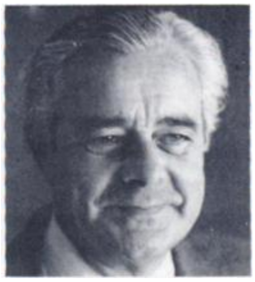
COMMENTARY

CHERNOBYL PREDICTIONS AND THE CHINESE CONTRIBUTION*

Ten months after the nuclear reactor accident in Chernobyl, Soviet Union (USSR), we can look back on the predictions made regarding health effects and look forward to future resolution of their incompatibility with regard to cancer risk.



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The health consequences are in two categories: early and late effects. In the first days after the accident a number of rash commentators, basing their opinions on the WASH-1400 report of the United States (US) Nuclear Regulatory Commission (NRC) (*1*) and similar "worst-case" assessments, predicted tens of thousands of early deaths from radiation exposure in the adjoining communities. The truth, however, was rapidly revealed: among 203 persons hospitalized with suspected radiation sickness, the number of early deaths disclosed by the USSR delegation to the International Atomic Energy Agency (IAEA) Vienna conference (*2*) in late August 1986 was 31. All were persons working at the reactor site, including two who were killed by the initial explosion and falling debris. Some of these fatalities were firefighters whose radiation injuries were compounded by severe burns. Thirteen persons received bone-marrow transplants, of whom two survived. Of six patients receiving fetal liver transplants, none survived. There were no radiation deaths among persons exposed off-site in the surrounding communities, including those in Pripyat less than two miles from the reactor. The mean dose received by the 45,000 Pripyat residents who were evacuated 36 hours after the accident was 3.3 rem.

The late health effects attributable to Chernobyl (excess cancer, genetic and fetal damage) are obviously speculative. As of this writing, the only certain effect has been the 31 early deaths, and therefore to-date the casualties are much smaller than the hundreds who died in each of the several recent crashes of jumbo jet aircraft, and the thousands who died in the chemical disaster at Bhopal, India. The further health consequences of Chernobyl remain to be determined, and may in fact be indeterminate.

The major focus of the late-effect predictions has been excess cancer, inside and outside the Soviet Union. Nuclear medicine physicians will be interested in those predictions because they involve primarily irradiation by cesium-137 both externally and internally, and by iodine-131 internally. Moreover, the estimated average internal activities in the exposed population are about 1 μCi (37,000 Bq) for cesium-137 and probably less for iodine-131, yielding absorbed doses well below those administered in diagnostic nuclear medicine. The predictions cover a wide range, heavily dependent on the assumptions made concerning the relation of cancer to low-level radiation exposure, and somewhat less dependent on the dose assessments. At the high end of the range are those of John Gofman, PhD, MD, (*3*) who has predicted a total excess of 330,000 cancer deaths over the next 70 years in Europe and the USSR.

Prediction of 330,000 Excess Cancers Based on Risk Estimate 40 Times Higher than ICRP's

This estimate includes only cancer resulting from cesium-137/134 on the ground (external dose) and entering the food chain (internal dose). Dr. Gofman's prediction is unique insofar as it employs his own estimate of lifetime cancer risk per rem, whereas most other predictions utilize the risk estimates adopted by the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and other international bodies. The Gofman risk estimate is 3,885 extra cancer deaths per million person-rems, which is about 40 times higher than the above "official" estimate of 100 per million person-rems.

Very large predictions have also been made by Frank von Hippel, PhD, and Thomas B. Cochran, PhD (*4*). They have predicted a lifetime increased cancer incidence for 200 million persons exposed to cesium-137 radiation which lies between 3,500 and 70,000. Their range of risk estimates per million person-rems was 250 to 1,000 excess cancer cases (a factor of four), the higher estimates in the 1980 Report of the National Academy of Sciences (NAS) (*5*). The remaining range factor of five is unexplained, but presumably is related to dose uncertainties. Drs. von Hippel and Cochran

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*Based on an invited paper delivered at the 4th World Congress of Nuclear Medicine and Biology, Buenos Aires, Argentina, November 6, 1986.

