NCRP REPORT No. 73

Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children

Recommendations of the
NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS

Issued 30 December 1983

National Council on Radiation Protection and Measurements
7910 WOODMONT AVENUE / BETHESDA, MD. 20814

LEGAL NOTICE

This report was prepared by the National Council on Radiation Protection and Measurements (NCRP). The Council strives to provide accurate, complete and useful information in its reports. However, neither the NCRP, the members of the NCRP, other persons contributing to or assisting in the preparation of this report, nor any person acting on the behalf of any of these parties (a) makes any warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, method or process disclosed in this report may not infringe on privately owned rights; or (b) assumes any liability with respect to the use of, or for damages resulting from the use of, any information, method or process disclosed in this report.

Library of Congress Cataloging in Publication Data

National Council on Radiation Protection and Measurements.

Protection in nuclear medicine and ultrasound diagnostic procedures in children.

(NCRP report, ISSN 0083-209X ; no. 73)

"Issued December 30, 1983."

Includes index.

1. Children—Diseases—Diagnosis. 2. Radioisotopes in medical diagnosis—Safety measures. 3. Diagnosis, Ultrasonic—Safety measures. 4. Radiosotopes in pediatrics—Safety measures. I. Title. II. Series.

[DNLM: 1. Nuclear medicine—In infancy and childhood. 2. Radiation dosage—In infancy and childhood. 3. Radiation protection—In infancy and childhood. 4. Ultrasonics—Diagnostic use. WN 650 N279pb]

RJ51.R33N37 1983 618.92'00757 83-61834

ISBN 0-913392-63-4

Preface

This report presents information on two different imaging techniques (nuclear medicine and ultrasound) used in the clinical examination of children. These two techniques may be used separately or in conjunction with each other to study various disease processes. A third technique (diagnostic x radiation) has been presented recently in NCRP Report No. 68, *Radiation Protection in Pediatric Radiology.* Other imaging techniques, e.g., nuclear magnetic resonance (NMR), computed tomography, positron emission tomography, are also becoming available but these are not addressed in this report. However, in some of these cases, such as NMR, little is yet known about the biological effects and thus the recommendations necessary for protection in these procedures have not yet been developed.

The purpose of this report is to provide information on the manner of conducting nuclear medicine studies in children to reduce the dose to these patients and those responsible for their care. A rationale for keeping the radiation dose as low as reasonably achievable consistent with the maximum useful information content is also presented.

This report also addresses the applications of ultrasound to children and discusses the factors that need to be considered to insure continued safe use in clinical practice. A detailed study of the biological effects of ultrasound and implications for clinical use will also soon be available from the NCRP.

The report is mainly for the use of pediatricians, radiologists, technologists and technicians, and other physicians and medical practitioners who order or use nuclear medicine and ultrasound studies in examining children. The guidelines in this report are intended to assist in the reduction of unnecessary radiation and ultrasound exposure. They should be construed as guides and not as specific rules.

The Council has noted the adoption by the 15th General Conference of Weights and Measures of special names for some units of the Systeme International d'Unités (SI) used in the field of ionizing radiation. The gray (symbol Gy) has been adopted as the special name for the SI unit of *absorbed dose, absorbed dose index, kerma,* and *specific energy imparted.* The becquerel (symbol Bq) has been adopted as the special name for the SI unit of *activity* (of a radionuclide). One

gray equals one joule per kilogram; and one becquerel is equal to one second to the power of minus one. Since the transition from the special units currently employed—rad and curie—to the new special names is expected to take some time, the Council has determined to continue, for the time being, the use of rad and curie. To convert from one set of units to the other, the following relationships pertain:

$$1 \text{ rad} = 0.01 \text{ Jkg}^{-1} = 0.01 \text{ Gy},$$
$$1 \text{ curie} = 3.7 \times 10^{10} \text{ s}^{-1} = 3.7 \times 10^{10} \text{ Bq (exactly)}.$$

Serving on Scientific Committee 51B on Radiation Protection in Pediatric Nuclear Medicine during the preparation of this report were:

A. Everette James, Jr., *Chairman*
Department of Medical Imaging and Radiological Sciences
Vanderbilt University School of Medicine
Nashville, Tennessee 37232

Members

Glenn V. Dalrymple
18 Othena Court
Little Rock, Arkansas 72207

David L. Gilday
Division of Nuclear Medicine
The Hospital for Sick Children
555 University Avenue
Toronto, Ont., Canada M5G 1X8

James G. Kereiakes
Radioisotope Laboratory
University of Cincinnati
College of Medicine
Cincinnati, Ohio 45219

Robert W. Miller (*Advisor*)
Epidemiology Branch
National Cancer Institute
Bethesda, Maryland 20205

John W. Poston
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Eugene L. Saenger
Radioisotope Laboratory
Cincinnati General Hospital
Cincinnati, Ohio 45267

Michael M. Ter-Pogossian
Washington University
Edward Mallinckrodt Institute of Radiology
510 S. Kingshighway Boulevard
St. Louis, Missouri 63110

NCRP Secretariat—Thomas Fearon (1975–1980)
James Spahn (1981–1983)

The Council wishes to express its appreciation to the members of the Committee for the time and effort devoted to the preparation of this report.

Warren K. Sinclair
President, NCRP

Bethesda, Maryland
August 1, 1983

Contents

1. Introduction and Scope

The use of nuclear medicine and ultrasound in pediatric patients has undergone rapid growth in recent years. As in other branches of the radiological sciences, nuclear medicine practice should minimize radiation dose and, consequently, possible biological damage, provided that necessary information desired from the procedure is not diminished. As no significant biological effects from ultrasound diagnostic studies in pediatric patients have been reported, the implications of use must be treated in a more theoretical context.

This report considers the special problems of radiation protection and the biological effects of radiation associated with pediatric nuclear medicine and the biological implications from studies using ultrasound in pediatric patients. Pediatric patients are affected by different diseases from adults and respond in a different manner to illness. Similarly, the implications of any imposed biological burden are different from those in adult patients. NCRP Report No. 68 has considered the biological effects of conventional radiographic studies in pediatric patients (NCRP, 1981).

Nuclear medicine and ultrasound equipment will be considered in general terms with special emphasis on specific application to the pediatric patient. The report includes a section devoted to the estimation of radiation dose, from a selected group of commonly used radionuclides, as derived from several pediatric phantoms. This report also presents an appendix with an extensive tabulation of mean doses per cumulative activity (S values).

The topic of positron emission tomography will not be considered for it represents a very specialized application of nuclear medicine technique and is not presently in routine use. Additionally, nuclear magnetic resonance (NMR) will not be discussed because clinical experience with this modality has only recently been initiated and other NCRP studies will be considering this topic. The report reviews what is known in regard to the basic interaction of ultrasound with biological media and the biological effects of ultrasound. A report being prepared by NCRP Scientific Committee 66 will involve a more general treatment of the biological effects of ultrasound, with emphasis on the mechanisms of action and the implications of use of ultrasound for clinical practice.

2. Pediatric Nuclear Medicine

2.1 Benefit-Risk Considerations

The prudent application of nuclear medicine in pediatrics must be cognizant of certain basic radiobiological principles. The first is that, in general, the younger the child, the greater the sensitivity to ionizing radiation. Second, although it has been demonstrated that repair of damage produced by low-LET radiations (the types used in nuclear medicine) can occur both in reproductive and in somatic tissues, it is appropriate to use the conservative model relating radiation dose to effect which is based on the linear, no-threshold hypothesis. This model assumes that the probability of the effects of ionizing radiation are proportional to dose, even though no clinical manifestations can be detected at low doses and dose rates. The probability of effect of radiation increases linearly with increasing total dose—hence, the higher the dose administered to an infant or child, the greater the probability of developing an effect.

The linear, no-threshold model has been chosen for the calculations in this report as a conservative one to characterize dose-response relationships for the practice of nuclear medicine. The implication is that even very small doses of radiation can produce subtle cellular effects immediately, some of which may become manifest in certain individuals later in life as a neoplastic process or in future offspring as hereditary defects (or diseases).

In the practice of pediatric medicine, the potential adverse effects of even small radiation doses require that, before requesting a nuclear medicine examination, a certain value judgement should be made (Wagner, 1968). The clinician and diagnostic imaging consultant should assure themselves that there exists a reasonable probability that the anticipated benefit of the examination will exceed the potential risk to the patient. It is not necessary that there be a guarantee that the test will yield a "positive" result, but only that, *a priori*, its use will aid in achieving a clearer understanding of the disease process for the particular child being studied. Thus, nuclear medicine should not be used for screening healthy populations or even for routine use in certain diseases unless it can be shown that this use has a reasonable probability of yielding significant clinical information. Although the

amount of radioactive material administered should be kept to a minimum, it should be sufficient to yield adequate diagnostic information with the available detection apparatus. In general, the information density of the nuclear medicine image is far less than that produced by a radiograph (Coulam *et al.*, 1981). However, the functional data obtained from many studies, relative to the anatomical detail, provide valuable clinical information that cannot be obtained by alternative means (Wagner, 1968).

As compared to ionizing radiation used externally in diagnostic radiology, the use of radiopharmaceuticals results in internally absorbed doses delivered at much lower dose rates, which generally are considered to have less biological effect. However, this difference in biological implications should not lead to a more permissive philosophy in the use of radiopharmaceuticals as compared to externally applied diagnostic radiation.

2.2 Instrumentation in Pediatric Nuclear Medicine

Instrumentation systems utilized in nuclear medicine usually are not specifically designed for a single procedure or for a single type of patient, such as the one in the pediatric age group, but must often be adapted to a specific situation or procedure (James *et al.*, 1974). Most pediatric nuclear medicine studies involve either static or dynamic imaging rather than laboratory assays.

There is a universal desire to minimize the radiation dose to children. However, a study that yields poor information is of limited clinical use and may compromise general patient care. Therefore, in order to minimize the administered dose of radioactive material and still obtain the needed information, the sensitivity of the detection system must be maximized. The spatial resolution of the system must be optimized in pediatric nuclear medicine studies because of the small size of the patient. The amount of administered radioactive material and the spatial resolution achievable with a radiation detection and imaging system often work in opposition, and must be balanced by weighing the benefits and risks in adjusting these two parameters when applied to clinical use in patients (Coulam *et al.*, 1981).

2.2.1 *Rectilinear Scanners*

Rectilinear scanning systems employ moving detectors to construct an image of the distribution pattern of the radioactivity in a two-

dimensional plane of interest in the patient. A collimated detector is moved in a back and forth pattern over the area of interest. This generates an activity map corresponding to the amount of the activity in the patient in given locations.

Many rectilinear scanning systems use two detectors in opposition to one another to provide anterior and posterior images simultaneously. This technique doubles the detection efficiency. Additionally, rectilinear scanners with multiple detectors have recently been developed. However, these detector crystals are much smaller than those of stationary devices and the spatial resolution is generally marginal. The focusing collimators provide a tomographic effect which improves resolution in the focal plane but may result in a "missed lesion" if the area of abnormality is not in the plane of focus. However, rectilinear scanners have some advantage in sensitivity when high energy radionuclides are employed. The disadvantages of slow data accumulation, long imaging time required to complete studies, and requirements of patient immobility limit the application of rectilinear scanners in clinical pediatric imaging. These factors have caused the devices to fall from favor in many laboratories and scintillation cameras have assumed the primary role as detection devices. Today, rectilinear systems are utilized only for specialized purposes.

2.2.2 *Stationary Imaging Systems*

Stationary imaging systems have detectors (usually scintillation crystals and an array of photomultiplier tubes) that allow the production of an image from a large area of the patient at one time without the necessity of moving the detector and the appropriate shield. Newer systems have thinner crystals which serve to increase spatial resolution significantly with losses in sensitivity which are acceptable with most radionuclides in current clinical use. Location of the "source" of the radioactive emission is achieved from collimation, either with a parallel hole or pinhole collimator, and from position information derived from a multiple array of photomultiplier tubes optically coupled to the scintillation crystal. Each detected radioactive event from the patient is displayed on an activity map which appears on a cathode-ray tube and is subsequently recorded on photographic film, videotape, movie film, or a magnetic tape.

Stationary imaging devices are required for dynamic imaging studies. The fact that rectilinear scanners require motion of the detector to produce an image precludes their use for this type of inquiry. Stationary imaging systems, on the other hand, have but a few detectors and,

therefore, require positioning of the detectors to provide various projections in order to obtain multiple views, e.g., anterior and posterior, of a given organ.

Current models of the scintillation camera achieve excellent sensitivity with acceptable resolution for both dynamic and static imaging. The use of large field of view (LFOV) cameras and the application of ultra-thin crystals and a greater number of photomultiplier tubes have increased the clinical utility of nuclear medicine procedures in pediatric patients due to improved spatial resolution. The use of sensitive instruments of high fidelity is an important factor in maximizing information and minimizing pediatric radiation dose. Dual camera instruments for emission computed tomography (ECT) are being introduced and offer promise in increased resolution at a chosen plane of interest.

An automatic photographic camera for rapid image recording and the addition of computer data collection devices allow use of the stationary imaging system in studies that previously employed external probe-type detectors. Studies such as renograms that were formerly obtained with probe-type detectors are now performed almost universally with the scintillation camera. The ability to simultaneously achieve an image while obtaining physiological information has increased the utility of nuclear medicine procedures for this and other studies in pediatric patients.

2.2.3 *Instrumentation and Clinical Procedures*

The scintillation camera is, in general, the imaging system of choice in pediatric nuclear medicine because of its positioning flexibility, sensitivity, resolution and retrieval capabilities via the computer. Also, the scintillation camera can be used to advantage for studies formerly performed with external probes. The scintillation camera has been used for rapid sequence visualization of the heart and great vessels after intravenous injection of ^{99m}Tc (Rosenthal, 1966; Mason *et al.*, 1968; Graham *et al.*, 1970) in pediatric patients. Bone imaging is widely used in benign and malignant disease (Gilday *et al.*, 1975; Gilday and Ash, 1976; Rosenfield and Treves, 1974). Renal diseases are commonly investigated by dynamic imaging (Pieretty *et al.*, 1974; McDonald *et al.*, 1974; Conway *et al.*, 1974). Inhalation and perfusion radionuclide studies using the scintillation camera are employed to investigate pediatric chest disease (Robinson *et al.*, 1969; Alderson *et al.*, 1974a, 1974b). Studies of biliary patency and function in the pediatric patient are performed with greater facility and flexibility with a scintillation

camera than with a rectilinear scanner. In acute gallbladder disease, this has become the study of choice, due to development of the hepatobiliary agents. Correlation of biliary scans using radionuclides with real-time ultrasound studies have increased the sensitivity and accuracy for rapid diagnosis in this clinical area.

2.3 Sedation, Injection, and Handling Techniques in Pediatric Nuclear Medicine

Lack of cooperation in the pediatric patient can make the acquisition of diagnostically useful information difficult. The development of shorter-lived radiopharmaceuticals and those which are more selectively localized in the organ of interest as well as instrumentation which is characterized by rapid data accumulation from a large anatomical area has somewhat diminished this constraint. However, there are times when patient immobilization by some means is necessary.

Immobilization is best achieved by obtaining the child's cooperation in a restful and relaxing atmosphere in the examining area. Immobilization has been attempted in the past by a variety of means including swaddling the child in towels or bed sheets, taping, sand bagging, head clamping, fixing to boards, and the holding of the child by a parent, volunteer, or employee. Each of these methods has certain disadvantages. Visual appraisal of patient's color and respiratory rate is inhibited by techniques which tend to envelop the child in a covering or some type of mechanical device designed to make voluntary motion physically impossible. Clamps or sand bags can absorb radiation and produce unwanted imaging artifacts, sometimes of clinically interpretative significance. Tape adheres to patients' skin and hair, produces discomfort during removal, and inhibits slight positioning changes during the course of examination. Some patients are allergic to adhesive and certain forms of surgical tape. Overheating may occur in infants who are swaddled or immobilized with sheets or sand bags. Although tape, straps, and sand bags may be used judiciously to inhibit subtle motion, they should not be used routinely. The use of mechanical means of immobilization rather than the holding of patients by parents or other personnel lessens the radiation exposure of these personnel. Thus, the nuclear medicine physician and technologist must consider many factors regarding patient movement prior to initiating the study. This often requires consultation with the referring physician to determine the specific information required from the examination procedure.

2.3.1 *Sedation*

As has been previously noted, imaging time has been reduced by the use of radiopharmaceuticals with short effective half-lives in combination with rapid imaging systems. The imaging time for most clinical studies that use a scintillation camera is approximately 5 minutes with a range of from 3 to 7 minutes. However, cooperation for this length of time, especially with toddlers, is virtually impossible and some form of sedation is often necessary.

The basic requirements for a satisfactory sedation technique include ease of dose administration, relief of pain and anxiety, and adequate immobilization during the period of examination with minimal attendant morbidity. A broad margin of safety in the dosage, administered to compensate for variable individual responses, is also very desirable. Sedation is not advisable for routine use in outpatients and is contraindicated in those with compromised central nervous system function.

Again, the necessity for any prolonged sedation should be discussed with referring physicians. Their assessment of the child's general health, activity, and clinical presentation warrants priority in the decision to order the sedation. Less than the usual dose required for sedation is suggested in debilitated children or in those with brain damage or respiratory depression. In weighing the risk associated with nuclear medicine procedures in pediatric patients, the pharmacologic effect of the drugs utilized should be accurately predicted, based upon adequate specific knowledge of drug potency and possible untoward side effects.

2.3.2 *Injection Technique*

The site chosen for the injection of radiopharmaceuticals is very important. The veins on the dorsum of the hand or foot are preferred in most pediatric patients. The veins in these areas have several advantages: (1) they are usually found in a preserved condition as they are rarely used for blood sampling, (2) their superficial location renders them visible and they are usually linear, enabling easy puncture, and (3) the hand or foot provides an accessible injection site when the child is partially hidden beneath the scintillation camera during dynamic studies as well as when static images are being obtained. For details of injection technique see a general reference such as James *et al.*, 1974.

2.4 Dosimetric Considerations

The main principle guiding diagnosis and treatment of patients is that the amount of radioactivity administered should be the minimum

consistent with adequate information for the diagnosis or procedure being performed. This consideration will ensure that the minimum radiation dose is delivered to the patient (ICRP, 1971).

In diagnostic work, estimation of the absorbed dose delivered to particular organs and tissues for different possible procedures is needed to determine the presumed risk for each procedure, in choosing between procedures, and, so far as practicable, in comparing risks attributable to the radiation with the possible benefits of the investigation.

The average absorbed dose to the total body and to specific organs for administered radionuclides can be calculated according to the schema of Loevinger and Berman (1968; 1976):

$$\bar{D}(r_k \leftarrow r_h) = \frac{\tilde{A}_h}{m_k} \sum_i \Delta_i \phi_i (r_k \leftarrow r_h) \tag{1}$$

by activity in source region r_h, which is absorbed in target volume r_k. The quantity ϕ_i, depends on the gamma-ray energy (MeV) and the source-target configuration. The decay of a radionuclide is assumed to give rise to radiations of types i = 1, 2, 3, $\cdots$, each with a mean number n_i of particles (or photons) per nuclear transformation, and a mean energy E_i per particle (or photon). Other quantities which are specifically related to a certain type of radiation can when necessary be so specified by a right subscript, e.g., $\bar{D}_i$ would be the mean absorbed dose due to i-type radiation.

When the target and the source are the same volume, then the above equation becomes

$$\bar{D}(r_k \leftarrow r_k) = \frac{\tilde{A}_k}{m_k} \sum_i \Delta_i \phi_i (r_k \leftarrow r_k) \tag{2}$$

where $\tilde{A}_k/m_k$ is the cumulative concentration in r_k.

The mean dose per unit cumulated activity, S, (rad $\mu Ci^{-1}h^{-1}$) has been introduced and incorporates all of the physical considerations of the dosimetry; namely, physical characteristics of the radiation and physical configuration of source and target organs (Snyder *et al.*, 1974; Loevinger and Berman, 1976).

$$S(\text{rad}\ \mu Ci^{-1}h^{-1}) = \frac{\Delta(\text{g rad}\ \mu Ci^{-1}h^{-1})}{m_k(\text{g})}\phi \tag{3}$$

Thus, the dosimetry problem reduces to one of *physiological considerations*, the cumulated activity $\tilde{A}$, and of *physical considerations*, the mean dose per unit cumulated activity, S.

$$\bar{D}(r_k \leftarrow r_h) = \tilde{A}_h S(r_k \leftarrow r_h) \tag{4}$$

Although these considerations may be universally applied, they have particular relevance to studies in pediatric patients. For a more com-

plete treatment of dosimetric considerations with illustrative examples see NCRP Report No. 70 (NCRP, 1982) and ICRU Report 32 (ICRU, 1979).

2.5 Physiological Considerations

Improved estimates of absorbed radiation dose can be made when information on radionuclide properties and decay scheme, amount injected, and its biological fate and distribution are available. Today's knowledge of radionuclide properties is adequate but biological data are often very limited. (NCRP, 1982).

2.5.1 *Estimated Blood Volumes*

For dose estimates, in specific cases, the data provided in Table 1 for estimated blood volumes at various ages may be used.

2.5.2 *Cumulated Activity*

The cumulated activity, $\tilde{A}_h$, is related to the activity function, A, by the expression

$$\tilde{A}_h = \int_{t_1}^{t_2} A_h(t)\, dt \tag{5}$$

where $t_2 - t_1$ is the exposure time interval for which the dose is computed. The activity, $A_h(t)$, in an organ or tissue at any time, t_1, is, in general, governed by the following factors: the amount of administered activity, the site and rate of radiopharmaceutical uptake and removal, and the physical decay of the radionuclide. Prior to administration of any radioactive materials, the identity and quantity must be known (NCRP, 1978; 1982)

TABLE 1—*Estimated Blood Volumes at Various ages*[a]

Age	Plasma Volume (PV) (ml/kg)	Red Cell Mass (RCM) (ml/kg)	Total Blood Volume (ml/kg)	
			(from PV)	(from RCM)
Newborn	41.3	43.1	82.1	86.1
	46.0		78.0	84.7
1–12 mo	46.1	25.5	78.1	72.8
5 y	48.5		80.0	
	49.6	25.5	85.6	67.5
10 y	51.9		87.6	
	46.2	26.3	83.2	67.4
15 y	51.2		88.3	
Adults	39–44	25–30	68–88	55–75

[a] Adapted from Handmaker and Lowenstein (1975)

2.5.2.1 *Administered Activity.* The initial activity in the area of interest will depend on the uptake of the administered activity. Table 2 shows the administered activity for children as a fraction of the adult administered activity, when computed on the basis of the two-thirds power of body weight. These fractions are intended only for application to imaging procedures. For function tests conducted in conjunction with imaging procedures, the schedule in Table 2 may be utilized. However, physiological measurements can be obtained with much lower administered activities.

2.5.2.2 *Measurement of In Vivo Activity.* Quantitative methods for *in vivo* measurement of radioactivity provide estimates of the accumulation of the radiopharmaceutical in the area of interest. Quantification using conjugate counting views has been reviewed by Budinger, (1974) and includes the work of Genna, (1966) and Sorenson, (1971). See also Thomas *et al.*, (1976). The approach provides corrections for source thickness, inhomogeneity, and attenuation.

2.5.2.3 *Effective Half-Life.* The effective half-life, T_e, is the time required for a radioactive element in a body to be diminished by 50 percent as a result of the combination of radioactive decay and biological elimination. Measurements are made for a period of time over the area or organ of interest and the effective half-life (T_e) is determined.

