原　著

Estimation of Residual Nuclear Radiation Effects on Survivors of Hiroshima Atomic Bombing, from Incidence of Acute Radiation Disease

急性放射線症状発症率から広島原爆被爆者に対する残留放射線影響評価

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Abstract

The effects of exposure due to radioactive fallout on survivors of the Hiroshima atomic bomb were estimated by analyzing the incidence rates of acute radiation diseases, epilation, purpura and diarrhea, among survivors. It was found that the effects of radiation exposure due to fallout exceeds, on the average, the initial nuclear radiation effects in people who were beyond about 1.2 km from the hypocenter of the Hiroshima bomb. The average effect of radiation exposure from fallout increases with distance from the hypocenter, reaches a peak at around 1.5 km, and then decreases gradually at farther distances but remains even at about 6 km. The peak value of estimated health effects from fallout is comparable with that of acute external exposure of gamma ray doses around 1Gy. The fact that the effects of residual nuclear radiation estimated from the incidence rate of acute diseases are significantly larger than physically measured residual nuclear radiation doses suggests that the main effects resulting from residual nuclear radiation were caused through internal exposure, especially intake of radioactive small particles from fallout via ingestion and inhalation.

要　旨

広島原爆被爆者の放射性降下物による被曝影響を急性放射線症状の脱毛、紫斑および下痢の発症率から評価した．放射性降下物による人々の平均的被曝影響は爆心地から 1.2 km 以遠で、初期放射線被曝の影響を上回ることを見出した．この降下物による平均的被曝影響は，爆心地からの距離とともに増大し、約 1.5 km で最大値に達して後ゆっくり減少するが、6 km でも残存する．評価した降下物による最大の健康影響はガンマ線による瞬間的な外部被曝の 1 Gy に相当する．急性症状発症率から推定した残留放射線の影響が物理学的に測定した線量よりかなり大きいことは、残留放射線の影響が内部被曝、とりわけ放射性降下物の中の放射性微粒子を呼吸や飲食で摂取したことによって起こったことを示唆する。

§1　Introduction

Doses of initial nuclear radiation emitted within one minute after the atomic bombs exploded on the cities of Hiroshima and Nagasaki are well estimated by the Dosimetry System 2002 (DS02) [1] in the regions within 1.2 km from the hypocenter. These estimates which are supported by experimental measurements on irradiated materials. On the other hand, the residual nuclear radiation emitted one minute or more after the bomb explosion has been not clarified as well as the initial radiation. There are two sources of residual nuclear radiation. One is from fallout and the other from neutron-induced radioactive substances. Estimates of fallout radiation dose that have been made to date are based on measurements of radiation emitted from radioactive matter produced by radioactive fallout in rain which had been absorbed into soil and retained. However, these measurements were made after heavy rains caused by a big fire involving the whole of Hiroshima city and also following major typhoon events. It follows that these measurements detected only a small fraction of the radioactive matter which remained without having been washed away. In most atmospheric nuclear explosion tests in dry deserts, there are no fallout rains and radioactive fine particles in the fallout that fill the air after the atomic cloud disappears are measured by equipment set up before the explosion over wide area. In Hiroshima and Nagasaki, the radioactive fine particles that would have filled the air under the atomic clouds were carried away by the wind long before measurements. In addition, the effects of residual nuclear radiation are the result of both external and internal exposure through intake of radioactive microscopic particles by inhalation and ingestion. In general, physical measurements of these exposure effects were not done and quantification through measurement is now difficult. These facts imply that there are severe limitations to estimation of the residual nuclear radiation doses delivered by the Hiroshima atomic bomb using physical methods.

There have been many investigations of acute radiation diseases among atomic bomb survivors, both from immediately after the bombing and later on, and all results of these investigations show that acute diseases such as epilation, purpura and diarrhea appeared even in regions 2 km or more from the hypocenter. The fact that the diseases have occurred systematically among survivors who were present in regions where the initial nuclear radiations scarcely reached suggests that they should be explained in terms of fallout radiation. In order to understand the effects of residual nuclear radiation comprehensively, it is necessary to study the results of such investigations of acute diseases as well as the risks of chronic diseases and frequency of chromosomal aberration, i.e. biological effects caused by radiation exposure among survivors.

If one can determine the relation between radiation exposure and incidence rates of a specific acute disease, then it is possible to obtain the effective dose from the sum of external exposure by the initial nuclear radiation and external and internal exposure by the fallout radiation. Then by subtracting the initial nuclear radiation dose from this resulting effective dose, the effective dose due to exposure from fallout radiation alone will be obtained. This biological dosimetry method will give only combined effects from both residual external and internal exposure to the survivors.

In this article, the incidence rates of acute radiation diseases among survivors of the Hiroshima atomic bomb are analyzed in order to clarify the effects of residual nuclear radiation from fallout. The fact that the obtained effects of residual nuclear radiation estimated from the incidence rate of acute diseases are significantly larger than would be expected from the physically measured residual nuclear radiation doses suggests that the main effects from residual nuclear radiation were caused through internal exposure, especially the intake of radioactive small particles from fallout via ingestion and inhalation, as well as external exposure from radioactive particles clinging to the skin or clothes. The results of the effects of residual nuclear radiation obtained here from the incidence rates are consistent with studies of the frequency of chromosomal aberration and mortality and incidence rates of chronic diseases, obtained from comparison with people who were truly unexposed from the nuclear radiation.

§2 Relation between Incidence Rate of Epilation and Exposed Dose

This section explores the relation between the exposure dose and the incidence rates of epilation, a typical acute radiation disease. Stram and Mizuno[2] first derived a relation between absorbed dose of acute external exposure from the initial nuclear radiation of the atomic bomb and the incidence rates of epilation. They employed the results of the Life-Span-Study (LSS, 58,500 Hiroshima people and 28,132 Nagasaki people) group of the Atomic Bomb Casualty Commission (ABCC, the predecessor of Radiation Effect Research Foundation, RERF), obtained around 1950 for the heavy epilation (above 67%) that appeared within 60 days after the detonation of the bomb. Their results are shown by small black circles in Fig. 1. The horizontal axis of Fig. 1 is scaled according to the initial nuclear radiation dose estimated by the Dosimetry System 1986 (DS86) [3]. As shown in Fig. 1 the incidence rate increases slowly up to 0.85 Gy of the initial nuclear radiation dose, then rapidly increases above 1 Gy and exceeds 50% at around 2.4 Gy. However, beyond 3 Gy the rates do not increase and even decrease as dose approaches 6 Gy. This unnatural behavior of the incidence rates in the high dose region can be explained by the fact that the LSS group contains only survivors who could survive even though they had been exposed at levels of near or more than a half-death-dose of about 4 Gy, as pointed out by Stewart et al.[4-6]

Incidence rates of epilation, shown by open circles in Fig. 1, are those obtained by Kyoizumi et al.[7] based on radiation exposure to human head skin transplanted onto immunodeficient mice. As seen in Fig. 1 the incidence rates increase very slowly in the low exposure region compared to those given by Stram and Mizuno, and increase to 95.5% and 97%, almost 100% at exposure of 4.5 Gy. From experimental studies with animals it is known that most of the dose dependence of incidence rates or death rates is represented by a normal (Gaussian) distribution[7]. The inci¦dence rates given by Kyoizumi et al. over the whole range of the exposure region can be fitted well by a normal distribution with an expectation value of 2.751 Gy and standard deviation of 0.794 Gy, i.e. N (2.751 Gy, 0.794 Gy), and shown by a solid curve in Fig. 1. The normal distribution N (2.751 Gy, 0.794 Gy) will be referred to as the KSTS relation. When one recognizes that the results of Stram and Mizuno[4] shown in Fig. 1 were obtained from examination data of the LSS on the basis of the assumption that the epilation was caused only by the exposure to initial nuclear radiation, and regarding the fallout radiation as the background, there is a possibility that the black circles in Fig. 1 will shift toward higher dose and higher incident rates, i.e. toward the KSTS relation if the exposure to the fallout radiation is included. The incidence rates of epilation below the 3 Gy exposure region given by Stram and Mizuno can be fitted by a normal distribution N (2,404 Gy, 1,026 Gy) except for the region near zero dose. However, the increases of the incidence rates in the region near zero dose, represented by black circles, are too rapid in comparison with the normal distribution. This different behavior between the incidence rates found by Stram and Mizuno and those of normal distribution can be explained by adding the increase of fallout exposure to their analysis.

