are unique to each chemical or radioactive isotope and soil type.
- Partitioning coefficients are the sum of environmental properties (chemical and physical)
- Soil and Contaminant Properties: Factors like organic matter, redox potentials, mineralogy, dissolved solids, pH, and contaminant type and concentration influence Kd values
- High K_d values indicate contaminants are tightly bound to soil particles, reducing leaching risks.
- Low K_d values suggest higher leaching risks, indicating potential groundwater contamination risk(s).

K_d Introduction (continued)

How it is Calculated

Values typically expressed in milliliters$_{water}$ per gram$_{water}$ (ml/g) representing the ratio of amount remaining in solution to the amount adsorbed to soil at equilibrium.



K_d Introduction

Calculating Soil Partitioning Coefficients (mL/g)

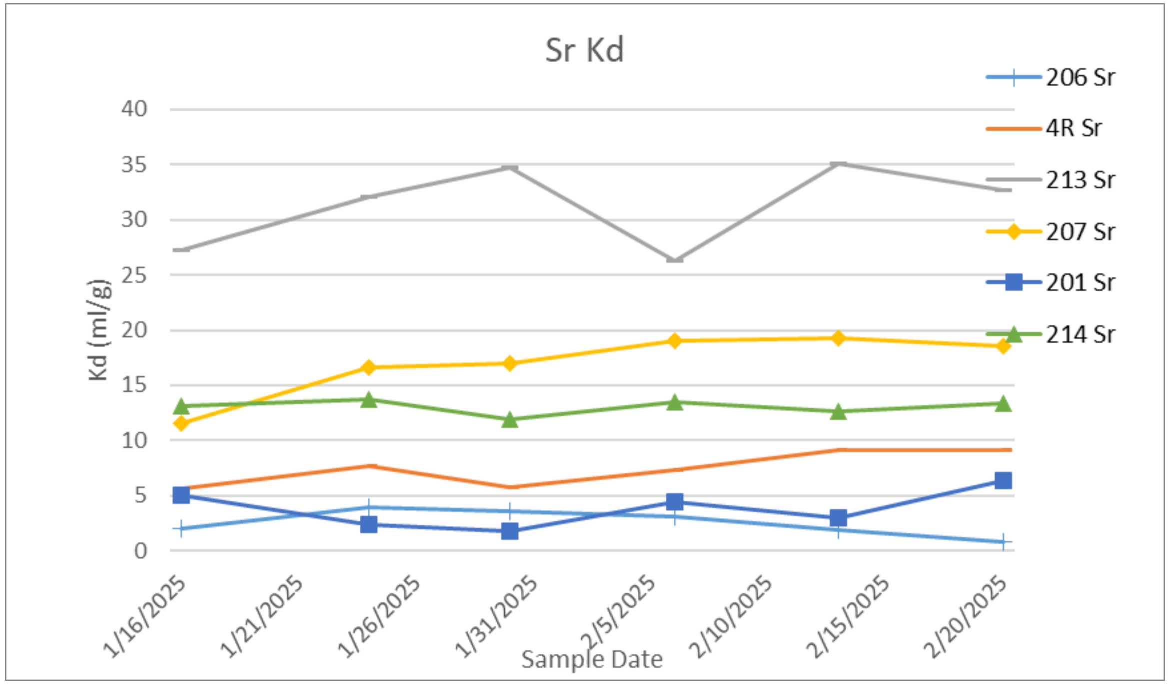
K_d is calculated using the following equation:

$$Kd = \frac{V \times (C_s - C_f)}{M \times C_f}$$

Where:

- V is the volume of the solution (mL)
- C_s is the initial concentration of the contaminant in the solution (mg/L)
- C_f is the final concentration of the contaminant in the solution (mg/L)
- M is the mass of the soil (g)

Soil partitioning coefficients can be used to predict/estimate soil or groundwater concentrations given a known concentration



Example

Sr-90 Kd: **8mL/g**, Sr-90 soil concentration: **10pCi/g**

To calculate soil solution (GW concentration) at equilibrium:

(10pCi/g) X (g/8mL) = 1.25pCi/mL X 1000mL/L = **1,250pCi/L**

Contaminant Mobility

Contaminant retardation factors and mobility as a function of K_d

Calculating Retardation Factors:

$Vc/Vgw = 1/(1(+\rho_b/n*Kd))$

Where:

