Is Chronic Radiation an Effective Prophylaxis Against Cancer?

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ABSTRACT

An extraordinary incident occurred 20 years ago in Taiwan. Recycled steel, accidentally contaminated with cobalt-60 (half-life: 5.3 y), was formed into construction steel for more than 180 buildings, which 10,000 persons occupied for 9 to 20 years. They unknowingly received radiation doses that averaged 0.4 Sv—a "collective dose" of 4,000 person-Sv.

Based on the observed seven cancer deaths, the cancer mortality rate for this population was assessed to be 3.5 per 100,000 person-years. Three children were born with congenital heart malformations, indicating a prevalence rate of 1.5 cases per 1,000 children under age 19.

The average spontaneous cancer death rate in the general population of Taiwan over these 20 years is 116 persons per 100,000 person-years. Based upon partial official statistics and hospital experience, the prevalence rate of congenital malformation is 23 cases per 1,000 children. Assuming the age and income distributions of these persons are the same as for the general population, it appears that significant beneficial health effects may be associated with this chronic radiation exposure.

The findings of this study are such a departure from expectations, based on International Commission on Radiological Protection (ICRP) criteria, that we believe that they ought to be carefully reviewed by other, independent organizations and that population data not available to the authors be provided, so that a fully qualified, epidemiologically valid analysis can be made. Many of the confounding factors that limit other studies used to date, such as those of the A-bomb survivors, the Mayak workers, and the Chernobyl evacuees, are not present in this population exposure. It should be one of the most important events on which to base radiation-protection standards.

The data on reduced cancer mortality and congenital malformations are compatible with the phenomenon of radiation hormesis, an adaptive response of biological organisms to low levels of radiation stress or damage–a modest overcompensation to a disruption–resulting in improved fitness. Recent assessments of more than a century of data have led to the formulation of a well-founded scientific model of this phenomenon.

The experience of these 10,000 persons suggests that long-term exposure to radiation, at a dose rate of the order of 50 mSv (5 rem) per year, greatly reduces cancer mortality, which is a major cause of death in North America. Medical scientists and organizations may wish to seriously assess this and other current evidence in deciding whether chronic radiation could be an effective agent for enhancing defenses against cancer.

Introduction

Recycled steel, accidentally contaminated with discarded cobalt-60 sources (half-life: 5.3 y), was formed into construction steel for more than 180 buildings containing about 1,700 apartments, and also public and private schools and small businesses, in Taipei City and nearby counties. While this construction occurred during 1982-84, most of the buildings were completed in 1983.[1,2]

In this preliminary assessment, we consider 1983 to be the first year of the incident. The radioactive state of the buildings was gradually discovered, beginning July 31, 1992.[2] Fewer than 100 contaminated apartments were identified in 1992. The number increased to more than 200 in 1993; 896 in 1995; 1,206 in 1996; and 1,277 in 1997. An intensive research program was conducted in 1998, and radiation levels in more than 1,600 apartments were finally documented by the Atomic Energy Council (AEC) of Taiwan.

After approximately four cobalt-60 half-lives, most of the apartments now have relatively low levels of radiation, less than 5 mSv (500 mrem) per year, and are still in use. In 1996, residents began to be evacuated from apartments with high radiation levels, and half of them have been moved as of 2003. They all lived in these buildings for at least 9 years, with some staying as long as 20 years.

Measurement of Dose Rate in Affected Apartments

Dose rates were measured with very accurate GM survey meters calibrated in dose-equivalent units: Sv/hr. Doses were carefully determined using an AEC procedure specifically designed for this project. For evaluating the average dose to residents, their average occupancy time was conservatively taken as 12 hours in living rooms, eight hours in bedrooms, and four hours at other locations (i.e., half of the residents were assumed to be outside eight hours per day.)[1] The dose evaluations were used to classify the apartment dwellers into three cohorts, based on contamination level (average dose rate), for government remedial measures and care:[3] The high-contamination cohort (~11%) received >15 mSv/y. The moderate-contamination cohort (~9%) received between 5 and 15 mSv/y. The low-contamination cohort (~80%) received between 1 and 5 mSv/y.

