Health Care After Chernobyl: Radiation, Scarcity, and Fear

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A slogan heard during the great expansion of nuclear energy in the Soviet Union in the 1970s, "a peaceful atom in every house," now has a bitter irony in the communities contaminated by Chernobyl. As central Soviet control loosened over the most heavily exposed republics, Byelorussia and Ukraine, there was, and continues to be, an angry outpouring of anecdotes of radiation illness [1,2] and resentment at the lack of Soviet response to these medical needs [3,4]. This article will trace some of the health issues following the nuclear disaster and is based on a variety of sources, including personal contacts with health care providers and accident victims in June 1986 and June 1991. Selected health studies will be discussed, recognizing that technical details are often missing from Soviet and republican publications.

The article proceeds through discussion of the following major categories of concern: why is Chernobyl of such interest? the social context in Byelorussia; the evolution of knowledge about the accident; the health consequences of the accident; the Soviet and republican health care systems; medical care in a contaminated region; and Western environmental and charitable groups. From this basis, conclusions are drawn about the degree to which acute deaths, birth defects, and cancer can be related to Chernobyl.

WHY IS CHERNOBYL OF SUCH INTEREST?

Many factors have converged to maintain interest and controversy about the causes, response, and implications of the Chernobyl nuclear accident of April 26, 1986, some general and others more specific to the accident. While ionizing radiation exposure from terrestrial and cosmic sources is a simple fact of nature, these exposures and those incurred during medical diagnosis and therapy rarely arouse public outcry. We are forced to look beyond physics and radiobiology to grasp Chernobyl and understand its interest and impact.

Radiation is an exotic and feared entity to most people. Imperceptible to senses, it can cause immediate burns, birth defects, and cancer decades after exposure [5]. Ionizing radiation is central to the horrors of Hiroshima and Nagasaki, and these horrors resonate with the threat of current nuclear weapons [6] and with centuries-old cultural themes of good and evil, alchemy, and mad science [7]. On the other hand, significant sectors of the military, business, and academic world have interests in the continuation and advancement of nuclear technology, ranging from the weapons laboratories, to nuclear utilities, to the medical diagnostic, therapeutic, and research communities.

In more recent years, a string of technological calamities has left the public less inclined to accept safety assurances from technical and scientific experts. These events include the Three Mile Island

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reactor accident of 1979 [8], the Bhopal chemical disaster of 1984 [9], and the Challenger space shuttle accident of 1986. Since Chernobyl, problems associated with nuclear weapons production and testing in the United States [10,11] and elsewhere [12,13] have received wider attention. Recent research continues to raise new questions about occupational health hazards for atomic workers [14–16], and studies continue to explore the possibility of an increase in radiogenic cancer near nuclear facilities [17]. Also during this period, radiation protection standards have tightened as the atomic bomb studies mature and indicate higher cancer risks than previously thought from ionizing radiation [5,18], and further changes have been advocated [19].

The past decade has seen a general increase in public concerns about the environment, ranging from local waste dumps [20,20a] to international issues such as global warming and stratospheric ozone depletion [21]. These environmental interests often clash with concerns about economic development and adequate energy resources [22] and have helped to make nuclear power a subject of intense worldwide controversy [23].

The Chernobyl accident was also one of great human drama. It occurred during a time of thawing relations between the two great nuclear belligerents of the world. It exposed populations throughout Europe to air-, water-, and soil-borne radiation and led authorities from Scandinavia to Greece to issue varied and sometimes conflicting food restrictions [24]. Fallout was even found near the South Pole [25], and it was estimated that radiation from Chernobyl would eventually cause 100 [26] or even 35,000 deaths [27] in the United States. In the months following the accident, perhaps 100,000 wanted pregnancies were aborted across Europe because of concerns about birth defects [24,28]. The cause of aiding victims of Chernobyl drew the attention of rock stars and even Mother Teresa [29].

The initial Soviet secrecy, the contradictory and inflammatory statements of Western government officials and media [30], the dramatic spy satellite photographs from the United States confirming the accident, and the worries of large Eastern European ethnic communities in the West for the safety of their families all served to heighten attention to the accident. The incident was quickly seized upon as offering lessons to support the positions of advocacy groups of all stripes on environmental, energy, military, and foreign policy issues. Their ensuing competition for media attention added to the melee, and the relative lack of information made controversies difficult to put to rest.

Finally, Chernobyl is of interest because of lessons it offers in preparedness for future nuclear incidents. Other Soviet reactors are at risk, with at least 118 unplanned shutdowns of Soviet nuclear reactors in 1990 [31]. While some plants have been closed, economic needs and political dislocations have prevented renovation or retirement of a number of marginal reactors, and 15 reactors of the Chernobyl design remain in operation. Similar concerns exist about reactors in Bulgaria, Czechoslovakia, and the former East Germany [32]. While civilian reactors in the United States and the West are generally agreed to be several orders of magnitude safer, serious incidents can and do occur [33,34]. In addition, the potential for events involving nuclear weapons or material remains very real as the Soviet empire collapses and as nations such as Iran, Iraq, Libya, and North Korea pursue nuclear ambitions.