The cumulated activity in the area of interest can then be calculated from

$$\tilde{A}(\mu\text{Ci h}) = 1.44\ T_e(\text{h})\ A_0(\mu Ci) \tag{6}$$

where 1.44 T_e is the mean life of the radiopharmaceutical and A_0 is the initial activity in the area of interest. Table 3 presents published values

TABLE 2—*Pediatric Administered Activity Based on Body Mass*[a]

Mass (kg)	Fraction of Adult Activity	Mass (kg)	Fraction of Adult Activity
2	0.09	25	0.50
3	0.12	30	0.57
4	0.14	35	0.63
5	0.17	40	0.69
6	0.19	45	0.74
7	0.21	50	0.80
8	0.23	55	0.85
9	0.25	60	0.90
10	0.27	54	0.95
15	0.36	70	1.00
20	0.43		

[a] Adapted from Webster *et al.* (1974)

TABLE 3—*Cumulated Activity for Various Radiopharmaceuticals*[a]

Radionuclide	Pharmaceutical	Cumulated Activity, $\tilde{A}$, (μCi h) per μCi Administered	
		Whole Body	Critical Organ
^{51}Cr	Red Blood Cells (heat treated)	346.0	250.0 (spleen)
	Red Blood Cells	450.0	150.0 (spleen)
	DTPA or EDTA	8.5	7.6 (kidney)
	Human Serum Albumin	319.2	—
^{67}Ga	Citrate	88.0	4.5 (liver, spleen)
^{99m}Tc	DTPA	8.9	5.0 (bladder)
	Human Serum Albumin	4.3	4.3 (blood)
	Iron Complex	3.7	1.7 (renal cortex)
	MAA	8.0	5.6 (lungs)
	Pertechnetate	7.0	0.1 (thyroid)
	Polyphosphate	7.1	4.3 (bone)
	EHDP	8.6	2.6 (bone)
	Sulfur Colloid	8.7	7.4 (liver)
^{111}In	Colloid	17.0	84.0 (liver)
	DTPA	3.3	3.3 (bladder)
	Fe-Hydroxide	7.8	5.5 (lung)
	Chloride	32.0	32.0 (liver)
^{123}I	Hippuran	0.6	0.2 (kidneys)
	Human Serum Albumin	17.9	17.9 (blood)
	MAA	12.8	6.2 (lung)
	Rose Bengal	12.0	1.9 (liver)
	Iodide	9.4	3.8 (thyroid)[b]
^{131}I	Hippuran	0.65	0.2 (kidneys)
	Human Serum Albumin	163.0	163.0 (blood)
	MAA	35.0	8.9 (lung)
	Rose Bengal	30.0	2.2 (liver)
	Iodide	—	48.4 (thyroid)[b]

[a] Adapted from Kereiakes *et al.* (1976b).
[b] Assumed uptake—20 percent.

for cumulated activities (whole body and critical organ) for six radiopharmaceuticals which are considered here. The critical organ is the organ receiving the highest μCi h cumulation per μCi administered. Most of the numerical data, from which the cumulated activities are obtained, are from animal studies and from adult clinical studies. There is a paucity of pediatric radionuclide distribution data available at present. A compelling need still remains for retention and distribution studies in children for most of the radiopharmaceuticals in general use. Allocation of resources to these studies must be made with due consideration to alternative imaging by contrast radiography, ultrasound, x-ray computed tomography, digital radiography and nuclear magnetic resonance.

2.5.3 *Mass of Target Organ*

Kereiakes *et al.*, (1965) have provided information for a series of standard children—newborn, 1, 5, 10 and 15 years old—derived by supplementing values of the 50th percentile for heights and weights of certain ages with pertinent information on organ weights and physiology. Body weights and weights of most organs of interest, largely obtained from Spector (1956), are listed in Table 4. The weights used for calculation of S (Poston, 1976) are given in this table and agree closely with previously reported values.

2.5.4 *Mean Dose per Unit Cumulated Activity*

The mean dose per unit cumulated activity, S, can be defined as the dose to the target organ, r_k, per unit cumulated activity in source organ, r_h. S (rad $\mu Ci^{-1}h^{-1}$) is given as:

$$\begin{aligned} S(r_k \leftarrow r_h) &= S_p(r_k \leftarrow r_h) + S_n(r_k \leftarrow r_h) \\ &= \Sigma_p \Delta_p \Phi_p(r_k \leftarrow r_h) + \Sigma_n \Delta_n \Phi_n(r_k \leftarrow r_h) \\ &= \Sigma_p \Delta_p \frac{\phi_p(r_k \leftarrow r_h)}{m_k} + \Sigma_n \Delta_n \frac{\phi_n(r_k \leftarrow r_h)}{m_k} \end{aligned} \tag{7}$$

TABLE 4—*Summary of Organ Weights (grams) for Pediatric and Adult Phantoms*

Organ	Newborn	1 y[a]	5 y[a]	10 y[a]	15 y[a]	Adult[c]
Brain	372	1005	1180	1355	1367	1451
Bladder Wall	3	7	14	22	34	45
Intestines	32[b]	140[b]	301[b]	—	1265	1770
Kidneys	19	68	116	179	230	284
Liver	110	300	608	896	1267	1809
Lungs	40	130	260	426	650	1000
Red Marrow	40	150	400	600	950	1500
Yellow Marrow	0	0	50	560	1500	1500
Ovaries	0.3	0.7	2	3.2	5	8
Pancreas	2.6	9	19	27	57	60
Skeleton	500	1600	2800	4573	8700	10500
Spleen	8.8	27	50	80	145	174
Stomach	5.9	27	52	88	118	150
Testes	0.8	1.5	1.6	1.9	16	37
Thyroid	1	2	5	8.8	13	20
Total Body	3990	10400	20000	32000	56980	70000
Total Height (cm)	52	76	112	140	167	174

[a] Poston (1976).

[b] Does not include contents for the lower large intestine.

[c] Snyder-Fisher phantom based on ICRP Reference Man, *ICRP Publication 23*, (ICRP, 1975).

TABLE 5—*Absorbed Dose to Whole Body for Selected Radiopharmaceuticals*[a]

Radionuclide	Pharmaceutical	Whole Body Dose (mrad/μCi administered)					
		Newborn	1 y	5 y	10 y	15 y	Adult
^{51}Cr	Red Blood Cells	7.00	2.50	1.50	1.00	0.60	0.50
^{67}Ga	Citrate	1.40	0.57	0.38	0.28	0.20	0.16
^{99m}Tc	DTPA	0.170	0.062	0.043	0.029	0.021	0.016
	HSA (Human Serum Albumin)	0.180	0.062	0.040	0.026	0.017	0.015
	Iron Complex	0.086	0.033	0.022	0.015	0.010	0.009
	MAA (Microspheres)	0.177	0.064	0.042	0.028	0.019	0.015
	Pertechnetate	0.151	0.055	0.037	0.024	0.016	0.013
	Polyphospate	0.131	0.049	0.034	0.021	0.013	0.011
	EHDP	0.173	0.065	0.045	0.028	0.017	0.015
	Red Blood Cells	0.200	0.070	0.040	0.030	0.020	0.020
	Sulfur Colloid	0.140	0.056	0.038	0.027	0.020	0.016
^{111}In	Colloid	4.807	1.927	1.342	0.931	0.693	0.563
	DTPA	0.126	0.038	0.023	0.014	0.0092	0.0072
	Iron Hydroxide	0.678	0.216	0.140	0.086	0.056	0.046
^{123}I	Iodide	0.35	0.13	0.08	0.05	0.045	0.030
^{131}I	Hippuran	2.40	1.10	0.77	0.56	0.40	0.30
	HSA	24.00	7.60	4.80	3.00	1.90	1.60
	MAA	5.20	1.90	1.00	0.65	0.42	0.35
	Iodide	10.00	2.00	1.30	0.81	0.53	0.45
	Rose Bengal	5.10	1.80	0.89	0.53	0.36	0.29

[a] Webster *et al.*, 1974; Kereiakes *et al.*, 1976b; Roedler *et al.*, 1978.

where p and n denote penetrating and nonpenetrating emissions, respectively; Δ is the mean energy emitted per unit cumulated activity (g rad $\mu Ci^{-1}h^{-1}$) for each emission; and Φ ($r_k \leftarrow r_h$) is the specific absorbed fraction (g^{-1}); $\phi(r_k \leftarrow r_h)$ is the absorbed fraction, i.e., the fraction of the energy emitted in r_h which is absorbed in r_k; and m_k is the mass of the target organ, r_k. If the source and target organ do not coincide ($r_h \neq r_k$), it is usually assumed that $\Phi_n(r_k \leftarrow r_h) = 0$. Thus, the last term in the above equation has a non-zero value only when $r_h = r_k$, in which case all of the energy emitted in r_h is assumed to be absorbed in r_k.

Based on the frequency of the use of certain radionuclides in clinical pediatric nuclear medicine, S factors for specific source organ-target organ configurations were calculated for the following radionuclides: ^{51}Cr, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{131}I and ^{201}Tl. The values of S (due to both non-penetrating and penetrating emissions) for uniform distribution of the radionuclide are given in Appendix A.

2.6 Radiation Doses from Radiopharmaceuticals

Table 5 gives a tabulation of published whole body doses (expressed in mrad per μCi administered) for the different radiopharmaceuticals

TABLE 6—*Absorbed Dose to Critical Organs for Selected Radiopharmaceuticals*[a]

Radionuclide	Pharmaceutical	Critical Organ	Critical Organ Dose (mrad/μCi administered)					
			Newborn	1 y	5 y	10 y	15 y	Adult
^{51}Cr	Red Blood Cells (heat treated)	spleen	336.00	90.10	56.20	30.50	24.10	22.50
^{67}Ga	Citrate	spleen	8.02	2.60	1.64	1.00	0.71	0.60
^{99m}Tc	DTPA	bladder[b]	5.00	1.70	1.10	0.80	0.56	0.45
		kidney	0.39	0.15	0.10	0.07	0.05	0.04
	HIDA	liver	0.79	0.37	0.25	0.15	0.11	0.09
	HSA	blood	0.81	0.24	0.15	0.09	0.06	0.05
	Iron Complex	renal cortex	5.20	1.80	1.20	0.77	0.61	0.55
	MAA (Microspheres)	lung	3.09	1.00	0.59	0.35	0.26	0.20
	Pertechnetate	LLI[c]	1.91	0.67	0.46	0.33	0.23	0.20
	Polyphosphate	bone	1.10	0.32	0.23	0.15	0.10	0.08
	Red Blood Cells (heat treated)	spleen	26.00	9.23	5.21	3.07	2.70	2.60
	Sulfur Colloid	liver	2.90	1.34	0.92	0.56	0.40	0.33
^{111}In	Iron Hydroxide	lung	14.70	4.45	2.50	1.46	1.11	0.77
	Colloid	liver	107.33	47.70	27.77	17.60	12.61	10.60
	DTPA	bladder[b]	24.60	7.45	4.43	2.82	1.89	1.48
^{123}I	Iodohippurate	kidney	0.69	0.23	0.18	0.13	0.10	0.07
	Rose Bengal	liver	1.89	0.75	0.46	0.32	0.25	0.20
^{131}I	Hippuran	kidney	9.52	4.44	3.08	2.22	1.20	1.00
	HSA	blood	309.50	92.50	55.50	32.70	20.80	16.00
	MAA	lung	73.80	22.20	13.10	7.80	5.60	4.00
	Rose Bengal	liver	8.10	3.00	1.77	1.22	0.84	0.67

[a] Webster *et al.*, 1974; Kereiakes *et al.*, 1976b; Roedler *et al.*, 1978; Kaul *et al.*, 1973.

[b] Assumes 6 hour bladder residence time.

[c] Perchlorate blocking dose (i.v. administration).

TABLE 7—*Absorbed Dose to the Thyroid Gland (rad/μCi administered)*[a].

Radiopharmaceutical	Newborn (1.5)[b]	1 y (2.2)	5 y (4.7)	10 y (8.0)	15 y (11.2)	Adult (16.0)
^{123}I (Iodide)[c]	0.160	0.081	0.038	0.022	0.016	0.011
^{131}I (Iodide)[c]	16.0	8.09	3.78	2.22	1.55	1.11
^{99m}Tc (Pertechnetate)[d]	0.0046	0.0018	0.0010	0.00063	0.00047	0.00027

[a] Kereiakes *et al.*, 1972, 1976a.
[b] Numbers in parenthesis indicate thyroid gland weight in grams.
[c] Assumed uptake—70 percent (newborn); 20 percent (1, 5, 10, and 15 year old).
[d] Assumed uptake—5 percent.

TABLE 8—*Absorbed Dose to Gonads for Selected Radiopharmaceuticals*[a]

Scinti-graphic Study	Radiopharmaceutical	Gonads	Gonadal Dose (mrad/μCi administered)					
			Newborn	1 y	5 y	10 y	15 y	Adult
Bone	^{99m}Tc (Phosphates)	M	0.289	0.224	0.207	0.187	0.041	0.034
	(Phosphonates)	F	0.561	0.193	0.115	0.083	0.055	0.046
Brain	^{99m}Tc (Pertechnetate)	M	0.102	0.079	0.073	0.066	0.014	0.012
		F	0.219	0.076	0.045	0.032	0.022	0.018
Cardiac	^{99m}Tc (Albumin)	M	0.340	0.264	0.244	0.220	0.048	0.040
		F	0.658	0.227	0.135	0.097	0.065	0.054
Kidney	^{99m}Tc (DTPA)	M	0.170	0.132	0.122	0.110	0.024	0.020
		F	0.329	0.113	0.068	0.049	0.032	0.027
Liver	^{99m}Tc (Sulfur Colloid)	M	0.161	0.125	0.116	0.104	0.023	0.019
		F	0.280	0.097	0.058	0.041	0.028	0.023
Lung	^{99m}Tc (MAA) (Micro-	M	0.060	0.046	0.043	0.038	0.008	0.007
	spheres)	F	0.110	0.038	0.022	0.016	0.010	0.009
Thyroid	^{123}I (Na Iodide)	M	0.085	0.066	0.061	0.055	0.012	0.010
		F	0.244	0.084	0.050	0.036	0.024	0.020

[a] Adapted from Handmaker and Lowenstein (1975)

TABLE 9—*Estimated Absorbed Dose to Embryo for Selected Radiopharmaceuticals*[a]

Radiopharmaceutical	Embryo Absorbed Dose (rad/mCi administered)
^{99m}Tc Human Serum Albumin	0.018[b]
^{99m}Tc Lung Aggregate	0.035[b]
^{99m}Tc Phosphate and Phosphonate	0.036[b]
^{99m}Tc Sodium Pertechnetate	0.037
^{99m}Tc Stannous Glucoheptonate	0.040[b]
^{99m}Tc Sulfur Colloid	0.032[b]
^{123} Sodium Iodide (15% uptake)	0.032
^{131}I Sodium Iodide (15% uptake)	0.100
^{123}I Rose Bengal	0.130
^{131}I Rose Bengal	0.680

[a] Adapted from Smith and Warner (1976).
[b] These values were calculated using cumulated activity ($\tilde{A}$) values from company product data and absorbed dose per cumulated activity (S) values.

TABLE 10—*Absorbed Dose to Fetal Thyroid Gland from Maternally Administered Iodine-131*[a]

Gestation Period	Fetal/Maternal Ratio (thyroid gland)[b]	Absorbed Dose to Fetal Thyroid (rad/μCi)[c]
10–12 weeks	—	.001 (precursors)
12–13 weeks	1.2	0.7
2nd trimester	1.8	6.0
3rd trimester	7.5	—
Birth imminent	—	8.0

[a] Book and Goldman (1975).
[b] μCi/g
[c] rad/μCi of ^{131}I ingested by mother.

and different age groups treated here. Tables 6–8 list the dose information for certain organs for the age groups. These dose data were obtained from the cumulated activity and *S* factors given in this report.

Tables 9 and 10 are provided to permit estimation of absorbed dose to the embryo and fetus following the administration of commonly used radiopharmaceuticals to the mother. It should be noted that the absorbed dose is measured in rads rather than in mrads.

From this discussion and calculations, it becomes apparent that the knowledge of the dose of radiation from each specific radionuclide for each particular nuclear medicine study in an individual pediatric patient is at best incomplete. However, a great deal is known and application of certain principles, dose calculations, and extrapolations from data that have been derived from adult patients has considerable merit.

3. Pediatric Diagnostic Ultrasound

3.1 Introduction

The use of diagnostic sonographic imaging in pediatric medical diagnosis has experienced rapid growth in recent years (Gates, 1978; Fleischer and James, 1980; Coulam *et al.*, 1981). This is due, in part, to the anatomical information that can be obtained rapidly and relatively inexpensively with little patient discomfort or demonstrated risk. Ultrasonic studies have become an expected and accepted part of pediatric practice. Despite the existence of an extensive ultrasound bioeffect literature, the majority of experiments have been at power levels far in excess of those used in clinical practice. Also, the physical characteristics of the ultrasound beams in these experiments have not always been well determined. The data contained and comments offered in this section reflect the best data available. A report being prepared by NCRP Scientific Committee 66 (NCRP Report No. 74, in press) will consider ultrasound biological effects and emphasize mechanisms of action and make recommendations for the continued safe use of ultrasound in clinical practice.

3.2 Interaction of Ultrasound with Matter

The term *ultrasound* is used to describe mechanical vibration of frequencies above the human limit of audibility, i.e., about 16 kHz. While ultrasound can be generated and detected at frequencies exceeding 1000 MHz, in current medical practice, the useful range is generally from about 900 kHz up to approximately 12 MHz. In this frequency range, sound is moderately absorbed as a result of relaxation phenomena occurring at the structural and molecular level (Hill, 1968).

Three general groups or modes of interaction of the sound waves with human tissues can be described; these are thermal effects, cavitation, and "direct" effects (Taylor, 1974; King and Lele, 1974). Each

of these effects will be briefly elaborated upon with no particular specific correlation to pediatric patients.

3.2.1 *Thermal Effects*

The mechanisms leading to the absorption of a sound wave in a medium (and particularly in complex biological media) are not fully understood. A temperature rise may be important in a biological system; its magnitude in a particular clinical or experimental situation will depend on the beam characteristics in time and space, upon the absorbing and scattering properties of the media, and on the thermal conductivity and heat capacity of the medium. In man and other mammals, the heat transfer and dissipation characteristics of the moving fluids in the vascular system influence the heating effects of ultrasound.

In physiotherapy ultrasound applications, a temperature rise of several degrees usually occurs in the course of a ten-minute treatment. With intense, strongly-focused beams, changes of the order of 10°C per second can be produced in small tissue volumes (Hill, 1968). Changes of this extent may have a special relevance to biological samples.

Pulse-echo techniques (a technique which measures the transit time from the transducer to the target and return) employed clinically for diagnostic purposes can be operated at intensity levels as high as 250 W cm^{-2} (spatial peak-pulse average intensity, SPPA)[1] and demonstrate no significant thermal effect (Carson, 1980). It should be emphasized that 250 W cm^{-2} is greater than the usual power levels employed in a clinical setting (time-averaged levels of 5–20 mW cm^{-2}). Research in energy and power delivery ranges equivalent to those applied in clinical studies on pediatric patients is needed.

3.2.2 *Cavitation*

The general term "cavitation" describes certain physical phenomena that can occur in liquids subjected to ultrasound. Most ordinary liquids contain stable micro-bubbles, or other minute nuclei around which bubbles of dissolved gas are found to grow during the negative pressure phase of a sound wave. After a critical size, characteristic of the sound

[1] Intensity levels for ultrasonic devices are generally given in terms of the total power output from the crystal divided by the beam cross-section area. This is expressed in terms of watts (W) per unit of transducer area. For a more complete description of the term *intensity* see *Recommended Nomenclature, Physics and Engineering,* American Institute of Ultrasound in Medicine (AIUM, 1980).

frequency employed, has been attained, these bubbles exhibit the phenomenon of mechanical resonance. This, together with the small-scale patterns of fluid movement or "microstreaming" that the ultrasound wave induces, can lead to localized regions of high shear and stress in the liquid sufficient to injure or fracture subcellular structures. This phenomenon is commonly termed *stable cavitation.* In the 1–4 MHz frequency range, stable cavitation may occur in the liquid state above a threshold intensity of 0.2–5.0 W cm^{-2} (Hill, 1968).

Sonication of a liquid with 1 MHz ultrasound causes a more violent form of cavitation when the intensity is sufficiently high (Wells, 1969). This phenomenon is characterized as *collapse cavitation*, or *transient cavitation.* In this circumstance, the mechanical energy is sufficiently great to cause the cavitation bubbles to collapse completely during a compression phase of its vibration. In aqueous media, one consequence of this collapse phemonenon is the production of a variety of short-lived, chemical free-radical species. Free radicals may form by the collapse of cavitation bubbles after which free radicals have the capacity to initiate a number of chemical reactions. In the specific consideration of free-radical formation, the effect of ultrasound is analogous to that of ionizing radiation.

Under some conditions, the intensity levels required for the production of cavitation in tissue are as high as 2000–5000 W cm^{-2} (Fry, 1970) but under other conditions, a few watts per square centimeter suffice (Lehmann and Herrick, 1953). At present it is not definitely known whether cavitation damage of any kind occurs in mammalian tissue under conditions typical of clinical diagnostic practice. If it does, it must be subtle since there is no reported evidence for its occurrence.

3.2.3 *"Direct" Mechanisms*

Most changes produced by ultrasound in both physical and biological systems can be explained on the basis of either thermal or cavitational effects. There is, however, a growing body of evidence which indicates that more "direct" mechanisms may be involved (Hill, 1968; James, 1980; Sanders and James, 1980; Coulam *et al.*, 1981). The implication of the term "direct" in this context is simply that the nature of any possible intermediate steps between the applied stimulus (mechanical vibration) and the observed response is not known.

Direct mechanical effects on particles of the medium may take place. Under certain circumstances, microstreaming, and circulation of particles in the transmitting medium, will occur. Such a *direct* effect can produce disruption of macromolecules and may also produce

significant damage to chromosomes. While phenomena such as shearing, particle agglomeration, and changes in the surface charge of cells have also been described in a laboratory setting, the magnitude of these effects *in vivo* is unknown (Chapman, 1974; Donald, 1974; Fleischer and James, 1980; Sanders and James, 1980).

Very likely the mechanisms of action of ultrasound will change with differences in the experimental conditions, the target tissue, and the irradiation parameters. However, the "direct" effects are of particular importance with regard to potential biological hazard, since it is very unlikely, on physical grounds, that the ultrasonic beams in pediatric medical diagnosis would induce either appreciable thermal change or significant cavitational action.

3.3 Ultrasound Equipment

A variety of ultrasound devices are used in clinical medicine. In these units, the sound wave may be generated continuously, as in Doppler devices and in the ultrasonic diathermy units used in physical therapy. However, most diagnostic units operate in a pulse-echo mode. In these devices, a sound pulse is generated for a short period of time, usually one microsecond. Following the pulse generation, the machine "listens" to the echoes returning from tissue interfaces for a time before the next interrogation pulse is generated. The duty factor gives the fraction of the time during which the sound beam is being generated from the transducer crystal. Duty factors for diagnostic ultrasound machines are typically in the range 0.05% to 0.2% when compared with the "listening" or "off" mode. These units produce time-average intensity levels (spatial peak) of 0.01 to 200 milliwatts per square centimeter. The instantaneous peak intensities of these instruments are 5 to 10 W cm^{-2}, although peak intensities as high as 100 W cm^{-2} have been reported from commercial pulse-echo diagnostic instruments (Dunn and Fry, 1971).

Continuous wave Doppler fetal heart detection instruments produce a beam with an intensity of 10 to 30 mW cm^{-2}. Treatment ultrasound beams used in physiotherapy which employ the continuous wave mode operate at intensities of 1 to 3 W cm^{-2}. The average period of examining time used for a scan with a pulse-echo device is approximately five minutes, and, for a Doppler unit, about two minutes. Physiotherapy

units are routinely used for 5–10 minutes. Table 11 presents the time required for various ultrasound examinations (James, 1980). These figures are subject to modification with the increased use of real-time ultrasound units (James, 1980; Coulam *et al.*, 1981).

