INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

H4.SMR/773-14

College on Medical Physics:
Radiation Protection and Imaging Techniques

5 - 23 September 1994

Patient Doses in Nuclear Medicine

S. Mattsson

Department of Radiation Physics
Lund University
Malmö University Hospital
Malmö, Sweden

Objectives for internal dosimetry of radiopharmaceuticals

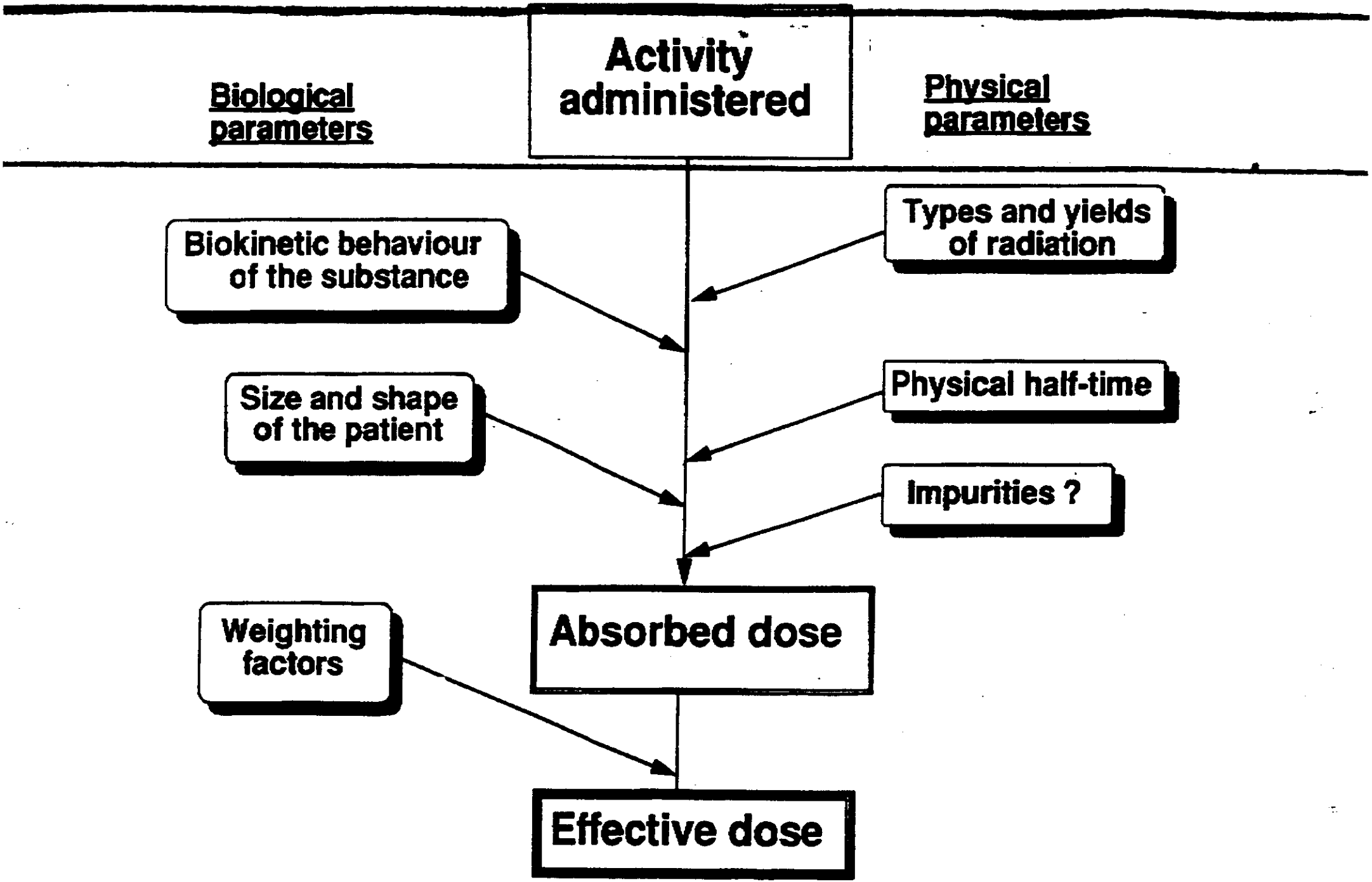
Diagnostics

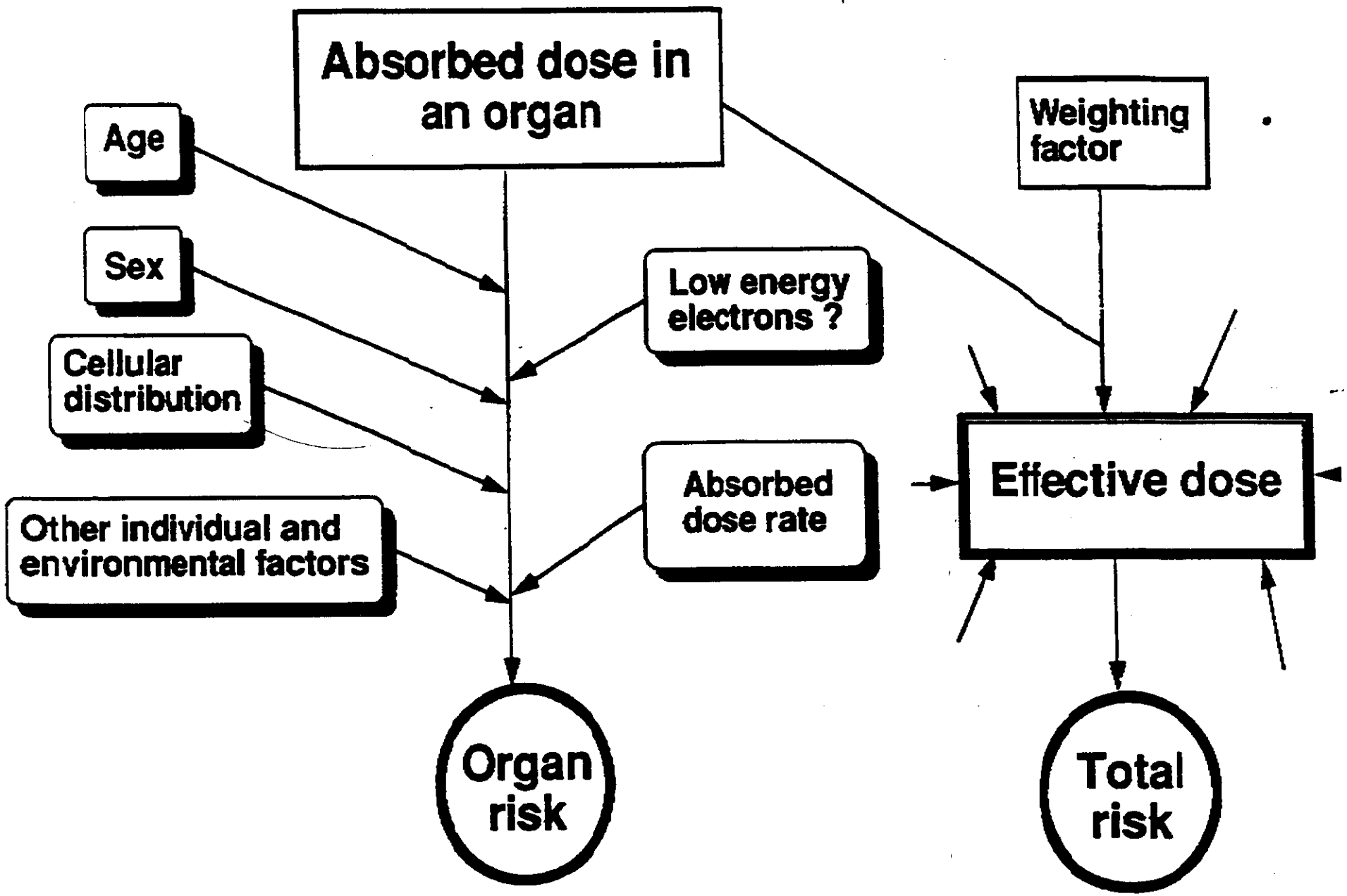
For comparison between different diagnostic methods in terms of *radiation risk.*

Population dose estimates

Therapy

Individual *dose planning*


Activity administered
Biological parameters
Physical parameters
Biokinetic behaviour of the substance
Size and shape of the patient
Types and yields of radiation
Physical half-time
Impurities ?
Weighting factors
Absorbed dose
Effective dose


Absorbed dose in an organ
Age
Sex
Cellular distribution
Other individual and environmental factors
Low energy electrons ?
Absorbed dose rate
Weighting factor
Effective dose
Organ risk
Total risk

Internal dosimetry
1948 - 1991

Marinelli 1948	geometrical factor
Loevinger 1956	point kernels
Ellet 1964	absorbed fractions for simple geometrical shapes
1965	Monte-Carlo calculations
Snyder 1969	absorbed fractions, MIRD phantom
1975	S - values
Cristy 1987	absorbed fractions for children

