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MINOR PARAMETERS NEEDED FOR INDIVIDUAL-DOSE CALCULATIONS:

Final Report for Tasks 7.1, 7.2, 8.1, 8.2, 9.1, 9.2, and 9.3

LR Anspaugh
BA Napier

October 2009

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MINOR PARAMETERS NEEDED FOR INDIVIDUAL-DOSE CALCULATIONS

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Final Report for Tasks 7.1, 7.2, 8.1, 8.2, 9.1, 9.2, and 9.3

US-Russian Joint Coordinating Committee on Radiation Effects Research
Project 1.4

Reconstruction of dose to the residents of Ozersk from Operation of the Mayak Production Association: 1948–2002

October 2009

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Minor Parameters Needed for Individual-Dose Calculations

This brief report documents the selection of parameters needed to support individual-dose calculations from ^{131}I released into the environment with gaseous effluents from the Mayak Production Association.

Age-dependent internal dose-conversion factors for ^{131}I

Normalized factors for converting inhaled or ingested radionuclides are presented in Tables 1 and 2. These were prepared using the computer code package DCAL (Eckerman et al. 2006). The factors are provided for six age groups (3 month, 1 year, 5 year, 10 year, 15 year, and adult). The inhalation factors are for the International Commission on Radiological Protection (ICRP)inhalation Class F. The set of dosimetric models is generally the same as that used in the ICRP's series of documents on doses to members of the public, as summarized in ICRP Publication 72 (1996). The biokinetic libraries used by DCAL include the latest ICRP model of the respiratory tract as described in ICRP Publication 66 (1994); the ICRP's gastrointestinal tract model first used in ICRP Publication 30 (1979); and the urinary bladder voiding model described in ICRP Publication 67 (1993). The nuclear decay library contains nuclear decay data currently used by the ICRP (1983) and the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine (Weber et al. 1989) and information on the energies and intensities of the radiations associated with spontaneous nuclear transformation. The photon specific absorbed fraction library is based on the data of Cristy and Eckerman (1987; 1993) as currently used by the ICRP. Organ masses for adults are taken from ICRP Publication 23 (Reference Man, ICRP 1975) and, for children, the values are taken from the phantoms of Cristy and Eckerman (1987; 1993), which are based on data from ICRP Publication 23.

The calculations for Tables 1 and 2 were made with the assumption that the ^{131}I decay progeny ^{131}Xe is rapidly eliminated from the human body with a transfer rate of 1000 day^{-1}. Uptake from gut to blood (f_1) is assumed to be 1.0 for all ages. Because the half-life of ^{131}I is short, these factors can be applied as annual (or even monthly) doses.

For use in stochastic calculations, each of these values is assumed to be the median of a lognormal distribution with a geometric standard deviation of 2.0 (Snyder et al. 1993).

Table 1. Ingestion committed absorbed dose coefficients (Gy Bq^{-1}) for ^{131}I.