The first of the ultrasound units to gain wide usage was the echoencephalograph. This unit was utilized to evaluate midline shifts in the brain (as well as related information). This unit employed the so-called "A-Mode" ultrasound, which provided information about a reflecting structure relative to the depth of this ultrasound-reflecting structure beneath the skin surface. When depth is measured along the X-axis, signal information is shown along the Y-axis. The amplitude and shape of the received signal is related to the size of the object producing the reflection, as well as the distance from the coupling interface. There is no scanning motion in an A-Mode study of this type. The transducer surface is placed upon the skin in conjunction with some type of interposed coupling agent (mineral oil, gel, etc.) and is held there during measurement.

The "B-Mode" ultrasound type of study provides depth and position information (Donald, 1974). The transducer crystal is electronically coupled with an articulated arm that provides information regarding the position of a particular reflection signal. Echo signals are converted from amplitude information to intensity or brightness-modulated line segments of sweeps or dots. Depth below the surface is displayed along one axis (usually the X-axis) and the position of the transducer is displayed along the other axis. B-Mode scan presentation is often achieved through lateral movement of the transducer. These machines have found wide usage in many areas. In the past five years, "real time" B-Mode scanners have become available for clinical imaging. These units use either an array of transducers or moving transducers

TABLE 11—*Pediatric Ultrasound Studies*[a]

	Full Time[b]	Actual[c]
Abdomen	30 minutes	10 minutes
Liver	30 minutes	10 minutes
Renal	20 minutes	7 minutes
Pancreas	30 minutes	10 minutes
Pelvic	15 minutes	10 minutes
Nodes	45 minutes	15 minutes
Thyroid	10 minutes	5 minutes
Chest	15 minutes	5 minutes
Head	10 minutes	5 minutes

[a] From James (1980).

[b] Refers to length of time for study.

[c] Refers to scanning time.

to send and detect ultrasound. The image of structures moving in real time (for example, the fetus *in utero*) is displayed. The third commonly used presentation is the "T-M" or "M-Mode" presentation. This is also known as the Time-Motion scan. The equipment is set to operate in the B-Mode with the transducer stationary. The trace on the oscilloscope is caused to sweep electronically, thus providing information pertaining to the motion of a pulsating or oscillating object, for example, cardiac motion.

The recent availability of high frequency transducers (3.5, 5 and 7 MHz) with a small diameter (6 mm) allows improved resolution and better sonographic imaging of pediatric patients than was previously available with the larger transducers. The improved resolution with real-time and mechanical sector scanners has increased flexibility in examining pediatric patients.

The ultrasound instruments previously described are pulse-echo devices which are primarily utilized to create anatomical images. Doppler ultrasound devices are used to measure flow velocity in vessels and are commonly employed as fetal heart monitors. The Doppler probe utilizes two crystals in a single probe with one crystal producing ultrasound continuously, and the other crystal receiving continuously. A major biomedical advance was achieved when Doppler technology was coupled to a real time imaging device. The ability to measure blood flow with simultaneous imaging of the vessel has provided significant information in a non-invasive manner. Since pediatric angiography has increased morbidity when compared with adult angiography, pulsed Doppler ultrasound studies may provide a viable and even preferred alternative in certain vascular disorders (James, 1980). Comparison with digital radiographic studies for intravenous angiography will provide the type of analysis necessary to determine the clinical utility of pulsed Doppler ultrasound in pediatric practice (Price *et al.*, 1982).

The flexibility, rapidity of data accumulation, and relative lack of dependence upon patient cooperation have markedly increased the use of real-time ultrasound studies in children. These have been especially important in evaluation of neonatal intracranial hemorrhage and abdominal masses.

3.4 Power Levels of Diagnostic Ultrasound Machines

Total power output for diagnostic ultrasound machines ranges from 0.06 to 40 mW and values for average intensity at the transducer face are in the range of 3 to 3570 W m^{-2} (Tables 12–15). Power outputs of

TABLE 12—*Characteristics of A/B MODE[a] Ultrasound Equipment*

Manufacturer	Ultrasound Unit	PRF[b] (Hz)	Transducer Characteristics			Total Power Output (mW)	Average Intensity at Transducer Face (W/m^2)	Temporal & Spatial Peak Int. (W/m^2)
			Code	Freq. (MHz)	Dia. (mm)			
Unirad	100 series echocardiography	1538	530 Unirad	2.25	13	4.4	33	8.6×10^4
			537 Unirad	3.50	13	1.12	8.4	2.5×10^5
			540 Unirad	3.50	19	2.4	8.5	1.1×10^6
	Sonograph II general purpose	1538	530 Unirad	2.25	13	5.3	40	—
			537 Unirad	3.50	13	1.87	14	—
Physionics	A/B mode with model 671-CA receiver/pulser	520	—	2.0	13	4.2	32	—
			—	2.0	13	2.8	21	—
Picker/Physionics	Portascan general purpose with model 661 receiver/pulser	676	—	2.2	13	5.8	44	—
			—	2.2	13	9.4	71	—
Rohe Rohnar	1975 model general purpose pulse-echo scanner	1000	5601 R-R	2.25	13	5.1	38	3.1×10^5
			5616 R-R	2.25	19	6.3	22	3.8×10^6
Picker	Echoview 80L scanner including 80C system	1000	—	2.25	19	14.4	51	1.7×10^7
			—			1.9	60	—
Smith Kline Industries	Eko-line 20A	—	C10–C25	1.9–5.0	—	—	3–40	—
Searle	Phosonic-SM engineering std.	806	B101	1.6	19	9.1	32	2.7×10^6
			B102	2.25	13	5.6	42	—
			B103	3.5	19	2.7	9.5	3.7×10^6
			B104	2.25	19	6.8	24	4.8×10^6
			B106	5.0	13	1.48	11.1	—
			B106	5.0	13	1.62	12.2	—
A.D.R.	Sonovision real time unit	2600	—	2.0	10×10	—	—	8.9×10^3
		2600	—	2.0	10×10	—	—	4.0×10^3
Institute of Fundamental Technological Research, Warsaw	UG4	1000	—	2.25	20	—	5.9	2.3×10^{5c}

[a] Carson *et. al.*, 1978

[b] Pulse repetition frequency

[c] Etienne *et. al.*, 1976

TABLE 13—*Characteristics of O/B DOPPLER[a] Ultrasound Equipment*

Manufacturer	Ultrasound Unit	PRF (Hz)	Transducer Characteristics			Total Power Output (mW)	Average Intensity at Transducer Face (W/m^2)	Temporal & Spatial Peak Int. (W/m^2)
			Code	Freq. (MHz)	Dia. (mm) (split disc)			
Picker/Hitachi	E61-1B doppler unit	Cont.	5Z10D	5.0	10	7.6	190	—
Metrix	ET05 doppler	Cont.	ST5-2	2.25	25	37	160	—
Medisonics	FP3A ultrasound stethoscope fetal pulse detector	Cont.	Integral probe	2.25	13	1.43	23	—
Metrix Inc.	PET S/N 1858 pocket doppler	Cont.	ST5-2	2.25	25	18.3	72	—
Hewlett-Packard	Fetal monitoring with 1508A transmitter model	Cont.	15154B	2.25	20	31.7	200	—
Imex	Micropower fetal heart detector	Cont.	Integral probe	2.2	31.8	1.75 3.1 0.95	4.4 7.8 2.4	— — —

[a] Carson *et. al.*, 1978

TABLE 14—*Characteristics of OPHTHALMIC[a] Ultrasound Equipment*

Manufacturer	Ultrasound Unit	PRF (Hz)	Transducer Characteristics			Total Power Output (mW)	Average Intensity at Transducer Face (W/m^2)	Temporal & Spatial Peak Int. (W/m^2)
			Code	Freq. (MHz)	Dia. (mm)			
Kretz	Model 7200MA A-mode	561	Integral	8.0	4	0.61	49	—
Gruman Health System	Bronson Turner opthalmic scanner model M9010	?	Integral	10	6	0.060	2.1	—

[a] Carson *et. al.*, 1978

TABLE 15—*Characteristics of PERIPHERAL VASCULAR DOPPLER[a] Ultrasound Equipment*

Manufacturer	Ultrasound Unit	PRF (Hz)	Transducer Characteristics			Total Power Output (mW)	Average Intensity at Transducer Face (W/m^2)	Temporal & Spatial Peak Int. (W/m^2)
			Code	Freq. (MHz)	Dia. (mm)			
Parks	Model 806 directional doppler unit	Cont.	Integral	9.3	2.6	36	6780	—
Colorado State University	Experimental pulsed doppler	48,000	EDO Western Corp. P-E EC-65	7.5	3	10.6	1500	—
Medisonics	Model D-9 versatone bidirectional doppler	Cont.	P92	8	4.4	5.7	380	—
			P92	8	4.4	14	930	—
			P82	8	3.7	6.1	550	—

[a] Carson *et. al.*, 1978

the continuous (Doppler) wave machines are, in general, higher than the power outputs of pulsed wave machines. The average intensity at the transducer face for the peripheral vascular Doppler instruments are typically 10–100 times greater than the overall average output intensity of the machines cited in Tables 12–14.

All of the measurements quoted in Tables 12–15 were made in water (a relatively echo loss-free liquid). In relating total power output measured in water to power measured *in vivo*, Etienne *et al*, (1976) found that there was a 6–14 db intensity loss of the ultrasound beam in the patients with a gravid uterus.

The equipment units listed in Tables 12–15 represent but a small fraction of all of the machines in present clinical use (Carson *et al.*, 1978). The results of such a limited survey could prove misleading, if not considered in context, and should be accepted with due caution. Hopefully, these values should be confirmed by several groups sampling a much wider range of instruments. The development of articulated arm scanners and, more recently, real-time machines has proceeded at such a rate that rigorous studies of this type have been difficult.

3.5 Biological Effects

Bioeffects information regarding ultrasound is available from a variety of test systems (Baker and Dalrymple, 1978; Siegel *et al.*, 1979). Because of the potential implications for future generations, and because of low or non-threshold response in certain circumstances, chromosome damage by ultrasound has been extensively studied.

Chromosome aberrations in lymphocytes and other cells in culture have not been demonstrated after sonication (Hill *et al.*, 1972; Coakley *et al.*, 1972; Buckton and Baker, 1972; Watts and Hall, 1972; Brock *et al.*, 1973; Rott and Soldner, 1973; Braeman *et al.*, 1974; Levi *et al.*, 1974; Macintosh *et al.*, 1975). In these studies, a variety of ultrasonic devices, both continuous and pulse echo, were operated at frequency ranges from 870 kHz to 2.5 MHz. Intensity levels ranged from 30 mW cm^{-2} to 8 W cm^{-2}. Sonication times as long as 20 hours were used. Evidence that genetic consequences do not ensue after ultrasonic irradiation was provided by Lyon and Simpson (1974) who sonated mice and observed no induction of dominant lethal mutations or sterility in males, no drop in testicular weight or sperm count, and no induction of translocations of chromosome fragments in spermatocytes for up to eight weeks after a treatment. Similarly, in females, no

dominant lethal induction was detected in the period from several days before mating to the day of mating. The experiments, involved exposure to ultrasound of a 1.6 MHz frequency for 15 minutes. Studies were made at 1.6 W cm^{-2} continuous intensity or 0.9 W cm^{-2} pulsed intensity. The pulse duty cycle was 1:49; that is, ultrasound was generated 2 percent of the time. Genetic studies in other systems have also failed to show significant effects due to ultrasound exposure (Khokhar and Oliver, 1975; Combes, 1975).

At a higher level of cellular organization, lymphocyte cultures from a group of human abortuses showed no chromosomal effects after ultrasonication for as long as 10 hours prior to therapeutic abortion (Abdulla *et al.*, 1971). The exposure of the ovaries of pregnant rats to high intensity (10–100 W cm^{-2}) pulsed ultrasound for ten minutes produced no apparent effect on fetal development (Garrison *et al.*, 1973). An extensive retrospective clinical study of obstetric patients revealed no evidence of fetal or maternal injury (Hellman *et al.*, 1970). The records of 1114 normal obstetric patients undergoing ultrasound examination were reviewed and no evidence of increased fetal abnormality or abortion in comparison to the general population was observed (Hellman *et al.* 1970). Bernstine (1969) reviewed a series of 720 patients who had 5–15 minutes of ultrasound at greater than ten weeks of gestation; no evidence of hazard from the ultrasound was found.

Some thermal effects ascribed to ultrasound have been described in fetal mice. In these experiments, in fetal mice exposed to diagnostic level ultrasound for five hours, it was demonstrated that there was some degree of lethality (Shimizu and Shoji, 1973). Shoji *et al.* (1975) have described some developmental anomalies of the face and cranium of mice after exposure to 2.25 MHz ultrasound at 40 W cm^{-2} for five hours.

Pizzarello *et al.* (1974) have reported a retardation of growth in a rapidly proliferating embryonic tissue after ultrasonic exposure. In the test system, a retardation of limb growth in newts was seen in approximately 75 percent of test animals after a 5–10 minute exposure to 2.25 MHz pulsed ultrasound. These studies have been neither confirmed nor refuted.

At intensities, levels, and time periods above those used in the diagnostic application of ultrasound, evidence of biological effects has been observed (Lerner *et al.*, 1973; Fallon *et al.*, 1973; Dunn *et al.*, 1975). However, some of the observed effects seem to be reversible (Acton, 1974; Karduck and Wehmer, 1974).

Taylor and Pond (1972a, 1972b) irradiated the spinal cords of adult rats at peak intensities of 25 or 50 W cm^{-2} at frequencies of 0.5–6.9 MHz in the pulsed mode. This treatment resulted in paraplegia and/

or gross hemorrhage into the spinal cord. Damaging ability was maximal at the lowest frequency employed (0.5 MHz). Ultrasonic damaging ability was found to decrease with increasing frequency up to 5 MHz, at which level neither paraplegia nor hemorrhage could be detected. By changing duty cycles, Taylor and Pond (1972a; 1972b) found that hemorrhage occurred whenever an accumulated dose-time had been received. The lesion was characteristically different at each intensity. This suggests an inability of the damaged system to repair, or recover from ultrasound induced injury. Other workers, using different systems, have also observed an apparent lack of repair when the ultrasound exposures were fractionated (Bleany and Oliver, 1972). The implications of these data are that repeated ultrasonic exposures may eventually produce sufficient accumulated damage to cause clinically apparent injury. It should be pointed out, however, that the probability of reproducing this circumstance in diagnostic ultrasound studies is small. Further investigation of the biological effects at levels employed for diagnostic ultrasound studies in pediatric patients appears warranted.

3.6 Current Status of Pediatric Ultrasound

The data suggest that there are apparently little or no significant biological implications associated with diagnostic ultrasound exposure at levels currently employed in clinical practice. Based on these data and on other available information, a committee of the American Institute of Ultrasound in Medicine issued a statement dealing with mammalian *in vivo* ultrasonic effects (AIUM, 1982):

> "In over twenty years of use of diagnostic ultrasound, no clinically significant adverse biological effects on patients or equipment operators have been reported caused by exposures at intensities typical of present diagnostic instruments. This does not, however, imply that no biological effects exist. There remains the possibility that such effects, not currently recognized, will be identified through future research. Until more is known, it is recommended that diagnostic ultrasound ultilization be limited to that extent necessary to obtain sufficient clinical information in each patient. At this time, however, the benefits to patients of use of diagnostic ultrasound appear to outweigh whatever risks may be present."

Most diagnostic instruments operate at average intensities of less than 15 mW cm^{-2}, with peak intensities in the 4 to 7 W cm^{-2} range (Holmes, 1974). Under present operating parameters, there is little possibility of approaching time-intensity levels that are potentially harmful. However, with the increasing use of diagnostic ultrasound, the possibility of repeated ultrasonic exposures becomes greater and

total time-intensity levels may come within the attainable limits of current clinical machines. Certainly, until more information is available on the biological effects of ultrasound and particularly on the time-intensity relationships, machine operation should be kept within recommended intensity-duration levels. Real-time studies, which will continue to play an increasingly important role in pediatric patients, should facilitate compliance with these guidelines.

Appendix A

Tables of Mean Dose per Cumulated Activity (S) in Units of rad $\mu Ci^{-1}h^{-1}$ for Selected Radionuclides in Children of Selected Ages

Symbols used in Appendix A Tables have the following significance:

* includes non-penetrating component $\sum\Delta_n/2m$ contents
\+ includes non-penetrating component $\sum\Delta_n/m$ target
± includes non-penetrating component $\sum\Delta_n/m$ total body

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{51}Cr 5 Year

Target organs	Source Organs					
	Bladder Contents	Kidneys	Liver	Red Marrow	Spleen	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	2.23E-07	4.16E-06	2.27E-06	1.37E-06	6.46E-06	2.45E-06
Bladder wall	3.25E-04*	4.56E-07	6.04E-07	4.92E-07	2.96E-07	1.11E-06
G.I. (stomach wall)	5.56E-07	1.44E-06	2.19E-06	7.77E-07	4.22E-06	9.12E-07
G.I. (ULI[a] wall)	2.48E-06	1.55E-06	1.94E-06	1.71E-06	1.01E-06	1.17E-06
G.I. (LLI[b] wall)	5.68E-06	4.60E-07	3.42E-07	1.90E-06	4.16E-07	1.67E-06
G.I. (SI[c] + contents)	2.70E-06	1.98E-06	1.49E-06	2.08E-06	1.10E-06	1.49E-06
Gall bladder wall	5.69E-07	1.53E-06	7.08E-06	5.87E-07	2.14E-06	8.70E-07
Heart	1.16E-07	6.87E-07	3.10E-06	8.12E-07	1.75E-03	1.39E-06
Kidneys	3.21E-07	1.01E-04+	1.46E-06	1.60E-06	5.73E-06	1.37E-06
Liver	3.52E-07	1.62E-06	3.37E-05+	7.63E-07	1.07E-06	1.22E-06
Lungs	9.16E-08	5.77E-07	1.35E-06	8.19E-07	1.56E-06	1.55E-06
Marrow (red)	9.02E-07	1.92E-06	7.98E-07	3.08E-05+	1.11E-06	3.33E-06
Ovaries	—	1.30E-06	—	1.43E-06	—	6.74E-07
Pancreas	2.01E-07	3.13E-06	2.73E-06	5.88E-07	9.51E-06	1.43E-06
Salivary glands	6.55E-09	1.98E-08	5.48E-08	3.49E-07	4.26E-08	1.17E-06
Skeleton	4.03E-07	7.08E-07	4.68E-07	2.29E-06	5.82E-04	2.87E-06
Skin	6.29E-07	8.88E-07	8.19E-07	3.55E-07	8.12E-07	9.66E-07
Spleen	2.51E-07	5.06E-06	9.65E-07	1.18E-06	3.17E-04+	1.32E-06
Testes	2.89E-06	9.72E-08	1.49E-07	—	1.30E-06	—
Thymus	9.99E-09	1.96E-07	5.75E-07	6.18E-07	3.64E-07	1.15E-06
Thyroid	—	5.90E-08	—	8.81E-07	1.71E-08	1.32E-06
Total tissue	1.26E-06	9.92E-07	8.40E-07	8.88E-07	1.07E-06	1.33E-06
Uterus	1.03E-05	2.23E-06	2.14E-06	1.65E-06	5.75E-07	1.08E-06
Total body	1.83E-06+	1.69E-06+	1.73E-06+	1.55E-06+	1.75E-06+	1.52E-06+

[a] Upper large intestine
[b] Lower large intestine
[c] Small intestine

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)

^{67}Ga 1 Year

Target organs	Source Organs					
	Bladder Contents	ULI Contents	LLI Contents	Kidneys	Liver	Lungs
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	2.06E-06	3.57E-06	1.44E-05	4.10E-05	1.58E-05	1.30E-05
Bladder wall	3.97E-03*	2.23E-05	3.84E-05	4.50E-06	3.97E-06	4.80E-07
G.I. (stomach wall)	5.72E-06	1.68E-05	1.25E-05	1.27E-05	1.68E-05	9.66E-06
G.I. (ULI wall)	2.60E-05	1.98E-03*	3.47E-05	1.24E-05	2.08E-05	2.15E-06
G.I. (LLI wall)	4.30E-05	2.64E-05	2.47E-03*	6.18E-06	4.00E-06	9.42E-07
G.I. (SI + contents)	2.39E-05	1.05E-04	4.66E-05	1.58E-05	1.69E-05	2.42E-06
Gall bladder wall	7.14E-06	3.94E-05	8.83E-06	1.77E-05	5.03E-05	8.38E-06
Heart	1.24E-06	2.98E-06	1.86E-06	6.48E-06	1.35E-05	4.00E-05
Kidneys	4.99E-06	1.23E-05	6.65E-06	1.60E-03+	1.26E-05	5.09E-06
Liver	4.20E-06	1.57E-05	4.50E-06	1.19E-05	4.05E-04+	1.31E-05
Lungs	8.77E-07	2.57E-06	1.50E-06	4.56E-06	8.43E-06	7.37E-04+
Marrow (red)	1.11E-05	1.83E-05	2.18E-05	2.01E-05	8.90E-06	1.52E-05
Ovaries	5.85E-05	9.23E-05	7.87E-05	1.43E-05	7.04E-06	1.05E-06
Pancreas	3.47E-06	1.23E-05	7.41E-06	1.77E-05	3.34E-05	1.40E-05
Salivary glands	3.54E-07	1.02E-07	—	1.32E-06	5.59E-07	3.54E-06
Skeleton	4.30E-06	5.49E-06	6.78E-06	6.18E-06	4.17E-06	1.05E-05
Skin	3.12E-06	5.69E-06	5.06E-06	3.08E-06	2.99E-06	2.81E-06
Spleen	3.60E-06	9.52E-06	6.02E-06	3.97E-05	8.63E-06	1.34E-05
Testes	3.60E-05	1.11E-05	3.01E-05	1.91E-07	2.74E-06	9.66E-08
Thymus	8.23E-07	6.98E-07	9.26E-07	1.51E-06	3.41E-06	2.31E-05
Thyroid	—	—	—	2.89E-08	2.53E-06	4.83E-06
Total tissue	1.04E-05	9.52E-06	9.82E-06	8.14E-06	7.71E-06	9.03E-06
Uterus	8.33E-05	3.90E-05	6.25E-05	1.09E-05	7.47E-06	9.95E-07
Total body	1.84E-05+	1.89E-05+	1.84E-05+	1.73E-05+	1.79E-05+	1.72E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{67}Ga 1 Year

