DOSIMETRY OF RADIOACTIVE IODINE WITH EMPHASIS ON IODINE-131 (^{131}I)

Steven L. Simon, Ph.D.
Radiation Epidemiology Branch
Division of Cancer Epidemiology and Genetics
National Cancer Institute

RADIATION EPIDEMIOLOGY COURSE
SPRING 2007

National Cancer Institute

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

There are 37 known isotopes of iodine. The isotopes of iodine have atomic masses (A=Z+N) from 108 to 144. All have Z=53!

All are unstable against radioactive decay except ^{127}I.

Examples of Iodine Isotopes: $^{123}_{53}I$, $^{124}_{53}I$, $^{125}_{53}I$, $^{126}_{53}I$, $^{127}_{53}I$, $^{128}_{53}I$, $^{129}_{53}I$, $^{130}_{53}I$, $^{131}_{53}I$, $^{132}_{53}I$

Why are radioiodine isotopes used in thyroid-related diagnostic and therapeutic procedures?

Iodine is one of the few nuclides that can target a specific organ by virtue of natural physiologic processes.

Examples of Iodine Isotopes: ${}^{123}_{53}\mathrm{I}$, ${}^{124}_{53}\mathrm{I}$, ${}^{125}_{53}\mathrm{I}$, ${}^{126}_{53}\mathrm{I}$, ${}^{127}_{53}\mathrm{I}$, ${}^{128}_{53}\mathrm{I}$, ${}^{129}_{53}\mathrm{I}$, ${}^{130}_{53}\mathrm{I}$, ${}^{131}_{53}\mathrm{I}$, ${}^{132}_{53}\mathrm{I}$

Which iodine isotopes are typically used?

Iodine-123 ($t_{1/2}$ = 2.3 hr): Used in diagnosis of thyroid function.

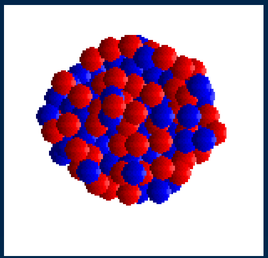
Iodine-125 ($t_{1/2}$ = 60 d): Used in cancer brachytherapy (prostate and brain), also diagnostically to evaluate the filtration rate of kidneys and to diagnose deep vein thrombosis in the leg; also used in radioimmuno-assays to show the presence of hormones in tiny quantities.

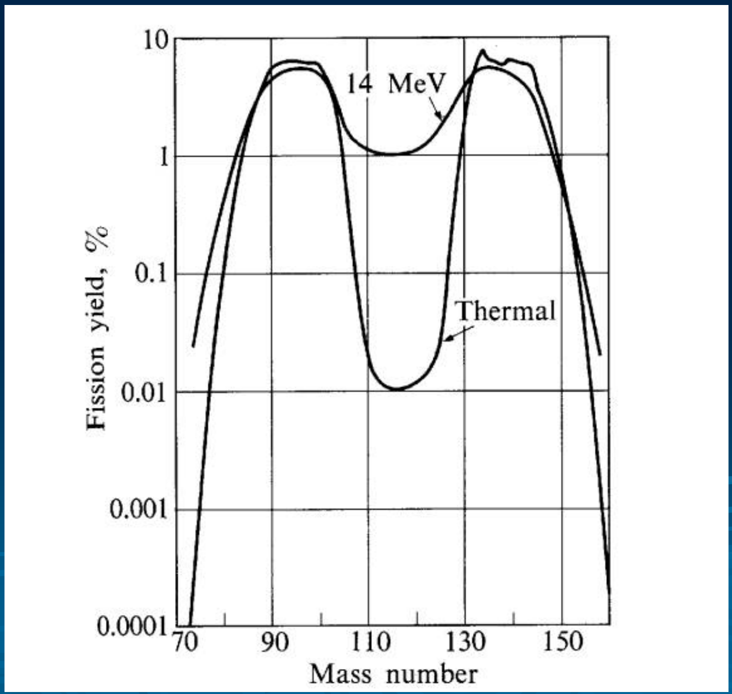
Iodine-131 ($t_{1/2}$ = 8 d): Widely used in treating thyroid cancer and hyperthyroidism; also in diagnosis of abnormal liver function, renal (kidney) blood flow and urinary tract obstruction.

