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METHODS FOR ESTIMATING DOSES TO ORGANISMS FROM RADIOACTIVE MATERIALS RELEASED INTO THE AQUATIC ENVIRONMENT

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SUMMARY

The U.S. Department of Energy recently published an interim dose limit of 1 rad d^{-1} for controlling the radiation exposure of native aquatic organisms. A computer program named CRITR, developed previously for calculating radiation doses to aquatic organisms and their predators, has been updated as an activity of the Hanford Site Surface Environmental Surveillance Project to facilitate demonstration of compliance with this limit. This report presents the revised models and the updated computer program, CRITR2, for the assessment of radiological doses to aquatic organisms and their predators; tables of the required input parameters are also provided. Both internal and external doses to fish, crustacea, mollusks, and algae, as well as organisms that subsist on them, such as muskrats, raccoons, and ducks, may be estimated using CRITR2. Concentrations of radionuclides in the water to which the organisms are exposed may be entered directly into the user-input file or may be calculated from a source term and standard dilution models developed for the National Council on Radiation Protection and Measurements.

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INTRODUCTION

Pathways of exposure associated with liquid effluents are generally the most significant contributors to radiation dose to organisms other than man. Aquatic organisms can concentrate radionuclides from their water environment either directly or via their food chains. The U.S. Department of Energy (DOE) recently published an interim dose limit of 1 rad d^{-1} for controlling the radiation exposure of native animal aquatic organisms (DOE Order 5400.5 [1990]). A computer program named CRITR, previously developed for calculating radiation doses to aquatic organisms and their predators (Soldat, Robinson, and Baker 1974; NCRP 1991), has been updated as an activity of the Hanford Site Surface Environmental Surveillance Project to facilitate demonstration of compliance with this limit. For purposes of calculating concentrations of radionuclides in aquatic organisms, the organisms can be divided into two classifications: "primary aquatic organisms," those for which element-specific ratios between concentrations in the water environment and the organism are available, and "secondary organisms," which feed upon primary organisms.

This report presents the revised models and the updated computer program, CRITR2, for the assessment of radiological doses to aquatic organisms and their predators; tables of the required input are also provided. The first section of the report describes the equations for calculating internal doses for primary and secondary organisms and presents a sample calculation. The next section describes the equations and methodology for calculating external doses to these two classes of organisms and also includes an example calculation. Appendix A is a user's guide that describes the CRITR2 program. Both internal and external doses to fish, crustacea, mollusks, and algae, as well as organisms subsisting on them, such as muskrats, raccoons, and ducks, may be estimated using CRITR2. Concentrations of radionuclides in the water to which the organisms are exposed may be entered directly into the user input file or may be calculated from a source term and standard dilution models being developed for the National Council of Radiation Protection and Measurements. Appendix B contains the input files and a sample problem.

INTERNAL DOSE

Radionuclide concentrations in primary organisms can be calculated directly from the water concentrations and bioaccumulation factors. The primary organisms considered are fish, crustacea, mollusks, and plants. Radionuclide concentrations for secondary organisms can be calculated from their diet of primary organisms. Representative secondary birds and mammals were selected such that each primary organism would be in the diet of at least one secondary organism. For the Hanford Site, predatory birds and mammals commonly selected are herons (fish-eating), raccoons (crustacea-, mollusk-, or fish-eating), muskrats (plant-eating), and ducks (plant- or fish-eating).

The internal total-body dose rate to an organism for N radionuclides is given as

$$R_c = \sum_{i=1}^{N} b_{i,c} E_{i,c} \qquad (1)$$

where R_c = dose rate to total body of organism c (rad d^{-1}),

$E_{i,c}$ = effective absorbed energy rate for nuclide i per unit activity in organism c (kg rad $Ci^{-1}d^{-1}$).

$$E_{i,c} = \epsilon_{i,c} \text{ MeV dis}^{-1} \times 3.70E10 \text{ dis s}^{-1} \text{ Ci}^{-1} \times 86{,}400 \text{ s d}^{-1} \times 1.602E\text{-}11 \text{ kg rad MeV}^{-1} = 5.12E4\ \epsilon_{i,c}$$

where ϵ is the effective absorbed energy for nuclide i in organism c.

$b_{i,c}$ = specific body burden of nuclide i in organism c (Ci kg^{-1}).

For a primary organism,

$$b_{i,c} = C_{i,c} B_{i,c} \qquad (2)$$

where $C_{i,c}$ is concentration of nuclide i in water to which organism c is exposed (Ci m^{-3}), and $B_{i,c}$ is bioaccumulation factor for nuclide i and organism c (m^3 kg^{-1}). Here the water concentration has already been corrected for

dilution and radioactive decay during transit from the point of release into the receiving water body to the region of the organism's habitat.

Combining equations (1) and (2) yields the dose rate in rad d^{-1} to the primary organism

$$R_c = \sum_{i=1}^{N} C_{i,c} B_{i,c} E_{i,c} \tag{3}$$

For the secondary organism, we can write an expression for a single radionuclide equating the change in body burden for the uptake and removal of the radionuclide

$$\frac{db^s}{dt} = \frac{P}{M} - \lambda b^s \tag{4}$$

where b^s = specific body burden of the secondary organism (Ci kg^{-1})

P = rate of uptake of radionuclide by body of organism (Ci d^{-1})

λ = $(\lambda_b + \lambda_r)$ effective decay constant in secondary organism, (d^{-1}), where $\lambda_b = \ln(2)/T_b$ is the biological removal rate constant for the nuclide in the secondary organism and $\lambda_r = \ln(2)/T_r$ is the radiological decay constant for the nuclide

M = mass of secondary organism (kg).

The secondary organism uptake rate is given by

$$P = b U f_1 \tag{5}$$

where b = body burden of primary organism (Ci kg^{-1})

U = intake rate of primary organism by predator (kg d^{-1})

f_1 = fraction of radionuclide initially retained in total body of secondary organism (unitless).

Solving equation (4) with $b^s = 0$ when $t = 0$:

$$b^s = \frac{P}{M}\frac{(1-e^{-\lambda T_e})}{\lambda} \tag{6}$$

where T_e is the period of exposure (d).

Then, for a secondary organism c, the dose rate in terms of the body burden b_i, of the primary organism for N radionuclides is

$$R_c = \sum_{i=1}^{N} \frac{b_i U_c f_{1,i}}{m_c} \frac{(1-e^{-\lambda_{i,c}T_e})}{\lambda_{i,c}} E_{i,c} \tag{7}$$

where U_c = intake rate of primary organism by secondary organism c (kg d^{-1})

$\lambda_{i,c}$ = effective decay constant of nuclide i in secondary organism c (d^{-1})

m_c = mass of secondary organism c (kg).

In the absence of specific data, the removal constants, $\lambda_{i,c}$, and uptake fractions, $f_{1,i}$, are taken to be that of Standard Man as derived from Publication 2 of the International Commission on Radiological Protection (ICRP 1959). See Table 1 for a list of representative values. The values of effective energy, $\epsilon_{i,c}$, are determined knowing the effective radius of the organism. Table 2 gives values for the energies in MeV dis^{-1} for selected nuclides and radii. Energies for radii falling between these values may be found by linear interpolation. However, for most estimates, selecting the energy associated with the radius closest to that of the organism suffices. The exposure time, T_e, is usually assumed to be one year for regulatory purposes, and the water concentration is averaged over one year. These doses to organisms may be obtained by hand calculation or the CRITR2 screening program for surface water pathways (see Appendixes A and B).

Example Calculation

As an example of how this methodology may be applied to some representative Hanford biota, an estimate was made of the internal dose rate from ^{60}Co to a fish residing in water having the concentration of 4.9E-8 Ci m^{-3} and to a

heron whose total diet consists of such fish. The radiological decay constant for ^{60}Co is 3.6E-4 d^{-1} (half-life of 5.27 y).

The solution is as follows: first the body burden of the fish is calculated. The bioaccumulation factor for fresh-water fish is obtained from Table 1 for cobalt: 330 L kg^{-1} or 0.33 m^3 kg^{-1}. The body burden of the fish using Equation (2) is then

$$b_{fish} = 4.9E\text{-}8\,Ci\ m^{-3} \times 0.33\,m^3\ kg^{-1} = 1.62E\text{-}8\,Ci\ kg^{-1}$$

From Table 3, we find the effective radius of a reference Hanford fish to be 5 cm. Then from Table 2, we find the energy absorbed in this radius for ^{60}Co is 0.437 MeV dis^{-1}. Then the dose rate, using Equation (1), is

$$R_{fish} = 1.62E\text{-}8\,Ci\,kg^{-1} \times (5.12E4 \times 0.437)\,kg\,rad\,Ci^{-1}\,d^{-1}$$
$$= 3.6E\text{-}4\,rad\,d^{-1}\ (3.6E\text{-}6\,Gy\,d^{-1})$$

The internal dose to the heron is estimated from Equation (7). As seen in Table 3, the typical heron has a mass of 5 kg, an effective radius of 10 cm, and eats 0.6 kg of fish per day. From Table 2, the effective energy of the secondary organism (heron) with an effective radius of 10 cm is 0 732 MeV dis^{-1}.

$$E = 5.12E4 \times 0.732 = 3.75E4\,kg\,rad\,Ci^{-1}\,d^{-1}$$

The biological half-life is 9.5 d from Table 1, which can be converted to a loss rate: 0.693/9.5 d = 0.0730 d^{-1}.

Then the effective decay rate is

$$\lambda = 3.6E{-4} + 0.0730 = 0.0734\,d^{-1}$$

Substituting the above values and the uptake fraction of 0.3 for cobalt from Table 1 into Equation (7), we get the following as the heron dose rate:

$$R_{heron} = \frac{1.62E{-8}\,Ci\,kg^{-1} \times 10.6\,kg\,d^{-1} \times 0.3 \times [1 - \exp(-0.0734\,d^{-1} \times 365\,d)] \times 3.75E4\,kg\,rad\,Ci^{-1}\,d^{-1}}{5\,kg \times 0.0734\,d^{-1}}$$

$$= 3.2E{-4}\,rad\,d^{-1}\,(3.2E{-6}\,Gy\,d^{-1})$$

EXTERNAL DOSE

The methods used for calculating external radiation dose rates to aquatic organisms from exposure to water and sediment are similar to those used for man. The external pathways for a crawling or fixed organism such as a crab or clam include immersion in water and contact with bottom sediment. From Soldat, Robinson, and Baker (1974), the water immersion dose rate in Gy d^{-1} from N nuclides is

$$R_{immers} = \sum_{i=1}^{N} C_{i,c} DF_{immers,i} F_{exp} \tag{8}$$

where $DF_{immers,i}$ is the water immersion dose factor for nuclide i, rad d^{-1} per Ci m^{-3}, and F_{exp} is the exposure fraction (unitless).

The model for the direct irradiation dose from bottom sediment or mud is similar to the shoreline dose equation of Soldat, Robinson, and Baker (1974). For N nuclides, the dose rate in rad d^{-1} is

$$R_{sed} = F_{sed} F_{ruf} F_{exp} \sum_{i=1}^{N} C_{i,c} DF_{gnd,i} (1-\exp^{-\lambda_r T_s})/\lambda_r \tag{9}$$

where F_{sed} = sediment deposition transfer factor, 0.07 Ci m^{-2} d^{-1} Ci^{-1} m^3 (Soldat, Robinson, and Baker 1974, p. 4-3)

F_{ruf} = geometry-roughness factor (unitless)

$DF_{gnd,i}$ = ground irradiation dose factor for nuclide i, rad d^{-1} Ci^{-1} m

T_s = time sediment is exposed to contaminated water, d.

The remaining parameters in Equations (8) and (9) were defined for the internal dose equation. For annual exposures, multiply the resulting dose rate by the number of days in a year (365). For Equation (9), T_s would be 1 year or 365 days, since the release is over 1 year. The buildup of previous

releases in the sediment is not included. The geometry-roughness factor modifies the "infinite plane" dose factor to account for the height of the organism above the surface, the relative size of the contaminated area, and the roughness of the surface, which causes scattering of the photons emitted from the sediment surface. The exposure fraction is the fraction of time the organism spends exposed to the medium.

For an organism such as a fish, which spends 100% of its time immersed in water, the exposure fraction would be 1; for a clam or crayfish living on the bottom, the water exposure geometry would be similar to that of the water surface. For ducks, geese, and other surface swimming animals, half of the immersion dose may be used as an estimate of external dose. If the animal spends time on the shore, a fraction of the sediment dose may be included. This factor may vary between one-fourth and one-half, depending on the habits of the animal. See Table 3 for some typical exposure fractions for some Hanford animals. The roughness factor is assumed to be 0.2 – the normal shore-width factor for humans standing on the shore of a river.