Target organs	Source Organs				
	Red Marrow	Ovaries	Spleen	Testes	Total Body ±
	S	*S*	*S*	*S*	*S*
Adrenals	1.34E-05	6.15E-06	3.57E-05	1.19E-06	1.50E-05
Bladder wall	1.15E-05	3.84E-05	2.29E-06	4.50E-05	1.62E-05
G.I. (stomach wall)	6.19E-06	9.79E-06	3.44E-05	1.84E-06	1.65E-05
G.I. (ULI wall)	1.27E-05	7.69E-05	6.68E-06	7.84E-06	1.52E-05
G.I. (LLI wall)	1.55E-05	6.18E-05	4.66E-06	2.34E-05	1.64E-05
G.I. (SI + contents)	1.72E-05	9.13E-05	1.01E-05	7.34E-06	1.79E-05
Gall bladder wall	7.14E-06	2.69E-05	3.24E-05	2.56E-06	1.55E-05
Heart	6.71E-06	2.80E-06	1.25E-05	3.25E-07	1.97E-05
Kidneys	1.64E-05	1.09E-05	3.57E-05	1.52E-06	1.53E-05
Liver	6.75E-06	7.31E-06	1.04E-05	1.51E-06	1.74E-05
Lungs	7.11E-06	1.43E-06	1.31E-05	4.60E-07	1.64E-05
Marrow (red)	6.26E-04+	2.08E-05	1.18E-05	6.02E-06	1.98E-05
Ovaries	4.93E-06	1.47E-01+	2.89E-06	1.02E-05	3.06E-05
Pancreas	1.11E-05	6.15E-06	7.14E-05	1.08E-06	1.78E-05
Salivary glands	3.37E-06	5.39E-08	1.25E-06	5.95E-08	1.37E-05
Skeleton	2.03E-05	6.08E-06	5.46E-06	4.07E-06	1.83E-05
Skin	3.24E-06	2.79E-06	2.76E-06	7.11E-06	1.22E-05
Spleen	8.07E-06	6.45E-06	3.97E-03+	8.40E-07	1.66E-05
Testes	1.66E-06	2.03E-05	9.79E-07	6.69E-02+	1.35E-05
Thymus	4.76E-06	4.86E-07	2.45E-06	5.13E-09	1.58E-05
Thyroid	2.89E-06	1.05E-07	3.08E-07	—	1.01E-05
Total Tissue	8.14E-06	1.19E-05	9.29E-06	7.44E-06	1.60E-05
Uterus	6.38E-06	1.17E-04	3.10E-06	1.11E-05	1.37E-05
Total body	1.75E-05+	1.91E-05+	1.82E-05+	1.60E-05+	1.65E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{67}Ga 5 Year

Target organs	Source Organs				
	Bladder	ULI Contents	LLI Contents	Kidneys	Liver
	S	*S*	*S*	*S*	*S*
Adrenals	9.29E-08	5.52E-06	1.34E-06	2.59E-05	8.40E-06
Bladder wall	2.61E-03*	1.07E-05	2.30E-05	2.49E-06	3.20E-06
G.I. (stomach wall)	2.24E-06	1.12E-05	6.08E-06	7.84E-06	1.30E-05
G.I. (ULI wall)	1.35E-05	1.13E-03*	1.96E-05	7.67E-06	7.47E-06
G.I. (LLI wall)	2.81E-05	1.15E-05	1.33E-03*	2.91E-06	1.80E-06
G.I. (SI + contents)	1.37E-05	6.78E-05	3.31E-05	1.08E-05	7.24E-06
Gall bladder wall	2.05E-06	2.14E-05	4.43E-06	1.13E-05	2.14E-05
Heart	4.43E-07	1.79E-06	7.51E-07	3.34E-06	1.46E-05
Kidneys	2.13E-06	8.47E-06	3.94E-06	9.67E-04+	7.57E-06
Liver	1.81E-06	8.90E-06	2.10E-06	8.17E-06	2.17E-04+
Lungs	4.07E-07	1.28E-06	4.40E-07	2.99E-06	7.64E-06
Marrow (red)	6.05E-06	1.04E-05	1.27E-05	1.18E-05	5.36E-06
Ovaries	3.80E-05	3.22E-05	7.80E-05	5.23E-06	1.59E-06
Pancreas	1.43E-06	5.13E-06	3.08E-06	1.60E-05	1.89E-05
Salivary glands	—	—	—	1.55E-07	5.06E-07
Skeleton	2.59E-06	3.44E-06	4.40E-06	4.33E-06	2.98E-06
Skin	1.65E-06	3.37E-06	2.87E-06	1.73E-06	1.79E-06
Spleen	1.47E-06	5.42E-06	3.74E-06	2.39E-05	5.32E-06
Testes	1.93E-05	4.56E-06	1.06E-05	3.21E-07	6.71E-07
Thymus	4.07E-07	3.05E-07	1.07E-07	1.06E-06	2.30E-06
Thyroid	6.38E-08	—	—	—	1.71E-07
Total tissue	6.08E-06	5.49E-06	5.85E-05	4.76E-06	4.07E-06
Uterus	3.30E-05	2.36E-05	2.23E-05	5.99E-06	2.88E-06
Total body	1.07E-05	1.10E-05+	1.07E-05+	1.00E-05+	1.03E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{67}Ga 5 Year

Target organs	Source Organs				
	Red Marrow	Ovaries	Spleen	Testes	Total Body ±
	S	*S*	*S*	*S*	*S*
Adrenals	6.98E-06	2.69E-06	3.26E-05	1.03E-07	8.41E-06
Bladder wall	1.89E-05	2.86E-05	1.37E-06	2.50E-05	7.59E-06
G.I. (stomach wall)	3.74E-06	3.77E-06	2.07E-05	9.89E-07	7.46E-06
G.I. (ULI wall)	7.77E-06	5.49E-05	4.56E-06	3.51E-06	7.34E-06
G.I. (LLI wall)	9.79E-06	1.29E-05	2.64E-05	1.36E-05	8.51E-06
G.I. (SI + contents)	1.09E-05	5.46E-05	5.75E-06	3.10E-06	8.77E-06
Gall bladder wall	4.53E-06	6.65E-06	1.15E-05	6.58E-07	5.98E-06
Heart	4.37E-06	1.01E-06	8.50E-06	2.33E-07	8.58E-06
Kidneys	9.06E-06	5.23E-06	2.50E-05	8.86E-07	8.34E-06
Liver	3.77E-06	4.46E-06	5.82E-06	5.89E-07	7.38E-06
Lungs	4.99E-06	6.68E-07	7.71E-06	8.76E-08	9.63E-06
Marrow (red)	2.46E-04+	1.26E-05	7.28E-06	3.01E-06	1.89E-05
Ovaries	8.50E-06	4.85E-02+	2.52E-06	6.00E-06	5.82E-06
Pancreas	6.25E-06	2.78E-06	4.76E-05	1.93E-07	8.15E-06
Salivary glands	1.36E-06	8.53E-11	5.52E-07	—	7.95E-06
Skeleton	1.27E-05	4.03E-06	3.80E-06	2.56E-06	1.63E-05
Skin	1.55E-06	1.41E-06	1.69E-06	2.48E-06	6.48E-06
Spleen	5.23E-06	1.90E-06	2.24E-03+	2.94E-07	7.78E-06
Testes	2.24E-06	1.45E-05	3.20E-06	6.17E-02+	9.96E-06
Thymus	2.45E-06	1.76E-07	1.87E-06	3.54E-08	7.95E-06
Thyroid	2.81E-06	—	3.87E-06	—	6.45E-06
Total tissue	4.33E-06	7.51E-06	5.19E-06	4.43E-06	8.18E-06
Uterus	6.61E-06	1.52E-04	3.16E-06	9.95E-06	5.34E-06
Total body	9.63E-06+	1.12E-05+	1.04E-05+	9.20E-06+	9.20E-06

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)

^{99m}Tc Newborn

Target organs	Source Organs							
	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	ULI Contents	LLI Contents	Kidneys	Liver
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	5.29E-06	1.73E-05	1.35E-05	1.63E-05	1.23E-05	4.92E-06	9.26E-05	2.57E-05
Bladder wall	7.30E-03*	1.71E-05	1.15E-05	4.07E-05	4.07E-05	5.45E-05	9.07E-06	1.61E-05
G.I. (stomach wall)	1.07E-05	3.41E-03*	6.69E-03+	3.11E-05	2.30E-05	2.02E-05	1.63E-05	3.38E-05
G.I. (ULI wall)	3.46E-05	2.90E-05	3.11E-05	1.71E-04	2.53E-03*	4.84E-05	2.37E-05	4.02E-05
G.I. (LLI wall)	5.61E-05	1.57E-05	1.78E-05	6.92E-04	2.90E-05	2.85E-03*	1.07E-05	7.32E-06
G.I. (SI + contents)	3.72E-05	2.85E-05	3.01E-05	1.57E-03+	1.31E-04	6.62E-05	3.33E-05	3.01E-05
Gall bladder wall	1.59E-05	8.27E-05	1.00E-04	6.54E-05	4.97E-05	1.55E-05	2.71E-05	9.84E-05
Heart	2.71E-06	1.85E-05	1.94E-05	6.52E-06	5.85E-06	2.52E-06	8.51E-06	1.75E-05
Kidneys	7.24E-06	1.76E-05	1.71E-05	3.25E-05	1.98E-05	1.23E-05	2.43E-03+	2.61E-05
Liver	1.09E-05	3.40E-05	3.62E-05	2.51E-05	2.98E-05	7.69E-06	2.38E-05	4.84E-04+
Lungs	3.03E-06	1.73E-05	1.87E-05	6.06E-06	4.81E-06	3.03E-06	1.60E-05	1.86E-05
Marrow (red)	1.49E-05	1.40E-05	1.43E-05	3.72E-05	3.11E-05	3.11E-05	3.62E-05	1.63E-05
Ovaries	4.95E-07	1.13E-05	1.34E-05	1.12E-04	1.48E-04	1.04E-04	3.01E-05	9.07E-06
Pancreas	1.36E-05	1.06E-04	1.03E-04	3.01E-05	2.09E-05	1.09E-05	3.43E-05	4.52E-05
Salivary glands	1.49E-07	1.60E-06	1.22E-06	4.58E-07	4.60E-07	3.91E-07	1.03E-06	3.09E-06
Skeleton	6.76E-06	7.90E-06	8.17E-06	1.36E-05	1.17E-05	1.25E-05	1.40E-05	8.94E-06
Skin	1.00E-05	1.85E-05	1.98E-05	1.59E-05	1.72E-05	1.34E-05	2.23E-05	2.00E-05
Spleen	8.38E-06	5.75E-05	5.85E-05	3.30E-05	1.49E-05	1.75E-05	7.13E-05	1.63E-05
Testes	—	6.60E-06	2.53E-06	1.09E-05	1.33E-05	4.76E-05	—	—
Thymus	8.70E-05	1.47E-05	1.36E-05	1.24E-05	1.30E-05	1.44E-05	6.28E-06	1.58E-05
Thyroid	—	2.05E-06	4.76E-06	5.51E-07	—	—	2.58E-06	2.04E-06
Total tissue	1.34E-05	1.21E-05	1.34E-05	1.39E-05	1.32E-05	1.44E-05	1.02E-05	1.13E-05
Uterus	8.72E-05	2.57E-05	1.80E-05	1.80E-04	8.03E-05	6.22E-05	2.30E-05	1.56E-05
Total body	2.33E-05+	2.38E-05+	2.38E-05+	2.52E-05+	2.45E-05+	2.40E-05+	2.13E-05+	2.37E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{99m}Tc Newborn

Target organs	Source Organs						
	Lungs	Red Marrow	Salivary Glands	Skeleton	Spleen	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.47E-05	2.21E-05	7.45E-07	9.12E-06	5.93E-05	2.61E-06	2.09E-05
Bladder wall	3.40E-06	1.11E-05	3.99E-07	6.17E-06	9.42E-06	2.64E-07	2.61E-05
G.I. (stomach wall)	1.43E-05	8.86E-06	1.05E-06	6.09E-06	5.29E-05	2.26E-06	2.25E-05
G.I. (ULI wall)	5.75E-06	2.23E-05	4.81E-07	6.41E-06	2.54E-05	9.98E-07	2.46E-05
G.I. (LLI wall)	3.40E-06	2.51E-05	3.06E-07	1.06E-05	1.42E-05	3.62E-07	2.24E-05
G.I. (SI + contents)	6.41E-06	2.50E-05	5.64E-07	9.90E-06	3.19E-05	9.15E-07	2.48E-05
Gall bladder wall	1.89E-05	1.56E-05	1.07E-06	5.16E-06	5.11E-05	1.49E-06	2.48E-05
Heart	5.43E-05	9.63E-06	4.89E-06	8.22E-06	1.55E-05	1.02E-05	2.45E-05
Kidneys	9.79E-06	2.74E-05	8.43E-07	1.09E-05	6.86E-05	1.51E-06	2.20E-05
Liver	2.09E-05	1.07E-05	1.22E-06	6.68E-06	1.70E-05	2.71E-06	2.28E-05
Lungs	1.06E-03+	1.23E-05	5.29E-06	9.41E-06	2.03E-05	1.08E-05	2.24E-05
Marrow (red)	1.62E-05	9.84E-04+	5.27E-06	3.25E-05	2.13E-05	6.70E-06	2.69E-05
Ovaries	5.43E-06	2.40E-05	3.19E-06	1.21E-05	1.34E-05	—	2.54E-05
Pancreas	2.65E-05	1.29E-05	6.06E-07	7.24E-06	1.32E-04	2.98E-06	2.73E-05
Salivary glands	5.85E-06	3.70E-06	6.56E-03+	1.40E-05	1.92E-06	7.18E-05	2.21E-05
Skeleton	1.34E-05	2.95E-05	1.90E-05	9.97E-05+	1.09E-05	1.36E-05	2.41E-05
Skin	1.96E-05	5.85E-06	1.27E-05	5.59E-06	1.81E-05	6.49E-06	1.63E-05
Spleen	2.38E-05	1.68E-05	1.73E-06	8.43E-06	5.06E-03+	2.42E-06	2.33E-05
Testes	—	—	—	3.80E-06	—	—	—
Thymus	2.41E-05	1.01E-05	6.65E-06	8.30E-06	9.39E-06	2.71E-05	2.59E-05
Thyroid	1.02E-05	3.67E-06	7.69E-05	9.66E-06	3.01E-06	4.05E-02+	1.89E-05
Total tissue	1.32E-05	1.11E-05	1.02E-05	8.67E-06	1.40E-05	1.67E-05	2.09E-05
Uterus	2.41E-06	1.84E-05	1.12E-06	6.09E-06	1.82E-05	9.26E-07	2.48E-05
Total body	2.25E-05+	2.21E-05+	2.11E-05+	2.10E-05+	2.40E-05+	2.38E-05+	2.11E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{99m}Tc 1 Year

Target organs	Source Organs								
	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	ULI Contents	LLI Contents	Kidneys	Liver	Lungs
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.91E-06	7.42E-06	9.95E-06	5.24E-06	5.64E-06	2.64E-06	3.30E-05	1.14E-05	7.85E-06
Bladder wall	1.81E-03*	5.48E-06	5.37E-06	3.78E-05	2.22E-05	3.83E-05	4.07E-06	4.87E-06	8.06E-07
G.I. (stomach wall)	4.44E-06	8.60E-04*	1.58E-03+	1.46E-05	1.46E-05	8.78E-06	9.36E-06	1.31E-05	7.02E-06
G.I. (ULI wall)	1.92E-05	1.37E-05	1.49E-05	1.15E-04	9.30E-04*	3.19E-05	9.20E-06	1.78E-05	1.89E-06
G.I. (LLI wall)	3.75E-05	6.92E-06	6.81E-06	2.36E-05	2.03E-05	1.18E-03*	3.94E-06	2.98E-06	6.36E-07
G.I. (SI + contents)	2.04E-05	1.31E-05	1.47E-05	6.74E-04+	8.46E-05	4.04E-05	1.36E-05	1.25E-05	1.62E-06
Gall bladder wall	3.54E-06	4.76E-05	4.52E-05	3.30E-05	2.82E-05	1.02E-05	2.11E-05	4.23E-05	3.70E-06
Heart	9.63E-07	1.02E-05	9.95E-06	2.52E-06	2.85E-06	9.60E-07	4.47E-06	1.35E-05	3.09E-05
Kidneys	3.40E-06	8.91E-06	9.10E-06	9.74E-06	1.01E-05	5.59E-06	7.30E-04+	1.05E-05	3.88E-06
Liver	3.70E-06	1.43E-05	1.43E-05	1.07E-05	1.29E-05	3.30E-06	9.87E-06	2.01E-04+	9.66E-06
Lungs	6.60E-07	6.78E-06	7.39E-06	1.69E-06	1.95E-06	9.23E-07	3.78E-06	7.82E-06	3.39E-04+
Marrow (red)	9.28E-06	7.55E-06	7.63E-06	1.40E-05	1.61E-05	1.90E-05	1.71E-05	7.79E-06	8.35E-06
Ovaries	3.19E-05	—	3.62E-06	7.29E-05	5.85E-05	6.33E-05	7.82E-06	7.10E-06	3.19E-06
Pancreas	3.25E-06	4.39E-05	4.12E-05	8.35E-06	7.93E-06	5.27E-06	1.54E-05	2.15E-05	1.17E-05
Salivary glands	5.59E-06	4.76E-07	4.97E-07	8.67E-08	1.24E-07	2.08E-08	2.66E-07	5.85E-07	3.01E-06
Skeleton	3.67E-06	3.38E-06	3.46E06	4.36E-06	4.87E-06	6.01E-06	5.29E-06	3.48E-06	5.77E-06
Skin	2.35E-06	5.19E-06	5.19E-06	4.15E-06	4.42E-06	3.78E-06	2.61E-06	2.30E-06	2.22E-06
Spleen	2.23E-06	2.65E-05	2.64E-05	6.57E-06	7.87E-06	4.84E-06	3.09E-05	7.82E-06	1.06E-05
Testes	3.51E-05	3.09E-06	9.15E-07	1.18E-05	3.78E-06	1.02E-05	8.06E-07	1.52E-06	—
Thymus	5.21E-07	3.09E-06	2.74E-06	8.83E-07	1.02E-06	2.44E-07	1.37E-06	4.12E-06	1.63E-05
Thyroid	3.75E-06	8.59E-07	1.34E-06	—	—	—	3.06E-08	3.33E-07	5.24E-06
Total tissue	8.54E-06	6.78E-06	7.21E-06	8.65E-06	7.74E-06	7.95E-06	6.52E-06	6.28E-06	6.84E-06
Uterus	7.98E-05	9.26E-06	2.31E-06	1.09E-04	4.81E-05	3.14E-06	7.79E-06	4.31E-06	9.68E-07
Total body	1.13E-05+	1.10E-05+	1.08E-05+	1.21E-05+	1.16E-05+	1.12E-05+	1.03E-05+	1.09E-05+	9.96E-06+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{99m}Tc 1 Year

Target organs	Source Organs							
	Red Marrow	Ovaries	Salivary Glands	Skeleton	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.39E-05	3.51E-06	4.92E-07	2.90E-06	3.17E-05	3.83E-07	—	1.02E-06
Bladder wall	6.57E-06	4.07E-05	—	2.52E-06	2.19E-06	3.43E-05	—	1.01E-06
G.I. (stomach wall)	5.13E-06	7.08E-06	5.05E-07	2.04E-06	2.74E-05	1.03E-06	7.77E-07	1.01E-06
G.I. (ULI wall)	1.24E-05	6.89E-05	1.85E-07	2.93E-06	6.60E-06	6.28E-06	1.89E-07	1.02E-06
G.I. (LLI wall)	1.18E-05	5.51E-05	8.70E-08	4.58E-06	4.31E-06	2.18E-05	9.10E-08	9.48E-06
G.I. (SI + contents)	1.35E-05	8.06E-05	1.96E-07	3.75E-06	7.87E-06	5.03E-06	2.31E-07	1.16E-06
Gall bladder wall	6.09E-06	1.24E-05	—	3.11E-06	2.11E-05	1.53E-06	1.75E-06	1.05E-06
Heart	5.77E-06	1.74E-06	1.86E-06	3.06E-06	1.11E-05	2.98E-07	3.43E-06	1.22E-06
Kidneys	1.15E-05	9.15E-06	3.78E-07	3.72E-06	3.11E-05	1.29E-06	3.78E-07	9.85E-06
Liver	5.19E-06	6.09E-06	6.14E-07	2.74E-06	8.70E-06	1.19E-06	9.20E-07	1.02E-06
Lungs	5.85E-06	1.40E-06	2.93E-06	4.10E-06	1.09E-05	2.47E-07	5.56E-06	9.46E-06
Marrow (red)	2.79E-04+	1.85E-05	2.95E-06	1.37E-05	1.07E-05	5.11E-06	4.10E-06	1.25E-06
Ovaries	1.26E-05	6.09E-02+	—	—	2.69E-06	1.44E-05	—	9.30E-06
Pancreas	7.34E-06	5.21E-06	1.22E-06	3.96E-06	5.37E-05	7.26E-07	8.03E-07	1.23E-06
Salivary glands	2.04E-06	4.07E-08	2.85E-04	6.46E-06	7.90E-07	—	3.48E-05	7.89E-06
Skeleton	1.35E-05	5.43E-06	9.55E-06	3.69E-05+	4.81E-06	3.51E-06	7.85E-06	1.14E-06
Skin	2.45E-06	2.19E-06	7.37E-06	2.50E-06	2.16E-06	5.77E-06	2.28E-06	6.32E-06
Spleen	6.33E-06	5.29E-06	6.09E-07	3.25E-06	1.79E-03+	8.91E-07	1.20E-06	1.06E-06
Testes	5.05E-06	8.46E-06	—	9.74E-07	2.50E-07	2.81E-02+	—	5.35E-06
Thymus	3.64E-06	6.44E-07	5.53E-06	3.14E-06	3.30E-06	1.53E-07	1.58E-05	1.05E-06
Thyroid	2.26E-06	—	3.94E-05	3.62E-06	4.87E-07	—	1.67E-02+	8.07E-06
Total tissue	6.36E-06	9.42E-06	4.81E-06	4.18E-06	7.47E-06	6.04E-06	8.88E-06	9.18E-06
Uterus	1.01E-05	1.06E-04	—	2.18E-06	4.31E-06	1.43E-05	—	4.60E-05
Total body	1.04E-05+	1.18E-05+	9.51E-06+	9.35E-06+	1.10E-05+	9.21E-06+	1.11E-05+	9.69E-06

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)

^{99m}Tc 5 Year

Target organs	Source Organs								
	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	ULI Contents	LLI Contents	Kidneys	Liver	Lungs
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	7.02E-07	6.04E-06	4.36E-06	2.87E-06	2.74E-06	5.77E-06	2.21E-05	6.92E-06	6.17E-06
Bladder wall	1.19E-03*	1.84E-06	1.80E-06	1.19E-05	9.58E-06	1.99E-05	1.68E-06	1.27E-06	4.23E-07
G.I. (stomach wall)	2.23E-06	4.89E-04*	8.45E-04+	8.01E-06	9.74E-06	4.92E-06	5.99E-06	9.34E-06	4.42E-06
G.I. (ULI wall)	1.00E-05	8.06E-06	9.63E-06	5.53E-05	5.38E-04*	1.65E-05	6.60E-06	7.29E-06	1.03E-06
G.I. (LLI wall)	2.23E-05	4.02E-06	3.51E-06	2.04E-05	1.20E-05	5.40E-04*	2.61E-06	1.19E-06	4.04E-07
G.I. (SI + contents)	1.14E-05	7.85E-06	8.70E-06	3.19E-04+	5.60E-05	2.74E-05	8.88E-04	5.88E-06	1.03E-06
Gall bladder wall	2.90E-06	3.01E-05	2.66E-05	1.55E-05	1.80E-05	3.33E-06	9.12E-06	2.24E-05	3.01E-06
Heart	3.86E-07	7.71E-06	8.27E-06	1.33E-06	1.33E-06	5.59E-07	2.82E-06	1.23E-05	1.77E-05
Kidneys	1.39E-06	6.22E-06	6.44E-06	7.98E-06	6.30E-06	3.22E-06	4.48E-04+	6.46E-06	2.21E-06
Liver	1.38E-06	8.65E-06	9.10E-06	5.32E-06	7.10E-06	1.60E-06	6.49E-06	1.12E-04+	5.75E-06
Lungs	2.74E-07	4.02E-06	4.42E-06	7.98E-07	9.31E-07	3.88E-07	2.41E-06	6.20E-06	1.83E-04+
Marrow (red)	5.69E-06	4.52E-06	4.55E-06	1.18E-05	9.39E-06	1.13E-05	1.04E-05	4.63E-06	5.16E-06
Ovaries	1.73E-05	4.39E-06	2.71E-06	3.86E-05	3.64E-05	4.28E-05	4.07E-06	2.59E-06	5.56E-08
Pancreas	1.21E-06	2.64E-05	2.71E-05	4.87E-06	5.43E-06	2.38E-06	1.25E-05	1.56E-05	6.14E-06
Salivary glands	3.83E-08	2.61E-07	2.05E-07	1.67E-07	9.60E-08	3.96E-08	7.45E-08	2.18E-07	1.63E-06
Skeleton	2.38E-06	2.33E-06	2.36E-06	3.72E-06	3.11E-06	3.88E-06	3.78E-06	2.58E-06	3.94E-06
Skin	1.32E-06	3.06E-06	3.06E-06	2.62E-06	2.66E-06	2.46E-06	1.39E-06	1.28E-06	2.93E-06
Spleen	1.07E-06	1.79E-05	1.76E-05	4.12E-06	4.04E-06	2.50E-06	2.19E-05	4.68E-06	5.75E-06
Testes	1.69E-05	5.08E-07	8.01E-07	1.39E-06	2.69E-06	7.93E-06	1.23E-08	8.17E-07	—
Thymus	4.02E-08	1.24E-06	1.34E-06	3.25E-07	2.85E-07	1.15E-07	6.94E-07	2.23E-06	1.06E-05
Thyroid	2.09E-08	6.06E-07	6.65E-07	—	1.08E-07	—	5.96E-08	2.28E-07	3.11E-06
Total tissue	5.03E-06	3.86E-06	6.30E-06	4.76E-06	4.52E-06	4.81E-06	3.88E-06	3.35E-06	3.96E-06
Uterus	3.40E-05	2.60E-06	2.74E-06	5.11E-05	2.59E-05	2.32E-05	2.30E-06	2.11E-06	2.10E-07
Total body	6.77E-06+	6.56E-06+	6.43E-06+	7.17E-06+	7.01E-06+	6.82E-06+	6.24E-06+	6.43E-06+	5.92E-06+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)

