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PLUTONIUM AND PUBLIC HEALTH

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For the sake of completeness let me give you some background on plutonium. It is an element that is virtually non-existent in the earth's natural crust. In the early 1940's it was first produced and isolated by Dr. Seaborg and colleagues; — Dr. Seaborg is presently Chairman of the Atomic Energy Commission. Plutonium has several isotopes, the most important being plutonium-239, which, because of its fissionable properties and its ease of production, is potentially the best of the three fission fuels. That is why it is of interest. Aside from its fissionable properties, plutonium-239 is a radioactive isotope of relatively long half-life (24,000 years), hence its radioactivity is undiminished within human time scales. When it decays, it emits a helium nucleus of substantial energy. Because of its physical characteristics, a helium nucleus interacts strongly with the material along its path; and as a consequence deposits its energy in a relatively short distance, — about four-hundredths of a millimeter in solid tissue. For comparison, a typical cell dimension is about 1/4 to 1/10 of that. A cell whose nucleus is intercepted by the path of such a particle suffers sufficient injury that its capacity for cell division is usually lost.

The cancer inducing potential of plutonium is well known. One millionth of a gram injected intradermally in mice has caused cancer (1); a similar amount injected into the blood system of dogs has induced a substantial incidence of bone cancer (2), because of plutonium's tendency to seek bone tissue. Fortunately the body maintains a relatively effective barrier against the entry of plutonium into the blood system. Also, because of the short range of the emitted helium nuclei, the radiation from plutonium deposited on the surface of human skin does not usually reach any relevant tissue. Unfortunately the lung is more vulnerable.

Before I describe why this is, I'd like to say something about the characteristics of an aerosol. An aerosol is physically like cigarette smoke, or fog, or cement dust. Because of their small size, the particles comprising an aerosol remain suspended in air for long periods of time. If an aerosol is inhaled, then, depending on its physical characteristics, it may be deposited at different sites in the respiratory tree (3). Larger aerosol sizes are usually removed by turbulence in the nose, particles deposited in the bronchial tree are cleared upward in hours by the ciliated mucus blanket that covers the structure. This clearance system does not penetrate into the deep respiratory structures, the alveoli, where the basic oxygen-carbon dioxide exchange of the lung takes place. Smaller particles tend to be deposited here by gravitational settling, and if they are insoluble they may reside in the alveoli for a considerable time. The problem is that, under a number of conditions, plutonium tends to form aerosols of a size that are preferentially deposited in deep lung tissue. Plutonium dioxide, which is a principal offender, is insoluble and may be immobilized in the lung for hundreds of days before being cleared to the throat or to the lymph nodes around the lungs.

An aerosol is comprised of particles of many different sizes, and their radioactivity may differ by factors of thousands or even more. I will simplify the argument and say that there is a class of these particles, the largest ones deposited in the deep lung tissue, that can be expected to have a different potential of cancer induction than the particles of the smaller class. This is because they are sufficiently radioactive to disrupt cell populations in the volume of cell tissue which they expose (4). An example might be a particle that emits 5000 helium nuclei per day. It would subject between 1 and 20 alveoli to intense radiation, sufficient to inflict substantial cell death and tissue disruption. For reference, the alveoli are the basic structural units of the deep lung. They are shaped and bunched roughly like hollow grapes 0.3 millimeter in diameter. Their walls are thin, a few thousandths of a millimeter, and they are a highly structured tissue with many cell types. Intense exposure of local tissue by a radioactive particle is referred to as the hot particle problem. The question is: does such a particle have an enhanced potential for cancer? No one knows. One can argue that cancer cannot evolve from dead cells, hence a depleted cell population must be less carcinogenic. This is believable, and must be true on occasion. The facts are, though, that intense local doses of radiation are extremely effective carcinogens, much more so than if the energy were averaged over a larger tissue mass (5). Furthermore, this can take place at high doses of radiation where only one cell in ten thousand has retained its capacity to divide. The cancer susceptibility of lung tissue to radiation has been demonstrated in many species; one can say in general that the lung is more susceptible to inhomogeneous exposures from particles and implants than it is to diffuse uniform radiation. Some very careful skin experiments of Dr. Albert have indicated that tissue disruption is a very likely pathway of radioactive induction of cancer after intense exposure (6-9). The experiments show that the most severe tissue injury is not necessary, nor even optimal, for the induction of cancer. When these notions are applied to a hot particle in the lung, the possibility of one cancer from 10,000 disruptive particles is realistic. This is disturbing because an appreciable portion of the total radioactivity in a plutonium aerosol is usually in the large particle component.

