Appendix 7

EVALUATION OF DOSE FROM THE DRINKING WATER PATHWAY AS OPPOSED TO OTHER POSSIBLE PATHWAYS OF EXPOSURE

Introduction

The transport of radionuclides through terrestrial and aquatic biota can result in the contamination of the human diet. Ingestion of radionuclides in foods can be an important contributor to the total dose received by an individual or critical (population) group.

The models presented here are intended to be simple screening models for the purpose of estimating the potential impacts, of specific water use scenarios, to hypothetical critical groups in the absence of any site-specific data.

The radionuclides of concern are the long-lived radionuclides of the ^{238}U and ^{232}Th decay chains.

Since simple transfer factors based upon concentration factors are used, steady state conditions are assumed with regard to the long term build-up of contaminants in the various environmental compartments i.e. it is assumed for example that the use of contaminated water has been a long term process.

The models are not intended for use in modeling infrequent events e.g. a discrete batch discharge. They are intended for situations in which the long term average radionuclide concentrations in water are reasonably well known; i.e. they are not intended to predict doses from single grab sample results.

The result merely indicates the range of potential hazard that may arise if the water is put to a particular use. This value is compared to a defined criteria (e.g. indicated dose >250 $\mu Sv.y^{-1}$) to assist in a decision making process to determine whether further investigations are required e.g. initiate further sampling programme; identify source: identify actual critical groups: implement control over source and/or initiate remedial action.

In reality an exposed group of individuals will receive widely varying doses from an exposure pathway, these models are intended to indicate the potential range of dose to a critical group or person for each exposure pathway.

Since the consumption factors and transfer factors are required to cover all possible situations and types of critical groups and taking into account the lack of data on transfer factors in semi-arid environments the maximum values used are conservative (in order to ensure that potential doses are not underestimated); and merely indicate the maximum likely dose within a poorly quantified scenario.

Where significant doses are indicated by the model, the implication is that the actual situation on the ground should be investigated further to define mitigating factors and the actual water uses.

Scaling

If site specific data is available the results obtained using the default values can be scaled to give a more realistic estimate of dose. For example if the water consumption of an identified group of adults is known to be only 250 litres from the contaminated source the resulting dose can be scaled i.e.

$\mu Sv/(a.Bq.l^{-1})$ x (250/730)

Scaling can be applied to any consumption rate, occupation factor, irrigation rates, transfer parameter etc where site specific information is available.

Interpretation

It is proposed that where a value exceeds 250 µSv/a that consideration be given to site specific investigations to better quantify the dose e.g. determine actual critical groups, their water use and food consumption rates.

Ingestion Dose Coefficients

These have been taken from ICRP-72 and indicate the committed effective dose per unit intake in $\mu Sv.Bq^{-1}$.

The Dose Coefficients used in the model are given below for a child (age range 1-2 years) and for adult members of the public.

Table 1: Ingestion Dose Coefficients

	DC_{child}	DC_{Adult}
^{238}U	0,12	0,05
^{234}U	0,13	0,05
^{230}Th	0,41	0,21
^{226}Ra	0,96	0,28
^{210}Pb	3,6	0,69
^{210}Po	8,8	1,2
^{232}Th	0,45	0,23
^{228}Th	0,37	0,07
^{228}Ra	5,7	0,69
^{224}Ra	0,66	0,07
^{235}U	0,13	0,05
^{231}Pa	1,3	0,71
^{227}Ac	3,1	1,1
^{227}Th	0,07	0,009
^{223}Ra	1,1	0,1

Transfer Factors

In the absence of data specific to arid South African conditions default values have been based mostly upon a literature survey of data applicable to temperate European and North American situations. The values selected are conservative and represent in most cases the upper bound of reported values (95% CL).

The more important references reviewed to obtain parameter and consumption values are given in the reference section at the end of this document.

Ranges of Parameter values are given in a number of cases to indicate the range of recorded variability and the degree of conservatism: these values are taken from various IAEA summaries. It should be noted that these ranges reflect variations associated with different parts of the world as well as between different crop species or types of farm animals. The values used in the simple model are not species specific but refer to very broad generic categories of edible pasture, vegetables, fruits, etc (e.g. leafy vegetables applies to all types of leafy vegetables and pasture includes grass, wild forage, browse, hay etc).

Uptake of Radionuclides from Soil by Edible Portions of Vegetation

The soil to plant concentration factor, F_v, can be applied to animal feeds (e.g. pasture, forage, browse and plant based feed) and is referred to as F_{v1}. In addition F_{v2} values are defined for fresh food crops consumed by humans.

