Natural Realm

- Intrusion
- Complex food chains
- Burrowing
- Bioturbation
- Issue of what to protect

Hilroy

=22

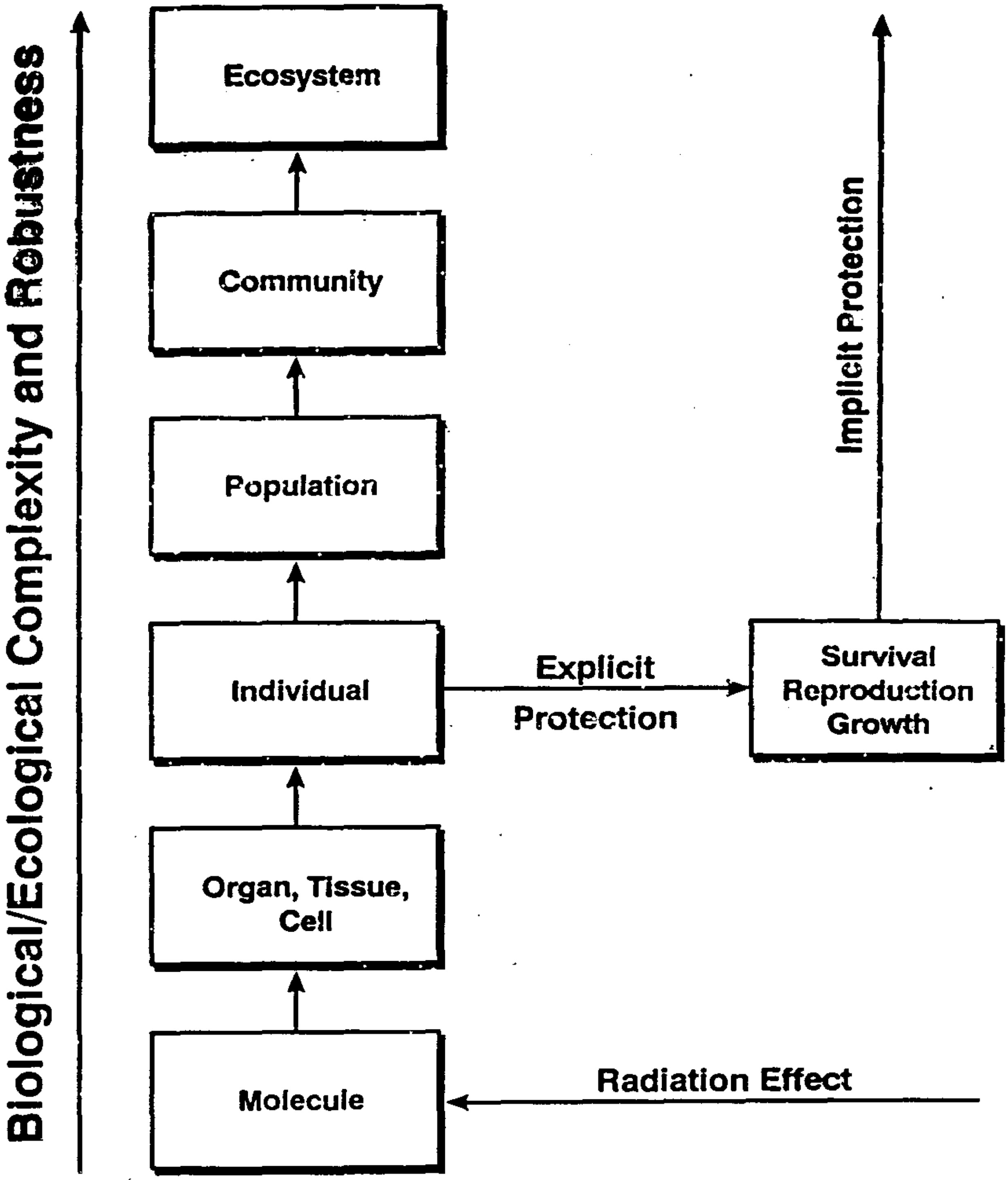
Protection of the Environment

To demonstrate environmental protection we have developed and applied a hierarchical screening methodology.

The methodology examines effects on:

1. Humans
2. Abiotic environment
3. Generic organisms
4. Specific organisms or species

R2
51


Biological/Ecological Complexity and Robustness
Ecosystem
Community
Population
Individual
Organ, Tissue,
Cell
Molecule
Explicit
Protection
Survival
Reproduction
Growth
Implicit Protection
Radiation Effect

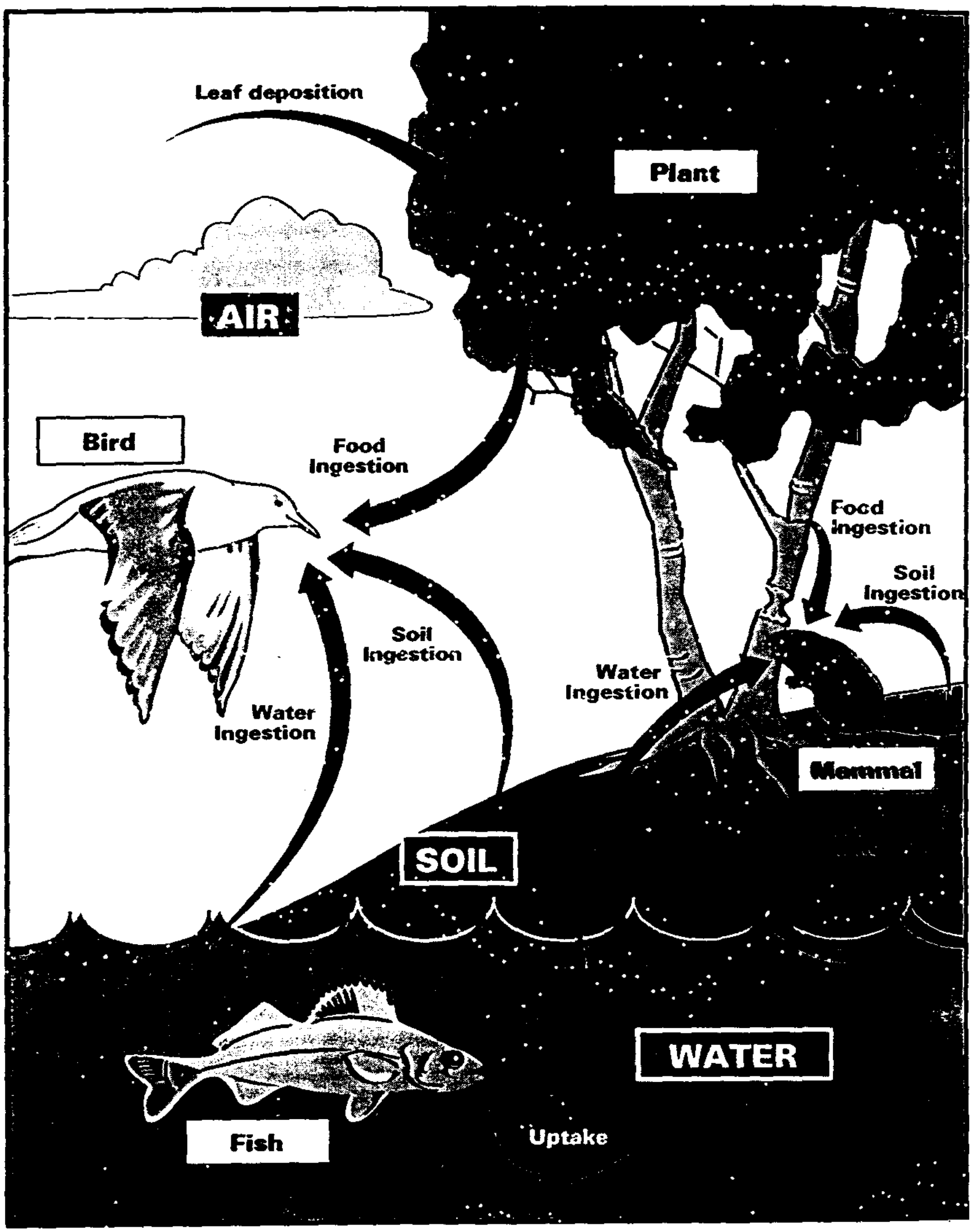
Generic Organisms

We use generic organisms because:

- A variety of such organisms can be defined
- Each generic organism can include many individual species and general biological characteristics
- Generic organisms can be supported by pooled databases
- Evaluation of the disposal concept is generic

Generic organisms selected:

- Fish
- Terrestrial plant
- Bird
- Mammal



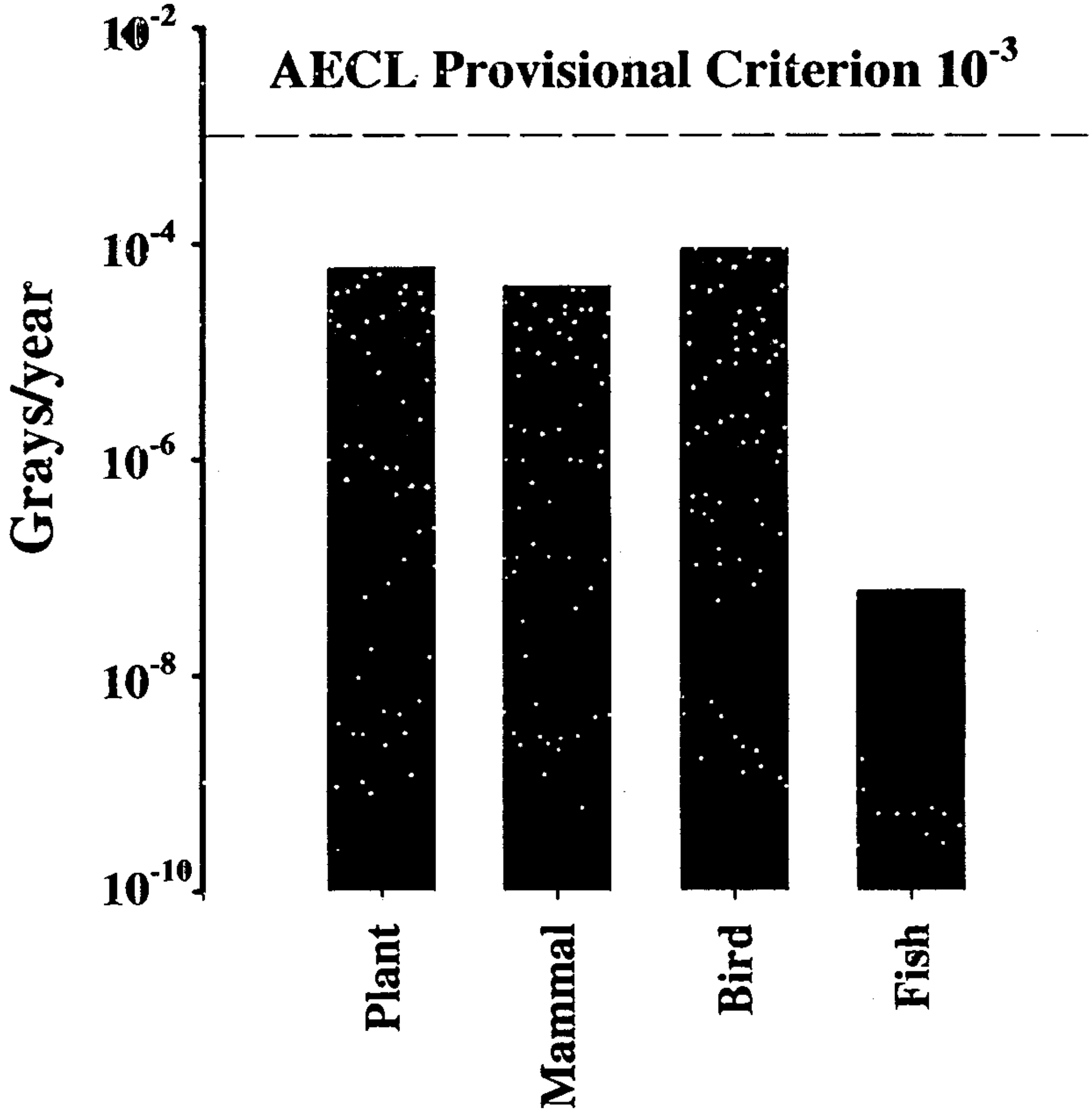
Leaf deposition
Plant
AIR
Bird
Food Ingestion
Food Ingestion
Soil Ingestion
Soil Ingestion
Water Ingestion
Water Ingestion
Mammal
SOIL
WATER
Fish
Uptake

