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The Need for Research Programs to Provide Data Applicable to the Estimate of Maximum Permissible Exposure Values for Internally Deposited Radionuclides[1,2]

Karl Z. Morgan[3]

Oak Ridge, Tennessee

There is a wide range in the Maximum Permissible Concentration (MPC) for both chemically and radioactively toxic agents, as indicated in Table I, but the values for many of the radionuclides are far lower than for any of the chemical agents. In some cases, the bases used in selecting MPC values for chemical agents are quite different from those applied in choosing recommended MPC values for the radionuclides. For example, some of the MPC values for the chemical agents are determined by the criteria of pronounced discomfort, such as odor, eye smarting and skin irritation, *e.g.* the MPC of 20 ppm for hydrogen sulfide is set on the basis of eye irritation and the MPC of 0.1 mg/m^3 for tellurium is set primarily because of objection to the garlic odor it causes in breath and perspiration. However, in many respects the criteria for selecting MPC values for the various agents are the same and differ only in degree. For example, both for radionuclides and for the chemical agents, MPC values are based on animal studies of limited duration and with animals of relatively short life span, although where possible these studies are confirmed by human experience. For example, the MPC values first used for the transuranic isotopes (^{239}Pu, ^{241}Am, ^{242}Cm, etc) were based for a 10-year period on studies of J. G. Hamilton (20), using 36 rats in each study. These studies have since been supplemented by large animal experiments and by the evaluation of human accidents involving the

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[3]Director, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

intake of these radioisotopes. Unfortunately, in many cases there is probably less information from animal experiments or from human observations on which to base MPC values for chemical agents than for the radionuclides. One may know that prolonged human exposure to a given air concentration of lead can lead to palsy or encephalopathy, and a given air concentration of mercury can lead to paralysis of the limbs, polyneuritis or insanity. As a consequence, the MPC values are set at some fraction of these concentrations and at a level of exposure to these chemical agents such that animal experiments and limited human observations would suggest that for occupational exposures lasting a *few years* no such sicknesses would be expected to manifest themselves in the *average* employee. Unfortunately, the available exposure history upon which MPC values are based gives little information concerning what would happen to the employee who is not the average individual because of peculiar eating habits, accident proneness, ill health or overweight. Likewise, the employee with impaired vision who works closer to the source of contamination (radioactive or chemical agent) than the average employee, or who must work in an area where the air ventilation is poor or who frequently works overtime may eventually be in serious difficulty. These uncertainties apply both to radionuclides and to chemical agents, but generally there is less consideration given to chronic damage when establishing values of MPC for chemical agents than is the case for radionuclides.

TABLE I

MAXIMUM PERMISSIBLE CONCENTRATION, MPC, OF VARIOUS STABLE SUBSTANCES AND OF RADIONUCLIDES

	MPC (mg/m³ of air)		*MPC (mg/m³ of air)*
Carbon dioxide	9000*	Natural uranium	Sol 0.05* Insol 0.25
^{187}Rhenium	10^{4}	Organic mercury	10^{-2}*
Methyl alcohol	10^{3}*	^{59}Nickel	10^{-2}
^{87}Rubidium	10^{3}	Beryllium	.002*
Trichloroethylene	200*	^{14}Carbon	10^{-3}
Carbon monoxide	10^{2}*	Tritium	10^{-6}
Hydrogen cyanide	10*	^{137}Caesium	10^{-7}
Sulfur dioxide	5*	^{226}Radium	10^{-8}
D. D. T.	1*	^{241}Americium	10^{-9}
^{147}Samarium	1	^{131}Iodine	10^{-10}
Chromic acid	10^{-1}*	Thoron	10^{-13}

*Values for the most part based on chemical toxicity as given by the American Conference of Government Industrial Hygienists. The other values are limited by the radiation hazard.

MPC levels that are established for the numerous benzene derivatives, or the derivatives of the petroleum series, for example, may provide adequate protection from the more obvious acute illnesses related to these poisons, only to lead in a subtle way to a high probability of developing a malignancy 20 to 40 years later.