Example Calculation

As an example of estimating the external dose rate, consider the ^{60}Co dose to a fish and to a muskrat residing in and near the surface water with the same concentration of ^{60}Co as in the previous example. The fish is assumed to feed on the bottom 50% of the time. The muskrat is a typical Hanford muskrat that, as shown in Table 3, spends a third of its time on the shore and a third totally immersed in the water.

For these creatures their external dose comes from both immersion in the surrounding water and direct radiation from sediment, so we will first calculate these dose rates, assuming exposure to each medium for the entire year.

For the immersion dose rate, we use Equation (8) with the dose factor for water immersion from Table 2, converting the dose factor of 28.2 mrad y^{-1} μCi^{-1} m^3 to rad d^{-1} Ci^{-1} m^3 gives 77.3, then

$$R_{immers} = 4.9E\text{-}8\ Ci\ m^{-3} \times 77.3\ rad\ d^{-1}\ Ci^{-1}\ m^{3}$$
$$= 3.8E\text{-}6\ rad\ d^{-1}\ (3.8E\text{-}8\ Gy\ d^{-1})$$

The sediment dose rate is estimated from Equation (9). The dose factor is found in Table 1; the value for λ is 3.6E-4 d^{-1} as before. Converting the dose factor of 227 mrad y^{-1} μCi^{-1} m^2 to rad d^{-1} Ci^{-1} m^2 gives 622; thus

$$R_{sed} = 4.9E\text{-}8 \times 0.070\ m\ d^{-1} \times 0.2 \times 1 \times 622\ rad\ d^{-1}\ Ci^{-1}\ m^{3}$$
$$\times [1 - \exp(-3.4E\text{-}4\ d^{-1} \times 365\ d)] / (3.4E\text{-}4\ d^{-1})$$
$$= 1.45E\text{-}4\ rad\ d^{-1}\ (1.45E\text{-}6\ Gy\ d^{-1})$$

Now the total external dose rate for the fish is made up of 100% immersion and 50% sediment:

$$R_{fish} = 3.8E\text{-}6\ rad\ d^{-1} + 0.5 \times 1.45E\text{-}4\ rad\ d^{-1}$$
$$= 7.6E\text{-}5\ rad\ d^{-1}\ (7.6E\text{-}7\ Gy\ d^{-1})$$

The total external dose rate to the muskrat is made up of 1/3 immersion and 1/3 sediment:

$$R_{muskrat} = 0.3 \times 3.8E\text{-}6\ rad\ d^{-1} + 0.3 \times 1.45E\text{-}4\ rad\ d^{-1}$$
$$= 4.5E\text{-}5\ rad\ d^{-1}\ (4.5E\text{-}7\ Gy\ d^{-1})$$

TABLE 1. Hanford-Specific Bioaccumulation Factors and Human Biological Half-Lives and Uptake Fractions[a]

	Fish		Crustacean		Mollusc		Plant		T_b	f_1
	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt		
	L kg^{-1}								d	
Ac	330	30	1000	1000	1000	1000	10000	1000	24000	0.001
Ag	100	300	200	350	200	580	1000	1000	5	0.05
Am	100	2500	100	360	100	290	3000	2900	20000	0.001
Ar	1	1	1	1	1	1	1	1	0	0
As	200	200	200	200	200	200	200	200	280	0.5
Ba	200	10	200	1	200	20	500	100	65	0.1
Be	10	1000	50	10000	50	10000	200	10000	180	0.005
Bi	15	15	100000	1000	100000	1000	1500	10000	5	0.05
Bk	50	50	500	500	20000	20000	1	1	65000	0.001
Br	420	10	330	10	330	10	50	10	8	1
C	9000	20000	9000	20000	9000	20000	4500	1800	10	1
Ca	200	2	2000	5	2000	1	1000	50	16400	0.3
Cd	200	2000	10000	5000	10000	10000	500	1000	200	0.05
Ce	500	100	1000	500	1000	500	4000	5000	563	3E-4
Cf	25	50	1000	500	1000	2000	5000	5000	65000	0.001
Cl	50	1	50	1	50	1	50	1	29	1
Cm	30	2500	1000	460	1000	460	10000	43000	24000	0.001
Co	330	100	2000	2000	2000	3000	1000	400	9.5	0.3
Cr	20	600	2000	500	2000	1140	4000	4000	616	0.1
Cs	2000	100	100	30	100	30	500	700	115	1
Cu	2500	1000	400	5000	400	5000	2000	1000	80	0.5
Dy	25	500	1000	1000	5000	5000	1	1	700	3E-4
Er	500	100	1000	500	1000	500	4000	5000	650	3E-4
Eu	300	300	3000	1000	3000	7000	5000	5000	635	0.001
F	10	4	100	4	100	4	2	1	808	1

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TABLE 1. (contd)

	Fish		Crustacean		Mollusc		Plant		T_b	f_1
	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt		
	L kg^{-1}								d	
Fe	2000	3000	100	5000	100	30000	1000	50000	800	0.1
Ga	1000	1000	10000	10000	10000	10000	1	1	6	0.001
Gd	500	500	2000	2000	5000	5000	1	1	550	3E-4
H	1	1	1	1	1	1	1	1	10	1
Hf	40	40	1000	1000	3000	3000	1	1	563	0.002
Hg	20000	20000	20000	20000	20000	10000	34000	34000	10	1
Ho	300	300	3000	1000	3000	1000	5000	5000	750	3E-4
I	50	10	100	50	100	50	300	1500	100	1
In	1000	1000	10000	10000	10000	10000	1	1	48	0.02
Ir	50	20	200	100	200	100	200	100	20	0.01
Kr	1	1	1	1	1	1	1	1	0	0
La	25	30	1000	100	1000	100	5000	300	500	0.001
Mn	400	400	100000	800	100000	6000	10000	10000	17	0.1
Mo	10	40	100	20	100	20	1000	100	5	0.8
N	1	1	1	1	1	1	1	1	90	1
Na	100	1	100	0.1	100	0.3	100	1	11	1
Nb	100	100	50	50	50	50	500	500	760	0.01
Nd	25	100	1000	1000	1000	1000	5000	1000	656	3E-4
Ni	100	100	500	500	500	500	500	3000	667	0.05
Np	2500	2500	30	10	30	150	300	6	39000	0.001
P	170	28000	100000	38000	1100000	45000	500000	00000	257	0.8
Pa	30	300	30	10	30	10	300	50	41000	0.001
Pb	2000	200	500	1000	500	1000	2000	50000	1460	0.2
Pd	50	50	2000	300	2000	300	2000	20000	5	0.005
Pm	300	500	3000	1000	3000	5000	5000	3000	656	3E-4

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TABLE 1. (contd)

	Fish		Crustacean		Mollusc		Plant		T_b	f_1
	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt		
	L kg^{-1}								--d--	-----
Po	50	2000	20000	50000	20000	10000	2000	1000	30	0.1
Pe	25	100	1000	1000	1000	1000	5000	1000	750	3E-4
Pu	250	1000	100	300	100	3000	890	3600	65000	0.001
Ra	50	950	1000	100	1000	100	30000	1000	8100	0.2
Rb	2000	500	1000	200	1000	200	1000	1000	45	1.0
Rh	10	10	300	100	300	100	200	100	10.4	0.05
Rn	57	1	1	1	1	1	1	1	0	0
Ru	100	10	300	100	300	2000	2000	1000	7.3	0.05
S	750	2	100	1	100	4	1	5	90	0.8
Sb	200	1000	100	100	100	1200	1000	100	38	0.1
Sc	100	750	1000	300	1000	100000	10000	1000	30	1E-4
Se	1000	6000	2000	5000	2000	6000	100	1000	11	0.8
Si	1000	50000	10000	50000	10000	50000	50000	50000	60	0.01
Sm	300	500	3000	1000	3000	5000	5000	5000	656	3E-4
Sn	1000	50000	10000	50000	10000	50000	50000	50000	35	0.02
Sr	50	4	100	1	100	40	3000	300	4000	0.3
Ta	60	60	3000	3000	3000	3000	1	1	240	0.001
Tb	25	60	1000	1000	1000	3000	5000	1000	670	3E-4
Tc	15	30	100	10	100	20	5000	5000	1	0.8
Te	400	1000	6100	1000	6100	1000	100	400	15	0.2
Th	100	600	100	1000	100	1000	3000	2000	57000	2E-4
Tl	5000	5000	1000	1000	5000	5000	1	1	5	1
Tm	500	500	1000	1000	5000	5000	1	1	675	3E-4
U	50	50	100	10	100	30	900	1000	100	0.05
W	1200	10	10	10	10	100	1200	100	1	0.3

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TABLE 1. (contd)

	Fish		Crustacean		Mollusc		Plant		T_b	f_1
	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt		
	L kg^{-1}								d	
Xe	1	1	1	1	1	1	1	1	0	0
Y	25	20	1000	1000	1000	1000	5000	300	14000	1E-4
Yb	200	200	1000	1000	3000	3000	1	1	685	3E-4
Zn	64	1000	10000	50000	10000	30000	20000	50000	933	0.5
Zr	200	50	50	50	50	50	5000	5000	450	0.002

(a) Sources: T_b: NUREG-0172 (NRC 1977), ICRP-2 (1959), ICRP-10 (1968)
f_1: ICRP-30 Parts 1 through 4 (1979-1988)
Biofactors: GENII BIOACH.DAT file dated 7 Mar 90 by JKS (Napier et al. 1988)

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TABLE 2. Half-Lives and Energies (MeV dis^{-1}) for Selected Effective Radii (cm) of Aquatic Organisms and External Dose Rate Factors[a]

Radio-nuclide	Half-Life	Energy by Radius (cm) 1.4	2	3	5	7	10	20	30	Immersion (mrad y^{-1} per $\mu Ci\ m^{-3}$)	Sediment (mrad y^{-1} per $\mu Ci\ m^{-2}$)
H-3	12.35 y	.0058	.0058	.0058	.0058	.0058	.0058	.0058	.01	0	0
C-14	5730 y	.05	.05	.05	.05	.05	.05	.05	.05	0	0
N-13	9.965 m	.538	.557	.587	.646	.701	.777	.983	1.13	1.11E+01	1.05E+02
F-18	109.77 m	.285	.304	.334	.391	.444	.518	.717	.861	1.08E+01	1.02E+02
NA-22	2.602 y	.286	.325	.387	.507	.619	.775	1.20	1.51	2.43E+01	2.10E+02
NA-24	15.00 h	.712	.771	.868	1.05	1.23	1.48	2.19	2.74	5.16E+01	3.56E+02
P-32	14.29 d	.695	.695	.695	.695	.695	.695	.695	.695	0.0	0.0
AR-39	269 y	.194	.194	.194	.194	.194	.194	.194	.194	0.0	0.0
AR-41	1.827 h	.519	.541	.576	.642	.705	.793	1.04	1.22	1.44E+01	1.15E+02
SC-46	83.83 d	.197	.232	.290	.399	.501	.644	1.03	1.32	2.28E+01	1.94E+02
CR-51	27.704 d	.00222	.00276	.00363	.00529	.00685	.00901	.0149	.0191	3.47E-01	3.41E+00
MN-54	312.5 d	.0364	.0514	.0758	.122	.166	.227	.392	.512	9.42E+00	8.41E+01
MN-56	2.5785 h	.875	.904	.951	1.04	1.13	1.24	1.57	1.82	2.01E+01	1.60E+02
FE-55	2.7 y	.00726	.00726	.00726	.00726	.00726	.00726	.00726	.00726	2.86E-04	2.21E-02
FE-59	44.529 d	.171	.191	.224	.286	.346	.428	.655	.824	1.34E+01	1.10E+02
CO-57	270.9 d	.0390	.0409	.0439	.0496	.0550	.0626	.0840	.100	1.44E+00	1.43E+01
CO-58	70.80 d	.0728	.0905	.119	.174	.226	.297	.492	.633	1.09E+01	9.87E+01
CO-60	5.271 y	.195	.237	.306	.437	.560	.732	1.21	1.56	2.82E+01	2.27E+02
NI-63	96 y	.0176	.0176	.0176	.0176	.0176	.0176	.0176	.0176	0.0	0.0
NI-65	2.520 h	.641	.651	.666	.695	.723	.762	.869	.949	6.20E+00	4.95E+01
CU-64	12.701 h	.133	.137	.143	.154	.165	.180	.220	.249	2.06E+00	1.95E+01
ZN-65	243.9 d	.0289	.0386	.0544	.0846	.113	.153	.261	.342	6.56E+00	5.48E+01
ZN-69M+D	13.76 h	.0400	.0477	.0603	.0842	.107	.138	.221	.282	4.52E-00	4.36E+01
ZN-69	57 m	.32	.32	.32	.32	.32	.32	.32	.32	6.52E-05	6.32E-04
AS-76	26.32 h	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	4.79E+00	4.27E+01
BR-82	35.30 h	.248	.294	.368	.510	.643	.828	1.33	1.70	2.96E+01	2.60E+02
BR-83+D	2.39 h	.363	.363	.364	.364	.364	.365	.366	.367	8.13E-02	7.68E-01
BR-84	31.80 m	1.31	1.34	1.39	1.47	1.56	1.67	2.00	2.25	2.21E+01	1.59E+02
BR-85	2.87 m	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	7.53E-01	6.52E+00
KR-83M	1.83 h	.0438	.0438	.0438	.0438	.0438	.0438	.0438	.0438	1.20E-03	1.14E-01
KR-85M	4.48 h	.245	.248	.252	.260	.268	.279	.309	.331	1.82E+00	1.80E+01
KR-85	10.72 y	.224	.224	.224	.244	.224	.225	.225	.225	2.43E-02	2.30E-01
KR-87	76.3 m	1.21	1.24	1.27	1.34	1.41	1.50	1.77	1.97	9.65E+00	7.40E+01
KR-88	2.84 h	.449	.475	.517	.599	.677	.786	1.09	1.33	2.45E+01	1.77E+02
RB-86	18.66 d	.666	.668	.671	.676	.680	.687	.705	.719	1.07E+00	8.99E+00