Radiological Dose Rate and Consequence

Dose Rate	Range	Consequence
$100\ Gy \cdot a^{-1}$		Some organisms affected, effects increase with increasing dose
$10\ Gy \cdot a^{-1}$		
$1\ Gy \cdot a^{-1}$		Potential subtle, chronic effects.
$10^{-1}\ Gy \cdot a^{-1}$		
$10^{-2}\ Gy \cdot a^{-1}$		Range of natural background dose rate to a wide variety of plants and animals.
$10^{-3}\ Gy \cdot a^{-1}$		
$10^{-4}\ Gy \cdot a^{-1}$		Much below background dose rate; effects unlikely, and not detectable.
[illegible]		
[illegible] Gy·a		

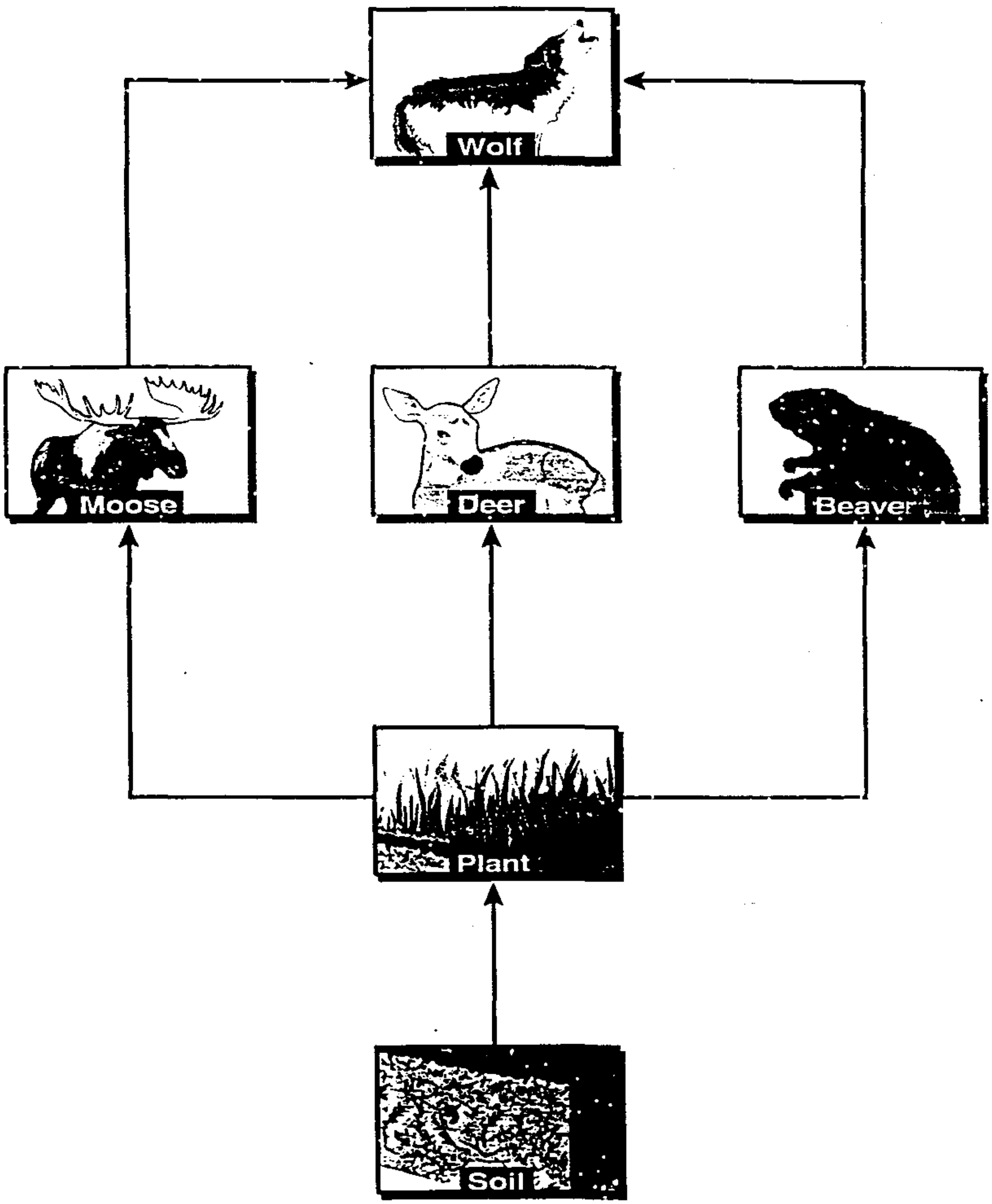
DOSES TO GENERIC ORGANISMS

Maximum dose in 100,000 years



EIS Case Study Including Chlorine-36

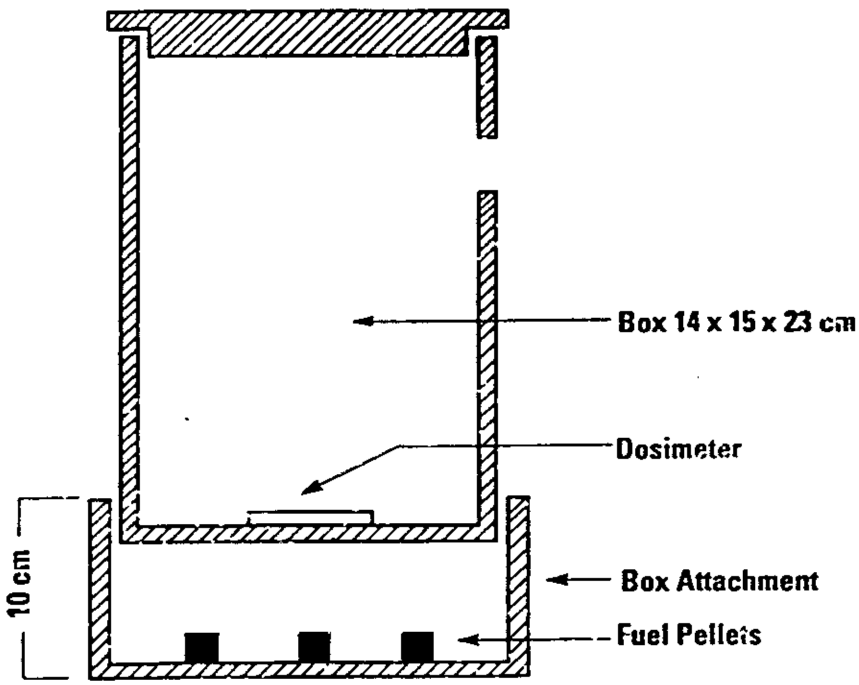
RADIONUCLIDE TRANSFER STUDY OF A BOREAL FOOD CHAIN



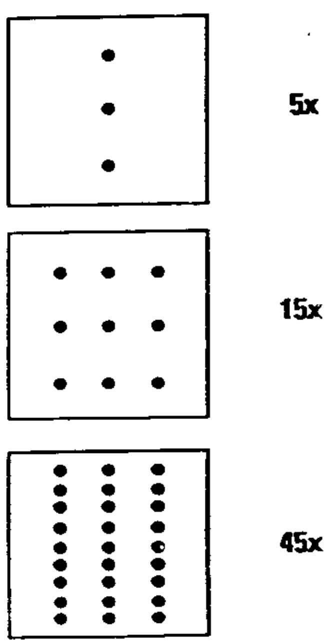
Summary

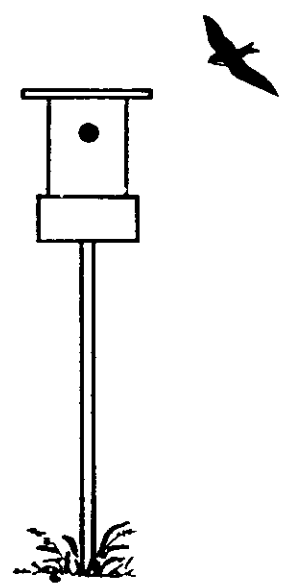
- We have developed and applied an environmental assessment methodology appropriate for assessing the disposal concept.
- Results show there would be no significant radiological effects on plants and animals.

TREE SWALLOW RADIATION-EXPOSURE EXPERIMENT



Section





Plans of Box Attachment

BREEDING PERFORMANCE OF TREE SWALLOWS

	Radiation Treatments			Control
Dose rate (mGy/h)	1.0	3.0	9.0	0.2
Number of nests	13	15	11	17
Clutch size	5.8	5.0	5.1	5.2
Hatching success (%)	97	88	87	93
Fledging success	99	88*	98	99
Body mass 15 d (g)	22.4	23.6	23.4	23.3

* $P<0.05$

Atomic Energy Control Board Risk Criteria for Humans Corresponds to about 2.5% of the Natural Background Dose or 0.005 μGy/h.