The concentration factor reflects only the uptake of radionuclides from the soil via roots and excludes the effects of deposition of nuclides onto plant surfaces by resuspension, deposition and fallout.

F_{v1} = (Bq.g^{-1} Dry weight plant) / (Bq.g^{-1} dry weight soil)

F_{v2} = (Bq.g^{-1} Fresh weight plant) / (Bq.g^{-1} dry weight soil)

Default Annual Consumption Factors for Exposed Individuals in Critical Groups

Dietary composition varies widely around the world and can vary widely within the same country e.g. South Africa. The great majority of default values reported in the literature and used in modeling are based upon European or North American diets with very limited data available on African diets and consumption rates.

The following should be noted:

1) Due to the difficulty in establishing an "average" South African diet given the first-world/third-world mixture of potential critical groups; two default diets have been derived (refer to IAEA 57 and IAEA 57 redraft) based upon per caput consumption values considered to be representative of different geographical regions. Diet 1 corresponds to African per caput values and Diet 2 to a European diet: the major difference in these diets being in the milk, meat and vegetable consumption factors. (Note: default water and fish consumption is assumed to be the same).

2) These consumption values are for use in screening assessments and should ensure that all types of potential critical groups are covered e.g. rural dwellers, subsistence farmers, modern farmers and other groups with a variable dietary intake.

3) Values for infants have been derived by scaling from default adult consumption rates based upon values from the literature (e.g. ICRP-29).

4) The values were derived after review of a wide range of literature (e.g. IAEA 1982, 1986, 1994, 1996, ICRP 1978). It should be noted that they are not the highest per capita consumption values reported in the literature. Extensive use was made of interpolation and rounding in deriving these values.

Table 2: Annual Food Consumption Parameters for Diet 1

CATEGORY (Kg per year fresh weight)	ADULT	Child (1-2 years)
Water	730	260
Freshwater Fish	25**	1
Milk (Litres)	80	180
Meat	35	10
Cereals and grains	120	50
Leafy Vegetables	55	22,5
Root crops	170	70
Fruit, nuts, pulses	40	15

Table 3: Annual Food Consumption Parameters for Diet 2

CATEGORY (Kg per year fresh weight)	ADULT	CHILD (1-2 years)
Water	730	260
Freshwater Fish	25**	1
Milk (Litres)	250	300
Meat	100	20
Cereals and grains	150	60
Leafy Vegetables	55	22,5
Root crops	170	70
Fruit, nuts, pulses	75	30

** (Applicable to both recreational and subsistence fishermen: there is uncertainty as to whether this value adequately represents the intake of certain subsistence groups utilising this resource in the Gauteng area)

Note: For comparison to the above diets maximal per capita (i.e. average) annual consumption rates are given below from around the world.

These values are average values for large geographical regions: therefore higher adult maxima can occur in specific countries or specific groups within such countries (e.g. meat: Finland and Laplanders).

Milk:	**Oceania:**	**410 liters**
Meat:	**North America:**	**205 kg**
Fresh water fish:	**Far East:**	**35 kg**
Vegetables, roots, grain, nuts etc:		**600 kg**

Default water consumption rates are highly variable around the world ranging from around 350-850 liters per annum.

Table 4: Animal Daily Food and Water Consumption Default Values

Animal	Water ($L\ d^{-1}$)	Dry Feed[a] ($Kg\ d^{-1}$)
Milk or Beef Cow	75	25

a. Feed, pasture, browse or forage

The above default values cover all breeds and intensities of dairy farming or beef production. Since dairy cows have higher intake demands the defaults are based on dairy cows. Ranges reported in the literature for all breeds and climates and milk production rates are as follows:

Water = 20 - 110 Litres per day.
Dry feed = 5 - 25 kg per day.

Models Involving Irrigation

Models involving irrigation were calculated in a three-stage approach:

1. Calculating the concentration (C_{iv}) in pasture and feed and crops

2. Calculating the concentration in milk, meat

3. Calculating the effective dose

An example of the approach used is given in Appendix 7A.

The various parameter values used to calculate C_{iv} in pasture, forage, feed and crops are given in the text.

MODEL CALCULATIONS

Introduction

A brief overview is given of the structure of the models used in the database. Relevant diet values from Diet 2 are provided as example values since these are the highest of the two diet groups.