Taking account of the above observations, the KSRF relation is adopted as the relation between incidence rates of epilation and exposed dose in the following analysis. The incidence rates of acute disease in the region below 1 km from the Hiroshima hypocenter are excluded from analysis because most of the people within 1 km were killed and the reported rates are statistically unreliable. Furthermore, the total sums of gamma ray and neutron doses at 1 km are 4.48 Gy from the estimation by DS02, by which the calculated incidence rate reached almost 100% on the basis of the assumed normal distribution of the KSTS relation.

§3 Estimation of Fallout Exposure from Incidence Rate of Epilation among LSS Group

In this section the radiation exposure effects from the fallout of the Hiroshima bombing are estimated on the basis of incidence rates of epilation among the LSS-Hiroshima group. Preston et al.[9] reported separately the incidence rates of epilation in Hiroshima and Nagasaki survivors among the LSS group, which was analyzed by Stram and Mizuno. The dependence of the incidence rates of epilation of 58,500 Hiroshima survivors among the LSS is shown by square of distance from the hypocenter in Fig. 2. The incidence rate of 100% at 0.75 km is scaled out of the frame. The black circles and dashed line in Fig. 1 for the initial nuclear radiation dose dependence are translated into distance dependence by use of the DS86 estimation neglecting shielding effects and are plotted by black diamonds and a broken line in Fig. 2. If the shielding effects are taken into account, the diamonds shown in Fig. 2 will move left toward the hypocenter and the difference between the squares will increase. In the following it is assumed that the systematic difference between the squares and diamonds shown in Fig. 2 represents exposed effects from fallout radiation.

It is known that the Hiroshima bomb at the time of detonation was not oriented vertically but inclined about 15 degrees, and the initial nuclear radiation was not uniform in angle because radiation was quite suppressed in the bomb nose direction. But this cylindrical asymmetry is limited to within 1 km from the hypocenter[1]. On the other hand, at the time of explosion there was ambient wind blowing at 1 to 3 meters per second toward the north-west. The strong updraft of the column part of the atomic cloud caused rapid extension of the wing part of the cloud along the tropopause (surface between troposphere and stratospheric) with a radius 10 to 15 km within one hour. Under this widely extended atomic cloud, strong wind blew toward the hypocenter. Small falling raindrops of the extended parts of the atomic cloud were drawn down by this wind and these raindrops returned the small radioactive particles. The atmosphere under the atomic cloud was then filled with floating radioactive small particles carried by wind toward the hypocenter. Heavy fallout rains fell from the central part of the atomic cloud. The atomic cloud moved toward the west-northwest along the ambient wind and heavy fallout rains fell in the regions located west-northwest from the hypocenter. The rains scavenged radioactive floating particles to a certain extent. It is supposed that the fallout fine particles were moved toward northwest direction by the ambient wind and toward the hypocenter by the centripetal wind. To clarify these complicated behaviors of particles, which were inferred to be taken in and to be an important cause of acute diseases among survivors, it is necessary to carry out a direction dependent analysis. However, data on acute diseases have so far only been examined separately by distance and not by direction from the hypocenter. In the following analysis, the distance dependence of radiation exposure means the average of the directions with the same distance. In these averages the northwest regions beyond 2 km from the hypocenter are not included though the fallout particles moved in this direction because the population northwest of Hiroshima was blocked by the mountains located about 2 km from the hypocenter.

In the analysis of the incidence rate of epilation it is assumed that the cylindrically symmetric total exposed dose D(r) at distance r km from hypocenter is given by the sum of the initial nuclear radiation exposure cP(r), with shielding effects represented by a parameter c, and exposure F(r) from fallout radiation as

$$D(r) = cP(r) + F(r). \quad (1)$$

The formula for exposure from fallout radiation F(r) is assumed to be

$$F(r) = a\ r \exp(-r^2 / b^2) + d \quad (2)$$

where parameters a, b, and d represent magnitude, extension and distance independent components of fallout exposure effects, respectively. Theoretical incidence rates are calculated from the exposure dose D(r) given in (1) by use of the KSTS relation between incidence rate and exposed dose. A set of four parameters in (1) and (2) is determined so that the x^2 value is minimum, which represents the fitness of the calculated incidence rates to those of the LSS group and obtained as c = 0.522, a = 0.808 Gy/km, b = 2.062 km, and d = 0.786 Gy. The resulting fitted incidence rates are shown with bold lines in Fig. 2. The doses of total, initial nuclear radiation and fallout exposure, D(r), cP(r) and F(r), with the obtained parameter set are shown by a bold dashed curve, a thin dashed curve and a bold solid curve, respectively, and the initial nuclear radiation doses estimated by DS02 are shown by a thin solid line in Fig. 3. As seen in Fig. 3, the effects of fallout exposure increases with distance from hypocenter up to 1 km, but this has large ambiguity because the incidence rates in the region below 1 km were not employed in the present analysis. Exposure from the initial nuclear radiation rapidly decreased with distance from the hypocenter and at about 1.2 km the fallout effects cross over the effect of initial nuclear radiation. Beyond this distance the fallout effects become dominant. The estimated exposure from fallout radiation reaches about 1.5 Gy at around 1.45 km, and then decreases slowly. Beyond 4 km the exposure effect of fallout takes an almost constant value of 0.79 Gy. This result from the incidence rates of epilation, one of the actual accepted and universally agreed conditions of the bomb survivors, indicates overwhelming effects of fallout beyond about 1.5 km from the hypocenter of Hiroshima. For example at 2.25 km and 2.75 km from the hypocenter, the dose estimations of the initial nuclear radiation by DS02 are 0.0302 Gy and 0.0053 Gy, while the incidence rates of epilation among the LSS-Hiroshima at these distances are 3.5 % and 2.1 %. The estimated fallout exposure effects from these incidence rates is 1.34 Gy and 1.16 Gy, about 44 and 219 times of the DS02 initial nuclear radiation.