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TABLE 2. (contd)

Radio-nuclide	Half-Life	Energy by Radius (cm) 1.4	2	3	5	7	10	20	30	Immersion (mrad y^{-1} per $\mu Ci\ m^{-3}$)	Sediment (mrad y^{-1} per $\mu Ci\ m^{-2}$)
RB-88	17.8 m	2.15	2.16	2.18	2.21	2.24	2.28	2.40	2.49	7.74E+00	5.77E+01
RB-89	15.2 m	.694	.733	.797	.919	1.03	1.20	1.64	1.98	2.46E+01	1.90E+02
SR-89	50.5 d	.564	.564	.564	.564	.564	.564	.564	.564	1.55E-03	1.36E-02
SR-90	29.12 y	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	0.0	0.0
SR-91	9.5 h	.702	.721	.752	.812	.867	.944	1.15	1.31	7.75E+00	6.77E+01
SR-92	2.71 h	.249	.272	.310	.381	.449	.543	.805	1.00	1.50E+01	1.19E+02
Y-90	64.0 h	.939	.939	.939	.939	.939	.939	.939	.939	0.0	0.0
Y-91M	49.71 m	.0518	.0615	.0773	.107	.135	.174	.280	.355	5.80E+00	5.46E+01
Y-91	58.51 d	.590	.590	.591	.591	.591	.591	.592	.592	4.06E-02	3.31E-01
Y-92	3.54 h	1.47	1.47	1.48	1.49	1.51	1.52	1.57	1.61	2.85E+00	2.42E+01
Y-93	10.1 h	1.18	1.18	1.18	1.19	1.19	1.20	1.22	1.23	1.05E+00	8.55E+00
ZR-95	63.98 d	.227	.254	.297	.380	.458	.565	.857	1.07	8.20E+00	7.47E+01
ZR-97	16.90 h	.763	.778	.802	.848	.891	.951	1.11	1.23	2.04E+00	1.74E+01
NB-95	35.15 d	.0767	.0906	.113	.156	.197	.253	.405	.515	8.56E+00	7.76E+01
NB-97	72.1 m	.500	.512	.532	.570	.606	.656	.790	.887	7.34E+00	6.79E+01
MO-99+D	66.0 h	.419	.423	.430	.444	.457	.475	.524	.561	1.73E+00	1.60E+01
TC-99M	6.02 h	.132	.134	.138	.144	.150	.158	.181	.199	1.49E+00	1.48E+01
TC-99	2.13E5 y	.084	.084	.084	.084	.084	.084	.084	.084	6.18E-06	6.26E-05
TC-101	14.2 m	.485	.492	.503	.524	.543	.570	.643	.697	3.78E+00	3.68E+01
RU-103+D	39.28 d	.116	.125	.140	.168	.194	.230	.328	.399	5.26E+00	5.00E+01
RU-105+D	4.44 h	.496	.508	.527	.563	.597	.644	.772	.865	8.69E+00	8.05E+01
RU-106+D	368.2 d	1.44	1.44	1.45	1.46	1.47	1.49	1.53	1.56	0.0	0.0
RH-105	35.36 h	.158	.159	.162	.167	.172	.179	.198	.212	8.55E-01	8.39E+00
PD-109+D	13.427 h	.389	.389	.309	.389	.389	.390	.390	.391	7.49E-03	7.11E-02
AG-110M+D	249.9 d	.188	.235	.311	.456	.593	.782	1.30	1.68	3.07E+01	2.68E+02
AG-111	7.45 d	.361	.362	.362	.364	.365	.367	.372	.376	2.90E-01	2.84E+00
SN-125	9.64 d	.906	.907	.910	.914	.919	.925	.942	.954	3.50E+00	2.91E+01
SB-124	60.20 d	.459	.491	.544	.644	.739	.871	1.24	1.51	2.15E+01	1.76E+02
SB-125	2.77 y	.105	.113	.126	.150	.173	.205	.291	.353	4.63E+00	4.43E+01
SB-127	3.85 d	.433	.448	.472	.518	.561	.620	.782	.899	7.30E+00	6.79E+01
TE-125M	58 d	.111	.111	.112	.112	.112	.113	.113	.114	1.24E-01	2.10E+00
TE-127M	109 d	.00197	.00197	.00197	.00198	.00199	.00200	.00203	.00205	3.97E-02	6.70E-01
TE-127	9.35 h	.223	.223	.223	.223	.223	.224	.224	.224	5.28E-02	5.12E-01
TE-129M+D	33.6 d	.599	.601	.605	.612	.619	.627	.651	.667	3.75E-01	3.67E+00
TE-129	69.6 m	.535	.538	.541	.548	.555	.563	.585	.601	5.94E-01	5.68E+00
TE-131	25.0 m	.786	.791	.800	.817	.833	.855	.916	.961	4.72E+00	4.36E+01
TE-132	78.2 h	.121	.125	.131	.143	.154	.169	.211	.242	2.43E+00	2.48E+01
TE-133M+D	55.4 m	.502	.542	.605	.726	.840	.998	1.43	1.74	2.53E+01	2.19E+02
TE-134	41.8 m	.114	.117	.122	.130	.138	.148	.175	.194	9.64E+00	9.08E+01
I-129	1.57E7 y	.0602	.0628	.0652	.0694	.0728	.0769	.0844	.0872	1.07E-01	2.20E+00

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TABLE 2. (contd)

Radio-nuclide	Half-Life	Energy by Radius (cm) 1.4	2	3	5	7	10	20	30	Immersion (mrad y^{-3} per $\mu Ci\ m^{-3}$)	Sediment (mrad Y_2^{-1} per $\mu Ci\ m^{-2}$)
TE-131M	30 h	.269	.291	.327	.396	.460	.550	.796	.978	1.61E+01	1.41E+02
I-130	12.36 h	.388	.427	.490	.611	.724	.881	1.31	1.61	2.36E+01	2.18E+02
I-131	8.04 d	.206	.213	.224	.245	.266	.293	.368	.422	4.17E+00	4.04E+01
I-132	2.30 h	.581	.624	.693	.826	.950	1.12	1.59	1.94	2.56E+01	2.29E+02
I-133	20.8 h	.467	.478	.497	.533	.566	.613	.738	.829	6.66E+00	6.16E+01
I-134	52.6 m	.779	.838	.934	1.12	1.29	1.53	2.19	2.67	2.98E+01	2.58E+02
I-135	6.61 h	.481	.514	.566	.667	.761	.893	1.26	1.53	1.81E+01	1.45E+02
XE-131M	11.9 d	.136	.136	.136	.137	.137	.137	.138	.139	1.04E-01	1.83E+00
XE-133M	2.188 d	.176	.177	.178	.180	.182	.184	.191	.196	3.37E-01	4.15E+00
XE-133	5.245 d	.137	.137	.138	.140	.141	.143	.148	.152	4.19E-01	5.08E+00
XE-135M	15.29 m	.118	.126	.139	.163	.186	.217	.302	.363	4.67E+00	4.43E+01
XE-135	9.09 h	.330	.335	.342	.355	.368	.386	.434	.469	2.74E+00	2.71E+01
XE-137	3.84 m	1.68	1.68	1.68	1.69	1.70	1.71	1.74	1.76	2.07E+00	1.89E+01
XE-138	14.17 m	.505	.527	.562	.630	.694	.784	1.04	1.23	1.36E+01	1.05E+02
CS-134M	2.90 h	.0483	.0496	.0517	.0558	.0597	.0652	.0805	.0922	2.40E-01	2.87E+00
CS-134	2.062 y	.230	.259	.306	.396	.480	.596	.913	1.14	1.73E+01	1.58E+02
CS-135	2.3E6 y	.058	.058	.058	.058	.058	.058	.058	.058	0.0	0.0
CS-136	13.1 d	.233	.273	.337	.458	.573	.732	1.17	1.49	2.44E+01	2.14E+02
CS-137+D	30.0 y	.257	.267	.284	.316	.346	.388	.500	.582	6.58E+00	6.11E+01
CS-138	32.2 m	1.18	1.22	1.27	1.38	1.48	1.62	2.02	2.32	2.76E+01	2.15E+02
CS-139	9.4 m	1.61	1.61	1.62	1.64	1.66	1.68	1.75	1.79	3.61E+00	2.73E+01
BA-139	82.7 m	.927	.927	.929	.931	.933	.936	.944	.950	4.01E-01	3.88E+00
BA-140	12.74 d	.315	.320	.328	.343	.357	.376	.428	.465	2.05E+00	1.98E+01
BA-141	18.27 m	1.10	1.11	1.12	1.16	1.19	1.23	1.36	1.44	1.00E+01	8.94E+01
BA-142	10.6 m	.601	.622	.656	.722	.783	.869	1.10	1.28	1.02E+01	8.82E+01
LA-140	40.272 h	.698	.734	.793	.907	1.01	1.16	1.58	1.89	2.66E+01	2.13E+02
LA-141	3.93 h	.966	.967	.967	.969	.970	.972	.977	.981	4.83E-01	3.79E+00
LA-142	92.5 m	.937	.973	1.03	1.14	1.25	1.40	1.82	2.14	3.38E+01	2.44E+02
CE-141	32.501 d	.173	.174	.175	.179	.182	.187	.199	.209	8.71E-01	8.78E+00
CE-143	33.0 h	.420	.426	.435	.453	.470	.493	.555	.601	2.89E+00	2.85E+01
CE-144+D	284.3 d	1.32	1.32	1.32	1.33	1.33	1.33	1.34	1.35	2.08E-01	2.16E+00
PR-143	13.56 d	.314	.314	.314	.314	.314	.314	.314	.314	9.93E-08	9.06E-07
PR-144	17.28 m	1.23	1.23	1.23	1.24	1.24	1.24	1.24	1.25	3.86E-01	2.98E+00
ND-147	10.98 d	.257	.259	.264	.272	.280	.291	.320	.342	1.48E+00	1.48E+01
PM-147	2.6234 y	.0620	.0620	.0620	.0620	.0620	.0620	.0620	.0620	4.15E-05	4.10E-04
PM-148	5.37 d	.727	.737	.755	.788	.819	.862	.982	1.07	6.45E+00	5.37E+01
PM-149	53.08 h	.366	.367	.367	.367	.368	.368	.370	.371	1.28E-01	1.25E+00
PM-151	20.40 h	.327	.332	.340	.356	.370	.390	.445	.484	3.68E+00	3.59E+01
SM-153	46.7 h	.270	.271	.272	.273	.275	.277	.283	.288	6.10E-01	7.08E+00
EU-154	8.8 y	.311	.311	.38	.428	.487	.570	.798	.965	1.41E+01	1.21E+02

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TABLE 2. (contd)

Radio-nuclide	Half-Life	Energy by Radius (cm) 1.4	2	3	5	7	10	20	30	Immersion (mrad y^{-1} per $\mu Ci\ m^{-3}$)	Sediment (mrad y^{-1} per $\mu Ci\ m^{-2}$)
EU-156	15.19 d	.471	.490	.521	.580	.636	.714	.930	1.09	1.59E+01	1.26E+02
W-181	121.2 d	.00316	.00316	.00317	.00318	.00320	.00322	.00327	.00331	4.04E-01	4.68E+00
W-185	75.1 d	.144	.144	.144	.144	.144	.144	.144	.144	3.16E-04	3.11E-03
W-187	23.9 h	.331	.339	.353	.379	.403	.437	.529	.595	5.25E+00	4.94E+01
U-234	2.445E5 y	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	1.86E-03	8.07E-02
U-235+D	7.04E8 y	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	1.72E+00	1.71E+01
U-237	6.75 d	.160	.160	.160	.180	.180	.180	.220	.220	1.53E+00	1.61E+01
U-238+D	4.468E9 y	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	1.29E-03	6.46E-02
NP-238	2.117 d	.263	.270	.282	.306	.327	.357	.440	.513	6.27E+00	5.38E+01
NP-239	2.355 d	.203	.205	.208	.212	.217	.223	.240	.260	1.89E+00	1.92E+01
PU-238	87.74 y	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.50	1.12E-03	8.58E-02
PU-239	24065 y	5.15	5.15	5.15	5.15	5.15	5.15	5.15	5.15	9.74E-04	3.78E-02
PU-240	6537 y	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	1.10E-03	8.20E-02
PU-241+D	14.4 y	.00535	.00535	.00535	.00535	.00535	.00535	.00535	.00636	0.0	0.0
PU-242	3.763E5 y	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.8	9.32E-04	6.82E-02
AM-241	432.2 y	5.51	5.51	5.51	5.52	5.52	5.52	5.52	5.4	2.33E-01	2.99E+00
AM-243+D	7380 y	5.28	5.28	5.28	5.29	5.29	5.29	5.30	5.2	6.09E-01	6.61E+00
CM-242	162.8 d	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.1	1.25E-03	9.34E-02
CM-244	18.11 y	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.8	1.07E-03	8.29E-02
CF-252	2.638 y	12.2	12.2	12.2	12.2	12.2	12.2	12.2	16.5	9.51E-04	6.34E-02

(.) Sources: Energies: Soldat, Robinson, and Baker (1974).
Dose Rate Factors: DOE (1988).
Half-Lives: ICRP (1979-1988).

