WASH-1400
(NUREG 75/014)

CALCULATION OF REACTOR ACCIDENT CONSEQUENCES

APPENDIX VI
to
REACTOR SAFETY STUDY

U.S. NUCLEAR REGULATORY COMMISSION
OCTOBER 1975

WASH—1400
(NUREG-75/014)

Reactor Safety Study

An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants

Appendix VI

United States Nuclear Regulatory Commission

October 1975

The dosimetric model for the gastrointestinal tract is essentially that due to Eve (1966), insofar as the subdivisions of the tract and the transit times through the sections are concerned. Four subdivisions of the tract are defined: the stomach, S, the small intestine, SI, the upper large intestine, ULI, and the lower large intestine, LLI. The estimates of dose are considered to be averaged over these sections.

Dose is computed by the method described by Snyder et al. (1974). In calculating the dose from photons, the specific absorbed fractions presented in that report are used.

Strictly a beta particle is an electron that originates in the nucleus. To simplify calculations, all electrons, whether nuclear or not resulting from radioactive decay and low-energy photons are lumped with beta radiation. To allow for the attenuation of the beta radiation between the surface and the regenerative cells of the lower large intestine (LLI). the ratio of the dose at 500-micron depth to that at the surface of the wall is computed. Then the ratio of the "beta" dose to the total dose at the zero depth is computed for a 7-day dose. This allows calculation of a correction factor for shielding in the gastrointestinal tract. The results are listed in Table VI 8-4.

Absorption from the gastrointestinal tract to blood varies greatly from element to element. For a particular element it may also depend on the chemical form. The metabolic models for the various elements are discussed in detail in Appendix D. The results are summarized in Table VI 8-5.

8.4.2.2 Ingestion Model

Essentially the same model as for inhalation is used, with the obvious assumption that 100% of the radionuclides enter directly into the gastrointestinal tract and the residence time in the respiratory system is zero. Ingestion is considered as a pathway only for long-term, low-level activity present in the diet. The only radionuclides for which estimates of dose following ingestion are given are strontium-89, strontium-90, iodine-131, iodine-133, cesium-134, cesium-136, and cesium-137. The gastrointestinal dose calculations are performed in the way described in section 8.4.2.1.

8.4.3 CORRECTION FACTORS FOR CHILDREN

Because of differences in body mass, ingestion rates, breathing rates and metabolism between children and adults, there is a variation of dose absorbed with age. For photon emitters, the dose per disintegration is higher for adults than for infants and children, and it can vary greatly with photon energy. For beta and alpha particles the dose per disintegration is inversely proportional to organ mass and will show considerable variation with age. The ratio of doses per particle to organs of individuals of different ages are found to be just inversely proportional to their organ masses. This result is illustrated in Table VI 8-6. Note that for the very young the dose can increase by an order of magnitude over the dose to the adult. The ingestion and breathing rates of children are lower than for adults, but the child's metabolism is higher and this can lead to more rapid elimination of radioactive material. Although the geometric and metabolic factor will tend to cancel each other, one cannot ignore the effect of age.

To correct for the dose received by children a correction factor D_{ch}/D_{ad} is calculated, by which the calculated adult dose should be multiplied. In considering age effects, only the isotopes iodine-131, cesium-137, strontium-89, and strontium-90 are included. The details of the calculation are given in Appendix D. The correction ratios D_{ch}/D_{ad} are given in Table VI 8-7. The dose-correction factors can be multiplied by the ratio of the breathing rates to give the ratio of doses to the critical organ of a child and an adult exposed to the same radioactive cloud. For exposure by ingestion, they should be multiplied by the ratio of activities of these radionuclides in the total diet of the child and the adult. For inhalation, the exposure might be increased by a factor of 2 or 3.

TABLE VI 8-5 DOSE CONVERSION FACTORS FOR INGESTION OF RADIONUCLIDES[a]