The maximum cumulative exposure from fallout of the Hiroshima bomb has been considered hitherto to be between 0.006 and 0.02 Gy in the Koi-Takasu region mentioned in the DS86 report, which are shown by cross marks in Fig. 3. These absorbed doses were obtained from measurement of radiation from fallout matter retained in the soil of these regions, which are located between 2 and 4 km to the west of the hypocenter where light radioactive fallout rain fell but heavy rain caused by the whole city fire did not. As seen in Fig. 3, exposure from fallout estimated from epilation incidence rates in the 2 to 4 km region are 1.4 Gy to 0.85 Gy, which are 40 to 230 times the physically obtained values. This large discrepancy suggests that the physically measured values are only measurements of part of the fallout, and that large effects of internal exposure which can only be deduced by biological methods should be taken into account. It is noteworthy that the values obtained here are average exposures in the same distant regions from the hypocenter, irrespective of direction. This result supports the understanding that fallout particles were distributed in the air over very wide regions under the expanded atomic bomb.

§ 5 Estimation of Fallout Exposure from Incidence Rates of Epilation Examinations Other than LSS

In Fig. 4 incidence rates of epilation examined by the Joint Commission for the Investigation of the Atomic Bomb[9] and Tokyo Imperial University[10] in 1945, and investigated by O-ho[11] in 1957, are shown together with those of LSS-Hiroshima. In the investigation by O-ho, all survivors were classified into four types according to whether they were exposed indoors or outdoors and did or did not enter the central region within 1 km from the Hiroshima hypocenter within 3 months. The O-ho examination of the No Entrance case is very important because the exposures from the induced radioactive matter in the central region were not included.

Except for two incidence rates at 2 km and 4 km* by O-ho all the examined incidence rates of epilation among the Hiroshima survivors closely coincide with each other, indicating the reliability of all these investigations. That the rates of the LSS-Hiroshima between 1.75 km and 2.75 km are slightly lower systematically than the others may be explained by the fact that in the LSS examination epilation is defined as only heavy epilation with 67% loss of hair within 60 days from the atomic bombing.

The same fitting method used in the LSS group is applied for these incidence rates of epilation. The resulting sets of parameters from application of formulae (1) and (2) are given in Table I. The fitted incidence rates curves are shown by thin dashed lines in Fig. 4. The calculated doses of total, initial nuclear and fallout exposure, D(r), cP(r) and F(r), obtained by fitting to the reported incidence rate curves of epilation, are shown by a bold dashed curve, a thin dashed curve and a bold solid curve, respectively, in Fig. 5.

Table I Parameters in formulae (1) and (2) of exposed doses from incidence rates of epilation examined by ABCC, Joint Commission, Tokyo Imperial University and O-ho.

	Initial nuclear rad. exposure $cP(r)$	Fallout radiation exposure $F(r)$		
	c shielding effect	a (Gy/km) magnitude	b (km) extension	d (Gy) constant part
ABCC LSS-Hiroshima (heavy epilation)	0.522	0.808	2.06	0.786
Joint Commission (outdoors or Japanese house)	0.600	1.272	2.34	0.300
Tokyo Imperial University (outdoors and indoors)	0.390	1.330	2.11	0.501
O-ho (indoors, no entrance into central region)	0.226	1.166	2.06	0.751

*[1] These data at 2 km and 4 km given by O-ho are omitted in the x^2 fitting.

The peak values of exposure by fallout are found to lie between 1.58 Gy and 1.78 Gy, slightly higher than that of the LSS, as expected from the small difference among incidence rates. In the region beyond 3 km from the hypocenter the fallout exposure estimation from O-ho's incidence rates is similar to those from the LSS. A rapid decrease of fallout exposure dose is seen beyond 3 km in the examination by the Joint Commission, where incidence rates of epilation in the region 4-5 km and beyond 5 km are zero based on examination of very few survivors compared with LSS.

§6 Comparison of Fallout Exposure Estimated from Incidence Rates of Three Different Acute Diseases

In the following it will be examined whether the incidence rates of three different acute diseases, epilation, purpura and diarrhea can be explained by the same exposure dose. The incidence rates of epilation, purpura and diarrhea among Hiroshima survivors who were exposed indoors and did not enter the central region found by O-ho11) are shown in Fig. 6. As is seen in this figure, the incidence rates of purpura shown by closed circles are of similar to those of epilation shown by squares. The same normal distribution of epilation is then used for the incidence rate-exposure relation of purpura. Incidence rates of diarrhea, shown by triangles, are very large compared to epilation or purpura in the distant regions beyond 1.5 km where the fallout exposure gave significant effects. The incidence rates of diarrhea were rather small in the short distance regions where the initial nuclear radiation exposure dominated. Therefore, in the case of diarrhea, a larger expectation value for the normal distribution than those for epilation and purpura is required for external exposure from the initial nuclear radiation, and a smaller expectation value is required for the fallout exposure. The adapted expectation values and standard deviations are listed in Table II and were obtained by multiplying the ratios shown there. Using the normal distributions with expectation values and standard deviations given in Table II, the incidence rates of epilation, purpura and diarrhea are fitted in Fig. 6 and the resulting incidence rates are displayed by thin dashed, solid and chain curves for epilation, purpura and diarrhea, respectively, whose parameters for formulae (1) and (2) are listed in Table III.

Table II Normal distributions of incidence rate-exposure dose relations of acute radiation diseases

Acute disease		Ratio	Expectation value (Gy)	Standard deviation (Gy)
Epilation		1	2.751	0.794
Purpura		1	2.751	0.794
Diarrhea	Initial nuclear radiation	1.1	3.026	0.873
	Fallout exposure	0.72	1.981	0.572

Table III Parameters in formulae (1) and (2) of exposed doses from incidence rates of epilation, purpura and diarrhea

	Initial nuclear rad. exposure $cP(r)$	Fallout radiation exposure $F(r)$		
	c shielding effect	a (Gy/km) magnitude	b (km) extension	d (Gy) constant part
Epilation (1,0.52)	0.5 (fix)	0.984	2.07	0.855
Purpura (3, 3.2)	0.5 (fix)	0.995	2.36	0.713
Diarrhea (5,12.7)	0.511	0.959	2.37	0.743

In this analysis of epilation and purpura the shielding effect parameter c is fixed at 0.5 and the data on incidence rates of these diseases at 1 km are omitted because when these data for epilation and purpura are used, unnaturally small values of c, 0.22 and 0.23 are obtained. These unnatural small values at 1 km may be explained by a similar reason to that for the incidence rates of epilation among the LSS in the large exposed region given by Stram and Mizuno, i.e., many died.

The results of exposure doses calculated from the calculated parameters listed in Table III are shown in Fig. 7. As seen in this figure, incidence rates of three entirely different acute diseases are reproduced with high accuracy by almost similar exposure doses. This fact tells us that epilation and diarrhea as well as purpura occurred in the regions where the initial nuclear radiation could scarcely reach and were caused by fallout radiation, not by mental shock or by poor sanitary conditions.

The fact that the expectation value of the normal distribution of diarrhea incidence is small for fallout exposure but large for the initial nuclear exposure can be explained by a difference between external and internal exposures, as follows. In the case of fallout exposure, radioactive fine particles and radionuclides with specific affinity for biological materials and tissues among fallout were taken into body, directly reached the intestinal wall and were retained there for a period of time. The emitted radiation, which had weak penetration power, then caused dense ionization and heavy damage to the thin membrane, and diarrhea followed. The exposure was chronic as the particulate and chemical radioisotopic material (e.g. Sr-90, Cs-137) was retained for some time. On the other hand, in cases of instantaneous acute initial nuclear radiation exposure only strong penetrative radiation such as gamma rays could reach from outside of the body to the intestinal wall, but passed away through the thin membrane leaving scarcely any damage.