Examples of Iodine Isotopes: ${}^{123}_{53}I$, ${}^{124}_{53}I$, ${}^{125}_{53}I$, ${}^{126}_{53}I$, ${}^{127}_{53}I$, ${}^{128}_{53}I$, ${}^{129}_{53}I$, ${}^{130}_{53}I$, ${}^{131}_{53}I$, ${}^{132}_{53}I$

Why are radioiodine isotopes used in associated with nuclear weapons fallout and nuclear reactor accidents?

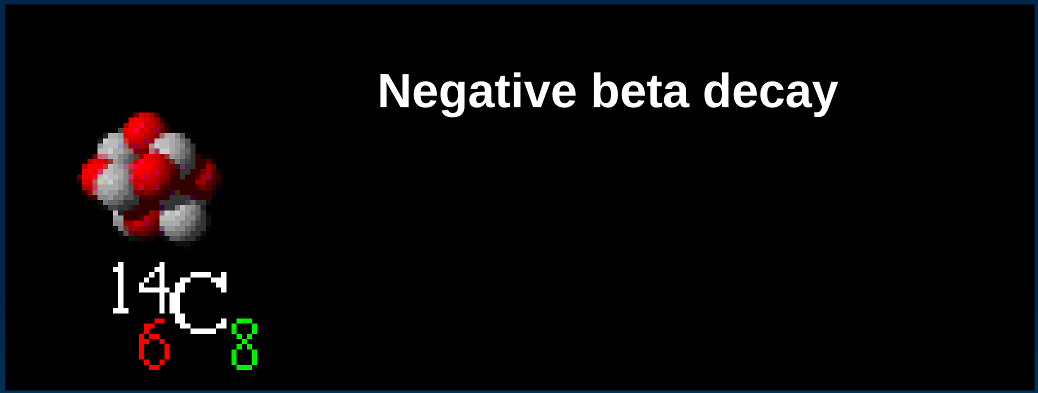
Nuclear fission of uranium (or plutonium) creates intermediate size mass products, primarily with masses of 90-100 and 130-140





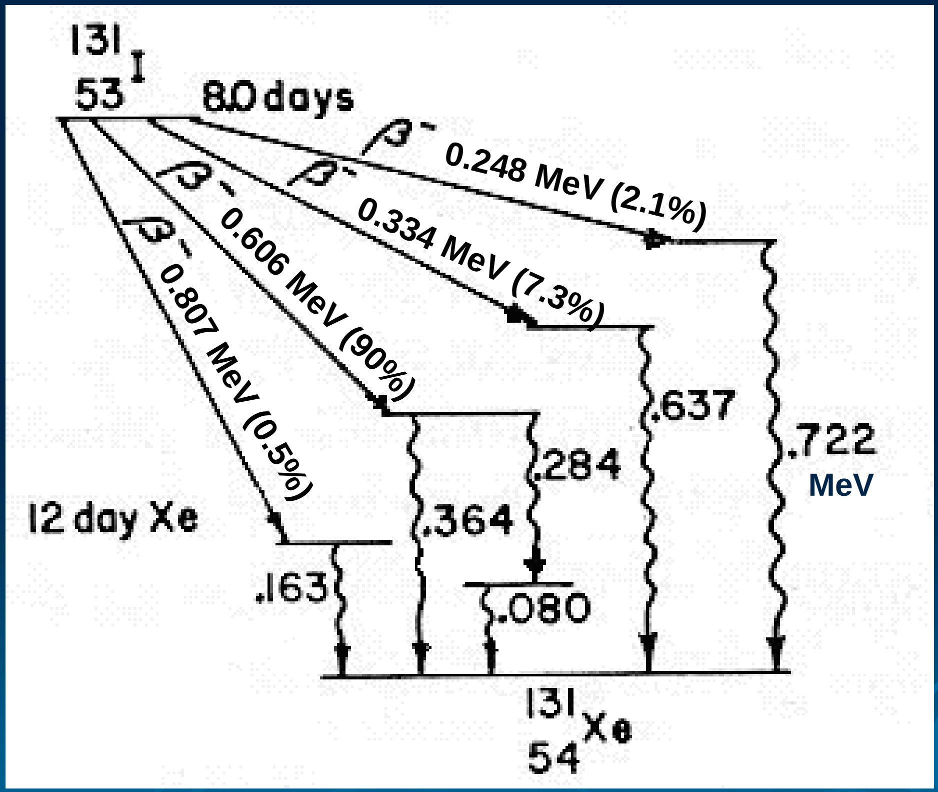
Most all of the iodine isotopes (except for a few meta-stable states) decay by positive or negative beta decay.