Number of Persons Affected

More than 1,600 persons who lived in apartments that were highly and moderately radioactive (dose rate > 5 mSv/y) were registered, and more than 2,400 persons in the apartments with low radioactivity (1 to 5 mSv/y).

The AEC studies, beginning in 1992, indicated that the average dose rate in 20 percent of the apartments was more than 5 mSv/y. Assuming the remaining 80 percent of the apartments had the same occupancy rate, the number in those apartments was estimated to be (1,600)(0.8/0.2) = 6,400, giving a total of approximately 8,000 residents.

A kindergarten child, who had occupied a radioactive classroom, died of leukemia in 1996, and another pupil died of leukemia in 2000. As a result, about 2,000 students were registered as affected. In international symposia in Taiwan and Japan, specialists recommended increasing the number of affected persons to approximately 10,000. Therefore, we used this number in this assessment.

The number of affected persons is open to discussion. The Radiation Safety and Protection Association in Taiwan (RSPAT) estimated that the total number might be as high as 15,000, but such a figure would include persons present in the public areas of the buildings who would have received only very short-term exposures.

Estimate of Doses in Contaminated Apartments

An estimation of the integrated doses to the residents was necessary to assess the health effects of the radiation exposures. Several dose-reconstruction studies were done and reported in national and international journals. Some used thermo-luminescent detectors (TLDs) at different positions of the body;[4] some used suspended TLDs in air;[5] some relied on TLD necklaces,[6] and some used Rondo phantoms.[7] Our evaluation used a simplified method to approximate the doses the residents received and to modify the AEC doses, estimated by the task team from the Institute of Nuclear Energy Research (INER), with reasonable factors.

In December 1996, the AEC estimated that 20 percent of the residents received an annual (1996) dose in the range from 5 to 160 mSv, and therefore, 80 percent of the residents received a dose of less than 5 mSv.[1] A crude estimate of the average 1996 dose for each cohort is: High-dose cohort (~11%), (160 + 15)/2 = 87.5 mSv; moderate-dose cohort (~9%), (15 + 5)/2 = 10 mSv; low-dose cohort (~80%), (5 + 1)/2 = 3 mSv.

Therefore, in 1996 the mean annual dose received by all the residents was approximately 13 mSv, or (87.5)(0.11) + (10)(0.09) + (3)(0.80), and the maximum dose was 160 mSv.

Table 1. **Annual and Accumulated Doses**

Cohort	Number of persons	Mean annual dose in first year 1983 (mSv)	1983 to 2003 individual dose (mSv)	1983 to 2003 "collective dose" (person-Sv)
High*	1,100	525	4,000	2,660
Medium	900	60	420	378
Low	8,000	18	120	960
Averaged	10,000	74	600	6,000
Adjusted	10,000	49	400	4,000

*after July 1996, 50% of residents relocated

For the year 1983, we calculate the mean dose to be about 74 mSv, and the maximum to be about 910 mSv. Adjusting the mean dose for a residency factor of 0.7 and a correction of 0.95 to TLD doses gives 49 mSv. The individual mean dose from 1983 until 2003 was 0.40 Sv for all cohorts. For the high-dose cohort, the mean dose was 4 Sv, with a maximum of 6 Sv, assuming half the residents moved out in 1996. The doses are summarized in Table 1.

A detailed reconstruction of individual doses for residents of apartments with moderate and low-level contamination was recently published.[8] These reconstructed doses are several times lower than the maximal doses assessed by the AEC.