	3 Month	1 Year	5 Year	10 Year	15 Year	20 Year
Adrenals	4.84E-10	3.39E-10	1.78E-10	1.06E-10	6.14E-11	5.06E-11
Bladder Wall	1.92E-09	1.51E-09	1.44E-09	1.17E-09	1.01E-09	7.57E-10
Bone Surfaces	6.19E-10	4.55E-10	2.89E-10	2.02E-10	1.46E-10	1.32E-10
Brain	5.29E-10	3.78E-10	2.49E-10	1.94E-10	1.52E-10	1.44E-10
Breast	5.69E-10	4.17E-10	2.32E-10	1.45E-10	7.30E-11	5.88E-11
GI-Tract						
St Wall	3.46E-09	1.98E-09	9.81E-10	5.66E-10	3.84E-10	3.04E-10
SI Wall	5.38E-10	3.61E-10	1.93E-10	1.12E-10	6.56E-11	5.39E-11
ULI Wall	1.72E-09	1.03E-09	4.49E-10	2.00E-10	1.13E-10	8.85E-11
LLI Wall	3.75E-09	2.15E-09	9.04E-10	3.77E-10	2.11E-10	1.62E-10
Kidneys	4.27E-10	2.90E-10	1.57E-10	8.91E-11	5.47E-11	4.60E-11
Liver	4.76E-10	3.33E-10	1.74E-10	9.97E-11	5.98E-11	4.89E-11
Respiratory Tract						
ET Region	5.55E-10	3.98E-10	2.60E-10	2.01E-10	1.56E-10	1.47E-10
Lung	7.25E-10	5.50E-10	3.28E-10	2.11E-10	1.26E-10	1.03E-10
Muscle	8.63E-10	6.58E-10	3.85E-10	2.53E-10	1.59E-10	1.27E-10
Ovaries	4.85E-10	3.31E-10	1.80E-10	1.03E-10	6.37E-11	5.22E-11
Pancreas	5.30E-10	3.69E-10	2.01E-10	1.22E-10	7.23E-11	6.10E-11
Red Marrow	5.14E-10	3.73E-10	2.22E-10	1.56E-10	1.16E-10	1.01E-10
Skin	4.75E-10	3.36E-10	1.80E-10	1.21E-10	8.13E-11	6.87E-11
Spleen	4.82E-10	3.35E-10	1.77E-10	1.10E-10	6.61E-11	5.36E-11
Testes	3.75E-10	2.52E-10	1.41E-10	8.11E-11	4.82E-11	4.04E-11
Thymus	2.26E-09	1.72E-09	8.45E-10	4.61E-10	2.24E-10	1.53E-10
Thyroid	3.66E-06	3.56E-06	2.06E-06	1.04E-06	6.81E-07	4.32E-07
G Bladder	4.87E-10	3.19E-10	1.75E-10	1.04E-10	5.78E-11	4.75E-11
Heart	7.00E-10	5.11E-10	2.72E-10	1.72E-10	9.01E-11	7.53E-11
Uterus	4.64E-10	3.22E-10	1.97E-10	1.15E-10	7.01E-11	5.91E-11

Table 2. Inhalation committed absorbed dose coefficients (Gy Bq^{-1}) for ^{131}I: Inhalation Type F; AMAD = 1 µm.

	3 Month	1 Year	5 Year	10 Year	15 Year	20 Year
Adrenals	1.96E-10	1.40E-10	6.39E-11	3.81E-11	1.99E-11	1.69E-11
Bladder Wall	7.51E-10	6.03E-10	5.08E-10	4.16E-10	3.30E-10	2.57E-10
Bone Surfaces	2.63E-10	1.98E-10	1.12E-10	7.84E-11	5.19E-11	4.87E-11
Brain	2.25E-10	1.64E-10	9.64E-11	7.60E-11	5.46E-11	5.40E-11
Breast	2.44E-10	1.83E-10	8.95E-11	5.58E-11	2.53E-11	2.11E-11
GI-Tract						
St Wall	5.94E-10	3.56E-10	1.50E-10	8.70E-11	4.77E-11	3.96E-11
SI Wall	1.88E-10	1.28E-10	5.99E-11	3.45E-11	1.83E-11	1.57E-11
ULI Wall	5.70E-10	3.39E-10	1.25E-10	5.06E-11	2.56E-11	2.04E-11
LLI Wall	1.20E-09	6.84E-10	2.37E-10	8.47E-11	4.12E-11	3.17E-11
Kidneys	1.69E-10	1.17E-10	5.57E-11	3.12E-11	1.74E-11	1.51E-11
Liver	1.91E-10	1.36E-10	6.22E-11	3.57E-11	1.96E-11	1.67E-11
Respiratory Tract						
ET Region	1.82E-08	1.48E-08	7.26E-09	4.43E-09	2.55E-09	2.15E-09
Lung	3.89E-10	3.01E-10	1.64E-10	1.11E-10	7.31E-11	5.96E-11
Muscle	3.83E-10	2.97E-10	1.52E-10	9.95E-11	5.68E-11	4.69E-11
Ovaries	1.85E-10	1.28E-10	6.10E-11	3.46E-11	1.95E-11	1.66E-11
Pancreas	2.02E-10	1.42E-10	6.69E-11	3.97E-11	2.08E-11	1.82E-11
Red Marrow	2.16E-10	1.60E-10	8.40E-11	5.97E-11	4.05E-11	3.69E-11
Skin	2.00E-10	1.45E-10	6.77E-11	4.62E-11	2.84E-11	2.50E-11
Spleen	1.90E-10	1.34E-10	6.12E-11	3.77E-11	2.03E-11	1.68E-11
Testes	1.47E-10	1.01E-10	4.95E-11	2.86E-11	1.57E-11	1.36E-11
Thymus	1.06E-09	8.15E-10	3.44E-10	1.85E-10	8.13E-11	5.72E-11
Thyroid	1.43E-06	1.43E-06	7.29E-07	3.70E-07	2.23E-07	1.47E-07
G Bladder	1.86E-10	1.25E-10	5.90E-11	3.48E-11	1.79E-11	1.54E-11
Heart	3.01E-10	2.24E-10	1.04E-10	6.54E-11	3.08E-11	2.68E-11
Uterus	1.80E-10	1.27E-10	6.81E-11	3.99E-11	2.23E-11	1.96E-11