1. Drinking Water

Assumptions:

- Activity Concentration: 1 $Bq.L^{-1}$ per radionuclide
- No dilution: No removal: No treatment prior to consumption
- Water consumption:
  Adult = 730 $L.y^{-1}$
  One year old = 260 $L.y^{-1}$

Drinking Water Equation

$\mu Sv\ y^{-1} = 1\ (Bq.L^{-1}) \quad X \quad 730\ (L.y^{-1}) \quad X \quad DC_{Adult} \quad (\mu Sv.Bq^{-1})$

$\mu Sv.y^{-1} = 1\ (Bq.L^{-1}) \quad X \quad 260\ (L.y^{-1}) \quad X \quad DC_{Child} \quad (\mu Sv.Bq^{-1})$

CED = water concentration x consumption x dose coefficient

(CED = Committed Effective Dose)

2. Consumption of Fish Living in Contaminated Water

Assumptions:

- Activity Concentration: 1 $Bq.L^{-1}$ of relevant radionuclide
- No dilution: no removal: no treatment.
- Assumes a long-term stable contamination situation.
- Fish Consumption (edible wet weight)
  Adult = 25 $kg.y^{-1}$
  One year old = 1 $kg.y^{-1}$

Fish Consumption Equation

$\mu Sv.y^{-1} = 1\ (Bq.L^{-1})\ X\ Bp\ (Bq.L^{-1} / Bq.Kg^{-1})\ X\ 25\ (Kg.y^{-1})\ X\ DC_{Adult}\ (\mu Sv.Bq^{-1})$

$\mu Sv.y^{-1} = 1\ (Bq.L^{-1})\ X\ Bp\ (Bq.L^{-1} / Bq.kg^{-1})\ X\ 1\ (kg.y^{-1})\ X\ DC_{Child}\ (\mu SV.Bq^{-1})$

CED = concentration x bioaccumulation factor x annual consumption x dose coefficient.

Bioaccumulation Factors for Freshwater Fish

Under equilibrium conditions, the incorporation of radioactivity into fish can be expressed as the bioaccumulation factor B_p defined as:

“The ratio of the activity concentration in fish tissue to that in water which is normally expressed as Bq.kg^{-1} wet weight fish per Bq.kg^{-1} (or L^{-1}) water (units of L.kg^{-1})”. The activity concentration in fish tissue usually refers to the edible portion of the fish wet mass.

The values can be used to predict activity levels in edible fish tissue from activity levels in water under steady state conditions.

Table 5: Bioaccumulation factor (B_{p}) values: Uptake from Water into Fish Tissue.

Element	Environment	Biota	Concentration Factors	Range
			B_p (Units: L.kg^{-1})	
U	Fresh water	Fish	5.00E+01	0,3-50
Ra	Fresh water	Fish	2.00E+02	0,3-200
Po	Fresh water	Fish	5.00E+02	10-500
Pb	Fresh water	Fish	2.00E+03	100-2000
Th	Fresh Water	Fish	1.00E+03**	30-10000*
Ac	Fresh Water	Fish	3.30E+02	15-330
Pa	Fresh Water	Fish	3.00E+01	10-30

*Higher values have been reported recently up to 60000 in a French study.
** A lower default value (1000) was used in the model based on South African data.

Bio-accumulation parameter values vary widely according to many factors e.g. fish type, type of water body, feeding patterns and feeding habits (e.g. carnivorous, omnivorous, herbivorous), trophic level, water chemistry, stable element concentrations, pH, nutrient levels, eutrophic level of water body, water temperature, size of fish, age, migratory behaviour, physico-chemical form of the radionuclide, dissolved mineral content, sedimentation and resuspension processes as well as with different radionuclides, in addition reported values in the literature for specific radionuclides in different freshwater environments can vary by several orders of magnitude. In addition to the above factors inadequate sampling and radiochemical analysis programs can contribute to uncertainties.

It should also be noted that the transfer factors express the summed fractional uptake into the fish via many pathways e.g. direct uptake from water through the gills, skin and gut: uptake from sediment; uptake through various trophic feeding levels and routes.

The range of this potential variation for fish is indicated in the above Table.

The availability of site specific data is of great importance to provide realistic estimates of effective dose through the consumption of fish.

3. Consumption of Milk from Cows Grazing on Feed Irrigated with Contaminated Water

Assumptions

- Concentration: 1 Bq.L^{-1} of relevant radionuclide.
- No dilution: no removal: no treatment of water prior to irrigation.
- The sole source of all milk is obtained from the cow i.e. no dilution with uncontaminated milk.
- Cows always graze on contaminated land e.g. pasture, lucerne etc.

