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# A SUMMARY OF THE DATA THAT WAS USED IN THE REVISION OF THE INTERNAL DOSE RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION*

By K. Z. MORGAN†, I. H. TIPTON‡ and M. J. COOK†

THE International Commission on Radiological Protection[1], ICRP, was organized in Stockholm, Sweden in 1928 under the auspices of the International Congress of Radiology for the purpose of making a study of the hazards associated with ionizing radiation and of making recommendations for procedures, technique and equipment that might be used to reduce radiation exposure. During the past 30 years, the ICRP has faithfully carried out its assigned task and has become recognized as the international authority on radiation protection. One of the most important responsibilities has been to work together as individual scientists—without instructions from any organization or country—in establishing levels of maximum permissible exposure from external and internal sources of ionizing radiation.

Since the beginning of its organization, the ICRP has made recommendations for the safe use of radium[2] and its daughter products and in 1955 it published the first internal dose recommendations[3] stating levels of maximum permissible occupational exposure for 86 radionuclides. Since that time a large number of radiological experiments have been conducted on various animals to determine the effects from external and internal exposure to ionizing radiation. In addition to animal studies, studies have been conducted on humans who received excessive occupational and medical exposure from x-rays, radium and thorium. In this manner, much valuable data have become available and used in the 1958 revision[4] of the internal dose recommendations of the ICRP. The basic principles and fundamental philosophy of protection from external and internal sources of ionizing radiation have not changed, but a number of important revisions have been made and the amount of information in the revised recommendations on internal dose has been increased considerably.

Occupational exposure values are given for body burden, $q$, and maximum permissible concentration, MPC, in air and in water, for some 240 radionuclides. The MPC and $q$ values when relevant are listed for (1) soluble

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* This is a review of the internal dose recommendations of ICRP by the authors and is not an official expression of opinion by the ICRP.

† K. Z. Morgan and M. J. Cook are with the Health Physics Division of Oak Ridge National Laboratory, operated by Union Carbide Corporation for the U.S. Atomic Energy Commission.

‡ I. H. Tipton, Physics Department, the University of Tennessee, Knoxville, Tennessee.



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compounds, (2) insoluble compounds, and (3) in a few cases for the equilibrium mixture of parent and daughter radionuclides. These values are based on exposure to the critical body organ and in addition exposure to the more important organs including total body, gastrointestinal, GI, tract and the lungs. These additions increased the number of MPC values in the ICRP recommendations from about 350 to about 3000.

In 1956, the ICRP decided[5] that an upper limit should be set for the maximum permissible accumulated dose from ionizing radiation to the total body and to the gonads in order to reduce the chances of inducing radiation mutations and to minimize the possibility of somatic damage, e.g. leukemia and shortening of the life span. In the 1958 internal dose publication of ICRP, this reduction was accomplished (1) by limiting the average permissible RBE dose rate to the total body and gonads for occupational workers to $\frac{1}{3}$ the maximum, i.e. $\frac{1}{3} \times 0{\cdot}3 = 0{\cdot}1$ rem per week (average), and (2) by limiting the average permissible dose rate for the population living just outside the control area (a control area is an area under the surveillance of a health physicist) to $\frac{1}{10}$ this value, i.e. 0·01 rem per week (average). This reduction (by a factor of $\frac{1}{3}$) of the permissible exposure to the total body lowers about 7% of the total MPC values (Table 1) or about 30% of the MPC values[6] exclusive of those for the GI tract. In no case was this reduction brought about because the gonads were the critical body organs. This resulted from two facts: (1) there is a paucity of information on the concentration of radionuclides in the gonads and (2) when a large amount of a radionuclide is in the gonads, apparently a corresponding concentration is in the total body so the total body may be taken equally well as the critical organ.

