Canadian Nuclear Safety Commission
Commission canadienne de sûreté nucléaire

Canadian Benthic Data Set

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RECAP: Thompson et al. (2005)

- 12 contaminants, As, Cr, Cu, Mo, Ni, Pb, Se, U, V, Pb-210, Po-210, Ra-226 (N=1,020 - 2,269)
- Uranium mining regions with co-located benthos sampling & organic depositional sediments
- 132 Ontario & Saskatchewan sites
- 190 genera and/or species
- Criteria/methods follow Persaud et al. (1992) as used for Ontario LEL / SEL guidelines (As, Cr, Cu, Ni, Pb)
- 90^{th} percentile SSLC for each taxon
  5^{th} percentile LEL, 95^{th} percentile SEL calculated
- Nonparametric percentiles, many selection criteria, no dose calculations, no bootstrapping, no multivariate

Original Methods

- "Weighted" percentile as in Persaud et al. (1992), also calculated "closest observation" percentile (SPSS)
- Weighted value typically higher
  Uranium LEL 104 vs 32, SEL 5,874 vs 3,410 ug/g
- Six data selection criteria
- Minimum of 10 sites per taxon, lost considerable data
- Concentration range 2 orders of magnitude (V, Cr x)
- Spatial range (35 reference sites, 97 contaminated)
- Mainly benthic species (81% defined as infaunal)
- Minimum of 20 SSLCs for LEL/SEL calculation
- Data mean ~30 for SSLCs, LEL/SEL range N=28-59

Suggested Follow-up

- Dose Calculations (CNSC)
  - PSL2 & ERICA approaches
- Multivariate Analyses (IRSN)
  - RDA & PCA
- Augmenting the data set (CNSC)
  - Trace Original Records
  - RCA for 2002-2009 data
- Other possible exercises
  - Parametric curve fitting for percentiles
  - Bootstrapping for confidence intervals
  - Sensitivity Analysis (sites, SSLCs, taxa)

Dose Questions from 2005

- Why does species richness decline at contaminated sites, e.g. the loss of bivalves and gastropods?

  - Multivariate analyses (metals vs radionuclides)

- Why are Pb-210, Po-210 LEL values so low?

  - Dosimetry or biased sampling of certain daughters

Sediments Bq / g dw	**LEL range** Thompson et al. 2005	Benthos screening at 10 µGy/h (ERICA)
Ra-226	**0.1 – 0.6**	**0.6**
Pb-210	0.5 - 0.9	80
Po-210	0.6 – 0.8	600

PSL2 Methods - INTERNAL dose only

Empirical: 3 decay series headed by U-238, Th-230, Rn-222

	Calculations, % Dose		Data	Issues	Notes
U-238	Nat uran 49%	15.9%	96%	Pooled DCC	
Th-234	Ignored			Equilibrium	
U-234	Nat uran 49%			Pooled DCC	Higher DCC
→ Th-230	= daughter	10.2%		Equilibrium	Empirical
Ra-226	Measured	15.6%	99%		
→ Rn-222	= 30% parent	18.7%		Retention %	Unknown
Pb-210	= Rn parent		74%		
Bi-210	= Rn parent				
Po-210	= Rn parent	39.4%	70%	Equilibrium	CRITICAL
U-235 ++	Nat uran 2%			Pooled DCC	Daughters

