Annex 1

THE POPULATION DOSE CRITERION

The decision to introduce a countermeasure should be based on a balance of the radiation risk avoided and the risks and disadvantages caused by the countermeasure itself. The intervention level determines the initiation of a particular type of remedial action and it is implicit in its selection that the exposed individual should be put in a "better" position by the remedial action, i.e., that the health risk to the individual should be reduced at a reasonable cost in financial and social terms.

The decision to introduce a remedial action can be based on a conceptual cost-benefit analysis, such that the action is taken only if the net benefit is positive. This benefit could be expressed as

$$B = Y_o - Y_I - R - X$$

where

B is the net benefit,

Y_o is the radiation detriment cost if the remedial action is *not* taken,

Y_I is the remaining radiation detriment cost if the remedial action is carried out,

R is the detriment cost caused by risks due to the remedial action itself, and

X is the cost of the remedial action.

In practice it is difficult to quantify all the terms in the equation and it is necessary to make subjective value judgements, similar to those involved in most social and economic decisions.

If intervention is decided on, then the selection of the appropriate intervention level may maximize the net social benefit. If the detriment cost due to the risks from the countermeasure itself is independent of the intervention level, the optimization condition is

$$\frac{dX}{dI} + \frac{dY_I}{dI} = 0$$

where I is the intervention level or any derived intervention level. The cost of the countermeasure (X) may appear minimal if assessed only locally; ideally, however, the cost assessment should be conducted on a wide basis and should include the costs of production of the foodstuff wherever they are incurred, as well as those of transportation and administration.

If one assumes that in the far field and long term only the so-called α-term of the detriment cost is relevant for optimization, the optimizing condition can be expressed as

$$\frac{dX(I)}{dI} + \alpha \frac{dS_I}{dI} = 0$$

where $X(I)$ is the part of the countermeasure cost that is a function of the intervention level, α is the monetary value assigned per unit collective dose, and S_I is the collective dose remaining after the countermeasure has been applied.

A simple optimization procedure can be formulated for situations where the intervention is fully effective while it is applied, and where both the collective dose and the cost of the countermeasure are proportional to the number of individuals affected by the countermeasure. If the countermeasure is applied for a time τ, during which individual doses are zero, and then removed, the cost and the remaining collective dose can be expressed as

$$X = CN\tau$$

$$S_I = N \int_{\tau}^{\infty} H(t)\, dt$$

where C is the cost of the countermeasure per person and per unit time, $H(t)$ is the individual dose as a function of time if the countermeasure is not applied, and N is the number of people affected by the countermeasure.

The optimizing condition described previously can now be expressed as

$$\frac{dX(\tau)}{d\tau} + \alpha \frac{dS_I}{d\tau} = 0$$

and therefore

$$H_o(\tau) = \frac{C}{\alpha}$$

where $H_o(\tau)$ is the optimum value for the individual dose intervention level. It should be noted that the ratio C/α is expected to be more insensitive to geographical location than either C or α, because richer countries where C would be higher are likely to assign higher values to α.

Annex 2

FOOD CONSUMPTION DATA

Food consumption data have been reviewed for about 140 countries and areas, and data for food components with a consumption rate of more than 20 kg per year (as well as for fish, see page 23) have been tabulated. Countries and areas with similar food consumption patterns have been grouped into regional types, from which an average consumption has been derived (Tables 7–14). Eight average dietary patterns can be discerned and these are listed in Table 1, page 22.

The following abbreviations are used in the tables:

DS	Diet Survey
FBS	Food Balance Sheet
HE	Household Expenditure
INT	Interview
INV	Inventory
RC	Recall
WS	Weighing Survey.

Dashes in table columns indicate that no data are available.

Table 7a. African-type cereal-based diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Botswana	FBS	404 8	27.7	76.7	48 6	90.0	4 2	309 1	1
Burkina Faso	FBS	441.3	41.2	24.9	20 5	26.9	4.2	59 6	1
Cape Verde	FBS	528 9	146.6	43.9	105 8	19.3	65 8	162.4	1
Gambia	FBS	529 5	27.3	33.8	14 3	39.3	65.2	62 3	1
Kenya	FBS	374.5	185.7	60.2	72.7	55 6	8.7	161.8	1
Kenya	HE	422 0	219.0	60.0	81 0	37 0	7.0	131.0	2
Lesotho	FBS	611 6	16.6	63 3	44 5	54.0	8.2	105 2	1
Madagascar	FBS	598.5	447.2	79 3	188.5	70 6	14 7	17 7	1
Malawi	FBS	505 9	64.5	80.2	86 3	14 9	24.4	21.3	1
Mali	FBS	461.6	45 4	45 7	4.1	53 0	26 6	59 8	1
Mauritius	FBS	545 9	41.8	74.9	31.8	39.1	44.6	267 8	1
Niger	FBS	682.5	93 1	63.4	20.0	56.8	2 8	102.8	1
Niger	INT	635 0	4.2	20.1	0.4	14.1	—	70.9	3
Réunion	FBS	519.1	54.9	71.3	158.5	116.4	63 8	159.0	1
Senegal	FBS	611.9	17.1	42 6	33 8	40.5	69.5	97 5	1
Senegal	WS	420.6	4.8	—	—	25 7	47 4	46.2	4
Senegal	HE	329.4	36.4	116.0	10 5	29 3	147.2	14 6	5
Sierra Leone	FBS	471 0	79.5	114 6	90.6	16.4	50.7	38.9	1
Somalia	FBS	333 2	19 6	15.9	113 3	126.6	5.1	470.9	1
Swaziland	FBS	431 9	63 5	53.1	108.6	106 8	0 0	180.5	1
Zambia	FBS	511 6	92.3	89.2	32.5	40.6	24 5	28.1	1
Zimbabwe	FBS	469 4	26.1	45.2	32.5	40.2	4 9	49.1	1
Average (g/day)		492 7	79.8	60.7	61.9	50.6	32 8	118 9	
Average (kg/year)		179.9	29 1	22.2	22.6	18 5	12.0	43.4	