^{99m}Tc 5 Year

Target organs	Source Organs							
	Red Marrow	Ovaries	Salivary Glands	Skeleton	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	9.26E-06	2.38E-06	—	5.53E-06	2.18E-05	1.54E-07	—	5.71E-06
Bladder wall	3.96E-06	2.58E-05	3.06E-08	1.64E-06	1.10E-06	2.06E-05	—	4.96E-06
G.I. (stomach wall)	2.69E-06	3.03E-06	2.20E-07	1.38E-06	1.69E-05	5.85E-07	3.88E-07	4.03E-06
G.I. (ULI wall)	6.22E-06	4.81E-05	8.78E-08	1.95E-06	4.12E-06	1.92E-06	9.34E-08	5.12E-06
G.I. (LLI wall)	7.08E-06	9.95E-06	6.17E-08	2.09E-06	1.82E-06	1.29E-05	1.73E-08	5.31E-06
G.I. (SI + contents)	8.09E-06	4.60E-05	4.36E-08	2.47E-06	4.55E-06	2.79E-06	9.63E-08	5.68E-06
Gall bladder wall	5.00E-06	7.45E-06	—	1.61E-06	9.36E-06	9.71E-07	2.66E-07	4.36E-06
Heart	2.79E-06	7.77E-07	9.10E-07	2.55E-06	6.86E-06	9.84E-08	1.80E-06	5.39E-06
Kidneys	7.05E-06	4.34E-06	1.58E-07	2.61E-06	2.19E-05	6.46E-07	1.78E-07	5.28E-06
Liver	2.87E-06	3.56E-06	2.93E-07	1.75E-06	4.76E-06	4.26E-07	4.39E-07	4.40E-06
Lungs	3.56E-06	5.35E-07	1.88E-06	2.63E-06	6.36E-06	6.30E-08	3.59E-06	5.79E-06
Marrow (red)	1.10E-04+	1.09E-05	1.98E-06	9.10E-06	6.25E-06	2.82E-06	2.63E-06	1.20E-05
Ovaries	8.11E-06	2.05E-02+	—	1.79E-06	1.93E-06	3.40E-06	—	2.95E-06
Pancreas	3.83E-06	2.22E-06	1.71E-07	2.74E-06	4.04E-05	3.14E-07	6.04E-07	4.80E-06
Salivary glands	1.43E-06	4.31E-08	2.24E-04	5.40E-06	1.57E-07		3.30E-05	4.25E-06
Skeleton	7.47E-06	3.48E-06	6.01E-06	2.24E-05+	3.30E-06	2.20E-06	4.73E-06	1.01E-05
Skin	1.26E-06	1.14E-06	6.62E-06	1.52E-06	1.28E-06	2.03E-06	2.45E-06	3.46E-06
Spleen	4.07E-06	1.90E-06	2.58E-07	2.28E-06	1.04E-03+	2.63E-07	3.35E-07	5.12E-06
Testes	6.14E-07	6.33E-06	—	2.47E-06	1.40E-07	2.60E-02+	—	3.79E-06
Thymus	2.21E-06	2.57E-07	3.37E-06	1.95E-06	1.59E-06	3.86E-08	1.29E-05	4.16E-06
Thyroid	9.63E-07	—	2.65E-05	2.79E-06	2.65E-07	—	8.45E-03+	4.32E-06
Total tissue	3.40E-06	5.91E-06	2.58E-06	2.69E-06	4.28E-06	3.54E-06	4.73E-06	4.91E-06
Uterus	4.42E-06	9.95E-05	—	1.04E-06	3.14E-06	6.14E-06	—	5.76E-06
Total body	5.65E-06+	7.25E-06+	5.25E-06+	5.41E-06+	6.53E-06+	5.49E-06+	6.24E-06+	5.55E-06

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{111}In Newborn

Target organs	Source Organs		
	Bladder Content	Kidneys	Total Body ±
	S	*S*	*S*
Adrenals	1.70E-05	3.70E-04	6.33E-05
Bladder wall	1.60E-02*	3.79E-05	7.56E-05
G.I. (stomach wall)	4.75E-05	6.90E-05	7.00E-05
G.I. (ULI wall)	1.40E-04	7.50E-05	7.54E-05
G.I. (LLI wall)	2.04E-04	3.75E-05	7.89E-05
G.I. (SI + contents)	1.30E-04	1.18E-04	7.16E-05
Gall bladder	8.04E-05	1.21E-04	1.19E-04
Heart	1.16E-05	2.97E-05	7.69E-05
Kidneys	2.42E-05	4.28E-03+	6.40E-05
Liver	3.23E-05	8.61E-05	7.04E-05
Lungs	8.91E-06	3.25E-05	6.77E-05
Marrow (red)	4.25E-05	1.27E-04	8.45E-05
Ovaries	2.87E-04	7.63E-05	4.76E-05
Pancreas	3.75E-05	1.50E-04	8.12E-05
Salivary glands	2.26E-07	2.91E-06	5.89E-05
Skeleton	1.89E-05	4.75E-05	7.15E-05
Skin	5.46E-05	7.77E-05	4.70E-05
Spleen	2.02E-05	2.97E-04	7.18E-05
Testes	—	—	—
Thymus	3.52E-04	1.76E-05	
Thyroid	1.92E-06	7.03E-06	4.56E-05
Total tissue	4.96E-05	4.31E-05	6.26E-05
Uterus	3.34E-06	8.08E-05	6.78E-05
Total body	7.10E-05+	6.97E-05+	6.38E-05+

S, Mean Dose Per Cumulated Activity (rad/μci·hr)
^{111}In 1 Year

Target organs	Source Organs		
	Bladder Contents	Kidneys	Total Body ±
	S	*S*	*S*
Adrenals	5.22E-06	1.28E-04	2.93E-05
Bladder wall	4.33E-03*	1.25E-05	3.13E-05
G.I. (stomach wall)	1.35E-05	2.66E-05	2.78E-05
G.I. (ULI wall)	6.82E-05	3.46E-05	2.95E-05
G.I. (LLI wall)	1.30E-04	1.44E-05	3.11E-05
G.I. (SI + contents)	6.63E-05	4.59E-05	3.45E-05
Gall Bladder wall	3.27E-05	3.60E-05	3.36E-05
Heart	2.39E-06	1.49E-05	3.41E-05
Kidneys	1.05E-05	1.89E-03+	2.77E-05
Liver	1.09E-05	3.16E-05	3.12E-05
Lungs	2.30E-06	1.12E-05	2.88E-05
Marrow (red)	2.39E-05	5.19E-05	3.70E-05
Ovaries	1.97E-04	1.99E-05	4.43E-05
Pancreas	7.02E-06	5.77E-05	3.20E-05
Salivary glands	1.74E-07	1.43E-06	2.17E-05
Skeleton	9.34E-06	1.56E-05	3.38E-05
Skin	1.20E-05	2.20E-05	1.76E-05
Spleen	7.94E-06	1.11E-04	2.75E-05
Testes	1.30E-04	—	1.97E-05
Thymus	1.07E-06	3.89E-06	2.90E-05
Thyroid	—	—	3.07E-05
Total tissue	2.92E-05	2.29E-05	2.75E-05
Uterus	3.22E-04	2.53E-05	2.29E-05
Total body	3.40E-05+	3.13E-05+	2.92E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{111}In 5 Year

Target organs	Source Organs					
	Bladder Content	Kidneys	Liver	Red Marrow	Spleen	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	1.58E-06	7.87E-05	2.16E-05	1.50E-05	5.62E-05	2.58E-05
Bladder wall	2.80E-03*	4.66E-06	6.41E-06	1.07E-05	4.14E-06	8.58E-05
G.I. (stomach wall)	4.55E-06	1.82E-05	2.70E-05	8.63E-06	5.85E-06	1.25E-05
G.I. (ULI wall)	3.27E-05	2.39E-05	2.23E-05	2.04E-05	1.07E-05	1.49E-05
G.I. (LLI wall)	6.63E-05	6.76E-06	3.70E-06	2.26E-05	4.83E-06	1.34E-05
G.I. (SI + contents)	3.51E-05	2.65E-05	1.83E-05	2.59E-05	1.40E-05	1.57E-05
Gall bladder wall	9.60E-06	2.80E-05	8.06E-05	1.06E-05	2.69E-05	9.01E-06
Heart	1.37E-06	9.34E-06	3.92E-05	1.05E-05	2.03E-05	1.37E-05
Kidneys	5.69E-06	1.18E-03+	1.97E-05	2.39E-05	7.51E-05	1.58E-05
Liver	4.29E-06	2.02E-05	3.19E-04+	8.55E-05	1.41E-05	1.20E-05
Lungs	8.73E-07	7.26E-06	2.00E-05	1.02E-05	2.13E-05	1.77E-05
Marrow (red)	1.37E-05	2.97E-05	1.18E-05	2.66E-04+	1.68E-05	4.14E-05
Ovaries	5.79E-05	9.43E-06	1.27E-05	3.20E-05	6.46E-06	9.23E-06
Pancreas	2.81E-06	3.56E-05	5.09E-05	1.13E-05	1.24E-04	1.37E-05
Salivary glands	—	—	1.44E-06	4.64E-06	1.15E-06	1.66E-05
Skeleton	5.89E-06	1.06E-05	6.84E-06	2.98E-05	9.08E-06	3.43E-05
Skin	7.25E-06	1.21E-05	1.00E-05	4.21E-06	1.06E-05	9.49E-06
Spleen	2.87E-06	7.20E-05	1.35E-05	1.06E-06	2.70E-03+	1.32E-05
Testes	4.95E-05	—	—	4.84E-06	—	5.04E-06
Thymus	—	2.13E-06	7.71E-06	6.61E-06	4.91E-06	1.26E-05
Thyroid	—	—	1.30E-06	8.00E-06	4.77E-07	1.40E-05
Total tissue	1.69E-05	1.32E-05	1.11E-05	1.12E-05	1.45E-05	1.41E-05
Uterus	1.30E-04	1.44E-05	7.34E-06	1.91E-05	1.06E-05	1.29E-05
Total body	2.06E-05+	1.88E-05+	1.95E-05+	1.71E-05+	1.97E-05+	1.66E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)

^{123}I Newborn

Target organs	Source Organs							
	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	Kidneys	Liver	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	7.00E-06	2.04E-05	2.44E-05	1.65E-05	1.97E-04	4.20E-05	3.00E-06	4.40E-05
Bladder wall	1.22E-02*	1.97E-05	1.14E-05	6.60E-05	1.47E-05	1.45E-05	6.30E-06	3.88E-05
G.I. (stomach wall)	1.70E-05	5.75E-03*	1.12E-02+	4.50E-05	3.31E-05	5.60E-05	3.33E-06	4.87E-05
G.I. (ULI wall)	7.00E-05	5.70E-05	6.20E-05	3.36E-04	4.30E-05	6.80E-05	1.02E-06	3.85E-05
G.I. (LLI wall)	1.06E-04	2.57E-05	2.29E-05	1.29E-04	1.69E-05	8.40E-06	7.00E-07	3.89E-05
G.I. (SI +contents)	6.40E-05	4.80E-05	5.20E-05	2.73E-03+	5.60E-05	5.10E-05	1.70E-06	4.26E-05
Gall bladder wall	4.20E-05	1.95E-04	1.92E-04	1.15E-04	5.90E-05	2.01E-04	—	4.30E-05
Heart	4.50E-06	2.36E-05	3.08E-05	7.80E-06	1.21E-05	3.22E-05	1.54E-05	4.23E-05
Kidneys	1.03E-05	2.45E-05	2.70E-05	5.00E-05	4.17E-03+	4.30E-05	1.87E-06	3.94E-05
Liver	1.55E-05	5.90E-05	6.40E-05	4.20E-05	4.00E-05	8.56E-04+	3.70E-06	4.05E-05
Lungs	3.45E-06	2.97E-05	3.28E-05	8.50E-06	1.52E-05	3.14E-05	1.54E-05	4.06E-05
Marrow (red)	2.65E-05	2.31E-05	2.33E-05	8.50E-05	8.10E-05	2.88E-05	1.19E-05	5.74E-05
Ovaries	1.51E-04	2.52E-05	3.70E-05	3.56E-04	5.20E-05	2.12E-05	—	3.41E-05
Pancreas	1.50E-05	1.84E-04	2.30E-04	4.60E-05	7.00E-05	8.80E-05	3.80E-06	4.82E-05
Salivary glands	4.80E-07	1.85E-06	2.64E-06	5.30E-07	8.40E-07	9.80E-07	1.26E-04	3.41E-05
Skeleton	1.14E-05	1.36E-05	1.38E-05	2.86E-06	2.96E-05	1.60E-05	2.64E-05	5.06E-05
Skin	2.34E-05	3.12E-05	2.90E-05	2.49E-05	3.46E-05	3.20E-05	1.39E-05	2.73E-05
Spleen	1.35E-05	7.50E-06	1.08E-04	5.20E-05	1.26E-04	2.47E-05	1.54E-06	4.01E-05
Testes	—	5.10E-06	6.90E-06	2.29E-05	—	—	—	—
Thymus	1.80E-04	1.99E-05	1.91E-05	2.17E-05	6.20E-06	1.88E-05	4.60E-05	4.76E-05
Thyroid	5.40E-07	1.60E-07	1.75E-06	1.29E-06	6.80E-07	8.60E-07	6.81E-02+	3.06E-05
Total tissue	2.39E-05	2.09E-05	2.31E-05	2.33E-05	2.03E-05	1.86E-05	3.90E-05	3.57E-05
Uterus	1.50E-04	2.51E-05	3.38E-05	3.08E-04	3.41E-05	2.52E-05	2.51E-07	4.96E-05
Total body	4.10E-05+	4.14E-05+	4.10E-05+	4.38E-05+	4.00E-05+	4.10E-05+	4.18E-05+	3.75E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μci·hr)
^{123}I 1 Year

Target organs	Source Organs						
	Bladder Contents	Small Intestine	Stomach Contents	Stomach Wall	Kidneys	Liver	Lungs
	S	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.32E-06	4.35E-06	1.47E-05	1.05E-05	5.64E-05	1.33E-05	1.79E-05
Bladder wall	3.09E-03*	5.70E-05	4.40E-06	4.00E-06	5.42E-06	4.78E-06	1.06E-06
G.I. (stomach wall)	5.64E-06	2.18E-05	2.64E-03*	2.69E-03+	1.42E-05	2.08E-05	1.03E-05
G.I. (ULI wall)	3.09E-05	2.23E-04	1.90E-05	2.50E-05	1.17E-05	3.08E-05	2.67E-06
G.I. (LLI wall)	6.36E-05	3.70E-05	7.90E-06	8.30E-06	4.96E-06	3.84E-06	7.97E-07
G.I. (SI + contents)	3.24E-05	1.18E-03+	1.79E-05	1.98E-05	1.77E-05	1.92E-05	2.28E-06
Gall bladder wall	1.08E-05	5.20E-05	7.80E-05	8.40E-05	1.66E-05	6.21E-05	8.23E-06
Heart	1.05E-06	3.60E-06	1.57E-05	1.52E-05	6.61E-06	2.16E-05	3.95E-05
Kidneys	4.20E-06	1.44E-05	1.30E-05	1.29E-05	1.28E-03+	1.38E-05	5.06E-06
Liver	4.71E-06	1.48E-05	2.23E-05	2.23E-05	1.45E-05	3.55E-04+	1.27E-05
Lungs	6.21E-07	2.25E-06	1.03E-05	1.29E-05	5.24E-06	1.23E-05	5.45E-04+
Marrow (red)	1.33E-05	2.17E-05	1.05E-05	1.13E-05	3.18E-05	1.18E-05	1.01E-05
Ovaries	5.78E-05	1.21E-04	1.28E-05	2.17E-05	1.51E-05	3.99E-06	—
Pancreas	2.12E-06	1.26E-05	6.70E-05	8.30E-05	2.34E-05	4.45E-05	1.66E-05
Salivary glands	3.04E-08	9.30E-08	5.00E-07	7.70E-07	6.54E-07	9.23E-07	4.09E-06
Skeleton	4.92E-06	6.30E-06	5.00E-06	5.50E-06	9.30E-06	5.53E-06	7.11E-06
Skin	3.66E-06	5.50E-06	7.50E-06	7.70E-06	4.13-06	3.28E-06	3.17E-06
Spleen	3.84E-06	8.30E-06	4.50E-05	4.20E-05	5.71E-05	9.34E-06	1.38E-05
Testes	6.97E-05	7.80E-06	8.20E-07	—	1.03E-06	5.24E-06	7.04E-07
Thymus	7.00E-07	6.50E-07	3.18E-06	3.70E-06	2.33E-06	4.78E-06	2.12E-05
Thyroid	—	—	5.90E-07	—	6.54E-07	1.07E-06	7.04E-06
Total tissue	1.39E-05	1.37E-05	1.08E-05	1.18E-05	1.06E-05	9.91E-06	9.23E-06
Uterus	1.35E-04	2.04E-04	9.10E-06	7.40E-06	9.16E-06	6.72E-06	1.77E-07
Total body	1.88E-05+	1.99E-05+	1.83E-05+	1.82E-05+	1.74E-05+	1.83E-05+	1.44E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{123}I 1 Year

Target organs	Source Organs					
	Red Marrow	Ovaries	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	2.11E-05	6.65E-06	5.78E-05	2.00E-06	1.79E-06	1.80E-05
Bladder wall	8.84E-06	5.85E-05	2.55E-06	5.60E-05	—	1.88E-05
G.I. (stomach wall)	8.33E-06	1.18E-05	4.49E-05	2.39E-06	7.10E-07	1.71E-05
G.I. (ULI wall)	2.03E-05	1.29E-04	7.72E-06	5.68E-06	5.90E-08	1.73E-05
G.I. (LLI wall)	1.57E-05	1.05E-04	3.74E-06	3.32E-05	—	1.76E-05
G.I. (SI + contents)	1.95E-05	1.52E-04	9.81E-06	7.26E-06	2.33E-07	1.72E-05
Gall bladder wall	1.01E-05	1.80E-05	2.78E-05	1.05E-06	—	1.96E-05
Heart	8.51E-06	2.44E-06	1.62E-05	3.07E-07	4.80E-06	1.72E-05
Kidneys	1.57E-05	1.07E-05	5.64E-05	1.63E-06	6.00E-07	1.60E-05
Liver	7.58E-06	8.05E-06	1.13E-05	1.55E-06	1.17E-06	1.79E-05
Lungs	8.66E-06	1.41E-06	1.81E-05	3.70E-07	8.10E-06	1.66E-05
Marrow (red)	4.94E-04+	3.44E-05	1.62E-05	6.86E-06	6.10E-06	2.42E-05
Ovaries	1.49E-05	1.02E-01+	6.32E-06	1.86E-05	—	9.40E-06
Pancreas	1.12E-05	8.44E-06	9.95E-05	8.37E-07	9.80E-07	1.63E-05
Salivary glands	3.44E-06	—	8.30E-07	1.07E-08	6.10E-05	1.20E-05
Skeleton	3.12E-05	9.27E-06	7.47E-06	5.03E-06	1.26E-05	2.21E-05
Skin	3.74E-06	2.82E-06	3.25E-06	1.06E-05	3.09E-06	1.04E-05
Spleen	9.59E-06	5.17E-06	3.14E-03+	9.23E-07	1.62E-06	1.78E-05
Testes	8.91E-07	1.10E-05	2.95E-06	4.77E-02+	—	9.61E-06
Thymus	4.96E-06	2.55E-07	3.28E-06	1.94E-07	2.54E-05	1.60E-05
Thyroid	3.25E-06	1.52E-07	1.45E-06	—	2.82E-02+	1.58E-05
Total tissue	9.30E-06	1.54E-07	1.21E-05	9.95E-06	1.56E-05	1.51E-05
Uterus	1.31E-05	1.99E-04	5.35E-06	1.52E-05	—	1.57E-05
Total body	1.76E-05+	1.97E-05+	1.84E-05+	1.55E-05+	1.87E-05+	1.65E-05

S MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{123}I 5 Year

Target organs	Source Organs					
	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	Kidney	Liver
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	3.50E-07	7.50E-06	6.40E-06	2.05E-06	3.22E-05	9.05E-06
Bladder wall	2.02E-03*	2.44E-06	2.80E-06	1.56E-05	2.42E-06	1.25E-06
G.I. (stomach wall)	2.53E-06	7.89E-04*	1.45E-03+	1.18E-05	8.44E-06	1.23E-05
G.I. (ULI wall)	1.24E-05	1.21E-05	1.34E-05	1.04E-04	8.33E-06	9.38E-06
G.I. (LLI wall)	3.66E-05	4.00E-06	5.10E-06	3.58E-05	3.66E-06	1.60E-06
G.I. (SI + contents)	1.52E-05	1.06E-05	1.22E-05	5.59E-04+	1.17E-05	7.26E-06
Gall bladder wall	3.84E-06	4.70E-05	6.30E-05	1.96E-05	1.43E-05	3.48E-05
Heart	4.67E-07	1.12E-05	1.07E-05	2.06E-06	3.84E-06	1.79E-05
Kidneys	2.04E-06	7.20E-06	8.30E-06	1.12E-05	7.83E-04+	8.33E-06
Liver	1.48E-06	1.27E-05	1.35E-05	7.30E-06	8.58E-06	1.97E-04+
Lungs	2.61E-07	5.90E-06	7.00E-06	1.12E-06	2.93E-06	9.16E-06
Marrow (red)	7.26E-07	5.90E-06	5.70E-06	1.94E-05	1.66E-05	5.96E-06
Ovaries	3.14E-05	3.39E-06	5.70E-06	7.70E-05	4.35E-06	6.03E-06
Pancreas	9.99E-07	4.40E-05	4.60E-05	5.70E-06	1.64E-05	2.13E-05
Salivary glands	9.48E-07	2.79E-07	3.15E-07	8.90E-08	6.65E-08	2.75E-07
Skeleton	2.96E-06	3.16E-06	3.15E-06	5.70E-06	5.78E-06	3.63E-06
Skin	1.85E-06	4.20E-06	4.60E-06	3.19E-06	2.11E-06	1.82E-06
Spleen	9.63E-07	2.61E-05	2.53E-05	5.00E-07	3.74E-05	5.24E-06
Testes	2.17E-05	5.80E-07	—	2.57E-06	1.62E-08	3.50E-06
Thymus	2.57E-07	1.65E-06	1.42E-06	4.70E-07	1.01E-06	2.32E-06
Thyroid	3.18E-07	4.20E-07	—	—	1.11E-07	1.01E-06
Total tissue	7.65E-06	5.70E-06	6.40E-06	7.00E-06	6.03E-06	4.99E-06
Uterus	6.11E-05	1.63E-06	6.50E-06	7.40E-05	4.92E-06	3.99E-06
Total body	1.08E-05+	1.06E-05+	1.05E-05+	1.14E-05+	1.01E-05+	1.05E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{123}I 5 Year

