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# Epidemiological Investigation of Radiological Effects in High Background Radiation Areas of Yangjiang, China

WEI LUXIN, ZHA YONGRU, TAO ZUFAN, HE WEIHUI, CHEN DEQING AND YUAN YONGLING

High Background Radiation Research Group, Laboratory of Industrial Hygiene, Ministry of Public Health, 2 Xinkang Street, Deshengmenwai, Beijing 100088, China

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## INTRODUCTION

The risk estimates of exposure to ionizing radiation in human populations are based largely on information from intermediate and high doses and dose rates, whereas radiological protection is usually concerned with low dose and low dose rates, specifically with evaluation of health risk associated with doses less than 0.05 Sv per year, received at low dose rates. Many studies have shown that the effects of low LET radiation of low dose exposures will be less detrimental than expected from a linear extrapolation of findings at moderate to high doses and high dose rates. However, how much less is debatable. The reason of debates is: opportunities to collect information pertinent to the exposure of a general population to low doses at low dose rates are scanty.

The purpose of this investigation is an attempt to provide some information for evaluating whether any detrimental effects exist in a large population whose families have been continuously exposed to a low dose rate radiation. In 1972, our research group (High Background Radiation Research Group) began a health survey in high background radiation areas (HBRA) and the neighboring control areas (CA).

As Figure 1 shows, the HBRA investigated are two separated areas, which cover a total area of about 540 square kilometers. The sources of background radiation are mountains nearly whose surface rocks are granites, from which fine particles of monazite are washed down continually year by year by rain and deposited in the surrounding basin regions; thus, the background radiation level in these areas was elevated. These areas were desolate and uninhabited until about 800 years ago, when many migrants from Jiangxi province moved into and settled there. Most inhabitants we observed are the decendants of the early migrants. Evidence revealed that about 80,000 of the inhabitants belong to families who have lived in these areas for more than two

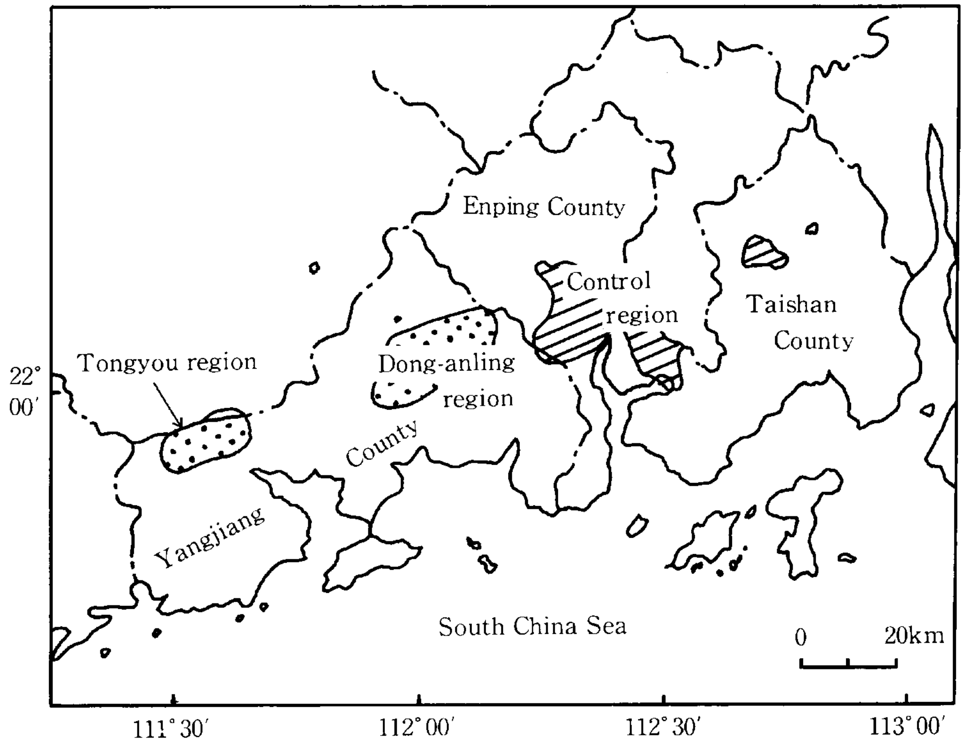


**Fig. 1.** Locations of the investigated areas[1].

generations, and more than 90 percent have lived there for more than six generations (Table 1).

The control areas with normal radiation background were selected not far from the HBRA (the closest points are about 10 km apart), at comparable altitudes.

To investigate the effects of radiation at such low dose rates in areas of limited population, we have set criteria necessary for this kind of investigation:

1. Criteria necessary for the investigation:

1) The disparity in radiation levels between high-background radiation areas and the control

**Table 1.** Distribution of inhabitants whose families lived in investigated areas for various numbers of generations*

| Generations | High Background Areas | | Control Areas | |
|---|---|---|---|---|
| | Persons | Percent | Persons | Percent |
| 2 to 5 | 6912 | 9.4 | 25126 | 32.6 |
| 6 to 10 | 25737 | 35.0 | 39230 | 50.9 |
| 11 to 15 | 17501 | 23.8 | 9172 | 11.9 |
| 16 or more | 23384 | 31.8 | 3545 | 4.6 |

* Based on data from 1975[1]

areas is large enough, sufficient to evaluate the health risk.

2) The population size and person-years of observation are suitable for statistical analysis.