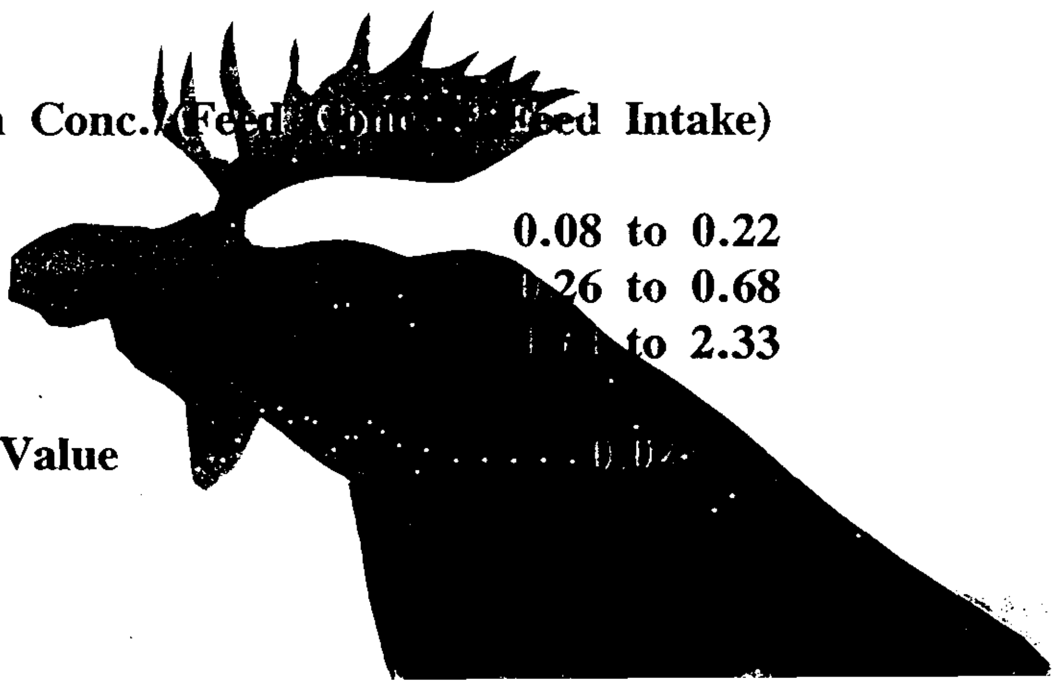
RADIONUCLIDE TRANSFER IN A NATURAL FOOD-CHAIN

Concentration Ratio (CR) for Cs-137

CR = Plant Conc. (wet)/Soil Conc. (dry)

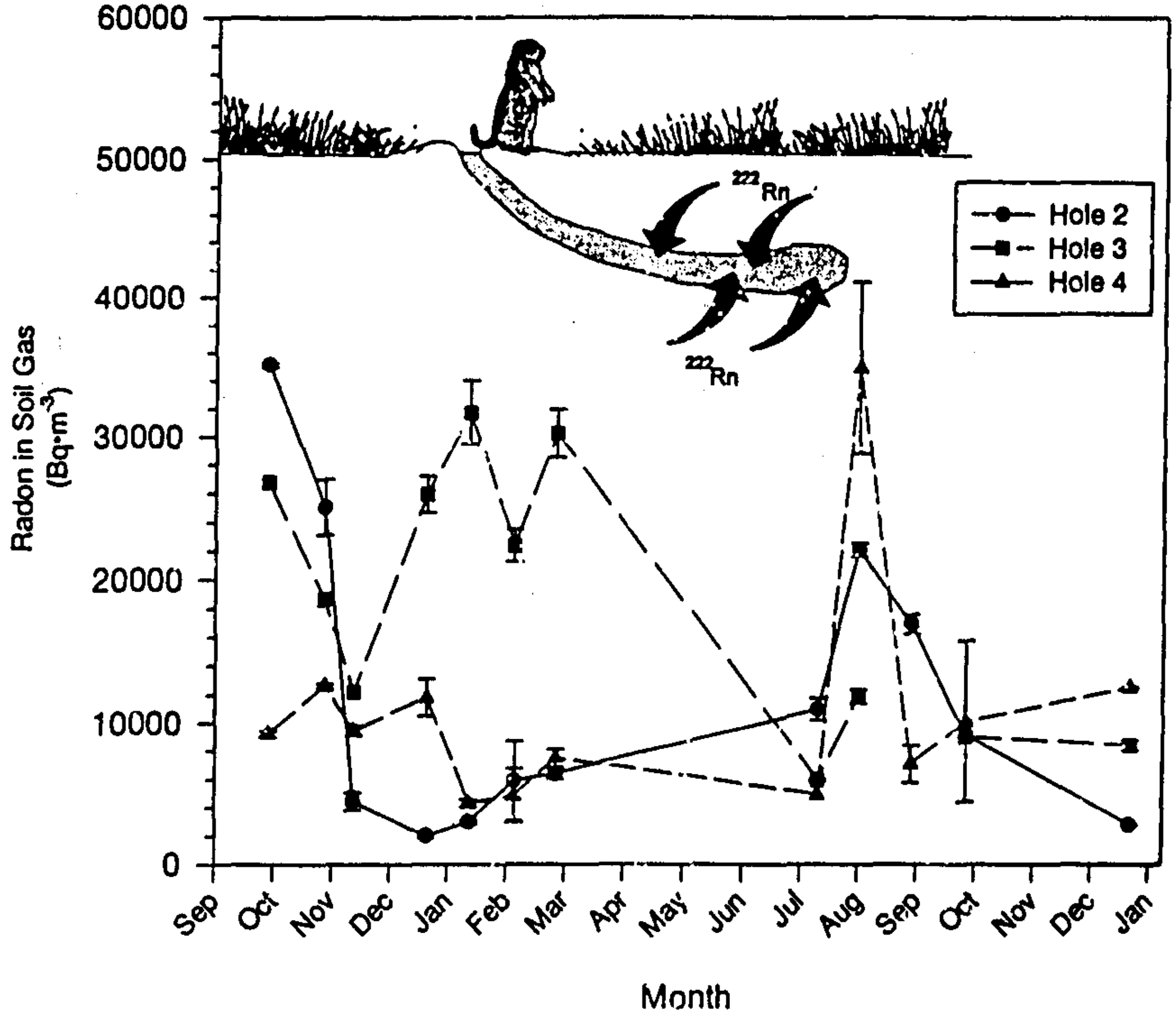
o	Soil Types	Clay	0.057±0.01
		Peat	0.027±0.00
		Sandy	0.224±0.06
o	Plant Species	Willow	0.042±0.07
		Dogwood	0.020±0.00
		Balsam Fir	0.176±0.03
o	Generic Value		0.08

Transfer Coefficient (TC) for Cs-137

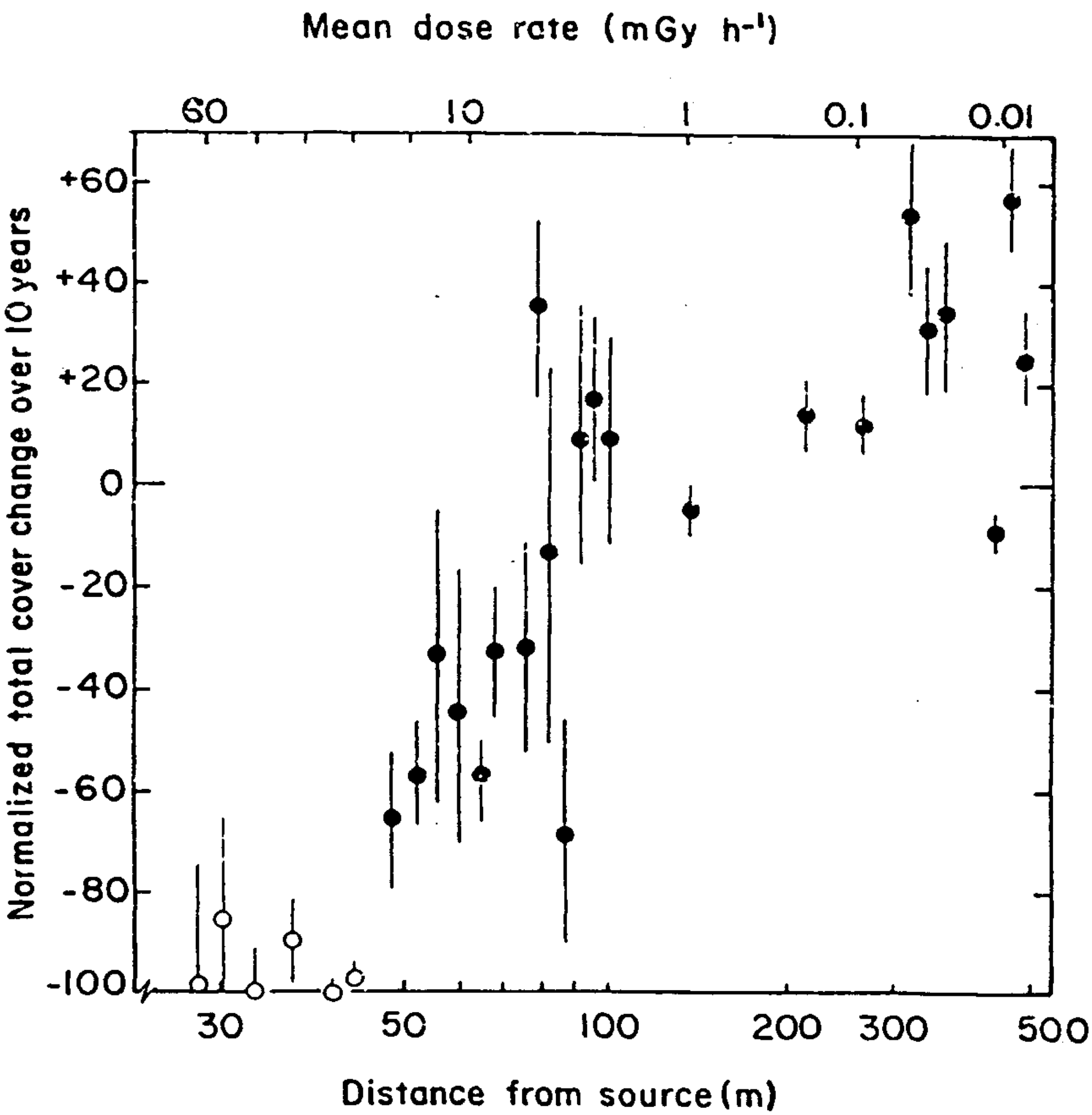


TC = Flesh Conc./(Feed Conc. [illegible] Feed Intake)

