The Atomic Bombings of Hiroshima and Nagasaki: A Summary of the Human Consequences, 1945-2018, and Lessons for Homo sapiens to End the Nuclear Weapon Age

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ABSTRACT
Seventy-four years have passed since the atomic bombings of Hiroshima and Nagasaki. Approximately 210,000 victims died, and another 210,000 people survived. The damage to their health has continued, consisting of three phases of late effects: the appearance of leukemia, the first malignant disease, in 1949; an intermediate phase entailing the development of many types of cancer; and a final phase of lifelong cancers for hibakusha who experienced the bombing as a child, as well as a second wave of leukemia for elderly hibakusha and psychological damage such as depression and post-traumatic stress disorder. Thus, the human consequences of the atomic bombings have not ceased; many people are still dying of radiation-induced malignant diseases. Therefore, it is too early to finalize the total death toll. Hibakusha have faced a never-ending struggle to regenerate their lives and families under the fear of disease. As the only group of Homo sapiens experiencing real nuclear attacks, hibakusha have continued to engage in a lifelong movement to eliminate nuclear weapons. Political leaders, especially of nuclear-weapon states, must learn the wisdom of the hibakusha to save Homo sapiens from possible global extinction by nuclear war.

Introduction
The first nuclear weapon was detonated in New Mexico on 16 July 1945. That test explosion was soon followed by the wartime use of two atomic bombs on Hiroshima and Nagasaki on August 6 and 9, respectively. This opened the nuclear weapon age in the history of humanity. In the long history of wars and weapons, Homo sapiens had finally gained an ultimate weapon of mass destruction capable of obliterating itself.

In 1939, President Theodore Roosevelt started an early-stage nuclear weapon development program – that would eventually become Manhattan Project – by agreeing with Albert Einstein’s letter to suggest making atomic bombs earlier than the Nazis.

The nuclear weapons were made by the knowledge of a group of eminent nuclear physicists, including winners of the Nobel Prize in Physics such as Enrico Fermi. The US
government started the Manhattan Project in high secrecy. President Harry Truman ordered the bombs to be dropped on Japan in 1945.

Seventy-one years later, President Barack Obama visited Hiroshima in 2016 as the first sitting US President to commemorate atomic-bomb victims and gave an address at Peace Memorial Park. In his speech, Obama asserted that the human wisdom of science had created the nuclear bombs, but humanity had not yet succeeded in creating the ethical wisdom to abandon nuclear weapons (Obama 2016).

On 7 July 2017, 122 member states adopted the Treaty on the Prohibition of Nuclear Weapons at the United Nations. Humanity has demonstrated great wisdom to create the first treaty of its kind. However, all nine of the nuclear-armed states and their allied nations, including Japan, declared that they opposed and would not sign the treaty. *Homo sapiens* remains unable to create the prospect of a nuclear-weapon-free world.

This paper chronologically summarizes the human consequences of the atomic bombings beginning from the immediate death followed by subsequent death within three months, then an earliest appearing late effect manifesting as leukemia which was first malignancy, and further followed by many solid cancers as a long-lasting delayed effect until the present, and psychological damage covering the whole lives of the atomic-bomb survivors, called *hibakusha* in Japanese.

The human consequences of the two atomic bombings are the history of the struggle by the *hibakusha* to survive and regenerate their life and families as well as their cities. On the basis of their experience of these consequences, the *hibakusha* have long been fighting for the elimination of nuclear weapons. They therefore represent the only group in *Homo sapiens* that has experienced the human consequences of the nuclear bombings, which is related to the survival of humanity. This article considers lessons for *Homo sapiens* from Hiroshima and Nagasaki for gaining the wisdom to realize a nuclear-weapon-free world and end the nuclear weapon age.

**Human Decision to Use Two Bombs on Humanity**

The atomic bombs probably were used in combat to end the Pacific War. Nuclear attacks were carried out without any warning and led to indiscriminate killings in both cities. After the bombings, US leaders explained that the two bombs were used just to accelerate the surrender of Imperial Japan to save the lives of several hundred thousand.

US soldiers and even Japanese citizens due to the possible cruel battles on the Japanese mainland (Stimson 1947). After the war, most American citizens believed that the war actually had ended earlier than expected, thus saving many lives. However, many US and Japanese historians now consider that a more important factor for the Japanese Empire’s surrender was the entry of the Soviet Army into the war in Manchuria on 9 August 1945 (Hasegawa 2005). The Japanese Emperor Hirohito eventually announced his surrender on August 15.

Before the bombings, some US military leaders, such as General Dwight D. Eisenhower, then the Commander in Chief of the Allied Forces in European theatre, and some of the nuclear physicists who were involved in the Manhattan Project considered that the bombs should not be used on humanity in the light of overwhelming magnitude of the bombs from ethical point of view (Eisenhower 1963). There had been no documents of the US government or military to evaluate the relationship between
such large detonations and the estimated humanitarian consequences of the bombs before President Truman’s decision was made.

Soon after receiving the first reports on the magnitude of human consequences in both cities, the Japanese government sent a telegram to the US government via the Swiss government to condemn the use of inhumane weapons. Seventy-two years later, the United Nations adopted the Treaty on the Prohibition of Nuclear Weapons based on the humanitarian consequences of the two atomic bombs and other nuclear explosive tests.

**Immediate Death and Early Lethal Consequences of the Bombings**

**Death-rate**

Under the two gigantic mushroom clouds, approximately 280,000 citizens in Hiroshima and 240,000 in Nagasaki were suddenly thrown into chaos and agony. A total of approximately 140,000 in Hiroshima (Hiroshima 1971) and 73,000 in Nagasaki (Nagasaki, 1977) died instantaneously or within five months due to the combined effects of three components of physical energy generated by nuclear fissions: blast wind (pressure), radiant heat, and ionizing radiation. A total of more than 210,000 remaining victims, 140,000 in Hiroshima and 74,000 in Nagasaki, survived the first five months of death and agony and became hibakusha (Figure 1).

A curve of death rates calculated in the aftermath by the surviving medical staff and students of Nagasaki Medical College showed almost 100% in residents living within a 500-meter radius of ground zero; 90% within 1,000 meters; 50% within 1,500 meters;

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**Figure 1.** Two atomic bombs used in war.
and 10% within 2,000 meters, making a clear concentric figure (Figure 2) (Shirabe 2006). Later the death-rate curve of Hiroshima was compared with Nagasaki’s, revealing that two curves were very similar, as if two scientific experiments were conducted. Among areas within 1,000 meters, the Nagasaki Medical School Hospital was exceptional – The death rate in the facility was as low as 43%. This is obviously because of the shielding effect of the thickest concrete walls of the hospital buildings.