3) Factors (except ionizing radiation) which might affect the prevalence or mortality of mutation-based diseases and carcinoma should be comparable on the whole between HBRA and CA. Any disparity must be taken into account in data analyses.

4) Quality control is carried out strictly in data collection and medical examination.

5) The results of investigation should be reasonably explainable.

2. Pursuant to the above criteria, we have investigated several related items:

1) Sources of the natural ionizing radiation.

2) Radiation levels and their distribution in HBRA and CA — external and internal.

3) Dose estimates — absorbed dose, effective dose equivalents, accumulated doses at different ages.

4) Survey of demographic data.

5) Comparison of confounding factors between HBRA and CA — environmental, host and socio-economic factors.

6) Cancer mortality.

7) Prevalence of mutation-based diseases.

8) Frequency of chromosomal aberration.

9) Explanation of results.

**Table 2.** Concentrations of natural radionuclides in soil based on field gamma spectrometry or sample analyses[2)]

| Method of analysis | | Uranium ($10^{-6}$ g/g) | Thorium ($10^{-6}$ g/g) | Radium ($10^{-12}$ g/g) |
|---|---|---|---|---|
| HBRA | | | | |
| Field | NaI (T1) | 7.1 ± 2.3 | 36.3 ± 12.7 | ... |
| Sample | NaI (T1) | 8.9 ± 3.3 | 57.5 ± 25.1 | 3.3 ± 1.1 |
| Sample | Ge (Li) | 9.6 ± 2.8 | 55.3 ± 20.7 | 3.7 ± 1.2 |
| Sample | Radiochemistry | 7.6 ± 1.7 | 60.4 ± 28.0 | 3.9 ± 1.5 |
| CA | | | | |
| Field | NaI (T1) | 2.0 ± 0.6 | 6.6 ± 2.6 | ... |
| Sample | NaI (T1) | 2.2 ± 0.7 | 8.8 ± 3.3 | 0.78 ± 0.24 |
| Sample | Ge (Li) | 2.4 ± 0.9 | 8.9 ± 4.1 | 0.8 ± 0.3 |
| Sample | Radiochemistry | 1.7 ± 0.7 | 7.9 ± 3.1 | 0.8 ± 0.3 |
| Ratio | | | | |
| Field | NaI (T1) | 3.6 | 5.5 | ... |
| Sample | NaI (T1) | 4.0 | 6.6 | 4.23 |
| Sample | Ge (L1) | 4.0 | 5.2 | 4.90 |
| Sample | Radiochemistry | 4.5 | 7.6 | 4.95 |

**Sources, levels and doses of ionizing radiation**

As mentioned above, the sources of higher background radiation are fine particles of monazite deposited on the basin region of HBRA. The results of analyses of soil samples by spectrometry and radiochemistry, as well as measurements of field gamma-spectrometry showed that the concentrations of natural radionuclides in soil are quite different between HBRA and CA, especially that of thorium, which is 5.2 to 7.6 times higher in HBRA than that in CA.

1. Radiation levels — external and internal

Repeated measurements of environmental gamma exposure rates, individual accumulated gamma exposures, concentrations of Rn-222, Rn-220 and the potential alpha energy of decay products, concentrations of thorium isotopes in human lung tissue and concentrations of Ra-226 and Ra-228 in human teeth and bone showed the higher level of ionizing radiation in HBRA than that in CA, ranged from 3 to 8 times. However, the concentrations of radon and decay products in the air were not so high as expected, because of the effective natural ventilation indoors in the investigated areas[3)]. The data of individual gamma exposures, distribution of absorbed doses and annual doses delivered by Ra-226 and Ra-228 in HBRA and CA are shown in Tables 3, 4 and Figure 2.

2. Dose estimated — absorbed dose, effective dose equivalent, accumulated dose at different ages

From the results of radiological measurements, dose estimates have been made. The results showed that the main contributor of the elevated background radiation is the terrestrial gamma radiation.

The individual absorbed dose (averaged) from terrestrial gamma radiation in HBRA is about four times higher than that in CA. If cosmic rays are included, the ratio of gamma radiation doses between HBRA and CA shall be about three: 2.1 mGy in HBRA, 0.77 mGy in CA per year. If we use the term "effective dose equivalent", which is an unit used for radiological protection, the inhabitants in HBRA would thus receive an average of about six mSv per year,

**Table 3.** Annual individual gamma exposures (mR/yr) in HBRA and CA based on results of various measurements[4)]

| Device or dosimeter | Annual gamma exposure | | HBRA/CA | Year of measurement |
|---|---|---|---|---|
| | HBRA | CA | | |
| RSS-111* | 337.1 ± 60.6 | 115.7 ± 21.2 | 2.9 | 1982 |
| TLD | | | | |
| $CaSO_4$ (Tm) | 351.4 ± 56.8 | 120.3 ± 27.2 | 2.9 | 1978 |
| LiF(Mg,Ti)-M | 330.0 ± 55.1 | 103.0 ± 23.6 | 3.2 | 1978 |
| $CaSO_4$ (Dy) | 330.0 ± 52.8 | 119.0 ± 29.4 | 2.8 | 1975 |
| RPL | 330.0 ± 35.6 | 119.4 ± 24.6 | 2.8 | 1975 |

*Results produced by Field Gamma-ray Spectrometry were similar to those obtained with the RSS-111 device.