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also predict an excess incidence of thyroid tumors, both malignant and benign, from inhalation of airborne iodine-131 and ingestion of milk contaminated with iodine-131. They estimate the total number of thyroid tumors as 2,000 to 40,000 from inhalation and 10,000 to 250,000 from milk ingestion, and that 75% of these tumors would be benign. The largest figure suggests an average thyroid dose of about 2 rem using the NAS risk (*5*) resulting from an *average* milk concentration of about 0.27 μCi (10,000 Bq) per liter of milk. However, this level is far above those which were found in dairy milk in countries close to the USSR, such as Poland and Sweden (*6*). These authors also cite Report 80, published in 1985 by the National Council on Radiation Protection and Measurements (NCRP) as one source for radiation risk estimates to the thyroid gland (*7*). A more reasonable average milk concentration of 0.0054 μCi (200 Bq) per liter produces thyroid doses of about 0.03 rem in adults and 0.08 rem in children (less than 18 years old) (*4,6*). Employing the above NCRP risks for iodine-131, the minimum number of thyroid tumors in adults and children would be less than 300 and certainly not 10,000 (see later discussion of iodine-131 cancer risk).

ICRP and Soviet Experts Estimate 0.05% Cancer Increase in USSR—Statistically Imperceptible

At the low end of the range of cancer predictions are those of the Soviet Union presented at the Vienna conference (2) for 75 million persons in the Ukraine and Byelo-Russia. These estimates were supported by the ICRP (Dr. D.J. Beninson, chairman). The Russian estimate of the total activity deposited inside the USSR was 50 MCi based on aerial ground surveys and local measurements. The lifetime estimate of collective external gamma ray dose was 29 million person-rem primarily from cesium-137. The collective internal dose over 70 years from cesium-137 from airborne activity and the food chain was 28 million person-rem. The latter figure was a downward revision by a factor of 7.5 from the earlier 210 million person-rem to reflect the use of *mean* doses instead of maximum doses. No collective thyroid dose was given. The mean external dose per person was therefore approximately equal to the internal dose at about 0.38 rem from each source. Thus on the average *per year* over a 70-year time span, the mean internal dose was estimated at about 5 mrem with 70 mrem and 35 mrem delivered in the first and second years, for a total much less than the lifetime background dose. The USSR estimate of total cancer mortality from these additional doses utilized the ICRP guideline of 100 excess deaths per 1 million person-rem (2,900 and 2,800 from external and internal exposure, respectively). Since in 75 million persons there would normally be about 12 million cancer deaths, the excess deaths would represent an increase of 0.05%, statistically imperceptible. The relative effect outside the USSR would be smaller, reflecting the smaller doses.

It is quite possible that the actual effects may be smaller than the ICRP/Russian estimates. It is questionable whether the health effects primarily based on large acute doses delivered at high dose rates—as in Japan and in most studies of therapeutic exposure to x-rays—are appropriate for predictions regarding Chernobyl. The doses received by the vast majority of exposed persons were low and all were received at a low dose rate (except those in the reactor plant). Even in the most exposed communities (24,000 persons at three- to-fifteen kilometers) which were evacuated, the mean doses were reported (2) as about 45 rem delivered over a three- to six-day period. Radiobiologically, these are low dose rates, even though they greatly exceed the typical dose rate of less than 1 rad in a year. There is good experimental evidence that such dose rates are considerably less damaging than single acute doses by factors up to 12 and some human evidence pointing to the same conclusion is emerging. [For a detailed discussion of this subject see NCRP Report 64 (*8*).] Two studies on beagle dogs (*9,10*), for example, have shown that the shortening of life span, which is principally due to excess cancer mortality, is about 12 times smaller after protracted exposure at 8 rads/day compared to 8 rads/minute. The quoted ICRP (Russian) risk of 10^{-4}/rem includes a low-risk reduction factor of 2.5 compared with the risk derived on a linear extrapolation from high dose data (*5*). The effect of protracted radiation may therefore be smaller by a further factor of four, yielding about 700 excess cancer deaths in the USSR from the internal exposure and also from the external exposure.