The $q$ and MPC values in the revised ICRP publication are primarily for occupational exposure. At a later date when more data are available on the concentration of radionuclides in the gonads and when a sufficient amount of reliable information is accumulated from which to predict the ecological effects of radioactive materials in the environment, it is anticipated that $q$ and MPC values will be recommended which are directly applicable to non-occupational exposure. Until such specific data are available, the ICRP recommends that the $q$ and MPC values for populations outside of and in the neighborhood of the control area should be reduced *ad interim* to 10% of the occupational exposure values. The ICRP further recommends that for the entire population the average dose resulting from man-made sources of ionizing radiation should not exceed a few times average natural background. Therefore, after making appropriate allowance for medical and other man-made sources of exposure, the $q$ and MPC values for the total population and for the disposal of radioactive wastes into the general environment must be selected with reference to the average natural background dose.

Several experiments[7] have indicated that somatic damage such as radiation-induced leukemia is related not only to the maximum absorbed dose in a given organ (or in a portion of it) but also it is related to the gram-rad absorbed dose. Some evidence indicates that the incidence of radiation-induced leukemia is more closely related to the gram-rad dose to the entire hematopoietic system than to the absorbed dose to the marrow or to the spleen. Consequently, the 1958

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ICRP internal dose publication allows larger doses to single organs or portions of them (excepting the gonads) than to the total body.

For bone-seeking radionuclides, the MPC values were calculated for a prolonged occupational exposure that would result in the same rem dose to the bone as that delivered by a body burden of 0·1 $\mu$g of $Ra^{226}$ plus its daughter products. This corresponds to an average RBE dose rate of 0·1 rem per week to the bone or an estimated localized RBE dose rate of 0·56 rem per week to the bone. This 0·56 rem per week RBE dose is obtained by making the assumption that for the particulate component of radiation (i.e. $\alpha$, $\beta^+$, $\beta^-$ and $\bar{e}$ radiation but not the x- and $\gamma$-radiation) emitted by radionuclides deposited in the bone, the non-uniform distribution factor (relative to $Ra^{226}$ plus daughter products) is equal to 5 and the relative biological effectiveness, RBE, of $\alpha$ radiation is equal to 10 for chronic damage. All of the $q$ and MPC values for bone have been reduced by 32% because now it is assumed that only 30% of the daughter products[8] of $Ra^{226}$ are retained in the body, while formerly, 55% of the daughter products[9] were assumed to have been retained in the body. The skin and thyroid are considered to be less susceptible to radiation damage than other body tissue; therefore, for the radionuclides for which the skin or thyroid is the critical body organ the MPC values correspond to a RBE dose rate of 0·6 rem per week. For all other organs of the body, the maximum permissible RBE dose rate remains at the old (1953) value of 0·3 rem per week. Table 1 summarizes the number of radionuclides for which the various organs are taken as the first critical body organ in the 1958 ICRP internal dose publication.

Although human data are preferable for determining the $q$ and MPC values most of the biological values are based on information from animal experiments because human metabolic information is lacking. However, even the animal data that are available (almost without exception) are limited to data obtained from single dose experiments[10] (i.e. the radionuclides were administered to the animals in single doses—usually intravenously—rather than continuously in the food, water or air), so the values of $q$ and MPC, which are given for continuous occupational exposure in the 1958 ICRP internal dose publication, have been obtained indirectly by calculation. Some of the human data that were used consisted of the following: (1) the results of many years of human experience in the use of radium[11], (2) the data from cases of accidental ingestion, wounds or inhalation[12] of certain of the radionuclides, e.g. $Sr^{90}$, $Pu^{239}$, $U^{235}$, $Am^{241}$, $Th^{227}$, and $Ra^{226}$, (3) a few studies of terminal patients that were administered radionuclides, e.g. a group of 8 patients[13] given massive doses of $U^{233}$, (4) human tracer studies[14] using human body counters, and (5) studies of the stable element distribution in the human body[15]. Figures 1–5 illustrate the above cases 1–5 respectively.

