Perspective

Chernobyl: A Radiobiological Perspective

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MORE THAN A YEAR HAS PASSED SINCE THE DESTRUCTION of the unit 4 reactor at the Chernobyl nuclear power plant. Much has been said about the heroic efforts to bring the accident under control and of the loss of 31 rescue and fire-fighting personnel. If this were all there was to the health toll, it would have been recorded as a very severe "industrial accident," and, in terms of total fatalities, somewhat analogous to a coal mine cave-in or a large construction site collapse. That the fatalities were due to massive radiation doses, complicated by thermal and radiation burns, raises this tragedy to a special position (*1*). Not since the atom bombings of Hiroshima and Nagasaki has the world confronted such a radiation toll. But as sad and tragic as it was, Chernobyl's global impact is what places the accident in a unique position. We now probably have enough information to attempt to put the potential for future health effects from Chernobyl's radioactive releases into perspective.

The cloud of radioactive material that was ejected from the reactor blanketed much of the Northern Hemisphere and precipitated a fallout of small radiation doses and large societal apprehensions. Especially in Europe, where early measurements indicated the potential for significant doses, concern heightened and several mitigating actions were undertaken (*2*). In some instances these measures markedly reduced radiation exposure, whereas in others the actions were of marginal utility.

Many people who were in the high-fallout area are concerned that their present and future exposure to radiation has not been accurately described, that such information may have been "classified," and that they are at considerable risk for latent health effects. On the other hand, there are those who, because the latent effects are largely obscured by the normal mortality of the maturing population, consider estimating such effects in the low-fallout area to be of limited utility. This latter judgment is based on the fact that the expected late effects are markedly fewer in number than what would normally be expected (fatal cancers, for example), and are likely never to be seen.

The topic of fatal cancer expectation has been presented in a variety of conflicting ways, and the discussion appears to the outsider as a genuine clash of expert opinions; thus the "risk coefficients" appear "soft" and perhaps not very realistic. When one adds the limited potential for genetic effects and birth defects, the seeds are sown for a long debate about what really happened and what we may reasonably expect to see in the future. After all, some level of uncertainty still surrounds the Three Mile Island radioactive releases and their potential consequences. I therefore expect the assessment of the Chernobyl release (which was a million times larger than TMI) to continue for several decades.

For the past year I have been intensively studying the Chernobyl accident and its aftermath (*3*). I am struck by the fact that outside of the "near-field" region (that is, outside a radius of 30 kilometers), almost all of the radiological impact can be ascribed to exposure to the volatile radionuclides, radioiodine and radiocesium, which were efficiently transported through the atmosphere. Because of its relatively high concentration in the "far-field" Chernobyl plume, its efficient entry into our food web, and its concentration in the thyroid after ingestion, iodine-131 (8-day half-life) dominated early concern. However, it now appears that the radiocesium, with its wide distribution, its 30-year half-life, its beta-gamma dose potential, and its ubiquitous distribution throughout all tissues (it is a potassium congener), poses the dominant threat to the population. Taken in full perspective, the impact of Chernobyl from a radiological aspect depends on two major radiobiological factors.

The most significant factor is the determination of actual radiation dose absorbed into tissues. Radiocesium in the environment can present an external dose to people exposed to its deposits on surfaces. These exposures will lessen as the radiocesium is washed away, as it leaches into soil, and as it decays. In addition, radiocesium deposited on plants, washed into waterways, and absorbed from soil into crops, can be ingested and uniformly distributed throughout the body to produce an internal radiation dose. Cesium is not strongly retained and has a biological half-life in the body of about 3 months. Practically speaking, the lifetime dose from exposure to Chernobyl's cesium is now about half completed. Most of the remaining half will be added in the next 2 years and will be complete in about a decade. Although this estimate grossly simplifies the situation, it is reasonably adequate for purposes of risk assessment. What is more significant is an accurate determination of the amount of radiocesium released and its distribution.

The Soviets estimated that about 1 million curies were released, on the basis of measurements of depositions in the European part of the Soviet Union (*1*). They have released no public estimate of the amount of cesium-137 and cesium-134 that may have passed beyond their borders. Some European estimates also cite a value of about 1 million curies for Europe (*4*). Measurable amounts were also found in North America, and a U.S. Department of Energy report states that the total radiocesium release is calculated to be about 2.4 million curies (*3*). Thus, depending on which source term is used, the hemispheric dose estimate may vary. The 2.4-million curie value is consistent with measurements made near Chernobyl as well as some more than 10,000 kilometers away. This amount represents almost half of the radiocesium present in the reactor at the time of the accident. At present, it appears that about one-third of the radiocesium released is in the European Soviet Union, one-third in central and western Europe, and one-third in Asia and the rest of the Northern Hemisphere. The collective population doses in these regions would also be approximately apportioned in a similar fashion and as a first fit to all of the available data would cause a collective population dose commitment for the next 70 years of about 120 million person-rem, which is the sum of all individual doses. About half of this collective dose has already been delivered. It is the accurate determination of the dose values that will permit the ultimate assessment of the health impact of the Chernobyl releases on the population of the earth.

