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ASH OF BIKINI AND ITS EFFECTS ON HUMAN BODY

by

H. Kakehi

1. Introduction (omitted).

2. Physical Properties of the Ashes:

According to the report of the fishermen of Fukuryu Maru, the ash began to come down about 3 hours after the hydrogen bomb explosion. It continued to fall about 5 hours at varying rates and covered the boat like the light snow that footprints were left on the deck as they walked around.

The ash consists of light and white grains of various size less than 1 mm in diameter. Microscopic examination shows that they are amorphous and porous. It might be the fragment of the coralline substance. (Fig. 1) Its radioactivity was surprisingly strong and even a few grains of ash showed ten-thousands counts per minute on March 16. The thickness of the absorber to reduce the intensity of radiation to a half (or the inverse of the absorption coefficient) is $47mg/cm^2 Al \fallingdotseq 0.2mmAl$ for the β- ray and 5.5mmPb for the γ - ray (March 17). The radioautograph of the β-ray from the ash is shown in Fig. 2. The half-life was about 8 days at first, but it is in these days (about April 5) of the order of 18 days. Extrapolating the damping curve of radioactivity observed after March 17, the intensity of the β- ray on the next day of the explosion (March 2) is estimated to be about 50 times larger than that of March 17. Similar result may be obtained for the γ- ray too.

The chemical analysis of the ash has been performed at Kimura laboratory (Department of Chemistry, Tokyo University). The result published so far is shown in Table 1. There are several definitions of the half-life according to the purpose as is shown below. The half-life given in Table 1 is the physical half-life defined as the period of time during which the amount of a particular radioactive isotope is reduced to half its initial value. The biological half-life is the time during which the amount of elements deposited in some part of the body decreases to half as a result of assimilation, dissimilation, alteration, excretion, etc. The effective half-life is the time during which the radioactivity of the deposited radioisotope is reduced to half as a result of combination of the two effects mentioned above. This is the quantity which must be taken account of in discussing the injury produced by the radioactive elements deposited in the human body.

*Printed in Journal of Japan Physicians Society, Vol. 31, No. 9 (May 1, 1954)
(Translated by Toichiro Kinoshita)

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In Table 2 the physical, biological, and effective half-lives of the main elements which are supposed to deposit in the human body are given together with the organs in which they tend to deposit.

As is evident from this, these elements have a tendency to deposit in the bone, thyroid, kidney and liver. There may be some rare earths which have not been detected yet. If they exist, they will also deposit in these organs.

In the animal experiments, the Bikini ash was given to the animals with the food and also by the hypodermic injection and then their auto-radiograph was taken. The result is the same as that of Table 2. Especially, the deposit is found to be the largest in the bone. This is very important in connection with the problem of prognosis of the patients.

The result up to March 26 of quantitative analysis making use of the radioactivity of these elements is shown in Table 3. (Kimura Lab.) To our slight relief in this unfortunate accident, more than 50% of the radioactivity is found in the rare earths while the amount of Sr^{90} is only of the order of 0.02%. The radioactive elements are absorbed in various ways through the digestive organ, respiratory organ, skin, etc. The rate of absorption of course depends on the elements and the chemical compounds which they form.

3. Clinical Problems:

Injury of patients of the Bikini accident has been caused by the radiation of the fallout in contrast to the atomic bomb injury at Hiroshima and Nagasaki. In the former, the injury is caused either by the irradiation of β- and γ- rays of fission products located outside or on the surface of the body or by the irradiation of special organs such as the bone, thyroid, kidney, and liver in which the fission products are deposited by means of absorption through the respiratory organ, digestive organ, skin, etc. In the latter, the main cause of the (radiation) injury is the exposure to the initial nuclear radiation though there may be some effects of the induced radiation from inside and outside of the body. Thus the characteristic danger of the Bikini ash lies in the fact that the fission products deposit in such organs as the bone, thyroid, kidney, and liver; irradiate them, and moreover, are difficult to take out of these organs.