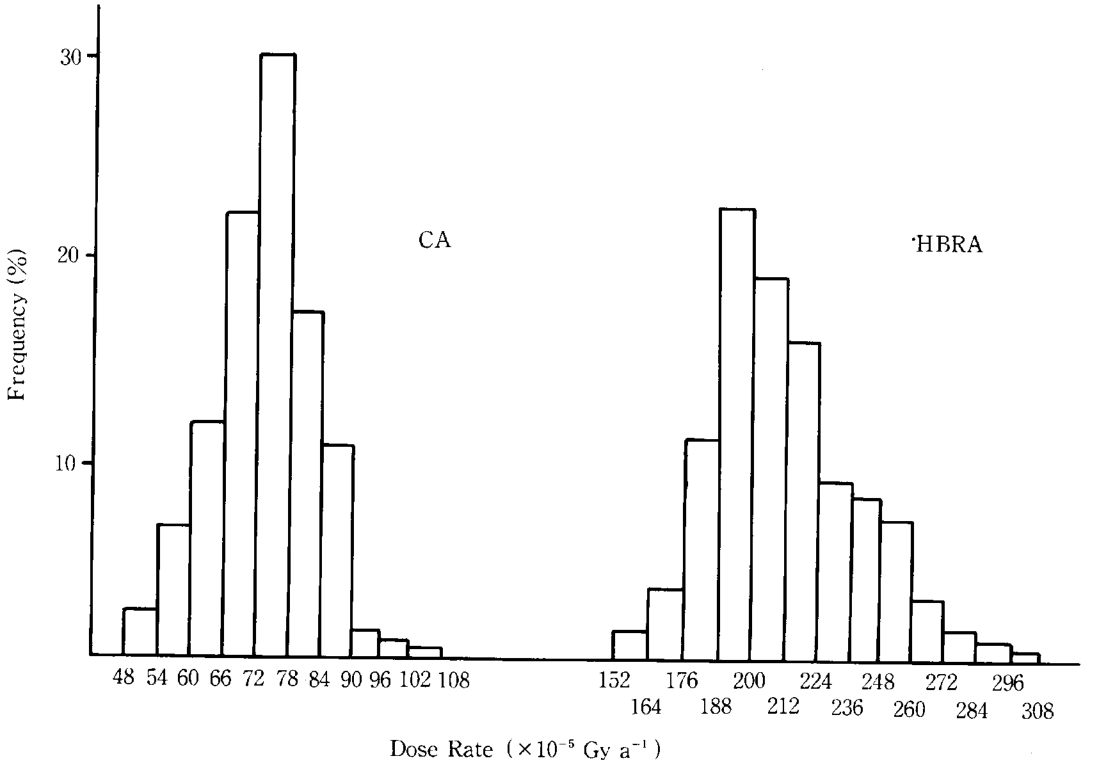


**Fig. 2.** Distribution of absorbed doses (whole body) of inhabitants in the HBRA and CA exposed to background gamma-radiation

**Table 4.** Annual doses delivered by Ra-226 and Ra-228 and their decay products based on different measured samples (mrad/yr)[4]

| Measured Sample | HBRA | | CA | |
|---|---|---|---|---|
| | Bone marrow | Bone surface | Bone marrow | Bone surface |
| 226-Ra and its decay products | | | | |
| Bone | 0.50 | 2.76 | 0.15 | 0.81 |
| Teeth | 0.38 | 2.74 | 0.11 | 0.80 |
| 228-Ra and its decay products | | | | |
| Bone | 1.20 | 6.60 | 0.36 | 2.00 |
| Teeth | 1.86 | 9.89 | 0.53 | 2.80 |

**Table 5.** Annual effective dose equivalents resulting from natural radiation sources in HBRA and CA

| Sources | Annual effective dose equivalents (mSv) | |
|---|---|---|
| | HBRA | CA |
| External exposures | | |
| Terrestrial | 1.83 | 0.50 |
| Cosmic rays | | |
| Ionizing components | 0.25 | 0.25 |
| Neutron components | 0.02 | 0.02 |
| Sub. total | 2.10 | 0.77 |
| Internal exposures | | |
| K-40 | 0.18 | 0.18 |
| Rb-87 | 0.006 | 0.006 |
| Ra-226 | 0.06 | 0.02 |
| Rn-222 | 0.03 | 0.01 |
| Rn's decay products | 1.63 | 0.66 |
| Ra-228 | 0.32 | 0.12 |
| Rn-220 + Po-216 | 0.10 | 0.10 |
| Pb-212 + Bi-212 | 1.04 | 0.29 |
| Sub. total | 3.37 | 1.30 |
| Total | 5.47 | 2.07 |

that is 4 mGv above the normal value of control areas. It seems likely that this higher quantity is chiefly due to the higher quality factor used for alpha particles deposited in the lung tissues.

Thus, an inhabitant living in HBRA receive doses near or more than that received by workers who work in an installation of the nuclear industry or a department of radiology or nuclear medicine.

The accumulated dose or dose equivalent received by an individual increases with the increase of his (her) age. People of 50 years old received accumulated doses from natural gamma radiation in HBRA of about 105 mGy (range 87 mGy to 129 mGy) and 274 mSv (range 248—369 mSv) of effective dose equivalents.

We concluded that the difference in doses between HBRA and CA is large enough to make evaluation of the health risks worthwhile.

## Survey of radiological effects

1. Survey of demographic data

The survey of demographic data has continued since 1975 with the help of local governments.