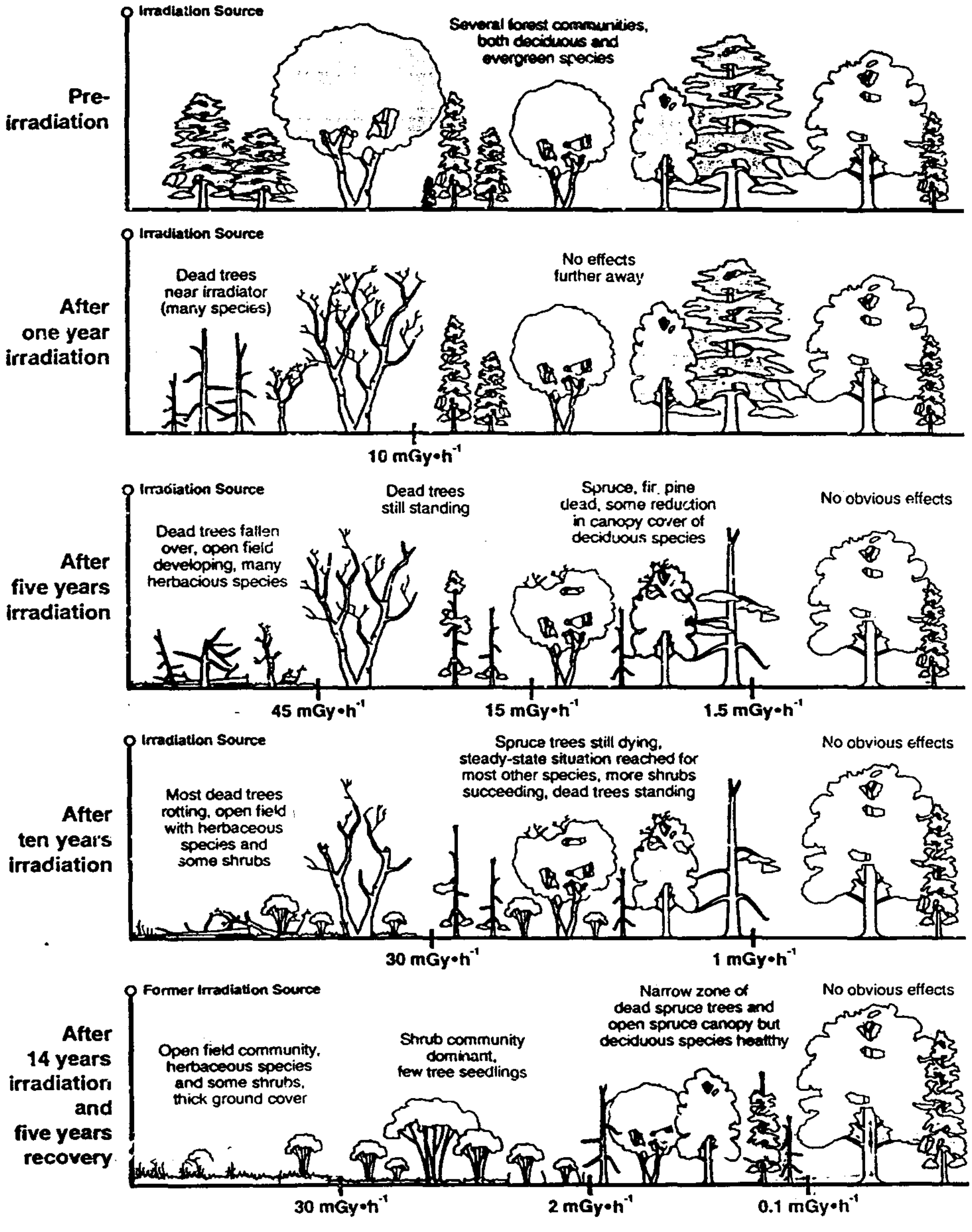
o	Moose	0.08 to 0.22
	Deer	0.26 to 0.68
	Beaver	[illegible] to 2.33
o	Generic Value	[illegible]



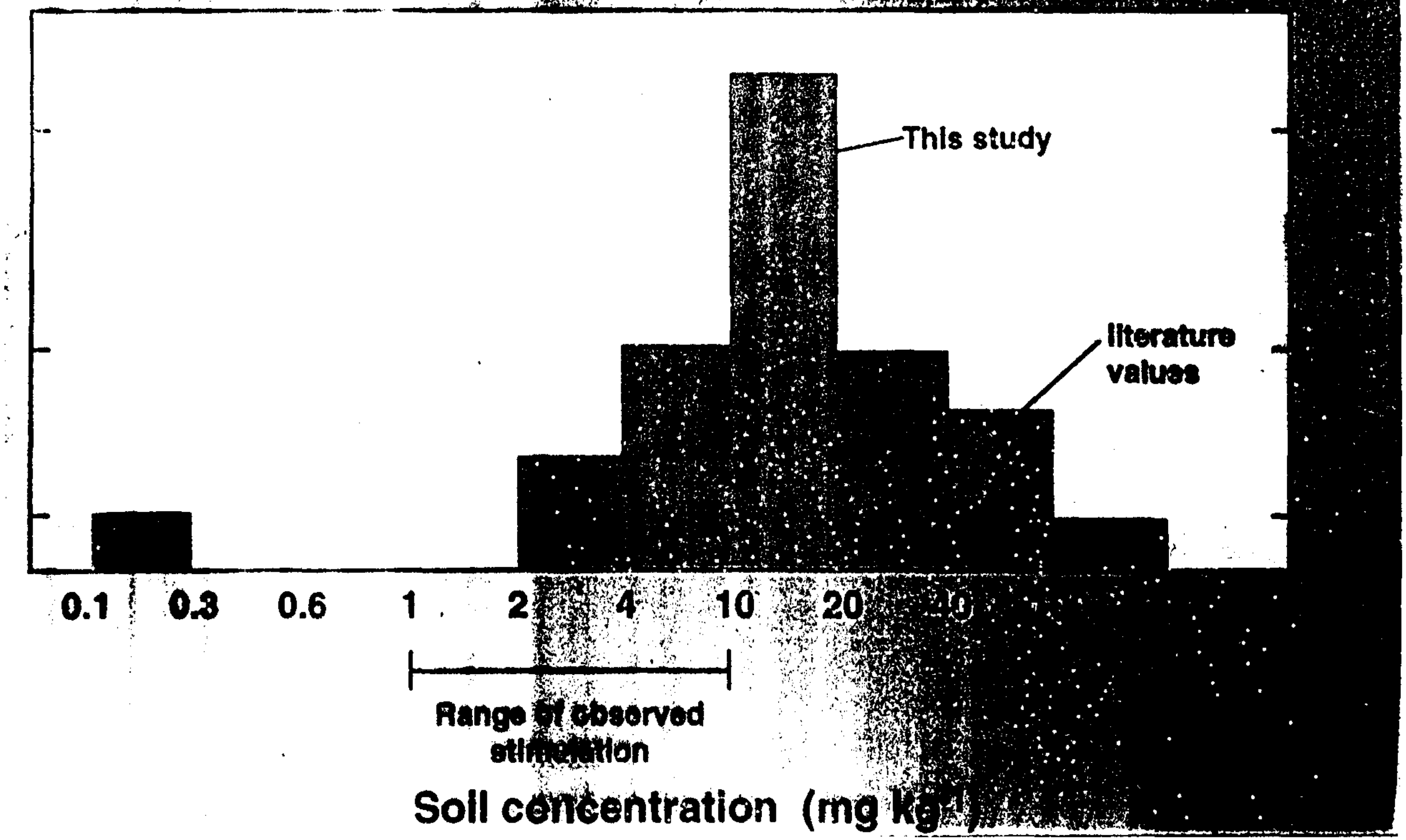
60000
50000
40000
30000
20000
10000
0
Radon in Soil Gas
(Bq·m-3)
222Rn
222Rn
Hole 2
Hole 3
Hole 4
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Month



Mean dose rate (mGy h-¹)
60
10
1
0.1
0.01
+60
+40
+20
0
-20
-40
-60
-80
-100
Normalized total cover change over 10 years
30
50
100
200
300
500
Distance from source (m)


Irradiation Source
Pre-irradiation
Several forest communities, both deciduous and evergreen species
Irradiation Source
After one year irradiation
Dead trees near irradiator (many species)
No effects further away
10 mGy•h⁻¹
Irradiation Source
After five years irradiation
Dead trees fallen over, open field developing, many herbacious species
Dead trees still standing
Spruce, fir, pine dead, some reduction in canopy cover of deciduous species
No obvious effects
45 mGy•h⁻¹
15 mGy•h⁻¹
1.5 mGy•h⁻¹
Irradiation Source
After ten years irradiation
Most dead trees rotting, open field with herbaceous species and some shrubs
Spruce trees still dying, steady-state situation reached for most other species, more shrubs succeeding, dead trees standing
No obvious effects
30 mGy•h⁻¹
1 mGy•h⁻¹
Former Irradiation Source
After 14 years irradiation and five years recovery
Open field community, herbaceous species and some shrubs, thick ground cover
Shrub community dominant, few tree seedlings
Narrow zone of dead spruce trees and open spruce canopy but deciduous species healthy
No obvious effects
30 mGy•h⁻¹
2 mGy•h⁻¹
0.1 mGy•h⁻¹

Frequency of NOEL



Arch. Environ. Contam. Toxicol. 29, 344–350 (1995)