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TABLE 3. Recommended Hanford-Specific Parameters for Use in the CRITR2 Program

Organism	Body Mass (kg)	Effective Radius (cm)	Source of Nuclide	Intake Rate ($g\ d^{-1}$)	Exposure Fraction		
					Sediment	Immersion	Water Surface
Primary							
Fish	(a)	5	Water	(a)	0	1	0
Crustacea	(a)	2	Water	(a)	1	0	1
Mollusks	(a)	2	Water	(a)	1	0	1
Algae	(a)	2	Water	(a)	0	1	0
Secondary							
Muskrat	1	6	Plant	100	0.3	0.3	0
Raccoon	9	20	Crustacean, Mollusk, and Fish	800	0.2	0	0
Heron	5	10	Fish	600	0.3	0	0.3
Duck	1	5	Plant, Fish	100	0.2	0.3	0.5

(a) Not required for calculation of dose to primary organisms.

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APPENDIX A

CRITR2 USER'S GUIDE

APPENDIX A

CRITR2 USER'S GUIDE

SCOPE

CRITR2 is a personal computer (PC) program used to estimate internal and external dose rates to aquatic organisms from liquid releases of radioactive materials to surface waters. Both primary organisms, such as fish, crustacea, and mollusks, and secondary organisms (those that prey upon the primary biota), such as aquatic birds and mammals, are considered. External dose rates from water immersion and sediment are considered. Radionuclide concentrations of the water in which the organism resides may be entered directly or may be estimated from a release source term and basic water-body parameters using the models developed by Yasuo Onishi,[a] to be discussed in an NCRP report (in preparation). Screening models for rivers, estuaries, lakes, and coastal waters are supported. For applications of this program to Hanford facilities, the authors suggest that the source term be entered as concentrations of the radionuclides in the waters immediately surrounding the primary organisms and that no dilution screening model be chosen. Use of the *RIVER* screening model for Hanford releases may result in an overly conservative estimate for the doses.

Input to the program is by generic files containing data that are usually the same from site to site. File setup, source terms, and site-specific data are entered into an ASCII text file by the user. Output is to a text file that may be edited and printed.

INPUT

Command Line

The command line consists of input of the name of the file containing case-specific parameter values supplied by the user. This file, called a user or "USR" file, contains the setup and parameter values required to run the program. For example, for the SAMPLE.USR file the command line would be

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(a) Personal communication.

>CRITR SAMPLE

The USR file must be prepared prior to running the program. Two typical USR files have been included as examples and templates. One is a long version called SAMPLE.USR, which contains numerous comments and examples of various dilution model parameters. The other is a minimal version called SHORT.USR with just the parameters needed for the sample problem. This latter version of the USR file is recommended for running Hanford cases.

Files

The input files required by the program are

USERFILE	USR file for setup and parameter input
BIOFILE	File containing elemental bioaccumulation factors, biological half-lives, and uptake fractions
ENERGYFILE	File containing half-lives, energies for various radii, and external dose rate factors.

The USR file (USERFILE) is the primary method for the user to input case-specific data to the program. The name of this file may be any eight-character file name compatible with DOS standards. The example file included may be used as a template for other applications. The example problem has been used as the basis for this template. The comments appended to the file with the symbols ' or | may be eliminated to produce a more compact file, but they serve as documentation as well as definitions of all the parameters involved.

The general format of the user file consists of a header, data blocks, and comments dispersed as needed for documentation and supplemental information. The data are divided into four blocks: SETUP, SOURCE, DILUTION, and CRITR. These names should always be used, although case is not important. Each block starts with the word BEGIN and ends with END. The SETUP block contains the title of the output file, the file specifications of the input and output files, the request for the optional quality assurance (QA) print-out, the output units for dose rates, and the buildup time for sediment. The SOURCE block contains the nuclide symbols, release rates (or concentrations),

units, and recirculation factor (if applicable) of any of the nuclides of interest. A maximum of 20 radionuclides may be entered at one time (see generic data files in Appendix B for those supported). The DILUTION block contains the water-body model of concern and the parameters required to calculate dilution in the body of water selected along with appropriate units. The CRITR block contains data applicable to the organisms involved. The information or parameter values are entered in free-form style (no definite columns to start and end) with either commas or spaces as delimiters. Thus, each parameter must contain no spaces. For parameters with dimensions, the units must be placed after them. The acceptable units are given at the end of the file in a comment section. Case is not critical, so units and key phrases may be entered in both upper, lower, or mixed case as desired. Comments may be indicated by any of four symbols: ' or | as in the example or ! or (.

By using a block structure, once a user file is created (using one of the sample files as a template), values that need revision may more easily be found and changed. The order of the data lines and blocks in the file is not critical except for the CRITR block, which must appear as shown in the sample files. The descriptions and definitions of the parameters are as follows, where the data to be entered into the file are indicated by bold italics:

SETUP block — This block is used to indicate the name and where the various input and output files are stored if you decide to keep them in a separate directory. If these are left out, default files are assumed to be on the default directory (current directory).

- TITLE — Any string of characters up to 80 columns wide can be entered here to provide a title to the run that will appear in the output file.
- BIOFILE — Complete file specification of the bioaccumulation factor file. If left blank, the default file named "CRITBIOH.DAT" is searched for in the current subdirectory. If it is not found, the program prompts for a file specification (drive, subdirectory, and name).

ENERGY FILE — Complete file specification of the dose rate factor file. If this line is left blank, the default file named "DFEXT.DAT" is searched for in the current subdirectory. If it is not found, the program prompts for a file specification.

OUTFILE — File holding the summary result tables. If this line is left blank, this file will be created in the current directory with the name "DEFAULT.OUT."

QAPRINT — Optional printout of results of intermediate calculations. Entering *TRUE* here will select the printout. If left blank or *FALSE* is entered, no QA printout will be created.

OUTUNITS — Units for the doses are selected: *Gy/D* for gray/day (default), *MRAD/Y* for mrad/year, *RAD/Y*, and *RAD/D*.

TB — Time of radionuclide buildup in sediment. Here a value and unit symbol is used. For example, *30 y*.

SOURCE block — This block contains the symbols of the nuclides involved in the calculation. The release rate or concentration may be entered with its unit; however, when no dilution model is selected (see below) the source term values must be in units of concentration. A recirculation factor may also be entered when applicable. A *D* or blank for this factor will run the internal default value of 1. Values for release may be entered in almost any convenient unit (see the bottom of the sample user file). Nuclide symbols may be entered with a dash between element symbol and mass number or no space between these symbols.

DILUTION block — This block contains the parameters used to calculate the dilution factor for a particular water body in which the organism resides. Dilutions for each of the water body types are calculated using a different model. Depending on the model selected, not all parameters may be used in some calculations. The only parameters necessary to run Hanford cases would be the *MODEL* and *SALINITY* parameters: *N* and *F* respectively.

MODEL — Type of water body under consideration:

RIVER, *ESTUARY*, *COASTAL*, *LAKE*, or just *R*, *E*, *C*, or *L*.
If no model is desired (Hanford case), enter *NONE* or *N* and enter concentrations in the SOURCE block that are typical of the organism habitat.

SALINITY — Flag designating whether the water body is primarily fresh or marine: *FRESH*, *SALT*, or just *F* or *S*.

After the salinity flag, a flag is required to designate whether or not a correction factor is desired to correct the stable element bioaccumulation factors of the tables for short-lived nuclides (~< 1 yr). If desired, enter *YES*; if not (usual case) leave blank or enter *NO*.

PIPE_FLOW	Volume flow rate for the effluent entering the water body – the outfall flow.
NEAR/FARSIDE	Designator for where the receptor is with respect to the source for river and estuarine sites: *N* for near and *F* for far shore.
RIVER_FLOW	Volume flow rate of the river or fresh-water component of an estuary.
WIDTH	Width of the river or estuary at the outfall.
DEPTH	Depth of the water body.
EBB_FLOW	Average flow of the ebb tide for an estuarine site.
FLOOD_FLOW	Average flow of the flood tide for an estuarine site.
TIDAL_PERIOD	Period for one tidal cycle.
COASTAL_CURRENT	Current velocity along coast for coastal site.
LAKE_VOL	Volume of lake for lake sites. If the volume is less than 1E11 m^3, the lake is considered small and an alternate model is used in the calculation.
NET_FLOW	Inflow minus outflow for lake site.

CRITR block — This block contains the types and names of the aquatic organisms considered by the program in order, followed by pathway related parameters. The following fields are denoted by words X, USAGES, etc., that are explanatory only – not key words. Note the line containing them is a comment line and thus is not used by the program. A maximum of nine organisms may be considered.

X	Distance from the source to the receptor.
DILUTION	Optional direct input of dilution factors. For most applications these factors should be entered as unity: *1*. However, when a specified near-field dilution value is pertinent, then the dilution at the end of an outfall pipe is found by using the model.

	and these dilution factors are applied to reduce the concentration to .3, .1, etc. of the dilution-flow concentration.
MASS	Mass of the organism.
RADIUS	Effective radius of the organism.
DIET	Primary organism that makes up the diet of the secondary organism: ***PLANT***, ***FISH***, ***CRUSTACEAN***, or ***MOLLUSK***. Only the first letter of the name is significant to the program.
INTAKE RATE	Intake rates for secondary organisms.
SEDIMENT	Fraction of time exposed to sediment.
IMMERSION	Fraction of time immersed in water.
SURFACE	Fraction of time floating on the surface of the water.
ROUGHNESS	Geometry-roughness factor.

The other two files contain generic values for the various parameters. The BIOFILE contains data shown in Table 1 (in the main report); the ENERGYFILE contains the data of Table 2 (in the main report). These files will usually not need to be changed by the user. However, if site-specific data are available, they may be used by editing these files using an ASCII text editor. The spacing of the values is not critical, because spaces are used to delimit the values and not column numbers. Be sure, however, that at least one space remains between data values. When changing any value, always give the new file a different name. Keep the original file backed up in a separate directory or disk for safety. The new revised file name then should be entered in the SETUP section of the user file beside the applicable file type: BIOFILE or ENERGYFILE. Note that comments may be entered into these files in the same manner as in the user file. These may be used freely for documentation purposes. Listings of these generic data files are included.

OUTPUT

Files

OUTFILE	File containing site-specific input parameters and calculated dose rates.

The output file for the sample problem is included as an example in Appendix B. Dose rates (units selectable) are given for each organism and nuclide for internal, immersion, and sediment doses. Surface swimming dose rates are included in the immersion rates. If a water dilution model is selected, the parameters specified in the user file are output first. Next the organism parameters are output, and finally a table of half-lives, release rates, and water concentrations for each organism by nuclide are output.

Printer

The output file may be copied to the printer. See below for optional QA printout.

DISPLAY

The progress of the program is indicated on the monitor. Either a monochrome or VGA display may be used. Common errors of input are displayed on the screen and remedies are suggested. Some errors are called "Warning" and will let the program proceed; others are termed "Fatal" and will end the program. Input data from the USR file is checked on input to be within a reasonable range. If the data are outside this range, the monitor will display a warning message and proceed.

QA CHECKING

For the printing of various intermediate values in the calculations, an optional flag may be set to *TRUE* in the USR file SETUP block next to the keyword QAPRINT. Various parameters and intermediate values will be sent to the printer. If this option is selected, be sure you have a printer connected and it is ready.