In the revised ICRP publication, a major objective has been to obtain reliable values for the distribution of radioelements in the human body following many years of exposure. Obviously, short range tracer studies—even when conducted on man—might yield misleading results. One of the more promising sources of such chronic data is the normal distribution of stable elements in the human body. For the past six years, a study of human tissue has been conducted by the Oak Ridge National Laboratory in co-operation with the University of

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TABLE 1

*Radionuclides for which the Various Organs are the Critical Body Organs*

| Critical organ | Dose rate (rem/week) | Number of radionuclides for which organ is the critical organ. Based on $q$ (Maximum permissible total body burden $\mu$c) | $(MPC)_w$ (Maximum permissible concentration in water, $\mu$c/cc) | $(MPC)_a$ (Maximum permissible concentration in air, $\mu$c/cc) |
|---|---|---|---|---|
| Total Body | 0·1 | 35 | 14 | 22 |
| Bone | 0·56 | 73 | 28 | 50 |
| Kidney | 0·3 | 68 | 12 | 28 |
| Liver | 0·3 | 21 | 1 | 9 |
| Thyroid | 0·6 | 10 | 8 | 8 |
| Spleen | 0·1 | 7 | 2 | 4 |
| Pancreas | 0·3 | 4 | 2 | 2 |
| Lung | 0·3 | 4 | 0 | 4 (227)* |
| Prostate | 0·3 | 2 | 0 | 1 |
| Skin | 0·6 | 1 | 0 | 1 |
| Fat | 0·3 | 1 | 1 | 1 |
| Gonads | 0·1 | 1 | 1 | 1 |
| Gastrointestinal Tract | | | | |
| Lower Large Int. | 0·3 | | 133 (203)* | 80 |
| Upper Large Int. | 0·3 | | 14 (23)* | 13 |
| Stomach | 0·3 | | 8 (5)* | 7 |
| Small Intestine | 0·3 | | 4 (2)* | 3 |

* Values in parentheses are for the relatively insoluble compounds; the other values are for the soluble compounds.

Tennessee. This study includes a spectrographic analysis for 36 elements in 35 body organs, from over 300 autopsies that were supplied from 15 countries. In some cases, the analyses are augmented by neutron activation and flame photometry. To avoid errors and deviations from the standard man due to prolonged illness or medication, the tissue used in this study is collected only from human subjects that have died from accidents. When the autopsy material is procured in the United States the tissues are placed in plastic bags, quick frozen, and later shipped in dry ice to Oak Ridge. When the autopsy material is obtained from another country, of necessity a more permanent type of preservation has to be used and formaldehyde was selected. The formaldehyde is analyzed spectrographically before the tissue is placed in it. The samples are shipped to the prosector in plastic bottles. (In this way the tissue is preserved in a solution of known chemical composition.) The tissue is ashed at the Oak Ridge National Laboratory and the ash is analyzed at the University of Tennessee. For elements such as Ca, Fe, Zn, Cu, Mn, etc., which are known to have a role in the body economy, the geographical variation is not large—

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reflecting the state of nutrition of the population. For other elements such as Cd, Pb, and Cr which may compete with necessary elements in their normal roles, the geographical variation is striking. Some elements, such as Cu and Zn in liver, Al in lung, and Cd in kidney, show marked variation with the age of the subject (Fig. 6)[16]. When data on the stable element distribution in the organs

