LA-UR - 74-1963

604-740550--3

TITLE: THE ORIGIN OF CURRENT STANDARDS

AUTHOR(S): J. W. Healy

SUBMITTED TO: 2nd Annual Life Sciences Symposium,
Los Alamos, New Mexico, May 22-24, 1974.

RECEIVED
JUN 10 1974
LOS ALAMOS
SCIENTIFIC LABORATORY

By acceptance of this article for publication, the publisher recognizes the Government's (license) rights in any copyright and the Government and its authorized representatives have unrestricted right to reproduce in whole or in part said article under any copyright secured by the publisher.

The Los Alamos Scientific Laboratory requests that the publisher identify this article as work performed under the auspices of the U. S. Atomic Energy Commission.

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

—NOTICE—

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

THE ORIGIN OF CURRENT STANDARDS

By

J. W. Healy

H-Division

University of California

Los Alamos Scientific Laboratory

Los Alamos, New Mexico

ABSTRACT

It is of importance that the basis for any standard be understood by those who propose to use it or change it. In the case of plutonium, the maximum permissible body burden was derived by biological comparison with radium for which the maximum permissible body burden was derived from human data. The dose distribution factor and present methods of calculation of dose equivalent in bone arose from this estimate on the assumption that all of the plutonium was in the bone of the test animals. The current MPC's for insoluble materials are based on dose only to the lung without consideration of the transfer to the remainder of the body.

A history can be a dangerous thing to prepare, particularly when many of the individuals who are in the audience were active participants. There is, however, enough to be learned from a brief review to warrant the risk, since much of the original basis has been obscured by Work performed under the auspices of the U. S. Atomic Energy Commission.

codification of the observations into equations and general rules for radiation dose calculations. These dose calculations have been invaluable in providing estimates of the maximum permissible body burden for internal emitters based on observations of radiation effects rather than requiring effects studies for each isotope. However, it must be remembered that a radiation dose calculation is meaningless unless data are available on the effects of the dose under conditions sufficiently similar to those of the calculation so that a meaningful comparison can be made. The more dissimilar the conditions the greater will be the uncertainty in the meaning of the dose.

As will be seen, plutonium is an interesting example because the maximum permissible body burden was derived by comparing the effects in animals with those of radium to permit cross-calibration with the human data on radium. The results were later used to derive general rules for dose calculation for bone seekers so that estimates of maximum permissible body burdens could be made for other materials without the necessity for time-consuming biological studies for each material. This was a commendable procedure for use at a time when values were badly needed and undoubtedly gave results sufficiently accurate for control of exposure. However, this has seemingly led to consideration of the quantity derived from such considerations, the radiation dose, as the primary standard and seems to be inhibitory toward further biological studies required to determine actual effects of different materials. Of particular concern is the fact that revisions or uses of standards frequently ignore the actual basis of the derivation and extrapolate to new bases

or estimate effects on the basis of the calculated radiation dose or dose equivalent. The following discussion is intended to describe some aspects of the early work so that those interested in applying the standards or in using the expanded data base in revision of standards, can be aware of the actual basis and make a conscious decision to accept or reject the earlier work. In addition it is hoped that it will stimulate further thought and discussion on the need to further expand our knowledge of the actual effects of internal emitters through appropriate biological studies so that the current generalized radiological dose concepts can be made more meaningful and useful in interpolating and extrapolating from dose distributions and observed effects.

At the start of the Manhattan Project there were three standards applicable for radiation protection. This seems almost incredible today when one looks at the proliferation of standards and regulations of all types. These three standards were: a limiting external exposure rate of 0.1 roentgen per day to X- or gamma radiation (NCRP, 1936); 0.1 microgram of radium fixed in the body (NCRP, 1941); and 10^{-11} curies per liter for radon in work rooms (NCRP, 1941). The data were meager, but they were based on actual human observations plus the innate wisdom of well-qualified and dedicated people who, incidentally, were willing to work themselves under the conditions prescribed by these standards.

At the start of the Manhattan Project the primary hazard concern was, of course, with the vast quantities of fission products which would be generated in the reactors and which would produce source terms absolutely unthinkable at that time when even radium was a rare material.