Table 7b. African-type root- and tuber-based diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Benin	FBS	261.8	767.2	85.7	99.9	21.1	29.3	14.8	1
Burundi	FBS	191.8	1020.3	87.0	224.7	14.9	8.6	48.8	1
Cameroon	FBS	255.2	483.0	110.0	260.7	38.5	30.1	25.9	1
Central African Republic	FBS	112.1	1159.9	47.5	160.1	48.1	15.2	9.9	1
Central African Republic	HE	41.9	328.2	57.5	40.0	76.0	18.3	—	6
Comoros	FBS	340.7	684.3	18.4	257.9	30.0	30.9	30.7	1
Congo	FBS	139.3	1155.4	54.2	313.7	30.0	79.7	26.5	1
Congo	HE	8.9	699.5	131.0	47.3	32.7	34.1	0.0	7
Côte d'Ivoire	FBS	391.7	705.2	102.3	248.2	50.3	55.3	57.6	1
Fiji	FBS	385.2	506.7	84.8	61.5	56.2	119.8	151.4	1
Ghana	FBS	192.7	633.5	82.5	179.9	28.9	63.9	11.7	1
Guinea	FBS	306.8	359.9	191.6	220.5	20.9	17.0	26.2	1
Kiribati	FBS	311.8	527.4	179.6	204.4	41.5	178.3	25.9	1
Liberia	FBS	478.3	483.5	83.2	155.4	30.6	45.6	27.5	1
Mozambique	FBS	222.1	685.3	43.2	71.1	18.7	9.1	25.6	1
Nigeria	FBS	326.8	667.3	98.4	75.5	32.1	44.2	30.5	1
Rwanda	FBS	77.5	988.5	87.6	263.9	16.1	0.7	26.7	1
Samoa	FBS	153.2	597.0	13.3	668.6	130.2	96.6	37.0	1
Sao Tome and Principe	FBS	308.5	419.0	72.5	116.0	20.4	56.4	76.0	1
Solomon Islands	FBS	170.9	897.2	48.9	150.6	30.3	138.2	39.2	1
Togo	FBS	293.6	815.7	66.0	38.0	25.1	29.7	5.7	1
Tonga	FBS	152.3	1393.7	147.8	219.9	135.6	98.7	34.9	1
Uganda	FBS	183.6	326.5	51.0	418.6	32.7	35.5	71.2	1
United Rep. of Tanzania	FBS	215.4	666.5	126.9	236.1	32.1	32.5	70.2	1
Vanuatu	FBS	202.4	422.3	147.1	119.7	112.5	94.8	124.0	1
Zaire	FBS	106.4	1182.4	43.5	193.7	18.7	16.6	7.7	1
Average (g/day)		205.6	658.7	81.3	185.7	41.2	49.4	39.5	
Average (kg/year)		75.0	240.4	29.7	67.8	15.0	18.1	14.4	

Table 7c. Averages for African-type diets (per caput)[a]

	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
g/day	349.2	369.2	71.0	123.8	45.9	41.1	79.2
kg/year	127.4	134.8	25.9	45.2	16.8	15.0	28.9

[a] North African-type diets are not included (see Table 13).