% = Reference Lake example where all data were collected

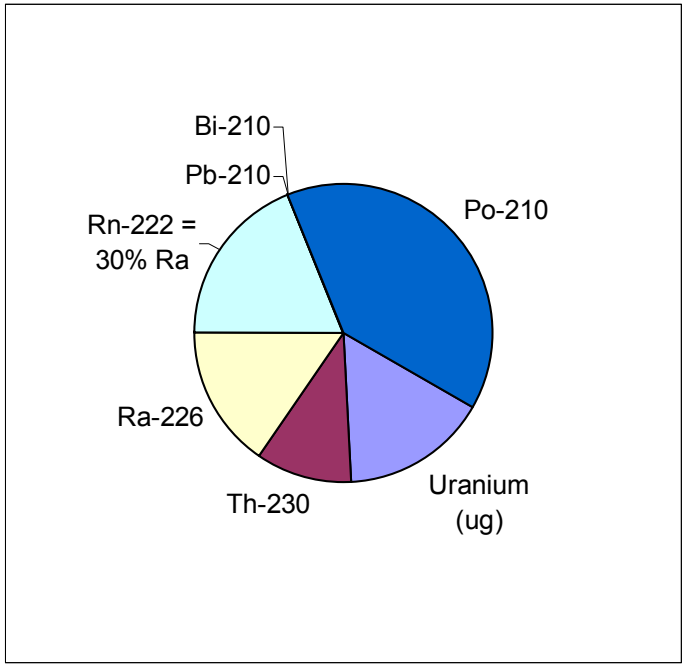
Dose example with measured data

- DW Sediment = Chironomid (90% water, PH data)
- Alpha RBE=40, Amiro (1997), Th-234 ignored
- Pooled Uranium (ug x 0.0252), U-238 DCC
- Rn-222 = 30% Ra-226 (vertebrate, long-term)
- Note lack of equilibrium (Po > Ra > U/Th)

Sample	April 2004 0-2 cm SEDIMENTS Mean					
Data Source	Fulton Creek Watershed 2004					
Fulton Lake	**Measured**	Estimated	Estimated	**PARAMETER**		
Reference	**Sediment**	DRY Sediment	WET Invertebrate	**DCF**	Dose	
Nuclide	**[Bq/g dw]**	Bq/g dry wt	Bq/kg wet wt	**Gy/a per Bq/kg**	Gy/a	**% Dose**
Uranium (ug)	1.66	0.042	4.2	**8.64E-04**	3.62E-03	**15.9%**
Th-230	0.024	0.024	2.4	**9.64E-04**	2.31E-03	**10.2%**
Ra-226	0.036	0.036	3.6	**9.84E-04**	3.54E-03	**15.6%**
Rn-222 = 30% Ra		0.011	1.1	**3.93E-03**	4.24E-03	**18.7%**
Pb-210	0.082	0.082	8.2	**2.17E-07**	1.78E-06	**0.0%**
Bi-210		0.082	8.2	**1.97E-06**	1.62E-05	**0.1%**
Po-210	0.082	0.082	8.2	**1.09E-03**	8.94E-03	**39.4%**

Interpretation of Natural Hazard

Reference site is approaching Protect 10 uGy/h threshold
Any assumptions about Ra-226 daughters are critical



Dose Rate	**0.02 Gy/a**
	0.1 mGy/d
	2.6 uGy/h

Hazard Quotients	
PSL2 Benthos	**0.01**
Protect Generic	**0.26**
Protect Invertebrate	0.01

ERICA Approach (Internal + External)

All calculations, radionuclides - except for dose from water

F	Differences vs PSL2	Data	PSL2
U-238	Explicit calculation	96%	Pooled with Nat U
Th-234	Included		Excluded
U-234	Explicit calculation		Pooled with Nat U
Th-230	Equilibrium with U		Equilibrium with Ra
Ra-226	Rn-222 in DCC	99%	Mostly measured
Rn-222	Included in Ra-226		30% of Ra-226
Pb-210	100% vs 30%	74%	30% of Ra-226
Bi-210	100% vs 30%		30% of Ra-226
Po-210	100% vs 30%	70%	30% of Ra-226
U-235 ++	Explicit calculations		Pooled with Nat U

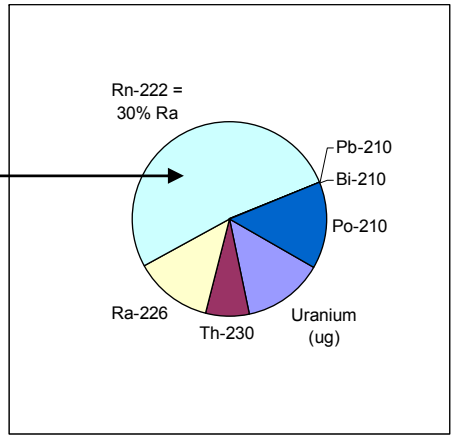
Alpha RBE = 10 vs 40, DCCs more realistic, Insect Larvae model

PSL2 using ERICA assumptions

Similar results as conservative parameters cancel out, especially when missing data for Ra-226 daughters