THE SOCIAL CONTEXT IN BYELORUSSIA

The response in the former Soviet republics to the Chernobyl accident cannot be understood without reference to a larger social and political context. In Byelorussia and Ukraine, anger toward the central government was increasing even before the Chernobyl disaster [3]. These nations have proud cultural and political heritages dating back for centuries. There is a deep reverence for the soil and waters, and their contamination was deeply grieved. In addition, an obvious gap between standards of living in the Soviet Union and the West played a role in growing public resentment, as did the modest loosening of control over information during the initial stages of glasnost.

In Moscow, atomic energy was seen as a critical element in Soviet economic revitalization, permitting the generation of critical hard currency through sales of oil and gas reserves, and there were enormous pressures to place and keep reactors on line. Reports documenting the substandard construction practices used in building the Chernobyl reactor complex began to be laid at the doorstep of the communist system in 1986 and 1987, a process furthered when the 1987 trials of some of the Chernobyl managers revealed the complicity and cowardice of party officials [35].

The accident and the ensuing evacuations caused great disruption to families and communities. In the Gomel district of Byelorussia alone, 170 villages were evacuated and 20 large collective farms were closed in 1989, with additional villages slated for later evacuation [4]. The Ministry of Public Health sent more than 350,000 children and pregnant women away to sanatoriums, rest homes, and pioneer camps in 1986 and 1987 [36]. A further irritation to the republics was the use of conscripts by the military and interior ministry for the cleanup of the contaminated regions [37]. During this turmoil came public awareness that the Soviet government, in its desire to minimize the seriousness of the accident, had failed to cancel the usual May 1 mass celebrations and public assemblies in 1986. Since the reactor emitted large amounts of radionuclides through May 6, this omission resulted in the exposures of large numbers of citizens and children to direct fallout—even while Communist Party officials were using their connections to send their own families away to safety [38,39].

Blatant official hypocrisy was apparent in the controlled press. For example, a May 1987 article in *Soviet Life* bald-facedly stated that the safety features of Western reactors "do not differ in degree from the Soviet reactors. . . .Soviet scientists are well ahead of their Western colleagues . . ." [40]. Adding salt to the wounds were the 1988 exposés showing that mass murders in Byelorussia during World War II, attributed to Nazi forces, were actually carried out by Stalin's forces. Nationalists quickly linked these events to Chernobyl, seeing both as examples of Soviet genocide [41].

The major gains made by reformers in the March 1989 election, together with increasing reports of leukemias, thyroid conditions, and deformed farm animals [35,42], made it quite clear to party officials that attempting to minimize the accident's consequences was a losing proposition. Moreover, since the horrors of nuclear war had been stressed heavily by central authorities during the superpower nuclear saber rattling earlier in the decade, it had become difficult to write off fear of radiation as "radiophobia." As dosimeters became available and food was found to be contaminated, controversies erupted between citizens and radiation health experts who complained that manageably contaminated food was being left to rot because of radiophobia. Dimitri Popov, a Soviet radiation authority, was quoted as saying that cesium-contaminated meat could be "processed according to the recommended technology, diluted with clean meat and components, and put on the worker's table. . . the only special medical treatment the population here is in need of is psychotherapy" [31].

Studies showed 40% of breast milk samples to be contaminated with low levels of radiocesium in 1989 to 1990 [43]. These levels were higher in places identified by authorities to have little ground contamination, such as Minsk, probably because of looser food restrictions in these areas. Although the highest levels were only about 40 Bq/L (becquerel/liter) (international action levels for food in general are roughly 1,000 Bq/L), it was small comfort to nursing mothers to be told that these were "acceptable" levels. Street demonstrations over misinformation occurred in Minsk in the fall of 1989 [44].

Over the next two years, the party position on the disaster evolved toward the outrage of the reformers. By April 1991, *Soviet Life* mourned, "The great tragedy for Byelorussia was not only that it received 70% of the fallout, but that it also had to endure a criminal silence about the accident for three long years" [45]. Unfortunately, this heritage of deceit made general public acceptance of more accurate and consistent information virtually impossible. Given the intense media scrutiny and the difficulty of translating responses to such a multifaceted technical disaster into understandable public policy, loss of public trust in institutions was inescapable.

THE EVOLUTION OF KNOWLEDGE ABOUT THE ACCIDENT

Information about Chernobyl tends to fall naturally into three areas. The first is the nature of the accident itself, its causes, and the adequacy of the initial Soviet emergency response. The second is more technical and concerns the doses and distribution of the radioactive fallout. The third is the most hotly contested area and concerns the current and future health consequences of the accident.