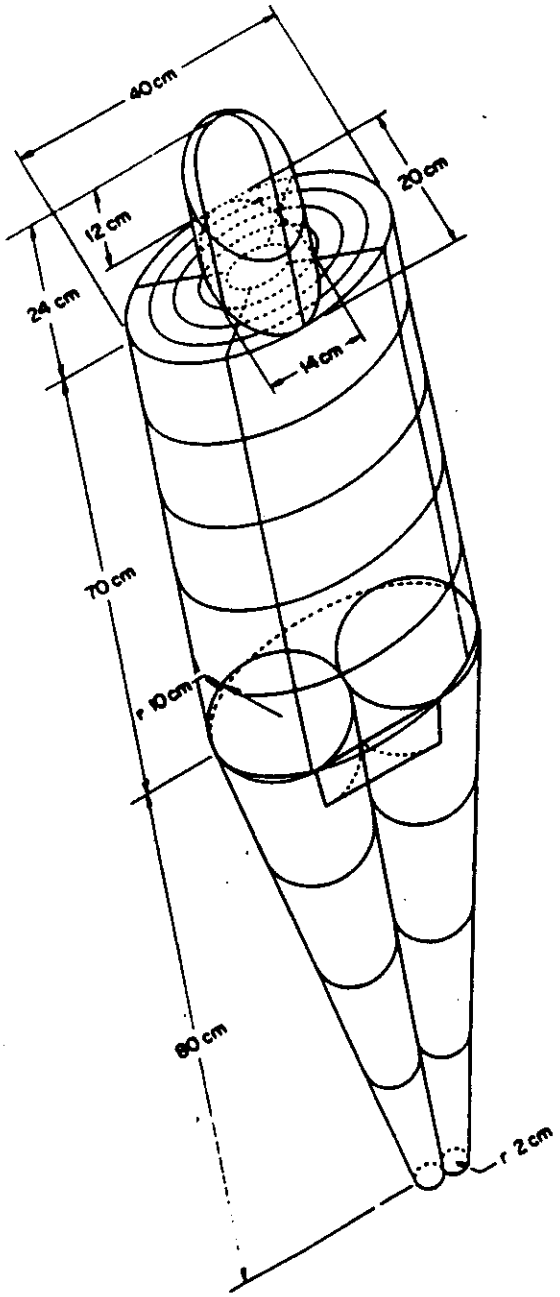
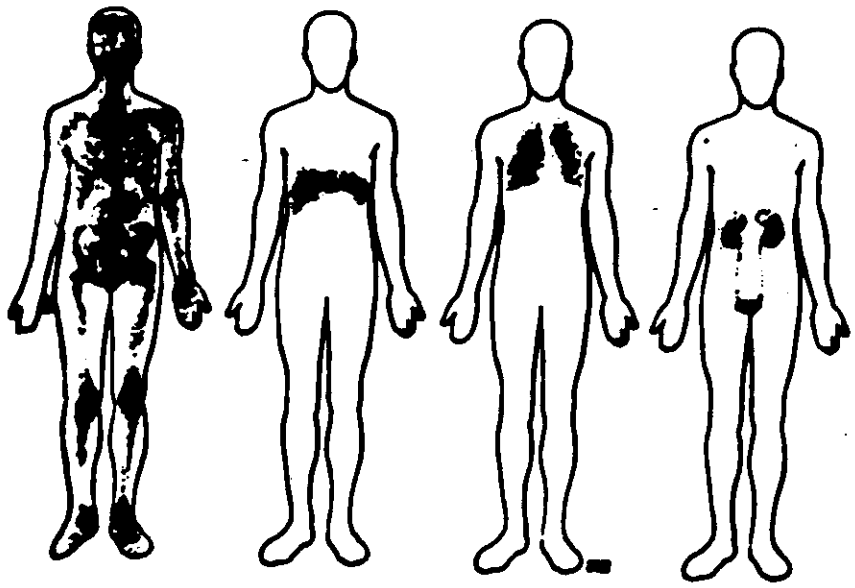


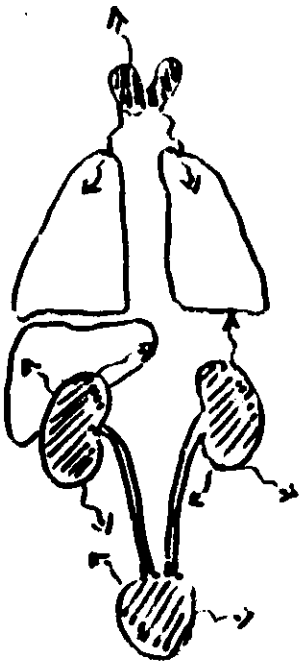
Figure 2. Reference Man showing the finite dimensions of the head, body and legs as used for the MIRD estimations.