Fetal thyroid-dose-conversion factors for ^{131}I

Ordinarily, our bias is to choose model results presented by the ICRP. However, in the case of uptake of radioiodine by the fetus that results from the ingestion or inhalation of radioiodine by the mother, we believe that the ICRP model is incorrect. The following explains our objections to the ICRP model and our choice of an alternate model due to Watson (1992). The latter model had previously been adopted by the NCRP (1998).

A number of models (Johnson 1982; Basic et al. 1988; Zanzonico and Becker 1991; Watson 1992; NCRP 1998; Berkovski 1999a,b; ICRP 2001) designed to provide dose coefficients for the case of dose to the fetal thyroid resulting from intake of ^{131}I by the mother were examined. The majority of these models are based on Johnson's model with further considerations of additional experimental data. The dependences of in utero fetal thyroid dose as a function of fetal age at the time of the mother's intake had a similar tendency for all models with the exception of the model presented by the ICRP, which was developed by Berkovski (see Fig. 1). As distinguished from the other models, the ICRP model shows a constant increase of dose coefficient versus fetal age. In addition, the increase of the dose coefficient at early fetal age in the range of 11 to 20 weeks after conception in the ICRP model is much less than that in the other models.

Also, a high value of 9% for fetal uptake of ^{131}I at term, which was used in the development of the ICRP model, was based on one pooled result in guinea pigs (Palmer and Preece 1998) rather than in the human fetus. Other authors (Evans et al. 1967; Stieve 1987) have reported substantially lower values for human fetal uptake in late gestation. The authors of many publications (Johnson 1982; Stieve 1987; Basic et al. 1988; Stabin et al. 1991; Zanzonico and Becker 1991; Watson 1992) concluded that although fetal uptake increases rapidly from the third month to term, the peak concentration of ^{131}I is reached at 20 to 24 weeks; thereafter it decreases, because the mass of the gland increases more rapidly than does the uptake. And, of course, the dose coefficient at the point of birth must be zero, as there is no time for the mother's intake to reach the fetus. In addition, the publications (Johnson 1982; Basic et al. 1988; Ng et al. 1991; Simon et al. 1990; Zanzonico and Becker 1991; Watson 1992) show more a rapid increase of dose coefficient versus fetal age in the range of 11 to 20 weeks compared to that in ICRP (2001). After analyzing data on the measurements of ^{131}I in 30 human fetal thyroids, Basic et al. (1988)