The Accident and its Causes

The initial information released by Soviet media was tardy and sketchy [46], though the record after Western nuclear accidents is similarly checkered

[30]. The presentation to the International Atomic Energy Agency (IAEA) in Vienna in August 1986 filled in many gaps, but the painted portrait focused narrowly on operator errors during a misguided safety experiment, rather than on the major flaws in the plant's design, construction, and operation [47]. The complacency about these latter aspects was apparent in a February 1986 *Soviet Life* feature in which managers asserted that "the environment is securely protected" and that chances of a serious accident are "one in 10,000 years" [48]. Although the rhetoric became more sober after the accident, the fundamental economic and political problems in the Soviet system and the implications for reactor safety systems were not openly discussed for several years [37].

Later Soviet information tended to focus on the heroism of the fire fighters [49,50], perhaps in part as a diversion from broader questions. For instance, Leonid Telyatnikov, then chief of the Chernobyl fire station, was made a Hero of the Soviet Union and then toured the United States and London, where he met with Margaret Thatcher [51].

Indicative of the paucity of data relative to the interest was that even a visit to Chernobyl could be the basis of an article in a scholarly scientific journal [52]. Knowledgeable Western observers were able to use the IAEA meetings, academic and professional contacts, and visits to the area in 1987 to provide lucid early impressions of the accident [3,53]. Journalistic accounts added valuable detail about the early medical care and evacuation [38].

Several things changed over the next few years. The April 1988 suicide of Valerii Legasov, heavily involved in the design of the Chernobyl-type RMBK reactors and head of the Soviet delegation to the August 1986 IAEA meeting, aroused considerable interest around the world [54]. In the summer of 1988, Kiev newspapers began to publish radiation levels along with the weather forecast in their Friday editions [55]. Perhaps foremost was the election of reformers in Ukraine and Byelorussia to the Congress of People's Deputies in March 1989, which left regional officials much less likely to defer to central interests and accounts of the accident. The general flowering of glasnost and the emergence of a more independent press also contributed to a better understanding of the event and deficiencies in the reactor design and emergency response [37,56].

The most recent information has focused on the political decisions to restart the other three reactors at the Chernobyl reactor complex, rather than simply contain and abandon the site. This choice resulted in the exposure of many more conscripts and reservists to high levels of radiation during the decontamination activities of the summer and fall of 1986 [57]. During the past five years, over 600,000 workers are said to have been involved in mitigating the accident, and 200,000 of these may have received high doses [58]. Some sense of the scope of the clean-up can be gained from Vladimir Chernousenko, a nuclear physicist and a consultant to the Ukrainian Academy of Sciences commission on Chernobyl. In 1991 he appeared on British television, reporting over 800 waste burial sites in the exclusion zone, which hold over 500 million m^3 of contaminated soil, hardware, and equipment [58a]. In the reactor, the remaining fuel is said to have melted, run down into basement areas, and then solidified into a stable mass resembling an elephant's foot. Real concern exists about the integrity of the sarcophagus and the possibility that partial structural collapse could stir up large amounts of intensely radioactive dust. This would present a significant hazard, at least to the workers who remain on the Chernobyl site with the two other reactors still in operation [59].

The degree to which informative research will emerge is highly uncertain as 1992 begins. Multiple international agreements have been concluded to study the accident's consequences, but their validity is often in some question given the dissolution of the Soviet Union, including the Soviet Ministry of Health and over 80 All-Union ministries and government departments in November 1991 [60]. Research agreements with the republics may be more durable, but the troubled political and economic conditions and the loss of key scientific personnel are major obstacles to meaningful research, given the long latencies of most radiogenic illnesses.

Source Term and Dose Estimation

The initial radionuclide release (source term) has become better understood, though significant uncertainty remains for estimates of doses to populations. The total activity, half-lives, and biological handling of four radionuclides quickly established them as the principal ones of study and concern. These are the thyroid-concentrated radioiodines, mainly iodine 131 ($t\frac{1}{2}$ 8.05 d), the potassium-like radiocesiums, especially cesium 137 ($t\frac{1}{2}$ 30 y), and the alpha-emitters strontium 90 ($t\frac{1}{2}$ 28 y) and plutonium 239 ($t\frac{1}{2}$ 24,000 y). No substantial neutron exposure was found [61].

In the initial months after the accident, some Soviet scientists with the position and will to challenge official denials of the extent of fallout had their dosimetric equipment confiscated [62]. American and European researchers were able to take extensive environmental measurements in non-Soviet Europe, and reports were quickly gathered under the auspices of the World Health Organization and U.S. Environmental Protection Agency. In August 1986 at the Vienna IAEA meeting, these surveys were supplemented with a substantial amount of Soviet information on the general radiation release.

By using dispersion models at Lawrence Livermore and elsewhere, calculations were made of "whole-body dose commitment" in person-rad, i.e., the estimated whole-body radiation dose in rad for a given group multiplied by the estimated exposed population in that group [63]. This estimate is in turn dependent on estimates of the source term, that is, the amount and character of radionuclides released from the Chernobyl reactor core during the 11 days of high releases, April 26 through May 6, 1986 [64,65]. Most of these estimates have centered around 100 million person-rem (1 million person-Sv) [66], though several issues bear examination.

