Rediscovery of an old article reporting that the area around the epicenter in Hiroshima was heavily contaminated with residual radiation, indicating that exposure doses of A-bomb survivors were largely underestimated

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ABSTRACT

The A-bomb blast released a huge amount of energy: thermal radiation (35%), blast energy (50%), and nuclear radiation (15%). Of the 15%, 5% was initial radiation released within 30 s and 10% was residual radiation, the majority of which was fallout. Exposure doses of hibakusha (A-bomb survivors) were estimated solely on the basis of the initial radiation. The effects of the residual radiation on hibakusha have been considered controversial; some groups assert that the residual radiation was negligible, but others refute that assertion. I recently discovered a six-decade-old article written in Japanese by a medical doctor, Gensaku Obo, from Hiroshima City. This article clearly indicates that the area around the epicenter in Hiroshima was heavily contaminated with residual radiation. It reports that non-hibakusha who entered Hiroshima soon after the blast suffered from severe acute radiation sickness, including burns, external injuries, fever, diarrhea, skin bleeding, sore throat and loss of hair—as if they were real hibakusha. This means that (i) some of those who entered Hiroshima in the early days after the blast could be regarded as indirect hibakusha; (ii) ‘in-the-city-control’ people in the Life Span Study (LSS) must have been irradiated more or less from residual radiation and could not function properly as the negative control; (iii) exposure doses of hibakusha were largely underestimated; and (iv) cancer risk in the LSS was largely overestimated. Obo’s article is very important to understand the health effects of A-bombs so that the essence of it is translated from Japanese to English with the permission of the publisher.

KEYWORDS: atomic bomb, black rain, exposure dose estimation, Gensaku Obo, hibakusha, Life Span Study

INTRODUCTION

At first, the exposure doses of hibakusha (A-bomb survivors) were estimated using data collected from A-bomb tests on the ground in the Nevada desert. A-bombs dropped on Hiroshima and Nagasaki were detonated at 600 m and 503 m heights, respectively. To obtain more accurate data, the ICHIBAN project was planned, in which a 510 m high tower was constructed in the Nevada desert [1]. A nuclear reactor or other radiation source was placed on the top of the tower and data were collected. The dosimetry of the ICHIBAN project was named tentative dose 1965 (T65D). Around the 1980s, it was found that T65D did not correctly reflect the intensity of A-bomb radiation. Exposure doses were reexamined and Dose System 1986 (DS86) was established [2]. In the period around the 1990s, DS86 was revised again and Dose System 2002 (DS02) was established [3]. DS02 is the current system used to estimate the exposure doses of hibakusha. Thus, T65D was the basic dosimetry system and DS86 and DS02 are modified versions. The ICHIBAN project was a large-scale simulation model of A-bombs, but fallout was not produced, as it is by real A-bombs, creating a major underestimation of exposure doses of hibakusha.

The energy of a typical A-bomb is divided into three components: 35% thermal radiation (heat and light), 50% blast energy
(pressure shock wave) and 15% nuclear radiation [4]. Of the 15%, 5% is initial radiation (released within 30 s) and 10% is residual radiation, which consists largely of fallout, plus a small amount of induced radioactivity [5]. Induced radioactivity is produced by the action of neutrons in making non-radioactive substances into radioactive ones, but its lifespan is very short and the activity becomes one hundredth and one thousandth one hour and one day after the blast, respectively. Thus, induced radioactivity is mostly negligible. On the other hand, a large fraction of fallout, 40–70%, is believed to fall down onto the ground within a day (although the situation depends largely on weather and geographical features). This makes calculation of the effects of fallout on the exposure doses difficult.

