Terrestrial and Aquatic Pathways

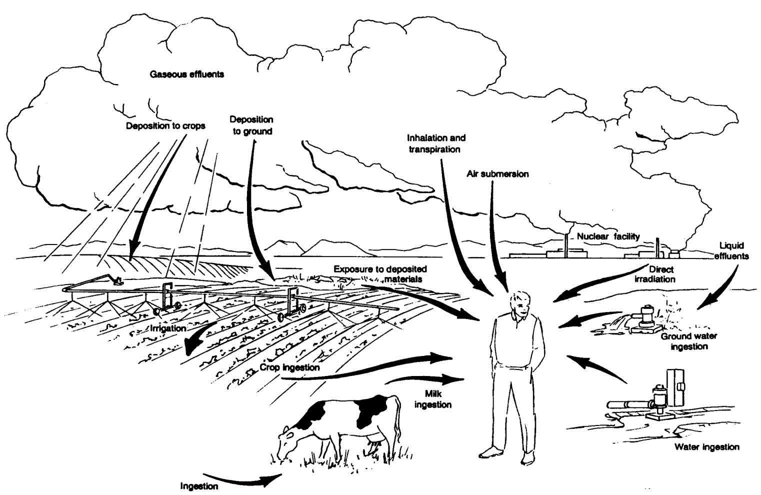
HPHY 6605

2012

Introduction

- Contamination of land can occur from:
  - – deposition of atmospheric material
  - – waste products placed in ground
- Contamination of water can occur from
  - – deposition of atmospheric material
  - – direct discharges to water
  - – mobilized land contamination

Pathway Chart



Introduction

- Concern of discussion is primarily for dose to people because
  - – we are more concerned about people
  - – plants and lower animals are more radiation resistant
  - – food may be grown on contaminated soil
  - – food can be contaminated by foliar deposition
  - – direct radiation from deposited radionuclides can deliver dose
- Recent concern for dose to non-human biota (limited regulation)

Soil

- Soil is composed of organic and mineral matter
- Texture and behavior of soil is governed by physical make-up
  - sand 20 - 2000 µm
  - silt 2 - 20 µm
  - clay < 2 µm

Soil

- Clay is the “active ingredient” in soil
  - small size means large surface area
  - 1 cubic foot of loam is estimated to have a surface area of 50,000 m^2
  - Chemistry results in negative surface charges
- Soluble radionuclides in soil can:
  - adsorb
  - undergo ion exchange
  - precipitate
  - complex with organic compounds
  - remain mobile in ionic or colloidal form
- Erosion and re-suspension also contribute to mobility

Soil Properties

TABLE 10–2 Physical Data of Soils

Soil Type	Diameter (μm)	Particles/g	Surface Area (cm^2/g)
Sand	20–2000	10^4	23
Silt	2–20	6×10^6	454
Clay	<2	9×10^{10}	8×10^6

Adapted from Whicker and Schultz (1982), p. 34.

- Partition of radionuclides between soil or sediment and interstitial water is expressed as

$$K_d = \frac{\left(\dfrac{\text{nuclide sorbed on soil}}{\text{mass of soil}}\right)}{\left(\dfrac{\text{nuclide dissolved in water}}{\text{volume of water}}\right)}$$

- Units of K_d are usually milliliters per gram
- K_d varies greatly with chemical species
- Ranges of measured values are large within chemical species

Some reported values of Kd (from NCRP, 1984)

Locale	Element	Reported values (mL g^{-1})
Lake Michigan	Cs	510 to >10^5
Clinch River	Cs	1360 to 88,000
Freshwater pond	Cs	4600
Different soils	I	0.007 to 52.6
Hudson River	Pu	7 x 10^5
Lake Michigan	Pu	3.3 x 10^5
Savannah River	Pu	0.4 to 4.1 x 10^5
Nevada tuff	Ra	6700
Utah soils	Ra	214 to 467
White Oak Lake, TN	Ru	$\leq$1
Laboratory studies	Ru	<1 to 9 x 10^4
Great Lakes	Sr	30 to 85
White Oak Creek, TN	Sr	100 to 150