The first issue is the quality of environmental sampling, particularly in the Soviet Union, where the heaviest exposures occurred. A closely related second issue is the extent to which individuals still living in more contaminated areas have internalized and will internalize radionuclides through breathing radioactive dust and consuming radioactive milk and foodstuffs. A recent IAEA report loosely corroborated the results of Soviet techniques for estimating external exposure but found that internal exposure from contaminated milk, vegetables, meat, and the like was often overestimated [67]. Despite this, Soviet credibility on food safety suffered greatly, in large part because of their initial denial of the need for food restrictions, even while countries in Western Europe and Scandinavia imposed strict bans of their own [68]. A cynical joke at the time had authorities assuring citizens that it was absolutely, completely safe to eat locally caught fish . . . as long as one buried the frying pan afterwards. Dosimeters were not permitted in private hands until 1988 to 1989 [37], and even then supplies were grossly inadequate [44]. A year or more later, food restrictions continued to receive publicity in Britain, Japan, and Scandinavia [69–71]. Contamination of the water table and drinking supplies of Ukraine continues to worry authorities [57].

There was wide variation in the actual percentage of each radionuclide released, because of age and inventory of the fuel, reactor behavior, and the Soviet engineering response; there was also incomplete understanding of the physicochemical processes affecting volatility and state [65]. For released radionuclides, there are complex interactions with rain showers (which pull airborne radionuclides down to the earth), with other meteorological conditions, and with terrain [72]. Calculation of external exposure to individuals from fallout must take into account shelter, occupation, and daily routines [73]. Once the material has reached water or soil, issues concern estimation of the direct and indirect transfer of radionuclides into crops, milk, and meat and the adequacy of food monitoring and regulation. Any one of these factors can be a matter of considerable complexity, involving as they do highly technical and detailed questions and judgments in physics, geology, and plant biology, as well as human behavior, radiobiology, and nutrition. It is not surprising that public debate will erupt over these matters [74], particularly in a suspicious and anxious setting.

Radiation maps began to leak into the republican press in 1988 [75], though the Soviet bureaucrats continued to hold detailed results secret, even from other Soviet researchers, despite considerable cooperation with the IAEA [76]. As recently as 1989, the Soviet minister of energy, Anatoly Mayorets, was reported as signing an order that severely restricted the publication of information on nuclear power accidents and contamination "in the open press or for export abroad" [77]. Films investigating adverse health effects from the fallout were censored, and, in at least one case, KGB presence was required for a reporter's interview with an environmental expert [76].

Scientists and physicians were both participants in and victims of the secrecy. Radiation illness was not permitted as a medical chart diagnosis in Ukraine in the first few years after the accident. Teams of physicians organized to provide medical care in the contaminated areas were not provided with their personal doses (I. Melnik, personal communication, August 1991). Hard currency problems restricted subscriptions to foreign scientific journals and limited computer literature searching. Inadequate photocopying facilities further hindered the flow of knowledge. These conditions persist. Further, at least into 1987, articles from prestigious international scientific journals with even a single reference to Chernobyl were removed from circulation, even in the Natural Sciences Library of the U.S.S.R. Academy of Sciences [78].

In late 1988, Soviet authorities proposed a lifetime "safe living concept" to establish areas where populations would not need to have their diet and lifestyle regulated [67]. A 70-year lifetime dose limit of 35 rem was established, below which relocation was unnecessary. This met with great criticism, and in 1989 a lower limit of 7 rem was proposed, below which no public health measures were needed. The areas where 70-year accumulated doses for inhabitants were calculated to fall between 7 rem and 35 rem were to be subject to varying public health interventions. In Ukraine alone, this doubled the number of "heavily contaminated" oblasts (districts) [79] and led to new waves of evacuations and uproar. In all, Soviet authorities planned the evacuation of over 200,000 from 1990 to 1992 [80].

Even more confusion was generated in April 1990 when the Supreme Soviet introduced measures of relocation and compensation on the basis of surface contamination of an area by cesium. The three categories created were above 40 Ci/km^2, 15 to 40 Ci/km^2, and 1 to 15 Ci/km^2. At the highest range, villages were evacuated or even bulldozed because of the problem of elderly pensioners and others refusing to leave or slipping back to live after evacuation. As an expert study group organized by the IAEA pointed out, the surface contamination concept is dubious since "there is no simple relationship between the surface contamination level and annual dose or lifetime dose because of differences in transfer factors, living conditions, and eating habits" [67]. In fact, residents of less contaminated areas were often found to have doses similar to those in the more contaminated areas. This presumably occurred because the internal doses received as the result of permissive food restrictions made up for the lesser external exposure from radionuclides deposited on the ground (F. Mettler, personal communication, July 1991). In general, Soviet restrictions were successful in reducing internal cesium contamination, as documented by 9,000 whole-body counts for incorporated cesium performed by the IAEA Project throughout the contaminated regions in mid-1990 [67]. However, restrictions on consumption of locally produced food and milk were at times ignored or evaded, and moderately contaminated food was shipped around the U.S.S.R. [62].