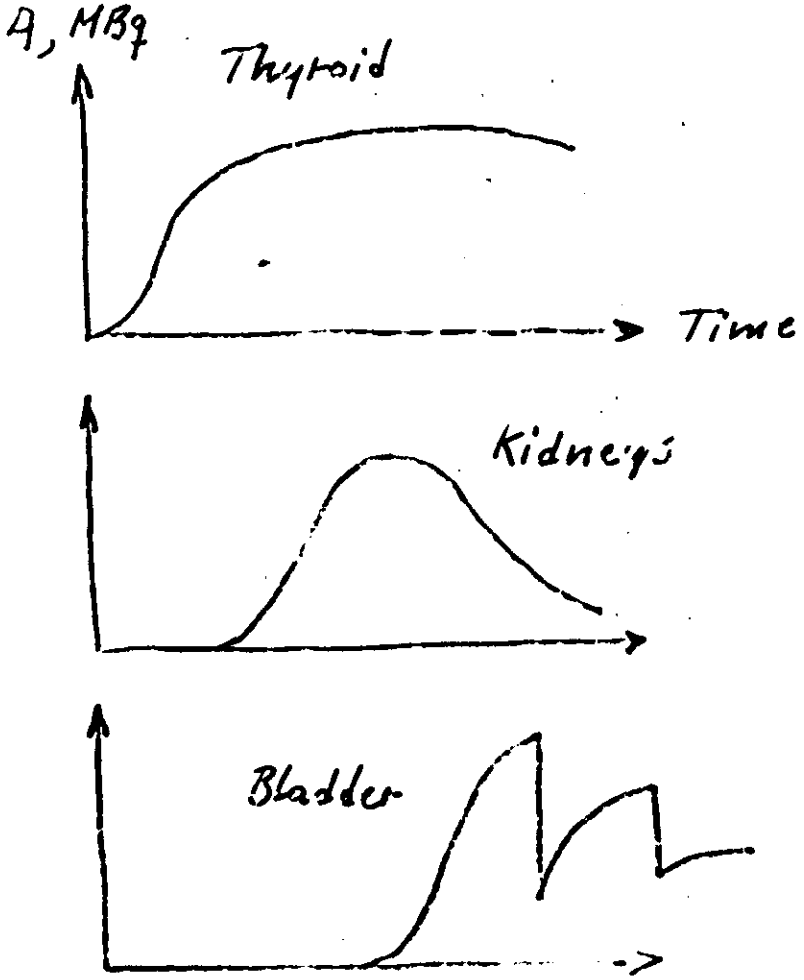
70 kg hermefrodite

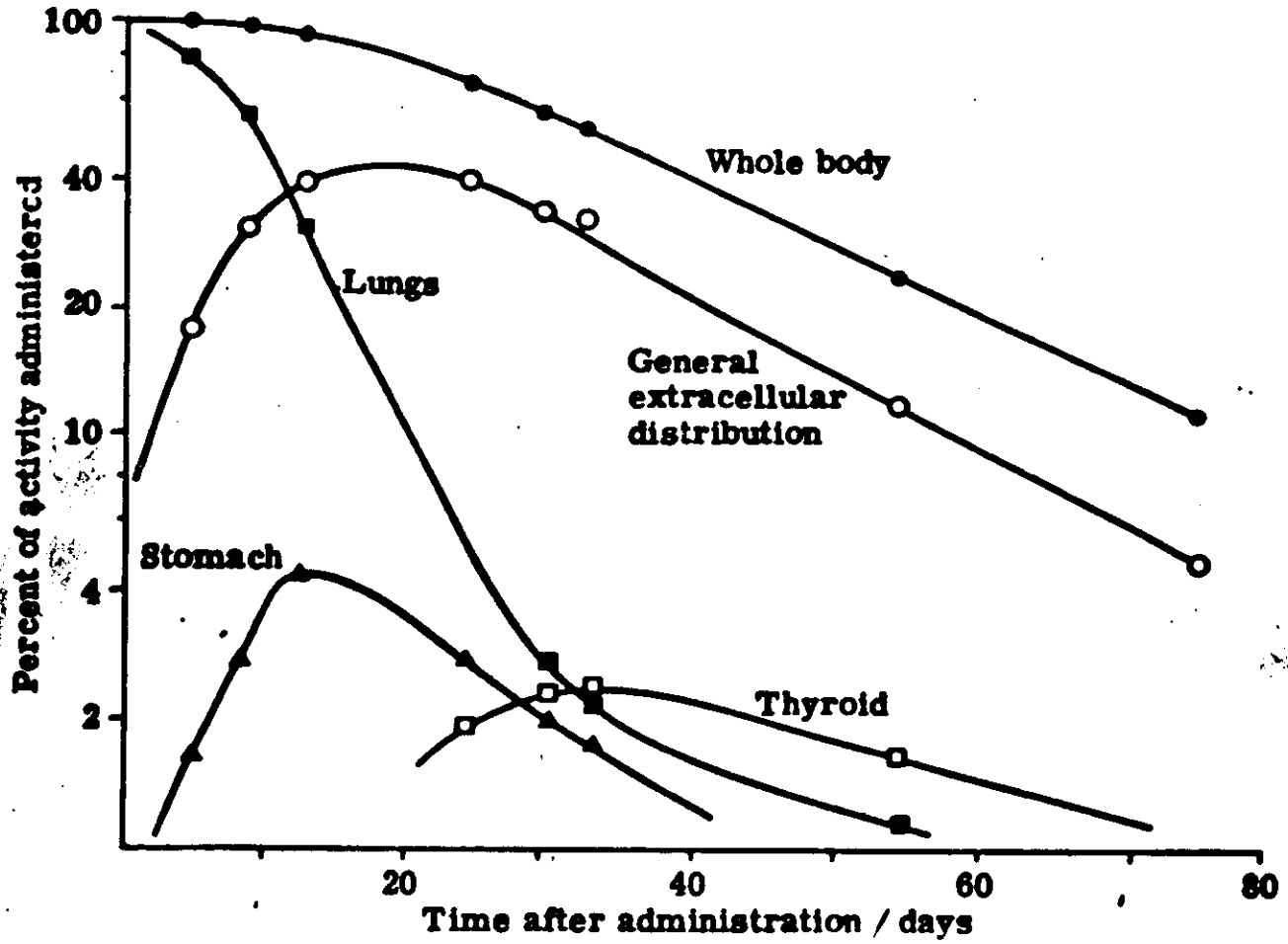
PATIENTSTRÅLDOSER



^{99m}Tc: MDP kolloid MAA DTPA

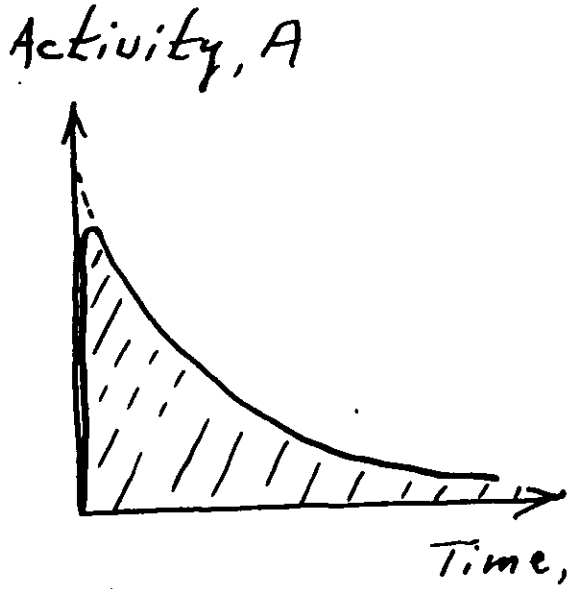



A, MBq
Thyroid
Time
Kidneys
Bladder


100
40
20
10
4
2
Percent of activity administered
Whole body
Lungs
General
extracellular
distribution
Stomach
Thyroid
20
40
60
80
Time after administration / days

^{131}I - MAA , iv.

$\tilde{A}$ – cumulated activity



In the simplest case:

$$\tilde{A}(0,\infty) = \int_0^\infty A(0)\, e^{-\lambda_{eff} t}\, dt = A(0)\frac{1}{\lambda}$$

$$\lambda_{eff} = \frac{0{,}693}{T_{eff}}$$

$$\tilde{A}(0,\infty) = 1{,}44 \cdot A(0) \cdot T_{eff}.$$

MIRD (Medical Internal Radiation Dose Committee)

Mean absorbed dose in a target organ T from a radionuclide, which is uniformly distributed in a source organ

$$\bar{D}(T \leftarrow S) = \tilde{A}_S \cdot \mathcal{S}(T \leftarrow S)$$

Cumulated activity in source organ S:

Mean absorbed dose per unit cumulated activity

$$\tilde{A}_S = \int A_S(t)\,dt$$

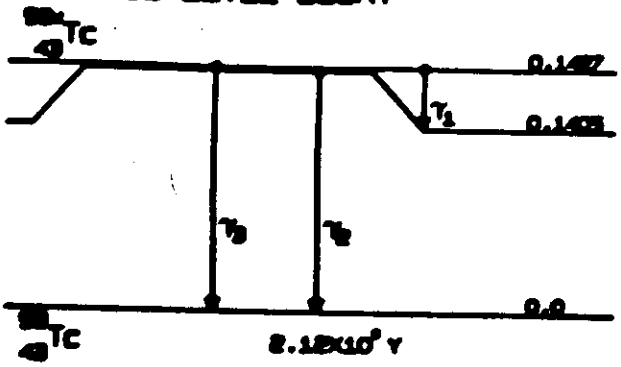
$$\mathcal{S}(T \leftarrow S) = \sum \Delta_i \frac{\phi_i(T \leftarrow S)}{m}$$

mass of target organ

Mean emitted radiation energy per unit cumulated activity for radiation of type i

Absorbed fraction in target organ T of radiation energy which is emitted by radiation of type i from source organ S

TECHNETIUM-99M
ISOMERIC LEVEL DECAY



Δi

--INPUT DATA--

43 TECHNETIUM 99M HALF LIFE = 6.03 HOURS

DECAY MODE- ISOMERIC LEVEL

TRANSITION		MEAN NUMBER/ DISINTE- GRATION	TRANSITION ENERGY (MEV)	OTHER NUCLEAR DATA
GAMMA	1	0.9060	0.0021	E1
GAMMA	2	0.9060	0.1405	M1, AR= 0.104 E/L= 7.70
GAMMA	3	0.0140	0.1426	M4, AR=21.0 ALFT = 0.21

REF.- LEDERER, C.M. ET AL. TABLE OF ISOTOPES, 6TH ED.
LEDERER, J. ET AL. INT. J. APPL. RAD. AND ISOTOPES 21, 190 119701.

--OUTPUT DATA--

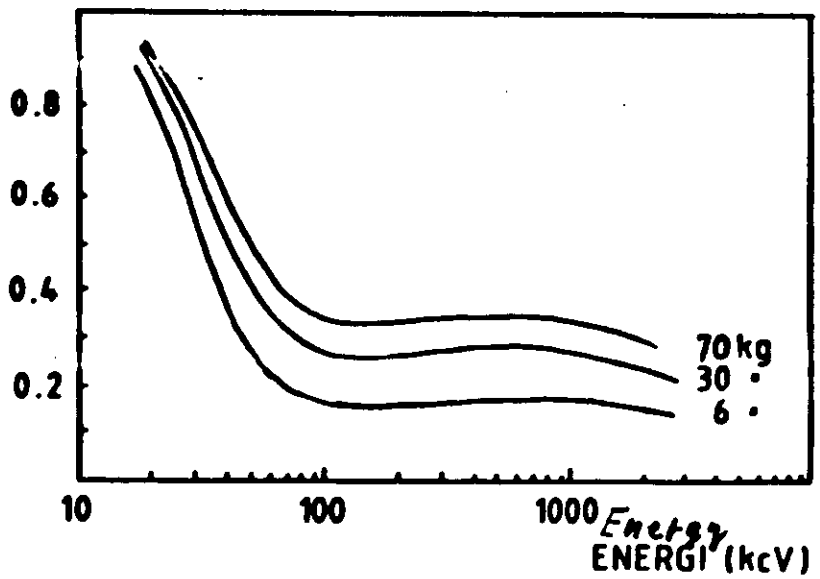
43 TECHNETIUM 99M HALF LIFE = 6.03 HOURS

DECAY MODE- ISOMERIC LEVEL

RADIATION		MEAN NUMBER/ DISINTE- GRATION n_i	MEAN ENERGY/ PAR- TICLE E_i (MeV)	EQUI- LIBRIUM DOSE CONSTANT Δ_i (g-rad/ μCi-h)
	GAMMA 1	0.0000	0.0021	0.0000
P INT CON	ELECT	0.9060	0.0016	0.0035
	GAMMA 2	0.8707	0.1405	0.7630
K INT CON	ELECT	0.0913	0.1194	0.0232
L INT CON	ELECT	0.0110	0.1377	0.0034
M INT CON	ELECT	0.0029	0.1400	0.0011
	GAMMA 3	0.0003	0.1426	0.0001
K INT CON	ELECT	0.0060	0.1215	0.0022
L INT CON	ELECT	0.0035	0.1390	0.0010
M INT CON	ELECT	0.0011	0.1422	0.0003
K ALPHA-1	X-RAY	0.0441	0.0183	0.0017
K ALPHA-2	X-RAY	0.0221	0.0182	0.0008
K BETA-1	X-RAY	0.0105	0.0206	0.0004
KLL AUGER	ELECT	0.0152	0.0194	0.0005
KLX AUGER	ELECT	0.0055	0.0178	0.0002
LMM AUGER	ELECT	0.1093	0.0019	0.0004
MXY AUGER	ELECT	1.2390	0.0004	0.0011

Penetrating radiation

Absorbed fraction
ABSORBERAD FRAKTION, ϕ_i (hela kroppen ← hela kroppen)



Den absorberade fraktionen av γ-strålning
för några olika kroppsvikter som funktion av foton-