Black rain never falls in the Nevada desert, because water and organic sources are scarce. At Hiroshima and Nagasaki, thermal radiation incinerated or scalded plants, animals (including humans), houses, and a variety of organic substances. From the many waterways in Hiroshima and Nagasaki, a large volume of water was evaporated, and even water itself seemed to have been sucked up as if by a tornado. The vapor and water went up into the sky and cooled, thereafter, to form raindrops containing soot and other debris; the resultant black rain started to pour down 20–30 min after the detonation. It is well known that the heavy black rain was highly radioactive. Therefore there is the possibility that the black rain included most fallout (two-thirds of the nuclear radiation energy), i.e. twice as much radiation as the initial radiation (one-third of the nuclear radiation energy). However, accurate estimation of exposure doses from residual radiation is quite difficult, in spite of long years of research, and the findings remain disparate and inconclusive [6]. A report indicated that rain exposure shortly after the A-bombings in Hiroshima and Nagasaki was unlikely to increase cancer risk [7]. However, exposure to the rain itself was not the main issue; what was critically important was whether or not people entered black rain–affected areas, as Obo’s article shows [8]. His article is entitled ‘Statistical observation of disorders induced by residual radiation of A-bomb.’ It was reported in a rather minor medical journal, ‘Nihon Iji Shinpo (Japan Medical Journal),’ in Japanese, 60 years ago. He wrote that all people who lived in the 7 km radius from the epicenter were personally interviewed, but the total population in the area was not reported; thus, the percentage of responders is not known. Students of Hiroshima University took part in this study, but the number of students is not reported. Self-report symptoms 12 years after the A-bomb were surveyed; however, people’s memories might not be always reliable. No data on radiation doses were available at the time when Obo carried out his research. Thus, his article contains some weaknesses from the present viewpoint, but is still worthy of being widely read. The report is so important that the essence of the article has here been translated into English, with full reproduction of all seven tables within it being reproduced (with permission from the publisher).

**RESULTS**

**A-bomb and black rain area in Hiroshima explanation (required for understanding Obo’s article)**

One-third of the energy of a typical A-bomb is thermal radiation (heat and light), and this energy contributed to the evaporation of water from the many waterways in Hiroshima. One half of an A-bomb energy is blast energy (pressure shock wave), and this energy leads to the whirling of soil and debris up to form a Mach wave mass. A mushroom cloud was formed by the action of joint actions of the thermal and blast energy (Fig. 1). The 15% nuclear energy leads to the whirling of soil and debris up to form a Mach wave mass. A mushroom cloud was formed by the action of joint actions of the thermal and blast energy (Fig. 1, left). The 15% nuclear radiation comprised of initial (one-third of the nuclear radiation energy) and residual radiation (two-thirds of the nuclear radiation energy). Most of the residual radiation consisted of fallout that was sucked into the mushroom cloud. Vapors and water went up into the sky and cooled to form raindrops containing fallout, soot and other debris; the resultant black rain started to pour down 20–30 min after the detonation and covered almost all of Hiroshima City (Fig. 1, right).

**Abstract of Obo’s article and reproduction of seven tables from that article**

**Introductory remarks by Obo**

There are several reports indicating the occurrence of disorders such as reduced leukocyte counts and radiation sickness in non-hibakusha who entered the central area around the epicenter after the A-bomb blast. Approximately the same number of reports support no hazardous effects from residual radiation. Therefore, a decisive conclusion has not been reached as to the effects of residual radiation.

Obo had been studying the relationship between the A-bomb radiation and the death rate by malignant neoplasm. During the study, he wanted to learn the effects of the residual radiation on human health, but he found that no statistical observation had been conducted. Thus, he decided to carry out a personal survey of all hibakusha within a certain area concerning their exposure conditions, their radiation sickness (and degree if applicable), and their behavior during the 3 months after the blast. Examinees were classified into two groups: those who entered the central area and those who did not. He also found 629 non-hibakusha who were not in Hiroshima City during the A-bomb blast, but who entered the City after the blast. They were also classified into two groups, as for hibakusha.