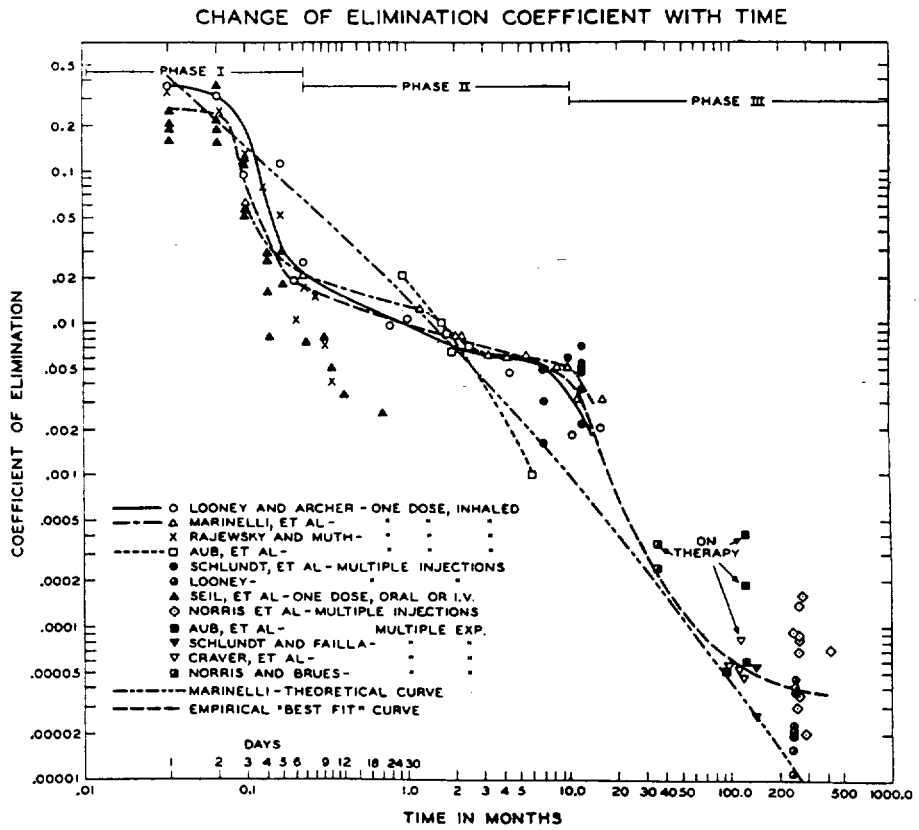


FIG. 1. An example of data obtained from studies of radium in humans. (LOONEY *et al.* (1956)[12])

of the body are considered along with similar data on the stable element distribution in the food and excretions of man, the biological half-life, the fraction going from the GI tract to the blood, the fraction going from the blood to the various body organs, and the fraction in each organ of that in the total body can be determined. All of the $q$ and MPC values in the ICRP internal dose publication are calculated with reference to the standard man; this tissue study has increased materially our knowledge. For example, the listing of the concentration of elements in the total body has increased from 15 to 38 and similar values are added for 36 elements in 35 body organs. Such data are useful, not

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only in calculating the MPC values for the standard man, but they may serve as a guide in making refinements to the MPC values when applying them to individuals of a given age, weight, eating habits, etc.

There are several minor changes in the 1958 ICRP internal dose publication. (1) The occupational exposure period is reduced from 70 years to the more realistic period of 50 years. (2) For the noble gases that emit $\gamma$-radiation (or $\beta$-

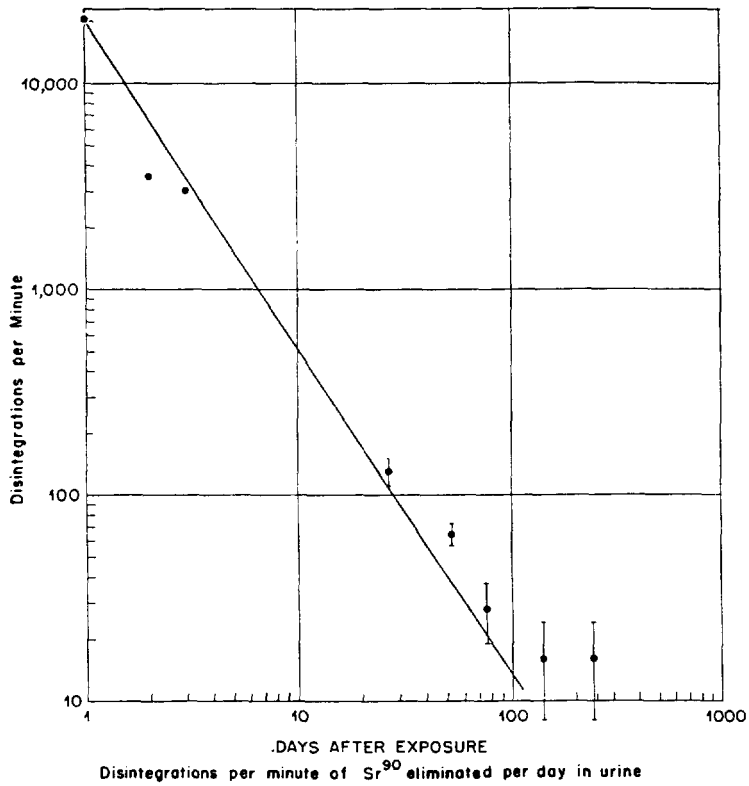


FIG. 2. An example of data obtained from accidental inhalation of $Sr^{90}$ (AECU-1169).