S

S, ABSORBED DOSE PER UNIT CUMULATED ACTIVITY, (RAD/UCI-H)
TECHNETIUM-99M HALF-LIFE 6.03 HOURS

TARGET ORGANS	SOURCE ORGANS: ADRENALS	BLADDER CONTENTS	INTESTINAL TRACT: STOMACH CONTENTS	INTESTINAL TRACT: SI CONTENTS	INTESTINAL TRACT: ULI CONTENTS	INTESTINAL TRACT: LLI CONTENTS	KIDNEYS	LIVER	LUNGS	OTHER TISSUE (MUSCLE)
ADRENALS	3.1E-03	1.5E-07	2.7E-06	1.0E-06	9.1E-07	3.6E-07	1.1E-05	4.5E-06	2.7E-06	1.4E-06
BLADDER WALL	1.3E-07	1.6E-04	2.7E-07	2.6E-06	2.2E-06	6.9E-06	2.8E-07	1.6E-07	3.6E-08	1.8E-06
BONE (TOTAL)	2.0E-06	9.2E-07	9.0E-07	1.3E-06	1.1E-06	1.6E-06	1.4E-06	1.1E-06	1.5E-06	9.8E-07
GI (STOM WALL)	2.9E-06	2.7E-07	1.3E-04	3.7E-06	3.8E-06	1.8E-06	3.6E-06	1.9E-06	1.8E-06	1.3E-06
GI (SI)	8.3E-07	3.0E-06	2.7E-06	7.8E-05	1.7E-05	9.4E-06	2.9E-06	1.6E-06	1.9E-07	1.5E-06
GI (ULI WALL)	9.3E-07	2.2E-06	3.5E-06	2.4E-05	1.3E-04	4.2E-06	2.9E-06	2.5E-06	2.2E-07	1.6E-06
GI (LLI WALL)	2.2E-07	7.4E-06	1.2E-06	7.3E-06	3.2E-06	1.9E-04	7.2E-07	2.3E-07	7.1E-08	1.7E-06
KIDNEYS	1.1E-05	2.6E-07	3.5E-06	3.2E-06	2.8E-06	8.6E-07	1.9E-04	3.9E-06	8.4E-07	1.3E-06
LIVER	4.9E-06	1.7E-07	2.0E-06	1.8E-06	2.6E-06	2.5E-07	3.9E-06	4.6E-05	2.5E-06	1.1E-06
LUNGS	2.4E-06	2.4E-08	1.7E-06	2.2E-07	2.6E-07	7.9E-08	8.5E-07	2.5E-06	5.2E-05	1.3E-06
MARROW (RED)	3.6E-06	2.2E-06	1.6E-06	4.3E-06	3.7E-06	5.1E-06	3.8E-06	1.6E-06	1.9E-06	2.0E-06
OTH TISS (MUSC)	1.4E-06	1.8E-06	1.4E-06	1.5E-06	1.5E-06	1.7E-06	1.3E-06	1.1E-06	1.3E-06	2.7E-06
OVARIES	6.1E-07	7.3E-06	5.0E-07	1.1E-05	1.2E-05	1.8E-05	1.1E-06	4.5E-07	9.4E-08	2.0E-06
PANCREAS	9.0E-06	2.3E-07	1.8E-05	2.1E-06	2.3E-06	7.4E-07	6.6E-06	4.2E-06	2.6E-06	1.8E-06
SKIN	5.1E-07	5.5E-07	4.4E-07	4.1E-07	4.1E-07	4.8E-07	5.3E-07	4.9E-07	5.3E-07	7.2E-07
SPLEEN	6.3E-06	6.6E-07	1.0E-05	1.5E-06	1.4E-06	8.0E-07	8.6E-06	9.2E-07	2.3E-06	1.4E-06
TESTES	3.2E-08	4.7E-06	5.1E-08	3.1E-07	2.7E-07	1.8E-06	8.8E-08	6.2E-08	7.9E-09	1.1E-06
THYROID	1.3E-07	2.1E-09	8.7E-08	1.5E-08	1.6E-08	5.4E-09	4.8E-08	1.5E-07	9.2E-07	1.3E-06
UTERUS (NONGRVD)	1.1E-06	1.6E-05	7.7E-07	9.6E-06	5.4E-06	7.1E-06	9.4E-07	3.9E-07	8.2E-08	2.3E-06
TOTAL BODY	2.2E-06	1.9E-06	1.9E-06	2.4E-06	2.2E-06	2.3E-06	2.2E-06	2.2E-06	2.0E-06	1.9E-06

DECAY DATA REVISED-MARCH, 1972. REFERENCE-MIRD PAMPHLET NO. 10.
DATE OF ISSUE-05-13-75

^{99m}Tc

S, ABSORBED DOSE PER UNIT CUMULATED ACTIVITY, (RAD/UCI-H) (CONTINUED)
TECHNETIUM-99M HALF-LIFE 6.03 HOURS

SOURCE ORGANS

TARGET ORGANS	OVARIES	PANCREAS	SKELETON			SKIN	SPLEEN	TESTES	THYROID	TOTAL BODY
			R MARROW	CORT BONE	TRA BONE					
ADRENALS	3.3E-07	9.1E-06	2.3E-06	1.1E-06	1.1E-06	6.8E-07	6.3E-06	3.2E-08	1.3E-07	2.3E-06
BLADDER WALL	7.2E-06	1.4E-07	9.9E-07	5.1E-07	5.1E-07	4.9E-07	1.2E-07	4.8E-06	2.1E-09	2.3E-06
BONE (TOTAL)	1.5E-06	1.5E-06	4.0E-06	1.2E-05	1.0E-05	9.9E-07	1.1E-06	9.2E-07	1.0E-06	2.5E-06
GI (STOM WALL)	8.1E-07	1.8E-05	9.5E-07	5.5E-07	5.5E-07	5.4E-07	1.0E-05	3.2E-08	4.5E-08	2.2E-06
GI (SI)	1.2E-05	1.8E-06	2.6E-06	7.3E-07	7.3E-07	4.5E-07	1.4E-06	3.6E-07	9.3E-09	2.5E-06
GI (ULI WALL)	1.1E-05	2.1E-06	2.1E-06	6.9E-07	6.9E-07	4.5E-07	1.4E-06	3.1E-07	1.1E-08	2.4E-06
GI (LLI WALL)	1.5E-05	5.7E-07	2.9E-06	1.0E-06	1.0E-06	4.8E-07	6.1E-07	2.7E-06	4.3E-09	2.3E-06
KIDNEYS	9.2E-07	6.6E-06	2.2E-06	8.2E-07	8.2E-07	5.7E-07	9.1E-06	4.0E-08	3.4E-08	2.2E-06
LIVER	5.4E-07	4.4E-06	9.2E-07	6.6E-07	6.6E-07	5.3E-07	9.8E-07	3.1E-08	9.3E-08	2.2E-06
LUNGS	6.0E-08	2.5E-06	1.2E-06	9.4E-07	9.4E-07	5.8E-07	2.3E-06	6.6E-09	9.4E-07	2.0E-06
MARROW (RED)	5.5E-06	2.8E-06	3.1E-05	4.1E-06	9.1E-06	9.5E-07	1.7E-06	7.3E-07	1.1E-06	2.9E-06
OTH TISS (MUSC)	2.0E-06	1.8E-06	1.2E-06	9.8E-07	9.8E-07	7.2E-07	1.4E-06	1.1E-06	1.3E-06	1.9E-06
OVARIES	4.2E-03	4.1E-07	3.2E-06	7.1E-07	7.1E-07	3.8E-07	4.0E-07	0.0	4.9E-09	2.4E-06
PANCREAS	5.0E-07	5.8E-04	1.7E-06	8.5E-07	8.5E-07	4.4E-07	1.9E-05	5.5E-08	7.2E-08	2.4E-06
SKIN	4.1E-07	4.0E-07	5.9E-07	6.5E-07	6.5E-07	1.6E-05	4.7E-07	1.4E-06	7.3E-07	1.3E-06
SPLEEN	4.9E-07	1.9E-05	9.2E-07	5.8E-07	5.8E-07	5.4E-07	3.3E-04	1.7E-08	1.1E-07	2.2E-06
TESTES	0.0	5.5E-08	4.5E-07	6.4E-07	6.4E-07	9.1E-07	4.8E-08	1.4E-03	5.0E-10	1.7E-06
THYROID	4.9E-09	1.2E-07	6.8E-07	7.9E-07	7.9E-07	6.9E-07	8.7E-08	5.0E-10	2.3E-03	1.5E-06
UTERUS (NONGRVD)	2.1E-05	5.3E-07	2.2E-06	5.7E-07	5.7E-07	4.0E-07	4.0E-07	0.0	4.6E-09	2.6E-06
TOTAL BODY	2.6E-06	2.6E-06	2.2E-06	2.0E-06	2.0E-06	1.3E-06	2.2E-06	1.9E-06	1.8E-06	2.0E-06

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DATE OF ISSUE-05-13-75

RADIATION PROTECTION

ICRP PUBLICATION 53

Radiation Dose to Patients from Radiopharmaceuticals

A report of a Task Group of Committee 2 of the International Commission on Radiological Protection

ADOPTED BY THE COMMISSION IN MARCH 1987

PUBLISHED FOR

The International Commission on Radiological Protection

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ICRP Standard biokinetic models

Gastro Intestinal tract

Model for bone dosimetry

(Lung model)