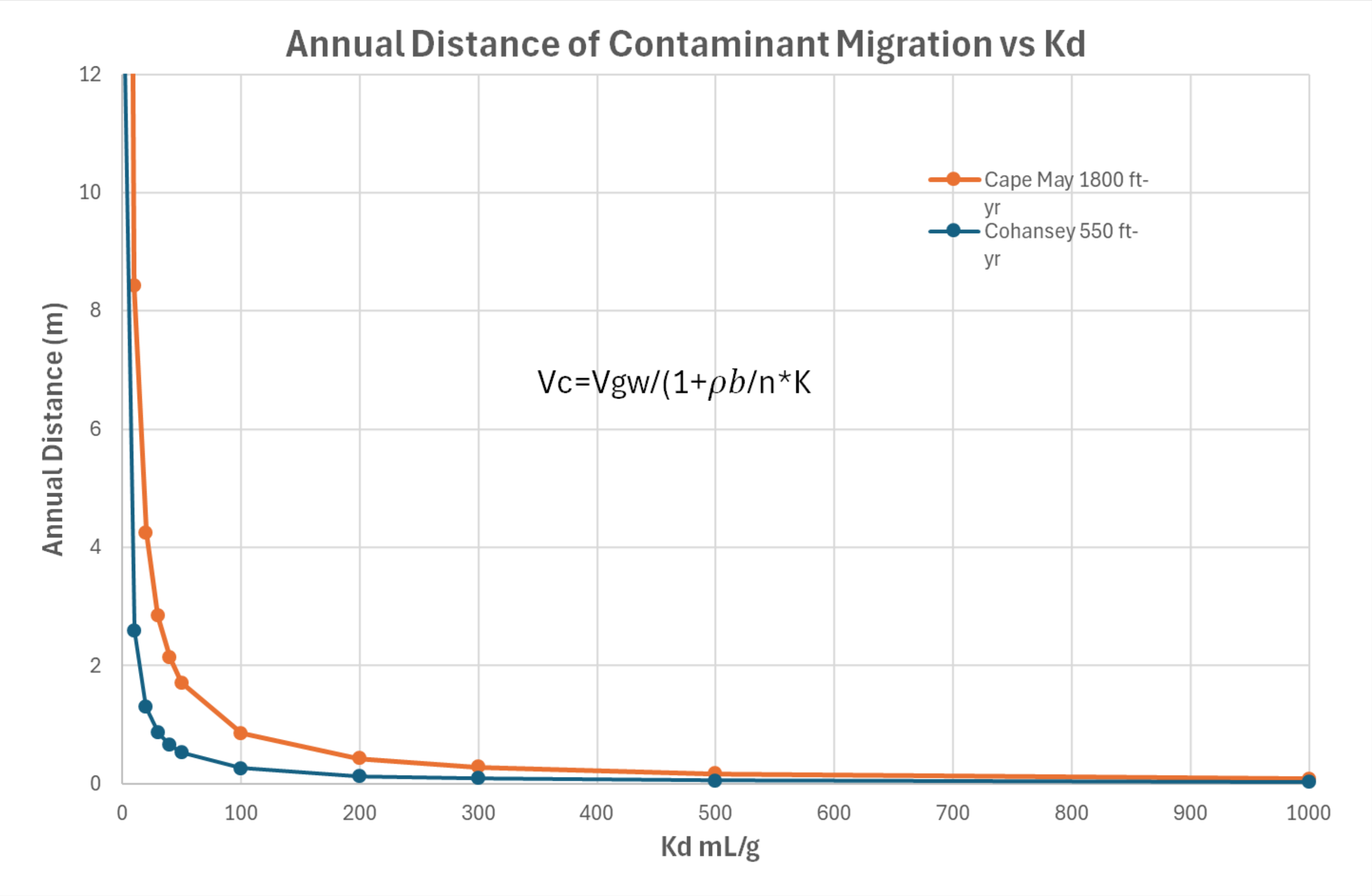
Vgw =groundwater velocity

Vc =contaminant velocity in groundwater

ρ_b = the dry bulk density of the aquifer (1.6 $g \cdot cm^{-3}$ for local sands),

n = the porosity (0.25 in sand) [6], and

Kd = the distribution coefficient (mL/g).



Objectives and Regulatory Guidance

Soil Partitioning Coefficients and Decommissioning

Objective:

- Develop Derived Concentration Guideline Limits (DCGLs) that include stie specific basis for contaminant mobility and exposure scenarios.

Guidance:

- **NUREG 1575 Rev 2 (MARSSIM):** Describes dose modeling, DCGL development, and their application.
- **NUREG-1757, Volume 2, Revision 2:** Discusses soil partitioning coefficients and provides information on selecting appropriate Kd values for various radionuclides to support decommissioning decisions.
- **DUWP-ISG-02:** Emphasizes the importance of Kd selection in the D&D/LTP process and discusses the development of site-specific distribution coefficients (Kd values).
- **ASTM C1733-21 [4]:** Analytical procedure guidance document outlining the basis for GEL analytical procedures methods

Benefits:

- Site specific values provide a strong technical basis for defined end-state conditions and DCGLs.
- Provide site with strong basis for remedial actions and cleanup goals
- Reduces DCGL conservatism for soils providing potential margin for other dose pathways

ASTM Laboratory

Method to Determine Kd

- GEL laboratory utilizes ASTM C1733-21.
- We utilize the batch method for K_d studies
- We are provided site specific soil, ground and surface water
- We spike the water with a know quantity of the radionuclide of interest
- We determine the activity over time that the soil absorbs
- The data is sent to RSCS soil science team to determine Kd

Kd Batch

Method

- The method utilizes the following process:
- **Prepare the mixture: Mix a mass of soil with a volume of water or another medium.**
- **Add the contaminant:** Add a known activity of radionuclide to the water “typically 500 pCi/ml” to the mixture.
- **Mix:** Gently mix the mixture, usually 2–48 hours.
- **Analyze:** Measure the concentration of the isotopes in the liquid phase.

