# Effects of Cobalt-60 Exposure on Health of Taiwan Residents Suggest New Approach Needed in Radiation Protection

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**Abstract** – *The conventional approach for radiation protection is based on the ICRP's linear, no threshold (LNT) model of radiation carcinogenesis, which implies that ionizing radiation is always harmful, no matter how small the dose. But a different approach can be derived from the observed health effects of the serendipitous contamination of 1700 apartments in Taiwan with cobalt-60 ($T_{1/2}$ = 5.3 y). This experience indicates that chronic exposure of the whole body to low-dose-rate radiation, even accumulated to a high annual dose, may be beneficial to human health.*

*Approximately 10,000 people occupied these buildings and received an average radiation dose of 0.4 Sv, unknowingly, during a 9-20 year period. They did not suffer a higher incidence of cancer mortality, as the LNT theory would predict. On the contrary, the incidence of cancer deaths in this population was greatly reduced – to about 3 per cent of the incidence of spontaneous cancer death in the general Taiwan public. In addition, the incidence of congenital malformations was also reduced – to about 7 per cent of the incidence in the general public. These observations appear to be compatible with the radiation hormesis model.*

*Information about this Taiwan experience should be communicated to the public worldwide to help allay its fear of radiation and create a positive impression about important radiation applications. Expenditures of many billions of dollars in nuclear reactor operation could be saved and expansion of nuclear electricity generation could be facilitated. In addition, this knowledge would encourage further investigation and implementation of very important applications of total-body, low-dose irradiation to treat and cure many illnesses, including cancer.*

*The findings of this study are such a departure from expectations, based on 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 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.*

## I. INTRODUCTION

An extraordinary incident occurred 20 years ago in Taiwan. Recycled steel, accidentally contaminated with discarded cobalt-60 sources ($T_{1/2}$ = 5.3 y), was formed into construction steel for more than 180 buildings containing about 1700 apartments, and also public and private schools and small businesses, in Taipei City and nearby counties. About ten thousand people occupied these buildings for 9 to 20 years. 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 on July 31, 1992.[2] Less than 100 contaminated apartments were identified in 1992. The number increased to more than 200 in 1993; then to a total of 896 in 1995, 1206 in 1996, and 1277 in 1997. An intensive research program was conducted in 1998, and more than 1600 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 today. Half of the residents in apartments with high radiation levels have been evacuated, starting in 1996. They all lived in these buildings for at least nine years, with some staying as long as 20 years.



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## II. MEASUREMENT OF APARTMENT DOSE RATES

Dose-rates were measured with very accurate GM survey meters calibrated in dose-equivalent units, μSv/hr. Doses were carefully determined using an AEC procedure specifically designed for this project. For evaluating the average dose to the residents, their average occupancy time was conservatively taken as 12 hours in living rooms, 8 hours in bedrooms, and 4 hours at other locations (i.e., half of the residents assumed to be outside 8 hours/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]

- High contamination cohort (~11%): > 15 mSv/y
- Moderate contamination (~9%): 5-15
- Low contamination cohort (~80%): 1-5

## III. NUMBER OF PEOPLE AFFECTED

More than 1600, who lived in apartments that were highly and moderately radioactive (dose rate > 5 mSv/y), were registered, and more than 2400, in the apartments with low radioactivity (1 to 5 mSv/y).

AEC studies, beginning in 1992, indicated that the average dose rate in 20% of the apartments was more than 5 mSv/y. Assuming the remaining 80% of the apartments had the same occupancy rate, the number in those apartments was estimated to be 1600 x 0.8/0.2 = 6400, giving a total of approximately 8000 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 two thousand students were registered as affected. In international symposia in Taiwan and Japan, specialists recommended increasing the number of affected people to approximately 10,000. Therefore, we used this number in this assessment.

The number of affected people is open to some discussion. The Radiation Safety and Protection Association in Taiwan (RSPAT) estimated that the total number of residents might 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.

## IV. ESTIMATE OF DOSES IN 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 have been carried out 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 received by the residents 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% of the residents received an annual (1996) dose in the range from 5 to 160 mSv, therefore, 80% 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 cohort (~11%): (160 + 15)/2 = 87.5 mSv
- Medium cohort (~9%): (15 + 5)/2 10
- Low cohort (~80%): (5 + 1)/2 3

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

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 cohort, the mean dose was 4 Sv, with a maximum of 6 Sv, assuming half of the residents moved out in 1996. The doses are summarized in Table 1.

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

## V. 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, thirteen 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 atomic bombing.[10]

### *Health Effects*

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

When the residents in one of the highly radioactive buildings sued the government for compensation, the concerned hospitals testified that they had no evidence

**Table 1: Annual and accumulated doses**

| Cohort | Number of people | 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 | 4000 | 2,660 (from July 1996, 50% of residents relocated) |
| 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 |

that the radiation had caused any harmful effects.[1] When a kindergarten child who had attended a school with a radioactive window frame later died of leukemia and another pupil who was in a radioactive classroom also died of leukemia, the media reported the opinion of a radiation specialist that a few children were shorter in stature than average and that some children showed indications of abnormal thyroids. These reports were not substantiated in our study.

*Cytogenetic Damage*

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 employees of INER.[13] Reports were also published in the AEC annual R & D 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 ICRP Models*

The "collective dose" of the exposed population is approximately 4000 person-Sv. Had the exposure been short term (acute), the linear no-threshold (LNT) hypothesis of radiation carcinogenesis would predict 4000 x 7.8 x $10^{-2}$ = 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 cancers 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 that the exposed population has the same age distribution as the population of Taiwan in 2002, about 40% of them were in the reproductive age range, and their collective dose would be 40% x 4000 = 1600 person-Sv. For this dose, the standard ICRP model predicts that 1600 x 1.3 x $10^{-2}$ 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 in total were born with congenital heart disease, and they are still in good condition. No other congenital malformations were observed.