**Definitions and methods**

‘Hibakusha’ are people who were in Hiroshima City at 8:15 a.m. on 6 August 1945. ‘Non-hibakusha’ are people who entered Hiroshima City within the period of 3 months after the blast. ‘Exposure conditions’ include locations within the blast, whether indoors or outdoors during the blast, presence or absence of shields, structure of buildings or houses from which shelter was obtained, and distance from the epicenter. The ‘central area’ is the circular area with a radius of 1 km from the epicenter. ‘Entrance into the central area’ means stepping in the area within the period of 3 months after the blast. Those who entered the central area after detonation are called ‘entrants’; entrants were asked about when they entered, how long they entered for, how many times they entered, and their behaviors. Those who did not enter the central area are called ‘non-entrants’. ‘People with symptoms’ are those who suffered from disorders caused by A-bomb radiation and from burns caused by thermal radiation. ‘People with no injury’ are those who showed neither objective nor subjective
symptoms during the 3 months after the blast. ‘People with external injury only’ are those who were injured externally by the blast, but who did not show any other symptoms. All hibakusha (3946) and non-hibakusha (629) who lived in the area 2.0–7.0 km from the epicenter were surveyed in January–July 1957. A house-to-house survey was made by voluntary students of Hiroshima University.

**Table 1** summarized the results of the survey of indoor hibakusha who were non-entrants. Of 1878 hibakusha, 380 (20.2%) showed disorders. The closer to the epicenter they were, the more they showed disorders. There was an approximately linear relationship between the distance from the epicenter and the proportion of disorders at that distance. Some outdoor hibakusha suffered from burns. Even if burns were excluded, the proportion of disorders was higher than that of indoor hibakusha (Tables 1 and 2).

**Table 4** summarized the results of the survey of outdoor hibakusha who were entrants. Of these 398 hibakusha, 203 (51.0%) showed disorders, which was a higher proportion than those of entrant indoor hibakusha and non-entrant outdoor hibakusha (Tables 1–3). In contrast with non-entrants (Table 3), the proportions did not decrease, as was also the case for indoor hibakusha who were entrants (Table 2).

**Table 5** summarized the results of the survey of non-hibakusha who were non-entrants. They did not show any disorders (proportion 0%).

**Table 6** summarized the results of the survey of non-hibakusha who were entrants. Of these 525 non-hibakusha, 230 (43.8%) showed disorders. These non-hibakusha consisted of 405 ordinary people and 120 fire fighters from Asa-Machi, north of Hiroshima City. The fire fighters entered Hiroshima City at 8 a.m. on 7 and 8 August 1945, and they were engaged in rescue of hibakusha and the maintenance of roads. They finished their work at 4 p.m. Their working areas were from Yokokawa Machi (1.5 km north of the epicenter) to the epicenter to Yamaguchi Machi (1.0 km south of the epicenter). They worked for 2 days, but some worked for more than 5 days to search for lost persons and on other duties around the epicenter. They did not drink river water, because countless bodies were floating on the rivers. One
### Table 1. Results of survey of indoor hibakusha who did not enter the central area after detonation