- Assumes an irrigation rate of 750 $L.y^{-1}$ per m^{-2} (source: mean value for irrigation farmers in Lower Vet river). The model assumes only 1 year of irrigation with contaminated water prior to the cows commencing grazing.

- Steady state conditions: i.e. minimal leaching of activity from soil.

- Excludes uptake through spray irrigation through deposition on leaves.

- Covers all types of irrigation.

- Excludes uptake arising from eating soil.

- Accounts for decay.

- Milk Consumption (litres)
  Adult = 250 $L.y^{-1}$
  One year old = 300 $L.y^{-1}$

- Feed consumption = 25 000 $g.d^{-1}$ (dry)

MILK CONSUMPTION EQUATION

$\mu Sv.y^{-1} = C_{iv}$ X 25000 (Dry $g.d^{-1}$) X F_M X 250 (L) X DC_{Adult} ($\mu Sv.Bq^{-1}$)

$\mu Sv.y^{-1} = C_{iv}$ X 25000 (Dry $g.d^{-1}$) X F_m X 300 (L) X DC_{Child} ($\mu Sv.Bq^{-1}$)

CED = concentration in feed ($Bq.g^{-1}$) x dry feed consumption: grams per day x f_m (feed to milk transfer factor: per $Bq.L^{-1}$ milk per Bq.day intake) x annual milk consumption (L) x dose coefficient.

Note: Refers to one year of irrigation: assumes a 15 cm plough depth containing 240 kg of dry soil per m^2.

Table 6: Default Soil to Plant Transfer Factors: F_{v1} for all Types of Pasture, Grass, Browse and Forage Vegetation.

Element	Concentration Factors	
	F_{V1}	
	Minimum	Maximum
U	1.00E-05	2.00E-01
Pa	1.00E-02	1.00E-01
Ac	4.00E-03	1.00E-01
Ra	1.00E-03	4.00E-01
Po	5.00E-04	1.00E-01
Pb	2.00E-04	5.00E-01
Th	5.00E-05	1.00E-01

Unit: ($Bq.g^{-1}$ dry plant per $Bq.g^{-1}$ dry soil)

Feed to Milk transfer Factors: (Fraction of daily intake taken into milk):
Transfer Coefficients F_m for Cow's Milk

The transfer of radionuclides from an animal's feed to milk is commonly described by using the transfer coefficient F_m defined as:

“The fraction of the animals total daily intake of a radionuclide that is transferred to each litre of milk per day”.

Note: The values given below may be applied to cow, goat or sheep milk.

Table 7: Feed to Milk transfer Factors: (Fraction of daily intake taken into milk): Transfer Coefficients F_m

Element	**Transfer Coefficient**	
	F_m	
	units.d.L^{-1}	
	Minimum	**Maximum**
U	7.30E-05	6.10E-04
Pa	2.50E-06	5.00E-06
Ac	2.00E-05	2.00E-04
Ra	7.00E-06	1.3E-03
Po	1.00E-04	3.00E-03
Pb	3.00E-05	3.00E-04
Th	2.50E-06	5.00E-06

4. Consumption of Milk from Cows Drinking Contaminated Water

Assumptions

- Concentration = 1 Bq.L^{-1} of relevant radionuclide.
- The sole source of all milk is obtained from the cow i.e. no dilution with uncontaminated milk.
- Cows only drink contaminated water.
- Steady state conditions apply.
- Concentration = 1 Bq.L^{-1} of relevant radionuclide.
- No dilution: no removal: no treatment of water prior to drinking.
- Milk is obtained direct from the animal i.e. no dilution with uncontaminated milk.
- Cow Water Consumption = 75 L.d^{-1}
- Milk Consumption (litres)
  Adult = 250 L.y^{-1}
  One year old = 300 L.y^{-1}

Milk Consumption Equation

µSv.y^{-1} = 1 (Bq.L^{-1}) X 75 (L.d^{-1}) X F_m X 250 (L) X DC_{Adult} (µSv.Bq^{-1})

µSv.y^{-1} = 1 (Bq.L^{-1}) X 75 (L.d^{-1}) X F_m X 300 (L) X DC_{Child} (µSv.Bq^{-1})

CED = concentration in water x w_c (daily water consumption) x F_m (water to milk transfer factor: Bq.day intake per Bq.L^{-1}) x annual milk consumption (L) x dose coefficient.

For F_m values refer to Table 7.