Kidney - bladder

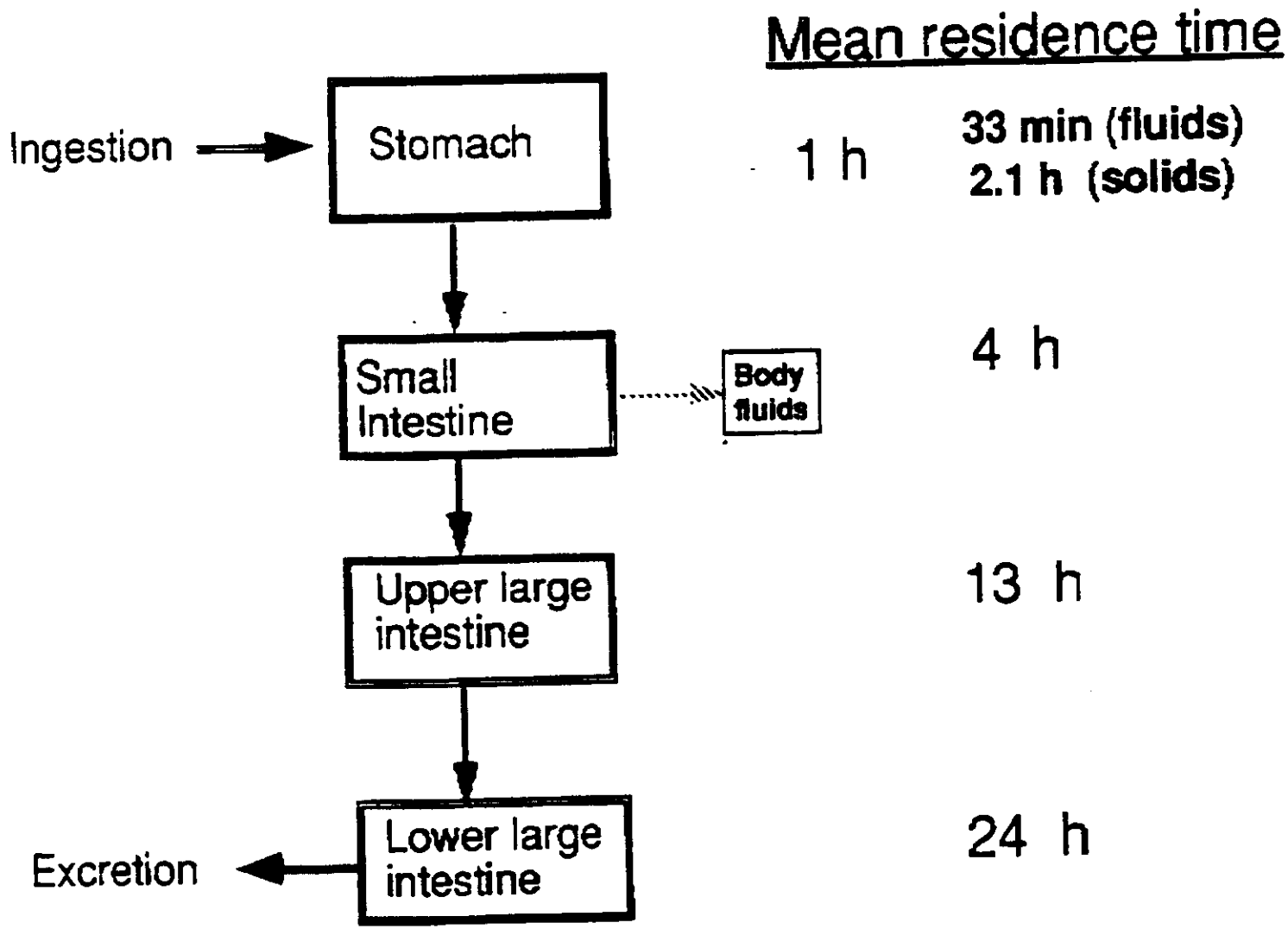
Intrathecally administered radionuclides

Gall bladder

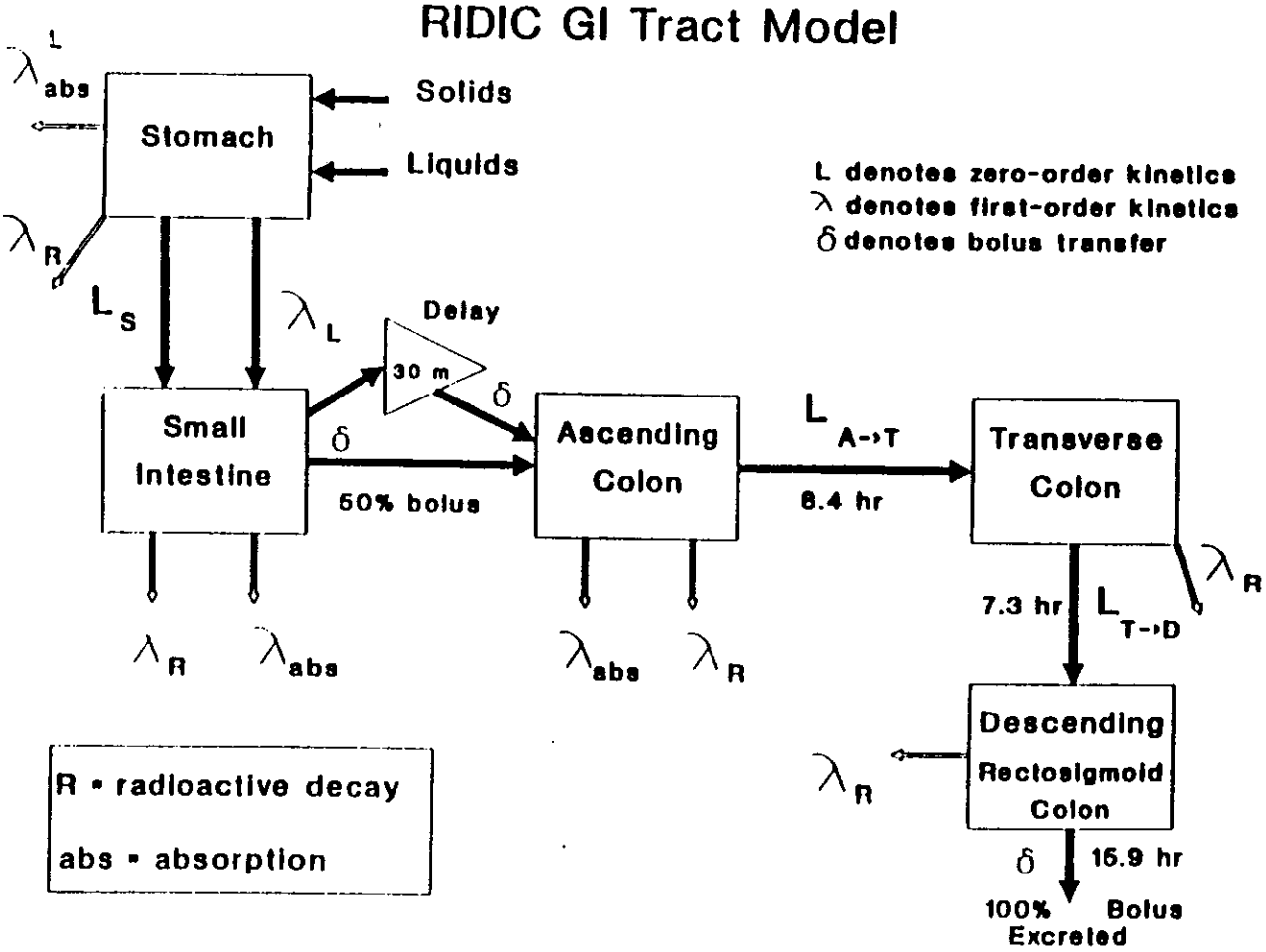
Distribution according to blood volume

Distribution according to fraction of cardiac output

G I - Tract model (ICRP 30)



RIDIC GI Tract Model



Biokinetic data

Organ *(S)*	F_S	T	a	$\tilde{A}_S/A_0$
Total body	1.0	5 d	0.50	42.4 d
		30 d	0.25	
		280 d	0.25	
Adrenals	0.004	1 d	-1.0	3.30 hr
		30 d	1.0	
Liver	0.5	6 hr	0.70	1.86 d
		5 d	0.25	
		30 d	0.05	

IODIDE

Thyroid uptake 45%

^{131}I 8.04 days

Organ	Absorbed dose per unit activity administered (mGy/MBq)				
	Adult	15 year	10 year	5 year	1 year
Adrenals	4.6E-02	5.6E-02	9.9E-02	1.6E-01	3.2E-01
* Bladder wall	3.4E-01	4.3E-01	6.5E-01	1.0E+00	1.9E+00
Bone surfaces	9.1E-02	1.4E-01	1.9E-01	2.8E-01	4.2E-01
Breast	7.9E-02	7.9E-02	1.6E-01	2.7E-01	4.9E-01
GI-tract					
* Stomach wall	4.6E-01	5.9E-01	8.6E-01	1.5E+00	3.0E+00
* Small intest	2.8E-01	3.5E-01	6.2E-01	1.0E+00	2.0E+00
* ULI wall	5.9E-02	6.8E-02	1.1E-01	1.8E-01	3.2E-01
LLI wall	4.0E-02	5.2E-02	8.2E-02	1.3E-01	2.5E-01
Kidneys	5.3E-02	7.0E-02	1.0E-01	1.7E-01	2.9E-01
Liver	4.0E-02	5.5E-02	9.2E-02	1.6E-01	3.1E-01
Lungs	1.1E-01	1.5E-01	2.6E-01	4.1E-01	6.9E-01
Ovaries	4.2E-02	5.8E-02	9.3E-02	1.5E-01	2.8E-01
Pancreas	5.6E-02	7.4E-02	1.3E-01	2.0E-01	3.6E-01
Red marrow	1.0E-01	1.5E-01	1.9E-01	2.6E-01	4.1E-01
Spleen	4.9E-02	6.5E-02	1.1E-01	1.7E-01	3.1E-01
Testes	2.6E-02	3.3E-02	5.6E-02	9.2E-02	1.8E-01
Thyroid	6.4E+02	1.0E+03	1.5E+03	3.3E+03	6.1E+03
Uterus	4.8E-02	6.3E-02	1.0E-01	1.7E-01	3.1E-01
Other tissue	1.4E-01	2.0E-01	3.2E-01	5.0E-01	8.8E-01
Effective dose equivalent (mSv/MBq)	1.9E+01	3.1E+01	4.6E+01	1.0E+02	1.8E+02

Thyroid uptake 55%

Organ	Adult	15 year	10 year	5 year	1 year
Adrenals	4.9E-02	5.8E-02	1.1E-01	1.7E-01	3.4E-01
* Bladder wall	2.9E-01	3.6E-01	5.4E-01	8.5E-01	1.6E+00
Bone surfaces	1.1E-01	1.7E-01	2.2E-01	3.2E-01	4.8E-01
Breast	9.1E-02	8.9E-02	1.9E-01	3.1E-01	5.6E-01
GI-tract					
* Stomach wall	4.6E-01	5.9E-01	8.6E-01	1.5E+00	3.0E+00
* Small intest	2.8E-01	3.5E-01	6.2E-01	1.0E+00	2.0E+00
* ULI wall	5.8E-02	6.7E-02	1.1E-01	1.8E-01	3.2E-01
LLI wall	3.9E-02	4.9E-02	7.8E-02	1.3E-01	2.4E-01
Kidneys	5.1E-02	6.8E-02	1.0E-01	1.7E-01	2.9E-01
Liver	4.3E-02	5.8E-02	9.7E-02	1.7E-01	3.3E-01
Lungs	1.3E-01	1.8E-01	3.0E-01	4.8E-01	8.0E-01
Ovaries	4.1E-02	5.6E-02	9.0E-02	1.5E-01	2.7E-01
Pancreas	5.8E-02	7.6E-02	1.3E-01	2.1E-01	3.8E-01
Red marrow	1.2E-01	1.8E-01	2.2E-01	2.9E-01	4.6E-01
Spleen	5.1E-02	6.8E-02	1.1E-01	1.7E-01	3.3E-01
Testes	2.6E-02	3.1E-02	5.2E-02	8.7E-02	1.7E-01
Thyroid	7.9E+02	1.2E+03	1.9E+03	4.1E+03	7.4E+03
Uterus	4.6E-02	6.0E-02	9.9E-02	1.6E-01	3.0E-01
Other tissue	1.6E-01	2.4E-01	3.7E-01	5.9E-01	1.0E+00
Effective dose equivalent (mSv/MBq)	2.4E+01	3.7E+01	5.6E+01	1.2E+02	2.2E+02

Estimated relative contribution of organs to the total detriment and
selected values of organ weighting factors (W_T)
(ICRP Publ.60, Annex B [1]).