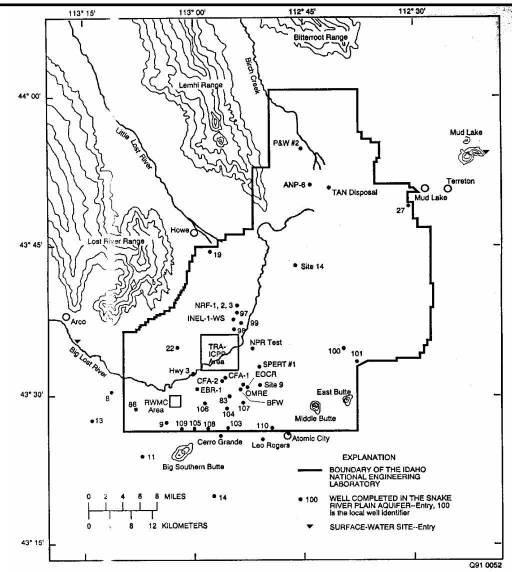
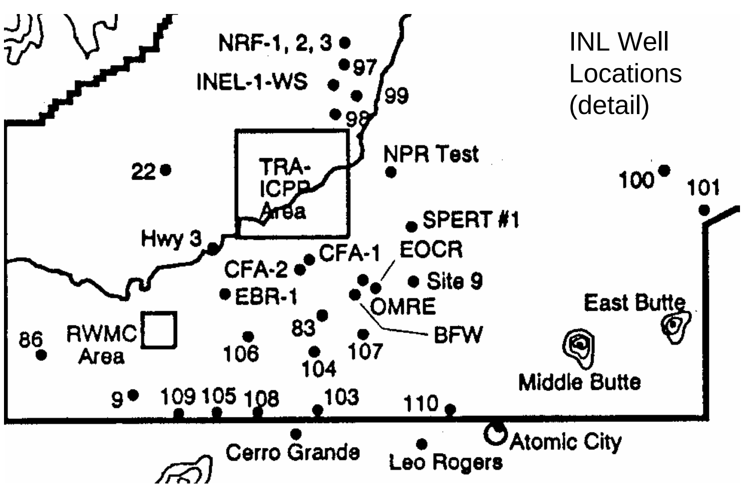


Figure 16. USG sample location map for the INEL Site and vicinity.

INL Well Locations

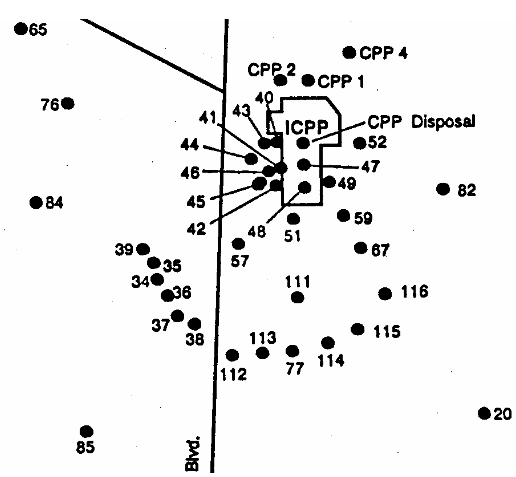
Soil

- K_d is a good general descriptor of how nuclides will move through soil when transported by water
  - discuss tritium, Cs, Sr, I, Pu
  - fallout and groundwater transport
- INL groundwater example
  - tritium and Sr-90 seen in plumes
  - other nuclides seen only near sources except for research-level measurements of ^{129}I & ^{36}Cl

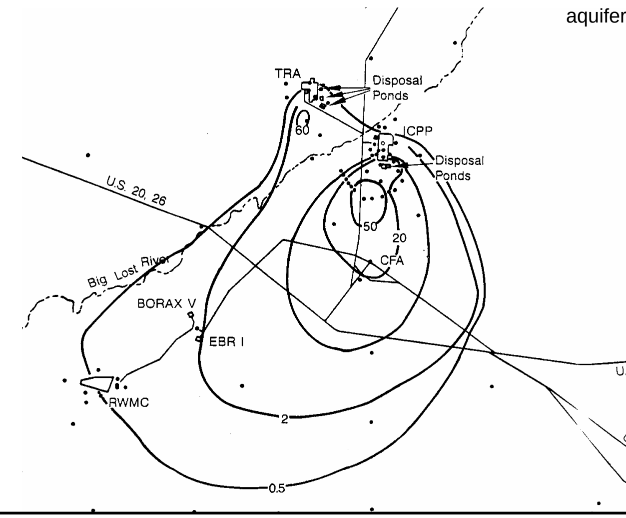


INL Well Locations (detail)