To understand better the effect of radiation on the living body, we shall first see what reaction will happen when the energy of the β - or γ - ray is absorbed by a cell, which is a unit of the life. In general the living body contains a lot of water which will be ionized by the radiation yielding the free radicals like H^+ and OH^- or the harmful molecules like H_2O_2. If this happens, the function of cells is damaged and such a biological change follows as the destruction of

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chromosome, the change of permeability of the cell membrane, the suppression of cell-division, the decrease of leucocyte, the induction of the boil, death, etc.

One of the most important facts about the biological effect of radiation is known as the law of Tribondeau-Bergony which asserts that the cell is most sensitive to the radiation when it is young and has the tendency of cell-division. For instance, in the human body, blood-producing organs (bone, spleen, lymphatic, etc.) and genital cells are most likely to be injured by radiation.

The injury of radiation from outside of the body may be classified into two categories. One is caused by the β- ray of fission products adhered to the skin. In this case, the skin turns to black, gives rise to bleb or fester, and the hair may be lost from the head. In fact, hands and faces of two patients who entered the Tokyo University Hospital on March 15 were black and had festers at some places. It was found by a Geiger counter that the radioactivity was strong at the head, ears, neck, armpits, abdomen, sole, parts of hands or feet between the fingers or toes. The result of measurement by the miliroentgenometer (distance 5 cm) is given in Table 4. The radioautograph of the hair is shown in Fig. 3.

The other is caused by the γ - rays of radioactive substances adhered to the deck, cabin, fishing implements, clothes, etc. Since the γ- ray has a large penetrating power, it will irradiate the whole body and cause the change of blood (decrease of leucocyte), recurrent anemia, depilation, injury to the genital cells, hereditary change, etc.

As is well-known, we are incessantly exposed to the cosmic-ray from the sky and the radiation of natural radioactive substances like radium and radon from the earth. Nevertheless, we are not injured by these radiations, not to a visible extent at least. This is due to the fact that even the exposure on successive days has no damage if the amount of irradiation is less than a certain limit. The maximum amount which the human body can tolerate is called the permissible dose. The international society of radiology determined that the permissible dose is 300 miliroentgen per week. People living on a boat are exposed to the radiation at any time so that the permissible dose is 1.8 mr per hour. The intensity of radiation on the Fukuryu Maru measured at Yaizu on March 17 was $10 \sim 100$ mr per hour which was $5 \sim 50$ times the permissible dose.

In Table 5, it is shown how the intensity of radiation changes from place to place in the boat and how it changes with time. It is seen that on the average the intensity decreased to about $20 \sim 30$ % of the value of March 17 during the period of a month. If one estimates the intensity of radiation on March 2 from the damping curve, it is about 50 times larger than that of March 17. Several hours after the ash began to come down many fishermen felt sick and some vomited. This is the so-called

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radiation crapulence. The estimated dose of radiation the fishermen received during the following two weeks is about 200 r. It is therefore not amazing that the bone and other organs suffered considerable injuries.

Next, we shall discuss the most important problem, namely, the deposit of the radioactivity in the body.

The outline of this problem was given already when we referred to the chemical analysis of the ash. We shall therefore begin here with the survey of the animal experiments. The radioactive deposits in various organs of mice are measured 12 hours and 48 hours after they were fed with the Bikini ash (fission products)(Tables 6 and 7 respectively). It is thus found that, though most part passes by the digestive organs, some part is absorbed and deposits selectively in the bone, thyroid, kidney, and liver (Table 8). When the fission product is given to the mice by hypodermic injection, it is found to deposit in the bone, thyroid, kidney, and liver in the same way as above and excreted through the digestive organs and with the urine (Table 9).

As to the patients, the radioactivity of the urine (15 cc) collected in a ________ tube at the early dates was measured and the number of counts was found to be several times the background counting. The same result is obtained for the concentrated urine. These are the evidences for the deposit of the radioactivity in the patient's body.

The radioactivity was also measured by a scintillation counter placed near the thyroid. In one case, the count was 8 times that of the background on March 26 (see Fig. 4) and 2 times on April 13. From the half-life and the absorption curve of the γ-ray, it is presumed that I^{131} deposited in the thyroid. Similar conclusion is arrived at for other patients, too.