Sample Planning

Sampling Basis and Guidance

Evaluation of Historical Documentation:

- Review historical site data and Hydrogeologic Conceptual Site Model (CSM)
- Review Historical Site Assessment(HSA), consider survey unit classifications:
  - **Class 1**: High potential for contamination
  - **Class 2**: Low to moderate potential for contamination
  - **Class 3**: Highly unlikely contamination
- Align with License Termination Plan (LTP) and HSA to select proper Radionuclides of Concern (ROCs)

Sample Planning (continued)

Sampling Basis and Guidance

Sample Plan Development:

- Data Quality Objectives (DQOs):
- Develop/identify hydrostratigraphic units
- Consider end-state and backfill materials
- Develop/identify basis for ROCs
- Data gaps and dose modeling “sensitivity”
- Basis for pairing soil/groundwater samples
- Consider laboratory requirements for soil and groundwater volumes
- Sample collection, preservations and shipping instructions (COC)

Sample Collection:

- Prioritize Class 1 and 2 areas for K_d sample collection
- Collect at least three samples from each identified unit

Reporting:

- Review of DQO’s
- Comparison with “default” values
- Recommendations: LTP, Remediation, etc.

Key Radionuclides of Concern

Selection of ROCs

- No generic list of ROCs exists to meet all site needs
- Varied by site and should be driven by a technical basis document looking at site specific end-state definition, exposure scenarios and sensitivity analysis derived form dose modeling
- K_d analysis is time consuming and relatively expensive, site-specific ROC selection basis will reduce cost and time
- Common ROCs evaluated*

Common Radionuclides of Concern (ROCs)**
Iron-55
Cobalt-60
Nickle-63
Strontium-90
Technetium-99
Cesium-137
Plutonium-238/239
Americium-241
Plutonium-241

**This not a comprehensive list. ROCs may vary based on site operating history, radioactive decay, hydrogeology, end-state assumptions and other site-specific factors*

***ASTM C1733-21 allows for the use of surrogate stable isotopes and chemical forms that approximate the same environmental fate and transport attributes as ROCs*

Factors Effecting K_d

Environmental and Laboratory Considerations during D&D

Redox potential:

- Some ROCs are sensitive to redox reactions i.e., Ferros Iron (Fe II, very soluble), Ferric Iron (Fe III, typically insoluble)
- Oxidation of iron and manganese can lead to sample acidification, altering ROC mobilities

Organic/inorganic contaminants in soil:

- Hydrocarbons (COD/BOD)
- Organics (BOD)
- Concrete rubble/dust suppressant leachate
- Deicing amendments (CMA, sodium chlorides)

Physical changes in soil:

- Backfill arrangement/aeration
- Offsite soils
- Change in cover and/or saturation

Physical changes to groundwater:

- Infiltration, cover, compaction/porosity, rubblized concrete, surface water and drainage interactions

Summary

- **Unique soil chemistry**, radionuclide properties, and environmental conditions at each site make generic Kd values potentially inaccurate for evaluating radionuclide movement in soils and water
- **Kd factors influence** the speed at which contaminants enter groundwater
- **Knowing soil Kd is essential** when decommissioning nuclear facilities to establish site-specific DCGL for each isotope
- **Accurate DCGL** calculations clarify end state dose limits

This results in improved remedial design and waste estimation

Literature (mL/g)	Tc-99	Sr-85/90	Fe-55	Cs-137	Co-60	Am-241
IAEA 2010 (Sand)[1]	0.23	22	320	530	640	1000
Sheppard & Thibault 1990 (Sand)[2]	0.10	15	220	280	60	1900
Rowan and Carr 2016 (Sand)[3]	N/A	77	260	1200	2400	2200
IAEA 2010 (Loam/Clay)[1]	N/A	69	1100	370	3800	4300
Sheppard & Thibault 1990 (Clay)[2]	1.00	110	5100	1900	550	8400
Current D&D Site (2025)	0.07-54	2.04-449	89-970	7-4841	77-6960	724-6646

Note 1 – Reference [3] IAEA, "Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments," International Atomic Energy Agency, 2010.
Note 2 - Reference [2] M. Sheppard and D. Thibault, "Default Soil Solid/Liquid Partitioning Coefficients, Kds, for Four Major Soil Types: A Compendium," *Health Physics,* Vols. Vol 59, No. 4, pp. 471-482, October 1990.
Note 3 – Reference [4], "Site-specific soil Kd for the environment near CANDU reactors," CANDU Owners Group Inc., 2016.

Matthew Darois, CGWP
Director of Environmental & Engineering
(603)988-3688 | medarois@radsafety.com

RSCS
Radiation Safety & Control Services

Robert Wills, RRPT, MBA
GEL Nuclear Programs Manager
(843)906-5929 | robert.wills@gel.com

GEL Laboratories

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