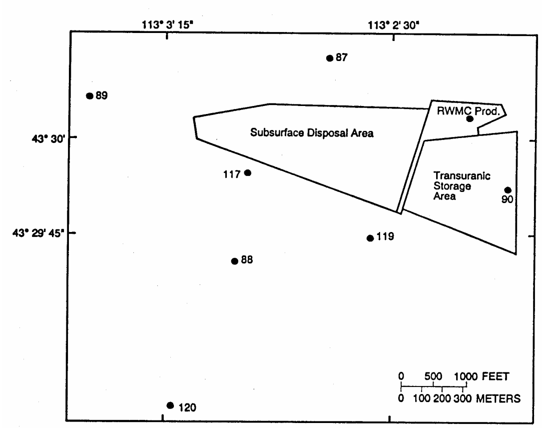
INL Well Locations – Detail around INTEC (ICPP)



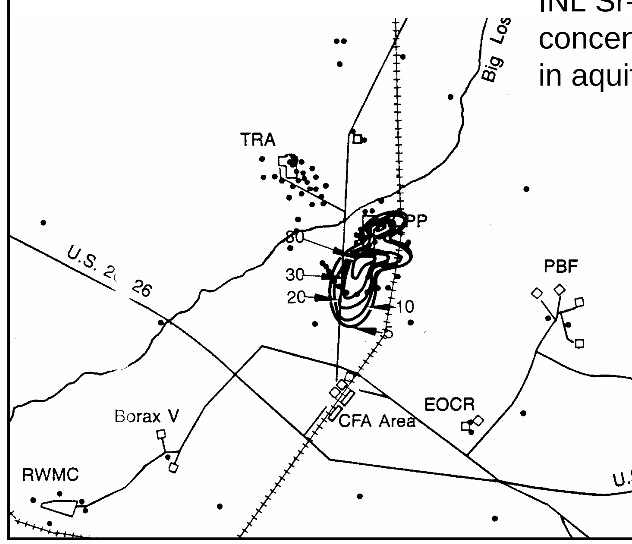
INL tritium concentrations in aquifer nCi/L

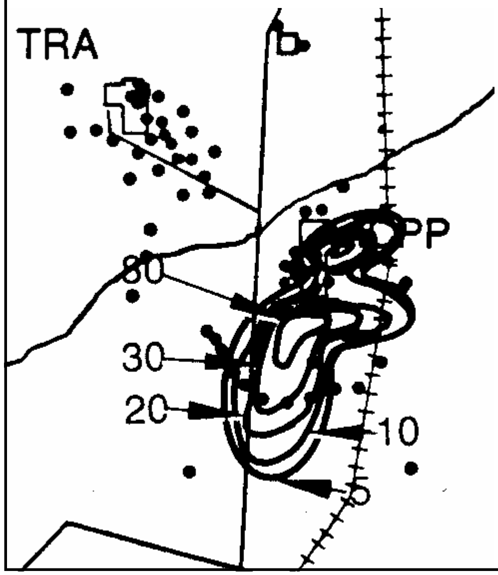


INL Well Locations – Detail around RWMC



INL Sr-90 concentrations in aquifer pCi/L





INL Sr-90 concentrations in aquifer pCi/L (detail)

Plants

- Uptake in plants is described by

$$UF_{plant} = \left(\frac{\text{concentration in wet vegetation}}{\text{concentration in dry soil}} \right)$$

- The uptake factor (UF_{plant}) is unitless
- Uptake factor is also known as Concentration Ratio, CR

Plants

- Plants take up radionuclides from soil
- Only sixteen elements are known to be needed by plants - C, H, O, N, P, S, K, Ca, Mg, Fe, Mn, Z, Cu, Mo, B, Cl
- However any element in soil, including radionuclides, will be found in plants in trace quantities

Plants

- UF_{plant} varies widely, dependent on numerous conditions
  - low calcium will increase uptake of strontium
  - low potassium will increase uptake of cesium
- Site-specific field data are best but seldom obtainable
- Default values are published in NCRP 76

TABLE 11-1 Typical Plant-Soil Concentration Ratios.