Observed Health Effects

Medical Examinations

Residents with annual doses greater than 5 mSv received medical examinations in AEC-contracted hospitals,[1] and those with annual doses of 1 to 5 mSv were provided examinations by the city of Taipei.[9] Residents of apartments that had normal background radiation (< 1 mSv/y) received medical examinations on request. Additionally, 13 of the highly exposed residents were sent to Mazda Hospital in Hiroshima, Japan, to undergo the medical examination protocol conducted for the survivors of the 1945 atomic bombing.[10]

Overall Health Effects

Although many of the residents had received high total doses of radiation, the medical examinations did not reveal the presence of any harmful radiation sickness syndromes such as were seen in survivors of the atomic bombing or in acutely irradiated reactor workers following the Chernobyl accident.[11,12]

When residents in one of the highly radioactive buildings sued the government for compensation, officials from the concerned hospitals testified that they had no evidence that the radiation had caused any harmful effects.[1] When a kindergarten child who had attended a radioactive school later died of leukemia and another pupil who was in a radioactive school also died of leukemia, the newspapers reported the opinion of a radiation specialist that a few children were shorter in stature than average, and that there had been indications of abnormal thyroids in some children. These reports were not substantiated in our study.

Cytogenetic Examinations

Because many chromosomal aberration studies were conducted on the Japanese atomic bomb survivors and on reactor workers following the Chernobyl accident, a number of chromosome aberration analyses were conducted on irradiated residents. All those who received annual dose rates greater than 15 mSv/y or accumulated doses greater than 1 Sv were asked to give a blood sample for chromosomal aberration studies. Analyses of these samples were carried out by the INER Laboratory.

No significant aberrations were observed, compared with test results of new INER employees.[13] Reports were also published in the AEC annual research and development achievements symposium and in several international journals. The reports indicated that no chromosome changes and no dose-effect relationships were observed.[14, 15] One group of specialists studying the residents in the Min-Sheng Villa, a highly radioactive building, found that the frequency of micronuclei formation was higher than that seen in controls and that the lymphocytes of another group of residents were different from those of the control group.[16,17]

The interpretation of these findings is that low-dose and low-dose-rate gamma radiation from any source of radiation induces cellular changes, but there is no indication that these changes produced any adverse health effect. The overall conclusion of the AEC is that the chromosome aberration studies indicated that groups that received higher doses seemed to have lower levels of chromosome aberrations.[1]

Comparison With the International Commission on Radiological Protection (ICRP) Models

The "collective dose" of the exposed population is approximately 4,000 person-Sv. Had the exposure been short term (acute), the linear no-threshold (LNT) hypothesis of radiation carcinogenesis would predict (4,000)(7.8)(10^{-2}) or 312 stochastic *excess* cancer fatalities, with a latency of approximately 20 years. Since it was a chronic exposure, a hypothetical risk reduction factor between 2 and 10 could be applied.[18]

From the experience of the Life Span Study (LSS) of the Radiation Effects Research Foundation (RERF), such hypothetical excess solid cancer deaths would be difficult to discern from the natural (spontaneous) cancer deaths of the residents, especially after 20 years. But excess leukemia deaths, which have a much shorter latency period, should be readily observable, especially among those who received a total dose greater than 1 Sv.[19] Based upon the ICRP model, 70 excess leukemia and solid cancers deaths would be reasonably expected after 20 years, in addition to the number of spontaneous cancer deaths. In fact, a total of only two leukemia and only five solid cancer deaths were actually observed. The AEC did not attribute the two (child) leukemia deaths to radiation exposure.

Assuming the exposed population has the same age distribution as the population of Taiwan in 2002, about 40 percent of the exposed persons were in the reproductive age range, and their collective dose would be (0.40)(4,000) = 1,600 person-Sv. For this dose, the standard ICRP model predicts that $(1600)(1.3)(10^{-2})$ or 21 children with observable congenital malformations would be born, in excess of the usual number of children born with such hereditary defects.[18] In fact, only three children were born with congenital heart disease, and they are still in good condition. No other congenital malformations were observed.