Table 8. Central American-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Antigua	FBS	259.6	35.8	43.1	314.3	83.8	63.1	353.6	1
Bahamas	FBS	244.9	36.6	195.3	181.2	188.4	35.9	254.6	1
Barbados	FBS	323.0	172.6	124.4	157.1	249.0	76.5	235.7	1
Barbados	WS	206.0	145.0	52.0	28.0	135.0	—	114.0	8
Belize	FBS	351.4	226.8	67.5	293.8	97.9	13.0	399.8	1
Bermuda	FBS	228.5	77.6	311.1	264.9	288.8	101.9	355.3	1
Costa Rica	FBS	344.5	31.5	57.0	273.1	90.5	17.1	331.3	1
Cuba	FBS	420.0	204.7	94.1	172.4	104.3	46.7	422.3	1
Dominica	FBS	232.0	364.3	138.3	519.2	73.3	58.5	168.5	1
Dominican Republic	FBS	279.2	76.5	80.1	534.0	64.7	21.0	217.6	1
Grenada	FBS	247.8	83.9	56.9	337.1	88.0	90.8	228.5	1
Guadeloupe	FBS	368.4	124.5	183.4	213.7	136.9	133.6	246.7	1
Guatemala	FBS	373.4	14.6	55.8	122.2	54.9	2.2	100.9	1
Haiti	FBS	256.9	243.0	119.9	332.9	34.2	8.5	34.5	1
Honduras	FBS	357.6	15.4	47.0	280.8	36.7	3.7	118.5	1
Jamaica	FBS	320.9	233.1	88.3	246.2	104.8	49.6	78.2	1
Martinique	FBS	336.8	151.7	282.7	284.5	145.0	127.5	181.0	1
Mexico	FBS	475.1	37.5	86.6	251.0	69.6	28.8	274.5	1
Netherlands Antilles	FBS	309.3	86.6	111.4	243.3	199.0	53.2	420.7	1
Panama	FBS	344.6	92.2	58.6	285.0	108.9	19.8	168.6	1
Saint Kitts and Nevis	FBS	206.1	149.1	76.6	104.1	107.6	83.4	138.6	1
Saint Lucia	FBS	253.2	230.4	33.4	715.3	138.9	83.6	160.7	1
Saint Vincent	FBS	250.3	44.5	16.4	226.6	80.0	33.9	166.1	1
Trinidad and Tobago	FBS	437.0	108.1	107.8	197.0	114.3	33.8	345.2	1
Trinidad and Tobago	INV	325.0	161.0	171.0	173.0	103.0	40.0	115.0	8
Average (g/day)		310.1	125.9	106.4	270.0	115.9	51.1	225.2	
Average (kg/year)		113.2	46.0	38.8	98.6	42.3	18.7	82.2	

Table 9. Chinese-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
China	FBS	627.1	300.9	180.7	30.0	62.7	15.6	13.4	1
China	DS	451.0	—	286.0	0.0	45.0	38.0	2.0	9
Viet Nam	FBS	387.0	273.0	—	—	43.5	4.6	5.4	10
Viet Nam	DS	416.0	131.0	—	—	13.0	39.0	0.0	10
Average (g/day)		470.3	235.0	233.4	15.0	41.1	24.3	5.2	
Average (kg/year)		171.7	85.8	85.2	5.5	15.0	8.9	1.9	

Table 10. Eastern Mediterranean-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Bangladesh	FBS	631.7	44.8	26.9	39.6	10.8	20.3	36.7	1
Democratic Yemen	FBS	469.5	6.3	80.3	206.3	34.5	50.4	204.8	1
Egypt	FBS	694.3	64.3	328.6	208.3	42.0	13.6	57.4	1
Kuwait	FBS	469.2	49.2	329.6	374.3	217.0	28.2	457.4	1
Saudi Arabia	FBS	454.7	28.0	220.7	520.7	133.1	25.1	319.0	1
Sudan	FBS	390.2	40.9	93.1	112.0	69.8	4.1	179.4	1
Syrian Arab Republic	FBS	525.7	68.3	563.0	474.6	61.2	4.7	184.8	1
Turkey	FBS	576.6	140.0	343.8	462.0	61.1	17.8	175.0	1
Turkey	RC	544.8	51.0	193.1	79.4	36.8	8.6	107.8	11
United Arab Emirates	FBS	366.0	40.3	467.3	449.4	188.6	67.7	378.7	1
Yemen	FBS	550.1	47.5	112.7	130.9	60.1	11.7	138.9	1
Average (g/day)		515.7	52.8	250.8	278.0	83.2	22.9	203.6	
Average (kg/year)		188.2	19.3	91.6	101.5	30.4	8.4	74.3	