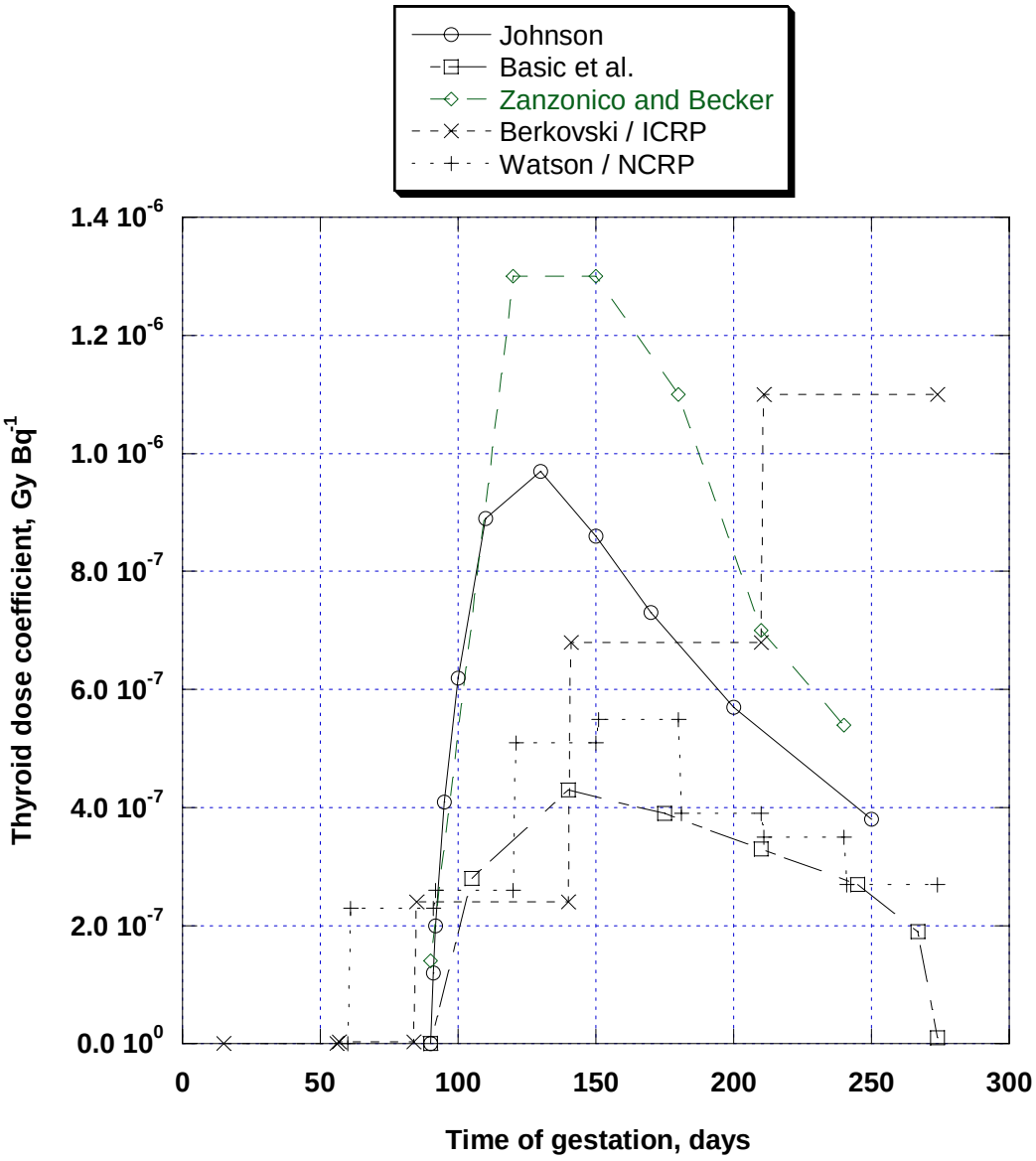

Fig. 1. The results of several models for the dose coefficient for the fetal thyroid resulting from the uptake of 131I by the mother as a function of time of gestation.

found that the maximum concentration of ^{131}I in human fetal thyroid was observed at about the fifth month of gestation with further substantial decrease.

Taking into account the information mentioned above and the inconsistency of the ICRP model with human data, we chose not to use the ICRP model. Rather we have chosen to use the model adopted by the NCRP (1998), which is based on the model of Watson (1992). We believe that the use of this model provides the best consistency with data from human feti. As indicated

in Fig. 1, however, this model is not a continuous function. In order to use the model for our purposes we have interpolated the values given by the NCRP; the results of these interpolations are given in Fig. 2 and in Table 3. The sharp decrease of the dose-coefficient near and at term is explained by the fact that, as term is approached, less and less of the iodine ingested by the mother can reach the fetus.

The values given can be considered as geometric means; a value of 2.2 is suggested for the value of the accompanying geometric standard deviation.