Fulton Lake Reference Nuclide	Measured Sediment [Bq/g dw]	Estimated DRY Sediment Bq/g dry wt	Estimated WET Invertebrate Bq/kg wet wt	PARAMETER DCF Gy/a per Bq/kg	Dose Gy/a	% Dose
Uranium (ug)	1.66	0.042	4.2	**8.64E-04**	3.62E-03	**13.3%**
Th-230		0.021	2.1	**9.64E-04**	2.02E-03	**7.4%**
Ra-226	0.036	0.036	3.6	**9.84E-04**	3.54E-03	**13.0%**
Rn-222 = 30% Ra		0.036	3.6	**3.93E-03**	1.41E-02	**51.9%**
Pb-210		0.036	3.6	**2.17E-07**	7.81E-07	**0.0%**
Bi-210		0.036	3.6	**1.97E-06**	7.09E-06	**0.0%**
Po-210		0.036	3.6	**1.09E-03**	3.92E-03	**14.4%**

Radon



Dose Rate	**0.03 Gy/a**
	0.1 mGy/d
	3.1 uGy/h

Hazard Quotients	
PSL2 Benthos	**0.01**
Protect Generic	**0.31**
Protect Invertebrate	0.02

ERICA – Patterns in DCCs (Insect)

IntAlpha of several radionuclides and ExtBG of Ra-226/223 have the most potential to affect results

U-235 & daughters not important (low % of natural uranium)

Organism	Insect larvae		U-235 series

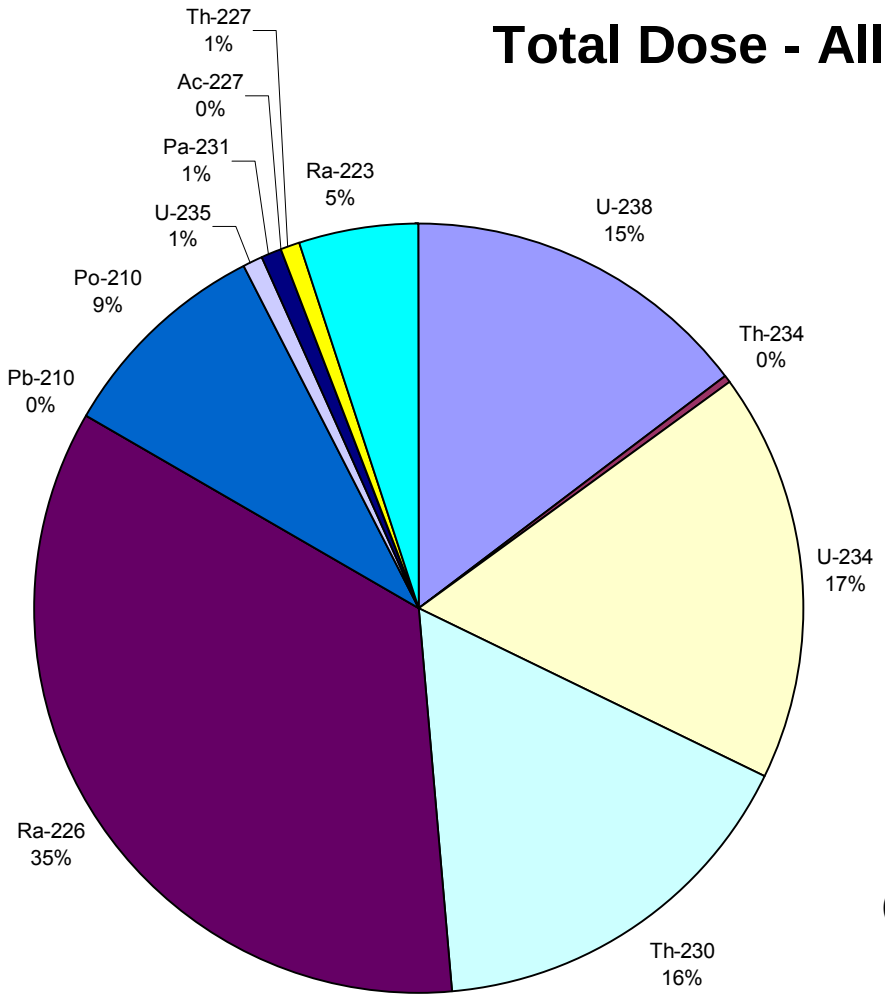
Average of DCC	Type				
Nuclide	ExtBG	ExtLowB	IntAlpha	IntLowB	IntBG
Pb-210	1.10E-04	0.00E+00	0.00E+00	4.20E-06	1.36E-04
Po-210	4.90E-09	0.00E+00	3.10E-03	0.00E+00	0.00E+00
Ra-226	1.30E-03	0.00E+00	1.37E-02	0.00E+00	2.80E-04
Th-227	6.40E-05	0.00E+00	3.37E-03	0.00E+00	3.40E-05
Th-230	9.00E-07	0.00E+00	2.70E-03	0.00E+00	0.00E+00
Th-234	3.70E-04	0.00E+00	0.00E+00	1.60E-06	1.58E-04
U-234	9.40E-07	0.00E+00	2.80E-03	0.00E+00	0.00E+00
U-235	1.10E-04	0.00E+00	2.59E-03	0.00E+00	1.08E-04
U-238	7.20E-07	0.00E+00	2.40E-03	0.00E+00	0.00E+00
Ac-227	1.46E-07	8.89E-28	3.93E-05	4.45E-06	4.66E-06
Ra-223	4.77E-04	4.98E-29	1.52E-02	4.73E-06	2.85E-04
Pa-231	2.75E-05	0.00E+00	2.87E-03	7.58E-06	2.99E-05