For the purpose of this investigation, we set up principles of selection of members of the populations in HBRA and CA[5] to be investigated as follows:

1) Only those individuals who met the following conditions are listed for observation and statistical analysis:

i) they are of Han nationality.

ii) they belong to families who have lived in these (HBRA or CA) areas for more than 40 years.

2) The inhabitants in HBRA or CA not listed for observations and statistical analysis are:

i) children of closely related parents or grand-parents.

ii) children of oversea Chinese parents or from foreign parents (one parent or both).

iii) inhabitants in CA who moved from higher background radiation areas or from areas with unknown background radiation level.

iv) workers occupationally exposed to ionizing radiation and their children.

Since the areas investigated are rural, most inhabitants are farmers (peasants) (Table 6). The structure and male-female ratios of the populations investigated are shown in Table 7. From the data, we can see that those in HBRA and CA are younger (75% 35 yrs old) than in the standard world population (62% 35 yrs old) and in European countries (50% 35 yrs old)[6].

2. Survey for comparison of confounding factors

For comparing confounding factors which might affect the incidence of cancers and hereditary diseases, several studies have been done, one of which was a case control study of HBRA and CA inhabitants.

Cases and controls were selected from HBRA and CA respectively using two stage sampling. Controls were matched to cases by sex and age, 459 case-control pairs were available for analysis. The purpose of this study was to assist in assessment of the effects of elevated natural radiation on disease presumedly caused by some form of mutation, a comparison of various factors either acceptedly of possibly affecting the occurrence of such results are summarized in Tables 8 and 9.

One point to note: although the percentage of male smokers was high, the smokers do not smoke cigarettes often; most of them smoke with a water pipe, which may diminish the detrimental effects of smoking.

**Table 6.** Occupations of the inhabitants in HBRA and CA*

| Area | No. of investigated persons for case-control study | Occupation | | | | P |
|---|---|---|---|---|---|---|
| | | Peasant | | Other** | | |
| | | No. | % | No. | % | |
| HBRA | 459 | 432 | 94.1 | 27 | 5.9 | >0.05 |
| CA | 459 | 428 | 93.2 | 31 | 6.8 | |

*Sample taken from inhabitants above 16 years old

**Other occupations include: teachers, country doctors, cadres, etc.

**Table 7.** Male-Female ratio* in the HBRA and CA (1970-1985) populations

| Age | HBRA | | | CA | | |
|---|---|---|---|---|---|---|
| | Male (pyr) | Female (pyr) | Ratio (M/F) | Male (pyr) | Female (pyr) | Ratio (M/F) |
| 5 | 124063 | 110312 | 1.12 | 96294 | 90794 | 1.06 |
| 15 | 120578 | 106736 | 1.13 | 112106 | 102288 | 1.10 |
| 25 | 79020 | 65256 | 1.21 | 89837 | 79416 | 1.13 |
| 35 | 52745 | 38115 | 1.38 | 54114 | 43458 | 1.25 |
| 45 | 43213 | 37770 | 1.14 | 40611 | 38918 | 1.04 |
| 55 | 32119 | 33853 | 0.95 | 35519 | 41360 | 0.86 |
| 65 | 20845 | 22678 | 0.92 | 21984 | 28766 | 0.76 |
| 75 | 9009 | 13702 | 0.66 | 9091 | 16926 | 0.54 |
| 85 | 1567 | 3624 | 0.43 | 1721 | 4416 | 0.39 |
| Total | 483159 | 432046 | 1.12 | 461274 | 446342 | 1.03 |

Note: Male-female ratio in this table = pyr(male)/pyr(female)

**Table 8.** Comparison of factors known to affect diseases caused by mutation process

| Factors | Constituent ratio (%) | | | Odds ratio* | |
|---|---|---|---|---|---|
| | HBRA | CA | P** | Matched analysis | Unmatched analysis |
| Pesticide use | 62.3 | 62.3 | NS | 1.00 | 0.95(0.72–1.24) |
| Occupations involving the use of poisonous and noxious substances | 1.5 | 2.0 | NS | 0.60(0.15–2.47) | 0.77(0.29–2.09) |
| Smoking | 37.9 | 37.6 | NS | 1.06(0.71–1.58) | 1.01(0.88–1.16) |
| Alcohol consumption | 37.2 | 38.6 | NS | 0.85(0.60–1.21) | 0.90(0.64–1.27) |
| Medical X-ray exposure | 20.0 | 26.4 | NS | 0.62(0.45–0.87) | 0.70(0.51–0.95) |

*Figures in parentheses represent 95% confidence intervals.

**NS means no significance

**Table 9.** Some data on smokers[5)]

| Area | Persons investigated | | | No. of smokers | | | Percentage | | |
|---|---|---|---|---|---|---|---|---|---|
| | Male | Female | Total | Male | Female | Total | Male | Female | Total |
| HBRA | 239 | 220 | 459 | 171 | 3 | 174 | 71.5 | 1.4 | 37.9 |
| CA | 238 | 217 | 455 | 167 | 4 | 171 | 70.2 | 1.8 | 37.6 |

* Selected by two stage sampling.
Sample taken from investigated persons above 16 years old.

For several years we have studied factors which might affect the incidence of malignancies and hereditary diseases, and the comparability between HBRA and CA. So far we have not found any significant differences between them in terms of environmental and host factors. However, the culture and education levels were higher in CA, which may influence hygiene status and family planning.