§7 Summary and Discussion

As described in the foregoing sections, the exposure effects of fallout from the Hiroshima atomic bombing estimated from incidence rates of acute diseases among survivors are very large and extended to a wide area. Effects of exposure to fallout radiation were greater than the effects of initial nuclear prompt radiation beyond about 1.2 km from the hypocenter and decreased slowly with distance, remaining at about 0.7-0.8 Gy even at 6 km. The maximum exposure effects from fallout of 0.02 Gy at Takasu, the special region located 3 km west from the Hiroshima hypocenter were obtained from physical measurement of radiation emitted from radioactive nuclei brought by fallout rain and retained in the soil. Fallout exposure effects estimated from acute diseases were between 1.1 Gy and 1.3 Gy at 3 km from the hypocenter, irrespective of direction from the hypocenter. This large difference between physical measurements and biological estimations of fallout exposure implies that the main exposure effects were either caused by widely distributed fine fallout particles, resulting in internal exposure due to their intake, or by an error in the currently accepted radiobiological effectiveness of certain ingested or inhaled isotopic components of the fallout.

Since the various examinations of incidence rates of acute radiation induced diseases analyzed here give almost the same results for fallout exposure, the greatest ambiguity of obtained exposure doses arises from ambiguity in the relations between the incidence rates and exposure dose used here; that is, ambiguity in the expectation values and values of the standard deviation of the generated normal distributions. However, if the fallout radiation exposure of 1.0 to 1.5 Gy obtained here is added to the initial nuclear prompt radiation exposures in the region between 1 Gy and 3 Gy, which corresponds to exposure distances between 1.0 km and 1.2 km, and to epilation incidence rates of about 10%, which correspond to the difference between the solid line and the broken line in the region between 1km and 1.2 km in Fig. 2, then the broken line in Fig. 1 shifts to the higher dose direction and higher incidence rate direction and almost overlaps with the solid line obtained by Kyoizumi et al., as shown by black squares in Fig. 8. The unnaturally rapid increase in the incidence rate of epilation in the near zero dose region of the Stram-

Mizuno relation, shown in Fig. 1, can be correlated to the decreases of incidence rates in the region between 1.5 km and 3 km from the hypocenter where the initial nuclear radiation exposures were between 0 to 1 Gy. This fact supports the conclusion that the relation between the incidence rates and exposure dose among survivors is not much different from that used here on the basis of the relation given by Kyoizumi et al.

The results obtained here do not contradict results of investigations of chromosomal aberration among survivors. The frequency of chromosome aberrations in circulating lymphocytes of survivors of the Hiroshima bombing was compared with 11 non-irradiated healthy controls visiting the Japan Red Cross Central Hospital in Tokyo between April 1967 and March 1968 by Miyata and Sasaki[12]. It was found that more than 1.6 km from the hypocenter, the effects of exposure from fallout estimated from frequency of chromosomal aberration exceeded the effects of the initial nuclear irradiation. If we note that the estimated dose based on the frequency of chromosomal aberrations in circulating lymphocytes represents the effects averaged over the whole body, and that local effects from insoluble radioactive particles or other internal isotopic exposures, which are considered in the incidence rates of acute diseases, are not included, then the present results from acute diseases do not contradict those obtained from chromosomal aberration.

The present results from incidence rates of acute diseases also do not contradict the similar results of investigation of chronic aftereffects in the LSS of RERF. Schmitz-Feuerhake[13] obtained the standard relative risks, mortality ratios, and incidence rates of various diseases in the LSS control groups, who were exposed to less than 0.09 Gy according to the 1965 tentative dosimetry system (T65D), compared with all Japanese. The standard risks for mortality from all causes and all diseases were less than unity (this was in the results for survivors in the early 1980's, but these risks are now almost unity or slightly larger than unity) indicating that the control cohort of LSS was healthier than the Japanese average. However, the high relative risk of death from leukemia and cancer of the respiratory system and the incidence of thyroid and female breast cancer in the control group showed that they had been affected by fallout radiation. A recent study by Watanabe et al.[14] on the mortality of the LSS Hiroshima group from all diseases and various cancers compared with those of all inhabitants of Hiroshima prefecture and with those of all Okayama prefecture, a neighbor prefecture of Hiroshima, indicates comparable effects of fallout exposure with the present estimation among extremely low exposure groups (exposed from initial nuclear radiation less than 0.005 Sv) and low exposure groups (exposed from initial nuclear radiation between 0.005 Sv and 0.1 Sv) of the LSS.

Using the same method employed here, similar effects from the residual nuclear radiation exposure can be estimated for the survivors of Nagasaki as well as for the 'entrant survivors' who entered regions about 1 km from the hypocenter after the explosion of atomic bomb and who were exposed to residual nuclear radiation emitted by induced radioactive matter. The estimated results from these cases will be reported elsewhere.

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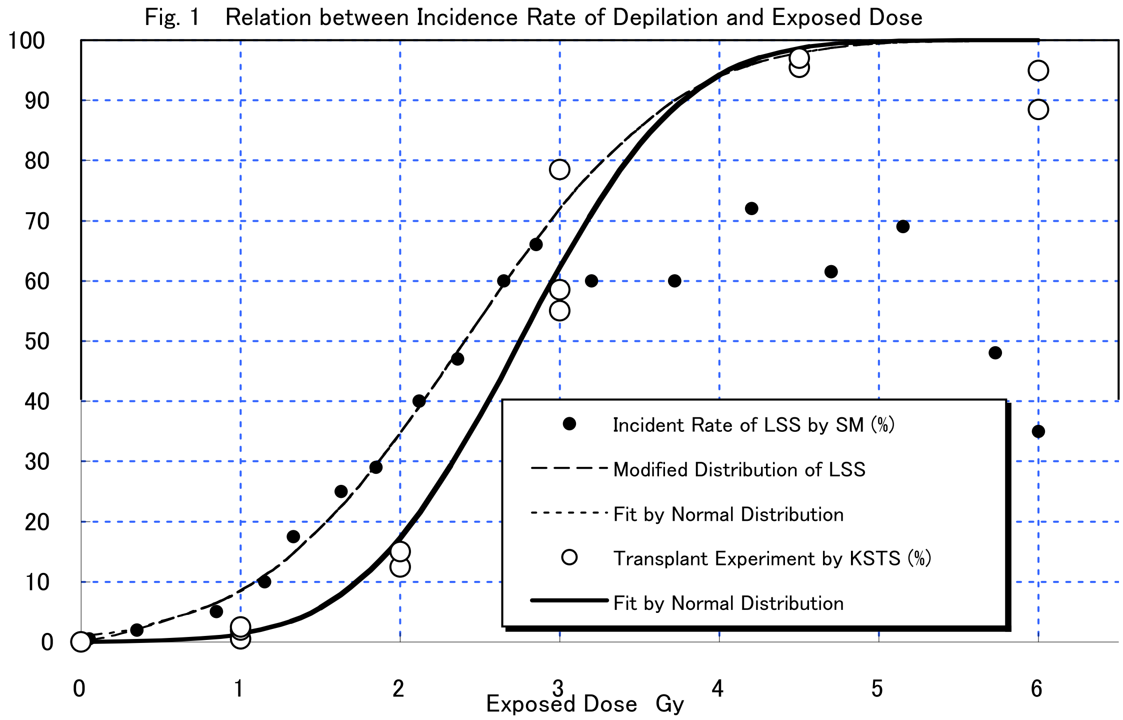

Fig. 1 Relation between incidence rates of epilation and exposure dose. Closed circles are incidence rates of epilation among the LSS-Hiroshima group against initial nuclear exposure dose obtained by Stram and Mizuno. The dashed line is the fitted curve of the modified normal distribution to the closed circles below the 3 Gy region. Open circles are incidence rates from the transplant experiment by Kyoizumi et al. The bold solid line is the normal distribution fitted curve.