In these early years we find such concepts as the rep, which was the predecessor of the rad, and the rem being developed on a more or less ad hoc basis by those responsible for radiation protection. H. M. Parker, for example, was quite instrumental in these units. The purpose was to extrapolate the standards then available to the different conditions encountered with fission products and other radiation from the reactors.

The first documented concern with plutonium arose with Dr. Seaborg, who on January 5th, 1944, wrote a letter to Dr. Stone expressing general concern with the potential hazards of plutonium because of its long half-life, the possibility of permanent quantities being imbedded in the body and the fact that it was an alpha emitter (Langham and Healy, 1973). On January 15th, 1944, Dr. Seaborg wrote a second letter to Dr. Stone, expressing considerably greater concern with the potential problems of plutonium. This arose from his having reviewed Dr. Evans' article in the Journal of Industrial Hygiene and Toxicology on the effects of radium in humans (Evans, 1943). Dr. Seaborg also recommended that 10 mg of plutonium be allocated to Dr. Hamilton at the Radiation Laboratory of the University of California for animal studies. At that time 10 mg was a considerable proportion of the entire available stockpile. On January 19th, Dr. Stone reviewed the matter at a project council meeting at Clinton Laboratories indicating that 1 to 2 micrograms of radium had been fatal in humans and that plutonium may be less toxic, by a factor of about 50. On January 29th, in the same month as the original letter from Dr. Seaborg, 11 mg was allocated and this was shipped

to Dr. Hamilton on February 1st with delivery on February 10th. In the Metallurgical Laboratory report for February 1944, (Allison, 1944) there is a very short statement on the initial results. It said, "Product studies-oral absorption of all valence states is less than 0.05%; lung retention high; absorbed material predominately in the skeleton; excretion very small in urine and feces."

The initial output is an excellent, if brief, statement of the metabolism of plutonium, and the entire period from Dr. Seaborg's initial concern to the time of reporting some actual results on animals was on the order of two months or less. Under today's conditions, this is a speed record.

Now, without detailing the many studies and hard work intervening, we will move to the derivation of the present standards. This occurred actually after the Chalk River Meeting, which was a tri-partite conference held on September 29 and 30 of 1949 (McMurtrie, 1949). There was some confusion at this meeting as to whether the results from the animal experiments were from acute or chronic experiments. A followup meeting was held on January 24th, in Dr. Warren's office with, among others, Dr. Langham and Dr. Brues to review this material and come up with a resolution. Doctor Langham indicated that he spoke for 2 hours at this meeting and Doctor Brues spoke for 5 minutes. If Dr. Brues had spoken first, the meeting would have been over in 6 minutes (Langham and Healy, 1973). It is this material which provides the primary basis for much of what has followed.

The toxicity ratios derived at this time for ^{239}Pu compared to ^{226}Ra based upon the quantity of each injected into small animals are given in Table 1. These results include both acute damage as well as that resulting after prolonged retention and indicate that on an injected basis plutonium is about 15 times as harmful as radium. However, the retention studies indicated that plutonium is retained in the rodent about three times greater than radium. Thus, converting to a retained basis would indicate that the plutonium retained in the animal was five times as damaging as the ^{226}Ra retained. This is still not the entire story, however, since the radium is retained in the body long enough for the radon to accumulate and deliver alpha energy. About 4.8 MeV results from the decay of the ^{226}Ra and about 19.2 MeV from the complete decay of the radon and its daughters. However, not all of the radon produced in the bone remains in the body following formation. Further the fraction that remains in man is larger than that which remains in the rodent so that a larger energy deposition will occur in man than in the rodent for a given burden of radium. At the time of this derivation, the retention of radon was believed to be about 15-20% in the rat and 50% in man. This resulted in about twice the energy deposition from one disintegration of radium as compared to plutonium or a human toxicity ratio on a retained basis of 2.5 for plutonium as compared to radium. Since the maximum permissible body burden for radium had been established from studies of humans at 0.1 μCi (NCRP, 1941) the application of this ratio resulted in the currently recommended value for plutonium of 0.04 μCi .