Element*	CR	Element*	CR
H	4.8	Mo	0.12
C	5.5	Tc	0.25
Na	0.052	Ru	0.05
P	1.1	Rh	13
Cr	0.00025	Ag	0.15
Mn	0.029	Te	1.3
Fe	0.00066	I	0.02
Co	0.0094	Cs	0.01
Ni	0.019	Ba	0.005
Cu	0.12	La	0.0025
Zn	0.4	Ce	0.0025
Rb	0.13	Pr	0.0025
Sr	0.017	Nd	0.0024
Y	0.0026	W	0.018
Zr	0.00017	Np	0.025
Nb	0.0094		

*Listed in order of increasing atomic number.
Source: USNRC 1977.

Metabolic transport through food chains

- Transport is often described in terms of chemical congeners
- Ability of organism to discriminate between element of interest and congener is expressed as "observed ratio"

$$OR_{sample-precursor} = \frac{(C_e/C_c)_{sample}}{(C_e/C_c)_{precursor}}$$

- The OR for cows between diet and milk for Sr-90 is about 0.1; also for humans
- The OR between diet and human bone is about 0.15
- Cows serve to filter Sr-90 out of the human diet

Plants

- Foliar deposition is important especially for short-lived radionuclides
  - Soil deposition is usually unimportant for short-lived radionuclides
- Rain-splash of soil contamination can also contribute to foliar deposition
- Activity may pass directly to man, pass via grazing animals, or be absorbed by a plant

Grazing Animals

- Sr-90 in milk from foliar and soil uptake by plants can be approximated with a linear model

$$C = p_r F_r + p_d F_d$$

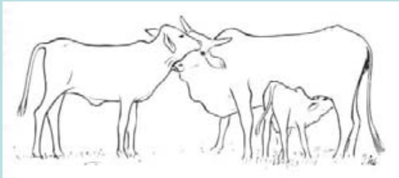
C = ratio of Sr-90 to Ca in milk [pCi of Sr-90 per g of Ca]
F_r = annual deposit of Sr-90 [mCi/km^2]
F_d = cumulative deposit of Sr-90 [mCi/km^2]
P_r = empirical fallout rate-dependent proportionality factor
P_d = empirical deposit-dependent proportionality factor

Radioactive Iodine

- Foliar deposition is primary Iodine-131path
  - half life too short for soil uptake to contribute
- Note that deposition velocity studies were conducted experimentally at INL
  - Experimental Field Station [formerly experimental dairy farm]

Grazing Animals

- Odd things can happen
  - cows eating stored feed in winter still have some iodine in milk
  - apparently due to grooming



Radioactive Iodine

- I-131 is especially important in fresh fission product contamination because…
  - cows may graze outdoors when forage is available
  - iodine deposited on forage transfers readily to milk
  - fresh milk pathway allows insufficient time for significant decay
  - humans concentrate iodine in the thyroid
  - the thyroid has a small mass
  - infants drink a lot of milk and have a very small thyroid, enhancing dose
- The trend in the US is to rely mostly on stored feed with minimal to no grazing even in summer
  - http://www.epa.gov/agriculture/ag101/printdairy.html#feed

Radioactive Iodine

- The cow-milk pathway increases dose by a factor of 700 over direct inhalation
- Intake of stable iodine (KI) within a few hours of intake of radioiodine can block uptake
- Use of KI is not without side effects
  - acne, loss of appetite, or stomach upset may occur

Cesium-137

- For cesium-137, root uptake occurs and foliar deposition is also important
- Cesium is found in fruits, vegetables and grains as well as milk
- A linear model relating cesium in milk to cesium concentration in air has had some success
- Model underestimated concentrations in Florida milk, apparently due to low potassium

Aquatic Systems

- A general approach to dispersion in receiving bodies of water is not possible
  - depth, bottom structure, tides, winds, temperature, physical configuration
- Organisms and bottom sediment play an important role
- Isotopes will sorb and desorb as a function of concentration of ions
  - Cl competes with Cs for adsorption sites, see Fig 5-9 in text.
- Local studies and modeling are the norm
  - example: USGS has studied SRP aquifer for over 50 years and they are still not finished

Cesium-137

- A situation involving wild boars, truffles and Chernobyl contamination occurs in Germany
- Truffles tend to absorb and retain Cs-137
- Boars plow through contaminated soil with their snouts to feed on truffles
- Boars become radioactive themselves
- Harvested boars are tested by a German agency and confiscated if found above 600 Bq/kg
- Of 640,000 boars harvested in 2009, ~3000 were confiscated and the hunters compensated
  - Verena Schmitt-Roschmann, Associated Press, 8/19/10