The residents of both cities were mostly noncombatant civilians, including many women and children. Military combatants were only a minority. There were fewer adult males than females, and most of the males worked at military arsenals. Many young men went to war in the later stages of World War II. Young students were employed by military arsenals located close to ground zero; that increased the number of victims.

Citizens were suddenly thrown into firestorms at home, factories, and schools; on open roads or on ground; in automobiles and trams; and in city offices, hospitals, pharmacies, fire stations, and almost all city structures.

Many survivors spent the night on the road or the ground (Figure 3). Subsequently, many severely injured victims were forced to remain where they survived the first strike without being provided any meaningful medical treatment. Most of them died there.

As shown in Figures 4, 5 and 6, three types of physical energy from the detonation were estimated by the US Army Manhattan Project Team (Atomic Bomb Disease Institute, Nagasaki University 1995).

In areas within 1 kilometer of ground zero, human bodies without any shielding, namely in open air on the roads and ground, were instantaneously squeezed by the blast wind (pressure) against walls, causing multiple fractures of skeletons and ruptures of the abdominal cavity causing escape of colons. Many people in open roads and grounds were carbonized by the direct effect of heat rays within 1.0 km from ground zero (Figure 7, Photo A). Many residential areas full of Japanese houses were crushed by the wind and burned out in which many victims were also burned to white bones (Figure 7, Photo B).
The skin of people on open roads or grounds within 0.5–1.5 km were deeply flash-burned due to heavy heat rays. The skins were soon peeled off because of necrosis in the deep skin layer (For an example of a boy whose back was entirely burned, see Figure 8). With large areas of skin peeling off, people suffered severe pain and bleeding.

In three months after the bombing, these deep skin flash burns began to heal. However, with tissue being regenerated, keloid was quite often formed as shown in Figure 9. It was characterized by marked thickening of the wounds, sometimes resembling cancerous proliferation of the skin.

Thus many residential areas full of Japanese wooden houses were crushed and burned. The fires that continued over to next day finally flattened city areas within a 4 km radius. According to the saddest memory of some survivors, the blast wind tore off the
heads of babies who were being carried on their mothers’ backs in the traditional Japanese way. Most of the mothers also died soon.

At the same time, the victims were irradiated by 100 grays (Gy)$^1$ or more of combined gamma and neutron rays generated by nuclear fissions (Figure 6). Thus it could be possible to say that they were killed in three ways at once.

The people within 1 km of ground zero who finally survived were mostly those who were working inside a concrete building with thick walls or in a basement. Some other survivors were inside private air-raid shelters or military arsenals set in large shelters. Heat rays were effectively blocked by the walls, and radiation and blast were partially shielded before victims were exposed, thus allowing them to survive. But there were only a few hundred of these people. Many of those who survived at various proximal points

\[1\] A unit of radiation dose in air.
were severely injured by debris and pieces of glass from damaged houses, heated and irradiated simultaneously. Many of them died within the first three months.

**Struggle for Survival**

Medical rescue teams perished and hospitals were all destroyed on the first day of the bombing. It therefore was impossible to find any meaningful medical aid. The situation was much severer in Hiroshima where over 90% of medical staffs, doctors, nurses, and pharmacists were dead. The Nagasaki Medical College Hospital, the largest and strongest concrete buildings in Nagasaki City, located 600 meters from ground zero, did provide fairly good shielding effects; the death rate was a relatively as low as 43%. Subsequently
900 lives in total – approximately half of the total number of professors, doctors, nurses and medical students were lost in the entire college facility including the hospital. Most of those who survived were severely injured by the blast wind and heat ray. The hospital had completely ceased to function. Within a few days, medical staffs and medical students who had survived opened first-aid stations around the margin of flattened areas.

In the late afternoon on the first day, several rescue trucks arrived carrying medical teams consisting of military doctors and nurses from Omura Navy Hospital, located 45 km north of Nagasaki City. They brought back approximately 700 severely injured victims, most of them severely burned, to the hospital and started treatment for burns and injuries consisting of bone fractures, cuts from pieces of glass, and embedding of debris and pieces of glass fragments deep in the skin. This number was very small compared to the total number of victims who suffered severe injuries, estimated to be approximately 30,000 in Nagasaki. A few hundred victims out of 700 were able to survive, thanks to intensive care at Omura Navy Hospital. They were indeed lucky people.

Several small rescue teams started their clinical activities within a few days. Some surgical operations were performed for those who had severe fractures due to the blast wind. There was no good treatment for severe skin burn, especially those cases with wide areas of skin burn. There were no stocks of drugs such as antibiotics and frozen blood plasma. Only oil and ointment were used. Even drip infusions of water and electrolytes such as salts and glucose (sugar) were not available in such small ambulatory facilities.

As a result of this lack of care, many survivors who were alive on the first and second days began to die due to severe bleeding from injuries such as severe fractures,
dislocations, abdominal ruptures, thoracic punctures, and scalp and brain damage and also from dehydration and lack of adequate food supplies.

**Initial Difficulty in Recognizing Radiation Effects**

In the early days after the atomic bombings, many doctors had difficulty in identifying the symptoms of radiation-related ailments. There was no information about the nature of this new type of bomb. They did not even know that the bombs were nuclear and that radiation was dangerous to human beings. This difficulty was resolved after several weeks by autopsy studies by US and Japanese pathologists, but it was too late for the early victims. As mentioned above, short-distance victims suffered various combinations of three major physical effects of the detonations. After doctors gained information about the radiation hazards associated with the atomic bomb, they began to use Japanese medical terms *genbaku-shou* (atomic-bomb symptoms), or *genshi-byou* (atomic disease), as a diagnosis for the severest condition seen among victims. This vague diagnosis limited efficient medical treatment for survivors with multiple clinical problems, as mentioned above. However, medical and pathological research done by academic groups gradually separated several symptoms and signs into different categories of disorders. It became apparent that the result of radiation-induced cellular damage in several organs was responsible for the major symptoms and signs described below; the most severely affected organs were bone marrow and intestinal mucosa as shown in Figure 10. Normal bone marrow is full of blood-forming cells as black-stained cells (above right), while heavily irradiated bone marrow is characterized by the eradication of blood forming cells replaced with fat and white-stained cells (above left). Normal colon is with many folds (below right), while colon exposed to radiation is flattened with some bleeding (below left). These pathological findings led to a clear recognition of acute radiation sickness or acute radiation syndrome (ARS), which is now used formally as a diagnosis for radiation victims in the field of nuclear or radiation accidents such as the Chernobyl accident.