ARCHIVES OF
Environmental
Contamination
and Toxicology

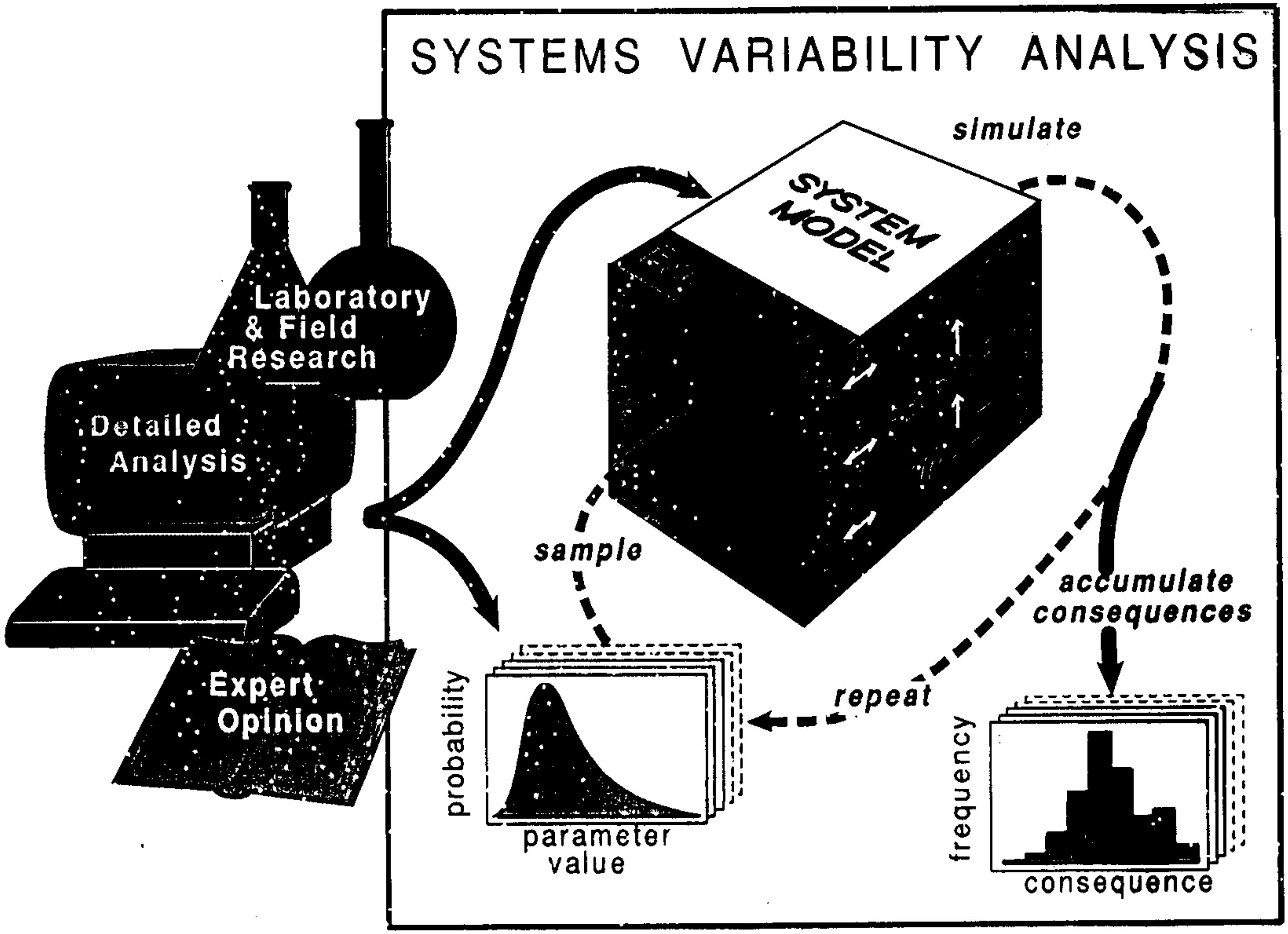
Toxicity of Iodine, Iodide, and Iodate to *Daphnia magna* and Rainbow Trout (*Oncorhynchus mykiss*)

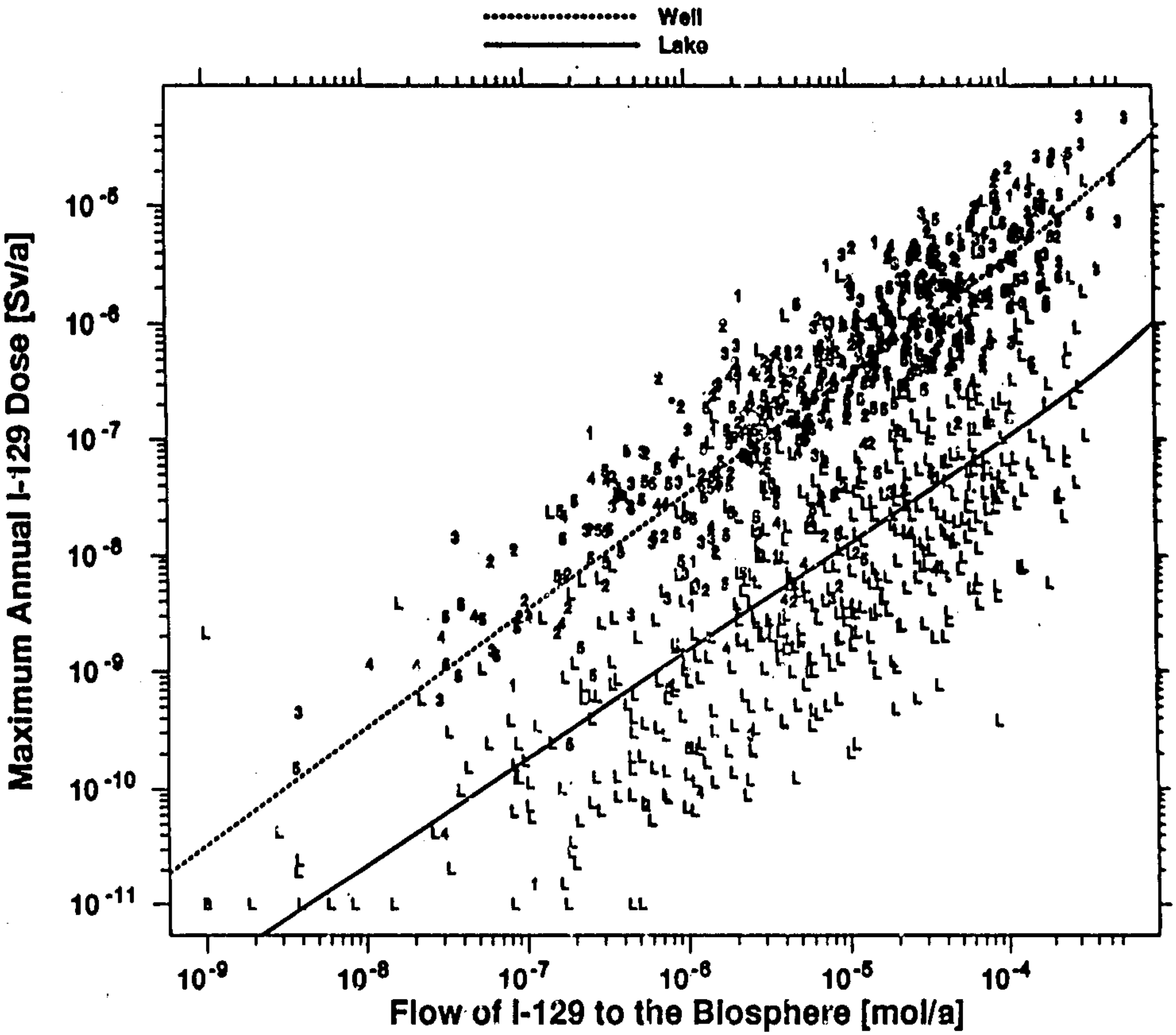
M. J. Laverock, M. Stephenson, C. R. Macdonald

AECL Research, Whiteshell Laboratories, Pinawa, Manitoba, ROE 1L0, Canada

Received: 29 September 1994/Revised: 21 February 1995

Abstract. The acute toxicity (96-h LC_{50}) of aqueous stable iodine species (I^-, IO_3^-, I_2) to rainbow trout and *Daphnia magna* were measured at three individual concentrations of hardness, total organic carbon, and chloride. Rainbow trout were most sensitive to I_2 ($LC_{50} \geq 0.53$ mg/L), and much less sensitive to $IO^-{}_3$ ($LC_{50} \geq 220$ mg/L) or I^- ($LC_{50} \geq 860$ mg/L). *Daphnia magna* were equally sensitive to I_2 ($LC_{50} \geq 0.16$ mg/L) and I^- ($LC_{50} \geq 0.17$ mg/L), but were less sensitive to IO_3^- ($LC_{50} \geq 10.3$ mg/L). The external and internal radiological dose imparted by equivalent molar quantities of radioactive ^{125}I, ^{129}I, and ^{131}I were calculated for both the *Daphnia* and trout using the LC_{50} values obtained from a standard water treatment. As expected, the dose from ^{125}I and ^{131}I would exceed the expected lethal dose rate long before a chemically toxic level is reached. In contrast, a molar concentration of ^{129}I likely to cause death by chemical toxicity would impart a radiological dose less than that expected to be lethal. Thus, for short-lived aquatic organisms, risks due to chemical toxicity of ^{129}I may exceed risks due to its radioactive emissions.


SYSTEMS VARIABILITY ANALYSIS
Laboratory & Field Research
Detailed Analysis
Expert Opinion
SYSTEM MODEL
simulate
sample
repeat
accumulate consequences
probability
parameter value
frequency
consequence



Well
Lake
Maximum Annual I-129 Dose [Sv/a]
Flow of I-129 to the Biosphere [mol/a]

AECL EACL

AECL Research EACL Recherche

AECL-10720, COG-93-10

The Disposal of Canada's Nuclear Fuel Waste: The Biosphere Model, BIOTRAC, for Postclosure Assessment