| Distance from epicenter (km) | Number of hibakusha | Three categories | Symptoms (%) | Acute radiation sickness (%) | Sore throat | Loss of hair |
|-----------------------------|---------------------|------------------|--------------|-----------------------------|-------------|-------------|
|                             |                     | No injury | Ext. injury only | With symptoms | Burn | External injury | Fever | Diarrhea | Skin bleeding |                  |
| 0.5                         | 3                   | 0      | 0                | 3              | 100 | 0              | 66.7 | 33.3    | 33.3          | 66.7          | 33.3        | 100         |
| 1                           | 60                  | 8      | 13               | 39             | 65  | 11.6          | 51.6  | 53.3    | 41.6          | 31.6          | 18.3        | 48.3        |
| 1.5                         | 167                 | 58     | 31               | 78             | 46.7| 6.5           | 27.5  | 32.9    | 37.1          | 18.5          | 11.3        | 16.7        |
| 2                           | 234                 | 75     | 88               | 71             | 30.3| 6.4           | 17.5  | 16.6    | 20.9          | 8.1           | 3.4         | 2.1         |
| 2.5                         | 219                 | 102    | 6                | 61             | 27.6| 6.8           | 16.4  | 13.2    | 18.7          | 5.9           | 0.9         | 5.4         |
| 3                           | 236                 | 135    | 56               | 45             | 19  | 3.3           | 10.1  | 8.8     | 14.8          | 2.5           | 2.1         | 2.9         |
| 3.5                         | 337                 | 238    | 46               | 53             | 15.7| 0.9           | 4.1   | 3.8     | 8.4           | 2.6           | 0.9         | 0.9         |
| 4                           | 200                 | 168    | 16               | 16             | 8   | 1             | 3.5   | 3.5     | 4             | 2             | 1           | 3           |
| 4.5                         | 305                 | 285    | 14               | 6              | 1.9 | 0             | 0     | 0.9     | 1.3           | 0             | 0.3         | 0           |
| >5                          | 117                 | 107    | 2                | 8              | 6.8 | 0             | 0     | 0       | 1.7           | 0             | 0.8         | 0.8         |
| Total                       | 1878                | 1176   | 322              | 380            | 20.2 (average) | 3.2     | 10.7    | 10.6          | 13.5          | 5.7         | 2.8         | 5           |
| Men                         | 646                 | 414    | 93               | 139            | 36.5 (average) | 3.6     | 17.4    | 21.3          | 26            | 11.4        | 5.6         | 10.4        |
| Women                       | 1232                | 762    | 229              | 241            |                 |         |         |               |               |             |             |

### Table 2. Results of survey of indoor hibakusha who entered the central area after detonation.

| Distance from epicenter (km) | Number of hibakusha | Three categories | Symptoms (%) | Acute radiation sickness (%) | Sore throat | Loss of hair |
|-----------------------------|---------------------|------------------|--------------|-----------------------------|-------------|-------------|
|                             |                     | No injury | Ext. injury only | With symptoms | Burn | External injury | Fever | Diarrhea | Skin bleeding |                  |
| 0.5                         | 8                   | 2      | 1                | 5              | 62.5| 0              | 50    | 50      | 42.5          | 62.5          | 25          | 50          |
| 1                           | 47                  | 2      | 7                | 38             | 80.7| 17             | 61.7  | 68      | 57.4          | 51            | 36.1        | 68          |
| 1.5                         | 101                 | 26     | 30               | 45             | 44.5| 3.9            | 28.7  | 28.7    | 32.6          | 14.8          | 7.9         | 17.8        |
| 2                           | 108                 | 36     | 25               | 47             | 43.5| 6.5            | 33    | 23.1    | 33.3          | 12.9          | 4.6         | 12.9        |
| 2.5                         | 102                 | 39     | 21               | 42             | 41.1| 5.8            | 22.5  | 18.6    | 30.3          | 12.7          | 5.8         | 6.8         |
| 3                           | 174                 | 64     | 39               | 71             | 40.8| 4              | 17.8  | 20.1    | 28.7          | 9.7           | 7.4         | 8.6         |
| 3.5                         | 172                 | 96     | 28               | 48             | 27.9| 1.7            | 8.1   | 16.8    | 21.5          | 4             | 1.7         | 4           |
| 4                           | 111                 | 79     | 11               | 21             | 18.9| 0              | 4.5   | 11.7    | 11.7          | 2.7           | 0.9         | 1.8         |
| 4.5                         | 119                 | 84     | 7                | 28             | 23.5| 0.8            | 4.2   | 11.7    | 16.8          | 6.7           | 0           | 2.5         |
| >5                          | 76                  | 46     | 3                | 27             | 35.5| 1.3            | 2.6   | 22.3    | 19.7          | 14.4          | 3.9         | 5.2         |
| Total                       | 1018                | 474    | 172              | 372            | 36.5 (average) | 3.6     | 17.4    | 21.3          | 26            | 11.4        | 5.6         | 10.4        |
| Men                         | 475                 | 207    | 83               | 185            |         | 3.6         | 17.4  | 21.3    | 11.4          | 5.6           | 10.4        |
| Women                       | 543                 | 267    | 89               | 187            |         | 3.6         | 17.4  | 21.3    | 11.4          | 5.6           | 10.4        |
### Table 3. Results of survey of outdoor hibakusha who did not enter the central area after detonation