Target organs	Source Organs					
	Red Marrow	Ovaries	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*
Adrenals	9.16E-06	2.17E-06	3.09E-05	—	5.50E-07	8.40E-06
Bladder wall	1.84E-05	3.59E-05	2.52E-06	3.92E-05	—	7.11E-06
G.I. (stomach wall)	3.84E-06	3.84E-06	2.86E-05	1.01E-06	7.00E-07	6.08E-06
G.I. (ULI wall)	8.37E-06	8.41E-05	4.96E-06	2.84E-06	3.29E-07	7.68E-06
G.I. (LLI wall)	8.44E-06	1.23E-05	2.35E-06	1.56E-05	—	7.65E-06
G.I. (SI + contents)	1.11E-05	8.23E-05	5.53E-06	2.91E-06	1.18E-07	7.61E-06
Gall bladder wall	8.05E-06	9.12E-06	1.21E-05	2.51E-06	—	6.07E-06
Heart	4.17E-06	1.12E-06	9.23E-06	8.51E-08	2.52E-06	8.04E-06
Kidneys	9.12E-06	5.28E-06	3.43E-05	5.57E-07	4.80E-07	7.68E-06
Liver	3.92E-06	4.31E-06	6.07E-06	5.60E-07	6.90E-07	6.75E-06
Lungs	4.85E-06	5.28E-07	9.70E-06	1.62E-07	4.50E-06	9.37E-06
Marrow (red)	1.75E-04+	1.67E-05	8.44E-06	3.21E-06	3.43E-06	2.54E-05
Ovaries	1.08E-05	3.43E-02+	2.73E-06	8.91E-06	—	8.87E-06
Pancreas	5.42E-06	3.37E-06	6.25E-05	3.59E-07	4.00E-07	7.43E-06
Salivary glands	1.82E-06	2.89E-08	5.71E-07	—	5.20E-05	8.65E-06
Skeleton	9.63E-06	5.14E-06	4.71E-06	2.68E-06	7.00E-06	2.15E-05
Skin	1.81E-06	1.47E-06	1.86E-06	3.36E-06	3.22E-06	5.34E-06
Spleen	5.35E-06	2.78E-06	1.18E-03+	3.53E-07	5.20E-07	8.11E-06
Testes	7.04E-07	5.03E-06	4.45E-06	4.41E-02+	—	8.76E-06
Thymus	2.67E-06	1.91E-07	1.71E-07	1.11E-07	1.72E-05	6.57E-06
Thyroid	1.96E-06	—	4.06E-07	—	1.43E-02+	1.14E-05
Total tissue	4.63E-06	9.27E-06	6.72E-06	5.39E-06	8.00E-06	7.50E-06
Uterus	5.60E-06	2.00E-04	4.09E-06	2.98E-06	—	7.90E-06
Total body	8.15E-06+	1.15E-05+	1.06E-05+	8.87E-06+	1.02E-05+	9.34E-06

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I Newborn

Target organs	Source Organs				
	Adrenals	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestines
	S	*S*	*S*	*S*	*S*
Adrenals	8.03E-02+	1.79E-05	5.94E-05	3.46E-05	5.95E-05
Bladder wall	1.43E-05	7.79E-02*	3.81E-05	3.20E-05	9.00E-05
G.I. (stomach wall)	4.37E-05	5.14E-05	3.56E-02*	7.03E-02+	1.09E-05
G.I. (ULI wall)	4.61E-05	1.26E-04	9.30E-05	9.20E-05	4.95E-04
G.I. (LLI wall)	1.71E-05	1.54E-04	5.09E-05	5.29E-05	1.98E-04
G.I. (SI + contents)	4.86E-05	1.06E-04	8.10E-05	8.90E-05	1.47E-02+
Gall bladder wall	6.72E-05	3.00E-05	2.56E-04	3.36E-04	1.42E-04
Heart	4.69E-05	9.20E-06	5.93E-05	5.51E-05	1.90E-05
Kidneys	3.01E-04	2.94E-05	5.07E-05	5.54E-05	9.90E-05
Liver	8.20E-05	3.60E-05	1.01E-04	1.06E-04	7.51E-05
Lungs	5.59E-05	7.31E-06	5.41E-05	4.86E-05	2.04E-05
Marrow (red)	8.10E-05	3.20E-05	3.17E-05	3.27E-05	8.60E-05
Ovaries	2.67E-05	2.01E-04	7.89E-05	2.42E-05	3.35E-04
Pancreas	9.60E-05	2.49E-05	2.82E-04	3.27E-04	1.13E-04
Salivary glands	3.99E-06	4.47E-06	4.08E-06	4.65E-06	6.28E-07
Skeleton	3.93E-05	1.53E-05	1.88E-05	1.88E-05	3.17E-05
Skin	6.98E-05	4.97E-05	7.16E-05	6.71E-05	5.21E-05
Spleen	1.55E-04	2.09E-05	1.87E-04	1.68E-04	9.30E-05
Testes	—	—	2.94E-05	2.44E-05	2.78E-05
Thymus	3.05E-05	2.70E-04	3.69E-05	4.26E-05	2.94E-05
Thyroid	8.90E-06	—	5.27E-06	8.90E-06	2.51E-05
Total tissue	3.89E-05	4.22E-05	3.85E-05	4.18E-05	4.28E-05
Uterus	3.37E-05	2.60E-04	4.99E-05	5.55E-05	5.12E-04
Total body	1.44E-04+	1.46E-04+	1.47E-04+	1.47E-04+	1.50E-04+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I Newborn

Target organs	Source Organs				
	Kidneys	Liver	Salivary Glands	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*
Adrenals	2.97E-04	6.58E-05	2.94E-06	7.64E-06	1.47E-04
Bladder wall	2.74E-05	3.15E-05	6.71E-07	3.53E-06	1.45E-04
G.I. (stomach wall)	5.10E-05	1.01E-04	7.35E-06	1.25E-05	1.40E-04
G.I. (ULI wall0	7.11E-05	1.33E-04	1.30E-06	4.44E-06	1.51E-04
G.I. (LLI wall)	3.92E-05	2.22E-05	2.47E-06	1.75E-06	1.60E-04
G.I. (SI + contents)	9.80E-05	9.10E-05	1.91E-06	2.92E-06	1.46E-04
Gall badder wall	1.13E-04	2.10E-04	—	2.62E-05	1.38E-04
Heart	2.31E-05	6.02E-05	1.38E-05	3.72E-05	1.48E-04
Kidneys	2.30E-02+	7.69E-05	4.47E-06	6.65E-06	1.48E-04
Liver	7.47E-05	4.10E-03+	4.20E-06	8.80E-06	1.45E-04
Lungs	3.23E-05	5.78E-05	2.03E-05	3.05E-05	1.41E-04
Marrow (red)	9.10E-05	3.73E-05	1.32E-05	1.68E-05	1.46E-04
Ovaries	3.19E-05	4.71E-05	—	—	1.99E-04
Pancreas	1.01E-04	1.32E-04	5.00E-06	8.30E-06	1.69E-04
Salivary glands	1.40E-06	3.80E-06	6.71E-02+	2.19E-04	4.63E-04
Skeleton	3.51E-05	2.04E-05	2.44E-04	3.31E-05	1.40E-04
Skin	7.76E-05	6.36E-05	4.39E-05	2.07E-05	1.28E-04
Spleen	2.22E-04	4.95E-05	3.89E-06	9.30E-06	1.38E-04
Testes	—	—	—	—	—
Thymus	2.37E-05	4.30E-05	2.03E-05	7.86E-05	1.56E-04
Thyroid	6.23E-06	6.65E-10	2.57E-04	4.29E-01+	1.49E-04
Total tissue	3.84E-05	3.52E-05	1.50E-04	5.29E-05	1.39E-04
Uterus	6.74E-05	6.44E-05	1.23E-05	2.90E-07	1.54E-04
Total body	1.45E-04+	1.45E-04+	1.39E-04+	1.47E-05+	1.39E-04

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I 1 Year

Target organs	Source Organs							
	Adrenals	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestine	Kidneys	Liver	Lungs
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	3.43E-03+	8.69E-06	2.69E-05	1.87E-05	7.55E-06	1.05E-04	2.87E-05	2.99E-05
Bladder wall	6.14E-06	1.78E-02*	1.54E-05	1.58E-05	1.21E-04	1.38E-05	1.76E-05	1.91E-06
G.I. (stomach wall)	2.16E-05	1.65E-05	8.30E-03*	1.56E-02+	4.08E-05	2.55E-05	3.64E-05	1.95E-05
G.I. (ULI wall)	1.33E-05	5.62E-05	3.99E-05	4.49E-05	3.23E-04	2.60E-05	4.97E-05	5.67E-06
G.I. (LLI wall)	6.38E-06	1.12E-04	1.79E-05	2.08E-05	6.52E-05	1.10E-05	6.66E-06	2.09E-06
G.I. (SI + contents)	1.70E-05	6.11E-05	3.53E-05	3.89E-05	5.93E-03+	3.81E-05	3.88E-05	5.50E-06
Gall bladder wall	3.23E-05	2.45E-05	1.32E-04	1.38E-04	9.10E-05	3.85E-05	9.33E-05	1.12E-05
Heart	3.07E-05	2.82E-06	3.37E-05	6.63E-05	6.89E-06	1.23E-05	3.48E-05	9.09E-05
Kidneys	1.00E-04	1.12E-05	2.96E-05	2.66E-05	2.95E-05	6.56E-03+	2.97E-05	1.11E-05
Liver	3.44E-05	1.09E-05	4.28E-05	4.34E-05	3.03E-05	3.01E-05	1.58E-03+	2.93E-05
Lungs	2.89E-05	1.92E-06	2.07E-05	2.11E-05	4.49E-06	1.26E-05	2.18E-05	3.34E-03+
Marrow (red)	3.86E-05	2.03E-05	1.62E-05	1.56E-05	2.82E-05	3.89E-05	1.65E-05	1.80E-05
Ovaries	4.34E-05	1.17E-04	9.90E-06	2.57E-05	2.26E-04	3.32E-05	3.94E-05	2.75E-06
Pancreas	7.06E-05	4.52E-06	1.38E-04	1.20E-04	2.63E-05	4.28E-05	7.36E-05	2.94E-05
Salivary glands	3.07E-06	3.85E-07	1.85E-06	1.83E-06	3.97E-07	9.66E-07	2.04E-06	9.25E-06
Skeleton	1.66E-05	7.98E-06	7.64E-06	7.58E-06	8.90E-06	1.23E-05	7.90E-06	1.29E-05
Skin	2.00E-05	8.05E-06	1.72E-05	1.81E-05	1.31E-05	8.69E-06	7.93E-06	7.74E-06
Spleen	9.70E-05	9.82E-06	7.76E-05	7.19E-05	2.07E-05	9.25E-05	2.46E-05	3.35E-05
Testes	—	1.20E-04	1.05E-06	6.90E-06	2.17E-05	3.18E-06	1.30E-06	—
Thymus	6.82E-06	2.41E-07	9.70E-06	9.90E-06	2.35E-06	4.54E-06	1.22E-05	4.60E-05
Thyroid	6.61E-06	1.15E-06	8.00E-07	3.34E-06	1.69E-06	3.15E-06	8.13E-07	1.03E-05
Total tissue	2.29E-05	2.53E-05	2.09E-05	2.20E-05	2.58E-05	2.07E-05	1.95E-05	2.11E-05
Uterus	1.19E-05	1.87E-04	3.75E-05	2.98E-05	2.80E-04	3.81E-05	2.92E-05	6.30E-06
Total body	6.01E-05+	6.17E-05+	6.15E-05+	6.08E-05+	6.37E-05+	5.97E-05+	6.11E-05+	5.84E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I 1 Year

Target organs	Source Organs						
	Red Marrow	Ovaries	Salivary Glands	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	2.64E-05	1.13E-05	4.55E-07	1.11E-04	1.76E-06	4.35E-06	6.85E-05
Bladder wall	2.04E-05	9.98E-05	—	6.11E-06	1.13E-04	7.47E-07	6.38E-05
G.I. (stomach wall)	1.31E-05	2.82E-05	1.55E-06	8.13E-05	4.11E-07	4.07E-07	6.20E-05
G.I. (ULI wall)	2.94E-05	1.94E-04	1.66E-07	1.63E-05	1.66E-05	3.62E-07	6.30E-05
G.I. (LLI wall)	3.61E-05	1.50E-04	1.68E-07	1.09E-05	5.99E-05	5.13E-07	5.63E-05
G.I. (SI + contents)	4.38E-05	2.30E-04	4.25E-07	2.37E-05	1.50E-05	1.15E-06	5.88E-05
Gall bladder wall	1.62E-05	4.37E-05	6.25E-07	7.29E-05	6.77E-06	5.83E-06	7.90E-05
Heart	1.77E-05	5.77E-06	6.57E-06	3.07E-05	2.36E-06	1.34E-05	6.45E-05
Kidneys	3.82E-05	2.65E-05	1.46E-05	9.57E-05	4.84E-06	1.88E-06	5.76E-05
Liver	1.55E-05	1.86E-05	2.24E-06	2.49E-05	3.86E-06	2.85E-06	6.09E-05
Lungs	1.70E-05	3.31E-06	9.90E-06	3.19E-05	1.13E-06	1.64E-05	5.79E-05
Marrow (red)	2.80E-03+	4.04E-05	6.86E-06	2.29E-05	1.11E-05	9.10E-06	6.01E-05
Ovaries	2.22E-05	6.41E-01+	—	1.46E-05	4.54E-05	—	8.03E-05
Pancreas	1.75E-05	1.34E-05	4.43E-06	1.67E-04	2.49E-06	3.86E-06	7.09E-05
Salivary glands	6.74E-06	4.28E-08	8.20E-04	2.29E-06	6.46E-09	1.05E-04	5.36E-05
Skeleton	3.28E-05	1.20E-05	2.40E-05	1.08E-05	7.98E-06	1.75E-05	5.78E-05
Skin	8.61E-06	7.05E-06	2.41E-05	7.67E-06	1.87E-05	8.90E-06	4.84E-05
Spleen	2.01E-05	1.54E-05	1.89E-06	1.62E-02+	3.03E-06	2.83E-06	6.09E-05
Testes	2.33E-06	1.92E-05	—	—	2.87E-01+	—	5.19E-05
Thymus	1.29E-05	2.00E-06	1.64E-05	9.74E-06	1.21E-06	4.90E-05	6.10E-05
Thyroid	3.81E-06	1.97E-06	1.01E-04	1.71E-06	—	1.75E-01+	5.03E-05
Total tissue	2.03E-05	2.85E-05	1.55E-05	2.29E-05	1.90E-05	2.70E-05	5.70E-05
Uterus	1.88E-05	3.37E-04	—	2.83E-05	3.07E-05	—	5.35E-05
Total body	5.93E-05+	6.34E-05+	5.71E-05+	6.14E-05+	5.65E-05+	6.13E-05+	5.75E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I 5 Year

Target organs	Source Organs						
	Red Marrow	Ovaries	Salivary Glands	Spleen	Testes	Thyroid	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.76E-05	7.45E-06	1.57E-06	7.10E-05	1.21E-06	1.34E-07	3.39E-05
Bladder wall	3.53E-05	8.05E-05	—	2.73E-06	6.86E-07	6.73E-05	2.55E-05
G.I. (stomach wall)	8.05E-06	1.06E-05	7.42E-07	4.78E-05	1.54E-06	2.63E-06	3.07E-05
G.I. (ULI wall)	1.96E-05	1.39E-04	3.41E-07	1.02E-05	2.12E-07	7.07E-06	3.00E-05
G.I. (LLI wall)	2.18E-05	2.70E-05	2.84E-07	5.50E-06	2.70E-07	3.52E-06	2.99E-05
G.I. (SI + contents)	2.47E-05	1.37E-04	3.85E-07	1.46E-05	3.59E-07	7.48E-06	3.09E-05
Gall bladder wall	1.17E-05	2.15E-05	1.43E-06	3.35E-05	—	4.25E-06	2.69E-05
Heart	1.05E-05	1.69E-06	3.38E-06	1.86E-05	6.59E-06	7.39E-07	3.05E-05
Kidneys	2.22E-05	1.35E-05	7.55E-07	6.48E-05	8.10E-07	1.86E-06	3.11E-05
Liver	8.61E-06	1.04E-05	1.34E-06	1.34E-05	1.64E-06	1.61E-06	2.84E-05
Lungs	1.05E-05	1.76E-06	5.91E-06	1.89E-05	1.01E-05	3.18E-07	3.25E-05
Marrow (red)	1.07E-03+	2.13E-05	4.76E-06	1.31E-05	5.49E-05	5.87E-06	4.53E-05
Ovaries	1.52E-05	2.18E-01+	—	1.20E-06	—	1.61E-05	2.87E-05
Pancreas	1.20E-05	6.44E-06	7.43E-07	1.07E-04	2.27E-06	8.61E-07	2.68E-05
Salivary glands	3.99E-06	5.51E-07	6.74E-04	1.52E-06	9.00E-05	1.79E-08	3.05E-05
Skeleton	1.89E-05	7.02E-06	1.47E-05	7.19E-06	1.03E-05	4.90E-06	4.10E-05
Skin	4.54E-06	3.66E-06	2.17E-05	4.28E-06	8.60E-06	6.48E-06	2.59E-05
Spleen	1.21E-05	5.19E-06	7.86E-07	9.09E-03+	2.08E-06	1.45E-06	2.98E-05
Testes	3.80E-07	1.64E-05	—	2.12E-06	—	2.63E-01+	2.33E-05
Thymus	5.94E-06	5.59E-07	1.28E-05	4.34E-05	3.84E-05	1.02E-07	2.95E-05
Thyroid	5.61E-06	9.25E-07	8.30E-05	2.37E-06	6.91E-02+	2.97E-08	2.90E-05
Total tissue	1.06E-05	1.74E-05	8.20E-06	1.28E-05	1.42E-05	1.11E-05	3.00E-05
Uterus	1.15E-05	2.99E-04	—	8.37E-06	—	5.51E-06	2.92E-05
Total body	3.16E-05+	3.60E-05+	3.07E-05+	3.39E-05+	3.30E-05+	3.14E-05+	3.12E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{131}I 5 Year

Target organs	Source Organs						
	Adrenals	Bladder Contents	Stomach Contents	Stomach Wall	Small Intestines	Kidneys	Liver
	S	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	6.90E-03+	1.04E-06	1.37E-05	1.50E-05	7.00E-06	7.27E-05	1.92E-05
Bladder wall	2.85E-06	1.19E-02*	6.82E-06	4.04E-06	3.64E-05	6.78E-06	7.34E-06
G.I. (stomach wall)	1.61E-05	5.86E-06	4.37E-03*	8.24E-03+	2.19E-05	1.67E-05	2.61E-05
G.I. (ULI wall)	8.40E-06	2.70E-05	2.40E-05	2.47E-05	1.66E-04	1.53E-05	1.82E-05
G.I. (LLI wall)	2.35E-06	5.92E-05	1.05E-05	1.09E-05	5.50E-05	7.10E-06	3.91E-06
G.I. (SI + contents)	8.40E-06	3.19E-05	2.21E-05	2.44E-05	2.64E-03+	2.29E-05	1.65E-05
Gall bladder wall	2.00E-05	1.05E-05	9.00E-05	1.07E-04	3.91E-05	3.03E-05	6.88E-05
Heart	1.98E-05	1.45E-06	2.18E-05	2.13E-05	3.28E-06	8.61E-06	3.41E-05
Kidneys	6.28E-05	4.27E-06	1.80E-05	1.71E-05	2.19E-05	4.09E-04+	1.96E-05
Liver	2.23E-05	4.43E-06	2.49E-05	2.57E-05	1.54E-05	1.89E-05	8.22E-04+
Lungs	1.96E-05	7.35E-07	1.16E-05	1.24E-05	2.51E-06	7.17E-06	1.67E-05
Marrow (red)	2.24E-05	1.03E-05	8.90E-06	9.30E-06	2.41E-05	2.34E-05	9.49E-06
Ovaries	2.50E-06	4.68E-05	9.70E-06	5.84E-06	9.30E-05	3.95E-06	2.15E-06
Pancreas	4.25E-05	3.35E-06	8.20E-05	7.51E-05	1.09E-05	3.09E-05	4.45E-05
Salivary glands	1.66E-06	4.43E-07	4.40E-07	1.52E-06	1.61E-07	5.32E-07	1.67E-06
Skeleton	1.16E-05	4.60E-06	4.78E-06	5.05E-06	7.61E-06	8.45E-06	5.58E-06
Skin	1.09E-05	4.50E-06	1.09E-05	9.90E-06	8.50E-06	4.93E-06	4.25E-06
Spleen	6.71E-05	2.98E-06	4.71E-05	4.80E-05	1.10E-05	6.10E-05	1.34E-05
Testes	—	4.71E-05	—	—	4.53E-06	5.67E-06	1.25E-06
Thymus	5/15E-06	1.09E-07	3.62E-06	5.14E-06	1.96E-06	1.50E-06	7.30E-06
Thyroid	—	—	4.59E-06	1.54E-06	—	3.43E-07	4.46E-06
Total tissue	1.31E-05	1.47E-05	1.15E-05	1.23E-05	1.40E-05	1.20E-05	1.01E-05
Uterus	3.04E-06	9.17E-05	1.26E-05	7.42E-06	1.21E-04	1.48E-05	1.17E-05
Total body	3.33E-05+	3.45E-05+	3.40E-05+	3.38E-05+	3.56E-05+	3.32E-05+	3.37E-05+