On the basis of the fundamental observation described above, we shall discuss the clinical symptoms.

It is convenient to cite the following statement published on April 14 by the clinical subcommittee of the Council for the Investigation of the Atomic Bomb Sickness of the Department of Public Welfare in the names of Yoshio ________, the Director of Tokyo University Hospital, and Shigenobu Kuriyama, the Vice Director of the First State Hospital of Tokyo:

> "On March 28, five of the patients of Bikini accident entered the Tokyo University Hospital (seven in all because two patients had been there already) and 16 patients entered the First State Hospital of Tokyo. Though the degree of injury varied from person to person, all of them were found to be the patients of the acute radiation sickness due to the radioactive ashes.
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> "The radioactivity inside and outside of the body was considerably high at the time of their entrance to the hospitals. But it decreased later on by an appropriate treatment. The content of

radioactivity in the patient's urine has also been reduced very much by now.

"The symptoms may be described separately for the external injuries to the body surface and the injuries to the organs, especially the blood producing organs.

"All patients suffered on the head and the upper half of the body such external injuries as the depilation, deposit of pigment, inflammation of the skin, ulcer, eruption with abcess and scab, and blister. They are recovering from these injuries by the treatment in the hospitals. But some of them are still suffering from the depilation in wide area.

"The injury to blood-producing organs was observed as the decrease of blood count of leucocyte, granulocyte and red blood corpuscles as well as the decrease of the number of cells in the marrow. It was getting worse since they were hospitalized. Especially, the blood count of leucocyte fluctuated around 1000 per cubic milimeter and the number of marrow cells has been of the order of 10,000 per cubic milimeter in several cases. It was thus hematologically diagnosed to be the general acute sickness of the marrow.

"In these cases, in spite of the ample blood transfusion and the use of pills for blood-production, the blood count of the leucocyte and granulocyte did not increase and even the hemorrhagic tendency appeared. Furthermore, their temperature had been as high as $39^{\circ}C$ though very effective pills of antibiotic ______ had been given, which has made us fear of an unfavorable prognosis. Such a dangerous condition continued until recently and we had to refrain from publishing the facts in order to avoid undesirable effects on the treatment of the patients. Fortunately, however, the fever began to leave the patients very recently and moreover the blood count of leucocyte in some of the serious cases began to increase. We are working hard to cure the patients completely. It would be our duty and also the hope of all people to save the lives of all patients of this unfortunate accident."

Summarizing the clinical symptoms, it may be said that the skin burn by the β - ray has almost been cured. There is now hardly any detectable radioactivity remaining on the skin surface. The most serious problem is the injury to the marrow. Two causes may be responsible for this. One is the radiation (especially the γ-ray) from outside, and the other is that of the radioactive elements deposited in the body. The clinical symptoms observed up to now may be mainly caused by the former although some part might have been played by the latter too. This may be evident in view of the fact that the estimated radiation to which the fishermen were exposed during the two weeks stay on the boat amounts to 200 r. The intensity of radiation from the elements deposited in the body (especially in the bone) is small compared to the external radiation. But it may give a considerable amount of injury during the long period since it will continuously irradiate the important organ, namely the marrow. It is therefore necessary to observe carefully the clinical development in the future. For this purpose, it is important to measure and analyze the quantity of radioactivity in the urine. The study is now being proceeded from this viewpoint. In order to discharge the fission products deposited in the bones, EDTA(Ethylene diamine tetra acetic acid) can be used which however is not very efficient. It is reported that in an animal experiment about 20% of the substances were discharged when EDTA-Na and EDTA-Ca were applied alternatively in an early stage of deposit. In our case, too, it may be possible, using EDTA, to discharge the fission products several times faster than otherwise. Since EDTA-Na, being poisonous, cannot be used to the human body, we are now trying to use EDTA-Ca.