Organ	Relative contribution	Values of W_T
Bladder	0.040	0.05
Bone marrow (red)	0.143	0.12
Bone surface	0.009	0.01
Breast	0.050	0.05
Colon	0.141	0.12
Liver	0.022	0.05
Lung	0.111	0.12
Desophagus	0.034	0.05
Ovary	0.020	-
Skin	0.006	0.01
Stomach	0.139	0.12
Thyroid	0.021	0.05
Remainder **	0.081	0.05
Gonads	0.183*	0.20

* - including hereditary changes
** - includes: adrenals, brain small intestine
kindney, muscle, pancreas spleen, thymus
uterus and upper large intestine (2)

NUCLEAR MEDICINE IVESTIGATION	RADIO-NUCLIDE	ACTIVITY MBq	EFFECTIVE DOSE EQUIVALENT mSv	x-ray EXAMINATION
			100	
›id scintigraphy	I - 131	3		
·eas scint	Se - 75	6		Cardioangiography
			10	
nbocyte scint	In - 111	10		Urography
ardial scint	Tl - 201	60		Large intest., Hip joint ♂
scint	Tc - 99m	440		Lumbar spine
scint	Tc - 99m	140		Pelvi metry
scint	Tc - 99m	420		Hip joint, ♀
turn-over	Fe - 59	0.2		Abdomen, small intestine
scint	Tc - 99m	100		Stomach and upper G.I.
scint (perfusion)	Tc - 99m	80	1	
y scint	Tc - 99m	140		Lung, photofluorography Dental
nbus detection	I - 125	3.7		
nbus detection	Tc - 99m	20		Lung fullsize
lingtest	Co - 58	0.03		
			0.1	
Na	Na - 24	0.2		
water	H - 3	3.7		
raphy	I - 131	0.6		Dental, (single exposure) Arm, leg (single exposure)
volume	I - 125	0.4	0.01	
y clearance	Cr - 51	4		
graphy	I - 125	0.6		
eral circ.	Xe - 133	3.5		
			0.001	

Table 31
Age-dependent analysis of effective dose equivalents to patients from diagnostic nuclear medicine examinations

Organ	*Radiopharmaceutical*	*Dose factor (mSv/MBq)*	*Average activity [a] (MBq)*	*Effective dose equivalent per examination (mSv)*	*Examinations per 1,000 population [a]*	*Effective dose equivalent per caput (μSv)*
Age group: 0-9 years						
Bone	Tc-99m phosphate	0.025	380	9.5	0.17	1.6
Brain	Tc-99m gluconate	0.024	460	11.1	0.05	0.6
Cardiovascular	Tl-201 chloride	2.0	37	73	0.004	0.3
	Tc-99m erythrocytes	0.025	555	13.9	0.006	0.08
Age group: 10-19 years						
Bone	Tc-99m phosphate	0.010	570	5.7	0.20	1.1
Brain	Tc-99m gluconate	0.011	690	7.6	0.19	1.5
Cardiovascular	Tl-201 chloride	0.36	55	19.7	0.004	0.08
	Tc-99m erythrocytes	0.011	830	9.1	0.006	0.05
Age group: adults						
Bone	Tc-99m phosphate	0.008	790	6.3	6.39	40.3
Brain	Tc-99m gluconate	0.009	962	8.7	4.47	38.7
Cardiovascular	Tl-201 chloride	0.23	76	17.5	0.79	13.8
	Tc-99m erythrocytes	0.0085	1156	9.8	1.19	11.7
Liver/spleen	Tc-99m colloid	0.014	117	1.6	4.81	7.9
	Tc-99m HIDA	0.024	226	5.4	0.16	0.9
Lung	Tc-99m MMA	0.012	114	1.4	1.83	2.5
Kidney	Tc-99m gluconate	0.009	523	4.7	0.75	3.5
Thyroid	Tc-99m pertechnetate	0.015	250	3.8	1.12	4.5
	I-131 ionic (uptake study)	6.6 [b]	0.38	2.5	1.36	3.4
Total					23.6	127.2

[a] Activity administered and examination frequency for Manitoba, Canada [H17]. For children, it was assumed here that activities administered were reduced according to Beentjes [B20].

[b]

3. EFFECTIVE DOSES PER UNIT ADMINISTERED ACTIVITY FOR THOSE RADIOPHARMACEUTICALS PUBLISHED IN *ICRP PUBLICATION 53*

(Data given in this table refers to adults)

Radionuclide	Substance	*E* mSv/MBq
^{3}H	Water	1.5E−02
^{3}H	Inulin	9.4E−04
^{11}C	Carbon monoxide (single inhalation with 20 s breath-hold)	4.8E−03
^{11}C	Carbon monoxide (continuous inhalation for 1 h)	3.2E−03
^{11}C	Carbon dioxide (single inhalation with 20 s breath-hold)	1.6E−03
^{11}C	Carbon dioxide (continuous inhalation for 1 h)	1.0E−03
^{11}C	COHb-labelled erythrocytes	5.0E−03
^{11}C	Spiperone	5.3E−03
^{14}C	Inulin	8.2E−03
^{13}N	Nitrogen gas (single inhalation with 20 s breath-hold)	3.8E−04
^{13}N	Nitrogen gas (continuous inhalation for 1 h)	4.3E−04
^{13}N	Nitrogen gas in solution	4.1E−04
^{13}N	Ammonia	2.0E−03
^{13}N	*l*-glutamate	3.9E−03
^{15}O	Carbon monoxide (single inhalation with 20 s breath-hold)	8.0E−04
^{15}O	Carbon monoxide (continuous inhalation for 1 h)	5.5E−04
^{15}O	Carbon dioxide (single inhalation with 20 s breath-hold)	5.1E−04
^{15}O	Carbon dioxide (continuous inhalation for 1 h)	3.8E−04
^{15}O	Oxygen gas (single inhalation with 20 s breath-hold)	3.7E−04
^{15}O	Oxygen gas (continuous inhalation for 1 h)	4.0E−04
^{18}F	Fluoride	2.4E−02
^{18}F	2-fluoro-2-deoxy-*d*-glucose (FDG)	2.0E−02
^{22}Na	Sodium (intravenous or oral administration)	2.6E+00
^{24}Na	Sodium	3.2E−01
^{24}Na	Sodium (oral administration)	3.6E−01
^{28}Mg	Magnesium	7.2E−01
^{32}P	Phosphate	2.4E+00
^{33}P	Phosphate	6.6E−01
^{35}S	Sulphate	9.0E−02
^{34m}Cl	Chloride	1.4E−02
^{36}Cl	Chloride	6.7E−01
^{38}Cl	Chloride	1.4E−02
^{38}K	Potassium (ultrashort-lived)	1.9E−02
^{42}K	Potassium	2.8E−01
^{42}K	Potassium (oral administration)	3.4E−01
^{43}K	Potassium	2.0E−01
^{43}K	Potassium (oral administration)	2.2E−01
^{45}Ca	Calcium	3.1E+00
^{45}Ca	Calcium (oral administration)	1.8E+00
^{47}Ca	Calcium	1.2E+00
^{47}Ca	Calcium (oral administration)	1.8E+00
^{46}Sc	Sc-labelled non-absorbable markers (fluids)	1.6E+00
^{46}Sc	Sc-labelled non-absorbable markers (solids)	1.7E+00
^{47}Sc	Sc-labelled non-absorbable markers (fluids)	4.7E−01
^{47}Sc	Sc-labelled non-absorbable markers (solids)	7.6E−01
^{51}Cr	Chromium (III) chloride	6.8E−02
^{51}Cr	Chromium EDTA	2.1E−03
^{51}Cr	Chromium EDTA (oral administration)	4.4E−02
^{51}Cr	Cr-labelled platelets (thrombocytes)	1.4E−01
^{51}Cr	Cr-labelled erythrocytes	1.7E−01
^{51}Cr	Cr-labelled denatured erythrocytes	1.8E−01
^{51}Cr	Cr-labelled white blood cells (leukocytes)	1.2E−01
^{51}Cr	Cr-labelled non-absorbable markers (fluids)	4.3E−02