Perhaps it is true (but I doubt it has been proven) that for many chemical agents the exposure or MPC can be set sufficiently low that there can be no detectable damage within the lifetime of the worker. Unfortunately, in the case of ionizing radiation, present evidence seems to indicate there is no dose or MPC so low that the probability of serious damage is zero. Thus, there is no safe threshold dose and certain types of radiation damage, such as leukemia, bone tumors, life shortening and genetic mutations, have a probability of occurrence that relates more or less linearly to the accumulated dose.[1] As a consequence, we were forced to arrive at the conclusion that in a sense, all ionizing radiation is harmful; regardless of how low the MPC values are set, some persons will be damaged severely if enough people are exposed for a long period of time. The only sound and prudent objective then was for the National Council[2] on Radiation Protection (NCRP) and the International Commission on Radiological Protection (ICRP) to set the MPC values for radionuclides so low that the probability of serious damage (such as leukemia) is very low and the magnitude of the more frequent types of damage (such as life shortening) is so small that the hazards are acceptable by the individual, and are considered much less than many of the more common industrial hazards. The realization that all exposure to ionizing radiation is potentially harmful led to the interesting philosophy that MPC values should be such that the risks of all types of radiation damage are outweighed by the expected benefits. This basis for the selection of MPC values resulted also in the interesting situation in which the person who receives the benefits may not necessarily be the same person who suffers the greatest risk or incurs the damage. For example, the grandchild of a radiation worker who is born with a mental defect resulting from a radiation-induced genetic mutation, and the person who eats contaminated fish from a river and, as a consequence, develops a bone sarcoma probably have not been the recipients of equivalent benefits. The problem is one of great importance to civilized man and probably applies in some degree to all environmental hazards. In the case of ionizing radiation, the maximum permissible exposure levels or the MPC values must not be set too low, for then the nuclear industry is unnecessarily penalized and man is deprived the many benefits in the use of ionizing radiation. The levels must not be set too high, for then damage to man, to his children and to his environment could increase and eventually result in suffering and death. This balancing act is very difficult and requires the serious considerations and action of men of all backgrounds—scientific, political and economic.

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[1]Throughout this paper, the author prefers and has chosen to use "dose" instead of "dose equivalent" when referring to dose equivalent in rem units.

[2]By an Act of Congress and the signature of the President on July 14, 1964, the National Committee on Radiation Protection and Measurements became the National *Council* on Radiation Protection and Measurements.

The maximum permissible body burdens and MPC values for the various radionuclides are related to the basic parameter of permissible dose rate to the critical body organ as later defined in this paper. These dose rate values are summarized (1) in Table II. There are two principal historical bench marks to which these dose rate values are related: (A) The NCRP (2) in 1934 set the maximum permissible occupational exposure rate at 0.1 R/d ($\approx$30R/yr). In 1943, NCRP further reduced this rate to 15 rem/yr. These limits (15 to 30 rem/yr) have been considered by several investigators to be in the range of the average total body exposures received by radiologists in this early period; and (B) the value of total body burden = 0.1 μc ^{226}Ra was established by the NCRP (2) in 1941 and corresponds to a dose rate of 30 rem/yr to the bone.

The accuracy of the body burden and MPC values for all of the radionuclides can be no greater than the validity of the basic dose rates and the many parameters upon which they are based. In a 50-year period, the values listed in Table II would add up to 250 rem to red bone marrow, total body, gonads, etc., 1500 rem to thyroid, bone or skin and 750 rem to most body organs. Fortunately, few persons at the present time are occupationally exposed to radiation at 100 per cent of the MPC because the NCRP and the ICRP have made it clear that the occupational exposure rates and the related MPC values are upper limits for normal operation, and every effort should be made to keep exposures as far below these values as practicable. One does not know the consequences if many persons were to be exposed to such accumulated doses. Probably the ICRP and NCRP should set a lower maximum permissible accumulated dose. For example, I might suggest maximum permissible occupational dose rates be reduced to one-third the values given in Table II when a person has accumulated 25 times any of the annual dose rates summarized in column 2 of Table II for critical body organs. Such a limitation would be in keeping with the present ICRP recommendation (3) that the external exposure to the total body be reduced from 5 rem/yr to 1.5 rem/yr for persons who have a body burden greater than q/2 but less than q; that it remain at 5 rem/yr if the body burden is less than q/2 and that it be reduced to zero if the body burden is greater than q (NOTE: q is the maximum permissible body burden given in μc). It should be made clear also that it would not be expected that an occupational worker be exposed at the maximum permissible dose rates or accumulate these 50-year doses to more than two body organs. In fact, the ICRP (3) has specified: "When radioactive isotopes in a mixture are taken up by several organs and the resulting tissue doses in such organs are of comparable magnitude, the combined exposure is considered to constitute essentially whole body exposure." In such case, the average dose rate limit to the several organs would be 5 rem/yr.