Let me demonstrate what I mean. Suppose a man received a maximum permissible lung burden for plutonium, and suppose roughly 10% of the mass of the burden was associated with the most active class of particles deposited (that is those emitting several thousand helium nuclei per day). This is reasonable. There would be something like a thousand of these particles and each would chronically expose 1 to 20 alveoli to intense radiation. If the risk of cancer is like 1 in 10,000 for one disruptive particle, then the total risk in this situation is one in ten, i.e., one man in ten would develop lung cancer.

Put another way, about 1 cubic centimeter of the lung is receiving high doses of radiation. It would not be surprising if intense exposure of such a localized volume led to a cancer one time in ten. The question is: if the individual volumes are separated from each other, is substantial protection afforded? No one knows. It is much easier to find two cancers using 50 exposures of 1 cubic centimeter each, than it is to find a couple of cancers in 50,000 single particle exposures. Certainly the length scales of injury are long enough that a disruptive carcinogenic pathway cannot be disregarded for isolated hot particles.

One can look to the relevant experience for reassurance. In an experiment done at Hanford by Dr. Bair and his colleagues, beagle dogs were given $Pu^{239}O_2$ lung burdens of a few hundred thousandths of a gram (10,11). At 9 years post exposure, or after roughly half of an adult beagle life span, 22 of 24 deaths involved lung cancer, usually of multiple origin. Five dogs remain alive. For comparison, these exposures are about 100 times larger than the present maximum permissible burdens in man.

There are two unsatisfactory aspects of this experiment. First, because all of the dogs are developing cancer, it is impossible to infer what would happen at lower exposures; simple proportionality does, however, suggest that present human standards are too lax by at least a factor of ten. Second, because the radiation dose is large, with tissue injury almost killing the dogs; and because large numbers of particles are involved, often acting in conjunction; it is improbable that the risk from disruptive particles can be inferred. And after all, this is what we need to know, since almost all human exposures will involve hot particles acting independently, and if there is a risk from these particles, it will be additive throughout the population; — there will be no question of a threshold burden; and there will be a possibility that a man with an undetectable burden of a few particles will develop a cancer as a consequence. For the exposures of concern, 1000 people with 100 disruptive particles each will suffer as many total cancers as 10,000 people with 10 particles each, or as 100 people with 1000 particles each.

Human experience does not give us the answer either. Plutonium has been around for 25 years, and people have been exposed. In 1964 through 1966 contractors indicated an average total of 21 people per year with over 25% of a maximum permissible burden of plutonium (12). Three out of four of these exposures derived from inhalation. To be reasonably useful, the documentation of exposure must go back more than 15 years, because of the latent period for radiation induced cancer. In recent years documentation has improved greatly, but from early days there is pitifully little of relevance to the hot particle problem in the lung.

Since I have mentioned maximum permissible lung burdens, you are aware that there is official guidance. I would like to comment on it. The maximum permissible lung burden is established by equilibrating the exposure from the deposited radioactive aerosol with that of an acceptable uniform dose of x-rays. The International Commission on Radiological Protection indicates this may be greatly in error, and specifically states in its publication 9, "In the meantime there is no clear evidence to show whether, with a given mean absorbed dose, the biological risk associated with a non-homogeneous distribution is greater or less than the risk resulting from a more diffuse distribution of that dose in the lung." (13). They are effectively saying that there is no guidance as to the risk for non-homogeneous exposure in the lung, hence the maximum permissible lung burden is meaningless for plutonium particles, as are the maximum permissible air concentrations which derive from it.

So there is a hot particle problem with plutonium in the lung, and the hot particle problem is not understood, and there is no guidance as to the risk. I don't think there is any controversy about that. Let me quote to you from Dr. K. Z. Morgan's testimony in January of this year before the Joint Committee on Atomic Energy, U. S. Congress (14). Dr. K. Z. Morgan is one of the United States' two members to the main Committee of the International Commission on Radiological Protection; he has been a member of the committee longer than anyone; and he is director of Health Physics Division at Oak Ridge National Laboratory. I quote: "There are many things about radiation exposure we do not understand, and there will continue to be uncertainties until health physics can provide a coherent theory of radiation damage. This is why some of the basic research studies of the USAEC are so important. D. P. Geesaman and Tamplin have pointed out recently the problems of plutonium-239 particles and the uncertainty of the risk to a man who carries such a particle of high specific activity in his lungs." At the same hearing, in response to the committee's inquiry about priorities in basic research on the biological effects of radiation, Dr. M. Eisenbud, then Director of the New York City Environmental Protection Administration, in part replied, "For some reason or other the particle problem has not come upon us in quite a little while, but it probably will one of these days. We are not much further along on the basic question of whether a given amount of energy delivered to a progressively smaller and smaller volume of tissue is better or worse for the recipient. This is another way of asking the question of how you calculate the dose when you inhale a single particle." (15). He was correct; the problem has come up again.