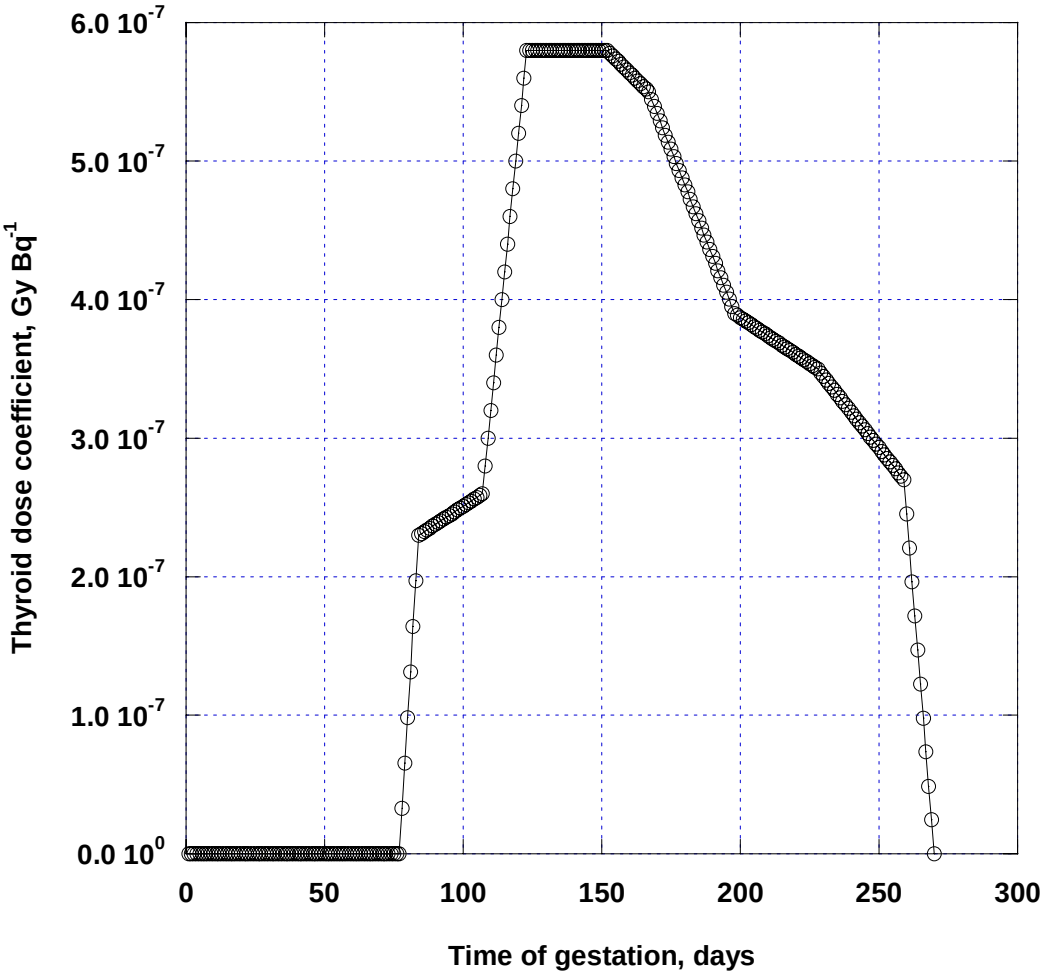

Fig. 2. Interpolated values of the Watson / NCRP (1998) model for dose coefficients of fetal thyroid dose resulting from intake by the mother.

Table 3. Interpolated values of dose coefficients for the fetal thyroid. The time is in days of gestation. The dose coefficient (DC) has units of Gy Bq-1 of intake by the mother.

