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KAMADA, Masao[1*]

[1]Synchrotron Light Application Center, Saga University, Saga 840-8502, Japan. kamada2013@hotmail.co.jp

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Mini Review

Radiation Effects on Men and Some Personal Histories

Masao KAMADA[1*]

[1*]Synchrotron Light Application Center, Saga University, Saga 840-8502, Japan.
kamada2013@hotmail.co.jp

1. Introduction

Radiographic examination using X-ray Computed Tomography (X-ray CT)[1] and Positron Emission Tomography (PET)[2] and radiation therapies using gamma-rays or ion-beams on various types of cancers have become popular and useful medical treatments. At the same time, the Great East Earthquake and subsequent Tsunami on March 11, 2011 severely damaged the northeastern area (Tohoku and Kanto) of Japan.[3] In particular, the coolant systems of the Fukushima Daiichi Nuclear Power Plant[4] were damaged by the tsunami, resulting in a nuclear emergency: i.e. nuclear meltdowns and releases of radioactive materials. As a result, Japanese citizens have been paying more attention to radiation levels in the environment and to the health effects of ionizing radiation. It is therefore important for us to have precise knowledge about radiation. In this review, basic scientific information about radiation and its effects on humans are briefly described, and I present some personal stories related to the development of the atomic bomb, including the history of a second-generation Japanese-American scientist who contributed to the investigation of the radiation effects of the atomic bombings of Hiroshima and Nagasaki.

2. Important Concepts and Units

There are several important concepts one must first understand in order to explain the effects of radiation on humans.[5] Firstly, some relevant and useful quantities and units are presented in Table I. Radioactivity was previously based on the activity of 1 gram of radium-226, and was given in a non-SI ("Système International d'unité", i.e. metric) unit, the ***curie*** (*Ci*), named after Marie Curie and Pierre Curie, who discovered Radium in 1898. Radioactivity is now given in a so-called "SI derived unit" (i.e., derived from SI base units) called the ***becquerel*** (*Bq*).[6] One *Bq* is defined as the amount of radioactivity of a material in which one nucleus decays per second. One *Bq* has dimensions of sec^{-1}, and is equivalent to 2.7×10^{-11} *Ci*.

Radiation reacts directly with the constituent molecules of DNA or produces reactive radicals in cells, which then react with the DNA. These direct and indirect reactions break DNA bonds, causing radiation effects on humans. These radiation effects are sensitive not only to the absorbed dose of radiation, but also to the degree of biological sensitivity of the living body to the absorbed radiation. The absorbed dose is represented by a physical quantity, the ***gray*** (*Gy*). Specifically, one *Gy* of absorbed dose is

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Table I. Important quantities and units for radiation effects.[5-12]

Quantity	Name (symbol, unit)	Meaning	Old Unit (symbol)
Radioactivity	*Becquerel (Bq, sec^{-1})*	Decay per second	*curie (Ci)*
Exposure	*Coulomb/kg (C/kg)*	Ionization per 1 kg air	*roentgen (R)*
Absorbed Dose	*Gray (Gy, joule/kg)*	Absorbed energy per 1 kg	*rad*
Equivalent Dose	*Sievert (Sv, joule/kg)*	Deposited energy per 1 kg	*rem*

defined as the absorption of one joule of radiation energy by one kilogram of matter. The biological sensitivity (or **Q-factors**) depends on the type and energy of the radiation as well as the location and size of the organs or tissues involved. The total radiation effects on humans including both the physical and biological effects are represented by the so-called "equivalent dose" which is given in the SI derived unit, **sievert** (*Sv*).[7] One **sievert** corresponds to the deposition of one **joule** of radiation energy per **kilogram** of human tissue. One *Sv* has the dimensions of *joule/kilogram*. Therefore, the **equivalent dose** (*Sv*) is equal to the **Q-factors** times the **absorbed dose** (*Gy*). Prior, and still occasionally seen, units for the absorbed dose and equivalent dose are the *rad* and *rem*, respectively, and they can be converted to the SI derived units: 1 *rad*=0.01 *Gy* and 1 *rem* = 0.01 *Sv*.