For many in the affected areas, these delayed relocations confirmed the perfidy of Soviet authorities, though an analysis by outside experts in 1991 concluded that the exposures so prevented were on the order of magnitude (or less) of background radiation (Fig 1) and that the "measures are not justified on radiological protection grounds." Resignedly, they continued, "however any relaxation of the current policy would almost certainly be counterproductive in view of the present high levels of stress

FIGURE 1. A Minsk public information board in December 1990 showing an ambient background gamma radiation level. This level of 12 microrad per hour is roughly the natural level expected for that area. Photograph courtesy of Michael Christensen

and anxiety amongst inhabitants of the contaminated areas of concern and people's present expectations" [67]. One measure of public expectations was a recent conference presentation proposing modifications in the construction of elementary schools. Suggestions included moving most sports indoors, adaptations for children "often or constantly sick," and extended cloakrooms to store and clean shoes contaminated with radiation by outdoor play [81].

Individual Doses

Dose can be estimated in three basic ways. The first is through physical dosimetry from various remote sensors, survey meters, and personal monitors. The second is through biological dosimetry, using chromosomal aberrations, peripheral blood counts, and less specific physical signs and symptoms, such as skin burns, hair loss, and the timing of vomiting. The third depends on accident history for the individual: reviewing an individual's proximity, duration of exposure, activities, and protection during those activities. As a rough guide, acute whole-body doses above 2 Gy (200 rad) require hospitalization because of significant bone marrow suppression, and doses above 10 Gy (1,000 rad) are usually fatal even with sophisticated support. The annual natural dose of ionizing radiation from terrestrial, cosmic, and other sources is about 0.0036 Gy (360 millirad) [82].

At the time of the accident, the monitors at the reactor site were largely destroyed or inaccessible, and available survey meters were only able to measure up to 0.036 Gy/h (3.6 rad/h). Although a few civil defense meters were able to register up to 250 rad/h, these were held by military and civil defense units, and even these were useless in ambient radiation fields in the reactor machine hall as high as 8,000 to 15,000 rad/h [37,47]. The personal radioprotection dosimeters were often lost, contaminated, or exposed beyond capacity, when workers stripped and tossed their garments in a pile as they changed clothing and left the site [83].

The most precise biological monitoring is done by finding characteristic chromosomal aberrations on cytogenetic analysis of dividing cells from the blood or bone marrow. This technique, however, is time-consuming, gives little information on acute whole-body doses of less than 15 rem, and requires considerable technical expertise to perform and interpret. In addition, dividing cells may rapidly become unavailable for analysis in heavily exposed patients, and the aberrations fade with time. More persistent markers of radiation dose, such as red blood cell enzymatic mutations, are under study [84,85]. The rate and degree of the fall in radiosensitive blood elements, particularly peripheral lymphocytes, offer useful guidance in the dose range of 100 to 1,000 rem. Since this fall occurs in hours, prompt repeated blood counts are needed. As important as dose is, in Chernobyl patients with acute radiation syndrome, radiation burns from beta particles often were as important for prognosis as whole-body dose, especially when they involved over 40% of body surface area [86]. Thermal burns can also lower peripheral white counts, unrelated to radiation exposure [87].

The least specific but most used method of dose estimation at Chernobyl was analysis of physical signs and symptoms. After fairly uniform, high-dose-rate, whole-body exposures over 100 rem (1 Sv), the timing of vomiting was used to assess the degree of exposure [88]. Other factors included skin burns, parotid swelling, and fever [89]. These factors were used to perform the initial triage, as organized by Dr. Angelina Guskova and her team from the Institute of Biophysics in Moscow. Of the roughly 200 patients hospitalized at Hospital #6 in Moscow, 154 also had confirmatory cytogenetic assays, and subsequent marrow suppression was predicted with high accuracy [88].

In contrast to the experience in June 1986, dosimetry information was rarely available to the clinicians of patients we saw in 1991, even when following patients who had had clearly significant exposures. Cytogenetic expertise, scarce anywhere in the world, was focused on the well-defined cases of acute radiation illness being cared for in Moscow and Kiev. Personal protective equipment and dosimetry were seriously lacking at the time of the accident and in the early days after the accident for plant and emergency crews. Even doses recorded by the better prepared and monitored liquidators (the common Soviet term applied to cleanup personnel) are at times open to question. For instance, a cameraman who we interviewed flew six passes in an unshielded helicopter at 100 to 150 m directly over the reactor on May 6, 1986, a day when the reactor discharged an estimated 100,000 Ci. Although he did not report vomiting at the time, he had marked diffuse alopecia six weeks later while in Poland. Despite this evidence of higher doses, his "liquidator" dose card had only 80 millirem recorded by the military for May 6 (Fig 2).