In these comparisons, the health effects observed strongly contradict the predictions of the ICRP models. The actual number of cancer deaths and the actual number of congenital malformations are many times *smaller* than the numbers expected, based on the natural incidence of cancer mortality and natural incidence of congenital malformations (see below), whereas the ICRP models predict numbers in *excess* of the natural incidences.

Comparison of Health Effects: Exposed vs. Non-Exposed Persons

Cancer

The mean cancer mortality in Taiwan during the period 1983-2002 (Figure 1) is 116 deaths per 100,000 person-years.[20] (The rising incidence is probably attributable to the increasing life expectancy of the population, as in most modern countries.) Assuming the cancer mortality in 2003 is the same as in 2002, the number of spontaneous cancer deaths that would be expected among the 10,000 persons over 20 years would be 232 deaths, that is (10,000)(20)(116/100,000).

Based on the investigation conducted by the RSPAT,[10] the total number of cancer deaths among these residents is only 7 in 200,000 person-years, or 3.5 deaths per 100,000 person-years–only 3 percent of the rate (i.e., 116) expected for the general population!

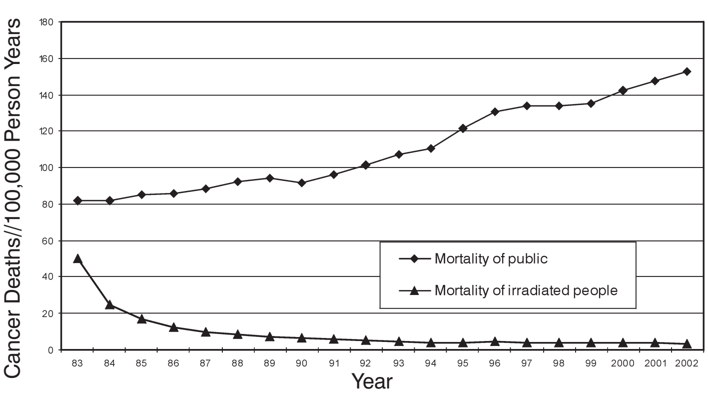

Figure 1. Cancer Mortality of the General Population and of the Exposed Population

The cancer mortality rate of the exposed population is also shown in Figure 1. Both the cancer deaths and the cancer mortality rate differences have high statistical significance ($P < 0.001$). The mortality rate from all causes was not studied; only cancer mortality and congenital malformations were considered to be of interest in this population.

Congenital Malformations

While there is no complete, official prevalence rate for congenital malformations in Taiwan, some estimates are available. Based upon partial official statistics[20] and hospital experiences described in the media, there are about 23 cases per 1,000 children, including two infant deaths attributed to congenital malformations in 1,000 births, about two cases of Down's syndrome, and about 0.4 cases of cerebral palsy per 1,000 children.

Assuming a population of 2,000 children under age 19 among the residents, an incidence of about 46 children with congenital abnormalities would be expected. Yet in fact, only three children, who are still in good condition, were observed to have congenital malformations (heart disease).[10] The congenital abnormality rate for this population appears to be only 6.5 percent of the rate for general population (3/46). This difference is also highly significant ($P < 0.001$).

Table 2 summarizes the comparisons between exposed and non-exposed populations.

Table 2. Natural, Predicted, and Observed 20-Year Results

Natural (expected) cancer deaths	Natural (expected) congenital malformations	ICRP model predicted cancer deaths	ICRP model predicted congenital malformations	Observed cancer deaths	Observed congenital malformations
232	46	302	67	7	3
Includes 4-5 leukemia deaths	All congenital diseases	232 natural plus 70 caused by radiation	46 natural plus 21 caused by radiation	3% of the general public cancer death rate	6.5% of the general public congenital disease rate

Discussion

Potential Confounding Variables

The results of this study strongly suggest that whole-body chronic irradiation, in the dose-rate range that the apartment residents received, caused no symptomatic adverse health effects, such as radiation sickness or the increased cancer or increased congenital disease that are predicted by ICRP theories. On the contrary, those who were exposed had lower incidences of cancer mortality and congenital malformations.