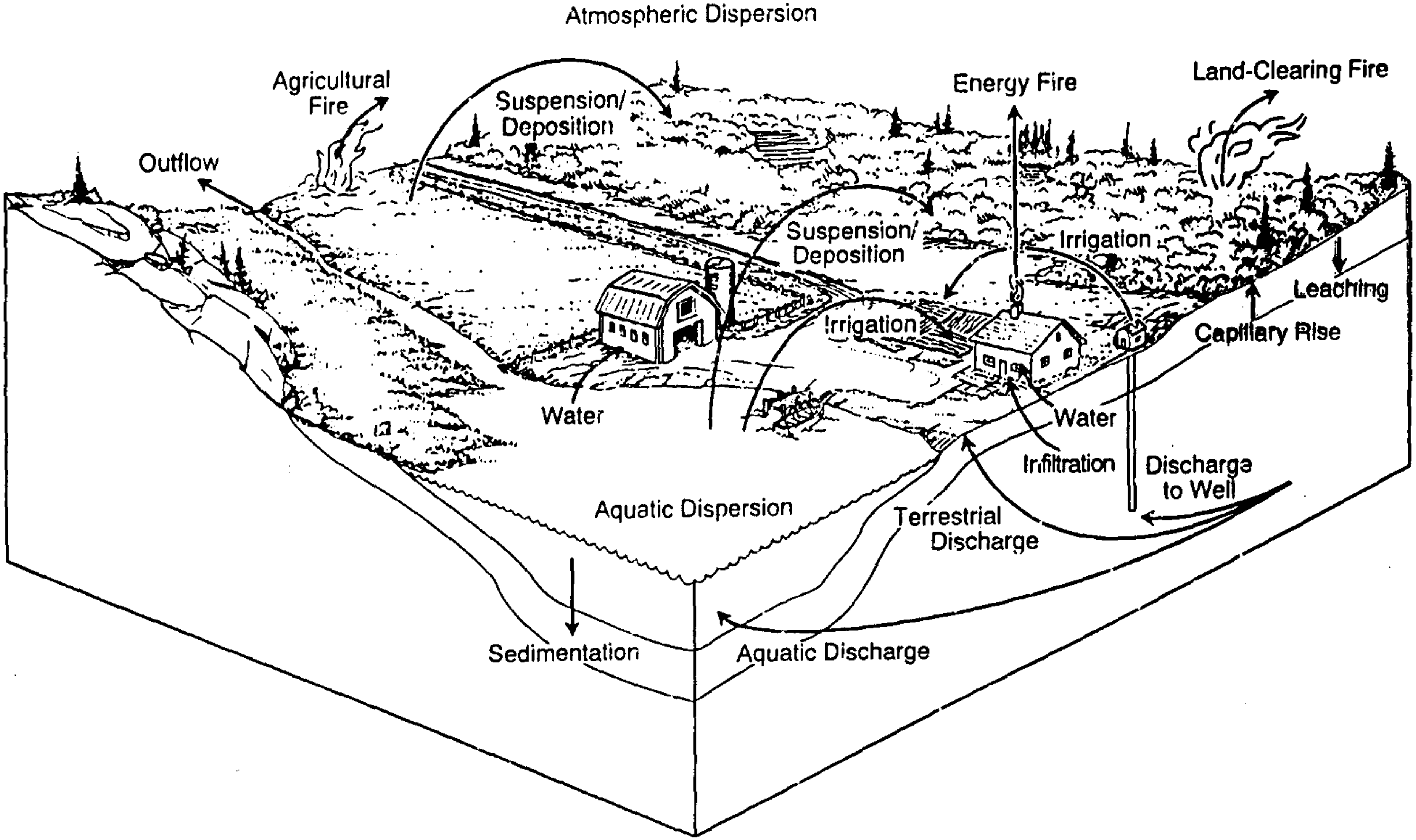
Le stockage permanent des déchets de combustible nucléaire du Canada : Le modèle de biosphère, BIOTRAC, pour l'évaluation de post-fermeture

P.A. Davis, R. Zach, M.E. Stephens, B.D. Amiro, G.A. Bird, J.A.K. Reid, M.I. Sheppard, S.C. Sheppard, M. Stephenson

October 1993 octobre

In ICRP 26 (1977), the International Commission on Radiological Protection gave its first guidance on the definition of the critical group. This Committee reflects international consensus at the time:

> "... the actual doses received by individuals will vary depending on factors such as their age, size, metabolism and customs, as well as variations in their environment... . With exposure of members of the public, it is usually feasible to take account of these sources of variability by selection of appropriate critical groups within the population, provided the critical group is small enough to be relatively homogeneous with respect to age, diet and those aspects of behavior that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest (dose), and the Commission believes that it will be reasonable to apply the appropriate (dose) limit for members of the public to the mean (dose received by members of this group). Because of the innate variability within an apparently homogeneous group, some members of the critical group will receive a (dose) somewhat higher than the mean."

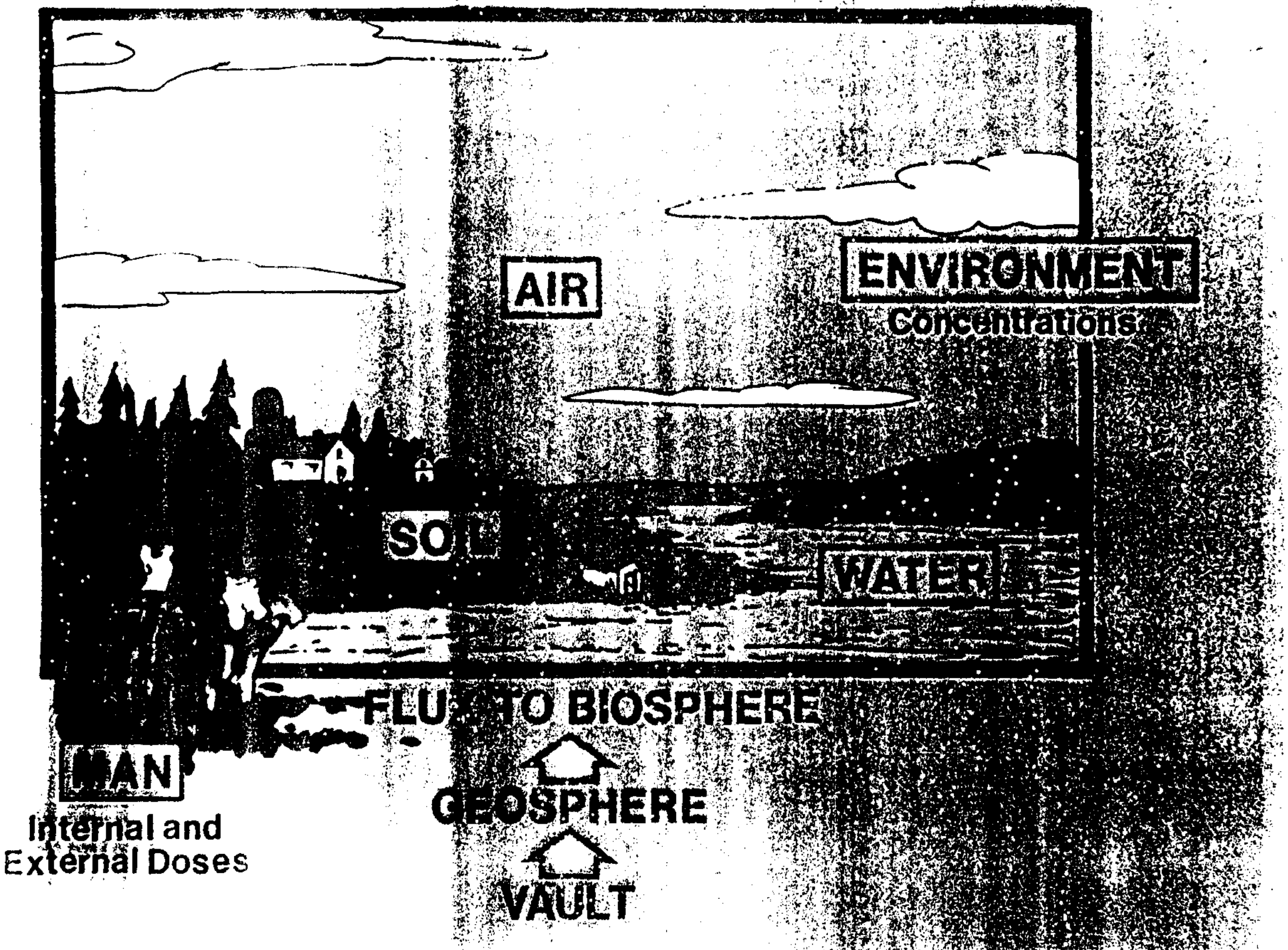


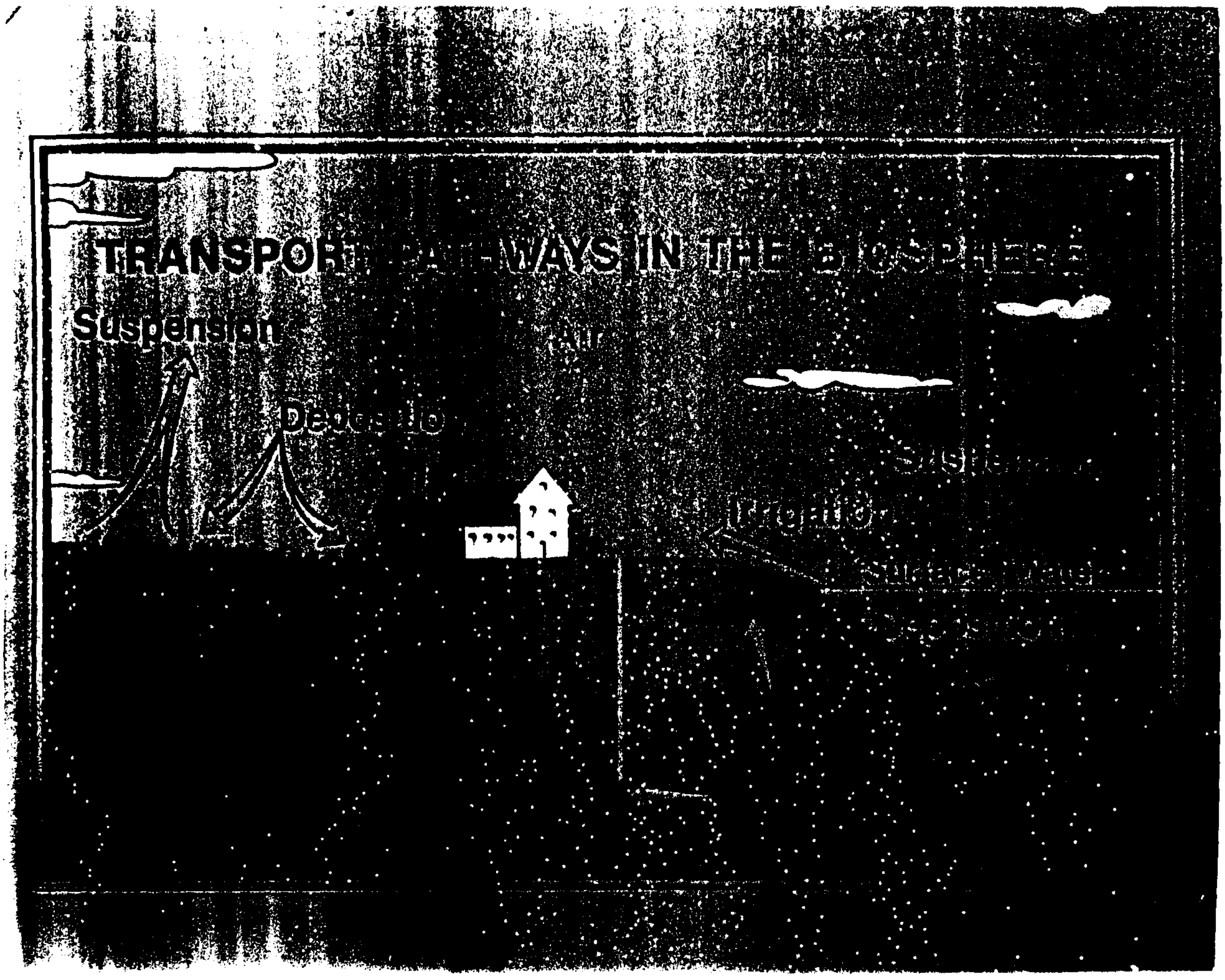
Atmospheric Dispersion
Agricultural Fire
Suspension/ Deposition
Outflow
Energy Fire
Land-Clearing Fire
Suspension/ Deposition
Irrigation
Irrigation
Leaching
Capillary Rise
Water
Water
Infiltration
Discharge to Well
Aquatic Dispersion
Terrestrial Discharge
Sedimentation
Aquatic Discharge