Studies of radiologists have shown that the incidence of leukemia among them during the early period was about 10 times that for other medical men less frequently exposed to ionizing radiation. Also, several studies have indicated that the average life span of the radiologists has been shorter than that of other medical men. For example, (4) Seltser found the mean life of radiologists in the U. S. has been shorter than that of medical men who are not radiologists and

TABLE II

RECOMMENDED PERMISSIBLE DOSE EQUIVALENT TO BODY ORGANS OF OCCUPATIONAL WORKERS EXPOSED TO IONIZING RADIATION. THESE VALUES ARE IN ADDITION TO DOSES FROM MEDICAL AND FROM BACKGROUND EXPOSURE*

*Maximum Dose Equivalent in any 13 weeks***	*Average Dose Equivalent† in 1 year*	*Accumulated Dose Equivalent to Age N > 18 Years*
	Red Bone Marrow	
3 (*3, 8, 10, 11*)	5 (*3, 8, 10, 16*)	5 (N–18) (*3, 8, 10, 11, 16*)
	Total Body	
3 (*3, 9, 10, 11, 15, 16*)	5 (*3, 9, 10, 15*)	5 (N–18) (*3, 9, 10, 11, 15, 16*)
	Head and Trunk	
3 (*10, 11*)	5 (*10*)	5 (N–18) (*11, 16*)
	Gonads	
3 (*3, 8, 9, 10, 11, 15*)	5 (*3, 8, 9, 10, 15, 16*)	5 (N–18) (*3, 8, 9, 10, 11, 15, 16*)
	Lenses of Eyes ∓	
3 (*8, 9, 10, 11, 12*)	5 (*8, 9, 10, 12, 16*)	5 (N–18) (*8, 9, 10, 11, 12, 16*)
	Skin	
8 (*3, 8, 15*)	30 (*3, 8, 9, 10, 13, 14, 15*)	30 (N–18) (*8, 9, 15*, §, ‡)
10 (*9, 11, 13*)	(*11*, ‡)	
	Thyroid	
8 (*3, 8, 9, 15*)	30 (*3, 8, 9, 10, 11, 15*)	30 (N–18) (§)
10 (*11*)		
	Feet, Ankles, Hands, Forearms	
20 (*3, 8*)	75 (*3, 8, 9, 11, 13, 14*)	75 (N–18) (§)
25 (*9, 10, 11*)		
	Bone	
8 (*3*)	30 (*3, 9, 15* §)	30 (N–18) (§)
10 (§)		
	Other Single Organs	
4 (*3, 8, 15*)	15 (*3, 8, 9, 10, 11, 14, 15*)	15 (N–18) (§)
5 (*11*)		

*The unit of dose equivalent (*17*) used in this table is the rem defined as: (No. of rem) = (No. of rad) × (QF) × n, in which QF (or RBE) is the quality factor related to linear energy transfer and n is the relative damage factor. In Column 3, N is the age. Reference numbers are in italics.

**These values may be used for the accumulated short-term exposures in any 13-week interval (*3, 12*).

†These values may be used for a planned emergency exposure (*3, 12*). For example, the persons cleaning up a spill of radioactive material in a section of a hospital may plan this emergency operation in such a way that the total body dose and skin dose does not exceed 5 rem and 30 rem, respectively.

∓The 1962 ICRP meeting in Stockholm recommended that exposures of lenses of eyes be restricted to this limit only in the case of high LET radiation, for example, from α, protons, neutrons, and so forth. For low LET radiation the ICRP values applicable to the eyes are given below after "other single organs" (*3*).

§Implied but not stated explicitly (*8, 9, 10, 11, 15*).