DCCs Bivalve Mollusc vs Insect

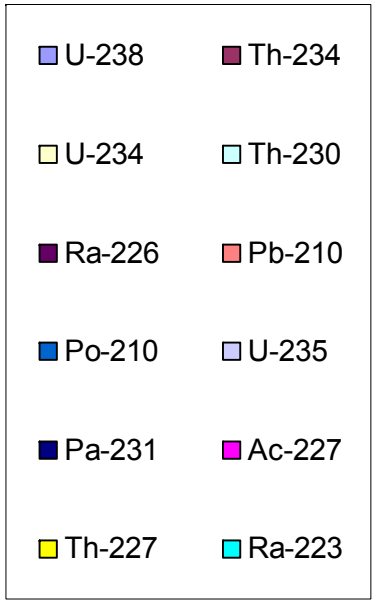
Choice of benthic model hardly affects dose due to small size and importance of internal alpha dose, external Radium

Organism	Bivalve mollusc		U-235 series		
Ratios of DCCs versus Insect larvae					
	Type				
Nuclide	ExtBG	ExtLowB	IntAlpha	IntLowB	IntBG
Pb-210	0.08			1.14	1.73
Po-210	0.94		1.00		
Ra-226	0.77		0.98		2.00
Th-227	0.89		1.00		1.00
Th-230	0.40		1.00		
Th-234	0.14				2.97
U-234	0.33		1.00		
U-235	0.85		0.99		1.25
U-238	0.31		1.00		
Ac-227	0.57	3.68E+12	1.00	1.00	1.01
Ra-223	0.38	3.74E+13	1.00	1.00	2.05
Pa-231	0.79		1.00	1.00	1.20