3. Cancer mortality study

Cancer mortality in HBRA and CA has been studied since 1972. The early data were obtained by means of retrospective survey (at 1972 for pilot study, at 1975 for 1970–1974 data, at 1979 for 1975–1978 data). Since 1979, a cancer registry system has been established for the investigated areas where local physicians, with the help of section hospitals and county hospitals and many health administrative organizations, report all cancer cases and cancer deaths to the

**Table 10.** Site specific cancer mortality (per $10^5$pyr) in HBRA and CA (1970-1986) for both sexes*

| Site of cancer | HBRA No. of deaths | HBRA Mortality Avg. | HBRA Mortality Adjusted** | CA No. of deaths | CA Mortality Avg. | CA Mortality Adjusted** | P value |
|---|---|---|---|---|---|---|---|
| Nasopharynx | 94 | 9.32 | 9.84 | 109 | 10.95 | 10.45 | >.05 |
| Esophagus | 13 | 1.29 | 1.40 | 16 | 1.61 | 1.49 | >.05 |
| Stomach | 53 | 5.25 | 5.60 | 47 | 4.72 | 4.44 | >.05 |
| Liver | 115 | 11.40 | 12.05 | 145 | 14.57 | 13.92 | >.05 |
| Intestine | 16 | 1.59 | 1.70 | 25 | 2.51 | 2.38 | >.05 |
| Lung | 25 | 2.48 | 2.65 | 35 | 3.52 | 3.29 | >.05 |
| Breast | 7 | 0.69 | 0.75 | 13 | 1.31 | 1.25 | >.05 |
| Cervix Uterus | 13 | 1.29 | 1.37 | 5 | 0.50 | 0.45 | <.05 |
| Leukemia | 31 | 3.07 | 3.02 | 33 | 3.32 | 3.39 | >.05 |
| Osteosarcoma | 5 | 0.50 | 0.52 | 6 | 0.60 | 0.59 | >.05 |
| Other | 95 | 9.42 | 9.91 | 99 | 9.95 | 9.44 | >.05 |
| Total | 467 | 46.29 | 48.81 | 533 | 53.56 | 51.09 | >.05 |

*1,008,769 pyr observed in HBRA, 995,070 pyr in CA.
**Adjusted with the combined population of HBRA and CA.

registry. Diagnoses are checked, sometimes re-examined, and confirmed by an expert group who meet twice a year at the investigated areas to evaluate cases. Meanwhile, deaths from all causes are also registered and analyzed. By the end of 1986, 467 cancer deaths were found among 1,008,769 person-years at risk in HBRA, resulting in a crude mortality rate of 46.29/100,000 pyr. The corresponding figures in CA were 533 cancer deaths, 995,070 pyr and a crude cancer mortality rate of 53.56/100,000 pyr. Mortality rates from all cancers, site specific cancer mortalities, sex specific cancer mortality are shown in the following Tables.

From the data shown in above, the mortality rate for all cancers was higher in CA than that in HBRA for male, female and for both sexes. However the differences were not large enough to be significant statistically. For site specific cancers, there were small differences between HBRA and CA, only the mortalities of cancer of uterus cervix were found to differ significantly between these two areas. However, the induction of this type of cancer is difficult to relate to ionizing radiation.

For examining the validity and reliability of the above findings, further analysis have been done:

1) As the data of age-specific mortalities show, most cancer cases appear within the age groups of 40 years and over. Furthermore, literature indicates that there is a latent period after which the solid cancers begin to be clinically distinguished, whether the solid malignancies are natural ("spontaneous") or induced by ionizing radiation[8].

For these reasons, we have analyzed the cancer mortality of all cancers except leukemia of HBRA and CA inhabitants aged 40–70 years. The results are somewhat different from those of analyses of cancer mortalities of all age groups. The mortality rate in HBRA was significantly lower, although the statistical power is weak with wide confidence interval. It is necessary to

**Table 11.** Site specific cancer mortality (per $10^5$pyr) in HBRA and CA (1970-1986) for males*

| Site of cancer | HBRA No. of deaths | HBRA Mortality Avg. | HBRA Mortality Adjusted** | CA No. of deaths | CA Mortality Avg. | CA Mortality Adjusted** | P value |
|---|---|---|---|---|---|---|---|
| Nasopharynx | 59 | 11.11 | 11.58 | 72 | 14.27 | 13.79 | >.05 |
| Esophagus | 10 | 1.88 | 1.97 | 7 | 1.39 | 1.32 | >.05 |
| Stomach | 36 | 6.78 | 7.11 | 29 | 5.75 | 5.49 | >.05 |
| Liver | 85 | 16.01 | 16.67 | 113 | 22.40 | 21.62 | >.05 |
| Intestine | 10 | 1.88 | 1.96 | 14 | 2.78 | 2.69 | >.05 |
| Lung | 17 | 3.20 | 3.36 | 18 | 3.57 | 3.39 | >.05 |
| Breast | 0 | 0 | 0 | 0 | 0 | 0 | |
| Leukemia | 17 | 3.20 | 3.21 | 18 | 3.57 | 3.70 | >.05 |
| Osteosarcoma | 4 | 0.75 | 0.78 | 4 | 0.79 | 0.77 | >.05 |
| Other | 61 | 11.49 | 11.91 | 55 | 10.90 | 10.48 | >.05 |
| Total | 299 | 56.31 | 58.55 | 330 | 65.42 | 63.25 | >.05 |

*530,952 pyr observed in HBRA, 504,458 pyr in CA.
**Adjusted with the combined population of HBRA and CA.