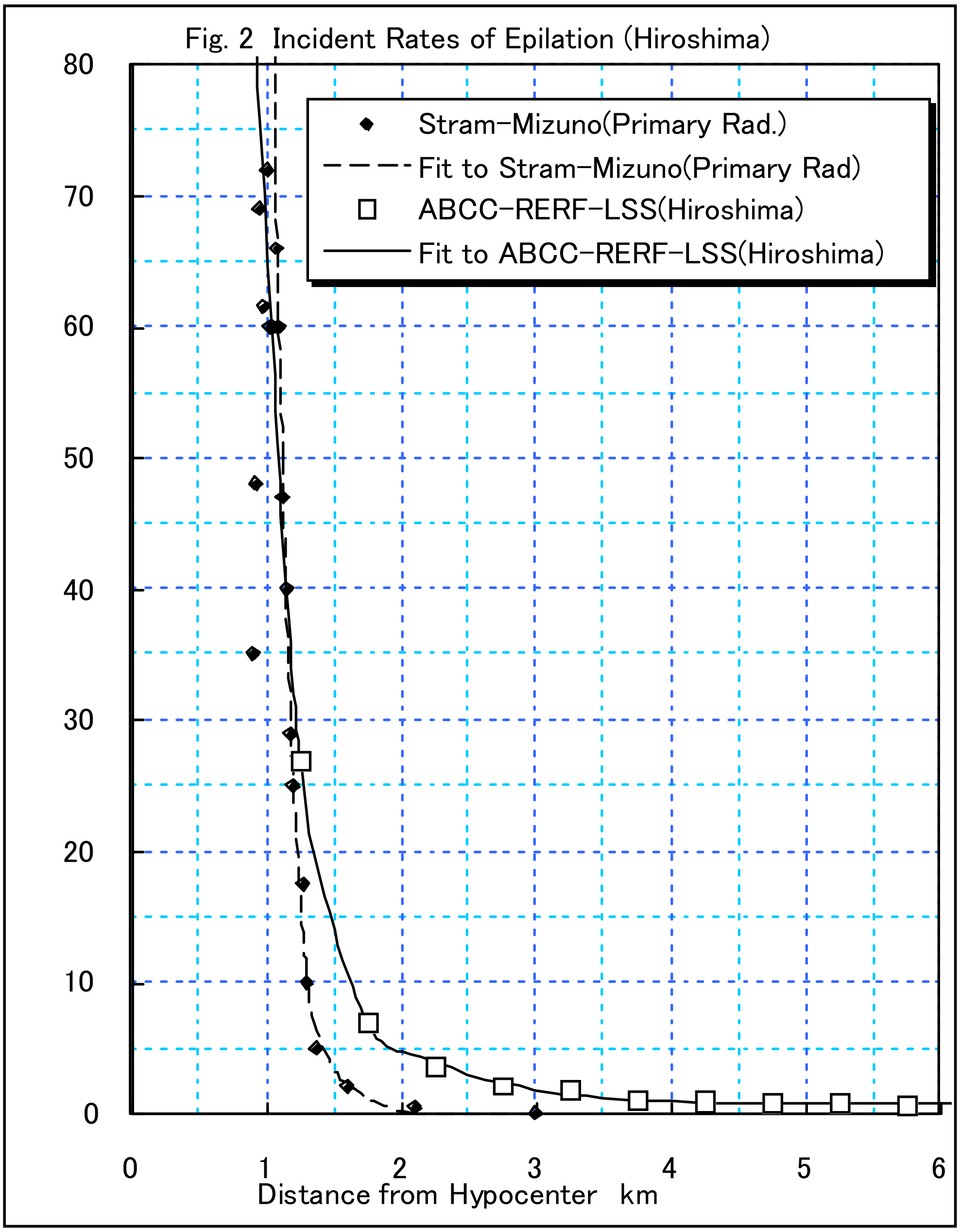

Fig. 2　Incidence rates of epilation of LSS Hiroshima.　Squares indicate the incidence rates of epilation among Hiroshima survivors of the LSS.　The solid line shows the curve fitted by formula (1) and (2) with the minimum value of χ^2 of about 10, which is below 14.1, the lower limit of 5% of the rejection area of χ^2 distribution of freedom degree (FD) 7.　Black diamonds show the approximate incidence rates corresponding to the initial nuclear radiation.