ERICA – Radionuclides

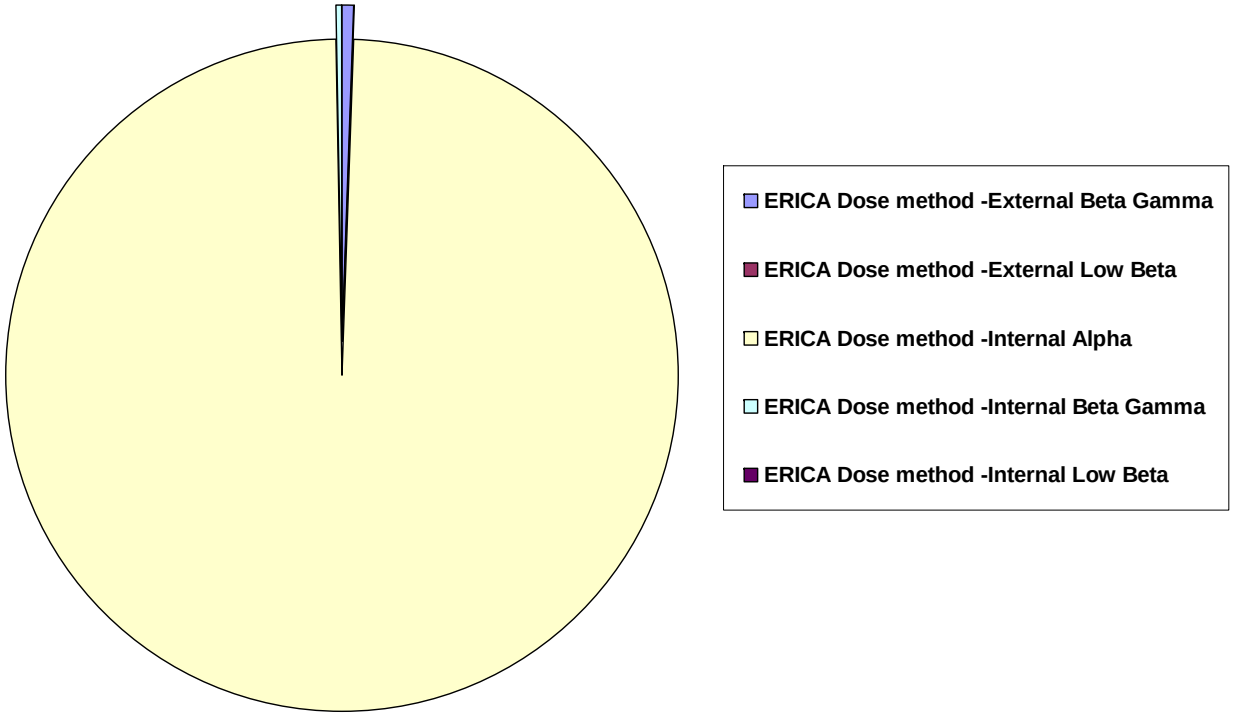


Total Dose - All data entries

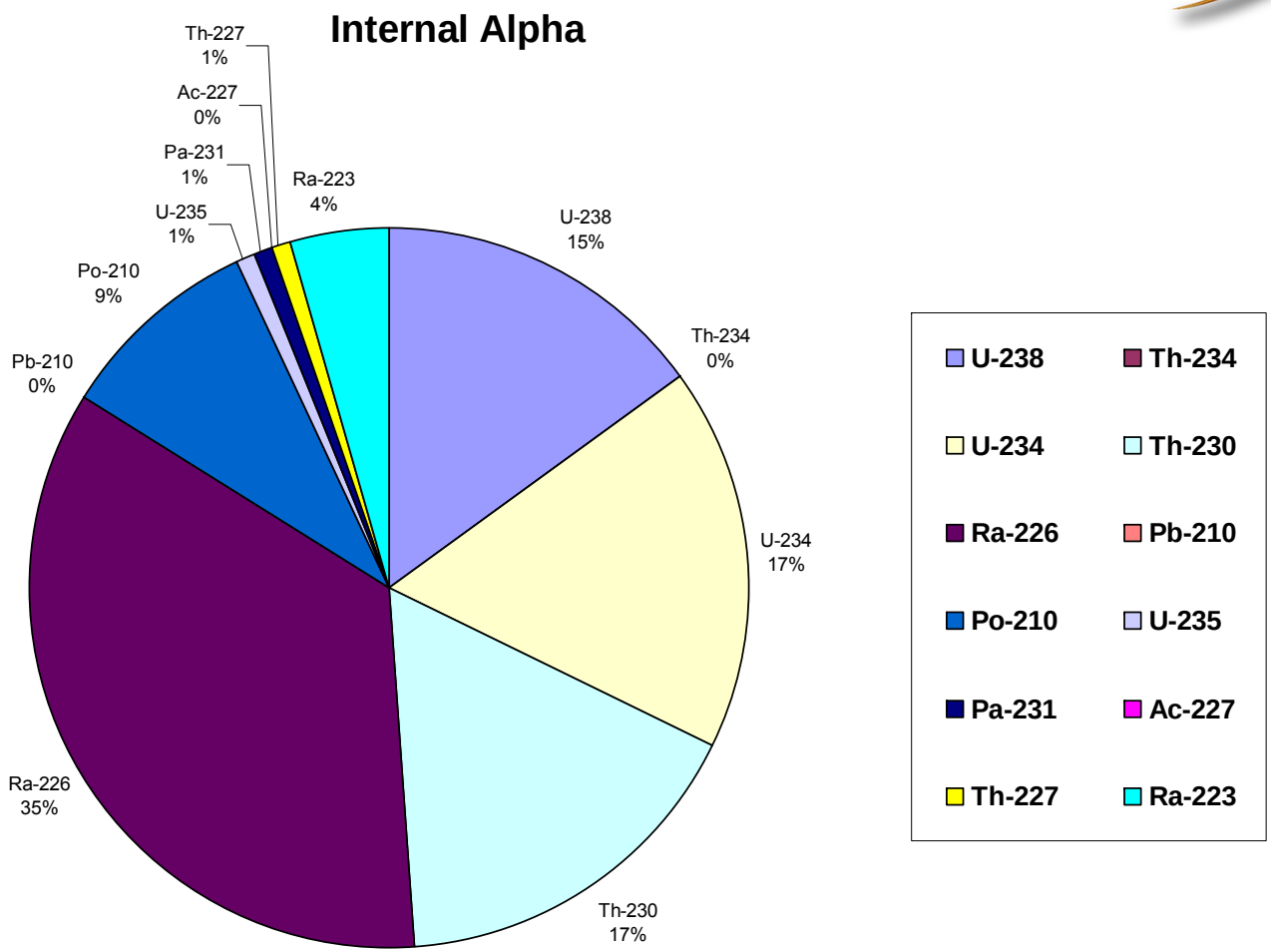


(Ra-226 includes Rn-222)

ERICA – Exposure Pathways



ERICA – Key Exposure Pathway



Results - Sensitive Organisms

ERICA Dose uGy/h sorted by Closest Observation SSLC

Taxon	Organism	N	Closest	Weighted
Valvata	snail	21	**10**	13
Sperchon	water mite	13	**12**	43
Eurycercus	water flea	14	**13**	19
Palpomyia	midge	11	**13**	44