The question of thyroid doses is difficult to assess at this point. An astonishing amount of radioiodine was released, with estimates of $1,300 \times 10^{-12}$ Bq (36 million Ci) for I-131 alone. Even though this radioactivity had essentially dissipated in three months (about 10 half-lives for I-131), in the first months 30% to 50% of milk from the hardest hit regions was contaminated above Soviet action levels [37]. Although the Soviet Ministry of Health reported that 5.4 million thyroid-blocking doses of nonradioactive iodine were distributed [90], it is not clear that this was of much benefit, since the prophylactic iodine should be administered within a few hours of exposure to be effective. The IAEA was also unable to corroborate Soviet actions in this area [67].

An interesting Soviet article reported a study of thyroid function in about 100 children, aged 1 to 14 years in May and June of 1986, noting a transient fourfold increase in serum thyroxine [91]. This may not have been due to the I-131 exposure; certainly, concentrated nonradioactive blocking iodine can also increase thyroxine through a jodbasedow effect [92], particularly in areas of chronic iodine deficiency, such as republics in the western region of the former U.S.S.R. Moreover, the median reported thyroid dose at autopsy in six patients who died of acute radiation syndrome at Hospital #6 was only about 1 Gy (100 rad), though an inverse relation between total-body gamma and thyroid doses was found [86]. By comparison, therapeutic doses of I-131 for hyperthyroidism seek to deliver over 100 Gy (10,000 rad) locally to the thyroid. The article also found mild increases in gland size, serum parathyroid hormone, and thyroglobulin antibodies, but data were sparse, and thyroid doses were not discussed.

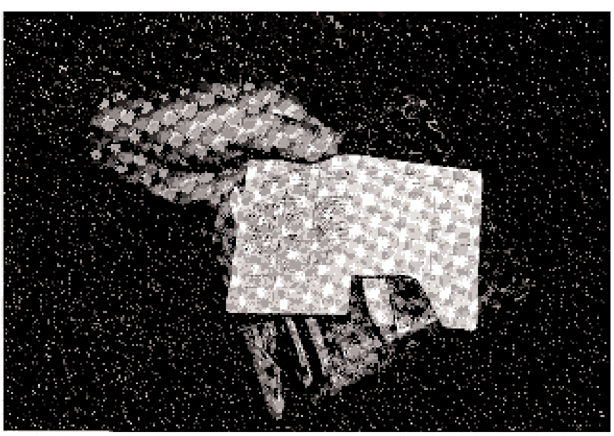

FIGURE 2. Radiation dose booklet issued by the Red Army to a photojournalist covering the accident at the reactor site. Only a total of 220 millirad are recorded for the first three weeks following the April disaster.

Dependence on signs and symptoms becomes much more problematic as doses fall below 0.5 Sv (50 rem), as dose rates fall, and as patients become more sophisticated about which symptoms would tend to support their perception of radiation illness. In part, signs and symptoms may have been due to injury from heat and toxic combustion products [87]. Even where effects were due to radiation, "nuclear tans," hair loss, and respiratory symptoms may have represented localized effects of inhaled "hot particles" (minute, intensely radioactive fragments of fuel) and dust with high beta activity, rather than manifestations of large whole-body exposures [37]. This possibility is pertinent because the short-term guidance levels for medical care and evacuation and the long-term cancer consequences are predicated on the better understood whole-body exposures.

THE HEALTH CONSEQUENCES OF THE ACCIDENT

The question of the health consequences for an individual or group exposed to ionizing radiation as a consequence of the Chernobyl accident can be examined for the short term, near term, and long term in at least three overlapping ways. This analysis sets aside for the moment health claims that are cynical attempts to win compensation or disability, or that represent political opportunism, and also makes the effort to distinguish illness arising from background disease or the serious pollution in the former Soviet Union and Eastern bloc nations [93].

A first group of health effects is defined primarily by the dose and rate of radiation and by plausibility of a given health effect as radiogenic under traditional precepts of radiobiology [94]. There are certainly debates about appropriate extrapolation from higher dose data sets to the lower doses typical of most of those exposed. However, participants in these debates generally make common assumptions about thresholds for direct effects such as cataract formation and about the types and latencies of probabilistic (stochastic) effects such as cancer induction. An important issue here is that even malignancies well linked to radiation, occurring at appropriate latencies, are usually "spontaneous" rather than radiogenic. For instance, when radiation-exposed and nonexposed groups were followed for 40 years after the bombings of Hiroshima and Nagasaki, only 11% of lung cancer and 22% of breast cancer could be attributed to radiation exposure from the bomb [18]. Certain laboratory findings are also plausibly related to the Chernobyl radiation, though their clinical significance is highly uncertain. An example is a recent report of a doubling of chromosomal aberrations, such as dicentric and ring forms, in children from heavily contaminated regions relative to controls elsewhere in Byelorussia [95].

