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CROCKER LABORATORY
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To: Shields Warren, M. D.
Director, Division of Biology & Medicine

From: Wendell M. Latimer and Joseph G. Hamilton

Subject: REVIEW OF THE GABRIEL PROJECT REPORT BY PROFESSOR WENDELL M. LATIMER AND DOCTOR JOSEPH G. HAMILTON

The four major considerations of injurious actions that might be provoked by the detonation of a large number of atomic bombs has been listed in the Gabriel Project report as follows:

A. Ingestion of plutonium deposited on the ground, concentrated by plants used for food, and its subsequent deposition in the skeleton.

B. Lodgement of particles from nuclear detonations in the alveoli of the lungs.

C. Absorption of plutonium following its inhalation with subsequent deposition in the skeleton.

D. External radiation from the fission products.

An evaluation of these factors in some instances is relatively easy but in others it becomes rather speculative due to the fact that there is not yet at hand sufficient information to permit the construction of quantitatively as well as qualitatively sound interpretations and predictions.

It is appropriate first to discuss the four toxic effects as enumerated in the Gabriel Project report. The first factor can be considered of relatively minor importance. In the first place, the absorption from the digestive tract of even the most soluble compounds of plutonium is in the order of a few thousands of a percent of the amount ingested. It would seem almost a certainty that plutonium contained in the particles arising from a nuclear detonation would not be absorbed with anything like the degree of efficiency following the oral ingestion of highly soluble compounds of this element. In other words, the particles, which are predominantly composed of oxides of iron, would tend to protect the contained plutonium from action by the digestive juices. Moreover, it should be recalled that the plutonium itself most probably would be in the form of an oxide and that the solvent properties of the digestive juices toward

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plutonium in this chemical and physical combination can be predicted to be minimum. Studies undertaken during the war and subsequently published relating to the uptake of plutonium by plants, indicated in the species studied that considerable accumulation took place in the region of the roots. There was very little translocated to the leafy portion of the plants. This evidence would suggest that it is improbable that with most plants, whose products are consumed by animals and man, that there would be sufficient plutonium contamination to present any very troublesome menace. The likelihood that the plutonium which might be contained in plants and plant derivatives would be in a form capable of ready assimilation seems most unlikely. This point, of course, cannot be considered conclusive, but it should be a relatively easy matter to determine if plutonium, complexed with the more common organic acids, etc. found in plant tissue, is more readily absorbed.

The third consideration listed in the report, namely the deposition of plutonium in the bone, following its inhalation, can likewise be considered of relatively minor significance. With regard to this situation, considerable experimental evidence has been accumulated to demonstrate that oxides of plutonium are absorbed through the alveoli into the blood stream to a very minimal degree. An exact limit cannot be fixed but experimental evidence indicates an upper limit of the order of 0.1% as definitely established.

The fourth factor, namely external radiation from fission products is readily subjected to calculation and has been investigated in considerable detail in the report. While admittedly for local areas, it can be a very serious problem, the number of bombs required to provoke lethal or sublethal levels for global areas is fantastically high, lying somewhere in the range of 10^6 to 10^8 bombs. At the present level of technological productivity in this country and that which may be extant in the Soviet Union, for the forseeable future, would appear remote.

The second item of the report, namely the breathing of plutonium in the air and lodgement of a radioactive particle in the alveolar region of the lung is worthy of very careful and detailed consideration. In our estimation, we have felt this factor to be of sufficient importance to explore the possible circumstances surrounding it in considerable detail. It was of interest to make some estimates as to the amount of radiation that would be delivered to regions of the lung where particles might be retained. By way of introduction, it is apparently generally considered that insoluble particles whose size falls within the range of 0.1 to 1.0 micrograms are most subject to prolonged retention in the lungs following their inhalation. The immediate site of deposition is in the alveoli and alveolar ducts. Their fate thereafter is not too clearly established in all instances. It has been demonstrated in man that particles of carbon and silicon dioxide eventually tend to accumulate in the lymphoid tissues of the lungs. This observation, of course, does not take into consideration

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those particles which, following entrapment by the alveolar structures, are subsequently moved out of those areas and on to the ciliated epithelium of the bronchial tree where they would be rapidly carried away and eventually swallowed in the sputum. Studies done at Chicago and in this Laboratory, using radioactive aerosols of both plutonium and fission products, demonstrated a rather high degree of entrapment within the alveolar structures but no accumulation was observed in the lymphoid tissues. Some consideration may be given to the fact that these studies were done with rats and that behavior of particles in the human lung might be significantly different. The point remains, however, that aerosols containing particles of the micron range composed of plutonium and fission products will lodge in the alveolar structures and be retained there for long periods of time. In the rat, as a first assumption, it can be stated that approximately 25% of the radioactive aerosols inhaled are initially retained in the alveolar structures. It is difficult to give a significant value for the biological half-life, as these materials were observed to be released from the lungs in ever decreasing rates. To give an idea of the order of magnitude of this effect of the retention, roughly 4% of the total activity inhaled was still present in the lungs at the end of a year. Admittedly, numbers such as these are only to be considered qualitatively and should be determined with greater precision by using larger animals such as possibly dogs or monkeys.

In any event, there is no question about the high probability of lodgement of these radioactive particles in the lung for protracted intervals of time following their inhalation.