Although most doctors did not clearly recognize that hair loss was the result of profound radiation effects, all doctors and even the victims themselves began to recognize that the beginning of hair loss was the most peculiar common symptom recognized by *hibakusha* themselves and, importantly, the earliest sign indicating that death would soon follow (Figure 11). Therefore, appearance of hair loss became the most horrifying sign for *hibakusha*. Every morning they tried to pull their hair to confirm it was intact.

Other than hair loss, major symptoms and signs are as described below.

**Purpura (Skin Blood Spot)**

Many survivors who became seriously ill after a few days and weeks began to suffer skin problems (bleeding known as “purpura”). In addition, mucosal bleeding from the oral cavity and gingiva and intestine caused bloody saliva and bloody diarrhea.

**High Fever**

A fever of 39–42°C was quite frequently observed. This symptom, which started within a week in many survivors, was accompanied by shivering and marked sweating. This sign made doctors think of bacterial infections, such as typhoid fever, pneumonia, and sepsis
in the severest cases. Later, high fever was recognized as a consequence of radiation-induced bone-marrow damage causing bone-marrow failure. This appeared as a rapid decline of the white-blood-cell count, which directly led to bacterial invasion through damaged wounds. The most important protection against bacterial invasions is white blood cells. (“neutrophils” is the medical term for the cells.) The disappearance of neutrophils from the blood allowed bacterial infections to become severe and subsequent death. A great number of people died because of infections. In such victims with high fever, the white-blood-cell sometimes fell below 1,000/mm$^3$, which is only 20% or less of normal counts.

Most victims of high-grade ARS suffer simultaneously from bacterial infections. Thus, the early diagnostic difficulty was clearly explained within a few months based on the concept of ARS. However, doctors were not yet able to use antibiotics, except a few samples of penicillin supply by Allied medical doctors for selected cases such as severe and wide-area skin burn.

**Bloody Diarrhea**
This symptom first started as simple diarrhea as early as a week after the bombing but soon was exacerbated by bloody stool. This symptom persisted for several weeks, leading
to a rapid deterioration in general condition, especially emaciation due to nutritional deficiency, dehydration, and anemia. This condition made doctors think of typhoid fever or other intestinal bacterial infections, which were seen fairly frequently among citizens living in poor sanitary conditions during wartime. Lack of antibiotics often led to lethal consequence among diarrhea cases.

**Combined Manifestations as ARS**
Diarrhea with bloody stool, skin burn with peeling and bleeding, high fever, and tissue necrosis often appearing in the oral cavity and throat were usually seen in various degrees of severity and combinations. Skin also showed bloody spots with a purple color (purpura). Survivors were severely dehydrated and thus felt a strong thirst, but they never were able to relieve it by drinking water because their intestinal-wall mucosa was destroyed by ARS (Figure 10) and could not absorb water at all.

**Drug Supply**
Within a few weeks of the bombing, items such as plasma and frozen plasma, drip infusion bags of water and electrolytes, and antibiotics began to be supplied. Victims, especially young men and women, who survived until early September began to show a rapid recovery. The restoration of a good food supply further accelerated their recovery. The rapid increase in the number of deaths in the early phase finally began.
to cease after mid-September, a month after the bombing. However, the severely injured, especially the elderly, continued to die. The total number of dead victims reached approximately 140,000 in Hiroshima and 73,000 in Nagasaki by the end of 1945.

**Hibakusha Who Finally Survived**

Medical care and social care for *hibakusha* were severely lacking in the first few months after the bombings but began to progress gradually, along with Japan’s broader recovery from the chaos caused by the surrender. Research on the human consequences of the bombing started in the second year after the bombing.

About three months after the bombing, the number of deaths among victims began to show a considerable decrease. The health of the victims recovered rapidly. However, due to the economic collapse and food shortage after Japan’s surrender, regeneration of city activities was still slow. It took almost five years for the Japanese economy to return to its prewar level. After the Korean War broke out in 1950, the Japanese economy, including the cities that were the targets of the atomic bomb, was dramatically activated by industrial regeneration as a result of war procurement.

After 1950, medical consequences were chronologically analyzed and the results of analysis were reported regularly by the cooperative efforts of Nagasaki University Medical School, Hiroshima University Medical School, the former Atomic Bomb Casualty Commission – now the Radiation Effects Research Foundation – and Municipal Centers for Survivors’ Health and Care.

Survivors gradually began to call themselves *hibakusha*. City officers, medical doctors, and ordinary citizens also began to use that term.

**Psychological Numbness**

During the five years after the bombings, there had often been observed among atomic-bomb survivors of both cities who were of working age an apparent emotional numbness typically seen as a loss of willingness to work. Even young survivors who were fortunate to have jobs in the social confusion of post-surrender Japan could not work well every day; some of them were laid off or fired. This mental condition was analyzed by psychiatrists at Nagasaki Medical College. They named this specific phenomenon as *genbaku bura-bura byo* (atomic-bomb numbness syndrome). Doctors believed that this numbness was a result of psychological damage, similar to what is now understood as post-traumatic stress disorder (PTSD). Experiencing disaster on an overwhelming scale, damage to their own bodies, the death of family members, and the feeling of nearness to death might have induced this syndrome.

In Hiroshima, US psychiatrist Dr. Jay Lifton conducted an intensive psychological survey on the emotional condition of atomic-bomb victims. They saw so many people dying in agony and screaming for help and asking for a sip of water. But they had to ignore them for their own survival. Their psychological damage was so severe that almost all the survivors encountered the negative feeling of “we are also dead although still alive.” They also felt that “We lost our humanity; we committed a sin.” Dr. Lifton named this negative frame of mind “death in life” (Lifton 1991).
It took many years for *hibakusha* with a sense of guilt to recover. But such a feeling occasionally returns repeatedly, causing a depressive state of mind, as mentioned below.