Time	DC	Time	DC	Time	DC	Time	DC
<77	0.00E+00	118	4.80E-07	159	5.66E-07	200	3.87E-07
78	3.29E-08	119	5.00E-07	160	5.64E-07	201	3.86E-07
79	6.57E-08	120	5.20E-07	161	5.62E-07	202	3.85E-07
80	9.86E-08	121	5.40E-07	162	5.60E-07	203	3.83E-07
81	1.31E-07	122	5.60E-07	163	5.58E-07	204	3.82E-07
82	1.64E-07	123	5.80E-07	164	5.56E-07	205	3.81E-07
83	1.97E-07	124	5.80E-07	165	5.54E-07	206	3.79E-07
84	2.30E-07	125	5.80E-07	166	5.52E-07	207	3.78E-07
85	2.31E-07	126	5.80E-07	167	5.50E-07	208	3.77E-07
86	2.33E-07	127	5.80E-07	168	5.45E-07	209	3.75E-07
87	2.34E-07	128	5.80E-07	169	5.40E-07	210	3.74E-07
88	2.35E-07	129	5.80E-07	170	5.35E-07	211	3.73E-07
89	2.37E-07	130	5.80E-07	171	5.29E-07	212	3.71E-07
90	2.38E-07	131	5.80E-07	172	5.24E-07	213	3.70E-07
91	2.39E-07	132	5.80E-07	173	5.19E-07	214	3.69E-07
92	2.40E-07	133	5.80E-07	174	5.14E-07	215	3.67E-07
93	2.42E-07	134	5.80E-07	175	5.09E-07	216	3.66E-07
94	2.43E-07	135	5.80E-07	176	5.04E-07	217	3.65E-07
95	2.44E-07	136	5.80E-07	177	4.98E-07	218	3.63E-07
96	2.46E-07	137	5.80E-07	178	4.93E-07	219	3.62E-07
97	2.47E-07	138	5.80E-07	179	4.88E-07	220	3.61E-07
98	2.48E-07	139	5.80E-07	180	4.83E-07	221	3.59E-07
99	2.50E-07	140	5.80E-07	181	4.78E-07	222	3.58E-07
100	2.51E-07	141	5.80E-07	182	4.73E-07	223	3.57E-07
101	2.52E-07	142	5.80E-07	183	4.67E-07	224	3.55E-07
102	2.53E-07	143	5.80E-07	184	4.62E-07	225	3.54E-07
103	2.55E-07	144	5.80E-07	185	4.57E-07	226	3.53E-07
104	2.56E-07	145	5.80E-07	186	4.52E-07	227	3.51E-07
105	2.57E-07	146	5.80E-07	187	4.47E-07	228	3.50E-07
106	2.59E-07	147	5.80E-07	188	4.42E-07	229	3.47E-07
107	2.60E-07	148	5.80E-07	189	4.36E-07	230	3.45E-07
108	2.80E-07	149	5.80E-07	190	4.31E-07	231	3.42E-07
109	3.00E-07	150	5.80E-07	191	4.26E-07	232	3.40E-07
110	3.20E-07	151	5.80E-07	192	4.21E-07	233	3.37E-07
111	3.40E-07	152	5.80E-07	193	4.16E-07	234	3.35E-07
112	3.60E-07	153	5.78E-07	194	4.11E-07	235	3.32E-07
113	3.80E-07	154	5.76E-07	195	4.05E-07	236	3.29E-07
114	4.00E-07	155	5.74E-07	196	4.00E-07	237	3.27E-07
115	4.20E-07	156	5.72E-07	197	3.95E-07	238	3.24E-07
116	4.40E-07	157	5.70E-07	198	3.90E-07	239	3.22E-07
117	4.60E-07	158	5.68E-07	199	3.89E-07	240	3.19E-07

Table 3. (Concluded).

Time	DC	Time	DC	Time	DC	Time	DC
241	3.16E-07	249	2.96E-07	257	2.75E-07	264	1.47E-07
242	3.14E-07	250	2.93E-07	258	2.73E-07	265	1.23E-07
243	3.11E-07	251	2.91E-07	259	2.70E-07	266	9.82E-08
244	3.09E-07	252	2.88E-07	260	2.45E-07	267	7.36E-08
245	3.06E-07	253	2.85E-07	261	2.21E-07	268	4.91E-08
246	3.04E-07	254	2.83E-07	262	1.96E-07	269	2.45E-08
247	3.01E-07	255	2.80E-07	263	1.72E-07	270	0.00E+00
248	2.98E-07	256	2.78E-07				