| Distance from epicenter (km) | Number of hibakusha | Three categories | Symptoms (%) | Acute radiation sickness (%) | Sore throat | Loss of hair |
|-----------------------------|---------------------|-----------------|--------------|-------------------------------|-------------|-------------|
|                             |                     | No injury       | Ext. injury only | With symptoms | Burn injury | External injury | Fever | Diarrhea | Skin bleeding |               |             |
|                             |                     |                 |               |                  |             |                 |       |           |                      |               |             |
| 0.5                         | 0                   | 0               | 0             | 0                | 0           | 0               | 0     | 0         | 0              | 0             | 0           |
| 1                            | 17                  | 2               | 1             | 14               | 82.3        | 64.7            | 41.1  | 64.7      | 64.7           | 47            | 17.6        | 52.9        |
| 1.5                          | 49                  | 7               | 5             | 37               | 75.5        | 48.9            | 22.4  | 48.9      | 34.6           | 24.4          | 10.2        | 24.4        |
| 2                            | 132                 | 25              | 18            | 89               | 67.4        | 56.3            | 21    | 42.8      | 36             | 20.2          | 6.7         | 18.7        |
| 2.5                          | 91                  | 26              | 4             | 61               | 67          | 53.8            | 26.3  | 35.1      | 23             | 10.9          | 6.5         | 10.9        |
| 3                            | 74                  | 21              | 8             | 45               | 60.8        | 45.9            | 13.5  | 35.9      | 22.9           | 6.7           | 6.7         | 12          |
| 3.5                          | 95                  | 55              | 13            | 27               | 28.4        | 18.9            | 7.3   | 8.4       | 12.6           | 7.3           | 0.2         | 0.1         |
| 4                            | 70                  | 57              | 4             | 9                | 12.8        | 4.2             | 4.2   | 7.1       | 7.1            | 4.2           | 4.2         | 2.8         |
| 4.5                          | 74                  | 65              | 7             | 2                | 2.7         | 0               | 0     | 2.7       | 0              | 1.3           | 0           | 0           |
| >5                           | 50                  | 45              | 2             | 3                | 6           | 0               | 0     | 2         | 2              | 0             | 4           |             |
| Total                        | 652                 | 303             | 62            | 287              | 44 (average)| 32.6            | 13.8  | 25.6      | 20.1           | 11.5          | 6           | 10.4        |
| Men                          | 275                 | 126             | 28            | 121              |             |                 |       |           |               |               |             |             |
| Women                        | 377                 | 177             | 34            | 166              |             |                 |       |           |               |               |             |             |