The dose distribution factor, which accounts for the increased damage of plutonium per unit of energy delivered in the bone as compared to radium, was derived from this value at a later date. In this derivation, the fraction of radon retained in the human was taken as 30% which resulted in an energy deposition per disintegration of 11 MeV for radium. Since ^{239}Pu emits a 5.15 MeV alpha particle, the ratio of the energies delivered is about a factor of 2. Thus, plutonium per unit of energy delivered is about five times as harmful as the radium if it is assumed, as was done then, that nearly all of the plutonium in the body is in bone. It may be noted that data on the distribution of plutonium in the organs (ICRP, 1972) indicate that a significant portion of the material is in organs other than bone (chiefly liver) following many routes of administration. If this were true on the animals used in the toxicity studies, then plutonium would be even more effective per unit of energy delivered than the current dose distribution factor indicates. If we assume, for example, that 50% of the plutonium in the body was in the bone, the dose distribution factor should be on the order of ten rather than five. While this could change the assessment of dose equivalent delivered to the bone, it would cause no change in the maximum permissible body burden since this value was not derived from dose considerations, but, instead, is traceable through biological comparison to the human data on radium.

To elaborate, the following statement which is the basis for much of the internal dosimetry for bone originated at the Harriman tri-partite conference in 1953 (Tri-Partite Conference, 1953). "Radium is assumed,

for purposes of calculation, to be uniformly distributed. Other alpha-emitting bone seekers are assumed to be non-uniformly distributed by a factor of 5." We know that radium is not uniformly distributed, but this assumption has served as a basis in making the comparison between the other alpha emitting bone seekers and radium. The factor of five is the one derived earlier for the comparison between bone and radium. The statement can be interpreted in two different ways. The first is that the critical organ is smaller for the other alpha emitting bone seekers by a factor of 5, or the second is that the alpha particles from the other emitters are more damaging by a factor of 5. We seem to have taken the latter interpretation in terms of our calculations and their interpretation. In other words, one frequently sees the statement that the alpha particles from plutonium are considerably more damaging than those from radium. The use of a smaller critical organ is probably a better interpretation of this statement and the data. In fact, the minutes of the Harriman Conference contain a statement attributed to Dr. Hamilton. "The problem of the different type of selective localization...I would put out a value of 5 in the case of actinium. In other words, the mass of the critical organ on the order of 1.4×10^3 instead of 7×10^3 grams, since it is not evenly distributed." Dr. Hamilton was proposing at this conference that if one discussed actinium, the results would be applicable to most of the other bone seekers. This accounts for his use of actinium rather than plutonium. In this interpretation, the mass of the critical organ would have been on the order of 1400 g instead of 7000 g. This is mentioned so that in future

calculations the possibility of using this concept rather than the dose distribution factor can be considered.

The limits for the other organs are based on a maximum permissible dose equivalent rate of 15 rems per year calculated as though the material were uniformly distributed. In the early recommendations (NCRP, 1953) values of the maximum permissible organ burdens as calculated on these assumptions were listed. While this method seemingly has the advantage of placing more emphasis on the limitation of radioactive material in the organ, it has been eliminated from later recommendations making the dose equivalent the primary limitation. The uniform distribution assumption will be discussed later in this symposium. However, I would like to introduce a brief quotation from the Chalk River Tri-Partite Conference in 1949 (McMurtrie, 1949). "Dr. Hamilton pointed out that the cells in the immediate neighborhood of a dust particle containing 1 or 2% of plutonium would be subjected to a dose of about 400 R/day. The general opinion which emerged from the discussion was that the carcinogenic effect per unit volume is probably considerably less for irradiation of small masses of tissue than for large." This is but one of a long series of deliberations from various organizations which have been concerned with radiation protection over the years indicating that they were aware of, and concerned with, the problems posed by this question. In view of the record of these groups in past problems with similar uncertainties, it is surprising to find individuals stating that no guidance has been given thereby implying that a potentially serious problem has been ignored. In fact the record clearly shows that

the question has been posed many times and the fact that changes have not been made in the methods of dosimetry is a clear indication that these groups did not feel that a change was needed.

Table 2 summarizes a history of the operating standards or occupational MPC's. The continuous exposure MPC's were chosen since the original values were derived on this basis and it made direct comparisons possible in this table. There are two points that are of interest. First, the original value of the MPC for air from the Chalk River Conference was based only on considerations of the so-called soluble plutonium. That is, the material which is taken into the systemic circulation and, presumably, deposited in bone. In the 1950 ICRP Manual, a value based on the radiation dose to the lung was calculated. However they then recommended that the value of 2×10^{-12} $\mu\text{Ci/ml}$ for soluble plutonium be used for both soluble and insoluble materials (ICRP, 1960).