**Studies on Immediate Effects of the Atomic Bombings**

A medical and physical survey on the immediate effects of atomic bombings by the Japan Academy of Science and a joint research team of the US Army and Navy had started as large-scale official investigations in mid-September, almost one month after the bombings (Barnett 1946; Oughterson and Warren 1956).

The US research team entered Nagasaki first and then Hiroshima. It consisted of military doctors, pathologists, and physicists specializing in nuclear physics and radiology. Japanese doctors and medical students cooperated in medical interviews of *hibakusha*. Pathologists, especially Japanese pathologists, performed many autopsies. The pathological examinations greatly facilitated the study of what happened deep inside the organs of the victims.

Organs obtained through the autopsies were later transferred to the US Armed Forces Institute of Pathology in Washington, DC, and further analyzed, providing many important findings on the acute effects of high-dose radiation. These studies firmly established the medical concept of ARS. The organs were returned to Hiroshima University and Nagasaki University in the early 1970s for further research.

**Radiation Dosimetry by the Atomic Bomb Casualty Commission**

US Army Manhattan Engineer District did not provide the US joint research team with radiation-dose data that would allow radiation-related medical consequences such as hair loss, bone marrow damage, and colon damage to be analyzed on the basis of the victims’ distance from ground zero. It was hypothesized that the distance is inversely proportional to radiation dose: the shorter the distance from ground zero, the larger the radiation dose to each *hibakusha*.

Later, in 1965, the first formal dosimetry system, named DS65 was developed by the Atomic Bomb Casualty Commission (ABCC), which had been established in 1947 by President Truman for studying the long-term influence of atomic-bomb radiation on humans. DS65 was further improved and revised in 1985, named DS85. The most recent dosimetry system is DS02, which was revised in 2002 (Young and Kerr 2005).

Presently, all statistical analysis of delayed effects of the atomic bombing is based on DS02, which is believed to be the most precise one, although there is still some ambiguity in the radiation dose, such as uncertainties due to radioactive fallout and internal exposure by inhaled radionuclides. The DS02 dose by distance from ground zero to 2,500 meter is shown in Table 1. Dose of gamma rays and neutron rays is shown separately.

Based on these dosimetry systems, it became possible to estimate an exposure dose for each *hibakusha* based on the distance from ground zero, and to correct it further by shielding effect obtained from intensive interview on how he or she was exposed to radiation. For example, the shielding effect from thick concrete walls was fairly large. These individualized dose estimates are considered the most precise to date.

There is also another dosimetry system, called biological dosimetry. One example of this is the electron-spin resonance method applied to survivors’ extracted teeth. This allows direct measurement of the dose at the enamel layer of a tooth, which represents the
dose of a given hibakusha at the time of bombings. Data from this electron-spin resonance method have been compared with DS02 data. The two sets of data matched fairly well. Therefore, it is considered scientifically reasonable to statistically analyze all observed disease incidences according to the DS02 although there still remains some small statistical ambiguity, as described above.

Residual Radiation and Internal Radiation

The most important factor that affects bodily injury by radiation is the distance from ground zero. The radiation emitted within one minute of nuclear fission constitutes over 90% of the total dose emitted. This hits hibakusha bodies directly as external exposure. However, there also exists residual radiation from the fallout of radionuclides as fission products that have fallen from the sky after an atomic explosion more than 500 meters above the ground. These radionuclides include cesium-134, strontium-90, plutonium-239, and many others. The fallout emitted gamma rays, beta rays, and/or alpha rays on the ground. The effects of residual radiation on the human body are still ill-defined, and it remains difficult to reproduce measurements scientifically. So this is the reason for some ambiguity in the total understanding of atomic-bombing effects.

An additional factor in radiation exposure by nuclear fission is induced radiation by neutrons. The total amount of neutron emitted from the atomic bombs was fairly large. Therefore, the total dose of neutrons to each hibakusha was carefully estimated in DS65, DS86, and DS02. Induced radiation from various materials, mainly metals and stones by neutron exposure, is another component of radiation exposure to human bodies, especially in the first 24 hours after the explosion. This component has not been officially estimated, especially in individual hibakusha and those people who entered areas near ground zero soon after the bombing for rescue activities or searches for family members. It is hypothesized at this moment that the magnitude of this component is so small that each DS can ignore its human effects.

The final radiation-exposure pattern is internal radiation due to radionuclides such as plutonium in the case of Nagasaki bomb. As one element of the fallout, unfissiooned plutonium fell and was spread over soil by wind currents and remained there for a long time. The half-life of plutonium is amazingly long, 24,100 years in case of Pu-239. Subsequently, an intensive survey of plutonium in the soil was conducted in the 1970s in the suburbs of Nagasaki City. Plutonium particles were found in areas from 10 to

| Distance from Hypocenter (m) | Slant Distance from Epicenter (m) | Gamma Rays (Gy) | Neutrons (Gy) |
|-----------------------------|----------------------------------|-----------------|---------------|
| 0                           | Hiroshima                        | 90              | 120           | 34.5          |
|                             | Nagasaki                         | 502             | 328           | 18.8          |
| 500                         | Hiroshima                        | 780             | 35.7          | 6.48          |
|                             | Nagasaki                         | 709             | 83.0          | 2.97          |
| 1,000                       | Hiroshima                        | 1,166           | 4.2200        | 0.26          |
|                             | Nagasaki                         | 1,119           | 8.6200        | 0.125         |
| 1,500                       | Hiroshima                        | 1,615           | 0.5270        | 0.00904       |
|                             | Nagasaki                         | 1,582           | 0.9830        | 0.00511       |
| 2,000                       | Hiroshima                        | 2,088           | 0.0764        | 0.00039       |
|                             | Nagasaki                         | 2,062           | 0.1380        | 0.00024       |
| 2,500                       | Hiroshima                        | 2,571           | 0.0125        | 0.00002       |
|                             | Nagasaki                         | 2,550           | 0.0228        | 0.00001       |
50 kilometers east of Nagasaki City, but the effect of these particles on the human body is thought to be very small and health effect is thought to be negligible.

There is a possibility that plutonium fallout could have been inhaled by some *hibakusha* in the first few hours after detonations. Plutonium is known to reside in the lungs for a long time. Therefore, there is a possibility that such residual plutonium particles continue to emit alpha rays intermittently and injure lung cells nearby, finally causing lung cancer. This possibility has not been formally confirmed scientifically although a group of Nagasaki University pathologists recently found evidence of plutonium particles remaining in the autopsied lungs and bones obtained from *hibakusha* who died very soon after the bombing (Shichijo et al. 2018). Epidemiological study is not performed yet on the health effect, such as lung cancer, induced by the residual radiation emitted from plutonium.