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{201}Tl 1 Year

Target organs	Source Organs								
	Bladder Contents	Kidneys	Liver	Lungs	Red Marrow	Ovaries	Spleen	Testes	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	1.13E-06	2.28E-05	8.23E-06	1.08E-05	8.15E-06	1.50E-06	2.72E-05	3.57E-07	1.35E-05
Bladder wall	3.81E-03*	2.81E-06	3.80E-06	6.56E-07	5.21E-06	3.26E-05	1.74E-06	3.17E-05	1.48E-05
G.I. (stomach wall)	3.07E-06	7.81E-06	1.06E-05	6.49E-06	4.19E-06	6.53E-06	2.39E-05	1.30E-06	1.35E-05
G.I. (ULI wall)	1.69E-06	7.78E-06	1.44E-05	1.36E-06	9.02E-06	5.60E-06	5.16E-06	4.04E-06	1.42E-05
G.I. (LLI wall)	3.26E-05	2.82E-06	2.49E-06	3.69E-07	9.00E-06	4.13E-05	2.59E-06	1.68E-05	1.36E-05
G.I. (SI + contents)	1.69E-05	1.06E-05	1.02E-05	1.46E-06	1.07E-05	6.28E-05	6.41E-06	4.27E-06	1.51E-05
Gall bladder wall	6.51E-06	1.05E-05	3.59E-05	4.92E-06	6.60E-06	1.25E-05	1.32E-05	1.40E-06	1.31E-05
Heart	5.66E-07	3.40E-06	1.04E-05	2.82E-05	4.09E-06	1.17E-06	9.73E-06	1.93E-07	1.46E-05
Kidneys	2.33E-06	1.49E-03+	7.92E-06	2.84E-05	8.84E-06	6.66E-06	2.41E-05	8.81E-07	1.29E-05
Liver	2.83E-06	7.90E-06	3.66E-04+	8.46E-06	3.88E-06	5.16E-06	6.91E-06	8.23E-07	1.43E-05
Lungs	3.82E-07	3.21E-06	6.64E-06	7.03E-04+	4.69E-06	7.86E-07	8.84E-06	1.97E-07	1.39E-05
Marrow (red)	1.15E-05	2.05E-05	9.25E-06	1.27E-05	6.14E-04+	2.32E-05	1.31E-05	5.85E-06	1.97E-05
Ovaries	3.46E-05	5.12E-06	4.98E-06	3.42E-07	9.85E-06	1.40E-01+	5.16E-06	3.01E-06	1.62E-05
Pancreas	1.63E-06	1.18E-05	1.83E-05	1.05E-05	5.43E-06	5.31E-06	4.36E-05	6.31E-07	1.50E-05
Salivary glands	1.29E-07	1.90E-07	1.64E-07	2.28E-06	1.12E-06	6.39E-08	6.22E-07	6.57E-09	1.11E-05
Skeleton	4.27E-06	6.14E-06	4.17E-06	8.73E-06	1.95E-05	6.55E-06	5.77E-06	4.11E-06	9.16E-06
Skin	1.82E-06	1.81E-06	1.61E-06	1.72E-06	1.84E-06	1.52E-06	1.65E-06	4.81E-06	1.05E-05
Spleen	1.83E-06	2.41E-05	6.39E-06	9.13E-06	5.66E-06	4.04E-06	3.70E-03+	5.87E-07	1.42E-05
Testes	1.78E-05	1.64E-07	5.70E-07	1.01E-07	4.17E-06	8.67E-06	4.15E-07	6.40E-02+	1.03E-05
Thymus	9.66E-08	9.75E-07	2.57E-06	1.52E-05	2.82E-06	5.62E-07	2.49E-06	6.86E-08	1.43E-05
Thyroid	8.52E-09	3.32E-08	1.11E-07	5.18E-06	1.49E-06	1.18E-07	3.75E-07	1.67E-07	1.43E-05
Total tissue	6.70E-06	5.14E-06	5.00E-06	5.93E-06	4.81E-06	7.94E-06	5.93E-06	4.63E-06	1.31E-05
Uterus	5.78E-02	5.31E-06	5.81E-06	2.05E-06	6.10E-06	8.86E-05	4.23E-06	6.43E-06	1.13E-05
Total body	1.52E-05+	1.44E-05+	1.49E-05+	1.42E-05+	1.47E-05+	1.58E-05+	1.50E-05+	1.35E-05+	1.41E-05

S, MEAN DOSE PER CUMULATED ACTIVITY (rad/μCi·hr)
^{201}Tl 5 Year

Target organs	Source Organs							
	Bladder Contents	Kidneys	Liver	Red Marrow	Ovaries	Spleen	Testes	Total Body ±
	S	*S*	*S*	*S*	*S*	*S*	*S*	*S*
Adrenals	2.41E-07	1.76E-05	6.26E-06	5.27E-06	1.38E-06	1.72E-05	—	6.75E-06
Bladder wall	4.87E-03*	1.16E-06	1.40E-06	1.38E-05	2.14E-05	1.20E-06	1.80E-05	5.85E-06
G.I. (stomach wall)	1.26E-06	4.71E-06	7.61E-06	2.34E-06	2.72E-06	1.48E-05	4.25E-07	6.27E-06
G.I. (ULI wall)	8.57E-06	4.60E-06	5.74E-06	5.54E-06	3.71E-05	3.43E-06	1.80E-06	6.73E-06
G.I. (LLI wall)	1.70E-05	1.59E-06	9.42E-07	5.43E-06	8.25E-06	1.51E-06	9.64E-06	7.16E-06
G.I. (SI + contents)	9.48E-06	6.39E-06	4.42E-06	7.09E-06	3.77E-05	3.82E-06	1.91E-06	7.27E-06
Gall bladder wall	2.66E-06	8.11E-06	1.83E-05	3.17E-06	5.35E-06	1.07E-05	1.34E-06	7.12E-06
Heart	2.34E-07	2.00E-06	9.56E-06	2.74E-06	5.33E-07	5.45E-06	3.90E-08	7.06E-06
Kidneys	9.98E-07	8.95E-04+	4.89E-06	5.91E-06	3.48E-06	1.66E-05	3.13E-07	6.83E-06
Liver	1.11E-06	5.10E-06	1.93E-04+	2.36E-06	2.82E-06	3.88E-06	2.49E-07	6.29E-06
Lungs	1.43E-07	1.66E-06	4.83E-06	3.19E-06	3.77E-07	5.12E-06	5.35E-08	7.81E-06
Marrow (red)	6.62E-06	1.21E-05	5.19E-06	2.37E-04+	1.33E-05	7.05E-06	2.82E-06	1.84E-05
Ovaries	1.78E-05	2.28E-06	2.05E-06	5.00E-06	4.69E-02+	3.11E-06	3.09E-06	5.39E-06
Pancreas	7.84E-07	9.17E-06	1.31E-05	3.73E-06	1.90E-06	2.94E-05	1.88E-07	6.87E-06
Salivary glands	—	4.56E-08	1.60E-07	9.40E-07	9.81E-08	1.37E-07	—	6.48E-06
Skeleton	2.68E-06	4.27E-06	2.99E-06	1.06E-05	4.11E-06	3.71E-06	2.32E-06	1.58E-05
Skin	9.89E-07	9.94E-07	1.00E-06	9.17E-07	8.19E-07	9.13E-07	1.55E-06	5.39E-06
Spleen	7.53E-07	1.64E-05	4.29E-06	3.42E-06	1.63E-06	2.07E-03+	1.30E-07	6.54E-06
Testes	1.58E-05	2.09E-07	2.55E-07	8.63E-07	3.34E-07	1.30E-07	5.89E-03+	5.56E-06
Thymus	5.08E-08	4.92E-07	1.78E-06	1.87E-06	1.02E-07	1.24E-06	3.19E-08	7.00E-06
Thyroid	—	2.28E-07	1.31E-07	6.93E-07	—	9.83E-07	—	6.89E-06
Total tissue	4.00E-06	2.97E-06	2.66E-06	2.74E-06	5.08E-06	3.36E-06	2.74E-06	6.56E-06
Uterus	2.61E-05	3.40E-06	8.11E-07	3.96E-06	7.88E-05	2.12E-06	3.57E-06	6.07E-06
Total body	8.64E-06+	8.14E-06+	8.39E-06+	7.97E-06+	9.11E-06+	8.43E-06+	7.50E-06+	7.81E-06

References

ABDULLA, U., DEWHURST, C. J., CAMPBELL, C., TALBERT, D., LUCAS, M., AND MULLARKEY, M. (1971). "Effect of diagnostic ultrasound on maternal and fetal chromosomes," Lancet **2,** 829.

ACTON, W. I. (1974). "The effects of industrial airborne ultrasound on humans," Ultrasonics **12,** 124.

AIUM (1980). American Institute of Ultrasound in Medicine. *Recommended Nomenclature, Physics and Engineering* (American Institute of U ltrasound in Medicine, Bethesda, Md.).

AIUM (1982). American Institute of Ultrasound in Medicine "AIUM clinical safety statement for physicians and patients." Personal communication from member of AIUM Bioeffects Committee.

ALDERSON, P. O., SECKER-WALKER, R. H., STROMINGER, D. B., MARKHAM, J., AND HILL, R. L. (1974a). "Pulmonary deposition of aerosols in children with cystic fibrosis," J. Pediat. **84,** 479.

ALDERSON, P. O., SECKER-WALKER, R. H., STROMINGER, D. B., MCALISTER, W. H., HILL, R. L., AND MARKHAM, J. (1974b). "Quantitative assessment of regional ventilation and perfusion in children with cystic fibrosis," Radiology **111,** 151.

BAKER, M. L. AND DALRYMPLE, G. V. (1978). "Biological effects of diagnostic ultrasound: A review," Radiology **126,** 479.

BERNSTINE, R. L. (1969). "Safety studies with ultrasonic Doppler technic: A clinical follow-up of patients and tissue culture study," Obstet. Gynecol. **34,** 707.

BLEANY, B. I. AND OLIVER, R. (1972). "The effect of irradiation of *Vicia faba* roots with 1.5 MHz ultrasound," Br. J. Radiol. **45,** 358.

BOOK, S. AND GOLDMAN, M. (1975). "Thyroidal radioiodine exposure of the fetus," Health Phys. **29,** 874.

BRAEMAN, J. M., COAKLEY, W. T., AND GOULD, R. K. (1974). "Human lymphocyte chromosomes and ultrasonic cavitation," Br. J. Radiol. **47,** 158.

BROCK, R. D., PEACOCK, W. J., GEARD, C. R., KOSSOFF, G., AND ROBINSON, D. E. (1973). "Ultrasound and chromosome aberrations," Med. J. Aus. **2,** 533.

BUCKTON, K. E. AND BAKER, N. V. (1972). "An investigation into possible chromosome damaging effects of ultrasound on human blood cells," Br. J. Radiol. **45,** 340.

BUDINGER, T. F. (1974). "Progress in atomic medicine," page 4 in *Recent Advances in Nuclear Medicine,* Lawrence, J. H., Ed. (Grune and Stratton, New York).

CARSON, P. L. (1980). "Diagnostic ultrasound emissions and their measurements," page 551 in *The Medical Physics of CT and Ultrasound: Tissue*

Imaging and Characterization. Fullerton, G. D. and Zagzebski, J. Eds. American Association of Physicists in Medicine (AAPM) Monograph No. 6 (AAPM Headquarters, New York).

CARSON, P. L., FISCHELLA, P. R., AND OUGHTON, T. V. (1978). "Ultrasonic power and intensities produced by diagnostic ultrasound equipment," Ultrasound Med. Biol. **3,** 431.

CHAPMAN, I. V. (1974). "The effect of ultrasound on the potassium content of rat thymocytes *in vitro*," Br. J. Radiol. **47,** 411.

COAKLEY, W. T., SLADE, J. S., AND BRAEMAN, J. M. (1972). "Examination of lymphocytes for chromosome aberrations after ultrasonic irradiation," Br. J. Radiol. **45,** 328.

COMBES, R. D. (1975). "Absence of mutation following ultrasonic treatment of *Bacillus subtilis* cells and transforming deoxyribonucleic acid," Br. J. Radiol. **48,** 306.

CONWAY, J. J., LUCK, S., FILMER, R. B., AND BELMAN, A. B. (1974). "Radionuclide differentiation of a unilateral flank mass in the newborn period," J. Nucl. Med. **15,** 485.

COULAM, C. M., ERICKSON, J. J., ROLLO, F. D., AND JAMES, A. E. JR., EDS. (1981). *The Physical Basis of Medical Imaging.* (Appleton-Century-Crofts, New York).

DONALD, I. (1974). "New problems in sonar diagnosis in obstetrics and gynecology," Am. J. Obstet. Gynecol. **118,** 299.

DUNN, F. AND FRY, F. J. (1971). "Ultrasonic threshold dosages for the mammalian central nervous system," IEEE Trans. Biomed. Eng. **BME-18,** 253.

DUNN, F., LOHNES, J. E., AND FRY, F. J. (1975). "Frequency dependence of threshold ultrasonic dosages for irreversible structural changes in mammalian brain," J. Acoust. Soc. Am. **58,** 512.

ETIENNE, J., FILIPCYNSKI, L., FIREK, A., GRONIOWSKI, J., LYPACEWICZ, G., KRETOWICZ, J., AND SALKOWSKI, J. (1976). "Intensity determination of ultrasonic focused beams used in ultrasonography in the case of gravid uterus," Ultrasound Med. Biol. **2,** 119.

FALLON, J. T., STEPHENS, W. E., AND EGGLETON, R. C. (1973). "An ultrastructural study of the effect of ultrasound on arterial tissue," J. Path. **111,** 275.

FLEISCHER, A. C. AND JAMES, A. E., JR., EDS. (1980). *Introduction to Diagnostic Sonography* (John Wiley and Sons, Inc., New York).

FRY, F. J. (1970). "Threshold ultrasonic dosages for structural changes in the mammalian brain," J. Acoust. Soc. Am. **48,** 1413.

GARRISON, B. M., BO, W. J., KRUEGER, W. A., KREMKAU, F. W., AND MCKINNEY, W. M. (1973). "The influence of ovarian sonication on fetal development in the rat," J. Clin. Ultrasound **1,** 316.

GATES, G. (1978). *Atlas of Abdominal Ultrasonography in Children* (Churchill Livingstone, Inc., New York).

GENNA, S. (1966). "Analytical methods in whole-body counting," page 38 in *Clinical Uses of Whole Body Counting,* IAEA/STI/PUB/122 (International Atomic Energy Agency, Vienna).

GILDAY, D. L. AND ASH, J. M. (1976). "Benign bone tumors," Semin. Nucl. Med. **6,** 33.

GILDAY, D. L., PAUL, D. J., AND PATERSON, J. (1975). "Diagnosis of osteomyelitis in children by combined blood pool and bone imaging," Radiology **117,** 331.

GRAHAM, T. P., JR., GOODRICH, J. K., ROBINSON, A. E., AND HARRIS, C. (1970). "Scintiangiocardiography in children," Am. J. Cardiol. **25,** 387.

HANDMAKER, H. AND LOWENSTEIN, J. M. (1975). *Nuclear Medicine in Clinical Pediatrics* (The Society of Nuclear Medicine, Inc., New York).

HELLMAN, L. M., DUFFUS, G. M., DONALD, I., AND SUNDEN, B. (1970). "Safety of diagnostic ultrasound in obstetrics," Lancet **1,** 1133.

HILL, C. R. (1968). "The possibility of hazard in medical and industrial applications of ultrasound," Br. J. Radiol. **41,** 561.

HILL, C. R., JOSHI, G. P., AND REVELL, S. H. (1972). "A search for chromosome damage following exposure of Chinese hamster cells to high intensity, pulsed ultrasound," Br. J. Radiol. **45,** 333.

HOLMES, J. H. (1974). Editorial, J. Clin. Ultrasound **2,** 87.

ICRP (1971). International Commission on Radiological Protection. *Protection of the Patient in Radionuclide Investigations.* Publication 17. (Pergamon Press, New York).

ICRP (1975). International Commission on Radiological Protection. *Reference Man: Anatomical, Physiological and Metabolic Characteristics.* Publication 23, (Pergamon Press, New York).

ICRU (1979). International Commission on Radiation Units and Measurements. *Methods of Assessment of Absorbed Dose in Clinical Use of Radionuclides.* Report 32 (International Commission on Radiation Units and Measurements, Bethesda, Maryland).

JAMES, A. E., JR., ED. (1980). *The Radiological Clinics of North America. Symposium on Advances in Ultrasonography.* (W. B. Saunders Co., Philadelphia).

JAMES, A. E., WAGNER, H. N., JR., AND COOKE, R. E., EDS. (1974). *Pediatric Nuclear Medicine* (W. B. Saunders Company, Philadelphia).

KARDUCK, A. AND WEHMER, W. (1974). "Morphologic studies of the influence of ultrasound upon the growing rabbit's larynx," Arch. Oto-Rhino-Laryng. **206,** 137.

KAUL, A., OEFF, K., ROEDLER, H. D., AND VOGELSANG, T. (1973). *Radiopharmaceuticals-Biokinetic Data and Results of Radiation Dose Calculations* (Klinikum Steglitz der Freien Unifersitat, Berlin).

KEREIAKES, J. G., SELTZER, R., BLACKBURN, B., AND SAENGER, E. (1965). "Radionuclide doses to infants and children: a plea for a standard child," Health Phys. **11,** 999.

KEREIAKES, J. G., WELLMAN, H. N., SIMMONS, G., AND SAENGER, E. L. (1972). "Radiopharmaceutical dosimetry in pediatrics," Semin. Nucl. Med. **2,** 316.

KEREIAKES, J. G., SIMMONS, G. H., AND FELLER, P. A. (1976a). "Whole body and critical organ dosimetry for ^{99m}Tc-labeled pharmaceuticals," page 101 in *Biophysical Aspects of the Medical Uses of Technetium-99m,* AAPM Monograph 1 (American Association of Physicists in Medicine, New York).

KEREIAKES, J. G., FELLER, P. A., ASCOLI, F. A., THOMAS, S. R., GELFAND, M. L., AND SAENGER, E. (1976b). "Pediatric radiopharmaceutical dosimetry" page 73 in *Radiopharmaceutical Dosimetry Symposium,* Cloutier, R. J.,

Coffey, J. L., Snyder, W. S., Watson, E. E. and Hamilton, D. R., Eds. HEW Publication (FDA) 76-8044 (National Technical Information Service, Springfield, Virginia).

KHOKHAR, M. T. AND OLIVER, R. (1975). "An investigation of chromosome damage in *Vicia faba* root tips after exposure to 1.5 MHz ultrasonic radiation," Int. J. Radiat. Biol. **28,** 373.

KING, D. L. AND LELE, P. O. (1974). "Biologic effects of diagnostic ultrasound," in *Diagnostic Ultrasound* (The C. V. Mosby Co., St. Louis).

LEHMAN, J. F. AND HERRICK, J. F. (1953). "Biologic reactions to cavitation, a consideration for ultrasonic therapy," Arch. Phys. Med. **34,** 86.

LERNER, R. M., CARSTENSEN, E. L., AND DUNN, F. (1973). "Frequency dependence on thresholds for ultrasonic production of thermal lesions in tissue," J. Acoust. Soc. Am. **54,** 504.

LEVI, S., GUSTOT, P., AND GALPERIN-LEMAITRE, H. (1974). "*In vivo* effect of ultrasound at human therapeutic doses on marrow cell chromosomes of golden hamster," Humangenetik **25,** 133.

LOEVINGER, R. AND BERMAN, M. (1968). "A schema for absorbed dose calculations for biologically-distributed radionuclides," MIRD Supplement No. 1, Pamphlet No. 1, J. Nucl. Med. **9,** 7.

LOEVINGER, R. AND BERMAN, M. (1976). *A Revised Schema for Calculating the Absorbed Dose from Biologically Distributed Radionuclides,* MIRD Pamphlet No. 1, Revised. (Society of Nuclear Medicine, New York).

LYON, M. F. AND SIMPSON, G. W. (1974). "An investigation into the possible genetic hazards of ultrasound," Br. J. Radiol. **47,** 712.

MACINTOSH, I. J. C., BROWN, R. C., AND COAKLEY, W. T. (1975). "Correspondence: ultrasound and *in vitro* chromosome aberrations," Br. J. Radiol. **48,** 230.

MASON, D. T., ASHBURN, W. L., HARBERT, J. C. *et al.* (1968). "Rapid-sequence visualization of the heart and great vessels in man using the wide-field Anger scintillation camera," Circulation **39,** 19.

MASON, D. T., ASHBURN, W. L., HARBERT, J. C. *et al.* (1968). "Rapid-sequence visualization of the heart and great vessels in man using the wide-field Anger scintillation camera," Circulation **39,** 19.

MCDONALD, P., TARAR, R., GILDAY, D. L., AND REILLY, B. J. (1974). "Some radiologic observations in renal vein thrombosis," Am. J. Roentgenol. **120,** 368.

NCRP (1978). National Council on Radiation Protection and Measurements, *A Handbook of Radioactivity Measurements Procedures,* NCRP Report No. 58 (National Council on Radiation Protection and Measurements, Bethesda, Maryland)

NCRP (1981). National Council on Radiation Protection and Measurements, *Radiation Protection in Pediatric Radiology,* NCRP Report No. 68 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1982). National Council on Radiation Protection and Measurements. *Nuclear Medicine—Factors Influencing the Choice and Use of Radionu-*

clides in Diagnosis and Therapy, NCRP Report No. 70 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

PIERETTI, R., GILDAY, D. L., AND JEFFS, R. (1974). "Differential kidney scan in pediatric urology," Urology **4**, 665.

PIZZARELLO, D. J., WOLSKY, A., BECKER, M. H., AND KEEGAN, A. F. (1974). "A new approach to testing the effect of ultrasound on tissue growth and differentiation," Oncology **31**, 226.

POSTON, J. (1976). "The effects of body and organ size on absorbed dose: there is no standard patient," page 92 in *Radiopharmaceutical Dosimetry Symposium*, Cloutier, R. J., Coffey, J. L., Snyder, W. S., Watson, E. E. and Hamilton, D. R., Eds., HEW Publication (FDA) 76-8044 (National Technical Information Service, Springfield, Virginia).

PRICE, R. R., JAMES, A. E., AND ROLLO, F. D. (1982) *Digital Radiology* (Grune and Stratton, New York).

ROBINSON, A. E., GOODRICH, J. K., AND SPOCK, A. (1969). "Inhalation and perfusion radionuclide studies of pediatric chest disease," Radiology **93**, 1123.

ROEDLER, H. D., KAUL, A., AND HINE, G. J. (1978). *Internal Radiation Dose in Diagnostic Nuclear Medicine* (Verlage Hoffman, Berlin).

ROSENFIELD, N. AND TREVES, S. (1974). "Osseous and extraosseous uptake of fluorine-18 and technetium-99m polyphosphate in children with neuroblastoma," Radiology **111**, 127.

ROSENTHAL, L. (1966). "Radionuclide venography using technetium-99m pertechnetate and the gamma-ray scintillation camera," Amer. J. Roentgen. **97**, 874.

ROTT, H. D. AND SOLDNER, R. (1973). "The effect of ultrasound on human chromosomes *in vitro*," Humangenetik **20**, 103.

SANDERS, R. C. AND JAMES, A. E., JR., Eds. (1980). *Principles and Practice of Ultrasonography in Obstetrics and Gynecology, Second Edition* (Appleton-Century-Crofts, New York).

SHIMIZU, T. AND SHOJI, R. (1973). "An experimental study of mice exposed to low intensity ultrasound," In *Proceedings of the II World Congress on Ultrasonics in Medicine*, de Vlieger, M., White, D. N., and McCready, V. R., Eds. International Congress Series, No. 227 (Excerpta Medica, Inc., Rotterdam).

SHOJI, R., MURKAMI, U., AND SHIMIZU, T. (1975). "Influence of low-intensity ultrasound irradiation on prenatal development of two inbred mouse strains," Teratology **12**, 227.

SIEGEL, E., GODDARD, J., JAMES, A. E. AND SIEGEL, P. (1979). "Cellular attachment as a sensitive indicator of the effects of diagnostic ultrasound exposure on cultured human cells," Radiology **133**, 175.

SMITH, E. M. AND WARNER, G. G. (1976). "Estimates of radiation dose to the embryo from nuclear medicine procedures," J. Nucl. Med. **17**, 836.

SNYDER, W. S., FORD, M. R., WARNER, G. G. AND WATSON, S. B. (1974). *A Tabulation of Dose Equivalent per Microcurie-Day for Source and Target Organs of an Adult for Various Radionuclides*, Report ORNL-5000, (Na-

tional Technical Information Service, Springfield, Virginia).

SORENSON, J. A. (1971). *Methods for Quantitating Radioactivity in vivo by External Counting Measurements*, PH. D. Thesis (University of Wisconsin, Madison, Wisconsin).

SPECTOR, W. (Ed.) (1956). *Handbook of Biological Data*, page 162 (W. B. Saunders Company, Philadelphia).

TAYLOR, K. J. W. (1974). "Biological effects of diagnostic ultrasound," in *Diagnostic Ultrasound* (The C.V. Mosby Co., St. Louis).