SYSTEM REQUIREMENTS

The program may be run on an IBM PC or compatible computer with a minimum of 180 KBytes of application memory. A coprocessor is optional. The IBM-DOS or MS-DOS operating system (Version 3 or higher) is required. A printer capable of printing at least a 132-character line (17 cpi) is also required; otherwise, output lines will be folded.

APPENDIX B

INPUT FILES AND SAMPLE PROBLEM FOR CRITR2

APPENDIX B

INPUT FILES AND SAMPLE PROBLEM FOR CRITR2

This Appendix includes the listings of the input files and a sample problem. Both a long and short form of the USR file are included for reference and for use as templates in user applications. The concentration of Co-60 is the same as that in the text example. The output file for the run from the SAMPLE.USR file is included along with a printout of the quality assurance output. The generic input data files CRITBIOH.DAT and DFEXT.DAT are also included.

```
SAMPLE.USR   This is the Header -- It will be output to the output file

|   Information can be placed here behind one of the four comment symbols supported:
|             | ' ! or (
|   Comments can also start after data.                ' This would be a comment.
'   This line is also a comment line and
(   so is this.    Blank lines are allowed.

|   Each of the blocks is made up of keywords which begin each data line and denote
|   the parameter; next is the value of the parameter or suitable flag setting.
|   The first three letters of the keyword are controlling.
|   The program will display a message for any keyword it does not accept.
|   Parameters requiring units are followed by at least one space and a unit symbol.
|   Acceptable symbols are found at the end of this file.  Powers of units are not
|   superscripted.  Thus the symbol for the volume in cubic meters would be m3.

|-----------------------------------------------------------------------------

BEGIN SETUP

'   This is the SETUP block containing run title, input file specs,
'   QA printout flag, output units, and sediment buildup time.  The key words,
'   TITLE, BIOFILE, etc., must be entered as shown; case, however, is optional.

  TITLE Sample problem using long format.
  BIOFILE      CRITBIOM.DAT          ' Element-dependent file for bioaccumulation factors
  ENERGYFILE   DFEXT.DAT             ' Nuclide-dependent file for half-lives, energies, and dose factors
  OUTFILE      SAMPLE.OUT            ' Name of output file with destination specification
  QAPRINT      FALSE                 ' Flag for optional printing of intermediate values: TRUE = yes; FALSE (or blank) = no.
  OUTUNITS     RAD/D                 ' Dose rate units: Gy/d  rad/d  mrad/y  rad/y
'                                      For the SI units concentrations are output as Bq/m3, or else they are
'                                      output as Ci/m3.
  TB 1 Y                             ' Sediment buildup time and unit.  See below for acceptable unit designators.
END SETUP

BEGIN SOURCE

'   The SOURCE block contains the source term entered as either release rate or concentration.
'   The program figures out which from the units.  If a recirculation factor is pertinent, it may be entered.
'   Otherwise enter 1.  Nuclide symbols may include the dash or not, but no spaces are allowed between
'   the element and number.
'   However, if the dilution model is not used, release values must be entered as concentrations.

|            RELEASE          RECIRCULATION
  Co-60       49   pCi/L          1                  ' Note same as sample problem in text.
  Sr-90      700   pCi/L          1
  Zn-65        3   pCi/L          1
  Ru-106      11   pCi/L          1
  SB125       43   pCi/L          '

END SOURCE

BEGIN DILUTION

'   In this block the parameters for dilution are entered.  Models for four water bodies are supported:
'                        River, Estuary, Coastal, and Lake.
'   For no further dilution enter NONE or N for model.  Then no other parameters except those specified
'   in the SALINITY line are needed.
'   Parameters not used by a model are ignored.
'   Note that all water bodies require the common parameters, but need only those parameters
'   specified for that body.  Thus, for a River the parameters for Lake and Coastal may be deleted.
'   (If they are left in the file, they will simply be ignored-- unless, of course, a model of
'   another water body is required.
'   Caution:  the parameter values given below for dilution calculations are for example only.
'   The user must supply parameter values for his specific case.

 MODEL              NONE                ' Also RIVER, ESTUARY, COASTAL, LAKE (or N, R, E, C, L)
 SALINITY           FRESH   No          ' Water salinity: FRESH or SALT (or F, S) and bioaccumulation
                                        ' correction for short-lived nuclides (Yes, No)

|-------- Common parameters             ' Parameters used for all water bodies

 PIPE_FLOW          800  CFS            ' Flow from outfall into water body
 DEPTH                5  M              ' Average depth of water body

|-------- River & Estuary

 NEAR/FARSIDE         N                 ' Flag to indicate location of receptor relative to outfall:
'                                          Nearside = N;  Farside = F

 RIVER_FLOW        2815  M3/S            ' Volume flow rate of river; fresh-water flow of estuary
 WIDTH              100  M              ' Width of river or estuary
```

```
|--------- Estuary                    ' Additional parameters for estuaries

 EBB_FLOW          2 m/s              ' Flow speed of the ebb tide
 FLOOD_FLOW        2 m/s              ' Flow speed of the flood tide
 TIDAL_PERIOD     12.5 h              ' Tidal period

|--------- Lake or reservoir

 LAKE_VOL       1000 m3               ' Volume of lake or reservoir
 NET_FLOW         10 cfs              ' Net volume flow rate

|--------- Coastal for Oceans & Large Lakes

 COASTAL_CURRENT   0.1 m/s            ' Current speed along coast

END DILUTION

BEGIN CRITR

'    This block contains the parameter values describing the organisms of interest.  Note that only spaces are
'    required between parameters.  Where units are required, they must be entered.
'    Type and Name must be one word. X is distance from outfall frequented by organism.  Dilutions in excess of that
'    calculated using one of the models may be entered for each organism separately.  This is useful when the dilution
'    calculated is that of the dilution flow and an extra near-field dilution may be applicable.  Note that these
'    dilutions are mixing ratios and are 0 < and < or = 1.  In most cases, however, this dilution value should be set to 1.
'    When no dilution model is selected, X is not used, so it may be any value.
'    Typical values for the remaining parameters may be found in Table 3. of the report.

|    Type        Name        X    Dilution    Mass    Radius   Diet  Intake Rate Sediment Immersion Surface  Roughness

  Primary       Fish        1 M     1        -   -    5 cm    -       -  -        .5       1       0        .2
  P             Crawdad     1 M     1        -   -    2 CM    -       -  -        1        0       1        .2

  Secondary     Duck-P      1 M     1        1   kg   5 cm    PLANT   100 g/d     .2       .3      .5       .2
  Sec           Duck-F      1 M     1        1   kg   5 cm    FISH    200 g/d     .2       .3      .5       .2
  S             Heron       1 M     1        4.6 kg   10 cm   FISH    600 g/d     .3       0       .3       .2

  Sec           Muskrat     1 M     1        1   kg   6 cm    PLANT   100 g/d     .3       .3      0        .2
  Sec           Rcoon-C     1 M     1        9   kg   10 cm   CRUS    800 g/d     .2       0       0        .2
  Sec           Rcoon-F     1 M     1        9   kg   10 cm   FISH    800 g/d     .2       0       0        .2

END CRITR

|------------------------- Notes ---------------------------------------------
| Here are the acceptable unit designators.  (Note that case is optional.)  Program units are given first.

| Length                  m       ft  cm  km  mi
| Area                    m2      ft2  A  acre  Ha  hectare
| Volume                  m3      L  Liter  mL  cc  cm3  qt  gal
| Density                 kg/m3   g/m3  g/cm3
| Mass                    kg      g
| Speed, current vel.     m/d     m/s  m/sec  cm/s  cm/sec  km/h  km/hr  mph  knot  f/f
| Flow                    m3/d    L/s  L/sec  L/d  L/y  cfs  m3/s  m3/sec  m3/y  m3/yr  gal/s  gal/sec
| Time (holdups, Exposure) d      da  day  y  yr  year  s  sec  h  hr  hour
| Intake Rates            kg/d    g/d  lb/d  L/d  kg/y  lb/y  L/y
| Water Concentration     Bq/m3   Bq/L  Ci/L  Ci/m3  pCi/mL  pCi/L
| Release rate            Bq/d    Bq/s  Bq/y  Ci/y  Ci/s  mCi/y  uCi/y

| Acceptable names for primary organisms (only first character significant):

|   Plant, Crustacean, Mollusk, Fish   ( P C M F )
|   Other names could be used provided they start with one of the key chracters.
|   However, care should be used in picking alternate names.  For instance,
|   Crawdad will be accepted as a Crustacean by the program; Clam will
|   also be accepted, but Clam would result in the wrong biofactor being used.

EOF ---------------- End of File ----------------------------------
```

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```
SHORT.USR   This is the minimum version of the sample user file
'           Use as template for Hanford Cases.

BEGIN SETUP
  TITLE Sample problem using short format.
  BIOFILE      CRITBIOH.DAT
  ENERGYFILE   DFEXT.DAT
  OUTFILE      SHORT.OUT
  QAPRINT                          ' No QA printout selected
  OUTUNITS     RAD/D
  TB 1 T
END SETUP

BEGIN SOURCE
  Co-60      49   pCi/L        1
  Sr-90     700   pCi/L        1
  Zn-65       3   pCi/L        1
  Ru-106     11   pCi/L        1
  SB125      43   pCi/L        1
END SOURCE

BEGIN DILUTION
 MODEL            N
 SALINITY         F    N
END DILUTION

BEGIN CRITR
| Type          Name        X    Dilution    Mass    Radius   Diet  Intake Rate Sediment Immersion Surface  Roughness

  P             Fish        1 M    1         -   -    5 cm    -       -   -      .5       1       0        .2
  P             Crawdad     1 M    1         -   -    2 CM    -       -   -      1        0       1        .2
  S             Duck-P      1 M    1         1   kg   5 cm    P     100 g/d     .2       .3      .5       .2
  S             Duck-F      1 M    1         1   kg   5 cm    F     200 g/d     .2       .3      .5       .2
  S             Heron       1 M    1         4.6 kg  10 cm    F     600 g/d     .3       0       .3       .2
  S             Muskrat     1 M    1         1   kg   6 cm    P     100 g/d     .3       .3      0        .2
  S             Rcoon-C     1 M    1         9   kg  10 cm    C     800 g/d     .2       0       0        .2
  S             Rcoon-F     1 M    1         9   kg  10 cm    F     800 g/d     .2       0       0        .2
END CRITR