A second group of health effects derives from a more expansive approach to the health impact of the accident. These might be described as the nonradiogenic paraphenomena of Chernobyl, such as illness from stress, nutritional deficits, increased alcoholism, induced abortions, and traumatic deaths incurred during the entombment of reactor #4. This category has not been well studied, though it would be intriguing to apply recent research on stress to this issue. Hatch and colleagues have recently suggested that a cancer cluster three years after the highly publicized Three Mile Island accident could be consistent with a promotional effect of stress on cancer [96]. A second recent study noted that subjects under psychological stress were more likely to become infected after the controlled nasal inoculation of a group with cold viruses [97]. This mechanism could provide an alternative explanation (other than direct effects of radiation) for the conviction in the republics that Chernobyl has resulted in more frequent respiratory infections. The limited republican data available suggest mixed effects of uncertain etiology. For instance, between 1985 and 1989, intestinal infections were reported as falling by over 50% in the Gomel region, perhaps as the result of closer food controls, while tuberculosis increased by 30% in more exposed sections of that area [98].

A third group of health effects consists of claims of types of radiation illness not traditionally recognized. One example would be cases of chronic lymphocytic leukemia, not recognized as a radiogenic illness in the A-bomb studies, but found to be increased in some atomic worker studies [16]. Others would be reports of autoimmune thyroiditis and premature cardiovascular mortality noted by a number of physicians in Byelorussia (Fig 3). While these conditions are fairly amenable to medical study, there is also a constellation of more vague symptoms such as fatigue and myalgias, which were reported after the bombings in Japan (S. Murata, unpublished data, 1988) and after the 1987 cesium 137 accident in Brazil [99].

Hard clinical information has remained relatively inaccessible. In the initial months, despite worldwide offers of therapeutic aid, bone marrow specialist Robert Gale, M.D. and a few of his colleagues were the only Western clinicians involved in direct medical care [100]. As such, Gale received wide Western media coverage [101,102], though he had input into a fairly limited aspect of the total medical care. He has continued to write extensively about Chernobyl [103,104,104a]. His estimates of future cancer mortality from Chernobyl, higher than the estimates by his central Soviet scientific hosts [105] and his controversial involvement in the 1987 Brazil cesium accident [106], have contributed to the attention his work has received.

The former U.S.S.R. had impressive expertise in radiation illness, especially at their specialized Institute of Radiobiology in Moscow. At the time of a Physicians for Social Responsibility-sponsored medical exchange visit in June 1986 [107,108], Soviet physicians displayed obvious interest and knowledge of radiation injury, acquired through clear familiarity with the world literature on radiation accidents and through their experience with patients

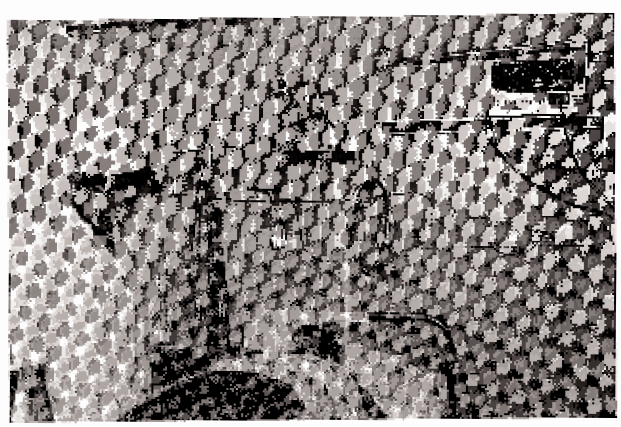

FIGURE 3. Scene in the intensive care unit of the major hematologic oncology referral center in Byelorussia, June 1991. The patient had had a myocardial infarction a few days previously.

from Kyshtym and other internal Soviet radiation accidents [109]. Dr. Angelina Guskova, chair of Hematology at Hospital #6, showed pride in Soviet capabilities and indicated that patient care and reliable data gathering were far larger priorities than international collaboration.

She noted a deluge of offers for medical assistance from the international radiation expert community but was confident in her institution's capabilities, particularly given the central organization present at the time that permitted staff and supplies to be brought in from around the country. The Soviets also judiciously supplemented their resources with items from abroad, such as third-generation cephalosporins, acyclovir, and GM-CSF (granulocyte-macrophage colony-stimulating factor, a sophisticated marrow stimulant) [110]. But, as Dr. Guskova commented dryly at the time, "had we given all the medicines suggested, none of our patients would have survived!" (A. Guskova, personal communication, June 1986). Of course, medical aid continues to be offered for the victims of Chernobyl, but its effectiveness is more uncertain, for a variety of reasons discussed below.

Soviet accounts of Chernobyl-related medical care published in the West have focused on the 128 patients triaged to Moscow in the first 36 hours of the accident [88,111]. Of these 128, 99 were found to have acute radiation sickness (ARS), and an additional 16 were admitted in Moscow in the following days and weeks, thus bringing to 115 the number of patients exposed to doses between 0.8 and 16 Gy (80–1,600 rad). These 115 patients with acute radiation sickness were analyzed by the same workers in later publications [88,112]. An additional 88 patients, most with minor degrees of ARS, were admitted to hospitals in Kiev. Roughly an additional 300 persons were admitted to hospitals in Moscow and Kiev in the first weeks but were not found to have ARS. Two patients died in the first hours after the accident, one from trauma and one from thermal burns [112,113].