‡I interpret this to apply only when dose is limited to skin; for example, it applies to low energy β-radiation external to body or originating in skin.

receive very little radiation exposure. Table III indicates that the mean age at death of members of the Radiological Society of North America (radiologists) was shorter than that of members of the American Academy of Ophthalmologists and Otolaryngologists (ophthalmologists and otolaryngologists) by 4.8 yr from 1935 to 1944, by 4.0 yr from 1945 to 1954 and by 2.4 yr from 1955 to 1961. Presumably, this life shortening of radiologists during the past decades is the result of an increasing awareness on their part of the desirability of minimizing exposure. The average annual dose received by radiologists during the above-indicated periods is not known. However, if, as some have speculated, it was in the range of 15 to 30 rem/yr of total body exposure, it would seem that the basic recommendation of the NCRP and the ICRP limiting exposure to ionizing radiation—namely, the dose rate limit of 15 rem/yr to most organs of the body—may be too high when viewed in relation to its effect on radiologists. Thus, it may be reasonable to apply a rule such as I am suggesting above; viz., reduce the maximum permissible dose rates to one-third the values given in Table II when an occupational worker has accumulated 25 times any of the annual dose rate values listed in column 2 of Table II.

The dose rate values given in Table II apply to the critical organ when radionuclides are taken into the body. The MPC values for occupational exposure are the concentrations in air, water and food that would deliver to the

TABLE III

MEAN AGE AT DEATH OF MEMBERS OF MEDICAL SOCIETIES
(Data by R. Seltser, November, 1963)

Society	*Specialty*	*Membership 1915-1961*	*Median Age at Death 1935-44*	*1945-54*	*1955-61*
Radiological Society of North America	Radiology	3697	71.4	72.0	74.6
American College of of Physicians	General Physicians	7052	73.4	74.8	76.5
American Academy of Ophthalmologists and Otolaryngologists	Opthalmologists Otolaryngologists	6059	76.2	76.0	77.0

critical organ of the standard man these dose rates after exposure 40 hr/wk, 50 wk/yr for 50 years. For the radionuclides of short effective half-life, this limiting dose rate is reached in the critical body organ very rapidly as a result of occupational exposure at the MPC, but for the radionuclides of long effective half-life, it requires 50 years of occupational exposure at the MPC to reach these dose rates. For example, as indicated in Table IV, it requires occupational exposure of the standard man at the MPC of ^{90}Sr for 44 years to reach 95 per cent of the maximum permissible dose rate (30 rem/yr) to the critical organ (bone), but exposure at the MPC of ^{131}I for only 33 days to reach 95 per cent of the maximum permissible dose rate (30 rem/yr) to the critical organ (thyroid). Although it takes much longer to reach the maximum permissible dose rate in the critical body organ when exposed at the MPC to radionuclides of long effective half-life, it should be remembered that when one takes into his body radionuclides of long effective half-life, they continue to irradiate the critical organ for a large fraction of one's remaining life. For example, if a person is exposed at the MPC for five years to ^{131}I, his thyroid receives a 50-year integrated dose of 150 rem, but if a person is exposed at the MPC for five years to ^{90}Sr, his bone receives a 50-year integrated dose of 147.6 rem. Thus, for practical purposes, and for the usual occupational exposure periods of a few years, the integrated doses from exposure at the MPC are relatively independent of the effective half-life.

Much more research should be done in determining the critical body organ for the various radionuclides. The critical body organ is defined as the organ receiving the radionuclide that results in the greatest body damage. Usually it is taken to be the organ with the highest concentration of the radionuclide but this organ is not necessarily the critical body organ. For example, ^{59}Fe has a much higher concentration in the erythrocytes than in other body tissue, but the spleen and lower large intestine are taken as the critical body organs because erythrocytes do not undergo further cell division once they enter the circulating

TABLE IV

TIME REQUIRED TO REACH 95% OF THE MAXIMUM PERMISSIBLE DOSE RATE TO THE CRITICAL ORGAN AS A RESULT OF OCCUPATIONAL EXPOSURE AT THE MPC