radiation of maximum energy > 100 keV) the assumption still is made—that the significant dose results not from lung irradiation but from submersion of the body in a cloud of radioactive gas. However, in the current publication it is assumed the body is irradiated from only $\frac{1}{2}$ the solid angle rather than from the total solid angle as assumed in the 1953 publication. (3) All of the $q$ and MPC values are calculated (as in 1953) on the assumption that the radionuclides are eliminated exponentially from the body. Even prior to the 1953 ICRP internal dose publication, it was realized that this is an oversimplification[17], but until recently it was believed that the data were insufficient and unreliable

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to warrant a more refined calculation. However, in the case of radionuclides of plutonium, uranium, radium and strontium, rather extensive data have now been accumulated and these radionuclides have been treated by means of

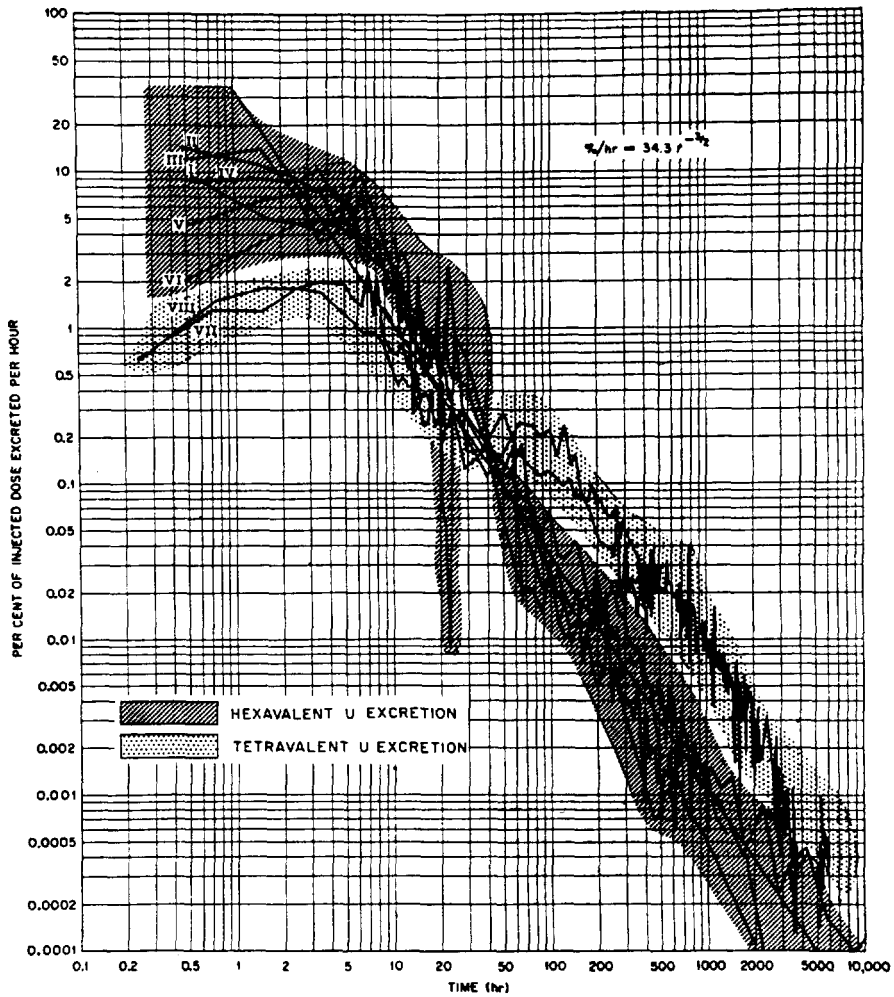


FIG. 3. Urinary rate of excretion for 8 terminal brain tumor patients following intravenous injection[18].

power functions (quantity of a radionuclide in the body organ at time $t$ is given by equation $Kt^{-a}$, in which $K$ and $a$ are constants) as well as by means of exponential functions in the revised publication. In these cases, the power function fits the data better than a single exponential function. Table 2 lists for comparison values determined by both methods.