EOF ----------------- End of File -----------------------------------
```

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OUT File Name: SAMPLE.OUT Created: 07:57 08-JUN-92 Page 1

USR File Name and Header: SAMPLE.USR SAMPLE.USR This is the Header -- It will be output to the output file

Version of Program used: V 1.0 of 19-May-92

****** CRITR2 -- Aquatic Biota Screening Dose Rates ******

TITLE: Sample problem using long format.

Organism Dose Rates

	Release	FISH	CRAWDAD	DUCK-P	DUCK-F	HERON	MUSKRAT	RCOON-C	RCOON-F
	Ci/y	Internal (rad/d)							
CO-60	---	3.6E-04	1.2E-03	4.5E-04	3.0E-04	3.2E-04	5.1E-04	1.3E-03	2.2E-04
SR-90	---	2.0E-03	4.1E-03	1.3E+00	4.3E-02	2.8E-02	1.3E+00	3.8E-02	1.9E-02
ZN-65	---	8.3E-07	5.9E-05	2.6E-03	1.7E-05	2.0E-05	3.1E-03	2.1E-03	1.4E-05
RU-106	---	8.2E-05	2.4E-04	8.5E-05	8.5E-06	5.7E-06	8.5E-05	1.2E-05	3.9E-06
SB-125	---	6.6E-05	2.5E-05	1.7E-04	7.0E-05	6.2E-05	1.9E-04	2.1E-05	4.2E-05
Totals ------->		2.6E-03	5.6E-03	1.3E+00	4.3E-02	2.8E-02	1.3E+00	4.2E-02	1.9E-02
	Ci/y	Immersion or Surface (rad/d)							
CO-60	---	3.8E-06	1.9E-06	2.1E-06	2.1E-06	5.7E-07	1.1E-06	0.0E+00	0.0E+00
SR-90	---	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
ZN-65	---	5.4E-08	2.7E-08	3.0E-08	3.0E-08	8.1E-09	1.6E-08	0.0E+00	0.0E+00
RU-106	---	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
SB-125	---	5.5E-07	2.7E-07	3.0E-07	3.0E-07	8.2E-08	1.6E-07	0.0E+00	0.0E+00
Totals ------->		4.4E-06	2.2E-06	2.4E-06	2.4E-06	6.6E-07	1.3E-06	0.0E+00	0.0E+00
	Ci/y	Sediment (rad/d)							
CO-60	---	7.2E-05	1.4E-04	2.9E-05	2.9E-05	4.3E-05	4.3E-05	2.9E-05	2.9E-05
SR-90	---	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
ZN-65	---	7.1E-07	1.4E-06	2.8E-07	2.8E-07	4.3E-07	4.3E-07	2.8E-07	2.8E-07
RU-106	---	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
SB-125	---	1.2E-05	2.3E-05	4.7E-06	4.7E-06	7.0E-06	7.0E-06	4.7E-06	4.7E-06
Totals ------->		8.5E-05	1.7E-04	3.4E-05	3.4E-05	5.1E-05	5.1E-05	3.4E-05	3.4E-05
Grand Totals >>>>>		2.6E-03	5.9E-03	1.3E+00	4.3E-02	2.8E-02	1.3E+00	4.2E-02	1.9E-02

OUT File Name: SAMPLE.OUT Created: 07:57 08-JUN-92

USR File Name: SAMPLE.USR

Version of Program used: V 1.0 of 19-May-92

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Parameters and Water Concentrations

No dilution model used.

Bioaccumulation Factors for: Fresh No bioaccumulation factor corrections used.

	Release Outfall Concentration	FISH	CRAWDAD	DUCK-P	DUCK-F	HERON	MUSKRAT	RCOON-C	RCOON-F
Distance (m) ------		1	1	1	1	1	1	1	1
Mixing Ratio ------		1	1	1	1	1	1	1	1
Radius (cm) -------		5.0	2.0	5.0	5.0	10.0	6.0	10.0	10.0
Mass (kg) ---------		--	--	1.0	1.0	4.6	1.0	9.0	9.0
Intake rate (g/d) -		--	--	100	200	600	100	800	800
Diet ----------		--	--	PLANT	FISH	FISH	PLANT	CRUS	FISH
Transit Time (h) --		0	0	0	0	0	0	0	0

Water Concentrations , (Decay during transit included)

	H. L.	--Ci/y-	Ci/m3 or uCi/mL								
CO-60	5.271 Y	---	4.9E-08	4.9E-08	4.9E-08	4.9E-08	4.9E-08	4.9E-08	4.9E-08	4.9E-08	4.9E-08
SR-90	29.12 Y	---	7.0E-07	7.0E-07	7.0E-07	7.0E-07	7.0E-07	7.0E-07	7.0E-07	7.0E-07	7.0E-07
ZN-65	243.9 D	---	3.0E-09	3.0E-09	3.0E-09	3.0E-09	3.0E-09	3.0E-09	3.0E-09	3.0E-09	3.0E-09
RU-106	368.2 D	---	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.1E-08	1.1E-08
SB-125	2.77 Y	---	4.3E-08	4.3E-08	4.3E-08	4.3E-08	4.3E-08	4.3E-08	4.3E-08	4.3E-08	4.3E-08

Note: Internal dose rates are ICRP-2 whole-body doses.
External dose rates are based on human effective dose rates as given in DOE/EH-0070.
Transit times assumed zero when dilution model selected as NONE.

CRITR QA Printout ··· User File: SAMPLE.USR Run of: 08:02 08-JUN-92

No Dilution Model used.

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DFSWIM	DFSED	FSOLD	FRUF	TB	BUILDUP	TTRANS	EXP
2.1E-11	1.7E-10	6.9E-02	0.2	3.7E+02	3.4E+02	0.0E+00	1.0E+00

INUC	K	NUKSYMS	NS	CONCRIT	BIO	KB	RINTAKE	ECRIT	TBIO	F1	LAMC	MASS	DOSECRIT		
1	1	CO-60	F	1.8E+03	3.3E-01	1.000	0.000	6.0E-09	9.5	3.0E-01	0.0E+00	0.0	3.6E-06	FISH	eats -
1	2	CO-60	C	1.8E+03	2.0E+00	1.000	0.000	3.3E-09	9.5	3.0E-01	0.0E+00	0.0	1.2E-05	CRAWDAD	eats -
1	3	CO-60	P	1.8E+03	1.0E+00	1.000	0.100	6.0E-09	9.5	3.0E-01	7.3E-02	1.0	4.5E-06	DUCK-P	eats PLAN
1	4	CO-60	F	1.8E+03	3.3E-01	1.000	0.200	6.0E-09	9.5	3.0E-01	7.3E-02	1.0	3.0E-06	DUCK-F	eats FISH
1	5	CO-60	F	1.8E+03	3.3E-01	1.000	0.600	1.0E-08	9.5	3.0E-01	7.3E-02	4.6	3.2E-06	HERON	eats FISH
1	6	CO-60	P	1.8E+03	1.0E+00	1.000	0.100	6.9E-09	9.5	3.0E-01	7.3E-02	1.0	5.1E-06	MUSKRAT	eats PLAN
1	7	CO-60	C	1.8E+03	2.0E+00	1.000	0.800	1.0E-08	9.5	3.0E-01	7.3E-02	9.0	1.3E-05	RCOON-C	eats CRUS
1	8	CO-60	F	1.8E+03	3.3E-01	1.000	0.800	1.0E-08	9.5	3.0E-01	7.3E-02	9.0	2.2E-06	RCOON-F	eats FISH

DFSWIM	DFSED	FSOLD	FRUF	TB	BUILDUP	TTRANS	EXP
0.0E+00	0.0E+00	6.9E-02	0.2	3.7E+02	3.6E+02	0.0E+00	1.0E+00

INUC	K	NUKSYMS	NS	CONCRIT	BIO	KB	RINTAKE	ECRIT	TBIO	F1	LAMC	MASS	DOSECRIT		
2	1	SR-90	F	2.6E+04	5.0E-02	1.000	0.000	1.6E-08	4000.0	3.0E-01	0.0E+00	0.0	2.0E-05	FISH	eats -
2	2	SR-90	C	2.6E+04	1.0E-01	1.000	0.000	1.6E-08	4000.0	3.0E-01	0.0E+00	0.0	4.1E-05	CRAWDAD	eats -
2	3	SR-90	P	2.6E+04	3.0E+00	1.000	0.100	1.6E-08	4000.0	3.0E-01	2.4E-04	1.0	1.3E-02	DUCK-P	eats PLAN
2	4	SR-90	F	2.6E+04	5.0E-02	1.000	0.200	1.6E-08	4000.0	3.0E-01	2.4E-04	1.0	4.3E-04	DUCK-F	eats FISH
2	5	SR-90	F	2.6E+04	5.0E-02	1.000	0.600	1.6E-08	4000.0	3.0E-01	2.4E-04	4.6	2.8E-04	HERON	eats FISH
2	6	SR-90	P	2.6E+04	3.0E+00	1.000	0.100	1.6E-08	4000.0	3.0E-01	2.4E-04	1.0	1.3E-02	MUSKRAT	eats PLAN
2	7	SR-90	C	2.6E+04	1.0E-01	1.000	0.800	1.6E-08	4000.0	3.0E-01	2.4E-04	9.0	3.8E-04	RCOON-C	eats CRUS
2	8	SR-90	F	2.6E+04	5.0E-02	1.000	0.800	1.6E-08	4000.0	3.0E-01	2.4E-04	9.0	1.9E-04	RCOON-F	eats FISH

DFSWIM	DFSED	FSOLD	FRUF	TB	BUILDUP	TTRANS	EXP
4.8E-12	4.1E-11	6.9E-02	0.2	3.7E+02	2.3E+02	0.0E+00	1.0E+00

INUC	K	NUKSYMS	NS	CONCRIT	BIO	KB	RINTAKE	ECRIT	TBIO	F1	LAMC	MASS	DOSECRIT		
3	1	ZN-65	F	1.1E+02	6.4E-02	1.000	0.000	1.2E-09	933.0	5.0E-01	0.0E+00	0.0	8.3E-09	FISH	eats -
3	2	ZN-65	C	1.1E+02	1.0E+01	1.000	0.000	5.3E-10	933.0	5.0E-01	0.0E+00	0.0	5.9E-07	CRAWDAD	eats -
3	3	ZN-65	P	1.1E+02	2.0E+01	1.000	0.100	1.2E-09	933.0	5.0E-01	3.6E-03	1.0	2.6E-05	DUCK-P	eats PLAN
3	4	ZN-65	F	1.1E+02	6.4E-02	1.000	0.200	1.2E-09	933.0	5.0E-01	3.6E-03	1.0	1.7E-07	DUCK-F	eats FISH
3	5	ZN-65	F	1.1E+02	6.4E-02	1.000	0.600	2.1E-09	933.0	5.0E-01	3.6E-03	4.6	2.0E-07	HERON	eats FISH
3	6	ZN-65	P	1.1E+02	2.0E+01	1.000	0.100	1.4E-09	933.0	5.0E-01	3.6E-03	1.0	3.1E-05	MUSKRAT	eats PLAN
3	7	ZN-65	C	1.1E+02	1.0E+01	1.000	0.800	2.1E-09	933.0	5.0E-01	3.6E-03	9.0	2.1E-05	RCOON-C	eats CRUS
3	8	ZN-65	F	1.1E+02	6.4E-02	1.000	0.800	2.1E-09	933.0	5.0E-01	3.6E-03	9.0	1.4E-07	RCOON-F	eats FISH

DFSWIM	DFSED	FSOLD	FRUF	TB	BUILDUP	TTRANS	EXP
0.0E+00	0.0E+00	6.9E-02	0.2	3.7E+02	2.6E+02	0.0E+00	1.0E+00

INUC	K	NUKSYMS	NS	CONCRIT	BIO	KB	RINTAKE	ECRIT	TBIO	F1	LAMC	MASS	DOSECRIT		
4	1	RU-106	F	4.1E+02	1.0E-01	1.000	0.000	2.0E-08	7.3	5.0E-02	0.0E+00	0.0	8.2E-07	FISH	eats -
4	2	RU-106	C	4.1E+02	3.0E-01	1.000	0.000	2.0E-08	7.3	5.0E-02	0.0E+00	0.0	2.4E-06	CRAWDAD	eats -
4	3	RU-106	P	4.1E+02	2.0E+00	1.000	0.100	2.0E-08	7.3	5.0E-02	9.7E-02	1.0	8.5E-07	DUCK-P	eats PLAN
4	4	RU-106	F	4.1E+02	1.0E-01	1.000	0.200	2.0E-08	7.3	5.0E-02	9.7E-02	1.0	8.5E-08	DUCK-F	eats FISH
4	5	RU-106	F	4.1E+02	1.0E-01	1.000	0.600	2.1E-08	7.3	5.0E-02	9.7E-02	4.6	5.7E-08	HERON	eats FISH
4	6	RU-106	P	4.1E+02	2.0E+00	1.000	0.100	2.0E-08	7.3	5.0E-02	9.7E-02	1.0	8.5E-07	MUSKRAT	eats PLAN
4	7	RU-106	C	4.1E+02	3.0E-01	1.000	0.800	2.1E-08	7.3	5.0E-02	9.7E-02	9.0	1.2E-07	RCOON-C	eats CRUS
4	8	RU-106	F	4.1E+02	1.0E-01	1.000	0.800	2.1E-08	7.3	5.0E-02	9.7E-02	9.0	3.9E-08	RCOON-F	eats FISH

DFSWIM	DFSED	FSOLD	FRUF	TB	BUILDUP	TTRANS	EXP
3.4E-12	3.3E-11	6.9E-02	0.2	3.7E+02	3.2E+02	0.0E+00	1.0E+00

INUC	K	NUKSYMS	NS	CONCRIT	BIO	KB	RINTAKE	ECRIT	TBIO	F1	LAMC	MASS	DOSECRIT		
5	1	SB-125	F	1.6E+03	2.0E-01	1.000	0.000	2.1E-09	38.0	1.0E-01	0.0E+00	0.0	6.6E-07	FISH	eats -
5	2	SB-125	C	1.6E+03	1.0E-01	1.000	0.000	1.6E-09	38.0	1.0E-01	0.0E+00	0.0	2.5E-07	CRAWDAD	eats -
5	3	SB-125	P	1.6E+03	1.0E+00	1.000	0.100	2.1E-09	38.0	1.0E-01	1.9E-02	1.0	1.7E-06	DUCK-P	eats PLAN
5	4	SB-125	F	1.6E+03	2.0E-01	1.000	0.200	2.1E-09	38.0	1.0E-01	1.9E-02	1.0	7.0E-07	DUCK-F	eats FISH
5	5	SB-125	F	1.6E+03	2.0E-01	1.000	0.600	2.8E-09	38.0	1.0E-01	1.9E-02	4.6	6.2E-07	HERON	eats FISH