4. About the Hygienics of the Environment and the Food:

(i) The Boat as the Living Place — As is discussed in the section of the physical properties of the ashes, the half-life of the fission products on the Fukuryu Maru was changing from time to time. It was about 8 days at March 17 and 20 days at April 22. By this time, the intensity also decreased to about 20% of that of March 17. On April 22, the intensity of radiation in the boat ranged from 2 mr/hr to 20 mr/hr. It may not be very long before the intensity becomes less than the permissible dose 1.8 mr/hr. As is seen from Table 5, the measured intensity for γ- ray alone and the total intensity of both β- and γ- rays are not very different. This may be understood as the result of the distance between the measuring instruments and the β- ray sources, the absorption of considerable amount of β- rays by the wooden parts of the boat into which the radioactive substance soaked, and the penetration of extra γ- rays from remote sources through the ceilings and the walls.

The radiation has an effect on the human body through the ionization so that the amount of injury should be measured by the miliroentgenmeter. It is not appropriate to use the GM -counter. The conversion of results from one to the other is not simple either.

There are many boats besides the Fukuryu Maru on which the ash fell when they were making voage several hundred miles off Bikini. The count of radioactivity on these boats varies from hundreds to ten-thousands by the GM-counter. But the intensity is at most 3 mr/hr when measured at a distance of 5 cm by the miliroentgenmeter. Since the intensity at 50 cm is only one-hundredth of the amount at 5 cm, it may have hardly any effect on the human body. The amount of radioactivity on these boats is therefore very small and trivial compared to the case of the Fukuryu Maru. However, if the radioactivity is present at all, it may have a chance of getting into the body through the mouth, skin or lung. Of course, it is better not to be exposed to the radiation, however a bit it is. It is therefore necessary to wash and remove the radioactivity from the boat, clothes and the human body. For reference, the radioautographs of the letters written by the oil which was on the deck of the Kōei Maru and the gloves of the crew are shown in Figure 5.

ii. About the Tuna.

Since different people have different interests in this subject, it involves many intricate problems. I will simply refer to the medical aspect of this problem. The question is then how much of the radioactive ash can be eaten together with the tuna without violating the safety of the human body. This is again not a simple problem. First of all, the ash itself consists of various elements and they are absorbed in the human body at various rates. Even the same element will be absorbed differently according to the form of compounds they constitute. Furthermore, they deposit in various organs such as the bone, kidney, liver and thyroid.

Different elements have different half-lives both physical and biological. To simplify the argument, we shall assume for the moment that the ash consists of only the most dangerous element Sr^{90}. In the usual form of compounds, about 60% of Sr^{90} is absorbed by the body through digestive organs and about 40% deposits in the bones. Its physical half-life is about 20 years, while the biological and effective half-lives are 3.9×10^3 days (about 10 years) and 2.7×10^3 days (about 7.4 years), respectively. It is therefore very difficult to discharge once it deposits in the bones. The permissible dose of deposit in the body is 1 microcurie. Since 40% of the absorbed strontium deposits in the bones, it is dangerous to eat more than 2.5 microcuries. It is not unambiguous how much count the radioactivity of 2.5 microcuries will give to the G.M. counter at 10 cm, since it depends on the geometry, measuring instrument, the thickness of the mica window of the G.M. counter, etc. But, roughly speaking, it may be about 5000 ct/min. Since the safety limit adopted today is 100 ct/min at the distance 10 cm, it may be concluded that it is not dangerous at all to eat the tuna though the above calculation is based on several assumptions.

What measure should be taken when the radioactive substance entered the body or one is exposed to the external radiation to such an extent that certain injury is expected? The first thing to do is to have the blood-counting several times. If any anomaly is found, one has to be checked carefully. Next, the radioactivity in the urine should be measured. We shall not discuss it in details here.

iii. Radioactive rain, etc.

Fall of ash, rain and snow with the radioactivity have been observed at several places in Japan. The detail is not available yet. But it may not be dangerous to the human body and others as far as the intensity of natural and artificial radioactivities remains to be of the present order of magnitude.

5. Conclusion. (omitted)