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By far the largest increase in the 1958 revision of the ICRP internal dose publication is the addition of a 150-page bibliography which is about half the page content of the publication. In the course of preparing this bibliography, a small internal dose library containing about 2000 separate reports has been assembled. It is anticipated that in time funds and staff will be made available to extend and duplicate this project.

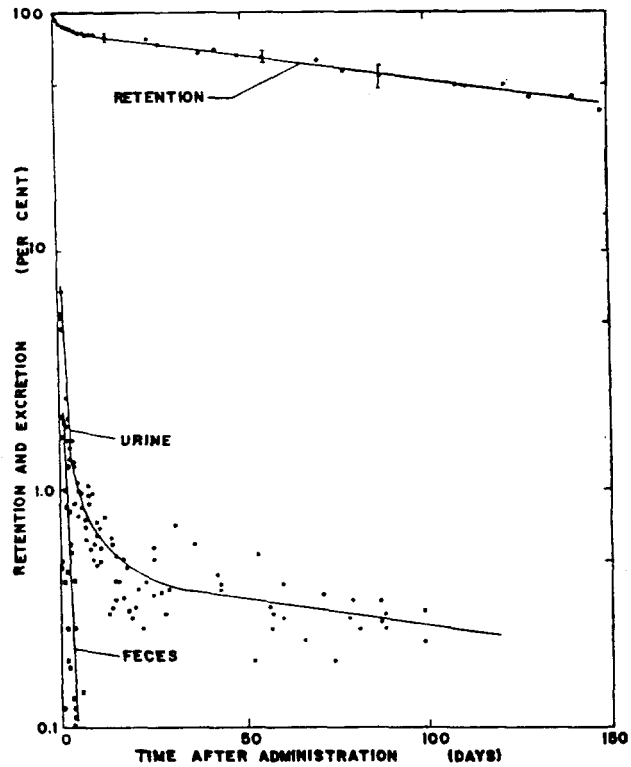


FIG. 4. An example of data obtained from human tracer studies with $Cs^{137}$ using human body counters[34].

From the above discussion it is clear that many limitations and inaccuracies exist in the 3000 individual MPC values appearing in the 1958 ICRP internal dose publication. However, this publication probably represents the best data that presently are available and should prove very useful to the many persons who are now working with and are exposed to radionuclides. The equations and other data—both in the text and available from the references—also make it possible for the reader to evaluate the data and determine what applications and modifications are appropriate in the case of an accident to an individual involving one or more of the radionuclides. For example, the data may be used to estimate the amount and distribution of a radionuclide in the body from

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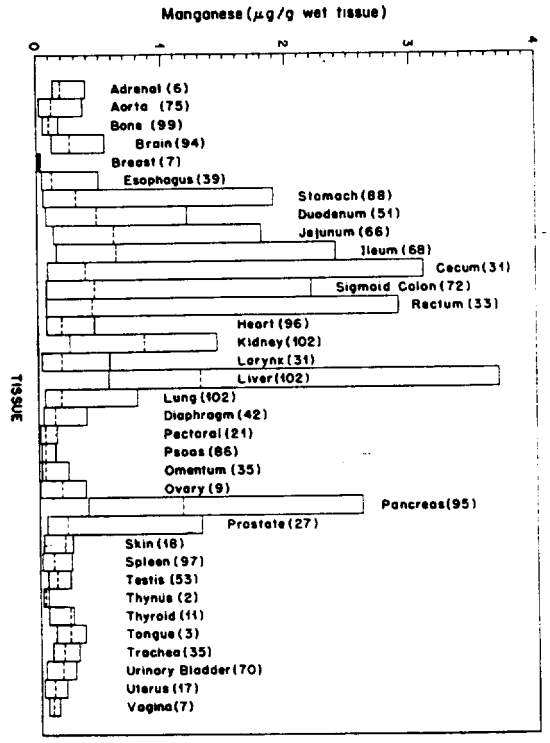