5	6	SB-125	P	1.6E+03	1.0E+00	1.000	0.100	2.2E-09	38.0	1.0E-01	1.9E-02	1.0	1.9E-06	MUSKRAT	eats PLAN
5	7	SB-125	C	1.6E+03	1.0E-01	1.000	0.800	2.8E-09	38.0	1.0E-01	1.9E-02	9.0	2.1E-07	RCOON-C	eats CRUS
5	8	SB-125	F	1.6E+03	2.0E-01	1.000	0.800	2.8E-09	38.0	1.0E-01	1.9E-02	9.0	4.2E-07	RCOON-F	eats FISH

Notes & Units:

Hanford biofactors used.

No bioaccumulation factor corrections used.

LAMDA	Rad. Decay constant	1/d	CONCRIT	Water Concentration	Bq/m3
DFSWIM	Immersion DF	Sv/d per Bq	BIO	Bioaccum factor	m3/kg
DFSED	Sediment DF	Sv/d per Bq	RINTAKE	Intake rate	kg/d
FSOLD	Nuclide sed. buildup rate	m3/m2-d	ECRIT	Energy absorbed	J/Bq-d
FRUF	Roughness factor	--	TBIO	Biological half time	d
TB	Sed. Buildup time	d	F1	Fraction to total body	--
BUILDUP	Sed. Buildup	Bq-d/Bq	LAMC	Effective decay const.	1/d
TTRANS	Transport time	d	MASS	Organism mass	kg
EXP	Fractional decay during trans.	--	DOSECRIT	Organism Dose	Gy/d

File Created: Monday, 1992 May 18 10.17

CRITBICH.DAT Hanford Bioacumulation factors, Human Bio half-times, & 14 May 92 dAb
Human Total-body retention fractions

	Fish		Crustacean		Mollusc		Plant		TBIO	-F1-	
	Fresh	Salt	Fresh	Salt	Fresh	Salt	Fresh	Salt			
	L/kg								--d--	-----	
AC	330	30	1000	1000	1000	1000	10000	1000	24000	0.001	Ac
AG	100	300	200	350	200	580	1000	1000	5	0.05	Ag
AM	100	2500	100	360	100	290	3000	2900	20000	0.001	Am
AR	1	1	1	1	1	1	1	1	0	0	Ar
AS	200	200	200	200	200	200	200	200	280	0.5	As
BA	200	10	200	1	200	20	500	100	65	0.1	Ba
BE	10	1000	50	10000	50	10000	200	10000	180	0.005	Be
BI	15	15	100000	1000	100000	1000	1500	10000	5	0.05	Bi
BK	50	50	500	500	20000	20000	1	1	65000	0.001	Bk
BR	420	10	330	10	330	10	50	10	8	1	Br
C	9000	20000	9000	20000	9000	20000	4500	1800	10	1	C
CA	200	2	2000	5	2000	1	1000	50	16400	0.3	Ca
CD	200	2000	10000	5000	10000	10000	500	1000	200	0.05	Cd
CE	500	100	1000	500	1000	500	4000	5000	563	3E-4	Ce
CF	25	50	1000	500	1000	2000	5000	5000	65000	0.001	Cf
CL	50	1	50	1	50	1	50	1	29	1	Cl
CM	30	2500	1000	460	1000	460	10000	43000	24000	0.001	Cm
CO	330	100	2000	2000	2000	3000	1000	400	9.5	0.3	Co
CR	20	600	2000	500	2000	1140	4000	4000	616	0.1	Cr
CS	2000	100	100	30	100	30	500	700	115	1	Cs
CU	2500	1000	400	5000	400	5000	2000	1000	80	0.5	Cu
DY	25	500	1000	1000	5000	5000	1	1	700	3E-4	Dy
ER	500	100	1000	500	1000	500	4000	5000	650	3E-4	Er
EU	300	300	3000	1000	3000	7000	5000	5000	635	0.001	Eu
F	10	4	100	4	100	4	2	1	808	1	F
FE	2000	3000	100	5000	100	30000	1000	50000	800	0.1	Fe
GA	1000	1000	10000	10000	10000	10000	1	1	6	0.001	Ga
GD	500	500	2000	2000	5000	5000	1	1	550	3E-4	Gd
H	1	1	1	1	1	1	1	1	10	1	H
HF	40	40	1000	1000	3000	3000	1	1	563	0.002	Hf
HG	20000	20000	20000	20000	20000	10000	34000	34000	10	1	Hg
HO	300	300	3000	1000	3000	1000	5000	5000	750	3E-4	Ho
I	50	10	100	50	100	50	300	1500	100	1	I
IN	1000	1000	10000	10000	10000	10000	1	1	48	0.02	In
IR	50	20	200	100	200	100	200	100	20	0.01	Ir
KR	1	1	1	1	1	1	1	1	0	0	Kr
LA	25	30	1000	100	1000	100	5000	300	500	0.001	La
MN	400	400	100000	800	100000	6000	10000	10000	17	0.1	Mn
MO	10	40	100	20	100	20	1000	100	5	0.8	Mo
N	1	1	1	1	1	1	1	1	90	1	N
NA	100	1	100	0.1	100	0.3	100	1	11	1	Na
NB	100	100	50	50	50	50	500	500	760	0.01	Nb
ND	25	100	1000	1000	1000	1000	5000	1000	656	3E-4	Nd
NI	100	100	500	500	500	500	500	3000	667	0.05	Ni
NP	2500	2500	30	10	30	150	300	6	39000	0.001	Np
P	170	28000	100000	38000	1100000	45000	500000	00000	257	0.8	P
PA	30	300	30	10	30	10	300	50	41000	0.001	Pa
PB	2000	200	500	1000	500	1000	2000	50000	1460	0.2	Pb
PD	50	50	2000	300	2000	300	2000	20000	5	0.005	Pd
PM	300	500	3000	1000	3000	5000	5000	3000	656	3E-4	Pm
PO	50	2000	20000	50000	20000	10000	2000	1000	30	0.1	Po
PR	25	100	1000	1000	1000	1000	5000	1000	750	3E-4	Pr
PU	250	1000	100	300	100	3000	890	3600	65000	0.001	Pu
RA	50	950	1000	100	1000	100	30000	1000	8100	0.2	Ra
RB	2000	500	1000	200	1000	200	1000	1000	45	1.0	Rb
RH	10	10	300	100	300	100	200	100	10.4	0.05	Rh
RN	57	1	1	1	1	1	1	1	0	0	Rn
RU	100	10	300	100	300	2000	2000	1000	7.3	0.05	Ru
S	750	2	100	1	100	4	1	5	90	0.8	S
SB	200	1000	100	100	100	1200	1000	100	38	0.1	Sb
SC	100	750	1000	300	1000	100000	10000	1000	30	3E-4	Sc
SE	1000	6000	2000	5000	2000	6000	100	1000	11	0.8	Se
SI	1000	50000	10000	50000	10000	50000	50000	50000	60	0.01	Si
SM	300	500	3000	1000	3000	5000	5000	5000	656	3E-4	Sm
SN	1000	50000	10000	50000	10000	50000	50000	50000	35	0.02	Sn

SR	50	4	100	1	100	40	3000	300	4000	0.3	Sr
TA	60	60	3000	3000	3000	3000	1	1	240	0.001	Ta
TB	25	60	1000	1000	1000	3000	5000	1000	670	3E-4	Tb
TC	15	30	100	10	100	20	5000	5000	1	0.9	Tc
TE	400	1000	6100	1000	6100	1000	100	400	15	0.2	Te
TH	100	600	100	1000	100	1000	3000	2000	57000	2E-4	Th
TL	5000	5000	1000	1000	5000	5000	1	1	5	1	Tl
TM	500	500	1000	1000	5000	5000	1	1	675	3E-4	Tm
U	50	50	100	10	100	30	900	1000	100	0.05	U
W	1200	10	10	10	10	100	1200	100	1	0.3	W
XE	1	1	1	1	1	1	1	1	0	0	Xe
Y	25	20	1000	1000	1000	1000	5000	300	14000	1E-4	Y
YB	200	200	1000	1000	3000	3000	1	1	685	3E-4	Yb
ZN	64	1000	10000	50000	10000	30000	20000	50000	933	0.5	Zn
ZR	200	50	50	50	50	50	5000	5000	450	0.002	Zr

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!-----------------------------------------------------------------------------------------
*Ref:  Biofactors:  GENII BIOACM.DAT file dated 7 Mar 90 by JKS.  AS changed to 200, 18 May 92
*      TBIO:        NUREG-0172, ICRP-2, ICRP-10
*      F1:          ICRP-30 Parts 1 thru 4

END -------------------------------------------------------------------------------------
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DFEXT.DAT --- Halflives, effective energies and aquatic external DFs for selected nuclides --- 26 May 92 --- dAb
' Energies (Mev/dis) for various effective radii (cm) of muscle

Radius(cm)			1.4	2	3	5	7	10	20	30	Immersion mrem/y per uCi/m3	Sediment mrem/y per uCi/m2
H-3	12.35	y	.0058	0058	.0058	.0058	.0058	.0058	.0058	.01	0	0
C-14	5730	y	.05	.05	.05	.05	.05	.05	.05	.05	0	0
N-13	9.965	m	.538	.557	.587	.646	.701	.777	.983	1.13	1.11E+01	1.05E+02
F-18	109.77	m	.285	.304	.334	.391	.444	.518	.717	.861	1.08E+01	1.02E+02
NA-22	2.602	y	.286	.325	.387	.507	.619	.775	1.20	1.51	2.43E+01	2.10E+02
NA-24	15.00	h	.712	.771	.868	1.05	1.23	1.48	2.19	2.74	5.16E+01	3.56E+02
P-32	14.29	d	.695	.695	.695	.695	.695	.695	.695	.695	0.0	0.0
AR-39	269	y	.194	.194	.194	.194	.194	.194	.194	.194	0.0	0.0
AR-41	1.827	h	.519	.541	.576	.642	.705	.793	1.04	1.22	1.44E+01	1.15E+02
SC-46	83.83	d	.197	.232	.290	.399	.501	.644	1.03	1.32	2.28E+01	1.94E+02
CR-51	27.704	d	.00222	.00276	.00363	.00529	.00685	.00901	.0149	.0191	3.47E-01	3.41E+00
MN-54	312.5	d	.0364	.0514	.0758	.122	.166	.227	.392	.512	9.42E+00	8.41E+01
MN-56	2.5785	h	.875	.904	.951	1.04	1.13	1.24	1.57	1.82	2.01E+01	1.60E+02
FE-55	2.7	y	.00726	.00726	.00726	.00726	.00726	.00726	.00726	.00726	2.86E-04	2.21E-02
FE-59	44.529	d	.171	.191	.224	.286	.346	.428	.655	.824	1.34E+01	1.10E+02
CO-57	270.9	d	.0390	.0409	.0439	.0496	.0550	.0626	.0840	.100	1.44E+00	1.43E+01
CO-58	70.80	d	.0728	.0905	.119	.174	.226	.297	.492	.633	1.09E+01	9.87E+01
CO-60	5.271	y	.195	.237	.306	.437	.560	.732	1.21	1.56	2.82E+01	2.27E+02
NI-63	96	y	.0176	.0176	.0176	.0176	.0176	.0176	.0176	.0176	0.0	0.0
NI-65	2.520	h	.641	.651	.666	.695	.723	.762	.869	.949	6.20E+00	4.95E+01
CU-64	12.701	h	.133	.137	.143	.154	.165	.180	.220	.249	2.06E+00	1.95E+01
ZN-65	243.9	d	.0289	.0386	.0544	.0846	.113	.153	.261	.342	6.56E+00	5.48E+01
ZN-69M+0	13.76	h	.0400	.0477	.0603	.0842	.107	.138	.221	.282	4.52E-00	4.36E+01
ZN-69	57	m	.32	.32	.32	.32	.32	.32	.32	.32	6.52E-05	6.32E-04
AS-76	26.32	h	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	4.79E+00	4.27E+01
BR-82	35.30	h	.248	.294	.368	.510	.643	.828	1.33	1.70	2.96E+01	2.60E+02
BR-83+0	2.39	h	.363	.363	.364	.364	.364	.365	.366	.367	8.13E-02	7.68E-01
BR-84	31.80	m	1.31	1.34	1.39	1.47	1.56	1.67	2.00	2.25	2.21E+01	1.59E+02
BR-85	2.87	m	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	7.53E-01	6.52E+00
KR-83M	1.83	h	.0438	.0438	.0438	.0438	.0438	.0438	.0438	.0438	1.20E-03	1.14E-01
KR-85M	4.48	h	.245	.248	.252	.260	.268	.279	.309	.331	1.82E+00	1.80E+01
KR-85	10.72	y	.224	.224	.224	.244	.224	.225	.225	.225	2.43E-02	2.30E-01
KR-87	76.3	m	1.21	1.24	1.27	1.34	1.41	1.50	1.77	1.97	9.65E+00	7.40E+01