Biosphere FEPs

- Features
- Events, and
- Processes

THE BIOSPHERE AND BIOSPHERE MODEL




TRANSPORT PATHWAYS IN THE BIOSPHERE
Suspension
Air

LIST OF BIOSPHERE FACTORS CONSIDERED IN SCENARIO DEVELOPMENT

	Factor	Treatment*	Reference**
1	Acid rain	C	SW
2	Alkali flats	Q	S
3	Animal grooming and fighting	C	F
4	Animal soil ingestion	C	F
5	Animal diets	C	F
6	Artificial lake mixing	C	W
7	Ashes and sewage sludge fertilizers	C	F
8	Bacteria and microbes in soil	C	FS
9	Bioconcentration	C	BF
10	Biogas production	Q	A
11	Biological evolution	Q	BF
12	Biotoxicity	C	BFT
13	Bioturbation of soil and sediment	C	SW
14	Building materials	C	BF
15	Burrowing animals	C	FS
16	Capillary rise in soil	C	BS
17	Carcasses	C	F
18	Carcinogenic contaminants	C	BFPT
19	Charcoal production	C	AB
20	Chemical precipitation	C	BSW
21	Chemical toxicity	C	BFP
22	Climate	C	ABFSW
23	Climate change	AC	BT
24	Collisions, explosions and impacts	Q	X
25	Colloids	C	SW
26	Convection, turbulence and diffusion		ABT
	(atmospheric)	C	AB
27	Correlation	C	ABFSW
28	Critical group - agricultural labour	C	ABF
29	Critical group - clothing and home furnishings	Q	BF
30	Critical group - evolution	Q	BF
31	Critical group - house location	C	BF
32	Critical group - individuality	C	BF
33	Critical group - leisure pursuits	C	BF
34	Critical group - pets	Q	F
35	Crop fertilizers and soil conditioners	C	F
36	Crop storage	C	BF
37	Cure for cancer	Q	X
38	Deposition (wet and dry)	C	BAFS

Factor	Treatment*	Reference**
39 Dermal sorption - nuclides other than tritium	Q	BF
40 Dermal sorption - tritium	C	BF
41 Dispersion	C	ABFSW
42 Dust storms and desertification	C	ABS
43 Earthmoving projects	Q	S
44 Earthquakes	Q	X
45 Erosion - lateral transport	Q	ABS
46 Erosion - wind	Q	ABS
47 Fires - agricultural	C	AB
48 Fires - forest and grass	C	AB
49 Fish farming	Q	BF
50 Flipping of earth's magnetic poles	Q	X
51 Flooding	Q	B
52 Flushing of water bodies	C	BW
53 Food preparation	C	BF
54 Game ranching	C	BF
55 Gas leakage into basements	C	BA
56 Glaciation	A	BT
57 Greenhouse food production	C	BF
58 Greenhouse effect	Q	AB
59 Groundshine (ground exposure)	C	BF
60 Heat storage in lakes or underground	Q	X
61 Herbicides, pesticides and fungicides	C	F
62 Household dust and fumes	C	BA
63 Houseplants	Q	X
64 Human diet	C	BF
65 Human soil ingestion	C	BF
66 Hydroponics	Q	F
67 Industrial water use	Q	X
68 Intake of drugs	Q	X
69 Intrusion - deliberate	Q	BT
70 Intrusion - inadvertent	A	I
71 Ion exchange in soil	C	BS
72 Irrigation	C	BSF
73 Lake infilling	C	BS
74 Mutagenic contaminants	C	BFP
75 Outdoor spraying of water	C	ABFS
76 Ozone layer failure	Q	X
77 Peat and leaf litter harvesting	C	S
78 Plant roots	C	BFS
79 Precipitation (meteoric)	C	BAS
80 Radioactive decay	C	ABFSW
81 Radiotoxic contaminants	C	BFPT
82 Radon emission	C	ABF

	Factor	Treatment*	Reference**
83	River-course meander	C	B
84	Runoff	C	BSW
85	Saltation	C	BA
86	Scavengers and predators	C	BF
87	Seasons	C	ABFSW
88	Sediment resuspension in water bodies	C	BW
89	Sedimentation in water bodies	C	BW
90	Sensitization to radiation	C	BF
91	Showers and humidifiers	C	ABF
92	Smoking	Q	F
93	Soil	C	BFS
94	Soil depth	C	BS
95	Soil leaching	C	BS
96	Soil porewater pH	C	S
97	Soil sorption	C	BS
98	Soil type	C	BS
99	Space heating	C	AB
100	Surface water bodies	C	BW
101	Surface water pH	C	W
102	Suspension in air	C	ABFS
103	Technological advances in food production	Q	BF
104	Teratogenic contaminants	C	BFPT
105	Terrestrial surface	C	ABFS
106	Toxicity of mined rock	Q	X
107	Tree sap	C	F
108	Uncertainties	C	ABFSWP
109	Urbanization on the discharge site	Q	X
110	Water leaking into basements	Q	F
111	Water management projects	Q	W
112	Water source	C	BFSW
113	Wetlands	C	ABFSW
114	Wind	C	AB

* A - alternative treatment
C - central group of scenarios
Q - qualitative treatment

** A - atmospheric submodel (Amiro 1992)
B - biosphere model (this EIS primary reference)
F - food-chain and dose submodel (Zach and Sheppard 1992)
I - intrusion analysis (Wuschke 1992)
P - postclosure assessment (Goodwin et al. 1994)
S - soil submodel (Sheppard 1992)
W - surface-water submodel (Bird et al. 1992)
T - topical reports
X - scenario analysis report

1.1 SOURCE TERM	1.2 Contamination	1.3 Contamination	1.4 Contamination	1.5 Contamination	1.6	1.7 No (No gaseous release)	1.8 Yes (Special local release)	1.9	1.10 B.C. (No mediation of the release)	1.11 Yes (Possibly)
2.1	**2.2 PERMANENT SATURATED ZONE (Aquifer)**	2.3 Flow water + solute (discharge)	2.4 Flow water + solute (discharge)	2.5 Water transport	2.6 Via irrigation Capillary rise	2.7 No	2.8 Not (main for our system) Irrigation due to human activities	2.9 Not (main for our situation) Drinking water	2.10 Use of water	2.11 Ingestion other water uses
3.1	3.2 Recharge	**3.3 SURFACE WATER**	3.4 Sedimentation Erosion Diffusion Advection	3.5 Recharge (through river bank)	3.6 Flooding Diffusion Sedimentation Erosion Irrigation	3.7 Aerosols formation Degassing Evaporation Suspension	3.8 Uptake Irrigation	3.9 Uptake	3.10 Water supply	3.11 Uptake External Immersion
4.1	4.2 Water + solutes	4.3 Sediment Resuspension	**4.4 SEDIMENTS**	[illegible] Conversion	4.6 Conversion Dredging	4.7 Aerosols formation Degassing Evaporation	4.8 Uptake External contamination	4.9 Uptake External contamination	4.10	4.11 External and direct contamination
5.1	5.2 Percolation Solid transport	5.3 Exfiltration discharge transport of eroded material	5.4 Bank collapse	**5.5 VARIABLE SATURATED ZONE**	5.6 Gas Capillary transfer Soil formation	5.7	5.8 Deep root species uptake	5.9 Burrowing species	5.10 Builders land use	5.11 External (digging)
6.1	6.2	6.3 Erosion Run off	6.4 Conversion Bank collapse	6.5 Infiltration	**6.6 SURFACE SOIL (Topsoil)**	6.7 Suspension Evaporation Gas transfer Resuspension	6.8 Uptake Rain splash	6.9 Soil contamination	6.10 Land uses Materials resource	6.11 Direct exposure
7.1	7.2 No	7.3 Precipitation Deposition	7.4 Wind erosion Rainfall of dust	7.5	7.6 Deposition Precipitation Wind erosion	**7.7 ATMOSPHERE (Air)**	7.8 Deposition Precipitation Snow Rain	7.9 Inhalation Deposition	7.10 Minimal on weather depending	7.11 Inhalation External immersion
8.1 Not or very small	8.2 Only for special plants	8.3 Contamination (by leaves)	8.4 Bioturbation Death	8.5 Deep rooting	8.6 Death Organic bioturbation Fertilisation Washout Water Extraction	8.7 Exhalation Transpiration Canopy Burning Reduction of wind speed	**8.8 FLORA**	8.9	8.10 Viability (Diet and Boundary Conditions)	8.11 Ingestion External
9.1	9.2	9.3 Contamination Drums	9.4 Bioturbation	9.5 Burrowing	9.6 Excretion Bioturbation Burrowing Erosion	9.7 Exhalation	9.8 Consumption Fertilising Direct contamination	**9.9 FAUNA**	9.10 Depending on Boundary Conditions	9.11 Ingestion External
10.1 Intrusion (Not considered)	10.2 Water extraction Pollution Recharge [illegible]	10.3 Water recharge Water extraction Pollution Treatments [illegible] Dam and drain	10.4 Dredging Removal	10.5 Pollution Civil engineer (Deep Plowing)	10.6 Agriculture Pollution Forestry Construction Irrigation	10.7 Pollution Filtration Ventilation	10.8 Recycling Storage Burning Making Furniture	10.9 Farming Storage Hunting	**10.10 HUMAN ACTIVITIES**	10.11 Depending on Boundary Conditions
11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9	11.10	**11.11 DOSE TO CRITICAL GROUP)**

Figure 2-1 Generic biosphere RES matrix for an inland groundwater release source term (taken from BIOMOVS II [1995]).