We found it of interest to make an estimate as to the amounts of radiation delivered by such particles. The details of the computations are included in the appendix. In making these computations, two situations were selected. First, the amount of radiation delivered by the plutonium and second, that delivered by the contained fission products assuming no disproportionation. The following assumptions were made for the calculations: size of particles - 2 microns in diameter, density - 5, content of plutonium by weight - 3%, range of plutonium alpha particles in tissue - 40 microns. In the case of the fission products, it was assumed that the same weight of fission products were present as that of plutonium and a period of seven days of decay from the time of the nuclear detonation to the moment of inhalation was employed. Finally, an average beta ray energy per disintegration of 0.4 Mev was taken and a range in tissue of 1 millimeter and the effect from gamma rays ignored. The result of the computations revealed that the amount of radiation delivered within the volume of tissue subjected to ionization from the alpha particles of plutonium was 390 roentgen equivalents physical per day and in the case of the beta rays from fission products, the value at 7 days was 72 roentgen equivalents physical per day.

These two numbers, and in particular, the value of plutonium on the basis of the high dosage level, very long half-life, and relatively greater

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effectiveness of alpha particle irradiation would appear most ominous particularly with respect to the possibility of carcinogenesis. There are some considerations, however, that may mitigate the especially alarming circumstances surrounding this. In the first place, it would seem plausible that carcinogenesis from irradiation must possess a most significant statistical factor. In other words, enormous numbers of cells, even under normal environment receive hits from alpha particles as a result of the natural contamination of radium in the body and other natural radio-elements as well as dense ionization trails from radiation associated with cosmic rays. Here, we have all of the body exposed to a very low level of radiation. In the case of the small particle bearing plutonium and its associated fission products, we have small volume of the body with a relatively limited number of cells exposed to varying intents of radiation. Now what are the potentialities of carcinogenesis in these two cases? We do not know, and it may well be that this point for the moment is very highly speculative and will remain so until settled by some long-term animal studies, especially on the species most closely allied to man. At the present time, a careful survey is being made of the lung sections of the rats exposed to radioactive aerosols, containing both fission products and plutonium. While these results will be informative and of interest, they cannot be considered as conclusive. Our personal opinion is that the carcinogenic potentialities of a few particles in the lungs is probably more comparable to the degree of carcinogenesis from radium in the skeleton of the order of 1 microgram. However, this is only an opinion based upon speculation and should be considered as such.

A number of other points come to mind in perusing the report some of which suggest a different assessment of the factors considered and others a correction to statements made. Among the corrections, which are actually quite minor, are the following. The biological half-time of plutonium in the skeleton is probably more in the order of 100 years than 10 years. The reason for this statement is that in this Laboratory, a human subject was followed for almost a year after the parenteral administration of a mixture of Pu^{238} and Pu^{239}. At the end of this interval, the daily rate of excretion was still falling and was only a few thousands of a percent per day. It has been demonstrated shortly after the plutonium was administered that the skeletal uptake was of the order of 70 to 80 percent. It may be noted in passing that this individual received the radioactive equivalent of 50 micrograms of Pu^{239} about 5 years ago and to date has shown no evidence of any manifest radiation injury. Another point which was referred to briefly earlier in our report is that the translocation of plutonium and most of the fission products into the leafy and seed bearing portion of plants is very small.

It may be of interest, when considering the amount of plutonium an individual might get inside of him when exposed to an environment containing this element, to recall the experiences of the radium refining industry. Here, one finds individuals who have personally handled in rather close contact and under relatively poor hygienic conditions, from 10 to 100 grams of radium. Upon examination of such people, one finds rather

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frequently that there has been an internal contamination of the order of from 1 to 10 micrograms. The radium differs from plutonium in that most of its compounds are very soluble which means absorption can readily take place following inhalation or ingestion. Assuming only 10% retention of that taken into the body as a rough figure, the factor of internal contamination versus quantity of radium handled is of the order of 10^6. In other words, it would seem likely that one might live in an environment where the plutonium concentration on the ground was in the range of a gram per square mile without getting into too serious difficulty. This of course, takes into consideration that very rapidly, the natural processes of weathering will cover up most of the material so that it will be inaccessible insofar as introduction into the body is concerned. If this assumption is valid, then it can be seen that the fission product beta and gamma internal radiation will probably be far more of a hazard than the plutonium once the particles have come to rest on the ground. With regard to the resuspension of particles containing fission products and plutonium, we have the feeling that here again, the processes of weathering together with the dilution would make this potential hazard appear to be without too much significance. Another point which comes to mind is that particles whose size falls in the 0.1 to 1.0 micron range will remain suspended in the air for very long periods of time provided there is no precipitation by rain or snow. However, this washing effect of the atmosphere would seem to reduce the menace of the over-all situation for once they are carried down, it seems very unlikely that they can be in a position to do any harm insofar as inhalation is concerned.

Another point of high significance to be considered in evaluating the conclusions of the Gabriel report, is the distribution of particles with respect to size. While the evidence points to real danger of carcinogenesis with particles of 0.1 to 2.0 micron radii, larger particles do not readily lodge in the alveolar region but are carried away and eventually swallowed. The data summarized in Tables A1 and A2 of the Gabriel report, indicate that less than 0.1 percent of the particles are in the small size range. Hence, if we accept the calculations made by N.M.Smith, the number of bombs required to give a probability of 1 that a person in the U.S.A. would recive a 0.1 - 2.0 micron particle would be 10^3 times the number required to give *a* particle or $10^3 \times 10^3 = 10^6$ bombs.

The theoretical calculations given by Smith on particle size are certainly overly simplified and it is doubtful if the problem can be handled by any theory of nuclei formation at present. However, additional study should be given to the problem along the lines developed by M. Volmer (Kenetokder Phasenbeldung, Edwards Bros., Ann Arbor, pp. 121-152, 1945) and amplified in recent studies by Victor La Mer of Columbia University. Also there is no assurance that the sampling methods used in previous bomb tests were adequate to determine the number of small particles. Indeed,

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the percentage of such particles may be considerably larger than the present data indicate. It appears that this phase of the problem should be thoroughly studied in future tests.

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