Rheotanytarsus	midge	12	**13**	49
Epoicocladius	midge	10	**18**	159
Microtendipes	midge	22	**21**	182
Eukiefferiella	midge	16	**30**	56
Cricotopus	midge	11	**38**	59
Pisidium	clam	73	**45**	58

Results – Draft LEL/SEL values

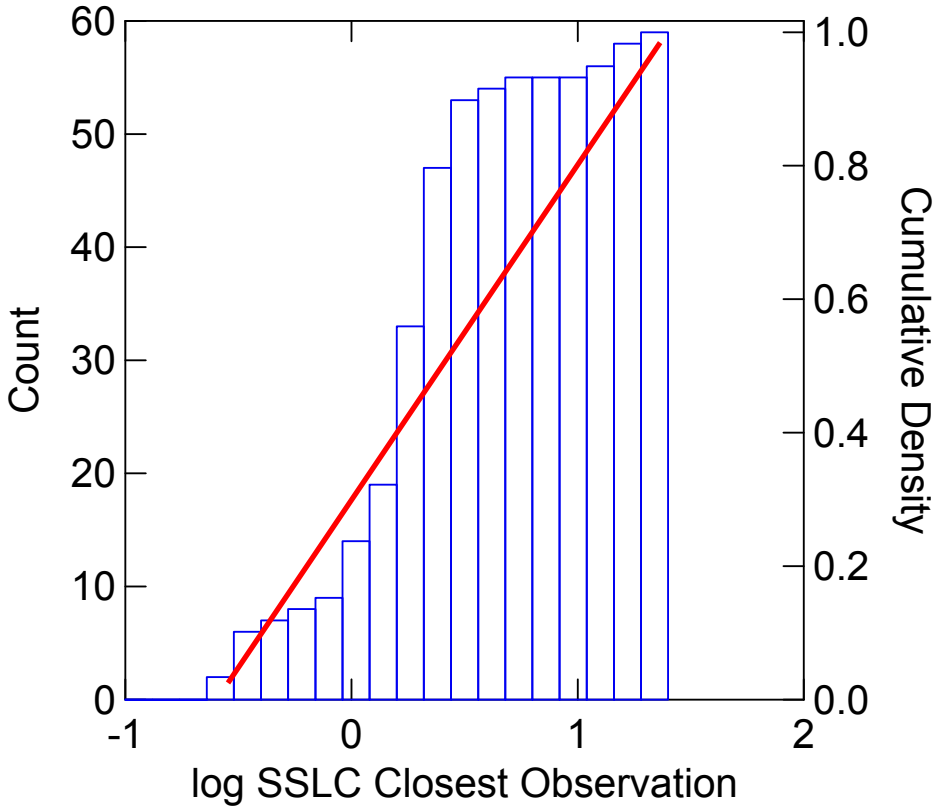
Dose uGy/h		ERICA	PSL2
LEL	Closest	13	36
	Weighted	43	97
SEL	Closest	175	1544
	Weighted	499	2113

PROTECT PNEDR = 17 uGy/h

Terrestrial - 1 mGy/d ~ 42 uGy/h

Curve Fitting – not worthwhile?