**Table 12.** Site specific cancer mortality (per $10^5$pyr) in HBRA and CA (1970-1986) for female*

| Site of cancer | HBRA | | | CA | | | P value |
|---|---|---|---|---|---|---|---|
| | No. of deaths | Mortality | | No. of deaths | Mortality | | |
| | | Avg. | Adjusted** | | Avg. | Adjusted** | |
| Nasopharynx | 35 | 7.33 | 7.82 | 37 | 7.54 | 7.08 | >.05 |
| Esophagus | 3 | 0.63 | 0.68 | 9 | 1.83 | 1.68 | >.05 |
| Stomach | 17 | 3.56 | 3.82 | 18 | 3.67 | 3.42 | >.05 |
| Liver | 30 | 6.28 | 6.76 | 32 | 6.52 | 6.14 | >.05 |
| Intestine | 6 | 1.26 | 1.37 | 11 | 2.24 | 2.09 | >.05 |
| Lung | 8 | 1.67 | 1.82 | 17 | 3.47 | 3.23 | >.05 |
| Breast | 7 | 1.47 | 1.60 | 13 | 2.65 | 2.51 | >.05 |
| Cervix Uterus | 13 | 2.72 | 2.94 | 5 | 1.02 | 0.94 | <.05 |
| Leukemia | 14 | 2.93 | 2.80 | 15 | 3.06 | 3.06 | >.05 |
| Osteosarcoma | 1 | 0.21 | 0.21 | 2 | 0.41 | 0.40 | >.05 |
| Other | 34 | 7.12 | 7.51 | 44 | 8.97 | 8.44 | >.05 |
| Total | 168 | 35.16 | 37.34 | 203 | 41.38 | 39.00 | >.05 |

*477,817 pyr observed in HBRA, 490,612 pyr in CA.
**Adjusted with the combined population of HBRA and CA.

**Table 13.** Crude cancer mortality ($10^{-5}$) in HBRA and CA, and prevalence ratio (1970-1986)

| Sex | Area | Crude mortality (95% C. I.) | Prevalence ratio* (95% C. I.) |
|---|---|---|---|
| Male | | | |
| | HBRA | 56.3 (50.1, 63.1) | 0.93 (0.81, 1.06) |
| | CA | 65.4 (58.6, 77.9) | P=0.65 |
| Female | | | |
| | HBRA | 35.2 (30.1, 41.0) | 0.96 (0.81, 1.14) |
| | CA | 41.4 (35.9, 47.5) | P=0.35 |

*Prevalence ratio is age adjusted.

accumulate it is more person-years of these older age groups.

2) Bench mark examination

We have set leukemia mortality and thyroid nodularity as bench marks, because among other tissues bone-marrow and thyroid gland are the most sensitive to radiation.

**Table 14.** Mortality rates of all cancers except leukemia of HBRA and CA inhabitants aged 40-70 years (1970-1986)*

| Area | Person-years observed | Mortality rate ($10^{-5}$) | β-value* (95% CI) | P-value |
|---|---|---|---|---|
| HBRA | 207,900 | 143.8 (299) | −14.6% (−24.8, −3.0%) | 0.04 |
| CA | 224,380 | 168.0 (377) | | |

*Computer program "AMFIT" (D. Preston, 1987) was used to fit a Poisson regression model. $R_{HB}$ (S,T,A) = $R_{CA}$(S,T) (1 + βA). $R_{HB}$ and $R_{CA}$ are mortality rates in HBRA and CA, respectively. S = sex, T = age, A = area, 0 represents CA, I represents HBRA. β is "excess" rate of HBRA to CA. Figures in parentheses are numbers of cancer deaths.

## Leukemia

Leukemia is well recognized by the scientific community as the malignancy most closely related to ionizing radiation. Further, fewer cases are missed or mis-diagnosed in cancer registries (in our study, 100% of cases were diagnosed with histopathologic evidence).

Data provided by WHO indicates that although there is considerable fluctuation of cancer mortality rates in various countries or areas, mortality rates from leukemia do not differ greatly from one other in Asian countries or areas. The mortality rate of leukemia in HBRA was within the range of spontaneous incidence.

**Table 15.** Mortality Rates of Malignant Neoplasms and Leukemia in Hong Kong and Some Asian Countries or Areas (per 100,000 population)

| Country or Area | Malignant Neoplasms (All ages) | | Leukemia (All ages) | |
|---|---|---|---|---|
| | Male | Female | Male | Female |
| Hong Kong (1986)* | 172.7 | 116.7 | 3.4 | 3.3 |
| Japan (1986)* | 191.1 | 126.9 | 5.2 | 3.7 |
| Korea (south) (1985)* | 95.0 | 54.7 | 2.9 | 2.4 |
| Singapore (1986)* | 127.5 | 95.2 | 3.1 | 3.2 |
| Sri Lanka (1982)* | 25.2 | 24.0 | — | — |
| China** | 84.35 | 63.16 | 2.80 | 2.24 |
| | (119.6) | (80.7) | | |
| HBRA | 56.31 | 35.16 | 3.20 | 2.93 |
| CA | 65.42 | 41.38 | 3.57 | 3.06 |

*Data from: World Health Organization: 1987 World Health Statistics Annual, Geneva 1987[9].