Radionuclide	*Radioactive Half-Life* T_r	*Biological Half-Life* T_b	*Effective Half-Life* T	*Critical Organ*	*Max Perm Dose Rate (rem/yr)*	*Time Required to Reach 95% of Max Perm Dose Rate*
^{239}Pu	24,413 yr	200 yr	200 yr	bone	30	47.6 yr
^{90}Sr	28 yr	50 yr	18 yr	bone	30	44.2 yr
^{137}Cs	30 yr	70 days	70 days	total body	5	303 days
^{131}I	8.05 days	138 days	7.6 days	thyroid	30	33 days

blood. As a consequence, they are thought to be relatively radiation-resistant to damage during their relatively short period of normal survival in the circulating blood. The best source of information available to the NCRP and the ICRP on the critical body organs as related to the organs of greatest body concentration has been a spectrographic study by Tipton *et al.* (5). She has studied the distribution of 30 trace elements in 35 organs of the human body. In these spectrographic studies she has examined tissue from over 600 human bodies. Obviously, if one knows where a stable element goes in the body following ingestion, such information provides a perfect lead as to where radioisotopes of the element would go. These data have been of particular value because they are on man (not animals) and they are representative of chronic exposure (not acute). Similar studies on foods have enabled us to calculate from the equilibrium equations the fractional uptake and the biological half-life of these trace elements and of radioisotopes of these elements. These studies have included some human tissues from other countries and from a few young people, but we have very little data on children and foetuses, and most of the tissues studied have come from the United States. It would be helpful if other researchers would extend these studies to additional elements, to children and foetuses and to tissues and food samples or typical diets from many parts of the world.

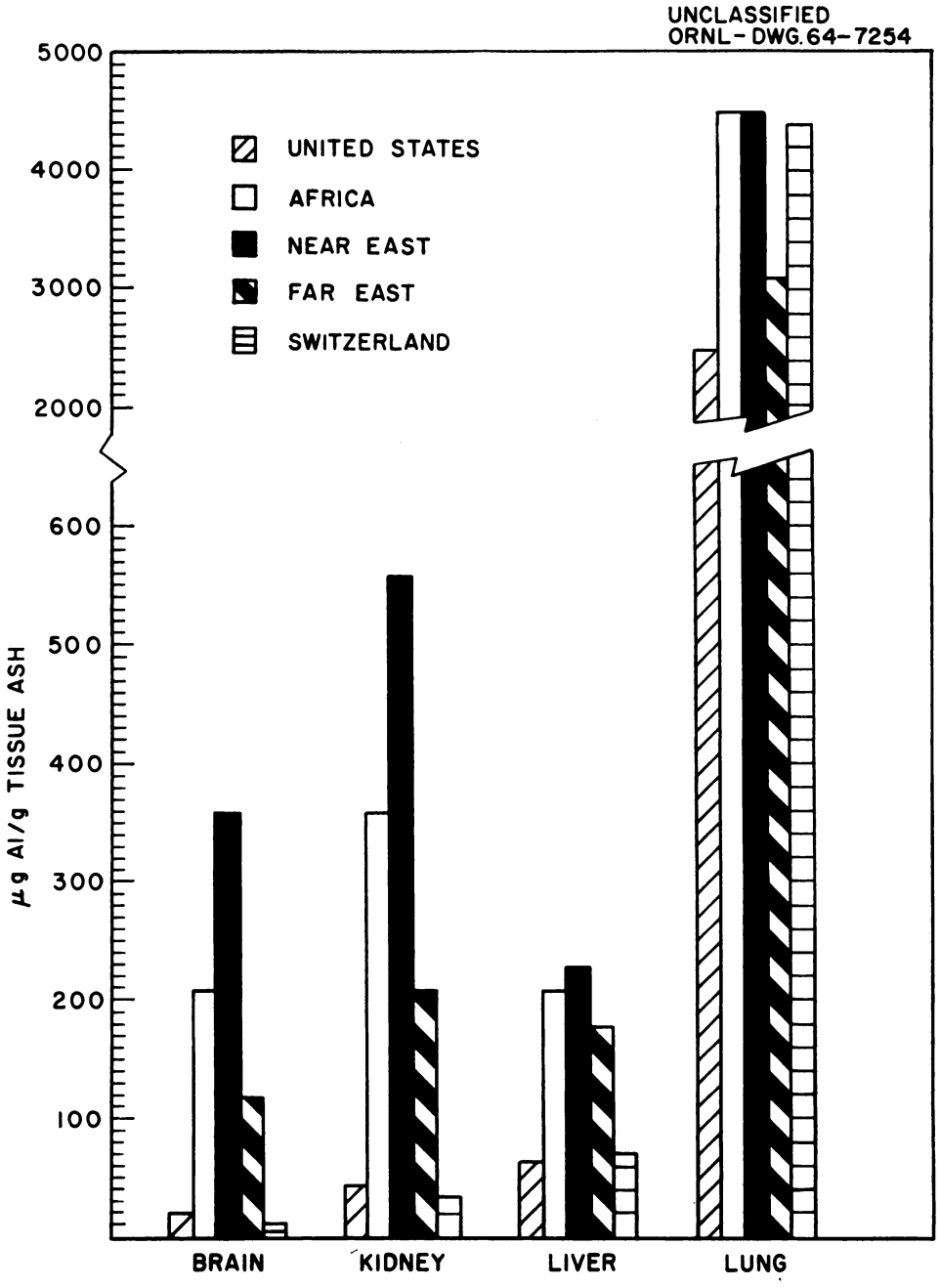
All the MPC values in the NCRP and ICRP handbooks are based on the standard man who has characteristics representative of the average American or average European, but they may be in considerable error when applied to the Japanese, to the Indian, or to other races. Extrapolations of these values to obtain MPC values for members of the population-at-large may lead to considerable risk because of lack of information on children, foetuses, pregnant women, etc. Also, there is a wide spread of metabolic characteristics of adult individuals of the same sex and race, and an extremely large amount of data is needed to obtain a better estimate of how much the dose to the critical body organ may vary when a number of individuals are similarly exposed at the same MPC of a radionuclide. Some very limited studies by Snyder and Cook (6) have indicated that for some of the trace elements, not more than 5 per cent of the adults have organ concentrations or doses greater than the mean by more than a factor of three. These studies should be extended, however, to many trace elements, for a number of body organs and for various races of people, including all ages of the population. Also, they should include studies on many different human diets and, in addition, they should include studies on the chemical forms of the elements in these diets. Such data are important because in future revisions of the NCRP and ICRP handbooks on internal dose, an effort is being made to give MPC values for a number of the more important chemical forms of the radionuclides that may be taken into the body. Such studies on chemical forms of trace elements in the human diet should be supplemented by metabolic studies of animals which are administered radionuclides in a number of chemical forms that are considered representative of possible human exposures. In previous publications, because of very limited data, MPC values were given only for the so-called common soluble and insoluble chemical forms. Likewise, trace element studies should be made of human