	0-10 Yr	0-20 Yr	0-30 Yr	0-40 Yr	0-50 Yr
			Whole Body		
Cs-134	7.14×10^{4}	7.14×10^{4}	7.14×10^{4}	7.14×10^{4}	7.14×10^{4}
Cs-136	8.96×10^{3}	8.96×10^{3}	8.96×10^{3}	8.96×10^{3}	8.96×10^{3}
Cs-137	5.49×10^{4}	5.49×10^{4}	5.49×10^{4}	5.49×10^{4}	5.49×10^{4}
Sr-89	1.91×10^{3}	1.91×10^{3}	1.91×10^{3}	1.91×10^{3}	1.91×10^{3}
Sr-90	5.52×10^{4}	7.55×10^{4}	8.29×10^{4}	8.37×10^{4}	8.40×10^{4}
I-131	8.79×10^{2}	8.79×10^{2}	8.79×10^{2}	8.79×10^{2}	8.79×10^{2}
I-133	2.70×10^{2}	2.70×10^{2}	2.70×10^{2}	2.70×10^{2}	2.70×10^{2}
			Total Marrow		
Cs-134	7.34×10^{4}	7.34×10^{4}	7.34×10^{4}	7.34×10^{4}	7.34×10^{4}
Cs-136	9.29×10^{3}	9.29×10^{3}	9.29×10^{3}	9.29×10^{3}	9.29×10^{3}
Cs-137	5.61×10^{4}	5.61×10^{4}	5.61×10^{4}	5.61×10^{4}	5.61×10^{4}
Sr-89	5.26×10^{3}	5.26×10^{3}	5.26×10^{3}	5.26×10^{3}	5.26×10^{3}
Sr-90	2.08×10^{5}	2.61×10^{5}	2.74×10^{5}	2.84×10^{5}	2.[illegible]7 $\times 10^{5}$
I-131	2.87×10^{2}	2.87×10^{2}	2.87×10^{2}	2.87×10^{2}	2.87×10^{2}
I-133	1.48×10^{2}	1.48×10^{2}	1.48×10^{2}	1.48×10^{2}	1.48×10^{2}
			Bone (Mineral)		
Cs-134	7.24×10^{4}	7.24×10^{4}	7.24×10^{4}	7.24×10^{4}	7.24×10^{4}
Cs-136	9.10×10^{3}	9.10×10^{3}	9.10×10^{3}	9.10×10^{3}	9.10×10^{3}
Cs-137	5.56×10^{4}	5.56×10^{4}	5.56×10^{4}	5.56×10^{4}	5.56×10^{4}
Sr-89	1.19×10^{4}	1.19×10^{4}	1.19×10^{4}	1.19×10^{4}	1.19×10^{4}
Sr-90	6.15×10^{5}	8.72×10^{5}	9.70×10^{5}	1.08×10^{6}	1.08×10^{6}
I-131	3.10×10^{2}	3.10×10^{2}	3.10×10^{2}	3.10×10^{2}	3.10×10^{2}
I-133	1.46×10^{2}	1.46×10^{2}	1.46×10^{2}	1.46×10^{2}	1.46×10^{2}
			Thyroid		
Cs-134	7.33×10^{4}	7.33×10^{4}	7.33×10^{4}	7.33×10^{4}	7.33×10^{4}
Cs-136	9.23×10^{3}	9.23×10^{3}	9.23×10^{3}	9.23×10^{3}	9.23×10^{3}
Cs-137	5.55×10^{4}	5.55×10^{4}	5.55×10^{4}	5.55×10^{4}	5.55×10^{4}
Sr-89	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}
Sr-90	3.18×10^{3}	3.24×10^{3}	3.26×10^{3}	3.26×10^{3}	3.26×10^{3}
I-131	1.68×10^{6}	1.68×10^{6}	1.68×10^{6}	1.68×10^{6}	1.68×10^{6}
I-133	3.21×10^{5}	3.21×10^{5}	3.21×10^{5}	3.21×10^{5}	3.21×10^{5}
			Lung		
Cs-134	7.31×10^{4}	7.31×10^{4}	7.31×10^{4}	7.31×10^{4}	7.31×10^{4}
Cs-136	8.82×10^{3}	8.82×10^{3}	8.82×10^{3}	8.82×10^{3}	8.82×10^{3}
Cs-137	5.59×10^{4}	5.59×10^{4}	5.59×10^{4}	5.59×10^{4}	5.59×10^{4}
Sr-89	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}	5.81×10^{2}
Sr-90	3.18×10^{3}	3.72×10^{3}	3.74×10^{3}	3.74×10^{3}	3.74×10^{3}
I-131	3.56×10^{2}	3.56×10^{2}	3.56×10^{2}	3.56×10^{2}	3.56×10^{2}
I-133	1.58×10^{2}	1.58×10^{2}	1.58×10^{2}	1.58×10^{2}	1.58×10^{2}

Table VI 8-5 DOSE CONVERSION FACTORS FOR INGESTION OF RADIONUCLIDES[a] (CONTINUED)

	0-10 Yr	0-20 Yr	0-30 Yr	0-40 Yr	0-50 Yr
		Lower Large Intestine Wall			
Cs-134	9.33×10^4	9.33×10^4	9.33×10^4	9.33×10^4	9.33×10^4
Cs-136	1.35×10^4	1.35×10^4	1.35×10^4	1.35×10^4	1.35×10^4
Cs-137	6.64×10^4	6.64×10^4	6.64×10^4	6.64×10^4	6.64×10^4
Sr-89	8.53×10^4	8.53×10^4	8.53×10^4	8.53×10^4	8.53×10^4
Sr-90	8.12×10^4	8.12×10^4	8.12×10^4	8.12×10^4	8.12×10^4
I-131	1.91×10^3	1.91×10^3	1.91×10^3	1.91×10^3	1.91×10^3
I-133	1.82×10^2	1.82×10^2	1.82×10^2	1.82×10^2	1.82×10^2

(a) Rem per curie ingested.

TABLE VI 8-6 MASSES OF ADULT ORGANS AND RATIOS OF ORGAN MASSES OF REFERENCE MAN BY AGE

Organ	Organ Mass (g) for Adult	Ratio 15 yr	10 yr	5 yr	1 yr	Newborn
Kidneys	310	1.2	1.7	2.8	4.2	13
Liver	1800	1.5	2.1	3.1	5.6	14
Lungs	950	1.4	2.2	2.7	6.1	18
Ovaries	10.7	2.3	4.1	7.1	15.0	32
Skeleton	10^4	1.3	1.7	2.2	10.0	30
Testes	35	2.2	18.0	22.0	29.0	41
Thyroid	16	1.4	2.2	4.5	9.1	16
Total body	7×10^4	1.2	2.1	3.7	7.0	20