PSL2 SSLC values are not log normal



PSL2 – logNormal Percentiles

Values if explicit 5th percentile calculated from nonparametric SSLCs (GeoMean – 2 Std Dev)

Dose uGy/h		logNor	PSL2
LEL	Closest	31	36
	Weighted	60	97
SEL	Closest	1337	1544
	Weighted	1701	2113

PROTECT PNEDR = 17 uGy/h

Terrestrial - 1 mGy/d ~ 42 uGy/h

Path forward – dose results

- Enough? or analyze some more
- Bootstrap LEL/SEL values
- Document sensitivity to sample sizes
- Fit parametric distributions
- Explore / modify dose calculations

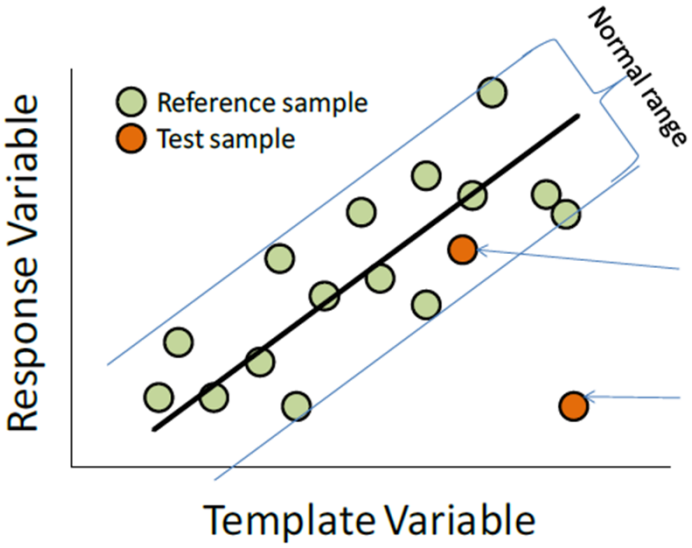
Path forward - Multivariate Analysis ?

DFA theoretically possible, but historical records not retained, everything has to be redone from scratch

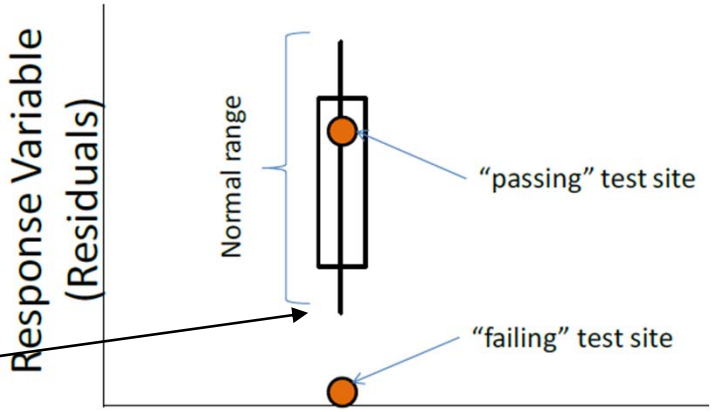
Station	# of Taxa	Abundance	Location	Year	% Difference vs Reference Impact	# Taxa	Abundance
mill effluent in this drainage							
Lake1	16	2340	**Mine1**	**1993**	reference		
Lake2	14	2917	Mine1	1993	not	-13%	25%
Lake3	7	4346	Mine1	1993	severe	-56%	86%
Lake4	6	1282	Mine1	1993	severe	-63%	-45%
mill effluent in this drainage							
Lake1	31	5519	**Mine1**	**1998**	reference		
Lake2	23	1592	Mine1	1998	mild	-26%	-71%
Lake3	5	1115	Mine1	1998	severe	-84%	-80%
Lake5	22	4956	Mine1	1998	mild	-29%	-10%
mine effluent in this drainage							
Lake6	20	1166	**Mine1**	**1998**	(reference)		
Lake7	20	2738	Mine1	1998	not	0%	135%
Lake8	18	2452	Mine1	1998	not	-10%	110%
Lake9	23	419	Mine1	1998	not	15%	-64%

New Insights - New Data vs Old Data

RCA analysis conducted on new 2002-2009 data
Species richness is key impact variable, simple regression approach and analysis of residuals was informative



Dose calculations not yet done, just metals



LEL values similar to 95% CI of RCA

A very simple suggestion

- Instead of DFA / multivariate analysis…
- Multiple linear regression of species richness versus all metals and dose

  Richness – Excel Pivot Table

  Problem will be missing data patterns, large error term from lack of other site variables

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Discussion

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