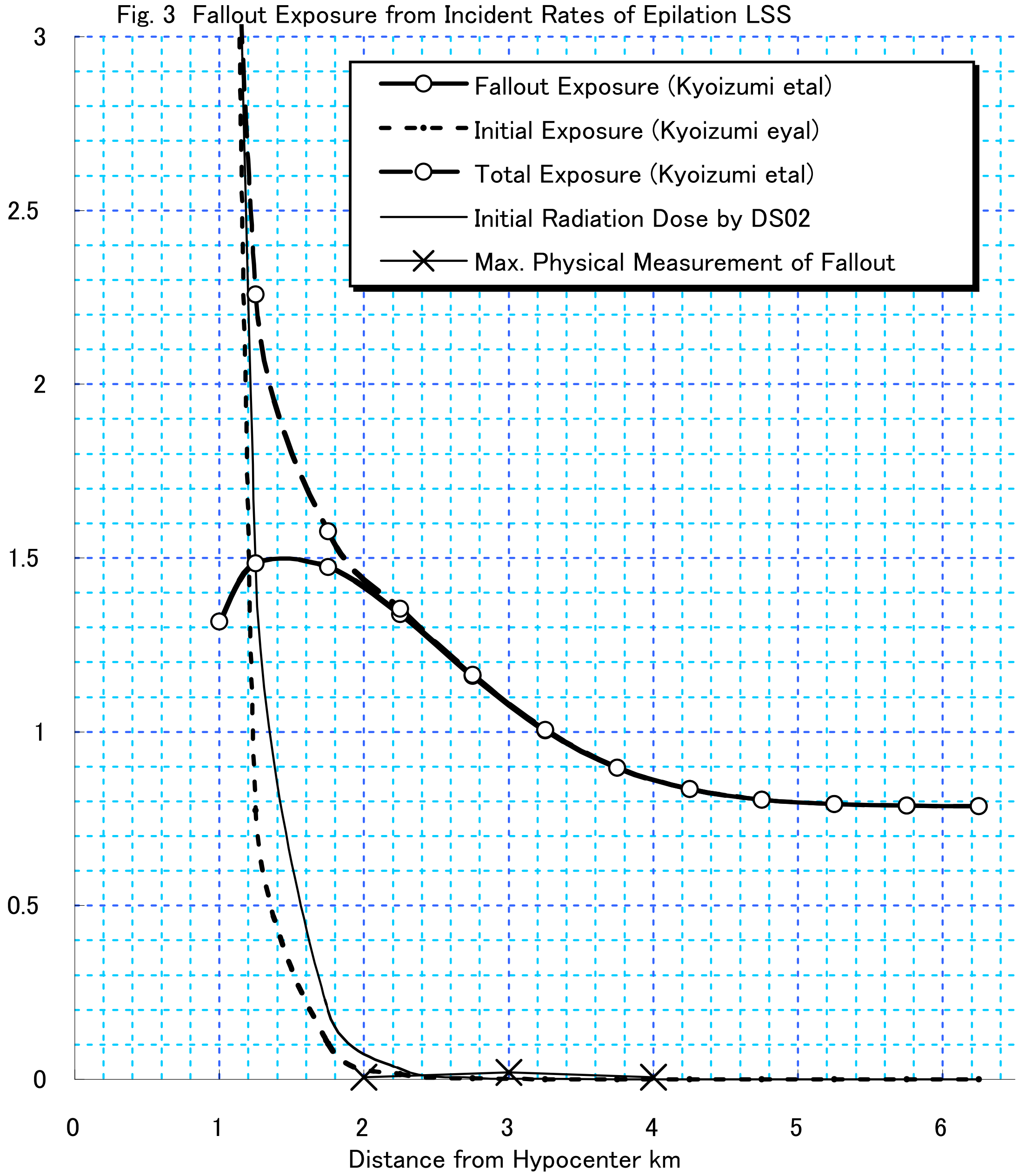

Fig. 3 Exposure doses estimated from the incidence rates of epilation among the LSS Hiroshima group. Total, initial nuclear and fallout exposures are given by bold dashed, bold solid, and thin dashed lines, respectively. The initial nuclear radiation absorption dose is estimated by DS02 and is shown by the thin solid line. Physically measured maximum exposures from fallout in Koi-Takasu region are shown by cross marks.

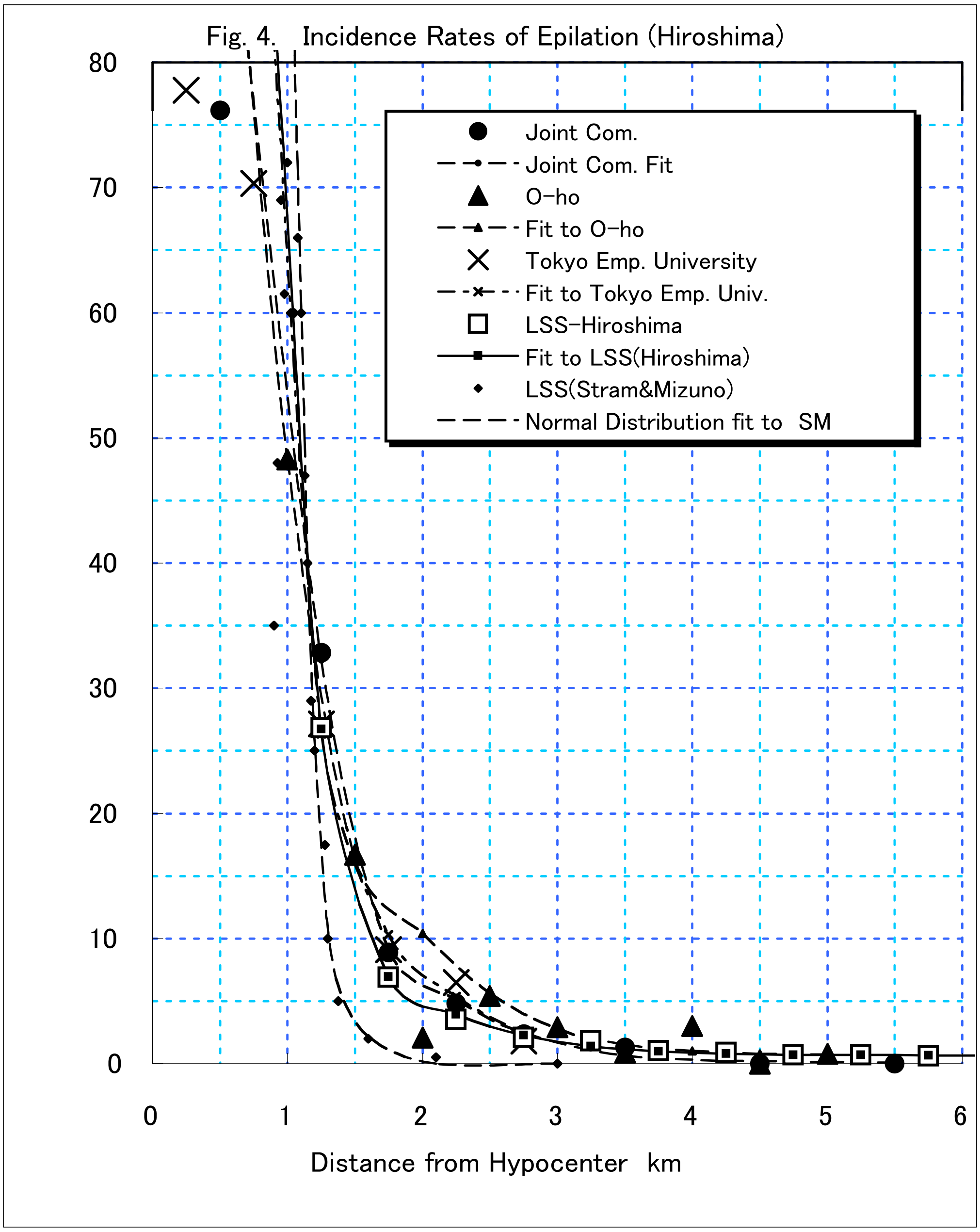

Fig. 4 Incidence rates of epilation among Hiroshima survivors. The marks □, ●, × and ▲ are incidence rates examined by ABCC, the Joint Commission, Tokyo Imperial University and O-ho, respectively. The χ^2 values fitted to Joint Com. and Tokyo Imp. Univ. examinations are 4.2 and 5.6, respectively, compared to 6.6, the lower limit value of the 1% risk region of χ^2 distribution of DF 1. The χ^2 value fitted to the O-ho case is 3.3 compared to 9.2, the lower limit of 1% risk region of χ^2 distribution of DF 2.