RADIONUCLIDES WITH DECAY CONSTANTS AND CHEMICALLY TOXIC ELEMENTS CONSIDERED IN BIOTRAC

Radionuclide	Decay Constant (a^{-1})	Radionuclide	Decay Constant (a^{-1})	Radionuclide	Decay Constant (a^{-1})
^{225}Ac	2.53×10^{1}	^{32}P	1.77×10^{1}	^{219}Rn	5.50×10^{6}
^{227}Ac	3.18×10^{-2}	^{231}Pa	2.12×10^{-5}	^{220}Rn	3.94×10^{5}
^{228}Ac	9.90×10^{2}	^{233}Pa	9.38×10^{0}	^{222}Rn	6.60×10^{1}
^{241}Am	1.60×10^{-3}	^{234}Pa	9.06×10^{2}	^{125}Sb	2.50×10^{-1}
^{39}Ar	2.58×10^{-3}	^{234m}Pa	3.11×10^{5}	^{126}Sb	2.04×10^{1}
^{217}At	6.80×10^{8}	^{205}Pb	4.85×10^{-8}	^{126m}Sb	1.92×10^{4}
^{10}Be	4.33×10^{-7}	^{209}Pb	1.87×10^{3}	^{79}Se	1.07×10^{-5}
^{208}Bi	1.88×10^{-6}	^{210}Pb	3.11×10^{-2}	^{32}Si	1.54×10^{-3}
^{210}Bi	5.06×10^{1}	^{211}Pb	1.01×10^{4}	^{126}Sn	6.93×10^{-6}
^{210m}Bi	2.31×10^{-7}	^{212}Pb	5.73×10^{2}	^{90}Sr	2.38×10^{-2}
^{211}Bi	1.70×10^{5}	^{214}Pb	1.36×10^{4}	^{182}Ta	2.20×10^{0}
^{212}Bi	6.03×10^{3}	^{107}Pd	1.07×10^{-7}	^{99}Tc	3.25×10^{-6}
^{213}Bi	7.98×10^{3}	^{210}Po	1.83×10^{0}	^{125m}Te	4.36×10^{0}
^{214}Bi	1.83×10^{4}	^{211}Po	4.23×10^{7}	^{227}Th	1.35×10^{1}
^{14}C	1.21×10^{-4}	^{212}Po	7.17×10^{13}	^{228}Th	3.62×10^{-1}
^{41}Ca	4.95×10^{-6}	^{213}Po	5.21×10^{12}	^{229}Th	9.44×10^{-5}
^{113m}Cd	5.09×10^{-2}	^{214}Po	1.33×10^{11}	^{230}Th	9.00×10^{-6}
^{135}Cs	3.01×10^{-7}	^{215}Po	1.23×10^{10}	^{231}Th	2.38×10^{2}
^{221}Fr	7.59×10^{4}	^{216}Po	1.46×10^{8}	^{232}Th	4.93×10^{-11}
^{223}Fr	1.67×10^{4}	^{218}Po	1.20×10^{5}	^{234}Th	1.05×10^{1}
^{3}H	5.61×10^{-2}	^{238}Pu	7.90×10^{-3}	^{206}Tl	8.68×10^{4}
^{182}Hf	7.70×10^{-8}	^{239}Pu	2.88×10^{-5}	^{207}Tl	7.63×10^{4}
^{129}I	4.41×10^{-8}	^{240}Pu	1.06×10^{-4}	^{208}Tl	1.19×10^{5}
^{40}K	5.42×10^{-10}	^{241}Pu	4.81×10^{-2}	^{209}Tl	1.65×10^{5}
^{81}Kr	3.30×10^{-6}	^{242}Pu	1.84×10^{-6}	^{232}U	9.63×10^{-3}
^{85}Kr	6.48×10^{-2}	^{223}Ra	2.21×10^{1}	^{233}U	4.37×10^{-6}
^{93}Mo	1.98×10^{-4}	^{224}Ra	6.93×10^{1}	^{234}U	2.83×10^{-6}
^{93m}Nb	5.10×10^{-2}	^{225}Ra	1.71×10^{1}	^{235}U	9.85×10^{-10}
^{94}Nb	3.41×10^{-5}	^{226}Ra	4.33×10^{-4}	^{236}U	2.96×10^{-8}
^{59}Ni	9.24×10^{-6}	^{228}Ra	1.21×10^{-1}	^{238}U	1.55×10^{-10}
^{63}Ni	7.22×10^{-3}	^{87}Rb	1.47×10^{-11}	^{90}Y	9.50×10^{1}
^{237}Np	3.24×10^{-7}	^{187}Re	1.39×10^{-11}	^{93}Zr	4.53×10^{-7}

Chemically Toxic Elements

Br	Cs	Se
Cd	Mo	Sm
Cr	Sb	Tc

RADIONUCLIDES WITH DECAY CONSTANTS AND CHEMICALLY TOXIC ELEMENTS CONSIDERED IN BIOTRAC

Radionuclide	Decay Constant (a^{-1})	Radionuclide	Decay Constant (a^{-1})	Radionuclide	Decay Constant (a^{-1})
^{225}Ac	2.53×10^{1}	^{32}P	1.77×10^{1}	^{219}Rn	5.50×10^{6}
^{227}Ac	3.18×10^{-2}	^{231}Pa	2.12×10^{-5}	^{220}Rn	3.94×10^{5}
^{228}Ac	9.90×10^{2}	^{233}Pa	9.38×10^{0}	^{222}Rn	6.60×10^{1}
^{241}Am	1.60×10^{-3}	^{234}Pa	9.06×10^{2}	^{125}Sb	2.50×10^{-1}
^{39}Ar	2.58×10^{-3}	^{234m}Pa	3.11×10^{5}	^{126}Sb	2.04×10^{1}
^{217}At	6.80×10^{8}	^{205}Pb	4.85×10^{-8}	^{126m}Sb	1.92×10^{4}
^{10}Be	4.33×10^{-7}	^{209}Pb	1.87×10^{3}	^{79}Se	1.07×10^{-5}
^{208}Bi	1.88×10^{-6}	^{210}Pb	3.11×10^{-2}	^{32}Si	1.54×10^{-3}
^{210}Bi	5.06×10^{1}	^{211}Pb	1.01×10^{4}	^{126}Sn	6.93×10^{-6}
^{210m}Bi	2.31×10^{-7}	^{212}Pb	5.73×10^{2}	^{90}Sr	2.38×10^{-2}
^{211}Bi	1.70×10^{5}	^{214}Pb	1.36×10^{4}	^{182}Ta	2.20×10^{0}
^{212}Bi	6.03×10^{3}	^{107}Pd	1.07×10^{-7}	^{99}Tc	3.25×10^{-6}
^{213}Bi	7.98×10^{3}	^{210}Po	1.83×10^{0}	^{125m}Te	4.36×10^{0}
^{214}Bi	1.83×10^{4}	^{211}Po	4.23×10^{7}	^{227}Th	1.35×10^{1}
^{14}C	1.21×10^{-4}	^{212}Po	7.17×10^{13}	^{228}Th	3.62×10^{-1}
^{41}Ca	4.95×10^{-6}	^{213}Po	5.21×10^{12}	^{229}Th	9.44×10^{-5}
^{113m}Cd	5.09×10^{-2}	^{214}Po	1.33×10^{11}	^{230}Th	9.00×10^{-6}
^{135}Cs	3.01×10^{-7}	^{215}Po	1.23×10^{10}	^{231}Th	2.38×10^{2}
^{221}Fr	7.59×10^{4}	^{216}Po	1.46×10^{8}	^{232}Th	4.93×10^{-11}
^{223}Fr	1.67×10^{4}	^{218}Po	1.20×10^{5}	^{234}Th	1.05×10^{1}
^{3}H	5.61×10^{-2}	^{238}Pu	7.90×10^{-3}	^{206}Tl	8.68×10^{4}
^{182}Hf	7.70×10^{-8}	^{239}Pu	2.88×10^{-5}	^{207}Tl	7.63×10^{4}
^{129}I	4.41×10^{-8}	^{240}Pu	1.06×10^{-4}	^{208}Tl	1.19×10^{5}
^{40}K	5.42×10^{-10}	^{241}Pu	4.81×10^{-2}	^{209}Tl	1.65×10^{5}
^{81}Kr	3.30×10^{-6}	^{242}Pu	1.84×10^{-6}	^{232}U	9.63×10^{-3}
^{85}Kr	6.46×10^{-2}	^{223}Ra	2.21×10^{1}	^{233}U	4.37×10^{-6}
^{93}Mo	1.98×10^{-4}	^{224}Ra	6.93×10^{1}	^{234}U	2.83×10^{-6}
^{93m}Nb	5.10×10^{-2}	^{225}Ra	1.71×10^{1}	^{235}U	9.85×10^{-10}
^{94}Nb	3.41×10^{-5}	^{226}Ra	4.33×10^{-4}	^{236}U	2.96×10^{-8}
^{59}Ni	9.24×10^{-6}	^{228}Ra	1.21×10^{-1}	^{238}U	1.55×10^{-10}
^{63}Ni	7.22×10^{-3}	^{87}Rb	1.47×10^{-11}	^{90}Y	9.50×10^{1}
^{237}Np	3.24×10^{-7}	^{187}Re	1.39×10^{-11}	^{93}Zr	4.53×10^{-7}

Chemically Toxic Elements

Br	Cs	Se
Cd	Mo	Sm
Cr	Sb	Tc

SHORT-LIVED RADIONUCLIDES CONSIDERED IN BIOTRAC

Radionuclides with Half-Lives Less than 1 d	Radionuclides with Half-Lives Between 1 d and 20 a
^{228}Ac	^{225}Ac (^{225}Ra)*
^{217}At	^{210}Bi (^{210}Pb)
^{211}Bi	^{93m}Nb (^{93}Mo)
^{212}Bi	^{93m}Nb (^{93}Zr)
^{213}Bi	^{32}P (^{32}Si)
^{214}Bi	^{233}Pa (^{237}Np)
^{221}Fr	^{210}Po (^{210}Bi)
^{223}Fr	^{223}Ra (^{227}Th)
^{234}Pa	^{224}Ra (^{228}Th)
^{234m}Pa	^{225}Ra (^{229}Th)
^{209}Pb	^{228}Ra (^{232}Th)
^{211}Pb	^{126}Sb (^{126}Sn)
^{212}Pb	^{182}Ta (^{182}Hf)
^{214}Pb	^{125m}Te (^{125}Sb)
^{211}Po	^{227}Th (^{227}Ac)
^{212}Po	^{228}Th (^{228}Ra)
^{213}Po	^{228}Th (^{232}U)
^{214}Po	^{231}Th (^{235}U)
^{215}Po	^{234}Th (^{238}U)
^{216}Po	^{90}Y (^{90}Sr)
^{218}Po	
^{219}Rn	
^{220}Rn	
^{126m}Sb	
^{206}Tl**	
^{207}Tl	
^{208}Tl	
^{209}Tl	

* Precursors shown in brackets.

** Not considered in the postclosure assessment because the parent, ^{210m}Bi, has a very low vault inventory.