**The Life Span Study as Official Statistics of Radiation-induced Diseases**

The Life Span Study (LSS), started in 1950 by ABCC (RERF), is an official epidemiological survey based on a population of approximately 100,000 *hibakusha* from Hiroshima and Nagasaki, called the LSS Cohort. All diseases from which each *hibakusha* died were registered to LSS. The public death-certificate system was employed to precisely follow up on the disease leading to death. Disease diagnosis for each case is intensively researched by collecting medical records from any hospitals where *hibakusha* died.

All kinds of malignant diseases are thus surveyed since the beginning of LSS in 1950. Medical statistics on each case of cancer or leukemia are based on LSS, and it is believed that the case detection rate was approximately 100%, covering all cohort members. In addition, dosimetry data are incorporated into this statistical analysis to reveal whether the radiation exposure is inducing leukemia or cancers. Relative risk (RR) is also calculated: The incidence of certain cancers or leukemia among the *hibakusha* group with high-dose exposure is compared to the incidence among *hibakusha* who received doses that were almost negligible (long-distance control group). The final scientific determination of leukemia or cancers induction is made based on the statistically significant elevation of RR with *p*-value less than 0.1. Moreover, the curve for leukemia incidence or cancer incidence increases along with increasing dose as later shown in Figures 12 and 13 in leukemia and cancer sections. Therefore, the cohort and the dosimetry are the most important basis for scientific research on the radiation-induced diseases resulting from the atomic bomb.

**Special Medical Care by Transplantation for Skin Burns and Plastic Surgery for Keloids**

Some young survivors with skin areas, such as the entire back, that were badly burned receive repeated normal autologous skin grafting (transplantations) from unaffected area such as the side of the abdomen. This procedure showed considerable effect on the recovery of skin wounds, especially successful relief of severe infectious contamination (*Figure 8*).

Nutritional support is also very important for survivors who suffer from malnutrition due to severe diarrhea. Food supply was severely deficient in the early days after the bombing, but the food shortage had gradually resolved within a month. Victims with
various wounds and organ disorders showed slow but steady recovery, and their general body condition improved dramatically as their nutrition improved.

The formation of keloids was the most frequently observed abnormal healing process of severe burns due to heat rays on deeply damaged skin (Figure 9). During a healing process from a few months to years, abnormal hyperplasia\textsuperscript{2} caused eventual thickening, 0.5–3.0 cm, somehow resembling cancerous tissue. Patients with keloids complained of an itchy sensation. After several decades, keloids become flattened, suggesting that the hyperplasia has subsided, denying cancerous nature. Medical research has not clearly

\textsuperscript{2}Hyperplasia is an excess reaction of cell growth of wound tissue consisting of thick layer of fibrocytes, which are major cell component of connective tissue surrounding primary skin epithelial cells.
explained why keloids were formed so often. It is speculated that radiation exposure plus heat ray exposure might have induced an unusual healing process leading to extensive skin thickening.

Many girls with severe keloids on their face experienced difficulty in finding partners for aesthetic reasons, as well as anxiety caused by high-dose exposure that might lead to malformations of babies in the future. From Hiroshima and Nagasaki, 25 young women with facial keloids were invited to US hospitals in 1955 by a group of US citizens for treatment with plastic surgery. With regard to aesthetic improvement, the results varied from one case to another. However, many of the women gained considerable improvement in the movement of their eyelids and mouth. This made speaking and swallowing much easier.

Late Effects of Atomic Bombings: 1948–2018

About 270,000 victims of Hiroshima and Nagasaki finally recovered their health. They had to start their new daily life with a serious shortage of food and other necessities. After spending three years of recovery with relatively good health, hibakusha encountered the first malignant disease: leukemia. It is classified as the earliest occurring malignant disease due to atomic-bomb radiation because it was clearly distinguished from the disorders caused by ARS. Therefore, leukemia was the first malignant disease derived from cells injured by initial radiation exposure; the cells then transformed to malignant leukemia cells. This earliest delayed, or “late”, effect was followed by many kinds of cancer of various organs. Thus, the late effect spans an extremely long period.

First Malignant Disease Observed as the Earliest Late Effect of Atomic Bombings

Leukemias

In 1949, doctors in Hiroshima and Nagasaki began to recognize a gradual increase in the number of hibakusha patients, including children, suffering from leukemia. The excess annual rate of leukemia continued to rise until 1955 and then continued at an elevated level for more than 10 years (Figure 12) (Gunz and Henderson 1974). Acute and chronic types of leukemia both were observed. These leukemias were later analyzed in detail when the first dosimetry system (DS65) became available. A clear radiation-dose dependency was revealed as a curve that elevated exponentially (called quadratic) from 100 milli-sieverts (mSv) at around 2.0 km from ground zero to more than 4 Gy at around 1.0 km (Figure 13). Dose is thus inversely proportional to the square of the distance. Total leukemia incidence was four to five times higher than the control group of Nagasaki citizens not exposed to the bombing (Preston et al. 1996).

From around 1955 to 1970, the excess rate of leukemia gradually declined. However, even around 2003, the number of leukemia case was still slightly higher among proximally exposed survivors (2 km or less) than distant survivors (2–8 km) (Preston et al. 2003). During the post-bombing period of 60 years, the statistics showed that about 300 victims actually died of leukemia out of the LSS cohort group of 100,000.

Moreover, recent epidemiological studies clearly showed that the risk of a specific type of leukemia that typically occurs among the elderly, called myelodysplastic syndromes (MDS), is three times higher among people who were at a short distance from the
bombing and therefore received a high dose of radiation. (Iwanaga et al. 2011). MDS, a disease that was identified in the mid-1980s, is characterized by anemia and a reduced number of neutrophils and platelets without the massive growth of immature blood cells typical of acute leukemia. The disease generally occurs in elderly population.

People who were children under the age of 10 at the time of the bombings are now in their seventies. Some of them suffer from MDS. The increase in MDS among childhood survivors indicates that the massive irradiation of the whole body injured blood cells in bone marrow, and that these cells have survived more than 70 years in the bodies of hibakusha, and finally resulted in leukemia-inducing gene abnormality. MDS patients occasionally develop acute leukemia 3–5 years after the first diagnosis, and mostly die. Therefore, it can be said that atomic bomb is still killing some hibakusha even after more than a half century.