Radionuclide	Substance	*E* mSv/MBq
^{51}Cr	Cr-labelled non-absorbable markers (solids)	4.5E−02
^{52}Fe	Iron	1.1E+00
^{52}Fe	Iron (oral administration)	7.1E−01
^{55}Fe	Iron	4.0E+00
^{55}Fe	Iron (oral administration)	4.2E−01
^{59}Fe	Iron	1.0E+01
^{59}Fe	Iron (oral administration)	2.0E+00
^{57}Co	Co-labelled bleomycin	4.7E−02
^{57}Co	Vitamin B12 (intravenous injection with no carrier)	4.4E+00
^{58}Co	Vitamin B12 (intravenous injection with no carrier)	8.2E+00
^{57}Co	Vitamin B12 (intravenous injection with carrier)	4.6E−01
^{58}Co	Vitamin B12 (intravenous injection with carrier)	8.9E−01
^{57}Co	Vitamin B12 (oral administration with flushing)	2.1E+00
^{58}Co	Vitamin B12 (oral administration with flushing)	4.0E+00
^{57}Co	Vitamin B12 (oral administration without flushing)	3.1E+00
^{58}Co	Vitamin B12 (oral administration without flushing)	5.9E+00
^{64}Cu	Copper	3.6E−02
^{67}Cu	Copper	1.5E−01
^{62}Zn	Zinc	3.5E−01
^{65}Zn	Zinc	8.4E+00
^{69m}Zn	Zinc	1.4E−01
^{66}Ga	Gallium citrate	3.2E−01
^{67}Ga	Gallium citrate	1.1E−01
^{68}Ga	Gallium citrate	2.0E−02
^{72}Ga	Gallium citrate	3.4E−01
^{72}As	Arsenate, arsenite	3.6E−01
^{74}As	Arsenate, arsenite	5.1E−01
^{76}As	Arsenate, arsenite	2.8E−01
^{75}Se	Selenite	2.6E+00
^{75}Se	Selenomethylcholesterol	1.5E+00
^{75}Se	1-Selenomethionine	2.5E+00
^{75}Se	Selenium-labelled bile acid (SeHCAT)	6.6E−01
^{76}Br	Bromide	2.8E−01
^{77}Br	Bromide	7.7E−02
^{82}Br	Bromide	4.0E−01
^{77}Br	Bromospiperone	8.5E−02
^{81m}Kr	Krypton	9.5E−04
^{81}Rb	Rubidium	2.8E−02
^{82}Rb	Rubidium	3.4E−03
^{84}Rb	Rubidium	2.8E+00
^{86}Rb	Rubidium	3.0E+00
^{81}Rb	Rb-labelled denatured erythrocytes	1.4E−01
^{85}Sr	Strontium	7.9E−01
^{87m}Sr	Strontium	6.4E−03
^{89}Sr	Strontium	3.1E+00
^{99m}Tc	Tc-labelled albumin (HSA)	6.1E−03
^{99m}Tc	Tc-labelled citrate complex	6.1E−03
^{99m}Tc	Tc-labelled large colloids	9.2E−03
^{99m}Tc	Tc-labelled small colloids	9.7E−03
^{99m}Tc	Tc-DMSA	8.7E−03
^{99m}Tc	Tc-DTPA	5.2E−03
^{99m}Tc	Tc-labelled plasmin	7.3E−03
^{99m}Tc	Tc-gluconate, glucoheptonate	5.4E−03
^{99m}Tc	Tc-penicillamine	7.3E−03
^{99m}Tc	Pertechnetate	1.2E−02
^{99m}Tc	Pertechnetate (blocking agent given)	4.7E−03
^{99m}Tc	Pertechnetate (oral administration, no blocking)	1.4E−02
^{99m}Tc	Tc-labelled IDA derivatives	1.5E−02
^{99m}Tc	Tc-labelled fibrinogen	6.2E−03
^{99m}Tc	Tc-labelled erythrocytes	6.6E−03

Radionuclide	Substance	*E* mSv/MBq
^{99m}Tc	Tc-labelled denatured erythrocytes	1.9E−02
^{99m}Tc	Tc-labelled phosphates and phosphonates	5.8E−03
^{99m}Tc	Tc-labelled aerosols (substances with fast clearance)	6.1E−03
^{99m}Tc	Tc-labelled aerosols (substances with slow clearance)	1.4E−02
^{99m}Tc	Tc-labelled heparin	5.5E−03
^{99m}Tc	Tc-labelled macroaggregated albumin	1.1E−02
^{99m}Tc	Tc-labelled non-absorbable markers (fluids)	2.0E−02
^{99m}Tc	Tc-labelled non-absorbable markers (solids)	2.2E−02
^{99m}Tc	Tc-labelled albumin microspheres	1.0E−02
^{99m}Tc	Tc-labelled platelets (thrombocytes)	1.2E−02
^{99m}Tc	Tc-labelled white blood cells (leukocytes)	1.1E−02
^{111}In	Indium	2.1E−01
^{113m}In	Indium	1.0E−02
^{113m}In	Indium hydroxide (colloidal)	1.1E−02
^{111}In	In-DTPA	2.1E−02
^{113m}In	In-DTPA	1.1E−02
^{111}In	In-aerosols (substances with fast clearance)	2.5E−02
^{111}In	In-aerosols (substances with slow clearance)	2.4E−01
^{113m}In	In-aerosols (substances with fast clearance)	1.6E−02
^{113m}In	In-aerosols (substances with slow clearance)	2.5E−02
^{111}In	In-labelled non-absorbable markers (fluids)	3.1E−01
^{111}In	In-labelled non-absorbable markers (solids)	3.2E−01
^{113m}In	In-labelled non-absorbable markers (fluids)	2.0E−02
^{113m}In	In-labelled non-absorbable markers (solids)	2.9E−02
^{111}In	In-labelled platelets (thrombocytes)	3.9E−01
^{111}In	In-labelled white blood cells (leukocytes)	3.6E−01
^{111}In	In-labelled bleomycin	1.0E−01
^{123}I	Iodide (thyroid blocked, uptake 0%)	1.1E−02
^{123}I	Iodide (thyroid uptake 35%)	2.2E−01
^{124}I	Iodide (thyroid blocked, uptake 0%)	9.5E−02
^{124}I	Iodide (thyroid uptake 35%)	1.5E+01
^{125}I	Iodide (thyroid blocked, uptake 0%)	9.1E−03
^{125}I	Iodide (thyroid uptake 35%)	1.4E+01
^{131}I	Iodide (thyroid blocked, uptake 0%)	6.1E−02
^{131}I	Iodide (thyroid uptake 35%)	2.4E+01
^{123}I	Iodoamphetamine (IMP)	2.7E−02
^{123}I	Iodine-labelled fibrinogen	2.0E−02
^{125}I	Iodine-labelled fibrinogen	8.0E−02
^{131}I	Iodine-labelled fibrinogen	4.2E−01
^{123}I	Iodine-labelled albumin (HSA)	2.0E−02
^{125}I	Iodine-labelled albumin (HSA)	2.2E−01
^{131}I	Iodine-labelled albumin (HSA)	6.4E−01
^{131}I	Iodine-labelled macroaggregated albumin (MAA)	4.5E−01
^{125}I	Iodine-labelled non-absorbable markers (fluids)	1.7E−01
^{125}I	Iodine-labelled non-absorbable markers (solids)	1.7E−01
^{131}I	Iodine-labelled non-absorbable markers (fluids)	1.2E+00
^{131}I	Iodine-labelled non-absorbable markers (solids)	1.2E+00
^{123}I	Iodine-labelled microaggregated albumin (MIAA)	1.8E−02
^{131}I	Iodine-labelled microaggregated albumin (MIAA)	2.2E−01
^{123}I	Hippuran	1.2E−02
^{125}I	Hippuran	7.7E−03
^{131}I	Hippuran	5.3E−02
^{131}I	Iodo-antipyrine	6.7E−02
^{125}I	Iodo-antipyrine	1.0E−02
^{125}I	Iothalamate	7.2E−03
^{131}I	Iodomethyl-19-norcholesterol (NP 59)	1.8E+00
^{125}I	Iodinated polyvinylpyrrolidone (PVP)	6.5E−01
^{131}I	Iodinated polyvinylpyrrolidone (PVP)	6.0E−01
^{125}I	Thyroxine (T4)	1.0E−01
^{131}I	Thyroxine (T4)	4.4E−01

Radionuclide	Substance	E mSv/MBq
^{125}I	Triiodothyronine (T3)	4.7E−02
^{131}I	Triiodothyronine (T3)	3.0E−01
^{125}I	Reverse triiodothyronine (rT3)	3.7E−02
^{131}I	Reverse triiodothyronine (rT3)	2.5E−01
^{125}I	Diiodothyronine	3.6E−02
^{131}I	Diiodothyronine	2.5E−01
^{123}I	Metaiodobenzylguanidine (MIBG)	1.4E−02
^{131}I	Metaiodobenzylguanidine (MIBG)	1.4E−01
^{123}I	Sodium Rose Bengal	5.9E−02
^{131}I	Sodium Rose Bengal	1.1E+00
^{127}Xe	Xenon-gas (single inhalation or i.v. inj., 30 s breath-hold)	1.3E−04
^{133}Xe	Xenon-gas (single inhalation or i.v. inj., 30 s breath-hold)	1.8E−04
^{127}Xe	Xenon-gas (rebreathing for 5 min)	7.1E−04
^{127}Xe	Xenon-gas (rebreathing for 10 min)	1.1E−03
^{133}Xe	Xenon-gas (rebreathing for 5 min)	7.3E−04
^{133}Xe	Xenon-gas (rebreaching for 10 min)	1.1E−03
^{129}Cs	Caesium	4.9E−02
^{130}Cs	Caesium	3.4E−03
^{131}Cs	Caesium	5.0E−02
^{134m}Cs	Caesium	6.7E−03
^{131}Ba	Barium	5.0E−01
^{133m}Ba	Barium	4.7E−01
^{135m}Ba	Barium	3.4E−01
^{131}Ba	Ba-labelled non-absorbable markers (fluids)	4.9E−01
^{131}Ba	Ba-labelled non-absorbable markers (solids)	5.1E−01
^{140}La	La-DTPA	1.5E−01
^{169}Yb	Yb-DTPA	3.6E−02
^{198}Au	Gold colloid	1.1E+00
^{197}Hg	Mercury chloride	1.4E−01
^{197}Hg	Bromo-mercuri-hydroxypropane (BMHP)	1.4E−01
^{203}Hg	Chlormerodrin	8.7E−02
^{201}Tl	Chlormerodrin	1.1E+00
	Thallium	2.3E−01