Reminder about negative beta decay: the decay of a neutron into a proton which remains in the nucleus, and an electron, which is emitted as a beta particle



For I-131, there are several beta-decay possibilities, each with their own probability of decay.

The energy released from β⁻ decay if I-131 is difference in the rest masses of iodine and its decay product, xenon. The most important parts of the I-131 decay scheme are shown below.



Beta Decays of ^{131}I (8.02 d)

E_β endpoint (keV)	I_β (%)	Decay mode
247.89	2.10	β^-
303.86	0.651	β^-
333.81	7.27	β^-
606.31	89.9	β^-
629.66	0.050	β^-
806.87	0.48	β^-

X-rays from ^{131}I (8.02 d)

E (keV)	I (%)	Assignment
4.11	0.215	Xe $L_{\alpha1}$
4.41	0.133	Xe $L_{\beta1}$
29.46	1.40	Xe $K_{\alpha2}$
29.78	2.59	Xe $K_{\alpha1}$
33.56	0.24	Xe $K_{\beta3}$
33.62	0.46	Xe $K_{\beta1}$
34.42	0.14	Xe $K_{\beta2}$

Gammas from ^{131}I (8.02)

Eγ (keV)	Iγ (%)	Decay mode
80.185	2.62	β^-
85.9	0.00009	β^-
163.93		β^-
177.21	0.270	β^-
232.18	0.0032	β^-
272.50	0.0578	β^-
284.31	6.14	β^-
295.8 *2*	0.0018	β^-
302.4 *2*	0.0047	β^-
318.09	0.0776	β^-
324.65	0.0212	β^-
325.79	0.274	β^-
358.4 *2*	0.016	β^-
364.49	81.7	β^-
404.81	0.0547	β^-
503.00	0.360	β^-
636.99	7.17	β^-
642.72	0.217	β^-
722.91	1.773	β^-

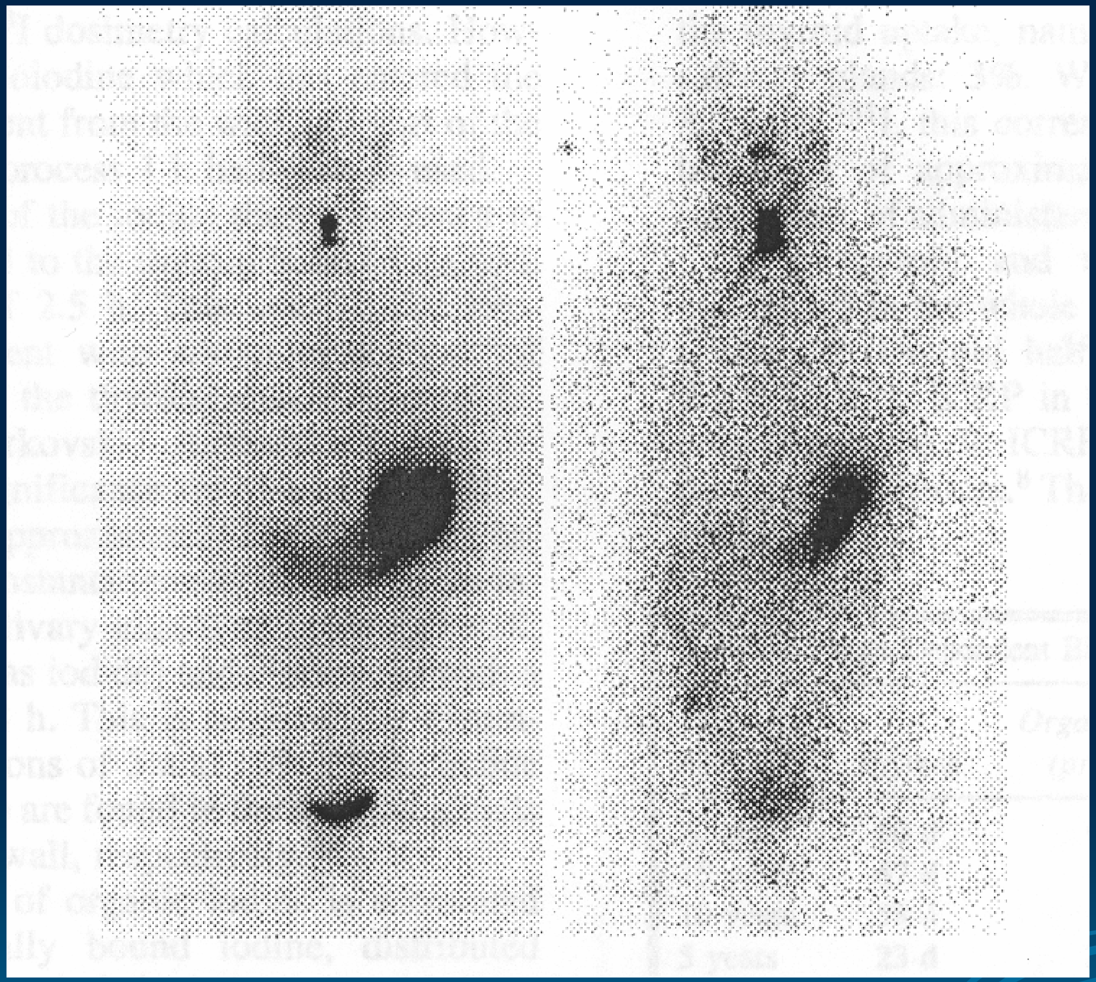
Whole-body nuclear medicine scan showing iodine gamma emissions