When leukemia first appeared in the period 1948–1960, its occurrence gradually increased simultaneously in children and adults among hibakusha. This is a sharp contrast to the present increase of MDS among elderly hibakusha who were exposed in their childhood, suggesting a complicated mechanism of leukemia induction inside their bodies. Precise gene analysis has not been available regarding most hibakusha cases because the molecular technique was developed only after 1980. Now it has become available with regard to cases who recently have developed leukemia or MDS. New findings will be obtained in the coming decades.

Intermediate to Life-long Delayed Effects of Exposure to Atomic-bomb Radiation

Cancers

Around 1960, the incidence of solid cancers began to rise gradually. The elevated cancer incidence lasted for a long time (Ozasa 2016). It peaked around the year 2000 and remained at that level until now. The types of cancer that appeared include lung, breast, thyroid, stomach, colon, liver, skin, and bladder. Cancers of the pancreas, gall bladder, and uterus, which are all deep-seated organs, have not yet been confirmed as radiation induced. The excess of these cancers was also clearly dependent on the total dose (gamma + neutron) of radiation that the survivors received. As noted above, 100 mGy is considered to be the lowest dose that produces a significant increase in cancer incidence. Figure 14 shows that cancer incidence by combining all types elevates linearly (Pierce et al. 1996). The risk is statistically significant between the range from 100 mGy to 3 Gy. Even in 2018, when the average age of hibakusha reached 82, the increased risk of all the types of cancer listed above still did not show a decline. In other words, the data show a continuing plateau.

Multiple Cancers

Recent epidemiological studies also show a distance-dependent increase in multiple cancers in individual survivors who were within 2 km of the hypocenter. The multiple cancers, namely second and third cancer, are independent of the primary cancer — that is, they are not a result of metastasis of the primary cancer to other organs. Some survivors suffered from three or more cancers, maximally five. Since atomic-bomb victims were usually exposed to radiation in their whole body, development of multiple cancers seems a reasonable consequence.
The data presented above suggest that the observed increased risk of leukemia and cancers among childhood hibakusha is a life-long phenomenon (Figure 15). Atomic-bomb radiation had instantaneously damaged each organ in 1945, but the organs regenerated enough to allow some of the survivors to live long, healthy lives.

Such a regenerative ability can be explained by the capability of stem cells of each organ, which constitute a very small minority of organ cells. Only stem cells can repair the damaged organ based on this capability of cell divisions. Nagasaki University researchers’ hypothesis is that such stem cells also had received high doses of radiation, but some of them could survive. However, some of the genes on their DNA might also have been injured. These DNA-injured stem cells can continue to live for the entire life of the survivor, but some of them eventually transform to malignant cells as a consequence.

**Stem-cell Target Hypothesis**

Figure 14. Cancer dose response based on a linear model: all cancers combined, Hiroshima/Nagasaki combined.

Source: Pierce et al. (1996)

Excess Relative Risk (ERR): Ratio of death rate (or rate of incidence) for the exposed population and the death rate (or rate of incidence) in the control group. An ERR = 0.5 means an increase of 50%.

Figure 15. Time trend of the late effect of atomic bomb radiation.
of the accumulation of gene abnormality over several decades, finally inducing leukemia and cancers.

**In-utero Radiation Exposure**

**Microcephaly**
In both Hiroshima and Nagasaki, many pregnant women were exposed to various doses of radiation. Miscarriages and malformation of newborn babies were frequently observed, but there were no good statistics showing radiation-dose effect. Some mothers who were in the early prenatal period at the time of the bombing sometimes bore babies who had a small head. The babies later became mentally disabled. There were 62 such babies recorded among 1,470 (Otake and Schull 1998). The larger the dose to the mother’s uterus was, the higher the incidence of microcephalic babies, suggesting high-dose radiation interrupted brain development. This is the most obvious phenomenon observed among fetuses exposed to radiation in utero.

**Cancers**
In-utero exposed babies were later found to have an increased risk of cancer development during their early adulthood. The follow-up study is now ongoing (Izumi et al. 2003).

**Acute Myocardial Infarction as Nonmalignant Disease**
One of the recent anxieties among the group of hibakusha exposed to high doses of radiation is an increase in the number of heart attacks due to acute myocardial infarction (AMI). It is well known that there are multiple factors for induction of heart attack, so it was not clearly confirmed by good statistics for the role of radiation exposure until recently. However, the most recent statistics suggested a dose-dependent increase in the incidence of heart attack in hibakusha who are more than 70 years old (Yamada et al. 2004). The mechanism for this risk is still unknown. AMI takes place on the basis of arterial sclerosis when it narrows the inner space of arteries by sclerotic thickening of the vascular wall due to cholesterol deposits. How radiation exposure affects this process is still unclear. Health care focusing on AMI is now very important for high-dose hibakusha.

**Ill-defined Second-generation Effect**
The children of atomic-bomb survivors have been intensively investigated to document any increase in the rate of malformation, leukemia, and cancers. So far, such investigations have not shown elevated rates for these disorders. The most recent study of transmission of gene abnormality from three cases of fathers exposed to higher doses of atomic bomb radiation to their three children was conducted by a Nagasaki University Atomic Bomb Disease Institute group at the DNA level by using a sophisticated new technology for DNA (genome) analysis. Their result again showed no positive results (Horai et al. 2017). However, many studies using animal experiments by irradiating parent mice and observing malformation and cancers in F1 mice (second generation) have not infrequently revealed positive results.
These findings in animals have added to the considerable anxiety among the second generation of survivors (Nomura 1989). A large-scale epidemiological study based on more than 10,000 second-generation people is currently continuing. The second-generation population, comprising more than 200,000 people, is now entering the cancer-prone age of fifties to sixties. If positive results with regard to the increased risk of leukemia and cancers are confirmed in the future, it can be concluded that atomic bomb is a weapon that targets human genes and induces hereditary transmission of malignant diseases.

**Long-lasting Psychological Effects of Experiencing Atomic Bombings**

The bodily effects of the atomic bombings mentioned above are widely known to hibakusha as the most important late effect of atomic-bomb radiation. Therefore, even healthy survivors have had fears of suffering from leukemia or cancers. In 1995, a large-scale psychological study employing the World Health Organization General Questionnaire (Goldberg 1972) to scale degrees of unhealthy daily conditions was applied to more than 7,000 people by interviewing them about their post-bombing lives (Honda et al. 2002).