5. Consumption of Meat from Cattle Grazing on Feed Irrigated with Contaminated Water

Assumptions

- Concentration = 1 $Bq.L^{-1}$ of relevant radionuclide.
- No dilution: no removal: no treatment of water prior to irrigation.
- The sole source of all meat consumed is obtained from the cattle.
- Cattle always graze on contaminated land e.g. pasture, lucerne etc.
- Assumes an irrigation rate of 750 $L.y^{-1}$ year per m^{-2} (source: mean value for irrigation farmers in Lower Vet River). The model assumes only 1 year of irrigation with contaminated water prior to the cows commencing grazing.
- Steady state conditions: i.e. no leaching of activity from soil.
- Excludes uptake through spray irrigation through deposition on leaves.
- Covers all types of irrigation.
- Excludes uptake arising from eating soil.
- **Meat Consumption (kg)**
  Adult = 100 $kg.y^{-1}$
  One year old = 20 $kg.y^{-1}$
- **Feed consumption**
  25 $kg.d^{-1}$

Meat Consumption Equation

$\mu Sv.y^{-1} = C_{iv}$ X 25000 (Dry $g.d^{-1}$) X F_F X 100 (kg) X DC_{Adult} ($\mu Sv.Bq^{-1}$)

$\mu Sv.y^{-1} = C_{iv}$ X 25000 (Dry $g.d^{-1}$) X F_F X 20 (kg) X DC_{Child} ($\mu Sv.Bq^{-1}$)

CED = concentration in feed ($Bq.g^{-1}$) x dry feed consumption g per day x F_F (feed to meat transfer factor: per $Bq.kg^{-1}$ meat per Bq.day intake) x annual meat consumption (kg) x dose coefficient.

Transfer Coefficients F_f for Animal Flesh

Beef and Cows

The transfer of radionuclides from an animal's feed (pasture, grass, forage) to edible animal products is commonly described by using the transfer coefficient F_f defined as:

"The fraction of the animals total daily intake of a radionuclide that is transferred to each kg of flesh at equilibrium or at time of slaughter".

The values below are derived for beef meat but may be may be applied to all types of edible beef and cow products as well as pigs, goats, horses and game animals.

Table 8: Transfer Coefficients F_f

Element	Transfer Coefficient	
	F_F	
	(Units: $d.kg^{-1}$)	
	Minimum	Maximum
U	1.60E-06	3.00E-02
Pa	1.60E-06	5.00E-03
Ac	2.00E-05	4.00E-04
Ra	1.00E-04	5.00E-03
Pb	1.00E-04	9.10E-04
Po	6.00E-04	5.00E-03
Th	1.60E-06	5.00E-03

6. Consumption of Meat from Animals Drinking Contaminated Water

Assumptions

- Concentration = 1 $Bq.L^{-1}$ of relevant radionuclide.
- The sole source of all meat is obtained from the cattle.
- Cattle only drink contaminated water.
- Steady state conditions apply.
- No dilution: no removal: no treatment of water prior to drinking.
- Water Consumption = 75 $L.d^{-1}$
- **Meat Consumption (kg)**
  Adult = 100 $kg.y^{-1}$
  One year old = 20 $kg.y^{-1}$

Meat Consumption Equation

$\mu Sv.y^{-1}$ = 1 ($Bq.L^{-1}$) X 75 ($L.d^{-1}$) X F_F X 100 (kg) X DC_{Adult} ($\mu Sv.Bq^{-1}$)

$\mu Sv.y^{-1}$ = 1 ($Bq.L^{-1}$) X 75 ($L.d^{-1}$) X F_F X 20 (kg) X DC_{Child} ($\mu Sv.Bq^{-1}$)

CED = water concentration x w_c (daily water consumption) x F_F (water to meat transfer factor: Bq.day intake per $Bq.kg^{-1}$) x annual meat consumption (kg) x dose coefficient.

7. Consumption of Crops Irrigated by Contaminated Water.

Assumptions

- Concentration = 1 $Bq.L^{-1}$ of relevant radionuclide.
- No dilution: no removal: no treatment of water prior to irrigation.
- The sole source of all food consumed is irrigated with contaminated water.
- Assumes an irrigation rate of 750 $L.y^{-1}$ year per m^{-2} (source: mean value for irrigation farmers in Lower Vet River). The model assumes only 1 year of irrigation with contaminated water)

- Steady state conditions: i.e. no leaching of activity from soil.
- Excludes uptake through spray irrigation through deposition on leaves.
- Covers all types of irrigation.
- **Annual Plant Consumption by Humans (f_c)**

  Cereals and Grains:

  Adult = 150 kg
  1 year old = 60 kg

  Root Crops

  Adults = 170 kg
  1 year old = 70 kg

  Leafy Vegetables

  Adults = 55 kg
  1 year old = 22,5 kg

  Fruits and other vegetables

  Adults = 75 kg
  1 year old = 30 kg

  Root crops, leafy vegetables and fruits, nuts etc refers to fresh weight consumption.