In the context of his comment it is interesting to refer to the National Academy of Sciences, National Research Council report of 1961 on the Effects of Inhaled Radioactive Particles (16). The first sentence reads, "The potential hazard due to airborne radioactive particulates is probably the least understood of the hazards associated with atomic weapons tests, production of radioelements, and the expanding use of nuclear energy for power production." A decade later that statement is still valid. Finally let me quote Drs. Sanders, Thompson, and Bair from a paper given by them last October (17). Dr. Bair and his colleagues have done the most relevant plutonium oxide inhalation experiments. "Nonuniform irradiation of the lung from deposited radioactive particulates is clearly more carcinogenic than

than uniform exposure (on a total-lung dose basis), and alpha-irradiation is more carcinogenic than beta-irradiation. The doses required for a substantial tumor incidence, are very high, however, if measured in proximity to the particle; and, again, there are no data to establish the low-incidence end of a dose-effect curve. And there is no general theory, or data on which to base a theory, which would permit extrapolation of the high incidence portion of the curve into the low incidence region." I agree and I suggest that in such a circumstance it is appropriate to view the standards with extreme caution.

There is another hazards aspect of the particulate problem in which substantial uncertainty exists. In case of an aerosol depositing on a surface, the material may be resuspended in the air. This process is crudely described by a quantity called a resuspension factor which is remarkable in that it seems generally known only to within a factor of billions (18). Undoubtedly it can be pinpointed somewhat better than this for plutonium oxide, but the handiest way to dispatch the problem is to say there is some evidence that plutonium particles become attached to larger particles and are therefore no longer potential aerosols. Unfortunately there is also evidence that large particles generate aerodynamic turbulence, and are hence blown about more readily, and on being redeposited tend to knock small particles free. In relation to this I'd like to give you a little subjective feeling for the hazard. There is no official guidance on surface contamination by plutonium. Two years ago, in an effort to determine some indication of the opinions of knowledgeable persons with respect to environmental contamination by plutonium, a brief questionaire was administered to 38 selected LRL employees. All were persons who were well acquainted with the hazards of plutonium. The group consisted of 16 Hazards Control personnel, primarily health physicists and senior radiation monitors. The remainder were professional personnel from Biomedical Division, Chemistry, and Military Applications, who had extensive experience with plutonium. I had nothing to do with the survey, nor was I one of the members who was queried. The conjectured situation was that their neighborhood had been contaminated by plutonium oxide to levels of 0.4 microcuries per square meter. For reference, this value is roughly ten times the highest concentrations Dr. Martell found east of the Rocky Flats Dow Chemical facility (19), – and bear in mind that a factor of ten is a small difference relative to the large uncertainties associated with the hazards from plutonium contamination. Several questions were asked. One was, would you allow your children to play in it? 86% said No. Should these levels be decontaminated? 89% said Yes. And to what level should the area be cleaned? 50% said to background, zero, minimum, or by a reduction of at least a factor of 40. This has no profound scientific significance, but indicates that many people conversant of the hazard are not blasé about the levels of contamination encountered east of Rocky Flats.

Finally I would like to describe the problem in a larger context. By the year 2000, plutonium-239 has been conjectured to be a major energy source. Commercial production is projected at 30 tons per year by 1980, in excess of 100 tons per year by 2000. Plutonium contamination is not an academic question. Unless fusion reactor feasibility is demonstrated in the near future, the commitment will be made to liquid metal fast breeder reactors fueled by plutonium. Since fusion reactors are presently speculative, the decision for liquid metal fast breeders should be anticipated and plutonium should be considered as a major pollutant of remarkable toxicity and persistence. Considering the enormous economic inertia involved in the commitment it is imperative that public health aspects be carefully and honestly defined prior to active promotion of the industry. To live sanely with plutonium one must appreciate the potential magnitude of the risk, and be able to monitor against all significant hazards.

An indeterminate amount of plutonium has gone off site at a major facility 10 miles upwind from a metropolitan area. The loss was unnoticed. The origin is somewhat speculative as is the ultimate deposition.

The health and safety of public and workers are protected by a set of standards for plutonium acknowledged to be meaningless.

Such things make a travesty of public health, and raise serious questions about a hurried acceptance of nuclear energy.

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