Table 11. European-type diet (per caput in g/day) *(continues on page 42)*

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Australia	FBS	311.2	136.9	182.7	247.7	283.0	39.0	331.3	1
Australia	RC	232.0	—	268.0	178.0	192.0	19.0	427.0	19
Austria	FBS	255.7	229.1	218.6	315.0	265.3	24.3	417.7	1
Belgium and Luxembourg	FBS	265.3	273.9	231.3	229.7	267.9	51.5	361.0	1
Bulgaria	FBS	616.9	77.7	270.3	312.3	185.2	15.2	243.2	1
Canada	FBS	253.7	218.3	260.5	326.9	262.0	59.7	468.3	1
Czechoslovakia	FBS	399.1	217.8	187.2	141.3	260.9	22.3	426.2	1
Denmark	FBS	239.3	207.4	137.4	172.3	220.0	133.4	432.2	1
Denmark	HE?	264.0	213.0	—	—	149.0	27.0	681.0	12
Faroe Islands	FBS	367.1	247.0	73.5	157.7	220.9	272.0	203.0	1
Finland	FBS	266.7	238.4	87.1	219.1	168.9	78.4	711.2	1
France	FBS	290.2	218.6	305.6	187.0	273.7	66.0	346.6	1
France	HE?	233.0	—	397.0	196.0	187.0	26.0	294.0	13
German Democratic Republic	FBS	362.8	389.1	206.0	195.5	293.1	38.1	389.3	1
Germany, Federal Republic of	FBS	254.3	221.1	187.5	104.8	267.7	27.2	328.7	1
Greece	FBS	414.1	182.2	495.7	453.7	185.7	44.7	262.1	1
Hungary	FBS	423.8	162.3	226.8	217.7	284.4	9.9	315.3	1
Iceland	FBS	226.8	171.4	60.5	160.0	250.1	291.2	695.9	1
Ireland	FBS	366.5	313.7	255.6	180.2	228.5	43.2	637.2	1
Ireland	HE	318.4	59.9	—	—	—	—	456.0	14
Israel	FBS	394.1	113.1	296.4	391.3	190.8	46.8	315.3	1
Israel	HE	215.0	67.0	232.0	297.0	99.0	17.0	400.0	16
Israel	FBS	306.5	107.3	318.9	400.4	178.6	23.3	330.0	17
Italy	FBS	503.1	112.8	457.0	353.8	200.3	34.2	299.7	1
Malta	FBS	391.3	62.8	261.8	176.4	154.7	57.5	416.8	1
Netherlands	HE?	329.0	276.0	210.0	256.0	—	9.0	602.0	15
New Zealand	FBS	291.8	157.9	232.3	212.3	320.8	27.2	856.9	1
Norway	FBS	296.3	233.5	120.5	220.3	146.5	141.2	692.6	1
Norway	HE	203.2	151.0	87.2	131.8	79.7	54.1	460.1	14
Poland	FBS	495.2	326.3	309.5	102.1	193.3	46.0	437.2	1
Poland	HE	318.4	291.5	185.5	105.2	148.8	15.6	389.9	14
Portugal	FBS	442.5	265.8	337.7	191.0	139.4	77.0	146.8	1
Romania	FBS	523.9	193.3	382.8	154.6	189.2	16.7	403.7	1

Table 11. European-type diet (per caput in g/day) *(continued)*

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Spain	FBS	324 6	306.9	405 0	347.8	187 2	86.8	328 7	1
Spain	HE	245 0	230 8	213.5	248.0	170.5	71.7	489 0	14
Sweden	FBS	230 5	202 2	129 8	218 8	179.7	83 3	502.0	1
Switzerland	FBS	271 9	133 4	191.9	312.7	239.6	29.4	460.9	1
United Kingdom	FBS	258.9	281.2	197.5	151.9	205 2	45 1	455.0	1
United Kingdom	HE	226.3	169 9	181 5	113 1	159 8	20.0	367.0	14
USA	FBS	250.0	146.7	271 6	309.3	312 2	44.2	462 3	1
USSR	FBS	504.1	300.5	258 9	106.8	169.7	69.7	382.1	1
Yugoslavia	FBS	599 4	158.7	217 2	194.8	176 7	8.5	298.3	1
Yugoslavia	HE	285.0	98.0	184.0	148.0	175 0	13 0	330.0	18
Average (g/day)		331 8	199 1	237 4	222 9	206 4	55.4	424.5	
Average (kg/year)		121.1	72.7	86.7	81 4	75 3	20.2	154 9	

Table 12. Far Eastern-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Brunei Darussalam	FBS	509.4	73.5	87.5	181.4	95.3	94.5	161.2	1
Burma	FBS	799.2	10.1	130.1	73.8	17.4	39.2	14.4	1
Hong Kong	FBS	387.4	35.3	253.4	180.8	203.4	135.5	95.2	1
India	FBS	502.2	53.6	160.4	63.4	3.7	8.4	104.7	1
India	WS	498.0	47.0	76.0	21.0	5.0	10.0	78.0	20
Indonesia	FBS	597.0	197.2	34.8	50.9	9.4	31.9	10.3	1
Indonesia	HE	624.0	284.1	147.8	100.4	32.3	43.4	20.1	21
Japan	FBS	502.8	72.0	299.1	178.2	82.4	231.8	135.5	1
Macao	FBS	437.8	17.8	202.1	141.5	170.3	130.9	45.7	1
Malaysia	FBS	536.8	61.5	91.4	130.2	51.5	123.6	55.4	1
Nepal	FBS	575.1	47.2	30.2	23.0	14.9	0.9	115.1	1
Pakistan	FBS	462.0	14.9	58.1	66.5	26.3	4.7	192.0	1
Pakistan	FBS	412.3	15.1	69.5	78.1	24.9	3.5	228.7	17
Pakistan	HE	409.0	24.0	63.1	70.0	20.4	2.0	170.7	14
Philippines	FBS	569.2	176.4	94.5	266.2	44.0	86.1	48.1	1
Philippines	WS	367.0	37.0	145.0	142.0	54.0	8.0	33.0	22
Republic of Korea	FBS	865.2	78.2	520.2	95.8	43.4	138.9	32.4	1
Singapore	FBS	559.3	84.9	190.0	219.8	174.5	86.6	113.1	1
Sri Lanka	FBS	511.0	94.1	47.4	215.8	6.6	38.6	72.0	1
Thailand	FBS	631.3	53.4	123.2	216.4	40.0	52.6	21.6	1
Average (g/day)		566.1	77.8	148.6	132.4	58.9	66.9	91.0	
Average (kg/year)		206.6	28.4	54.3	48.3	21.5	24.4	33.6	