The analysis clearly indicated long-persisting psychological damage, including depression and occasional mood changes similar to those associated with PTSD, among many survivors. Those who lost their relatives due to the bombs and those who suffered from ARS tended to have more pronounced psychological damage. Their health typically deteriorates around August every year. Fear of radiation is a common clinical problem when physicians examine survivors’ health condition once a year, as the Japanese government requires.

**Socioeconomic Destruction of the Whole City and the Regeneration of Society and the Daily Lives of Hibakusha**

Hiroshima and Nagasaki were entirely devastated and flattened by the atomic bombings. More than 50% of the citizens died in Hiroshima and more than 30% in Nagasaki. The destruction of residential buildings created a threat to survivors, especially those who suffered from radiation sickness and who also lost their family members and possessions.

The Japanese government and local governments could not provide any meaningful support until Japan’s economic recovery, which started around 1955 as the result of procurement for the Korean War.

Medical support and social aid to hibakusha by the Japanese government officially started only in 1957. The financial support was inadequate at first but gradually improved with the economic development of Japan after 1970. At present, all medical expenses to hibakusha – not only for cancer diagnosis and treatment, but also for almost all diseases except infectious diseases – are completely covered by the government. Moreover, almost all hibakusha are given monthly health-care support of 37,000 yen; for cancer patients, it is 140,000 yen if they were exposed to radiation within 3.5 km. The Japanese government sets aside a huge amount of money – for example, about 129 billion yen in 2017 – for improving the quality of lives of hibakusha, such as providing free medical care. This is very different from the situation from 1945 to 1960.
Simulation Study on 16 Kiloton and 1 Megaton Nuclear Bomb Detonations upon One Million Modern City

Researchers at Nagasaki University and Hiroshima University who had been engaged in the studies on the delayed atomic-bomb effects were asked by the Japanese Ministry of Foreign Affairs to conduct a simulation study to prepare for the second International Conference on the Humanitarian Impact of Nuclear Weapons held in Nayarit in Mexico in 2014. I served as the chairperson of the panel Tomonaga et al., (2014).

Based on the scientific data obtained from the actual detonations of the 16-kiloton Hiroshima bomb and the 21-kiloton Nagasaki bomb, such as statistics on the deaths caused by leukemia and cancers (Table 2), and data from a US government report on the effects of nuclear-weapon detonations, especially for a 1-megaton hydrogen bomb, we simulated the effects of nuclear detonations on a virtual modern city with a population of 1 million. As shown in Figure 16, the following two cases were examined: a 16-kiloton atomic bomb that explodes 600 meters above the ground, exactly as Hiroshima’s “Little Boy” did, and a 1-megaton hydrogen bomb that explodes 2,400 meters above the ground. As shown in Table 3 we estimated (1) the number of immediate deaths and injuries, (2) the long-term consequences such as leukemia and cancers, (3) the magnitude of damage to city area and infrastructure, and (4) the magnitude of economic collapse.

For the 16-kiloton atomic bomb, the area of visible destruction has a radius of 4.5 km from ground zero, exactly the same as the one observed in Hiroshima City in the 1945 bombing. As for the hydrogen bomb, the radius of the completely destroyed area is approximately 18 km, which covers the entire city of 1 million people and additional neighborhood areas with 400,000 people. Heat and radiation rays from the atomic bomb reached 2.8 km, the same as Hiroshima. About 40 percent of the city area is devastated. In the case of the hydrogen bomb, the major destructive powers are blast wind and heat rays. But, curiously, radiation reaches only 3 km from ground zero. This can be explained by the height of the detonation. The radiation beams emitted from a height of 2,400 meters tend to diminish gradually during their transmission through the air. Only a small portion of the total radiation actually reaches the ground surface.

We have also calculated immediate and late casualties. As shown in Table 3, the 16-kiloton atomic bomb causes 66,000 immediate deaths and 205,000 severe injuries. The population affected by radiation is 155,000. The excess death cases for leukemia and cancers over 50 years after the bombing are 220 and 12,000, respectively. Explosion of a 1-megaton hydrogen bomb – this is a small hydrogen bomb – at a height of 2,400 meters causes 370,000 immediate deaths and 460,000 injuries. Over 90% of the injured are expected to die soon due to subsequent firestorms. In contrast, the population affected by radiation is 36,000, much

|                     | Fixed population of survivors | No. of death in 50 years | expected No. of death | Excess cases | Percent Radiation-related |
|---------------------|-------------------------------|--------------------------|-----------------------|--------------|---------------------------|
| Leukemia all doses  | 86,611                        | 296                      | 203                   | 93           | 46%                       |
| 2 Gy<               | 2,709                         | 64                       | 8                     | 56           | 88%                       |
| Cancers all doses   | 1,05,427                      | 17,448                   | 16,500                | 853          | 10.7%                     |
| 2 Gy<               | 2,211                         | 185                      | 111                   | 74           | 61%                       |
smaller than that affected by the 16-kiloton bomb. Also, there are 70 excess leukemia deaths and 670 excess cancer deaths over 60 years after detonation. Again, these are much smaller than the atomic-bomb victims. This is due to the greatly reduced amount of total radiation from the high altitude of 2,400 meters that reaches people on the ground.

These numbers clearly indicate that any relief by rescue teams and medical personnel is not possible because most of these people will be dead or severely injured. Various city buildings will be completely or partially destroyed by the blast and firestorms. City functions such as traffic, electricity, and schools will be totally lost instantaneously. It takes many years to regenerate the city. It may be even impossible in the case of the detonation of a hydrogen bomb.

The abovementioned result of the simulation deals with only one case. In an actual full-scale nuclear war in which several hundred average-size (100-kiloton) atomic bombs are exchanged, the total damage to humanity and urban infrastructure is beyond our imagination and calculation. A possible outcome caused by such a large-scale nuclear war is an extinction of Homo sapiens, as has already been simulated in Sagan et al. study.