FIG. 5. An example of data obtained by the spectrographic analysis of normal human tissue giving the average and the range of values. Number in parentheses indicates the number of tissues analyzed. (I. H. TIPTON *et al.*)

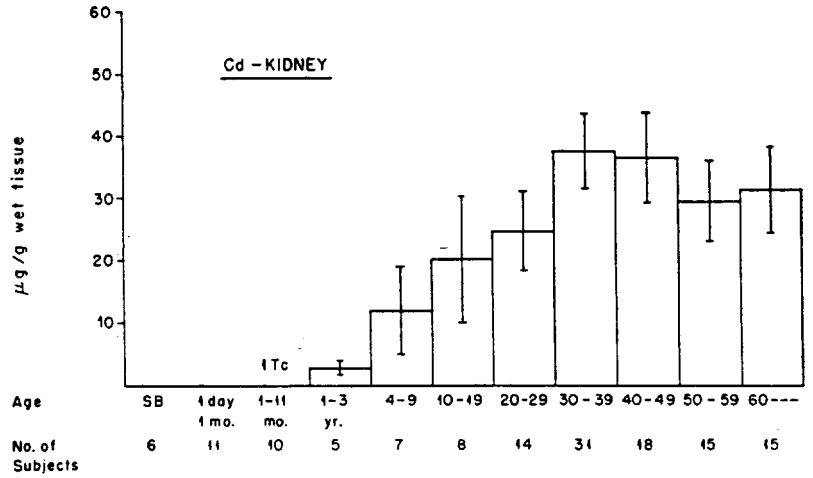


FIG. 6. An example of an element which shows marked variation with the age of the subject. (I. H. TIPTON *et al.*)

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information accumulated from the urine and fecal excretion data. This information in turn indicates the internal dose received by the various organs and may serve as a guide in the treatment of the accident case and in the establishment of measures to be taken to prevent the recurrence of the accident.

TABLE 2

*Examples of* $(MPC)_w$ *and* $(MPC)_a$ *Values Calculated* by the Exponential Law and by the Power Law*

| Radionuclide | Critical organ | $q$ ($\mu$c) | Values based on exponential law | | Values based on power law | |
|---|---|---|---|---|---|---|
| | | | $(MPC)_w$ ($\mu$c/cc) | $(MPC)_a$ ($\mu$c/cc) | $(MPC)_w$ ($\mu$c/cc) | $(MPC)_a$ ($\mu$c/cc) |
| $_{38}Sr^{90} + Y^{90}$ | Bone | 2·1 | $5{\cdot}4 \times 10^{-7}$ | $4{\cdot}4 \times 10^{-11}$ | $8{\cdot}3 \times 10^{-6}$ | $6{\cdot}9 \times 10^{-10}$ |
| $_{88}Ra^{226}$ + 30% drs. | Bone | 0·1† | $1{\cdot}2 \times 10^{-7}$ | $9{\cdot}8 \times 10^{-12}$ | $1{\cdot}2 \times 10^{-6}$ | $1{\cdot}0 \times 10^{-10}$ |
| $_{92}U$-natural | Kidney (chem. toxicity) | $4{\cdot}7 \times 10^{-3}$ | $2{\cdot}9 \times 10^{-4}$ | $1{\cdot}3 \times 10^{-11}$ | $8{\cdot}4 \times 10^{-4}$ | $3{\cdot}7 \times 10^{-11}$ |
| $_{94}Pu^{239}$ | Bone | 0·044 | $4{\cdot}5 \times 10^{-5}$ | $5{\cdot}9 \times 10^{-13}$ | $4{\cdot}0 \times 10^{-5}$ | $5{\cdot}3 \times 10^{-13}$ |

* Values in this table are "calculated" values given only for comparison of the exponential and the power law and are not necessarily the final $q$ and MPC values recommended by the ICRP.

† National Bureau of Standards, Handbook H27, Safe Handling of Radioactive Luminous Compound, (1941) Superintendent of Documents, Washington 25, D.C.

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