Table 13. North African-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Algeria	FBS	527.2	80 9	104.9	142.9	30 7	5.7	221 0	1
Libyan Arab Jamahiriya	FBS	569 3	80.4	265.7	402.3	145.2	22 0	280.2	1
Mauritania	FBS	383.0	14.5	10 1	30 7	82.0	44.7	421.1	1
Morocco	FBS	589 0	49.0	107.0	111.7	41.2	15.2	85.9	1
Morocco	HE	592.9	—	243 0	127 4	49.0	9.9	81.1	23
Tunisia	FBS	531 7	49.2	312 1	235.8	46.6	21 9	179 6	1
Average (g/day)		443.6	54.8	173.8	175.1	65 8	19 9	211 5	
Average (kg/year)		161 9	20 0	63.4	63.9	24.0	7.3	77.2	

Table 14. South American-type diet (per caput in g/day)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk	Reference
Argentina	FBS	380.2	212.0	181.6	288.9	346.5	16.0	269.6	1
Bolivia	FBS	298.5	335.2	122.6	195.6	90.4	7.9	83.7	1
Brazil	FBS	371.3	264.0	75.9	205.6	96.2	19.4	183.2	1
Brazil	HE	224.0	99.0	47.0	53.0	—	—	138.0	24
Chile	FBS	466.8	127.4	188.6	183.3	92.6	78.1	250.1	1
Colombia	FBS	295.5	297.7	118.6	272.3	96.5	11.3	168.1	1
Ecuador	FBS	253.9	131.5	75.2	447.6	78.4	47.0	220.9	1
French Guiana	FBS	361.7	148.1	123.0	266.0	215.3	80.0	163.7	1
Guyana	FBS	514.6	37.0	24.9	114.9	61.5	65.6	171.7	1
Guyana	WS	322.0	95.0	91.0	39.0	93.0	—	70.0	8
Paraguay	FBS	287.1	515.5	80.6	586.4	197.4	2.3	140.5	1
Peru	FBS	339.6	275.7	90.1	206.9	64.2	81.5	130.1	1
Suriname	FBS	522.6	50.4	56.1	81.6	105.4	61.7	109.9	1
Uruguay	FBS	368.4	140.5	123.0	172.0	255.0	20.3	441.8	1
Venezuela	FBS	353.2	80.9	58.4	325.3	133.3	30.2	366.4	1
Venezuela	HE	317.4	155.2	41.6	208.2	62.4	29.2	190.1	25
Average (g/day)		354.8	185.3	93.6	227.9	132.5	39.3	193.6	
Average (kg/year)		129.5	67.6	34.2	83.2	48.4	14.4	70.7	

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RADIATION DOSE PER UNIT INTAKE

ICRP (1979, 1980) has recommended dosimetric models and metabolic data based on "reference man" for estimating radiation doses from intakes of radionuclides. These models and data have been developed for adults exposed to radiation at work, and ICRP does not recommend their use for calculating the committed dose equivalent for individual members of the public from the intake of radionuclides in the environment. Several factors will influence the average dose to a mixed population.

Body size and biokinetics

Even if there were no differences between children and adults in the uptake and retention of a radionuclide, the dose equivalent in a particular tissue per unit intake of the radionuclide would be greater in the former, because of the smaller mass of their organs and tissues. For short-lived radionuclides emitting low-penetrating radiation (β-particles, α-particles, photons with energies below 10 keV), the dose equivalent per unit intake will be greater in children than in adults according to the inverse ratio of organ or tissue masses. For long-lived radionuclides emitting low-penetrating radiation, which are retained longer in the body, this ratio will be only about 2, because, as the mass of an organ or tissue increases with age, the activity concentration of the retained radionuclide decreases. For radionuclides emitting penetrating radiation (photons with energies above 10 keV) the modifying factor for body size is smaller, because the dose per unit intake factor in a particular organ is less dependent on the mass of the organ. Even if only differences in body size are allowed for, the committed dose equivalents per unit intake calculated for young members of the public will therefore be greater than those for adults, by factors ranging from less than 2 to 10, depending on the type of radiation emitted by the radionuclide and its effective half-life in the body organs or tissues.