TAYLOR, K. J. W. AND POND, J. B. (1972a). "A study of the production of haemorrhagic injury and paraplegia in rat spinal cord by pulsed ultrasound of low megaHertz frequencies in the context of the safety for clinical usage," Br. J. Radiol. **45**, 343.

TAYLOR, K. J. W. AND POND, J. B. (1972b). "Experimental ultrasonic injury and safety limits in its use," Acta. Radiol. Diag. **13**, 743.

THOMAS, S. R., MAXON, H. R., AND KEREIAKES, J. G. (1976) "*In vivo* quantitation of lesion radioactivity using external counting methods," Med. Phys. **3**, 252.

WAGNER, H. M. (1968). *Principles of Nuclear Medicine*, (W. B. Saunders, Philadelphia)

WATTS, P. L. AND HALL, A. J. (1972). "Ultrasound and chromosome damage," Br. J. Radiol. **45**, 335.

WEBSTER, E. W., ALPERT, N. M., AND BROWNELL, G. L. (1974). "Radiation doses in pediatric nuclear medicine and diagnostic x-ray procedures," page 34 in *Pediatric Nuclear Medicine*, James, A. E., Wagner, H. N., and Cook, R. E., Eds. (W. B. Saunders Company, Philadelphia).

WELLS, P. N. T. (1969). *Physical Principles of Ultrasonic Diagnosis*, page 222, (Academic Press, Inc., London).

The NCRP

The National Council on Radiation Protection and Measurements is a nonprofit corporation chartered by Congress in 1964 to:

1. Collect, analyze, develop, and disseminate in the public interest information and recommendations about (a) protection against radiation and (b) radiation measurements, quantities, and units, particularly those concerned with radiation protection;
2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units, and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations;
3. Develop basic concepts about radiation quantities, units, and measurements, about the application of these concepts, and about radiation protection;
4. Cooperate with the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units, and measurements and with radiation protection.

The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee.

The Council is made up of the members and the participants who serve on the eighty one Scientific Committees of the Council. The Scientific Committees, composed of experts having detailed knowledge and competence in the particular area of the Committee's interest, draft proposed recommendations. These are then submitted to the full membership of the Council for careful review and approval before being published.

The following comprise the current officers and membership of the Council:

Officers

President	WARREN K. SINCLAIR
Vice President	S. JAMES ADELSTEIN
Secretary and Treasurer	W. ROGER NEY
Assistant Secretary	EUGENE R. FIDELL
Assistant Treasurer	JAMES F. BERG

Members

Seymour Abrahamson
S. James Adelstein
Roy E. Albert
Edward L. Alpen
John A. Auxier
William J. Bair
John D. Boice, Jr.
Victor P. Bond
Robert L. Brent
Antone Brooks
Reynold F. Brown
Thomas F. Budinger
Melvin W. Carter
George W. Casarett
Randall S. Caswell
Arthur B. Chilton
Gerald Dodd
Patricia W. Durbin
Joe A. Elder
Mortimer M. Elkind
Thomas S. Ely
Edward R. Epp
R. J. Michael Fry
Robert A. Goepp
Barry B. Goldberg
Robert O. Gorson
Douglas Grahn
Arthur W. Guy
Eric J. Hall
John H. Harley
Naomi Harley
John W. Healy
John M. Heslep
Seymour Jablon
Donald G. Jacobs
A. Everette James, Jr.
Bernd Kahn
James G. Kereiakes
Charles E. Land
Thomas A. Lincoln
Ray D. Lloyd
Arthur C. Lucas
Charles W. Mays
Roger O. McClellan
James McLaughlin
Barbara J. McNeil
Charles B. Meinhold
Mortimer L. Mendelsohn
William E. Mills
Dade W. Moeller
A. Alan Moghissi
Paul E. Morrow
Robert D. Moseley, Jr.
James V. Neel
Wesley Nyborg
Frank Parker
Andrew K. Poznanski
Norman C. Rasmussen
William C. Reinig
Chester R. Richmond
James T. Robertson
Leonard A. Sagan
Warren K. Sinclair
Glenn E. Sheline
Roy E. Shore
Lewis V. Spencer
John B. Storer
Roy C. Thompson
James E. Turner
Arthur C. Upton
George L. Voelz
Edward W. Webster
George M. Wilkening
H. Rodney Withers

Honorary Members

Lauriston S. Taylor, *Honorary President*

Edgar C. Barnes
Austin M. Brues
Frederick P. Cowan
James F. Crow
Merril Eisenbud
Robley D. Evans
Richard F. Foster
Hymer L. Friedell
Louis H. Hempelmann, Jr
Paul C. Hodges
George V. LeRoy
Wilfrid B. Mann
Karl Z. Morgan
Russell H. Morgan
Robert J. Nelsen
Herbert M. Parker
Harald H. Rossi
William G. Russell
John H. Rust
Eugene L. Saenger
J. Newell Stannard
Harold O. Wyckoff

Currently, the following subgroups are actively engaged in formulating recommendations:

SC-1:	Basic Radiation Protection Criteria
SC-3:	Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Performance and Use)
SC-16:	X-Ray Protection in Dental Offices
SC-18:	Standards and Measurements of Radioactivity for Radiological Use
SC-38:	Waste Disposal
	Task Group on Krypton-85
	Task Group on Carbon-14
	Task Group on Iodine-129
	Task Group on Disposal of Accident Generated Waste Water
	Task Group on Disposal of Low-Level Waste
	Task Group on the Actinides
	Task Group on Xenon
SC-40:	Biological Aspects of Radiation Protection Criteria
	Task Group on Atomic Bomb Survivor Dosimetry
	Subgroup on Biological Aspects of Dosimetry of Atomic Bomb Survivors
SC-42:	Industrial Applications of X Rays and Sealed Sources
SC-44:	Radiation Associated with Medical Examinations
SC-45:	Radiation Received by Radiation Employees
SC-46:	Operational Radiation Safety
	Task Group 1 on Warning and Personnel Security Systems
	Task Group 2 on Uranium Mining and Milling- Radiation Safety Programs
	Task Group 3 on ALARA for Occupationally Exposed Individuals in Clinical Radiology
	Task Group 4 on Calibration of Instrumentation
SC-47:	Instrumentation for the Determination of Dose Equivalent
SC-48:	Apportionment of Radiation Exposure
SC-52:	Conceptual Basis of Calculations of Dose Distributions
SC-53:	Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Radiation
SC-54	Bioassay for Assessment of Control of Intake of Radionuclides
SC-55:	Experimental Verification of Internal Dosimetry Calculations
SC-57:	Internal Emitter Standards
	Task Group 2 on Respiratory Tract Model
	Task Group 3 on General Metabolic Models
	Task Group 4 on Radon and Daughters
	Task Group 6 on Bone Problems
	Task Group 7 on Thyroid Cancer Risk
	Task Group 8 on Leukemia Risk
	Task Group 9 on Lung Cancer Risk
	Task Group 10 on Liver Cancer Risk
	Task Group 12 on Strontium
	Task Group 13 on Neptunium
SC-59:	Human Radiation Exposure Experience
SC-60:	Dosimetry of Neutrons from Medical Accelerators
SC-61:	Radon Measurements
SC-62:	Priorities for Dose Reduction Efforts
SC-63:	Control of Exposure to Ionizing Radiation from Accident or Attack

SC-64: Radionuclides in the Environment
- Task Group 2 on Identification and Evaluation of Environmental Models for Estimate of Dose from Discharge to Surface Waters
- Task Group 3 on Identification and Evaluation of Environmental Models for Estimate of Dose from Discharge to Atmosphere
- Task Group 5 on Public Exposure to Nuclear Power
- Task Group 6 on Screening Models

SC-65: Quality Assurance and Accuracy in Radiation Protection Measurements
SC-66: Biological Effects and Exposure Criteria for Ultrasound
SC-67: Biological Effects of Magnetic Fields
SC-68: Microprocessors in Dosimetry
SC-69: Efficacy Studies
SC-70: Quality Assurance and Measurement in Diagnostic Radiology
SC-71: Radiation Exposure and Potentially Related Injury
SC-72: Radiation Protection in Mammography
SC-73: Population Exposure from Technologically Enhanced Sources
SC-74: Radiation Received in the Decontamination of Nuclear Facilities
SC-75: Guidance on Radiation Received in Space Activities
SC-76: Effects of Radiation on the Embryo-Fetus
SC-77: Guidance on Occupational and Public Exposure Resulting from Diagnostic Nuclear Medicine Procedures
SC-78: Practical Guidance on the Evaluation of Human Exposures to Radio Frequency Radiation
SC-79: Extremely Low-Frequency Electric and Magnetic Fields
SC-80: Radiation Biology of the Skin (Beta-ray Dosimetry)
SC-81: Assessment of Exposure from Therapy

Committee on Public Education
Committee on Public Relations
Ad Hoc Committee on Policy in Regard to the International System of Units
Ad Hoc Committee on Comparison of Radiation Exposures
Study Group on Acceptable Risk (Nuclear Waste)
Study Group on Comparative Risk
- Task Group on Comparative Carcinogenicity of Pollutant Chemicals

Task Force on Occupational Exposure Levels

In recognition of its responsibility to facilitate and stimulate cooperation among organizations concerned with the scientific and related aspects of radiation protection and measurement, the Council has created a category of NCRP Collaborating Organizations. Organizations or groups of organizations that are national or international in scope and are concerned with scientific problems involving radiation quantities, units, measurements and effects, or radiation protection may be admitted to collaborating status by the Council. The present Collaborating Organizations with which the NCRP maintains liaison are as follows:

American Academy of Dermatology
American Association of Physicists in Medicine

American College of Nuclear Physicians
American College of Radiology
American Dental Association
American Institute of Ultrasound in Medicine
American Insurance Association
American Medical Association
American Nuclear Society
American Occupational Medical Association
American Podiatry Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society of Radiologic Technologists
American Society of Therapeutic Radiologists
Association of University Radiologists
Atomic Industrial Forum
Bioelectromagnetics Society
College of American Pathologists
Federal Emergency Management Agency
Genetics Society of America
Health Physics Society
National Bureau of Standards
National Electrical Manufacturers Association
Radiation Research Society
Radiological Society of North America
Society of Nuclear Medicine
United States Air Force
United States Army
United States Department of Energy
United States Department of Labor
United States Environmental Protection Agency
United States Navy
United States Nuclear Regulatory Commission
United States Public Health Service

The NCRP has found its relationships with these organizations to be extremely valuable to continued progress in its program.

Another aspect of the cooperative efforts of the NCRP relates to the special liaison relationships established with various governmental organizations that have an interest in radiation protection and measurements. This liaison relationship provides: (1) an opportunity for participating organizations to designate an individual to provide liaison between the organization and the NCRP; (2) that the individual designated will receive copies of draft NCRP reports (at the time that these are submitted to the members of the Council) with an invitation to comment, but not vote; and (3) that new NCRP efforts might be discussed with liaison individuals as appropriate, so that they might have an opportunity to make suggestions on new studies and related

matters. The following organizations participate in the special liaison program:

Defense Nuclear Agency
Federal Emergency Management Agency
National Bureau of Standards
Office of Science and Technology Policy
Office of Technology Assessment
United States Air Force
United States Army
United States Coast Guard
United States Department of Energy
United States Department of Health and Human Services
United States Department of Labor
United States Department of Transportation
United States Environmental Protection Agency
United States Navy
United States Nuclear Regulatory Commission

The NCRP values highly the participation of these oganizations in the liaison program.

The Council's activities are made possible by the voluntary contribution of time and effort by its members and participants and the generous support of the following organizations:

Alfred P. Sloan Foundation
Alliance of American Insurers
American Academy of Dental Radiology
American Academy of Dermatology
American Association of Physicists in Medicine
American College of Radiology
American College of Radiology Foundation
American Dental Association
American Hospital Radiology Administrators
American Industrial Hygiene Association
American Insurance Association
American Medical Association
American Occupational Medical Association
American Osteopathic College of Radiology
American Podiatry Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society of Radiologic Technologists
American Society of Therapeutic Radiologists
American Veterinary Medical Association

American Veterinary Radiology Society
Association of University Radiologists
Atomic Industrial Forum
Battelle Memorial Institute
National Center for Devices and Radiological Health
College of American Pathologists
Commonwealth of Pennsylvania
Defense Nuclear Agency
Edison Electric Institute
Edward Mallinckrodt, Jr. Foundation
Electric Power Research Institute
Federal Emergency Management Agency
Florida Institute of Phosphate Research
Genetics Society of America
Health Physics Society
James Picker Foundation
National Association of Photographic Manufacturers
National Bureau of Standards
National Cancer Institute
National Electrical Manufacturers Association
Radiation Research Society
Radiological Society of North America
Society of Nuclear Medicine
United States Department of Energy
United States Department of Labor
United States Environmental Protection Agency
United States Navy
United States Nuclear Regulatory Commission

To all these organizations the Council expresses its profound appreciation for their support.

Initial funds for publication of NCRP reports were provided by a grant from the James Picker Foundation and for this the Council wishes to express its deep appreciation.

The NCRP seeks to promulgate information and recommendations based on leading scientific judgment on matters of radiation protection and measurement and to foster cooperation among organizations concerned with these matters. These efforts are intended to serve the public interest and the Council welcomes comments and suggestions on its reports or activities from those interested in its work.

NCRP Publications

NCRP publications are distributed by the NCRP Publications' office. Information on prices and how to order may be obtained by directing an inquiry to:

NCRP Publications
7910 Woodmont Ave, Suite 1016
Bethesda, Md. 20814

The currently available publications are listed below.

Proceedings of the Annual Meeting

No.	Title
1	*Perceptions of Risk*, Proceedings of the Fifteenth Annual Meeting, Held on March 14–15, 1979 (Including Taylor Lecture No. 3) (1980)
2	*Quantitative Risk in Standards Setting*, Proceedings of the Sixteenth Annual Meeting Held on April 2–3, 1980 (Including Taylor Lecture No. 4) (1981)
3	*Critical Issues in Setting Radiation Dose Limits*, Proceedings of the Seventeenth Annual Meeting, Held on April 8–9, 1981 (Including Taylor Lecture No. 5) (1982)
4	*Radiation Protection and New Medical Diagnostic Procedures*, Proceedings of the Eighteenth Annual Meeting, Held on April 6–7, 1982 (Including Taylor Lecture No. 6) (1983)

Lauriston S. Taylor Lectures

No.	Title and Author
1	*The Squares of the Natural Numbers in Radiation Protection* by Herbert M. Parker (1977)
2	*Why be Quantitative About Radiation Risk Estimates?* by Sir Edward Pochin (1978)
3	*Radiation Protection—Concepts and Trade Offs* by Hy-

mer L. Friedell (1979) [Available also in *Perceptions of Risk*, see above]

4 *From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review* by Harold O. Wyckoff (1980) [Available also in *Quantitative Risks in Standards Setting*, see above]

5 *How Well Can We Assess Genetic Risk? Not Very* by James F. Crow (1981) [Available also in *Critical Issues in Setting Radiation Dose Limits*, see above]

6 *Ethics, Trade-offs and Medical Radiation* by Eugene L. Saenger (1982) [Available also in *Radiation Protection and New Medical Diagnostic Approaches*, see above]

7 *The Human Environment-Past, Present and Future* by Merril Eisenbud (1983) [Available also in 1983 in *Environmental Radioactivity.*]

NCRP Reports

No.	Title
8	*Control and Removal of Radioactive Contamination in Laboratories* (1951)
9	*Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users* (1951)
12	*Recommendations for the Disposal of Carbon-14 Wastes* (1953)
16	*Radioactive Waste Disposal in the Ocean* (1954)
22	*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (1959) [Includes Addendum 1 issued in August 1963]
23	*Measurement of Neutron Flux and Spectra for Physical and Biological Applications* (1960)
25	*Measurement of Absorbed Dose of Neutrons and Mixtures of Neutrons and Gamma Rays* (1961)
27	*Stopping Powers for Use with Cavity Chambers* (1961)
30	*Safe Handling of Radioactive Materials* (1964)
32	*Radiation Protection in Educational Institutions* (1966)
33	*Medical X-Ray and Gamma-Ray Protection for Energies Up to 10 MeV—Equipment Design and Use* (1968)
35	*Dental X-Ray Protection* (1970)
36	*Radiation Protection in Veterinary Medicine* (1970)

37 *Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides* (1970)
38 *Protection against Neutron Radiation* (1971)
39 *Basic Radiation Protection Criteria* (1971)
40 *Protection Against Radiation from Brachytherapy Sources* (1972)
41 *Specification of Gamma-Ray Brachytherapy Sources* (1974)
42 *Radiological Factors Affecting Decision-Making in a Nuclear Attack* (1974)
43 *Review of the Current State of Radiation Protection Philosophy* (1975)
44 *Krypton-85 in the Atmosphere—Accumulation, Biological Significance, and Control Technology* (1975)
45 *Natural Background Radiation in the United States* (1975)
46 *Alpha-Emitting Particles in Lungs* (1975)
47 *Tritium Measurement Techniques* (1976)
48 *Radiation Protection for Medical and Allied Health Personnel* (1976)
49 *Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma-Rays of Energies Up to 10 MeV* (1976)
50 *Environmental Radiation Measurements* (1976)
51 *Radiation Protection Design Guidelines for 0.1–100 MeV Particle Accelerator Facilities* (1977)
52 *Cesium-137 From the Environment to Man: Metabolism and Dose* (1977)
53 *Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women* (1977)
54 *Medical Radiation Exposure of Pregnant and Potentially Pregnant Women* (1977)
55 *Protection of the Thyroid Gland in the Event of Releases of Radioiodine* (1977)
56 *Radiation Exposure From Consumer Products and Miscellaneous Sources* (1977)
57 *Instrumentation and Monitoring Methods for Radiation Protection* (1978)
58 *A Handbook of Radioactivity Measurements Procedures* (1978)
59 *Operational Radiation Safety Program* (1978)
60 *Physical, Chemical, and Biological Properties of Radi-*

ocerium Relevant to Radiation Protection Guidelines (1978)

61 *Radiation Safety Training Criteria for Industrial Radiography* (1978)

62 *Tritium in the Environment* (1979)

63 *Tritium and Other Radionuclide Labeled Organic Compounds Incorporated in Genetic Material* (1979)

64 *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980)

65 *Management of Persons Accidentally Contaminated with Radionuclides* (1980)

66 *Mammography* (1980)

67 *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements* (1981)

68 *Radiation Protection in Pediatric Radiology* (1981)

69 *Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV* (1981)

70 *Nuclear Medicine—Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy* (1982)

71 *Operational Radiation Safety—Training* (1983)

72 *Radiation Protection and Measurement for Low Voltage Neutron Generators* (1983)

73 *Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children* (1983)

Binders for NCRP Reports are available. Two sizes make it possible to collect into small binders the "old series" of reports (NCRP Reports Nos. 8–31) and into large binders the more recent publications (NCRP Reports Nos. 32–71). Each binder will accommodate from five to seven reports. The binders carry the identification "NCRP Reports" and come with label holders which permit the user to attach labels showing the reports contained in each binder.

The following bound sets of NCRP Reports are also available:

Volume I. NCRP Reports Nos. 8, 9, 12, 16, 22
Volume II. NCRP Reports Nos. 23, 25, 27, 30
Volume III. NCRP Reports Nos. 32, 33, 35, 36, 37
Volume IV. NCRP Reports Nos. 38, 39, 40, 41
Volume V. NCRP Reports Nos. 42, 43, 44, 45, 46

Volume VI. NCRP Reports Nos. 47, 48, 49, 50, 51
Volume VII. NCRP Reports Nos. 52, 53, 54, 55, 56, 57
Volume VIII. NCRP Report No. 58
Volume IX. NCRP Reports Nos. 59, 60, 61, 62, 63
Volume X, NCRP Reports Nos. 64, 65, 66, 67

(Titles of the individual reports contained in each volume are given above).

The following NCRP Reports are now superseded and/or out of print:

No.	Title
1	*X-Ray Protection* (1931). [Superseded by NCRP Report No. 3]
2	*Radium Protection* (1934). [Superseded by NCRP Report No. 4]
3	*X-Ray Protection* (1936). [Superseded by NCRP Report No. 6]
4	*Radium Protection* (1938). [Superseded by NCRP Report No. 13]
5	*Safe Handling of Radioactive Luminous Compounds* (1941). [Out of Print]
6	*Medical X-Ray Protection Up to Two Million Volts* (1949). [Superseded by NCRP Report No. 18]
7	*Safe Handling of Radioactive Isotopes* (1949). [Superseded by NCRP Report No. 30]
10	*Radiological Monitoring Methods and Instruments* (1952). [Superseded by NCRP Report No. 57]
11	*Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water* (1953). [Superseded by NCRP Report No. 22]
13	*Protection Against Radiations from Radium, Cobalt-60 and Cesium-137* (1954). [Superseded by NCRP Report No. 24]
14	*Protection Against Betatron—Synchrotron Radiations Up to 100 Million Electron Volts* (1954). [Superseded by NCRP Report No. 51]
15	*Safe Handling of Cadavers Containing Radioactive Isotopes* (1953). [Superseded by NCRP Report No. 21]
17	*Permissible Dose from External Source of Ionizing Radiation* (1954) including *Maximum Permissible Exposure to Man, Addendum to National Bureau of Stan-*

dards Handbook 59 (1958). [Superseded by NCRP Report No. 39]

18 *X-Ray Protection* (1955). [Superseded by NCRP Report No. 26

19 *Regulation of Radiation Exposure by Legislative Means* (1955). [Out of print]

20 *Protection Against Neutron Radiation Up to 30 Million Electron Volts* (1957). [Superseded by NCRP Report No. 38]

21 *Safe Handling of Bodies Containing Radioactive Isotopes* (1958). [Superseded by NCRP Report No. 37]

24 *Protection Against Radiations from Sealed Gamma Sources* (1960). [Superseded by NCRP Report Nos. 33, 34, and 40]

26 *Medical X-Ray Protection Up to Three Million Volts* (1961). [Superseded by NCRP Report Nos. 33, 34, 35, and 36]

28 *A Manual of Radioactivity Procedures* (1961). [Superseded by NCRP Report No. 58]

29 *Exposure to Radiation in an Emergency* (1962). [Superseded by NCRP Report No. 42]

31 *Shielding for High Energy Electron Accelerator Installations* (1964). [Superseded by NCRP Report No. 51]

34 *Medical X-Ray and Gamma-Ray Protection for Energies Up to 10 MeV—Structural Shielding Design and Evaluation* (1970). [Superseded by NCRP Report No. 49]

Other Documents

The following documents of the NCRP were published outside of the NCRP Reports series:

"Blood Counts, Statement of the National Committee on Radiation Protection," Radiology 63, 428 (1954)

"Statements on Maximum Permissible Dose from Television Receivers and Maximum Permissible Dose to the Skin of the Whole Body," Am. J. Roentgenol., Radium Ther. and Nucl. Med. 84, 152 (1960) and Radiology 75, 122 (1960)

X-Ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements (National Council on Radiation Protection and Measurements, Washington, 1968)

Specification of Units of Natural Uranium and Natural Thorium (National Council on Radiation Protection and Measurements, Washington, 1973)

NCRP Statement on Dose Limit for Neutrons (National Council on Radiation Protection and Measurements, Washington, 1980)

Krypton-85 in the Atmosphere—With Specific Reference to the Public Health Significance of the Proposed Controlled Release at Three Mile Island (National Council on Radiation Protection and Measurements, Washington, 1980)

Preliminary Evaluation of Criteria For the Disposal of Transuranic Contaminated Waste (National Council on Radiation Protection and Measurements, Bethesda, Md, 1982)

Copies of the statements published in journals may be consulted in libraries. A limited number of copies of the remaining documents listed above are available for distribution by NCRP Publications.

INDEX