3. Radiation effects on men

Table II shows radiation effects on humans in the old unit, the *rem*.[5,8] When a person receives an equivalent dose below 200 rem (2 Sv), it can induce many effects on their health: i.e. it can cause changes in blood chemistry, nausea, fatigue, vomiting, diarrhea, amongst others. Doses higher than 200 rem (2 Sv) may cause even more serious results, such as internal hemorrhage, destruction of the gastrointestinal tract, damage to central nervous system, loss of consciousness, and death.. The equivalent dose is designed by the International Commission on Radiological Protection (ICRP) to be a "limiting quantity": i.e. it measures stochastic risk such as to keep unacceptable damage and reactions within statistically low limits. The equivalent dose is calculated by multiplying the absorbed energy by the biological Q-factors over the affected organs or tissues as well as by summing over all types of radiation. The term rem for the unit of equivalent dose originated from the abbreviation of "roentgen equivalent on man",[9,10] or "roentgen equivalent man, mouse, or mammal"[11].

4. Atomic bombardments on Hiroshima and Nagasaki

A number of new concepts and units had been born in the radiation fields, but there were still difficulties in calculating the equivalent dose for real health effects since the measured data on experimental animals and clinical trial data on human patients were insufficient to make the data applicable for all humans. Further developments were made during the 1950s after World War II.[12] This history indicates that radiation science and medical applications were developed and established in the close relation to the atomic bombardments on Hiroshima and Nagasaki in 1945.[13] The U.S Air Force

Table II. Radiation effects at different equivalent doses for humans.[5,8]

Dose (rem)	Health Effects	Incidence of death
0-100	Possible chromosomal damage, some blood-cell destruction	None
100-200	Decrease in white blood-cell, vomiting, diarrhea, fatigue, reduction in resistance to infection	None
200-600	Severe decrease of white blood-cell, internal hemorrhage, infection, loss of hair, marrow and intestinal destruction	0-80% within 2 months
600-1000	Acute illness, early death	80-100% within 2 months
1000-5000	Damage in gastrointestinal tract, early death in days	Nearly 100% within 2 weeks
5000 and above	Damage in central nervous system, convulsions, loss of consciousness	100% within 2 days

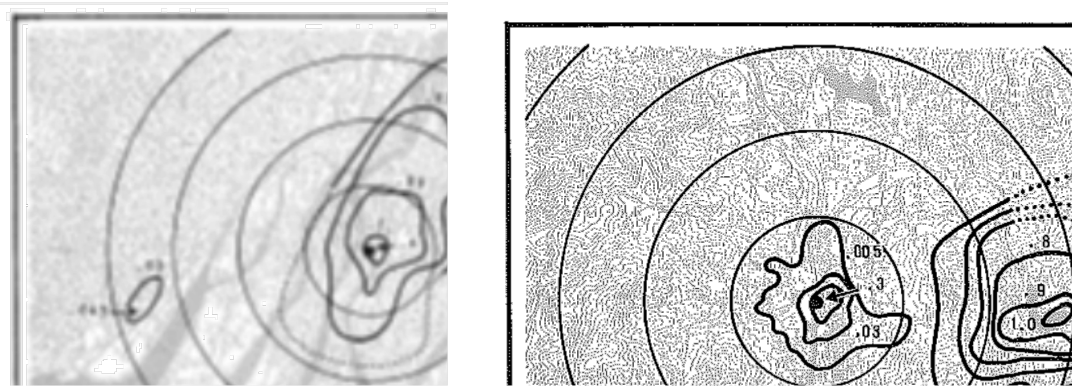

Figure 1. Isodose contour of residual radiations evaluated in milliroentgens per hour on October 3-7, 1945.[14] Left is Hiroshima and right is Nagasaki.