The biokinetics of radionuclides may also differ substantially between children and adults. This may result in a larger fraction of the radionuclide being deposited in the organs or tissues of children or, frequently, in the more rapid elimination of a radionuclide by children. For example, since caesium-137 has a more rapid turnover in children, the dose equivalent in body tissues from a unit intake of caesium-137 for a one-year-old is only about three-quarters that for an adult.

The biological half-life of iodine in the thyroid increases with age, but the deposition of iodine in the thyroid is slightly higher in the first months of life than in the young child, adolescent, and adult. However, because of the comparatively short half-life of iodine-131, age-related differences in biological turnover are of little consequence to the effects of this radionuclide, so that the greater thyroid mass in adults (10 times that of infants) is the major factor influencing the ratio of the dose equivalent per unit intake for the young child to that for the adult.

The committed dose equivalent per unit intake of long-lived strontium-90 for the six-month-old child is about five times the adult value. However, for strontium-89, which has a much shorter half-life, the corresponding ratio lies in the range 20–40, depending on the "bone model" used for calculations.

The differences between children and adults in the biokinetics of radionuclides (and in the mass of organs and tissues) are reflected in organ dose factors. For an infant these range from 0.7 to 40 times the values for the adult.

Gastrointestinal absorption

Animal experiments have shown that the absorption of radionuclides from the gastrointestinal tract is higher in the newborn than in adults, but falls to adult values by about the time of weaning. Although the extent of absorption in the very young is dependent on the radionuclide considered, in general, the smaller the rate of gastrointestinal absorption in adults, the greater is the ratio of the rate in the newborn to that in the adult. If, for a six-month-old infant, the age-dependency of absorption of plutonium-239 from the gastrointestinal tract is taken into account, and the body-mass-dependent factor of 2 for long-retained radionuclides is applied, the committed dose equivalent per unit intake of dietary plutonium-239 is about 20 times that for the adult.

The dose per unit intake factors for calculating the Annual Limits on Intake given by ICRP (1979, 1980) are usually appropriate for the chemical forms of a radionuclide most likely to be encountered in the workplace. Chemical forms of the same radionuclide found in the environment, or in food, may differ markedly from these, and may therefore exhibit a different biokinetic behaviour. Other factors that may influence the absorption of radionuclides from the gastrointestinal tract are nutritional status, valence, and the presence of other elements in foodstuffs that could compete with transport mechanisms. Consequently, the dose equivalent per unit intake is liable to vary, especially if the absorption of the radionuclide in the upper gastrointestinal tract is enhanced, which will decrease the absorbed dose per unit intake to the large intestine.

Exposure of the fetus

ICRP has so far made no recommendations on methods to be used for calculating radiation doses to the fetus after intakes of radionuclides by the mother. A number of dosimetric models have been published for specific radionuclides. However, human data are available only for a few radionuclides such as caesium-137, strontium-90, and iodine-131.

In the case of intakes of iodine-131 by pregnant women, the value of the dose equivalent per unit intake for the fetal thyroid is of special concern. Before week 12 after conception, no iodine accumulation occurs in the fetal thyroid; therefore the dose per unit intake factor for iodine-131 before week 12 is comparable to that for maternal soft-tissue, which is orders of magnitude below that for the maternal thyroid. After the first trimester, the fetal thyroid gradually develops and increases in function, so that the dose per unit intake factor for the fetal thyroid is approximately half that for the maternal thyroid in the second trimester, and approximately equal to it towards the end of pregnancy.

Exposure of children

For the 10-year-old age group, the dose factors for caesium-134 and caesium-137 are lower than the adult values. The factors for strontium-90 and plutonium-239 are marginally higher than for the adult, but only to a degree that should be compensated for by the lower food consumption rates associated with the younger age group; that is, the smaller intake of radioactive contamination will balance out the higher dose per unit intake factors. For these four nuclides, therefore, derived intervention levels designed to protect adults will also protect the 10-year-old age group.

For iodine-131, however, the adult dose per unit intake factors are less than half of those for 10-year-olds, which in turn are lower than those for infants. The application of the derived intervention level for infants would give more than adequate protection not only to adults but also to the 10-year-old age group.

Conclusions

Except for a limited number of elements, such as strontium, iodine, and caesium, attempts to extend the "reference man" dosimetric and metabolic criteria to members of the general public are hampered by lack of information regarding the biokinetic behaviour of ingested or inhaled radionuclides. With some exceptions, a conservative approach, in the absence of relevant information on age-dependent biokinetics, is to use the metabolic data for the adult for the derivation of dose per unit intake factors.

The dose per unit intake factors for different radionuclides listed in Table 4 (page 25) are based on such considerations and on a review of the age-dependent dose per unit intake factors published by CEC, IAEA, the Institute for Radiation Hygiene, Federal Health Office, Federal Republic of Germany, and the National Radiological Protection Board, England. The values in Table 4 should be used when critical-group calculations are undertaken. For calculating guideline values for derived intervention levels for the general population, however, the two rounded-off dose per unit intake factors of 10^{-6} and 10^{-8} Sv/Bq have been used here (Table 5, page 26).