Rivers

- Flowing streams and rivers are easiest to handle
- Till & Grogan*, provide semi-empirical approaches to estimating concentrations for regions that are…
  - Unmixed near discharge
  - Mixed vertically but not laterally
  - Mixed Completely

*Radiological Risk Assessment and Environmental analysis, Oxford Press, 2008

Rivers

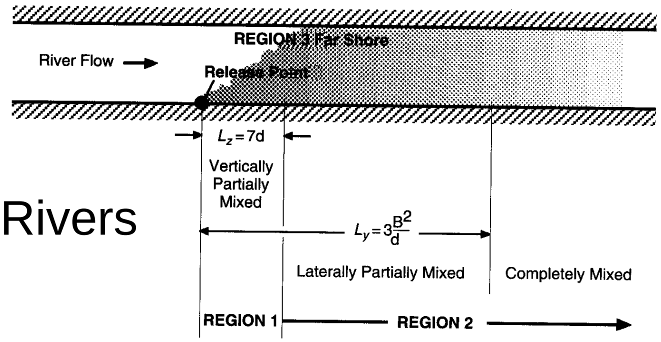


Figure 4.2 River mixing regions.

L = length along river   d = depth of river   B = breadth of river

Estuaries

- Estuaries are important:
  - major receptors of effluents
  - productive; shellfish, finfish
- Each estuary or river must be studied on an individual basis
- Physical models have been used to experimentally study mixing (Delaware river example in text, p. 126)

Oceans

- Oceans tend to be stratified so vertical mixing is slow
- Vertical mixing has been studied using uranium decay products, Ra-226 and Th-230 as tracers
- Data indicate that mixing is most rapid near the bottom and near the surface with a minimum at the thermocline
- Near surface mixing and transport is large, however because of currents

Concentration Factors

- The concentration of an element (radionuclide) in an aquatic organism is expressed simply in terms of the concentration in water

$$CF = \frac{CONCENTRATION\ IN\ ORGANISM}{CONCENTRATION\ IN\ WATER}$$

- CF's are wide ranging; NRC provides default values handout for use in models when site-specific data are unavailable

TABLE 11–2 Typical Concentration Ratios for Aquatic Organisms.

Element*	Freshwater Fish	Invertebrate	Saltwater Fish	Invertebrate
H	0.9	0.9	0.9	0.93
C	46,000	91,000	18,000	14,000
Na	100	200	0.067	0.19
P	100,000	20,000	29,000	30,000
Cr	200	2,000	400	2,000
Mn	400	900	550	400
Fe	100	3,200	3,000	20,000
Co	50	200	100	1,000
Ni	100	100	100	250
Cu	50	400	670	1,700
Zn	2,000	10,000	2,000	50,000
Br	420	330	0.15	3.1
Rb	2,000	1,000	8.3	17
Sr	30	100	2	20
Y	25	1,000	25	1,000
Zr	3.3	6.7	200	80

Other Pathways

- Other pathways include
  - uptake by edible seaweed
  - use of river water for irrigation
  - aquiculture

TABLE 11–2 Typical Concentration Ratios for Aquatic Organisms.

Element*	Freshwater Fish	Invertebrate	Saltwater Fish	Invertebrate
Nb	30,000	100	30,000	100
Mo	10	10	10	10
Tc	15	5	10	50
Ru	10	300	3	1,000
Rh	10	300	10	2,000
Te	400	6,100	10	100
I	15	5	10	50
Cs	2,000	1,000	40	25
Ba	4	200	10	100
La	25	1,000	25	1,000
Ce	1	1,000	10	600
Pr	25	1,000	25	1,000
Nd	25	1,000	25	1,000
W	1,200	10	30	30
Np	10	400	10	10

Intervention Levels for Food

Table 1

FDA AND FSIS DERIVED INTERVENTION LEVELS FOR IMPORTED FOOD AFTER THE CHERNOBYL ACCIDENT, Bq/kg (pCi/kg)

Radionuclide	FDA LOC Infant Food	FDA LOC Other Food	FSIS Screening Value Meat and Poultry
I-131	55 (1500)	300 (8000)	55 (1500)
Cs-134 + Cs-137	370 (10,000)	370 (10,000)	370 (10,000)

- FDA – Food and Drug Administration
- LOC – Limit of concentration
- FSIS – Food Safety and Inspection Service
- From “Accidental Radioactive Contamination Of Human Food And Animal Feeds: recommendations For State And Local Agencies, U.S. Department Of Health And Human Services, 1998