Effective dose

Advantages / Disadvantages

(+) **Simplifies comparison of risk between different radiological methods.**

(-) **Valid for the "working population" or the general population, not for a population of patients.**

(-) **Weighting factor may change with time, due to the present limited knowledge of the risk.**

(-) **Still low weight to curable cancer and loss of life length.**

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ICRP PUBLICATION 52

Protection of the Patient in Nuclear Medicine

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Table 2. Methods used for the reduction of organ doses in various nuclear medicine procedures

Method	Radioisotope	Procedure	Organ
Hydration and frequent voiding	^{99m}Tc-phosphates	Bone scintigraphy	Bladder region
		Myocardial scintigraphy	Bladder region
	^{99m}Tc-DTPA	Renal scintigraphy	Bladder region
	^{131}I-hippurate	Renography	Bladder region
	^{99m}Tc-O_4^-	Radionuclide angiography	Bladder region
	^{111}In-DTPA	Cisternography	Bladder region
	^{99m}Tc-O_4^-	Scrotal scintigraphy	Bladder region
	^{99m}Tc-microspheres	Lung perfusion scintigraphy	Bladder region
	^{201}Tl-chloride	Cardiac scintigraphy	Bladder region
$KClO_4$ given before administration of radiopharmaceutical	^{99m}Tc-O_4^-	Radionuclide angiography	Thyroid
	^{99m}Tc-O_4^-	Dacrocystography	Thyroid
$KClO_4$ administration after data acquisition	^{99m}Tc-O_4^-	Meckel's diverticulum scintigraphy	Thyroid and salivary gland
	^{99m}Tc-O_4^-	Salivary gland scintigraphy	
KI or $KClO_4$	^{131}I MIBG	Scintigraphy of adrenal medulla	Thyroid
	^{131}I Rose Bengal	Hepatobiliary scintigraphy	Thyroid
Catheterization of infant's neurogenic bladder	^{99m}Tc-O_4^-	Radionuclide cystography	Bladder
Laxatives	^{67}Ga citrate	Scintigraphic detection of neoplastic and inflammatory foci	Bowel
Diuretics	^{99m}Tc-DTPA	Renal scintigraphy	Kidney
	^{131}I-hippurate	Renography	Kidney
Cholecystokinin (fatty meal)	^{99m}Tc-IDA compounds	Hepatobiliary scintigraphy	Gall bladder

2.1.13. *Pregnant women*

(53) Irradiation of the fetus results from placental transfer and distribution of radiopharmaceuticals in the fetal tissues, or from external irradiation from the radiopharmaceutical present in the mother's organs and tissues. The chemical and biological properties of the radiopharmaceutical are the critical factors in possible placental transfer. Some radiopharmaceuticals cross the placenta freely and are taken up in fetal tissues, where they irradiate the tissues. This may, for example, result from the concentration of ^{131}I as iodide or ^{99m}Tc as pertechnetate in the fetal thyroid, occurring during the last two trimesters of pregnancy. Some analogues of natural metabolites (e.g. radiostrontium for calcium, and radiocaesium for potassium) are not so readily transferred. Radiocolloids that are retained by the reticuloendothelial system of the mother, and do not cross the placenta, act only as external sources of irradiation to the fetus. In the case of radiopharmaceuticals that are rapidly eliminated by the kidneys, the urinary bladder, acting as a reservoir, can become a major source of radiation to other organs and tissues and to the fetus. After the administration of short-lived radiopharmaceuticals, frequent voiding should, therefore, be ensured. This contribution to the fetal dose can be further reduced by administering the radiopharmaceutical when the bladder is partially filled, rather than immediately after voiding. When a nuclear medicine examination is proposed for a pregnant woman, great care has to be taken to ascertain that the examination is indeed indicated. If, in consultation with the referring physician, it is deemed that the risk of not making a necessary diagnosis is greater than that of irradiating the fetus, the examination should be performed (Taylor, 1979). When ultrasound diagnostics are available and can provide useful information, radionuclide studies for localization of the placenta should be discouraged.

(54) Exposure of the pregnant patient, at a time when the pregnancy was unrecognized, often leads to her apprehension, because of concern about possible effects on the fetus, even though the absorbed doses to the conceptus are generally small. Such concern may even lead to a suggestion that the pregnancy be terminated. However, on the basis of relative risk increment, fetal irradiation from a diagnostic procedure rarely justifies terminating a pregnancy. When such a concern arises, an estimate of the absorbed dose, and the associated risk to the fetus, should be made by a qualified expert. With such expert and carefully worded advice, the patient should then be in a position to take a decision regarding abortion.

IF YOU ARE BREAST-FEEDING,
PLEASE NOTIFY THE STAFF

(56) It is recommended that the following actions should then be taken for various diopharmaceuticals (Ahlgren *et al.*, 1985; Coakley and Mountford, 1985):

Group I: *Stop nursing for at least 3 weeks**
- —All ^{131}I- and ^{125}I-radiopharmaceuticals except labelled hippuran
- —^{22}Na, ^{67}Ga, ^{201}Tl, ^{75}Se-methionine

Group II: *Stop nursing for at least 12 hours*
- —^{131}I-, ^{125}I- and ^{123}I-hippuran
- —All ^{99m}Tc-compounds except labelled red blood cells, -phosphonates and -DTPA

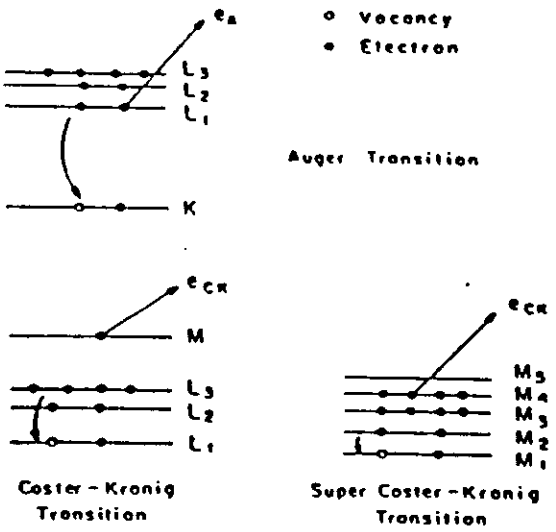
Group III: *Stop nursing for at least 4 hours*
- —^{99m}Tc-red blood cells, -phosphonate and -DTPA

Group IV: *No necessity to stop nursing*
- —^{51}Cr-EDTA

Fig. 2

Low energy electrons

Auger electrons

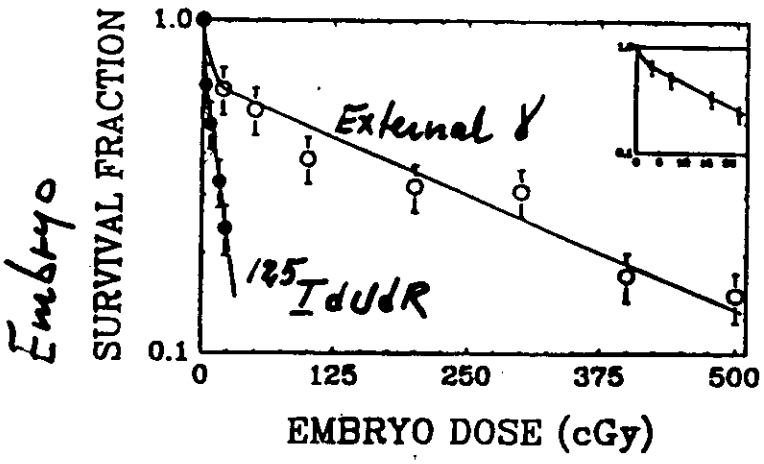


^{99m}Tc

^{123}I, ^{125}I

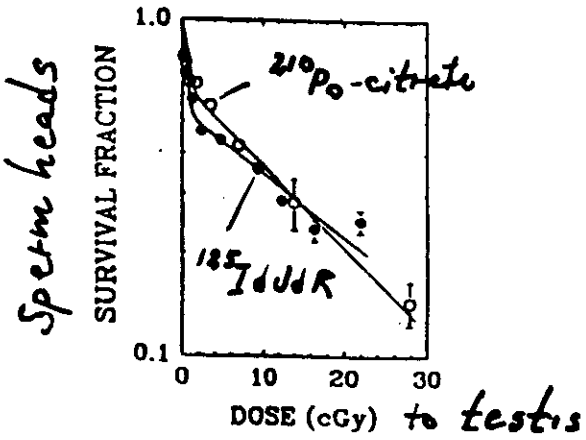
^{201}Tl

^{111}In



Varma et al, 1991

Fig. 4



Rao et al, 1989

More knowledge required:

Biokinetic data for children

Transfer of radiopharmaceuticals to the fetus

Methods for calculation of the absorbed dose in the fetus from a source in the mother.

Excretion of radiopharmaceuticals in breast milk

Risk and "organ or tissue weighting factors" for a patient population.

Which is the optimal activity to be used (children, adu

Current research areas

Age dependent biokinetc data

Voxel phantom

More realistic model for the gastrointestinal tract

Improved dosimetry for bone tissues

Microdosimetry (cellular distribution)

Dosimetry for monoclonal antibodies (therapy)