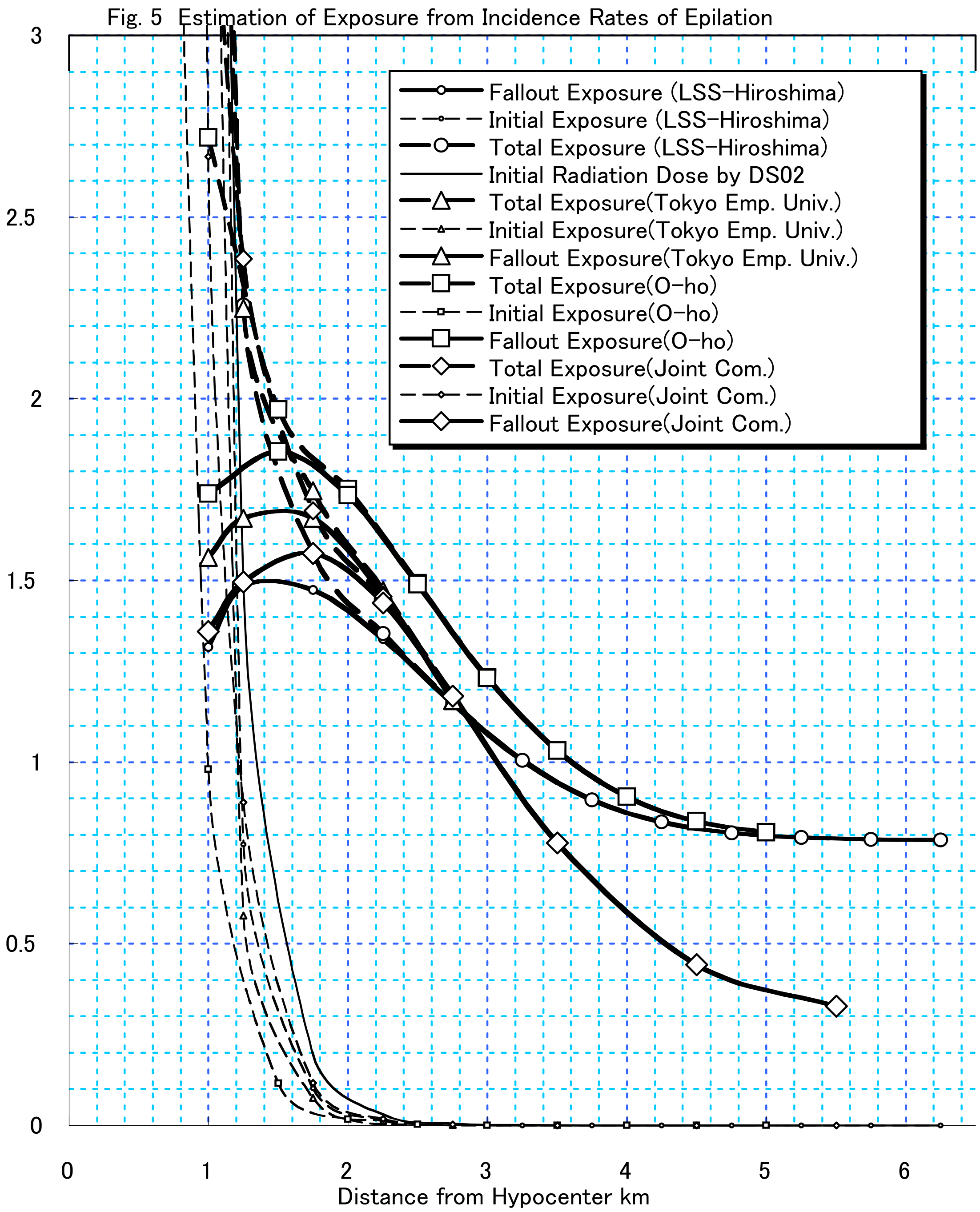

Fig. 5 Estimation of exposures from incidence rates of epilation among the Hiroshima survivors. Total, initial nuclear and fallout exposures are shown by bold dashed lines, thin dashed lines and bold solid lines, respectively. The marks ○, ◇, △ and □ indicate findings by ABCC, Joint Commission, Tokyo Imperial University and O-ho.

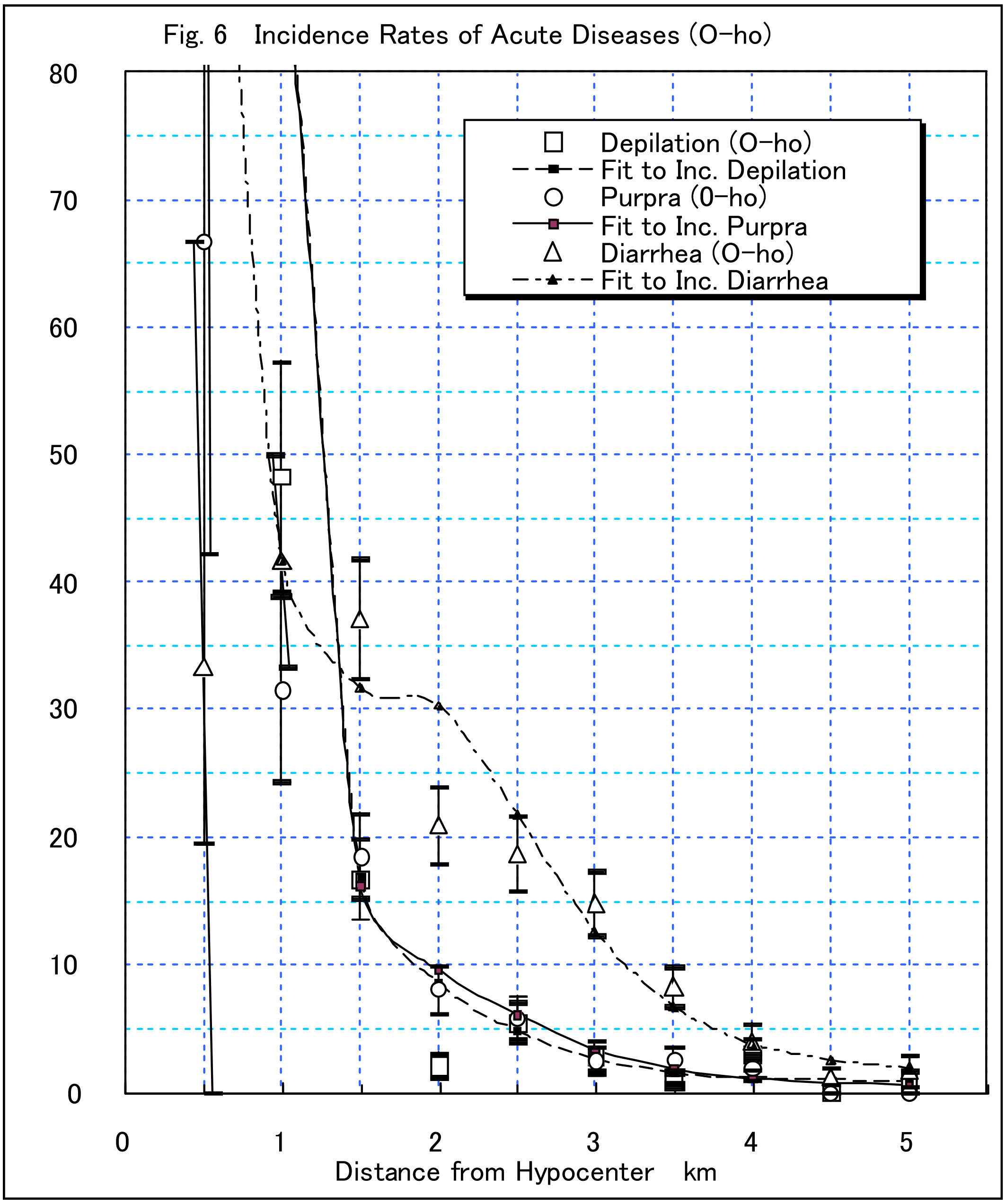

Fig. 6 Incidence rates of acute diseases among survivors who were exposed indoors and did not enter the central region within 1 km from the hypocenter within 3 months. Marks □, ○ and △ indicate incidence rates of epilation, purpura and diarrhea, respectively. Solid line, dashed line and chain line are fitted curves to the incidence rates of epilation, purpura and diarrhea with χ^2 values 0.52, 3.2 and 13.3 compared to 9.5, 12.6 and 16.9, and the lower limit of 5% rejection area of χ^2 distribution of FD of 4, 6 and 9, respectively.

