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Uranium · Plutonium Transplutonic Elements

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that injection of graded solution, i.e. comprising a narrow range of particle size, containing 30 percent ultrafilterable plutonium from which both larger and smaller particles had been removed, resulted in a significantly different organ distribution of plutonium as compared with previously used ungraded solutions, i.e. containing a variety of particle sizes, of the same ultrafilterability, as shown in the table. In the case of the graded solution 68 percent of the retained dose was retained in the skeleton, and of the ungraded solution 39 percent was retained in the skeleton though both solutions were 30 percent ultrafilterable (LINDENBAUM et al., 1968). They conclude that the pattern of deposition in mouse tissues appears to depend on aggregation of plutonium-containing particulates to some critical particle size and conclude that this particle size is below 0.5 μ and well above 0.01 μ in diameter.

In the mouse, the factors influencing the relative retention of plutonium in skeleton and liver following intravenous injection are the proportion of colloidal plutonium and the particle size of the colloidal particles in the solution injected. Unfortunately no exactly comparable information is at present available on any animal other than CFF mice[1]. It would be of very great interest to know what would happen in dogs, pigs and man with solutions known to be extremely monomeric or extremely polymeric of defined particle size.

The classic report of the tissue distribution of an intravenous injection of plutonium in man is that made by LANGHAM and his colleagues in 1950 (LANGHAM et al., 1950) on 16 patients. This included 12 patients with short life-expectancy to whom they had given ^{239}Pu citrate intravenously, 3 patients previously reported by RUSSELL and NICKSON in 1946 who had received hexavalent ^{239}Pu citrate in 0.9 percent salt solution at pH 7 and a patient with gastric carcinoma already reported by CROWLEY and his colleagues (CROWLEY et al., 1946) who had received ^{238}Pu nitrate. The mean figures for these 16 patients as shown in Table 10.5 gave the highest retention in the skeleton, the figures being very similar to those for pigs and dogs also given a citrate solution.

These classical data on the results of intravenous injection in man have recently been reviewed by DURBIN (DURBIN, 1971). Her analysis makes little difference to the figures for total retention but results in a significant difference in organ retention. She estimates, that, in healthy humans, bone and liver will retain equal amounts of plutonium 15 years after exposure and that at later intervals the liver may gain further at the expense of the skeleton. This new assessment of the old data is dependent on a variety of factors, the most important of which is that allowances have been made for the fact that the patients investigated were extremely ill. Abnormalities in their circulatory system, in the capacity of their plasma proteins to bind plutonium, in their liver function and their dietary intake have been taken into account in making these new calculations. The same conclusion has been reached by a recent ICRP Task Group Report (International Commission on Radiological Protection Report, 1972) and by MAYS and his colleagues reviewing both human and animal data (MAYS et al., 1970).

2. Gastrointestinal

Early experiments on the gastrointestinal absorption of plutonium are somewhat confused as the authors do not always discriminate clearly between ^{238}Pu and ^{239}Pu (CARRITT et al., 1947; HAMILTON, 1947; SCOTT et al., 1948; KATZ and WEEKS, 1954; WEEKS et al., 1956). Where possible a distinction has been made in Table 10.6 though there appears to be no significant difference in the gastric ab-

1 See footnote page 455.

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III. Other Plutonium Isotopes

DAVID M. TAYLOR

Compared with ^{239}Pu the metabolic behaviour of ^{238}Pu and ^{237}Pu has been studied to a very limited extent. These latter two nuclides have a much greater specific activity than ^{239}Pu and this may result in apparent differences in metabolic behaviour when tissue distributions and retention of the three nuclides are compared on a microcurie for microcurie basis.

A. ^{238}Pu

In 1946 HAMILTON and his colleagues published the results of administering ^{238}Pu to man and rats by intravenous injection (CROWLEY et al., 1946). This is the earliest record found of plutonium administration to man and as such is of some historical interest. They describe the solution used as $PuO(NO_3)_2$ in isotonic sodium chloride at pH 5.5. The man was a patient with gastric carcinoma and after 4 days a piece of rib was examined. The greater part of the plutonium was found on the endosteal surface of trabecular bone and in the marrow; little plutonium was present in the periosteum or cortical bone. They calculate that at this time 87 percent of the injected plutonium was in the skeleton. At the end of 296 days only 5 percent of the plutonium injected had been excreted largely in the urine while in the rat 50 percent had been eliminated largely in the faeces. The chart for excretion is shown in Fig. 10.15. Their final comment is that in man the half time of plutonium excretion is probably greater than 50 years.

^{238}Pu has been given to rats, rabbits, pigs and dogs as shown in Table 10.26 by intravenous, intragastric, intramuscular routes and by inhalation.

1. Intragastric

Early experiments feeding ^{238}Pu were carried out on rats by KATZ and his colleagues at HANFORD, the results being published in a series of reports (KATZ, 1952; KATZ, 1955; KATZ and WEEKS, 1954; KATZ and KORNBERG, 1955). It is a little difficult to be certain how far some of the results in these reports are included in a publication in 1955 in the open literature. The results are in close agreement. They concluded (KATZ et al., 1954) that the concentration of the plutonium in the solution fed had no effect on absorption over the range 10^{-5} μg/ml to 1 μg/ml and that the average absorption was 0.0028 percent of the amount fed with 0.0025 percent of the amount fed being deposited in the skeleton. In 1955 KATZ and his colleagues (KATZ et al., 1955) published a series of experiments on the deposition of ^{238}Pu in bone and soft tissues after 517 low level feedings of $Pu(NO_3)_4$ at doses that varied from 0.04 to 1.2 times the currently accepted maximum permissible concentration of plutonium in drinking water, 10^{-6} to 3×10^{-5} μg/ml. The feeding lasted $9^1/_2$ months and the rats were given 1–4 doses a day. The dosage schedule is shown in Table 10.6. Within the 95 percent limits of confidence the mean percent total body, soft tissue and skeletal deposition was 0.00261 ± 0.00038, 0.00021 ± 0.00010 and 0.00234 ± 0.00028 respectively for rats receiving levels equivalent to 1.2 the maximum permissible concentration. No significant decrease in skeletal plutonium was observed over a period of 250 days following cessation of feeding.

2. Intravenous and Intramuscular Injection

When ^{238}Pu is given to rats, by intravenous injections as the citrate, at dose levels of 4 μCi or 78 μCi/kg 40 to 60 percent of the radioactivity is found in the

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