In such studies, it is very important to examine the confounding factors that could possibly affect the comparisons being made between the exposed population and the general population of Taiwan. Are there qualitative differences in the two populations? Although it is a critical factor, the age distribution of the exposed population has not yet been determined, and it was assumed that the age distribution of the exposed population is the same as that of the general Taiwan population.

However, the 2,000 students who were included definitely have a different distribution. Those in kindergarten are ages 3 to 5, and those in elementary school are ages 6 to 12. Their average cancer mortality is only 2-4 persons/100,000. They should not be included in the affected cohort, and should be subjects of a separate study. If the students are not included, the expected and predicted cancer death rates in the 8,000-person cohort would be 20 percent lower

Table 3. Natural, Predicted, and Observed Results for 8,000 Apartment Residents

Natural (expected) cancer deaths	Natural (expected) congenital malformations	ICRP model predicted cancer deaths	ICRP model predicted congenital malformations	Observed cancer deaths	Observed congenital malformations
186	46	242	67	5	3
Includes 4-5 leukemia deaths	All congenital diseases	186 natural plus 56caused by radiation	46 natural plus 21 caused by radiation	2.7% of the general public cancer death rate	6.5% of the general public congenital disease rate

than those in the 10,000-person cohort, and the number of cancer deaths would be five, as shown in Table 3. But the number of congenital malformations will remain the same because the 2,000 students were not born in the affected apartments.

Another important consideration is standard of living, as this affects diet and quality of medical care. This factor was reviewed, and it was determined that the residents have approximately the same distribution of income as the general populace.

Radiation Hormesis

How can such reductions in cancer and congenital malformations be explained?

Radiation scientists, medical practitioners, and toxicologists have long recognized beneficial health effects from acute, whole-body exposures to low doses and from chronic exposures to low dose rates of ionizing radiation. Many scientists over the past century have studied this phenomenon of radiation hormesis. It is an adaptive response of biological organisms to low levels of radiation stress or damage–a modest overcompensation to disruption–resulting in improved fitness. Recent assessments of more than a century of data have led to the formulation of a well-founded scientific model of this phenomenon.[21-24]

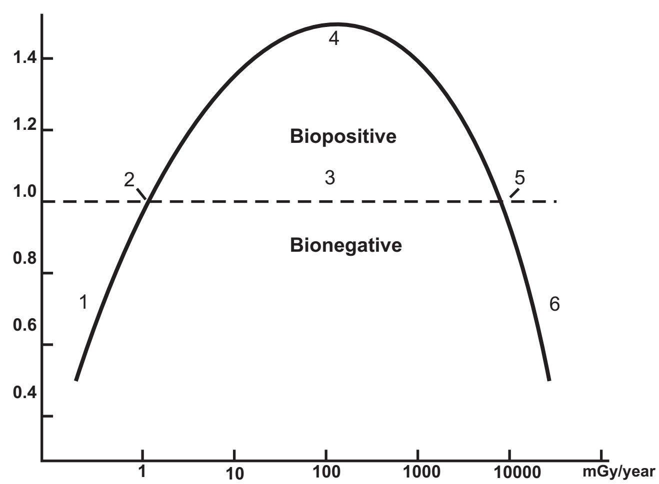

Figure 2. Idealized Dose-Response Curve. The ordinate indicates approximate responses compared with the controls. The abscissa suggests mammalian whole-body exposures as mGy/year. The numbered areas are (1) deficient, (2) ambient, (3) hormetic, (4) optimum, (5) zero equivalent point, and (6) harmful.