Subpopulation Offers Chance to Learn Whether Higher or Lower Estimates Are Valid

In the above 24,000 persons (with 1 million person-rem) the excess cancer deaths over their lifetime could be as low as 25 compared with the ICRP-predicted 100, and the normal expectation of 4,000 cancer deaths. These increases would be statistically undetectable. The Gofman prediction would be 4,000 excess deaths, or a doubling of the normal expectation, readily detectable. An epidemiologic follow-up of this smaller population therefore offers an excellent opportunity to determine whether a large risk estimate, such as Dr. Gofman's, or a small estimate closer to that of the ICRP is correct.

The effect of protraction may be the reason why iodine-131 has been judged to be three times less effective as a carcinogen per unit dose than x-rays delivered at high dose rates (*7*). This conservative judgment was largely based on the investigation by Holm *et al.* (*11*) which found no excess thyroid cancer in 10,000 patients who had received gland doses between 58 rem (adults) and 159 rem (persons aged less than 20) after an 18-year follow-up. This study suggests that the iodine-131 thyroid cancer risk is most probably smaller by a factor considerably greater than three (*7*). Thus, if some persons received as much as 100 rem of thyroid dose in areas of high "rain-out" of iodine-131, the lifetime risk of thyroid cancer could be as low as one in 10,000.

Lower Cancer Rates Found in Regions of High Background Radiation Levels in China

An increase in radiation dose of about 10 mrem/year over 70 years suggests that the cancer experience of the high-background Chinese population may be relevant. In a series of reports since 1980 (*12*), the cancer mortality has been presented in adjacent similar and static communities each of about 50,000 persons living with background radiation dose rates of 330 mrem/year and 114 mrem/year respectively. The increased background is due to penetrating gamma radiation arising from the soil. The aggregate extra dose to the high-background group is therefore about 6 rem during the first 30 years of life. In the most recent report (*13*), cancer statistics for a 14-year period (1970–1983) are reported in the two areas. In the high-background area the cancer rate was *lower* than that in the low-background area; specifically, 326 cancer deaths were recorded in the high-background area for 764,696 person-years at risk, while in the low-background area there were 412 deaths for 777,482 person-years. The rates standardized for the combined population were 44.60 ± 2.42 at high background and 51.00 ± 2.56 at low background per 100,000 person-years. This difference would exclude ($p < 0.05$) a radiation-induced cancer mortality rate of five excess cancer deaths per year per rem per million persons, which is the risk underlying the ICRP (Russian) assumed lifetime risk of 100 excess deaths per million person-rem. It follows that higher risks such as those employed by Drs. Gofman and von Hippel would be excluded with very high probability.

Potential Far-Reaching Impact

The Gofman risk estimate (*3*) appears particularly improbable in the light of the Chinese study. The 50,000 persons at high background would accumulate a collective extra dose of about 300,000 person-rem by age 30. The Gofman risk for all cancer except leukemia is stated as a lifetime increase of one extra cancer death for each 268 person-rem. This risk predicts about 1,100 increased cancer deaths in a 70-year period, or in 14 years of observation about 220 extra cancer deaths beyond the 396 ± 20 observed (standardized) in the low-background area. The 56% projected increase is clearly unsupported. Alternatively, if the Gofman *relative* risk per rem (based on a 46.5 rem doubling dose) is applied to the Chinese population, which has a lower normal cancer rate than Western populations, 51 extra deaths would be predicted, which are not in evidence.

The Chinese evidence at present suggests that the excess cancer mortality from the long-term exposure to low levels of external and internal radioactivity of many millions in Russia and Europe could be less than 100 and is almost certainly below a few thousand. The Chinese contribution to our knowledge of low-level radiation epidemiology is still developing, and the present provocative findings may change or may reveal an explanation which will admit support for current risk estimates. Potentially, the impact of a larger statistical study with a zero or negative index of low-level radiation effect could be very far-reaching.

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