Transfer of radioiodine to human-breast milk

Data on transfer of radioiodine into human milk are rare in the literature. Simon et al. (2002) evaluated data from sixteen publications to estimate the transfer coefficient (f_1^*), having units of d L^{-1}). The data on the radioiodine concentration in breast milk were analyzed by two methods: direct numerical integration and integration of a fitted exponential model. In general, the integrated fitted functions were greater and the fitted functions likely better describe the transfer into milk, because few data sets sampled mothers' milk near the time of maximum excretion. The derived transfer coefficient values seem to represent two populations. The first group was those individuals who had very low excretions, including those where thyroid and mammary uptakes were impaired by the administration of stable iodine or iodinated compounds. The second group included those with much higher excretions. The second group, termed the "normal-excretion" group, had transfers of iodine-to-milk that were more than ten-fold higher than in the "low-excretion" group. The derived milk-transfer-coefficient data for the low- and normal-excretion groups fitted to lognormal distributions gave geometric means, (geometric standard deviations), of 0.043 d L^{-1} (2.1, n = 14) and 0.37 d L^{-1} (1.5, n = 12). The value of 0.37 d L^{-1} with a GSD of 1.4 is recommended for use for individuals who have not had any iodine prophylaxis.

Various biologic and metabolic parameters have been considered as possibly important to the excretion of radioiodine via breast milk, one being the milk-production rate. However, the daily volume of milk produced by lactating women and ingested by infants averages over a narrow range, from about 750 to 800 mL d^{-1} (IOM 1991). This volume varies little among women with different caloric intakes, nutritional status, age, parity, and anthropometric indices though the volume of milk secreted declines

rapidly if suckling is discontinued. Thus, maternal milk-production rate is not a significant determinant of iodine transfer to milk.

Rate of consumption of breast milk by the infant

Based on the information above, the rate of consumption of breast milk by an infant should be taken as an uniform distribution of 750 to 800 mL day^{-1}.

Inhalation rates

It is well known that inhalation rates change substantially due to a variety of factors, which include age, weight, health, and activity level. The literature abounds with detailed data relating to each of these factors. However, our goal here is to provide an average-inhalation rate as a function of age and which is appropriate for application to monthly average values of airborne concentrations of ^{131}I. We have decided to adopt the values presented by Apostoaei (2005) for a similar type of assessment of dose from inhalation of ^{131}I; these values were based to a considerable extent on a report from the National Cancer Institute (NCI 1997) on dose from ^{131}I due to nuclear weapons fallout. The adopted values are shown in Table 4.

It is well to remember that inhalation is not one of the primary pathways of dose to man for ^{131}I; however, for a person who does not drink milk or eat fresh vegetables, it may be the only pathway of internal exposure. Thus, it would be necessary to include this pathway in any projected epidemiologic study of thyroid disease.

Table 4. Values of inhalation rates for use in assessing dose from the inhalation of ^{131}I. These values for lognormal distributions are adopted from those given by Apostoaei (2005).

Age	Geometric mean, m^3 day^{-1}	Geometric std. dev.
Newborn	3.5	1.4
1–4 y	7	1.4
5–9 y	12	1.4
10–14 y	17	1.4
15–19 y males	19	1.4
15–19 y females	18	1.4
Adult males	23	1.4
Adult females	18	1.4

Ratio of indoor air concentration-to-outdoor air concentration

There are not many simultaneous measurements of indoor and outdoor air concentrations of airborne radionuclides. A general rule of thumb has been that the ratio is about 0.5; this "lore" appears to be based more on supposition than on fact. As typical for the period of time of interest, there would not have been air conditioning in homes in Ozersk. And typically, Russian homes tend to be overheated in wintertime with regulation achieved by opening windows. Or, if homes are underheated, it is typically due to air exchange being higher than desirable. Thus, averaged over a month it seems likely that the ratio of indoor to outdoor concentration would have been closer to 1.0 rather than 0.5.

For use in this assessment, we have adopted the values given in Apostoaei (2005); the values are given in Table 5.

Table 5. Values to be used for the ratio of indoor-to-outdoor air concentration. Values given are for triangular distributions and are adopted from Apostoaei (2005).

Form of iodine	Ratio of indoor-to-outdoor concentration		
	Minimum	Mode	Maximum
Elemental	0.3	0.8	0.9
Organic	0.3	0.8	0.9
Particulate	0.4	0.8	0.9

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