**Data from: Office for Research of Prevention and Treatment of Cancers: Data Collection of Malignant Neoplasms Mortalities in China, Beijing, China, 1980[10]. Figures in parentheses are world standardized mortality rates.

**Table 16.** Thyroid nodularities found on physical examination of women residing in HBRA and CA*

| Type of nodularity | HBRA (N = 1001) | CA (N = 1005) | Prevalence ratio | 95% confidence interval |
|---|---|---|---|---|
| All nodular disease | 95 | 93 | 1.02 | 0.76–1.35 |
| Single nodule (any) | 74 | 66 | 1.13 | 0.82–1.55 |
| with goiter | 61 | 48 | 1.28 | 0.88–1.84 |
| without goiter | 13 | 18 | 0.73 | 0.36–1.48 |
| Multiple nodules (any) | 21 | 27 | 0.78 | 0.44–1.37 |
| with goiter | 21 | 26 | 0.81 | 0.46–1.43 |

*This thyroid research was partially supported by Contract No 1-CP-61018 with the National Cancer Institute, United States Public Health Service.

### Thyroid nodularity

Since thyroid nodularity may be a predisposing factor in thyroid cancer, we conducted a collaborative study with the National Cancer Institute of USA, in HBRA and CA to determine whether the high-background radiation would produce a detectable increase in thyroid nodularity. Since the female thyroid is more sensitive to radiation, and older people have received larger doses, women aged 50–65 (N = 1,001 in HBRA and 1,005 in CA) who had resided in HBRA or CA throughout their entire lives were selected. Personal interviews and physical examinations by physicians experienced in thyroid diseases were conducted on all women; thyroid hormone levels, urinary iodine, and chromosomal aberrations were measured and analyzed on some of the women, selected randomly. There was no evidence that nodular thyroid disease was elevated among women in HBRA, compared to the CA. The prevalences of nodular thyroid diseases were: 9.5% in HBRA, 9.3% in CA.

These data suggest that continuous exposure to low level radiation of the HBRA is unlikely to increase appreciably the risk of nodular thyroid disease.

### Causes analysis — case-control study

As the mortality rates of cancers of liver and stomach were conspicuously elevated compared to other cancers, and the effective dose equivalence of lung tissue was largest among other tissues, further analyses were deemed necessary.

A task group conducted a case (cancer deaths) control (non-cancer deaths) study specifically to explore the possible causes of these cancers among the HBRA.

Data collection was done by means of interviews with the relatives, close friends and (or) neighbors of the deceased. Data analysis was conducted with matched and unmatched analyses. Fifteen items were selected in this study, which include: social economic condition, quantity of pesticide used, status of cigarette smoking, exposure to medical X-rays, and others.

The results of analysis showed that the factors which seemed to be related to single site cancer induction were pesticide use, low family income, drinking water source other than well (surface water), occupation involving use of poisonous and noxious substances and alcohol consumption.

If we exclude those factors whose magnitude and level were comparable between HBRA and CA, only pesticide use, lower family income and drinking water source other than well (surface water) were implicated in this investigation. If we use the combined data from both HBRA and CA, only lower family income and surface water source are implicated.

The conclusions from this preliminary study were:

1) No evidence was found to implicate ionizing radiation in the induction of cancers of stomach, liver and lung.

2) It is likely that the use of pesticide is related to the higher mortality rate of liver cancer in CA. However, the difference of cancer mortality rates of liver between HBRA and CA was not statistically significant.

**Source of uncertainty**

One source of the uncertainty was that a small fraction of cases among the death certifications did not have clear diagnoses.

The term "death with unknown causes" means that the deceased had not received any medical examination or diagnosis for a period of time before his (her) death, or the previous data did not record any serious illness. Usually, it relates to the cases of very senile people, who most likely died of cardiovascular diseases. However, we do not have any evidence to say so. About two percent of total deaths fell into this category in each area.

The term "deaths with underfined diagnosis" means that the deceased had received some medical examination but without definite diagnosis (diagnosis with a question mark). About one percent of the total deaths fell into this category in each area. The differences of these kinds of uncertainties are not significant between HBRA and CA, so, we believe that the data of cancer mortality are appropriate for analysis.

**Table 17.** Death cases analysis — causes and uncertainties (1979 through 1985)

| Areas | Person-Years observed | Deaths from all causes | Deaths with definite diagnosis | | Deaths with unknown causes | | Deaths with undefined diagnosis | |
|---|---|---|---|---|---|---|---|---|
| | | | No. | Percent | No. | Percent | No. | Percent |
| | | (1) | | (2) | | (3) | | (4) |
| HBRA | 538840 | 3181 | 3085 | 97.0 | 67 | 2.1 | 29 | 0.9 |
| CA | 506418 | 3055 | 2970 | 97.2 | 51 | 1.7 | 34 | 1.1 |

Differences of (1), (2), (3) and (4) between HBRA and CA are not statistically significant.

**4. Prevalence of Down's syndrome**

Information concerning the frequency of hereditary diseases and congenital defects was gathered from a sample of children examined during one of two years (1975 to 1979) who were under 12 years of age at the time of examination. The prevalence rates were almost identical in the two areas, 22.64 cases/1000 people in the HBRA (N = 13,425) and 22.54 cases/1000 people in CA (N = 13,087). However, the frequency of Down's syndrome in HBRA was significantly higher than that in CA (see Tables 18 and 19).