The second major factor to be considered is the "radiation risk coefficient." A radiation risk factor or coefficient can be developed for several radiation effects. There are three such effects that must be considered here. The most publicized is the risk of fatal cancers. The studies of survivors of the atom bombings of Japan, the evaluation

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of patient cohorts given large medical radiation doses, and other sources provide a database that constitutes the foundation of human radiation risk assessment. For the past decade, a rough estimate of 1×10^{-4} to 2×10^{-4} fatal cancers per rem has been used (*5*). On this basis, we predict that if 1 million people each received 1 rem, about 100 to 200 additional fatal cancers would ultimately be added to the approximately 190,000 spontaneous cancers that would be expected. It is not likely that any epidemiological study could ever detect such a small increment, and, given the statistical variation in the data, we cannot rule out a zero increment. The value is based on a fit to the high-dose data, extrapolated by means of an absolute risk model. Absolute risks are constant dose-effect increments, added to any age-specific fatal cancer rate. More recently, newer data support a model mainly predicated on the basis of a relative risk projection (*6*). In this model, the risk is proportional to the age-specific cancer mortality rate. The risk value for very low doses is about 2.3×10^{-4}, somewhat larger than the older value.

Serious genetic effects have been predicted in a heavily irradiated population. There are no human epidemiological data supporting such effects, but we know that the effects are manifested on the basis of exposure of the reproductive cells from animals and plants. It is currently estimated that less than 2000 such cases will be induced (almost all in Europe and the European part of the Soviet Union) and added to the 50 million that normally manifest in the population. As with the cancer fatality risk, it is unlikely that any ill health from genetic effects will be detected.

The recent work of Otake and Schull (*7*) focused on a third latent radiation effect, that of possible severe mental retardation in children in Hiroshima and Nagasaki who were in the 8th to 15th week of gestation at the time of irradiation. Their analysis indicates that this effect does not appear to have a threshold and follows a linear dose response. Other teratological effects are thought to require high doses and may actually have a high threshold. The size of the absorbed doses, the dose rate, and other factors make it difficult to directly transfer their model to the Chernobyl situation. If one were to do so, as many as 700 cases may have been induced from exposure to Chernobyl's radiation and added to the 70,000 cases that normally would be expected in the European population during 1986. If pregnant women were not immediately evacuated from the 30-kilometer "exclusion zone" around the accident site, the initially reported doses (*1*) were sufficient to cause a doubling of the risk to this specific group (from a normal expectation of about 13 to a total of about 30).

Almost without exception, radiation risk assessments are based on analyses of populations that received high doses, usually delivered at high rates. There appears to be a consistent dose rate amelioration effect for latent health effects, mainly on the basis of animal experimental data. For the population doses and rates under consideration from the Chernobyl accident, I would expect that a factor of from 2 to 10 may prevail; that is, the actual latent health effects may be two to ten times less than the established models would predict.

One of the results of radiation exposure that has received considerable attention over the years is myelogenous leukemia. This rare disease is relatively easily induced by whole body irradiation and has a relatively short latent period of 2 to 5 years; about a decade after exposure, it shows a risk potential that has returned to preirradiation levels (*5, 6*). Some 24,000 of the Soviet evacuees were reported to have received a collective dose of about 10,000 person-Gy (that is, 1 million person-rads, averaging about 43 rads per person) (*1*). Modern methods of molecular biology and cytogenetic analysis of blood cells can aid in quantifying the radiation dose. If the doses were received at a high enough rate, and if the current risk models are correct, one might find about 26 excess cases of myeloid leukemia in the next 2 to 8 years. Within about 50 months, one could begin to see the increase, especially since almost none would be normally expected. Thus it is of particular importance that a carefully designed epidemiologic study of people from the "evacuation zone" be mounted soon. Animal studies of this disease also suggest that the risk is dose rate–dependent. The nature of the Chernobyl exposures suggests that a dose rate reduction factor could have been operative, in which case almost no excess is likely to be detected. There is not yet a proven method by which we can accurately scale the latency and dose rate factors derived from experiments on short-lived animals to human risks.

The Chernobyl accident thus provides us with some radiobiological challenges. There is a real opportunity to advance our understanding of the role of dose rate and latency by careful study of the Soviet evacuated population, exposed workers, and rescue personnel. Furthermore, for two of the latent health effects, there is a reasonable chance that significant information could be available in the next 2 to 4 years. The accurate finding of no or many fewer effects than expected, on the basis of today's models for radiation risk assessment, would have a major impact on the degree of conservatism that one might include in radiation regulations for the public.

The analysis in the Department of Energy report presents latent health risk expectations for the entire Northern Hemisphere (*3*). Because of the nonthreshold nature of the models, the higher average population density in central and western Europe compared to the European part of the Soviet Union, and the distribution of population doses, the authors of the report estimated that about 50 percent of the risk would be in the European part of the Soviet Union. The lower doses, multiplied by much higher population densities, places most of the remaining 50 percent of the global risk in central and western Europe. For example, the global fatal cancer risk increment of up to 28,000 from Chernobyl's radioactive material is estimated to increase the spontaneous expectation of over 600 million by no more than 0.004 percent.

For most of these populations, the individual doses range from a fraction of a year's background radiation to 2 to 4 years worth. On an individual basis, the associated risks are minuscule. It is the size of the population over which the dose is distributed that has received the most attention. The irony may be that even in the highest exposed groups there may never be any demonstrable deleterious effects, whereas in the lesser exposed, larger, and more distant populations, attention will be focused on any clusters of health effects that show up in the next decades. The question will be whether these effects could be a consequence of the Chernobyl accident. On the basis of what we know now, the answer is "not likely."

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