### Table 3. Comparison of immediate effects and late effects (leukemia/cancer) over 50 years between atomic bomb and hydrogen bomb.

|                      | 16 kiloton atomic bomb | 1 megaton hydrogen bomb |
|----------------------|------------------------|-------------------------|
| Immediate Death      | 66,000                 | 3,70,000                |
| Immediate Injury     | 2,05,000               | 4,60,000                |
| Radiation-affected   | 1,55,000               | 36,000                  |
| population           | (within 2.8 km)        | (within 3 km)           |
| Excess Leukemia      | 220                    | 70                      |
| Excess Cancers       | 12,000                 | 650                     |
(Turco et al. 1983) on nuclear winter and another study on nuclear famine (Toon, Robock, and Bardee 2007).

Dr. Sagan reported for the first time that a large-scale nuclear war could cause a nuclear winter after several years and that the winter would induce a global collapse of agriculture and a large-scale famine, finally destroying humanity. More recently, International Physicians for the Prevention of Nuclear War (IPPNW) and meteorologists simulated an outcome of a nuclear war in South Asia. According to them, even a localized nuclear exchange in the region would cause a famine that could lead to the deaths of 2 billion people (Hellfand 2016). All these simulations make clear the risk of extinction of Homo sapiens.

Summary of Hibakusha Life, 1945–2018

Can Homo Sapiens Gain the Ethical Wisdom to End the Nuclear Weapon Age and Survive?

The consequences of the atomic bombings linger on. First generation hibakusha population will cease to exist probably around 2045. If genetic transmission of radiation-related diseases to the second generation of hibakusha would be proved in the future, atomic bombs will continue to affect those descendants forever. The year 2045 will mark the 100th annniversary of the Hiroshima and Nagasaki nuclear bombings and of the nuclear weapon age. If we human beings fail to eradicate nuclear weapons before the first century ends, what should we do? This is the question that all hibakusha have posed in their 70-year struggle for survival all the time after bombings.

The medical consequences of atomic-bomb radiation almost all result from DNA damage to organ cells. Despite great advances in cancer treatment in the present era 72 years after the bombings, more than half of the hibakusha who have developed cancer or leukemia when they become elderly eventually have died of fatal outcome. Therefore, it can be said that the atomic bombs still continue to kill a number of hibakusha every year, increasing the total number of deaths due to the delayed effects of atomic-bomb radiation. We have not yet calculated the total number of deaths. It is still premature to calculate the number of overall deaths due to the atomic bombings, starting from the immediate deaths in 1945 and including the late deaths since 1946 to around 2045 (100 years). As of today, there are approximately 150,000 survivors still alive.

Thus, the lives of the hibakusha after the bombings have been full of anxiety and fear of dying due to the atomic bombing. After the surrender of Japan, hibakusha struggled economically to rebuild their houses, raise families, get new jobs, and steadily succeed in regenerating their own lives, families and their home towns.

Their experience of the atomic-bomb disaster influenced them profoundly in shaping their basic understanding of the nature of nuclear bombs. Hibakusha faced the question of why and how we human beings created such bombs and used them in war, and why we still cannot abandon them. Because of the use of bombs in the war and Japan’s unconditional surrender to Allied Forces, hibakusha had no way to protest and make claims against the state that used the bombs for the inhumane casualties they caused. Instead, many hibakusha were determined deep in their mind to begin and promote the movement for nuclear abolition. In 2017, the Treaty on the Prohibition of Nuclear Weapons
was finally adopted and the Nobel Peace Prize was awarded to the International Campaign for the Abolition of Nuclear Weapons (ICAN), to which hibakusha movement has greatly contributed.

The hibakusha movement for delivering testimonies and calling for nuclear abolition has created a firm international norm that any political leader of a nuclear-weapon state cannot use nuclear bombs again. Nagasaki continues to be the last atomic bomb-destroyed city. Added to this is the new treaty’s more intense pressure on nuclear-weapon states toward nuclear disarmament and final elimination of their nuclear weapons.

Nevertheless, nuclear-weapon states still keep nuclear weapons on the basis of nuclear deterrence policy derived from the theory of mutually assured destruction. They insist that it is their responsibility to protect their citizens by defending against invaders.

It might be impossible to realize a nuclear-weapon-free world by abandoning all nuclear warheads. Nuclear deterrence is firmly embedded in international security politics and the military balance involving all the nuclear-weapon states.

Article 6 of the Nuclear Non-Proliferation Treaty (NPT) clearly says that all parties to the treaty have an obligation to seek nuclear disarmament and a nuclear-weapon-free world. They made the promise 50 years ago, when the NPT regime started, but today nuclear deterrence policy is still alive and even being strengthened by a recent acceleration of the nuclear arms race between major nuclear-weapon states.

No person or state has yet devised a novel political approach to overcome the policy of nuclear deterrence. This is why hibakusha continue their movement by repeating their testimonies, seeking to share their ethical wisdom with global citizens, especially with new generations and new political leaders of the nuclear-weapon states. Those leaders undoubtedly have a responsibility not only for the survival of their own nations and citizens, but also for the survival of global humanity. Once used in war or by accident, nuclear weapons can destroy the human environment and induce a nuclear winter and subsequent famine due to a collapse of global agriculture (Toon, Robock, and Bardee 2007).

We will have to continue to live under a nuclear threat with the fear of extinction of Homo sapiens from the earth. Hibakusha, as the only group of Homo sapiens with real experience of nuclear attacks, continue to fight for the survival of Homo sapiens.

The political leaders of both nuclear-weapon and non-nuclear-weapon states must learn from the wisdom of hibakusha and take it seriously as members of humanity. Political leaders of nuclear-weapon states absolutely have to be held accountable for producing, possessing, and using nuclear weapons for nuclear deterrence, which aims at cities and citizens in enemy states. If a nuclear war takes place, all global citizens face extinction. So far, Homo sapiens has failed to eradicate nuclear weapons due to the lack of wisdom. Human wisdom should understand the possibility that Homo sapiens will become an endangered species in the near future.

To decide to abandon nuclear weapons, all the political leaders of the nuclear-weapon states need to make a great decision based on ethical thoughtfulness and responsibility for safety and survival of global citizens, which might be more difficult than President Truman’s decision to use the bombs. For this decision the leaders must create by themselves innovative measures for maintaining international security and peace without nuclear deterrence policy. I ask them be courageous for the sake of Humanity.
Hibakusha are still living to regenerate their life to prove that Homo sapiens can overcome the nuclear weapon age.

Disclosure Statement

No potential conflict of interest was reported by the author.

Notes on Contributor

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