excreta, urine and feces, because these data can be useful in calculating the fractional uptake and biological half-life of trace elements. Also, there is an effort by the ICRP and the NCRP to obtain better methods of estimating the organ and body burdens of the radionuclides and one of the best means of making these estimates is to relate that quantity of nuclide found in the urine and feces to the amount in the body organs. These studies of human tissues, diets and excreta should include the sick in addition to the well persons, because of the values of MPC applicable to the population-at-large must provide adequate protection to all groups of people. Only when a large amount of such data is obtained will it be possible to make reasonably accurate estimates of the organ and body burdens of the radionuclides.

Needless to say, trace element studies must be supplemented by careful studies of all human accidents with radionuclides. In such cases, excretion and total body scanning records should be continued over as long a time as possible; the results should be carefully analyzed and the findings published so others may benefit when similar problems arise. Since, at best, human metabolic data have always been rather limited and usually autopsy data are completely lacking, there will be a need for many types of animal metabolic studies. Animal studies should be conducted over a wide range of doses. First, effects-studies to obtain the dose-effect relationships should be carried out but, more importantly, studies must be conducted at very low trace levels to obtain the uptake, distribution and elimination pattern under conditions where body damage, metabolic blocking or stimulation will not influence the study. Unfortunately, many of the present radiobiological data are almost useless in calculating MPC values for the radionuclides because the biologists gave large doses to the animals to obtain effects that they were interested in studying, but these effects influenced the normal metabolic pattern in which we are interested.