In order to verify the accuracy of the data for Down's syndrome frequency, in 1985 we enlarged the size of cohort to include almost all of the children in this age category at the time of examination. Chromosomal analysis was done for those who had one or more positive clinical indications, including minor mental disturbance. The results are shown in Table 19.

From the figures in Table 19 we can see that the frequency in HBRA is significantly higher than that in CA.

However, there is a wide range of spontaneous incidence of Down's syndrome (1–2 per thousand new born, UNSCEAR, 1982)[11)], so that the first thing we should know is whether the prevalence in HBRA is within the normal range. If we compare HBRA with other places of the same province (Guangdong Province), the difference is not significant (Table 20).

**Table 18.** Prevalence rate of 31 hereditary diseases and congenital defects in children of the two areas. (1975, 1979)

| Area | No. of examinees | Total of 31 diseases | | Down's syndrome | |
|---|---|---|---|---|---|
| | | No. of cases | Frequency ($10^{-1}$) | No. of cases | Frequency ($10^{-3}$) |
| HBRA | 13425 | 304 | 22.64* | 14 | 1.04** |
| CA | 13087 | 295 | 22.54* | 4 | 0.31** |

*P>0.05 **P<0.05

**Table 19.** Prevalence of Down's syndrome in HBRA and CA

| Years of examination | HBRA | | | CA | | |
|---|---|---|---|---|---|---|
| | No. of examinees | No. of cases | Rate ($10^{-3}$) | No. of examinees | No. of cases | Rate ($10^{-3}$) |
| 1975 | 3,504 | 7 | 2.00 | 3,170 | 0 | 0 |
| 1979 | 9,921 | 7 | 0.71 | 9,917 | 4 | 0.41 |
| 1985 | 11,833 | 8 | 0.68 | 8,705 | 0 | 0 |
| Total | 25,258 | 22 | 0.87 | 21,837 | 4 | 0.18 |

If we compare HBRA with other places of China, we see the frequency in HBRA is a little higher, but within the normal (spontaneous) range (see Table 21).

Many studies have already discovered and confirmed that incidence of Down's syndrome is maternal age dependent. Mothers over 35 years of age at delivery have very high frequencies of Down's syndrome.

Table 22 shows the comparison of ages at maternity between HBRA and CA.

The Table shows that the women in HBRA who gave births at the age more than 35 years old constitute a higher percentage.

It is clear that in both population groups, the frequency of Down's syndrome is maternal

**Table 20.** Significance test

| Area of examination | Cases of Down's syndrome | No. of examinees | Rate ($10^{-3}$) |
|---|---|---|---|
| HBRA (1) | 22 | 25,258 | 0.87 |
| CA (2) | 4 | 21,837 | 0.18 |
| Zhanjiang and Foshan (3) of Guandong Province | 16 | 26,504 | 0.60 |

(1) and (2) $P<0.01$ (2) and (3) $P=0.01$ (1) and (3) $P>0.05$

**Table 21.** Frequencies of Down's syndrome in some places in China[12)]

| Place and year of investigation | Age of examinees | No. of examinees | No. of Down's syndrome cases | Frequency ($10^{-3}$) |
|---|---|---|---|---|
| Wuhan, 1980 | 0–12 | 177057 | 48 | 0.27 |
| Hepei, Prov. 1981-82 | 0–14 | 275642 | 106 | 0.39 |
| Hunan Prov. 1982 | 0– 7 | 4880 | 3 | 0.62 |
| Guiyang, 1981 | 0–11 | 7894 | 16 | 2.02 |
| Guangdong Prov. | | | | |
| Zhanjiang, 1982 | 0–14 | 20084 | 12 | 0.60 |
| Foshan, 1982-83 | 0–14 | 6420 | 4 | 0.62 |
| HBRA 1975,79,85 | 0–12 | 25258 | 22 | 0.87 |
| CA 1975,79,85 | 0–12 | 21837 | 4 | 0.18 |

**Table 22.** Comparison of the age of mothers at delivery

| Area | Age < 35 yrs old | | Age > 35 yrs old | | p value |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| HBRA | 14,837 | 87.98 | 2,027 | 12.02 | <<0.01 |
| CA | 13,872 | 95.56 | 645 | 4.44 | |

age dependent which may partially explain the higher frequency in HBRA. A further explanation may be that in CA, the frequency of Down's was below expectation, therefore giving the appearance of a spuriously high frequency in the HBRA.

## Conclusions

1. We investigated areas in Yangjiang County that have definitely high background radiation, characterized by homogeneous distribution of environmental gamma exposure, large population size and long-term inhabitants. These areas are suitable for the study of late effects.

2. Up to 1986 about one million person-years in each area (HBRA and CA) have been observed. No increase of cancer mortality has been found in HBRA, but on the contrary, there was a tendency for the cancer mortality in HBRA to be lower than that in CA.

3. The prevalence of hereditary diseases and congenital defects was similar in both areas (HBRA and CA), but the frequency of Down's syndrome was higher in HBRA (through within the normal range) than that in CA. A possible explanation is the difference of age of maternity between HBRA and CA, and the extremely low frequency in CA.

4. The factors which might influence the incidence of mutation based diseases have been studied. In general, they are comparable between HBRA and CA. However, the cultural and educational levels were somewhat different, which might affect health status and family planning.

5. It is likely that there may be a dose threshold for cancer incidence, but this remains to be determined by further research. Further work is needed to come to a definite conclusion.

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