KR-88	2.84	h	.449	.475	.517	.599	.677	.786	1.09	1.33	2.45E+01	1.77E+02
RB-86	18.66	d	.666	.668	.671	.676	.680	.687	.705	.719	1.07E+00	8.99E+00
RB-88	17.8	m	2.15	2.16	2.18	2.21	2.24	2.28	2.40	2.49	7.74E+00	5.77E+01
RB-89	15.2	m	.694	.733	.797	.919	1.03	1.20	1.64	1.98	2.46E+01	1.90E+02
SR-89	50.5	d	.564	.564	.564	.564	.564	.564	.564	.564	1.55E-03	1.36E-02
SR-90	29.12	y	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	0.0	0.0
SR-91	9.5	h	.702	.721	.752	.812	.867	.944	1.15	1.31	7.75E+00	6.77E+01
SR-92	2.71	h	.249	.272	.310	.381	.449	.543	.805	1.00	1.50E+01	1.19E+02
Y-90	64.0	h	.939	.939	.939	.939	.939	.939	.939	.939	0.0	0.0
Y-91M	49.71	m	.0518	.0615	.0773	.107	.135	.174	.280	.355	5.80E+00	5.46E+01
Y-91	58.51	d	.590	.590	.591	.591	.591	.591	.592	.592	4.06E-02	3.31E-01
Y-92	3.54	h	1.47	1.47	1.48	1.49	1.51	1.52	1.57	1.61	2.85E+00	2.42E+01
Y-93	10.1	h	1.18	1.18	1.18	1.19	1.19	1.20	1.22	1.23	1.05E+00	8.55E+00
ZR-95	63.98	d	.227	.254	.297	.380	.458	.565	.857	1.07	8.20E+00	7.47E+01
ZR-97	16.90	h	.763	.778	.802	.848	.891	.951	1.11	1.23	2.04E+00	1.74E+01
NB-95	35.15	d	.0767	.0906	.113	.156	.197	.253	.405	.515	8.56E+00	7.76E+01
NB-97	72.1	m	.500	.512	.532	.570	.606	.656	.790	.887	7.34E+00	6.79E+01
MO-99+0	66.0	h	.419	.423	.430	.444	.457	.475	.524	.561	1.73E-00	1.60E+01
TC-99M	6.02	h	.132	.134	.138	.144	.150	.158	.181	.199	1.49E+00	1.48E+01
TC-99	2.13E5	y	.084	.084	.084	.084	.084	.084	.084	.084	6.18E-06	5.26E-05
TC-101	14.2	m	.465	.492	.503	.524	.543	.570	.643	.697	3.78E+00	3.68E-01
RU-103+0	39.28	d	.116	.125	.140	.168	.194	.230	.328	.399	5.26E+00	5.00E+01
RU-105+0	4.44	h	.496	.508	.527	.563	.597	.644	.772	.865	8.69E+00	8.05E+01
RU-106+0	368.2	d	1.44	1.44	1.45	1.46	1.47	1.49	1.53	1.56	0.0	0.0
RH-105	35.36	h	.158	.159	.162	.167	.172	.179	.198	.212	8.55E-01	8.39E+00
PD-109+0	13.427	h	.389	.389	.389	.389	.389	.390	.390	.391	7.49E-03	7.11E-02
AG-110M+0	249.9	d	.188	.235	.311	.456	.593	.782	1.30	1.68	3.07E+01	2.62E+02
AG-111	7.45	d	.361	.362	.362	.364	.365	.367	.372	.376	2.90E-01	2.84E+00
SN-125	9.64	d	.906	.907	.910	.914	.919	.925	.942	.954	3.50E+00	2.91E+01
SB-124	60.20	d	.459	.491	.544	.644	.739	.871	1.24	1.51	2.15E+01	1.76E+02
SB-125	2.77	y	.105	.113	.126	.150	.173	.205	.291	.353	4.63E+00	4.43E+01
SB-127	3.85	d	.433	.448	.472	.518	.561	.620	.782	.899	7.30E+00	6.79E+01

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TE-125M	58	d	.111	.111	.112	.112	.112	.113	.113	.114	1.24E-01	2.10E+00
TE-127M	109	d	.00197	.00197	.00197	.00198	.00199	.00200	.00203	.00205	3.97E-02	6.70E-01
TE-127	9.35	h	.223	.223	.223	.223	.223	.224	.224	.224	5.28E-02	5.12E-01
TE-129M+D	33.6	d	.599	.601	.605	.612	.619	.627	.651	.647	3.75E-01	3.67E+00
TE-129	69.6	m	.535	.538	.541	.548	.555	.563	.585	.601	5.94E-01	5.68E+00
TE-131M	30	h	.269	.291	.327	.396	.460	.550	.796	.978	1.61E+01	1.41E+02
TE-131	25.0	m	.786	.791	.800	.817	.833	.855	.916	.961	4.72E+00	4.36E+01
TE-132	78.2	h	.121	.125	.131	.143	.154	.169	.211	.242	2.43E+00	2.48E+01
TE-133M+D	55.4	m	.502	.542	.605	.726	.840	.998	1.43	1.74	2.53E+01	2.19E+02
TE-134	41.8	m	.114	.117	.122	.130	.138	.148	.175	.194	9.64E+00	9.08E+01
I-129	1.57E7	y	.0602	.0628	.0652	.0694	.0728	.0769	.0844	.0872	1.07E-01	2.20E+00
I-130	12.36	h	.388	.427	.490	.611	.724	.881	1.31	1.61	2.36E+01	2.18E+02
I-131	8.04	d	.206	.213	.224	.245	.266	.293	.368	.422	4.17E+00	4.04E+01
I-132	2.30	h	.581	.624	.693	.826	.950	1.12	1.59	1.94	2.56E+01	2.29E+02
I-133	20.8	h	.467	.478	.497	.533	.566	.613	.738	.829	6.66E+00	6.16E+01
I-134	52.6	m	.779	.838	.934	1.12	1.29	1.53	2.19	2.67	2.98E+01	2.58E+02
I-135	6.61	h	.481	.514	.566	.667	.761	.893	1.26	1.53	1.81E+01	1.45E+02
XE-131M	11.9	d	.136	.136	.136	.137	.137	.137	.138	.139	1.04E-01	1.83E+00
XE-133M	2.188	d	.176	.177	.178	.180	.182	.184	.191	.196	3.37E-01	4.15E+00
XE-133	5.245	d	.137	.137	.138	.140	.141	.143	.148	.152	4.19E-01	5.08E+00
XE-135M	15.29	m	.118	.126	.139	.163	.186	.217	.302	.363	4.67E+00	4.43E+01
XE-135	9.09	h	.330	.335	.342	.355	.368	.386	.434	.469	2.74E+00	2.71E+01
XE-137	3.84	m	1.68	1.68	1.68	1.69	1.70	1.71	1.74	1.76	2.07E+00	1.89E+01
XE-138	14.17	m	.505	.527	.562	.630	.694	.784	1.04	1.23	1.36E+01	1.05E+02
CS-134M	2.90	h	.0483	.0496	.0517	.0558	.0597	.0652	.0805	.0922	2.40E-01	2.87E+00
CS-134	2.062	y	.230	.259	.306	.396	.480	.596	.913	1.14	1.73E+01	1.58E+02
CS-135	2.3E6	y	.058	.058	.058	.058	.058	.058	.058	.058	0.0	0.0
CS-136	13.1	d	.233	.273	.337	.458	.573	.732	1.17	1.49	2.44E+01	2.14E+02
CS-137+D	30.0	y	.257	.267	.284	.316	.346	.388	.500	.582	6.58E+00	6.11E+01
CS-138	32.2	m	1.18	1.22	1.27	1.38	1.48	1.62	2.02	2.32	2.76E+01	2.15E+02
CS-139	9.4	m	1.61	1.61	1.62	1.64	1.66	1.68	1.75	1.79	3.61E+00	2.73E+01
BA-139	82.7	m	.927	.927	.929	.931	.933	.936	.944	.950	4.01E-01	3.88E+00
BA-140	12.74	d	.315	.320	.328	.343	.357	.376	.428	.465	2.05E+00	1.96E+01
BA-141	18.27	m	1.10	1.11	1.12	1.16	1.19	1.23	1.36	1.44	1.00E+01	8.94E+01
BA-142	10.6	m	.601	.622	.656	.722	.783	.869	1.10	1.28	1.02E+01	8.82E+01
LA-140	40.272	h	.698	.734	.793	.907	1.01	1.16	1.58	1.89	2.66E+01	2.13E+02
LA-141	3.93	h	.966	.967	.967	.969	.970	.972	.977	.981	4.83E-01	3.79E+00
LA-142	92.5	m	.937	.973	1.03	1.14	1.25	1.40	1.82	2.14	3.38E+01	2.44E+02
CE-141	32.501	d	.173	.174	.175	.179	.182	.187	.199	.209	8.71E-01	8.78E+00
CE-143	33.0	h	.420	.426	.435	.453	.470	.493	.555	.601	2.89E+00	2.85E+01
CE-144+D	284.3	d	1.32	1.32	1.32	1.33	1.33	1.33	1.34	1.35	2.08E-01	2.16E+00
PR-143	13.56	d	.314	.314	.314	.314	.314	.314	.314	.314	9.93E-08	9.06E-07
PR-144	17.28	m	1.23	1.23	1.23	1.24	1.24	1.24	1.24	1.25	3.86E-01	2.98E+00
ND-147	10.98	d	.257	.259	.264	.272	.280	.291	.320	.342	1.48E+00	1.48E+01
PM-147	2.6234	y	.0620	.0620	.0620	.0620	.0620	.0620	.0620	.0620	4.15E-05	4.10E-04
PM-148	5.37	d	.727	.737	.755	.788	.819	.862	.982	1.07	6.45E+00	5.37E+01
PM-149	53.08	h	.366	.367	.367	.367	.368	.368	.370	.371	1.28E-01	1.25E+00
PM-151	28.40	h	.327	.332	.340	.356	.370	.390	.445	.484	3.68E+00	3.59E+01
SM-153	46.7	h	.270	.271	.272	.273	.275	.277	.283	.288	6.10E-01	7.08E+00
EU-154	8.8	y	.311	.331	.38	.428	.487	.570	.798	.965	1.41E+01	1.21E+02
EU-156	15.19	d	.471	.490	.521	.580	.636	.714	.930	1.09	1.59E+01	1.26E+02
W-181	121.2	d	.00316	.00316	.00317	.00318	.00320	.00322	.00327	.00331	4.04E-01	4.68E+00
W-185	75.1	d	.144	.144	.144	.144	.144	.144	.144	.144	3.16E-04	3.11E-03
W-187	23.9	h	.331	.339	.353	.379	.403	.437	.529	.595	5.25E+00	4.94E+01
U-234	2.445E5	y	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	1.86E-03	8.07E-02
U-235+D	7.04E8	y	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	1.72E+00	1.71E+01
U-237	6.75	d	.160	.160	.160	.180	.180	.180	.220	.220	1.53E+00	1.61E+01
U-238+D	4.468E9	y	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	1.29E-03	6.46E-02
NP-238	2.117	d	.263	.270	.282	.306	.327	.357	.440	.513	6.27E+00	5.38E+01
NP-239	2.355	d	.203	.205	.208	.212	.217	.223	.240	.260	1.89E+00	1.92E+01
PU-238	87.74	y	5.51	5.51	5.51	5.51	5.51	5.51	5.51	5.50	1.12E-03	8.58E-02
PU-239	24065	y	5.15	5.15	5.15	5.15	5.15	5.15	5.15	5.15	9.74E-04	3.78E-02
PU-240	6537	y	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	1.10E-03	8.29E-02
PU-241+D	14.4	y	.00535	.00535	.00535	.00535	.00535	.00535	.00535	.00636	0.0	0.0
PU-242	3.763E5	y	4.90	4.90	4.90	4.90	4.90	4.90	4.90	4.8	9.32E-04	6.82E-02
AM-241	432.2	y	5.51	5.51	5.51	5.52	5.52	5.52	5.52	5.4	2.33E-01	2.99E+00
AM-243+D	7380	y	5.28	5.28	5.28	5.29	5.29	5.29	5.30	5.2	6.09E-01	6.61E+00
CM-242	162.8	d	6.11	6.11	6.11	6.11	6.11	6.11	6.11	6.1	1.25E-03	9.34E-02
CM-244	18.11	y	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.8	1.07E-03	8.29E-02
CF-252	2.638	y	12.2	12.2	12.2	12.2	12.2	12.2	12.2	16.5	9.51E-04	6.34E-02

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'Organ Equivalents: I Thy    C Thy    A Thy    C Kid    C Lung    A Livr    C TBod    A TBod

'Sources:  Energies:  BNWL-1754, Soldat, et al.  1974.
'          DFs:  DOE/EH-0070, 1988.  "External Dose-Rate Conversion Factors for Calculation of Dose to the Public."
'          Half lives:  ICRP 30.

'--Notes:------
'    Half lives checked -- 23 Oct 91 dAb
'    Immersion & sediment DFs checked --  23 Oct 91 dAb
'    No daughters included in DFs except for Cs-137 (Ba-137m)
'    Eu-154 added 25 Mar 92 dAb
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