### Table 4. Results of survey of outdoor hibakusha who entered the central area after detonation

| Distance from epicenter (km) | Number of hibakusha | Three categories | Symptoms (%) | Acute radiation sickness (%) | Sore throat | Loss of hair |
|-----------------------------|---------------------|-----------------|--------------|-------------------------------|-------------|-------------|
|                             |                     | No injury       | Ext. injury only | With symptoms | Burn injury | External injury | Fever | Diarrhea | Skin bleeding |               |             |
|                             |                     |                 |               |                  |             |                 |       |           |                      |               |             |
| 0.5                         | 1                   | 0               | 0             | 1                 | 100         | 0               | 100   | 100       | 100            | 100           | 100         | 100         |
| 1                            | 16                  | 0               | 0             | 16                | 100         | 50              | 56.2  | 81.2      | 68.7           | 56.2          | 25          | 56.2        |
| 1.5                          | 28                  | 4               | 4             | 20                | 71.4        | 42.8            | 25    | 28.5      | 39.2           | 17.8          | 10.7        | 14.2        |
| 2                            | 65                  | 13              | 6             | 47                | 72.3        | 32.3            | 26.1  | 43        | 44.4           | 24.6          | 7.6         | 24.6        |
| 2.5                          | 40                  | 13              | 5             | 22                | 55          | 30              | 10    | 5         | 30             | 10            | 0           | 7.5         |
| 3                            | 57                  | 29              | 6             | 30                | 50.6        | 19.2            | 17.5  | 19.2      | 28             | 21            | 7.2         | 12.2        |
| 3.5                          | 65                  | 29              | 6             | 30                | 46.1        | 13.9            | 9.2   | 23        | 24.6           | 12.3          | 4.6         | 7.6         |
| 4                            | 52                  | 33              | 4             | 15                | 28.8        | 1.8             | 3.8   | 17.3      | 21             | 5.7           | 1.8         | 7.6         |
| 4.5                          | 32                  | 22              | 1             | 9                 | 28.1        | 0               | 3.1   | 12.4      | 18.7           | 9.3           | 3.1         | 9.3         |
| >5                           | 42                  | 29              | 0             | 13                | 39.9        | 7.1             | 7.1   | 16.6      | 14.2           | 7.1           | 4.2         | 2.3         |
| Total                        | 398                 | 163             | 32            | 203               | 51 (average)| 19.3            | 15    | 24.6      | 29.9           | 16.1          | 6           | 13.3        |
| Men                          | 223                 | 91              | 19            | 113               |             |                 |       |           |               |               |             |             |
| Women                        | 175                 | 72              | 13            | 90                |             |                 |       |           |               |               |             |             |
to five days after returning home, a lot of the firefighters suffered from fever, diarrhea, sticky bloody stools, bleeding from the mucous membrane of the skin, loss of hair, and generalized weakness. These symptoms are the same as those of the A-bomb radiation sickness from which the hibakusha suffered. The proportion of symptoms was high in those who entered the central area within the 20 days after the blast. The proportion was extremely low in those who entered the area after 1 month. Among the 525 non-hibakusha, 26.4% got a fever (this was severe and lasted for more than 3 weeks for 10.3%, i.e. approximately two-fifths of the fever patients’, so there is no ambiguity), 30.8%
suffered from acute diarrhea, and 11.6% complained of high temperature and sticky bloody stools, as if they were dysentery patients. Several days to 3–4 months were needed to get rid of the symptoms. Fortunately, no victims were found in entrant non-hibakusha including firefighters.

Table 7 summarizes the ‘staying time’ and incidence of acute radiation sickness in non-hibakusha who entered Hiroshima after detonation and then entered the central area. Those who stayed in the central area for <4 h suffered less, and those stayed >10 h suffered more. A large fraction (78.1%) of people who stayed more than 2 weeks showed fever, diarrhea, and other symptoms.

**Graphic summary**

The main purpose of the present communication is to make Tables 1–7 public in English. To understand the essence of the tables at a glance, I extracted symptoms (in percentages) from them and then graphically displayed the results for hibakusha (Fig. 2) and for non-hibakusha (Fig. 3). Few people survived the A-bomb at 0.5 km from the epicenter. Outdoor hibakusha generally showed higher proportions of symptoms than indoor hibakusha. Non-entrants’ proportions of symptoms decreased with distance from the epicenter fairly proportionally, but entrants’ proportions seemed to reach plateaus at 4 km or more. The plateau levels were 20–30%, and are likely to reflect hazardous health effects of residual radiation.

**Arbitrary excerpts from summary and discussion**

The disorders caused by the radiation were listed as: burns, external injuries, fever, diarrhea, bleeding from the mucous membrane of the skin, sore throat and loss of hair. Other symptoms included feeling of malaise, loss of appetite, feeling of vomiting, headache, and vertigo. These were rather subjective and thought to be difficult to treat statistically, and they were omitted from the survey list.