Salivary glands

thyroid

stomach

bladder



^{123}I ($t_{1/2}$=13.2 h) at 4 and 24 fhr after injection (158 keV γ)

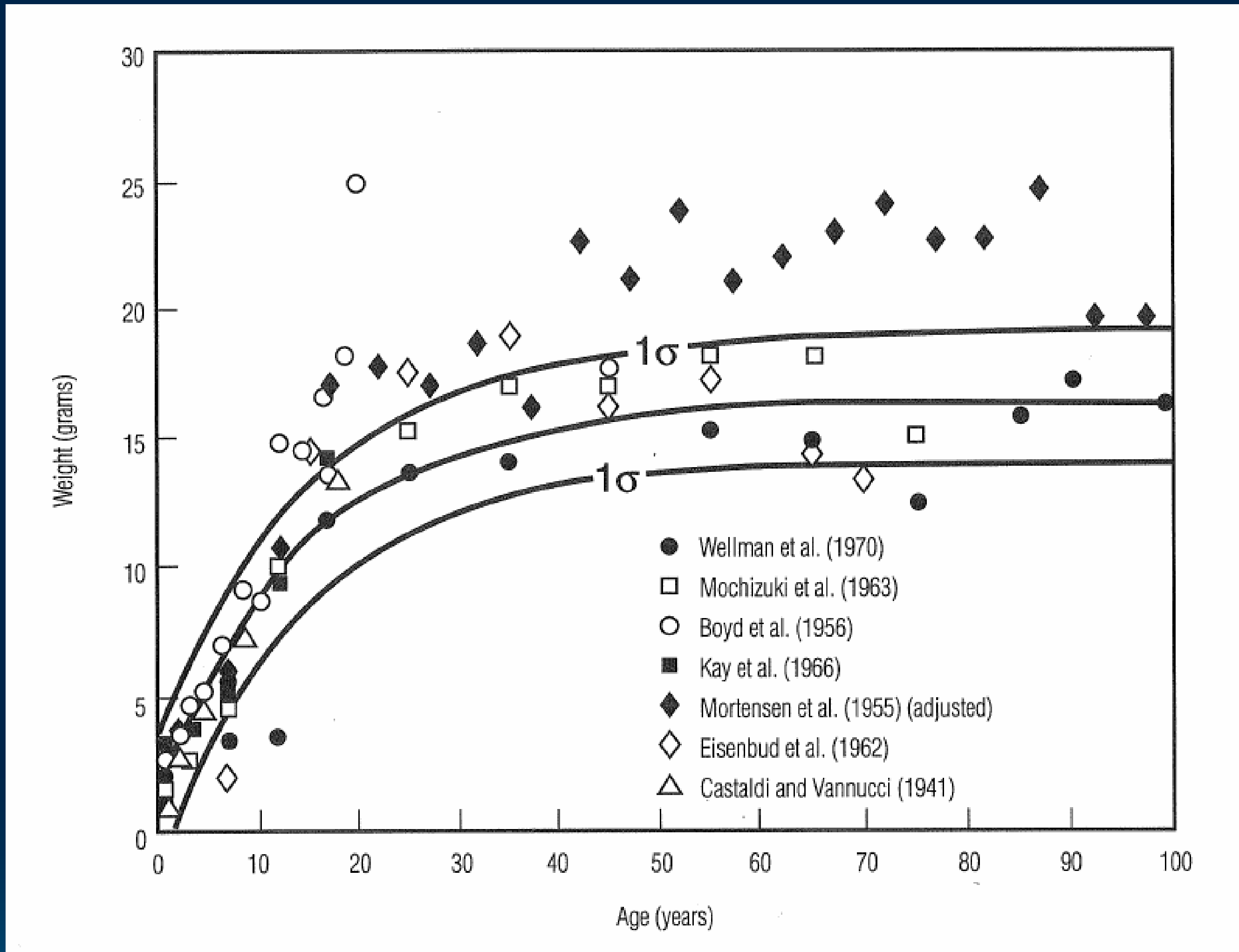
The general equation (shown yesterday) to determine the thyroid absorbed dose following an intake of ^{131}I is:

$$D = \int_0^{\infty} \frac{A\ f_1\ f_2\ R(t)}{M_T(a)} [\sum_{i=1}^{n} Y_i\ E_i\ AF_i(T \leftarrow S, a)]dt$$

Some typical assumptions that affect the estimated dose:

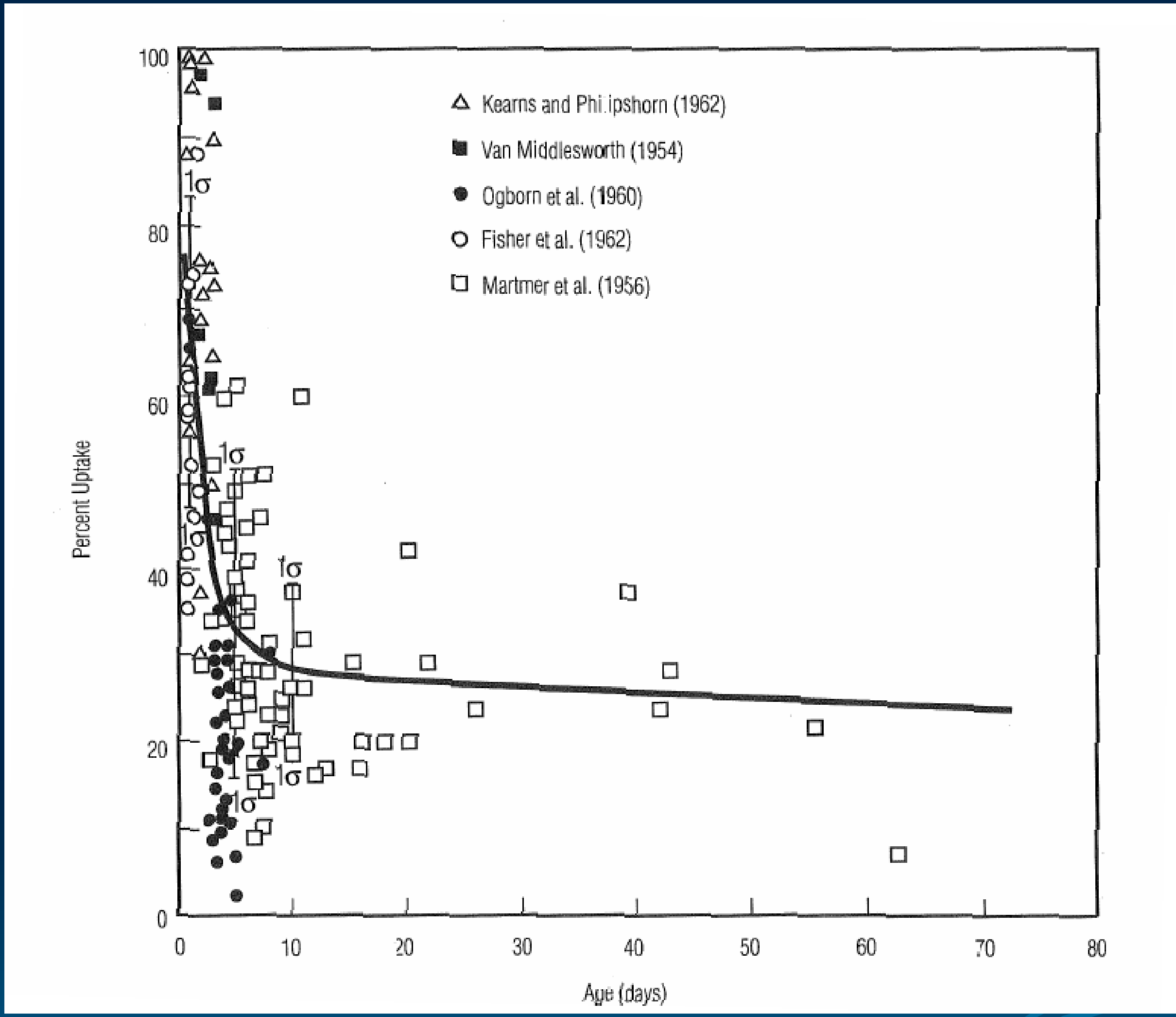
1) The kinetic energy of beta particles and photons <10 keV are fully absorbed in the target organ.
2) The fractional uptake by the gland is 25-30%, from age 3 mos. and afterwards.
3) Everyone has a normal inventory of stable iodine (^{127}I) in their thyroid which is about 10 mg for the adult.
4) In countries where stable iodine intake is low, a physiologically-based increase in thyroid mass usually occurs (sometimes resulting in goiters).
5) If stable iodine inventory is low, additional uptake of radioiodine may take place but is generally compensated by the increase in mass.
5) The retention of iodine in the thyroid gland follows a 2-component exponential loss. The "apparent" retention half-time in adults is assumed to be 80 days, and 15, 20, 30, 70 days for 3 months, 1 yr, 5 yr, 10yr old children, respectively.
6) Thyroid mass is predictable (though uncertain on an individual level) based on age alone.
7) Absorbed dose within the thyroid gland is moderately uniform.
8) Doses received by other organs from radioiodine are small compared to the thyroid.