Figures 1 and 2 summarize some of the data of Tipton *et al.* Here, for tissue samples from five widely separated parts of the world, it is very interesting to note the large spread of values of body organ concentrations (by more than an order of magnitude) of nonessential elements, such as Al, and the rather invariant values for the essential elements, such as P. Publications by Snyder and Cook (7) have indicated a similar variation with age of the individual. That is, the concentration of an element in a body organ may vary considerably with age and with nationality of the individual for nonessential elements, such as Al, but it is rather invariant with age and with nationality of individuals for essential elements, such as Zn and Cu. Thus, it should not be surprising if we find that the MPC values for radioisotopes of essential elements are applicable to man with less variation than are the values for radioisotopes of nonessential elements.

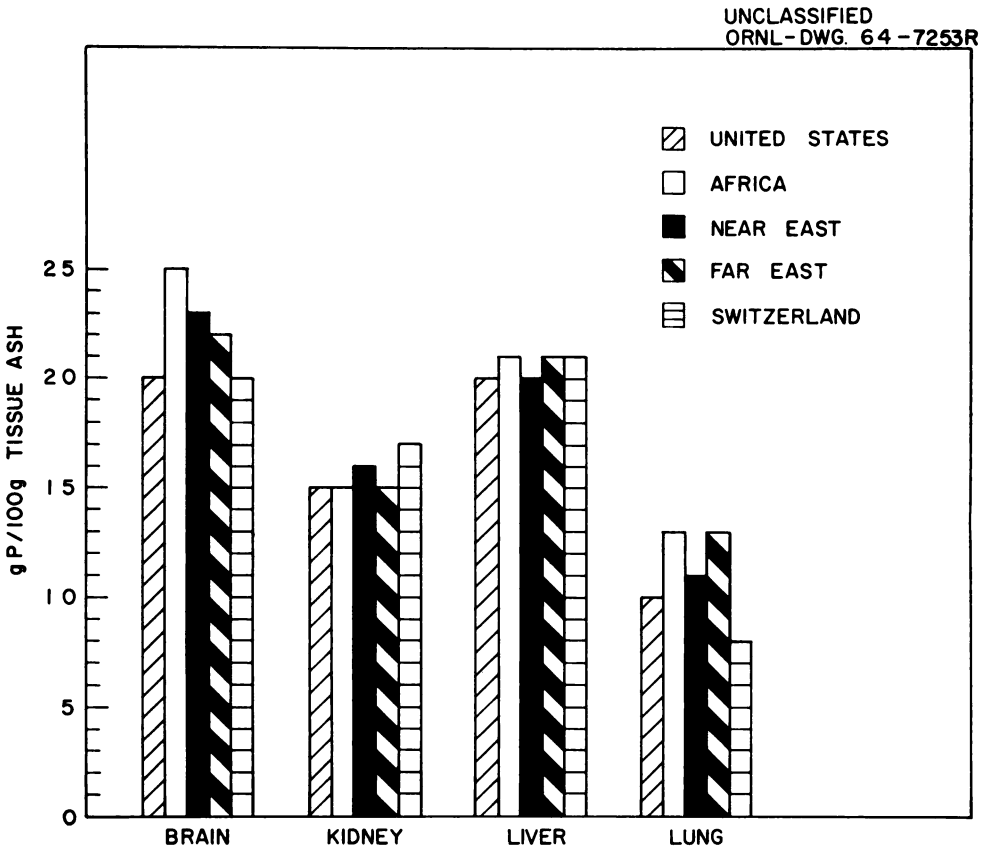
In addition to those mentioned above, there is an almost endless variety of interesting and extremely important internal dose studies that should be conducted. Clinicians and others could make a valuable contribution toward the development of more reliable MPC values by furnishing human metabolic data



MEAN VALUES FOR ALUMINUM IN 4 TISSUES FROM PERSONS ≥ 20 YEARS OF AGE FROM 5 GEOGRAPHICAL LOCATIONS

on many chemical substances—both with and without radioactive tracers. A few of these studies may be listed as follows:

1. Metabolic factors of uptake of radionuclides in many chemical forms from GI tract, lungs, through the skin and by way of wounds.
2. Distribution to various organs and to parts of organs.
3. Turnover and elimination from the various organs.
4. Synergistic relation to body damage of simultaneous irradiation of several body organs.
5. Effect on metabolic pattern of isotopic dilution, dilution by related chemicals or of the presence of certain bacteria or virus.
6. Relative radiosensitivity of various body organs and of the various classes of tissue.
7. Effect of age, sex, weight, race, etc., on the metabolic factors and in relation to radiation damage.