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SAMPLE CALCULATIONS OF DERIVED INTERVENTION LEVELS

The derived intervention levels presented in Table 5 (page 26) have been calculated on the basis of a single radionuclide in a single foodstuff leading to the intervention level of dose. The recommendation is made that, if more than one food category is affected, or if there are several radionuclides present, modified derived intervention levels should be calculated according to the additivity formula

$$\sum_i \sum_f \frac{C(i,f)}{DIL(i,f)} \leqq 1 \qquad (1)$$

where $C(i, f)$ is the activity concentration of nuclide i in foodstuff f and $DIL(i, f)$ is the derived intervention level calculated on the assumption that only nuclide i is present and only in foodstuff f. The effect of using the additivity formula is to control the radiation dose to individuals so that it does not exceed the intervention level of dose (5 mSv effective dose equivalent).

In any given situation there will be many ways of meeting the dose criterion. In this Annex a number of examples are given in which derived intervention levels are calculated for various combinations of radionuclide concentrations in several food categories. Before these situation-specific derived intervention levels (DIL^* values) can be calculated, the inequality in equation (1) needs to be transformed. It can be shown that, for a given set of contamination assumptions, the resulting DIL^* for nuclide i in foodstuff f will be

$$DIL^*(i,f) = \frac{g(i,f)}{\sum_i \sum_f \frac{g(i,f)}{DIL(i,f)}} \qquad (2)$$

where $g(i, f)$ is a function that represents the specific pattern of contamination. As $g(i, f)$ appears in both the numerator and the denominator of equation (2), it can be expressed simply in relative terms, i.e., as the ratio of activity concentrations found in different foodstuffs, or the ratio of activities of different radionuclides. This is illustrated in the examples below.

It should be emphasized that, although the results are presented with arithmetic accuracy, they should be rounded off before application, as in Example 1.

Example 1. Base case: all foodstuffs contaminated with caesium-137

In this case the total diet is taken to be contaminated with a single radionuclide, caesium-137, which has a dose per unit intake factor of 10^{-8} Sv/Bq. Food intake is taken as 550 kg per year, so that the DIL^* leading to 5 mSv is given by

$$5 \times 10^{-3} \text{ (Sv/year)} = 550 \text{ (kg/year)} \times DIL^* \text{ (Bq/kg)} \times 10^{-8} \text{ (Sv/Bq)}$$

$$\therefore \quad DIL^* = \frac{5 \times 10^{-3}}{550 \times 10^{-8}} \text{ Bq/kg}$$

$$DIL^* = 909 \text{ Bq/kg.}$$

Thus if all foodstuffs are uniformily contaminated with caesium-137, the specific derived intervention level can be taken as 1000 Bq/kg, which would also be applicable to any radionuclide or mixture of radionuclides whose dose per unit intake factor were 10^{-8} Sv/Bq.

Example 2. Two food categories contaminated with caesium-137

In this example it is assumed that caesium-137 has been found in two food categories, meat and milk. The general derived intervention levels for caesium-137 are (from Table 5, page 26):

meat	10 000	Bq/kg
milk	4500	Bq/kg.

For the first calculation it is assumed that the activity concentration found is the *same* in both meat and milk. The ratio of the $g(i,f)$ values for equation (2) can be taken as 1 for both milk and meat.

Thus for both milk and meat

$$DIL^* = \frac{1}{\frac{1}{10\,000} + \frac{1}{4500}} = 3103 \quad \text{Bq/kg.}$$

For the second calculation, it is assumed that the activity concentration in meat is four times that in milk. Thus the relative $g(i,f)$ for meat is 4 and that for milk is 1, which gives

$$DIL^*(meat) = \frac{4}{\frac{4}{10\,000} + \frac{1}{4500}} = 6429 \quad \text{Bq/kg}$$

$$DIL^*(milk) = \frac{1}{\frac{4}{10\,000} + \frac{1}{4500}} = 1607 \quad \text{Bq/kg.}$$

The *DIL** values from both calculations can be compared with the derived intervention levels quoted for milk and meat in Table 5 (page 26).

Example 3. Three food categories contaminated with one radionuclide

In this example it is assumed that meat, milk, and cereals are contaminated with caesium-137. The reference derived intervention levels from Table 5 (page 26) are:

meat	10 000	Bq/kg
milk	4500	Bq/kg.
cereals	3500	Bq/kg.

For the first application it is assumed that milk and cereals are contaminated at the same activity concentration of caesium-137 and that meat has twice that concentration. Thus the relative $g(i,f)$ values are:

meat	2
milk	1
cereals	1

and the *DIL** values are given by

$$DIL^*(meat) = \frac{2}{\frac{2}{10\,000} + \frac{1}{4500} + \frac{1}{3500}} = 2825 \quad \text{Bq/kg}$$

$$DIL^*(milk) = \frac{1}{\frac{2}{10\,000} + \frac{1}{4500} + \frac{1}{3500}} = 1412 \text{ Bq/kg.}$$

The *DIL*(cereal)* is 1412 Bq/kg because the same activity concentration was assumed as for milk.