Table 3 can be used to indicate some of the problems with this concept of separate MPC's. This table gives the model which was used for current MPC's, because the new ICRP lung model (ICRP, 1966) has not been applied to any of the values which are in current use, at least through the United States. This lung model was derived originally at the Chalk River Conference, was revised at the Harriman Conference and later revised further by the ICRP and NCRP.

As can be seen, strict application of this model would result in the insoluble MPC for long-lived emitters never being greater than twice the MPC for soluble materials since 12.5% of the insoluble materials are

eventually taken into the body and, presumably, deposited in the appropriate organs. However, in the calculations, this was ignored with only the dose to the lung considered for the insoluble materials. The newer ICRP lung model does make more realistic allowances for this uptake with the result that the uptake is generally lower than given in Table 3. However, the point can be made that the differentiation between soluble and insoluble is based upon a calculational technique and that only the lung is considered of importance in exposure to insoluble materials.

REFERENCES

- Allison, S. K., 1944, Metallurgical Laboratory Report, MUC-NH-807.
- Evans, R. D., 1943, J. Industr. Hyg. 25, 253.
- International Commission on Radiological Protection (ICRP) 1950 National Bureau of Standards Handbook 47.
- International Commission on Radiological Protection (ICRP) 1953 Brit. J. Radiol. Supple. 6, 1 (1955).
- International Commission on Radiological Protection (ICRP) 1960 Health Phys. 3, 1.
- International Commission on Radiological Protection, Task Group on Lung Dynamics 1966 Health Phys. 12, 173.
- International Commission on Radiological Protection (ICRP) Publication 19, 1972 (Oxford, Pergamon Press).
- Langham, W. H. and Healy, J. W. 1973, in "Handbook of Experimental Pharmacology XXXVI, Uranium, Plutonium, Transplutonic Elements," Hodge, H. C., Stannard, J. N., and Hursh, J. B., Editors Springer-Verlag New York, Heidelberg, Berlin.
- McMurtrie, G. E. (Secretary) 1949, Report M-10.

National Committee on Radiation Protection and Measurements (NCRP) 1936,
National Bureau of Standards Handbook 20.

National Committee on Radiation Protection and Measurements (NCRP) 1941,
National Bureau of Standards Handbook 27.

Table 1

TOXICITY RATIOS FOR ^{239}Pu COMPARED TO ^{226}Ra
 USED FOR DERIVATION OF ^{239}Pu MAXIMUM PERMISSIBLE
 BODY BURDEN - INJECTED DOSE BASIS

Acute Toxicity in Small Animals	15
Chronic Survival.....	10
Bone Tumors in Rats and Mice	15
Bone Tumors in Rabbits	8
Bone Fractures in Rats & Rabbits	10

TABLE 2
LUNG MODEL USED FOR CALCULATING
CURRENT MPC'S IN AIR

	<u>Soluble</u>	<u>Insoluble</u>
Exhaled	25%	25%
Deposited in Upper Respiratory Tract	50%	50%
Deposited in Lower Respiratory Tract	* 25%	25%
Eliminated in 24 Hr	---	12.5%
Retained in Lung and Taken Up in Body Fluids	---	12.5%

*Taken up into body.

TABLE 3
HISTORICAL SUMMARY OF CHANGES
IN MPC'S FOR PLUTONIUM

	Air		Water	
	Soluble	Insoluble	Soluble	GI Tract
Chalk River - 1949 *	1.5×10^{-12}	---	1.2×10^{-6}	---
ICRP - 1950	2×10^{-12}	2×10^{-12} (7.5×10^{-12})	1.5×10^{-6}	---
NCRP - 1953	2×10^{-12}	2×10^{-12}	1.5×10^{-6}	---
ICRP - 1954	2×10^{-12}	2×10^{-12}	6×10^{-6}	3×10^{-6}
ICRP - 1959) NCRP)	6×10^{-13}	10^{-11}	5×10^{-5}	3×10^{-4}

*McMurtrie 1949.