MEAN VALUES FOR PHOSPHORUS IN 4 TISSUES FROM PERSONS ≥ 20 YEARS OF AGE FROM 5 GEOGRAPHICAL LOCATIONS

8. An evaluation of the n-factor (the ratio of absorbed dose x QF of Ra to produce a given bone damage to the absorbed dose x QF of a bone-seeking radionuclide to produce the same damage). Is it related primarily to the distribution of the radionuclide in the organ, to the radiosensitivity of the irradiated tissue, to the essentialness of the tissue to normal body function and/or to other factors?

9. A study of the quality factor, QF, as it relates to type of damage, organ irradiated, linear energy transfer (LET), dose rate, total dose, etc. QF (formerly RBE) is the ratio of absorbed dose (in rad) of reference radiation with LET of 3.5 kev per micron of water (corresponds approximately to LET of 200 kev x-rays) in producing a biological effect to the absorbed dose (in rad) of a radiation with another LET in producing the same effect.

10. Radiation damage as related to dose rate, dose fractionation, accumulated dose, gram rad dose, etc.

11. How do the habits of eating, drinking, breathing, excreting, smoking, washing, etc., of an individual effect the uptake, distribution and elimination of radionuclides and the resulting radiation damage?

12. How best should concurrent external and internal exposure be treated in providing proper radiation protection?

13. What is the best method of calculating the hazard and/or the MPC for a mixture of radionuclides in the environment. Should calculation of MPC be based on the limiting dose rate to a single organ or on some fraction of the limiting dose rate to the organs that are irradiated?

14. What special factors should be considered in setting appropriate MPC values for the population-at-large?

15. How can one best establish appropriate limits for single exposure or for emergency exposures in view of the many special problems involved?

16. What are the best mathematical models to use in calculating the MPC values for a given radionuclide?

17. There are a number of radionuclides being produced—especially by the (n,p), (p,n), a,p), (n), etc., reactions associated with high voltage accelerators—for which MPC values have not been established. Animal and human data are needed before reliable values can be recommended by the NCRP and the ICRP.

18. Very little information is available relative to the importance of large radiation doses to small volumes of body tissue in the neighborhood of a radioactive particle. For example, the dose in the neighborhood of a 1 μc particle of ^{239}Pu can be hundreds of rem/day. What is the biological effect of this dose from a particle in a wound, a bronchioli of the lung or a pulmonary lymph node?

19. Which values for the standard man need revision?

20. Why not set up a standard child, a standard woman, a standard Indian, a standard American, etc.? Such data could be very useful in assessing the

internal dose hazard in individual exposure cases as well as exposures to critical population groups.

21. One of the most important health physics studies is that of the effects of ionizing radiation on the environment itself. The future nuclear energy industry will discharge radionuclides into the environment at some level, and we should know if this is a safe level from a long range point of view. Many radionuclides which are diluted by large factors, e.g. 10^6, when released into the environment are reconcentrated by much the same factors by certain organisms in the ecosystem (18). Likewise, some common living system in the environment may be as radiosensitive (or even more so) than man. For example, the mid-lethal dose for certain types of pine trees may be lower than the mid-lethal dose for man (19). This could be of considerable importance in planning a civil defense program for recovery following a nuclear war.

22. Finally, of greatest importance both to external and internal dose studies is the development of more fundamental information on the effects of ionizing radiation on matter. Basic studies in health physics research should be conducted at all levels—nuclear, atomic, molecular, solid, gas, liquid, plasma, crystal, cell, organism and ecosystem—in order to develop a more complete and coherent theory of radiation damage. Only when such a theory is available can we extrapolate with reliance radiobiological findings on animals to man.

In summary, more is known perhaps about radiation hazards, and the MPC values for radionuclides are probably more reliable than for many of the common chemical agents. However, much remains to be done before great reliance can be placed on any of the MPC values. Many new radionuclides are being produced and becoming available in a great variety of chemical and physical forms. Both animal and human studies should be conducted with all of the more common chemical forms of the radionuclides in order to establish acceptable MPC values and to make it possible to weigh the benefits in their use against the hazards they may produce to man and his environment.

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