Some of the data →



Thyroid gland mass increases with age and is one reason why absorbed dose decreases with age.

Figure from NCI (1997).



Thyroid uptake decreases immediately after birth.

Figure from NCI (1997).

In the dose equation, only R(t) has any time-dependence within the short half-life of 8 days. The age dependence arises from the $AF_i(T \leftarrow S,a)$ and $M_T(a)$.

Absorbed Dose (Gy) Received per Bq of ^{131}I Ingested for Selected Organs (ICRP 1989)

ORGAN	3 mos	1 Year	5 Year	10 Year	15 Year	Adult
Bladder wall	3.70E-10	2.40E-10	1.30E-10	7.30E-11	4.50E-11	3.80E-11
Breast	5.60E-10	4.10E-10	2.30E-10	1.50E-10	7.30E-11	5.80E-11
Stomach wall	3.40E-09	2.00E-09	9.80E-10	5.6E-10	3.80E-10	3.00E-10
Liver	4.60E-10	3.20E-10	1.70E-10	9.8E-11	5.90E-11	4.70E-11
Ovaries	3.90E-10	2.70E-10	1.40E-10	7.80E-11	4.70E-11	4.00E-11
Testes	3.40E-10	2.30E-10	1.10E-10	6.60E-11	4.00E-11	3.40E-11
Thymus	2.30E-09	1.70E-09	8.50E-10	4.70E-10	2.30E-10	1.50E-10
Thyroid	3.70E-06	3.60E-06	2.10E-06	1.10E-06	6.90E-07	4.40E-07

Note: these values, while are useful for clinical applications, are only for a typical person.

Note: The **true** thyroid absorbed dose received an individual is not only a function of the administered activity, but also a function of:

- Individual biokinetics (function of health status), and
- Amount of stable iodine in the diet.

What are typical therapeutic dosages of I-131 and typical absorbed doses?

Treatment of hyperthyroidism:

Dosages of 200 to 500 MBq

Target absorbed doses of ~70 Gy

Destruction of tumor remnants after incomplete tumor surgery:

Dosages of 1 to 10 GBq (10^9 Bq)

Target absorbed doses of >400 Gy

Though I will not discuss doses from I-131 in fallout, if you were born in the U.S. before 1951, you might be interested to estimate your dose from radioactive fallout:

http://ntsi131.nci.nih.gov/