Living organisms have very capable defense mechanisms, which are significantly affected by radiation.[24] The typical, non-linear shape of the effect is shown in Figure 2.[21] Unlike the adverse effects of increased rates of cancer and congenital disease associated with chronic dose rates greater than about 10 Gy/year or acute doses greater than about 0.3 Gy–which are stochastic and may have long latency periods–the beneficial effects of low doses are typically observed very soon after the initial radiation exposure and affect all the individuals exposed. In the case of chronic exposure, significant bio-positive effects are observed over a wide range of dose rate: four orders of magnitude, from 1 to 10,000 mGy/y. Hence, similar beneficial effects would be expected for all three exposure cohorts. Recent studies on humans suggest that acute exposures can be employed to treat cancers and prevent metastases.[25]

The concept of beneficial health effects following any exposures to ionizing radiation is very controversial because the LNT hypothesis of radiation carcinogenesis, which is based on the Hiroshima-Nagasaki LSS linear extrapolation to zero dose, is very well established. However, evidence presented in this assessment is quite different from the LSS evidence, and more relevant to chronic population exposures to long-lived radioactive contamination. Accordingly, a detailed, official, government-sponsored epidemiologic study of these residents ought to be carried out to address uncertainties arising from the assumptions made in this study. Such studies have been promised.[26-28]

Dose Estimates

Methods used for dose estimation in this review are simplified. They are probably as accurate as the estimation methods used in the review of the radiation health effects on the Japanese atomic bomb survivors and of the public affected by the Chernobyl accident. In 1997, Cardarelli et al. estimated the doses could be up to 500 times the natural background rate.[4] In 1998, Tung et al. estimated that the maximal annual dose rate in 1983 was as high as 600 mSv/y, and that in 1996 the individual doses ranged from few mSv to several Sv.[5] Even so, we believe that refined dose assessments would not significantly affect the conclusions.

Conclusions and Recommendations

The observation that the cancer mortality rate of the exposed population is only about 3 percent of the cancer mortality rate of the general public (2.7 percent if the students are excluded) is particularly striking and is consistent with the radiation hormesis model. This assessment suggests that chronic irradiation may be a very effective prophylaxis against cancer.

The findings of this study are such a departure from those expected by ICRP criteria that it is important that they are carefully reviewed by other, independent organizations, and that population data not available to the authors be provided, so that a fully qualified, epidemiologically valid analysis can be made. Many of the confounding factors that limit other studies used to date, such as those of the A-bomb survivors, the Mayak workers, and the Chernobyl evacuees, are not present in this population exposure. It could be and should be one of the most important studies on which to base radiation protection standards.

The LNT hypothesis of radiation carcinogenesis results in the notion that all exposures to any amount of radiation are potentially harmful. Because this hypothesis is very well established and because many strong radiation protection organizations are in place, scientists and government officials are very reluctant to seriously consider the implications of the radiation hormesis phenomenon, which has very important public health consequences.

There are many studies in the literature suggesting use of low-dose radiation in cancer treatment.[25] Unfortunately, physicians are generally not taught and are consequently not aware of the scientific evidence for radiation hormesis. The extreme concern about the safety of all nuclear technology applications is largely driven by fears of potential cancers and genetic effects from relatively small exposures to radiation. Ironically, such exposures have been shown to be associated with decreased incidences of cancers and genetic effects.

Over the past 25 years, medical scientists in Japan have been carrying out many studies designed to reveal both beneficial and adverse health effects of low doses of radiation on animals and humans. Scientific investigations on low-dose effects have recently been underway in many other countries. However, in most cases the experiments are either not designed to detect beneficial health effects or, when such effects are observed, they are ignored.[22] Therefore, we recommend that future studies be designed to detect effects consistent with the radiation hormesis model.

The medical evidence from this "serendipitous experiment" suggests that current radiation protection policies and standards are inappropriate. We therefore recommend a reevaluation of these standards, taking into consideration the beneficial as well as harmful effects of radiation.

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