If the relative activity concentrations are now given as:

meat	7
milk	2
cereal	1

the *DIL** values are

$$DIL^*(meat) = \frac{7}{\frac{7}{10\,000} + \frac{2}{4500} + \frac{1}{3500}} = 4895 \text{ Bq/kg}$$

$$DIL^*(milk) = \frac{2}{\frac{7}{10\,000} + \frac{2}{4500} + \frac{1}{3500}} = 1398 \text{ Bq/kg}$$

$$DIL^*(cereal) = \frac{1}{\frac{7}{10\,000} + \frac{2}{4500} + \frac{1}{3500}} = 699 \text{ Bq/kg.}$$

Restricting the activity concentrations of caesium-137 in these three foodstuffs to below these *DIL** levels would ensure that no individual received a dose of 5 mSv from intakes in the first year after the accident.

Example 4. One foodstuff contaminated with two radionuclides

In this example it is assumed that milk is the only foodstuff affected, but that both iodine-131 and caesium-137 are present. Calculations have been done for three ratios of activity concentration of iodine-131 to caesium-137:

(*a*) 10 : 1
(*b*) 3 : 1
and (*c*) 1 : 10.

This covers the range of possibilities from there being 10 times as much iodine-131 as caesium-137, to there being 10 times as much caesium-137 as iodine-131. The reference derived intervention levels are taken as 1600 Bq/l for iodine-131 (the value for infants) and 4500 Bq/l for caesium-137.

$$(a)\ DIL^*(I\text{-}131,\ milk) = \frac{10}{\frac{10}{1600} + \frac{1}{4500}} = 1545\ \text{Bq/l}$$

$$DIL^*(Cs\text{-}137,\ milk) = \frac{1}{\frac{10}{1600} + \frac{1}{4500}} = 155\ \text{Bq/l}$$

$$(b)\ DIL^*(I\text{-}131,\ milk) = \frac{3}{\frac{3}{1600} + \frac{1}{4500}} = 1430\ \text{Bq/l}$$

$$DIL^*(Cs\text{-}137,\ milk) = \frac{1}{\frac{3}{1600} + \frac{1}{4500}} = 477\ \text{Bq/l}$$

$$(c)\ DIL^*(I\text{-}131,\ milk) = \frac{1}{\frac{1}{1600} + \frac{10}{4500}} = 351\ \text{Bq/l}$$

$$DIL^*(Cs\text{-}137,\ milk) = \frac{10}{\frac{1}{1600} + \frac{10}{4500}} = 3512\ \text{Bq/l}$$

From these three examples it can be seen that for a given radionuclide the *DIL** value moves closer to the reference value as the nuclide becomes dominant in terms of activity concentration.

Example 5. Two foodstuffs contaminated with two radionuclides

Here the assumption is made that cereals and meat are contaminated by plutonium-239 and caesium-137 in different relative activity concentrations. Suppose that the relative activity concentrations are:

	Pu-239	Cs-137
meat	1	10 000
cereals	10	1000.

The reference derived intervention levels from Table 5 (page 26) are for meat: plutonium-239 100 Bq/kg, caesium-137 10 000 Bq/kg; and for cereals: plutonium-239 35 Bq/kg, caesium-137 3500 Bq/kg. Consequently

$$DIL^*(Pu\text{-}239,\ meat) = \frac{1}{\frac{1}{100} + \frac{10}{35} + \frac{1000}{3500} + \frac{10\,000}{10\,000}} = 0.63 \text{ Bq/kg}$$

$$DIL^*(Pu\text{-}239,\ cereals) = \frac{10}{\frac{1}{100} + \frac{10}{35} + \frac{1000}{3500} + \frac{10\,000}{10\,000}} = 6.3 \text{ Bq/kg}$$

$$DIL^*(Cs\text{-}137,\ meat) = \frac{10\,000}{\frac{1}{100} + \frac{10}{35} + \frac{1000}{3500} + \frac{10\,000}{10\,000}} = 6323 \text{ Bq/kg}$$

$$DIL^*(Cs\text{-}137,\ cereals) = \frac{1000}{\frac{1}{100} + \frac{10}{35} + \frac{1000}{3500} + \frac{10\,000}{10\,000}} = 632 \text{ Bq/kg.}$$

Finally, for relative activity concentrations of:

	Pu-239	Cs-137
meat	10	1000
cereals	1	100

the denominator in the equation is

$$\frac{1}{35} + \frac{10}{100} + \frac{100}{3500} + \frac{1000}{10\,000} = 0.257$$

and the resulting *DIL** values are (in Bq/kg):

	Pu-239	Cs-137
meat	39	3889
cereals	3.9	389.

Annex 5

WHO MEETINGS ON DERIVED INTERVENTION LEVELS

Working Group on Guideline Values for Derived Intervention Levels

Geneva, 6-9 April 1987

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Task Group on Guideline Values for Derived Intervention Levels

Geneva, 21–25 September 1987

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