dropped a uranium-type atomic bomb (Little Boy) on Hiroshima on August 6, 1945 and a plutonium-type atomic bomb (Fat Man) on the city of Nagasaki on August 9, 1945. The atomic bombings killed 90,000–146,000 people in Hiroshima and 39,000–80,000 in Nagasaki, and more than 460,000 survivors suffered after-effects from the bombings. Just after the end of World War II, the Atomic Bomb Casualty Commission in Japan (ABCC) investigated the effects of radiation on exposed areas (of the body). Figure 1 shows the levels of residual radiation which were investigated by ABCC for Hiroshima and Nagasaki. The radiation dosimetry and residual radioactivity were reported by E. T. Arakawa[14,15], and the examination of A-Bomb survivors exposed to fallout in "black rain" was reported by H. Yamada and T. D. Jones[16]. It was supposed that the large amount of data collected from Japanese victims and survivors would be useful in establishing quantitatively the effects of radiation on humans, although there was severe criticism of the investigation at the time.

5. Personal histories concerning the atomic bomb

Albert Einstein[17] signed a letter to President Roosevelt recommending that the U.S. seek to make atom bombs so as to stay ahead of Hitler, but a year before his death, Einstein said, "I made one great mistake in my life—when I signed the letter." J. Robert Oppenheimer[18] became the head of Los Alamos Laboratory and led the wartime effort at the Manhattan Project to make the atomic bombs. After the war, however, he wanted to stop the nuclear arms race but was effectively stripped of his direct political influence.

One group of young women from Oak Ridge, Tennessee, USA unwittingly played a crucial role in the making of the bomb, and their story was recently told on a Japanese TV in a program entitled "Girls of Atomic City".[19,20] These young women were responsible for precisely operating the thermal control machines used to concentrate the Uranium-235 that was used in the bombs. They were not informed of the

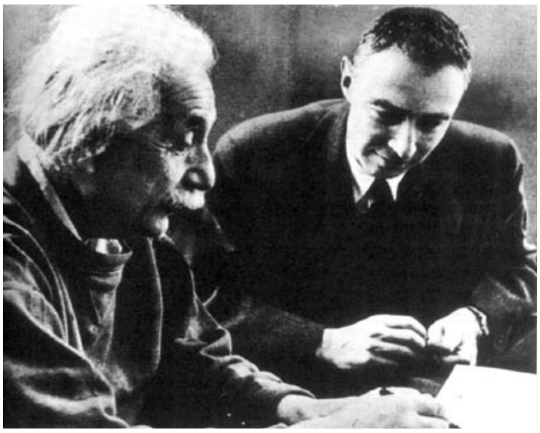

Fig.2. Einstein and Oppenheimer circa 1950[18]

Fig.3. Young women operating calutron, the heart of the uranium electromagnetic separation process, at Y-12 plant in Oak Ridge, Tennessee. (in a US government photo by Ed Westcott).[19,20]

purpose of their efforts nor of the workings of the machines they were using. Though they were happy in those days, some became nervous and deeply regretful after being informed of the true objective of the project.

Lastly, I would like to make note of the experience of Dr. Arakawa, who as mentioned above, studied and reported on the levels of residual radiation and the effects of radiation on survivors of the Hiroshima and Nagasaki bombings. He was a second-generation Japanese-American scientist living in America at the time of the war. Prior to the war, many Japanese immigrated to North and South America. However, because Japan was an enemy country during World War II, almost all Japanese-Americans were sent to concentration (internment) camps and their property was confiscated. Many suffered severe discrimination even after the war was over.[21] In spite of this severe anti-Japanese sentiment, Dr. Arakawa was able to study hard and become a very important radiation scientist at Oak Ridge National Laboratory. He was the member of the ABCC assigned to investigate the radiation effects of the A-bomb in Hiroshima and Nagasaki. Hiroshima was the birth place of his father. However, he himself only saw the ruins of the city, which had been almost completely destroyed. Since he was a radiation scientist, he knew not only the science behind nuclear weapons, but also realized in a personal way the effects of radiation on humans, due to the bombing of his father's hometown, Hiroshima. It is understandable that he might have had no words for such cruel reality. In fact, he never told this story during his life. He was a religious christian, and was a chorus member in his church known for his melodious voice.

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