Entrants of non-hibakusha who entered the central area and worked for more than 10 h showed a high incidence of symptoms (43.8%) that was similar to acute A-bomb disorders. Among them, 20% suffered from severe bowel inflammation with high fever and sticky bloody stools. Some scientific researchers insisted that the disorders were the results of complications caused by bacterial infection, neglect of health, and poor living conditions. This would not have been the case. When experimental animals were irradiated with neutrons, the intestinal mucous membranes were destroyed, suggesting that A-bomb radiation induced acute diarrhea in

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**Table 7. Relationship between time spent in the central area and incidence of acute radiation sickness in non-hibakusha who entered Hiroshima after detonation and then entered the central area**

| Staying time | 1 h | 4 h | 1 d | 2 d | 3 d | 4 d | 7 d | 10 d | 15 d | 20 d | >30 d | Total |
|--------------|-----|-----|-----|-----|-----|-----|-----|------|------|------|-------|-------|
| No. of non-hibakusha | 102 | 28 | 113 | 102 | 58 | 40 | 36 | 21 | 14 | 3 | 8 | 525 |
| With symptoms | 12 | 8 | 48 | 51 | 31 | 28 | 22 | 14 | 11 | 2 | 3 | 230 |
| No symptoms | 90 | 20 | 65 | 51 | 27 | 12 | 14 | 7 | 3 | 1 | 5 | 295 |
| With symptoms (%) | 11.7 | 28.6 | 42.5 | 50 | 53.4 | 70 | 61.1 | 66.6 | 78.1 | 66.6 | 37.5 | 43.8 |
hibakusha. The shorter the distance from the epicenter, the higher was the incidence of fever and diarrhea. This could not be caused by epidemics of dysentery. Non-entrants of non-hibakusha showed neither fever nor diarrhea, while 30% of entrants showed these disorders. Families of these sufferers did not show any symptoms (as firefighters, municipal authorities, and medical doctors testified). Diffuse bleeding and necrosis along the whole digestive tract were reported in autopsy records of A-bomb victims, but erosive bleeding enteritis confined only to the colon was not reported. Taken together, a reasonable conclusion is that acute diarrhea was caused by destruction of the intestinal mucous membrane by A-bomb radiation. Several grays are necessary in order to induce acute diarrhea, indicating that the residual radiation must have reached the level of several grays.

Regardless of whether they were hibakusha or non-hibakusha, people who entered the central area soon after the blast showed a high incidence of disorders. This fact indicates that there was something there that damaged humans, and it can only have been residual radiation. The incidence was marginal when people entered the central area one month or later after the blast. By that time, most residual radiation must have decayed. Many reports indicate that no abnormalities were found in the blood tests; the results were reasonable because most tests were carried out one month or more after the blast. ($^{235}$U could not be one of components of the residual radiation, because its half-life is very long.)

Data indicate that 43.1% and 30.8% of male and female hibakusha, respectively, were doubly exposed to direct and residual radiation. Although delayed occurrence of fatal illness associated with A-bombs had not been obvious at the time of Obo’s study, he was anxious about the occurrence in the future.

Conclusions by Obo

(i) Regardless of whether they were hibakusha or non-hibakusha, those who entered the area of 1 km radius from the epicenter after the blast and stayed there for more than 10 h frequently suffered from acute A-bomb sickness, which must have been caused by residual radiation. The symptoms were not mild.

(ii) Almost no non-hibakusha who entered the central area after 1 month showed symptoms.

(iii) The period when residual radiation affected the human body was <1 month. This fact indicates that the radioactive isotopes produced secondarily by the A-bomb had short half-lives.

**DISCUSSION**

The exposure doses of hibakusha were estimated solely on the basis of the initial radiation; the effects of residual radiation on hibakusha have been considered controversial. However, Obo’s article clearly indicates that the area around the epicenter in Hiroshima was heavily contaminated with residual radiation [8]. Since this was written in Japanese, I translated the essence of the article into English, with full reproduction of all of the seven tables contained in it.