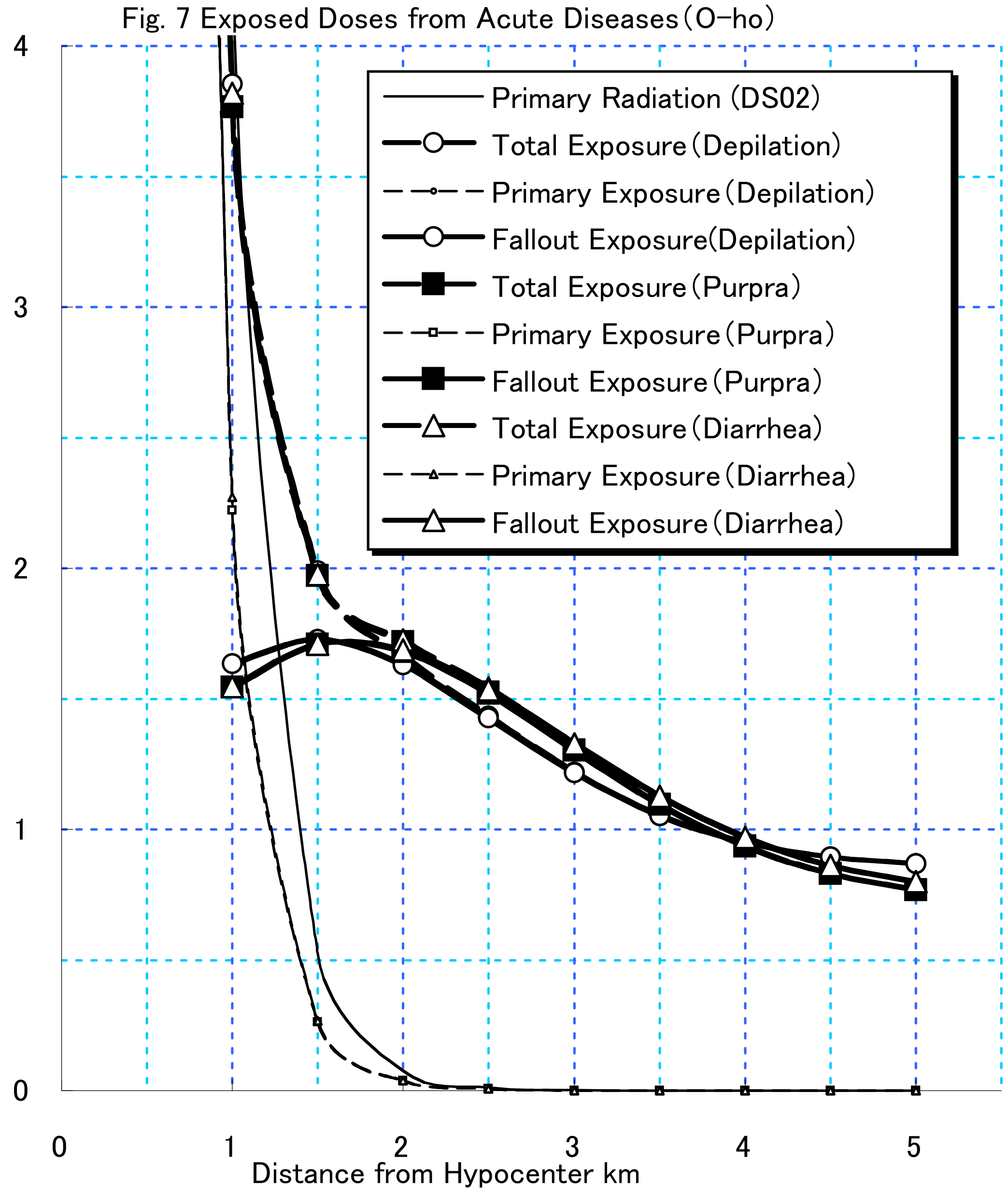

Fig. 7 Exposed doses from acute diseases. Attached marks ○, ■ and △ indicate estimations from incidence rates of epilation, purpura and diarrhea. Total, initial nuclear, and fallout exposure are specified by bold dashed, thin dashed and bold solid lines, respectively. The initial nuclear radiation dose given by DS02 is represented by a thin solid line.

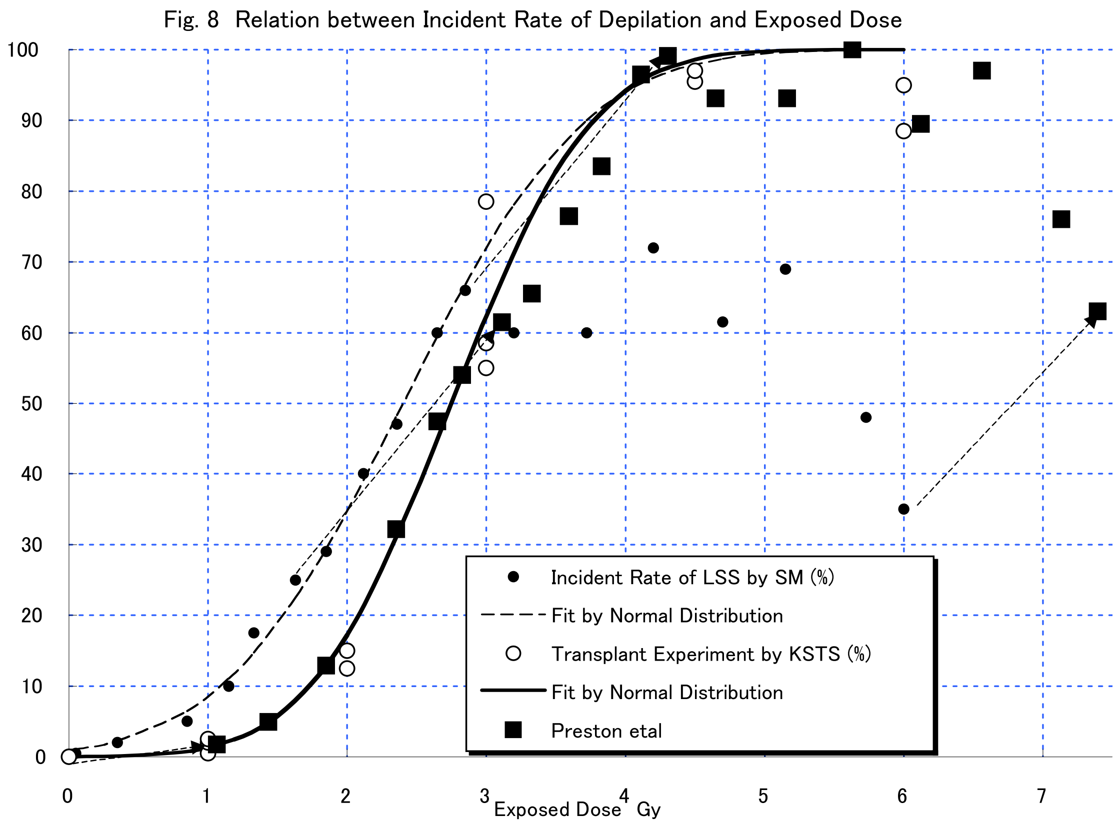

Fig. 8 Relation between incidence rates of epilation and exposure dose. Closed circles are incidence rates of epilation among LSS-Hiroshima group against initial nuclear exposure dose obtained by Stram and Mizuno. Open circles are incidence rates from the transplant experiment by Kyoizumi et al. The bold solid line is the normal distribution fitted curve. The black squares are incidence rates of epilation among LSS-Hiroshima group by Preston et al. against total exposure dose including fallout radiation.