Generic Equation

The generic equation applies to the consumption of grains or leafy vegetables or root vegetables or fruits. Insert the appropriate f_{v2} value for the crop to determine the concentration (C_{iv})(Bq.g^{-1}) in the crop (refer to attachment A) and the age specific annual consumption values f_{ca} (adult) and f_{cc} (child).

µSv.y^{-1} = C_{iv} X f_{ca} (g.y^{-1}) X DC_{Adult} (µSv.Bq^{-1})

µSv.y^{-1} = C_{iv} X f_{cc} (Dry g.y^{-1}) X DC_{Child} (µSv.Bq^{-1})

CED = concentration in food x annual food consumption (g.y^{-1}) x dose coefficient.

Table 9: Default Concentration factors F_{v2} for all Types of Grains and Cereals e.g. Maize, Wheat, Barley, Sunflower Seeds etc.

Element	Concentration Factor	
	F_{v2}	
	MINIMUM	MAXIMUM
U	2.00E-04	1.30E-03
Pa	2.00E-02	2.00E-02
Ac	3.00E-04	3.00E-04
Ra	2.40E-04	1.00E-02
Pb	4.70E-04	5.00E-02
Po	1.00E-03	2.00E-03
Th	3.40E-06	1.00E-03

Unit: (Bq.g^{-1} dry plant and soil)

Table 10: Concentration Factors F_{v2} For Leafy Vegetables, Root Vegetables And Fruits, Nuts And Pulses.

Element	Concentration Factor F_{v2}					
	Leafy Vegetables		Root Vegetables		Fruits	
	Minimum	Maximum	Minimum	Maximum	minimum	maximum
U	1.20E-04	1.00E-02	2.00E-04	3.00E-02	4.00E-04	4.00E-04
Pa	8.00E-03	8.00E-03	1.00E-02	1.00E-0	5.00E-03	5.00E-03
Ac	1.50E-03	1.50E-03	2.00E-03	2.00E-03	3.00E-04	3.00E-04
Ra	1.00E-04	4.00E-02	4.00E-05	4.00E-02	4.30E-04	4.00E-02
Pb	8.50E-05	3.00E-02	3.00E-05	2.00E-02	1.00E-02 .	1.00E-02
Po	3.00E-04	2.00E-03	2.00E-04	2.00E-03	1.00E-03	1.00E-03
Th	5.00E-06	1.00E-02	1.00E-06	8.00E-04	4.00E-04	4.00E-04

(Unit: $Bq.g^{-1}$ wet plant per $Bq.g^{-1}$ dry soil)

Default % dry weights were used in calculating the above wet weight parameter values: green vegetables (15%): roots (20%) and fruits(10%).

8. External Exposure Arising from Radionuclides in Water

Assumptions

- Concentration = 1 $Bq.L^{-1}$ of relevant radionuclide (radium) in river or lake.
- Steady state conditions.
- The model covers the following exposure scenarios and assumes a total occupancy factor of 300 hours per annum: Swimming, fishing, boating, ski boating, sailboard.

The exposure model is based upon the external gamma dose arising from exposure to radionuclides in the water. It does not estimate any dose that may arise from contaminated sediment, which would require a separate measurement.

Since the primary gamma emitter of the decay chain is radium the concentration of radium should be used in the equation. If radium concentration is not available use the 238U concentration.

The conversion factor calculated below was derived from a simple conservative model given in IAEA 57 page 5+4-56 (1982).

The following assumptions were used:

- 1 $Bq.L^{-1}$ radium
- Mean gamma energy per decay: 1 MeV
- Occupation factor 300 hours per annum.
- Geometry modification factor : 2
- Conversion factor = 0,2 $\mu Sv.y^{-1}$ per $Bq.L^{-1}$ Radium (OF= 300 hours).

Note:

(a) The above dose is minimal compared to other exposure pathways.

(b) The above model can be used for sediments where more significant doses are likely to arise from external exposure to contaminated sediments: in this case the activity per kg (dry) of the sediment would require to be measured for input into the above model.

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