Table 6 shows that entrants from the non-hibakusha suffered from severe acute radiation sickness, including burns, external injuries, fever, diarrhea, skin bleeding, sore throat, loss of hair, feeling of malaise, loss of appetite, nausea, headache, and/or vertigo—as if they were real hibakusha. Since it is now known that several grays are necessary in order to induce acute diarrhea some people were apparently exposed to several grays of residual radiation. Residual radiation is far from negligible. When Obo carried out his research, however, no data on radiation doses were available. Therefore, it is impossible to discuss the linear no-threshold (LNT) hypothesis in relation to Obo’s data. When distances from the epicenter are used as substitutes for doses, it is of interest to learn that, overall, the declining slopes shown in Fig. 2 seem to suggest a kind of dose–response linearity between symptoms and distances (doses) at higher dose levels.

According to the LNT hypothesis, even the smallest amount of radiation is hazardous [11]. Although the LNT is not based on solid data and is a product of fabrication [12], it constitutes the basis of the recommendation for radiation regulation by the International Commission on Radiological Protection [13]. The lifespan study of Atomic bomb survivors (LSS) has provided fundamental data in support of the LNT [14]. The LSS used ‘in-the-city-control’ people who entered Hiroshima or Nagasaki after the blast as the negative control. These people were assumed have been exposed to no radiation. Actually, they were exposed, to a greater or lesser degree, to residual radiation, as Obo’s data clearly indicate, and they are not an appropriate negative control. Residual radiation must be one of the reasons for the large fluctuations in cancer risk at lower doses in the LSS. Another reason must reside in hormesis, as has been observed in cases of both leukemia and solid cancer [15, 16]. The large deviation from linearity at lower doses up to 600 mSv indicates that LNT is invalid [17]. Indeed, appropriate statistical analysis (the Bayes method) indicates that the LSS does not support the LNT hypothesis [18]. Because dose–response for cancer risk is sigmoidal, and several responses were less than that of the negative control, hormesis obviously occurred and a threshold can be set [19]. Taking the residual radiation into account, the exposure doses of hibakusha and ‘in-the-city-control’ people were largely underestimated; thus, the cancer risk for subjects involved in the LSS has, accordingly, been largely overestimated. Thus, the LNT hypothesis has lost its basis. The title of my article is “Tremendous human, social, and economic losses caused by obstinate application of the failed linear no-threshold model [20].” In the face of this misconception, I recently felt obliged to encourage the Fukushima people not to fear radiation [21].

There are many articles that allegedly support the LNT hypothesis. These articles usually include theoretical, methodological, analytical and/or statistical flaws; none of them are convincing. Recently, results of a large-scale international cohort study—analyses of more than 300 000 nuclear workers from France, the UK and the USA—was reported as evidence that strongly supported the LNT hypothesis [22]. This study was praised in the internationally prestigious journal Nature [23]. Soon, however, the study was criticized by more than 20 specialists. Let me cite some. The authors chose a linear model a priori for the relationship between radiation risk and cumulative dose, thereby neglecting other possibilities, e.g. hermetic responses or existence of thresholds. In statistical analyses, one-sided $P$ values and corresponding 90% confidence intervals (CIs)
were used instead of the usual two-sided $P$ values and 95% CIs, making significant differences easier to obtain. There was no negative control; the significant difference that the authors insisted was present disappeared when appropriate control data was introduced. Personal dosimeters were used to measure cumulative doses. There were, however, a lot of potential confounders, such as country, sex, calendar period, natural versus medical radiation exposure, and age. These were not taken into consideration. Since cumulative radiation dose is strongly correlated with age, and most cancer risk is also strongly correlated with age, the minor increase in deaths by leukemia might have been a simple reflection of the age effect. The original paper contained many obvious errors. For example, it was stated that 531 cases of leukemia were found and 134 were expected by 1 Sv exposure, indicating 397 deaths by radiation. However, the exposure dose was wrong; the calculation was incorrect. The story has been corrected to reflect this [23].

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**CONFLICT OF INTEREST**

The author declares that he has no competing interest related to this report.

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