Bone marrow transplantations were performed on 13 patients, two of whom survived [61]. Consideration of bone marrow transplantation is now felt by authorities in the former Soviet Union to be appropriate only after whole-body exposures of over 9 Gy (900 rad) [88]. Radiation-associated deaths occurred in 28 patients, on days 10 through 96 following the accident. Fatalities included six firefighters and one plant physician [100], with the remainder being other plant personnel [53] (Fig 4). Although over 85% of persons with ARS have survived, rehabilitation of patients with ARS has been difficult. Over half of 209 such patients assessed at 18 months stated that they experienced fatigue, chest pains, rhinitis, and impotence [114].

There has been much less discussion of the clinical health data of liquidators (civilian and military), the 115,000 initially evacuated, and those later evacuated. Soviet accounts discuss the examination of 600,000 persons, with 37,500 hospitalized at physician and patient request from 1986 through 1988. A fairly detailed plan of registration and monitoring has been outlined [36,114]. The Ukrainian Ministry of Health reports a registry of 129,000 liquidators, with dose estimates available for 56,000 and ranging from 100 to 200 mSv (10–20 rem) [115]. However,

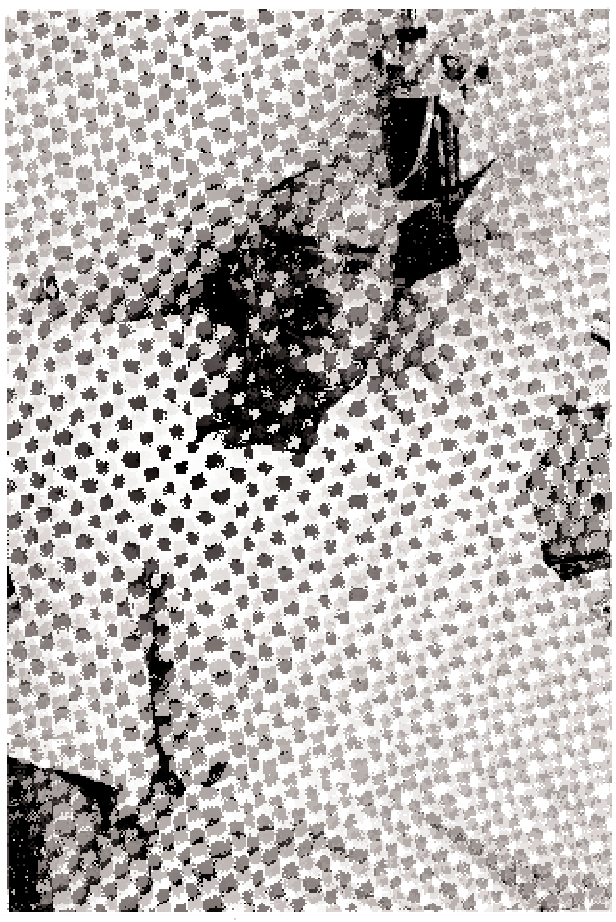

FIGURE 4. A 46-year-old turbine engineer in early June 1986 who had received a whole-body dose of about 600 rad (6 Gy). Herpetic skin lesions are evident. Despite marrow transplantation, he died nine days later. Photograph courtesy of Susan Alexander.

the sophistication and nature of these dose estimates and medical examinations are unclear, the adequacy of resources is questionable, and the degree of cooperation between central and republican authorities has become problematic with the dissolution of the U.S.S.R.

Available Soviet accounts of the health status were reassuring, though details are often lacking. Problems of diagnostic terminology and translation are significant [116]. There are also questions about the quality of statistics, both baseline and those gathered in the turmoil following the accident. For instance, *Pravda Ukrainy* reported in 1991 that no records were kept of military reservists operating in the contaminated zones in the summer of 1986 [79]. At least until the recent political changes, researchers not holding to the "party line" were unlikely to receive access to data or the support needed to attend international conferences. That said, a typical statement comes from Romanenko and colleagues:

> Generalizing the results of the examination of the population subjected to radioactive exposure, we can say that there are no diseases directly connected with ionizing radiation among population[s] But it doesn't mean that the accident had no influence upon the people's health. In our opinion it is very important to study vegetative dysfunctions (the so-called vegeto-vascular dystonia), the somatic effects of combined influence of low doses of ionizing radiation and other factors . . . [90].

Some Soviet commentators noted "high tension, enhanced excitement, stress and radiophobia" in exposed populations and suggested that these conditions may be more dangerous than the radiation itself [117].

Important work was done by the three medical teams of the IAEA "International Chernobyl Project" who went into contaminated and relatively noncontaminated areas for two weeks in 1990. These teams examined over 1,300 persons (methods of sampling, examination, and analysis were clearly specified) and conducted laboratory testing for blood count, thyroid-stimulating hormone, and heavy metals. Significant medical problems were found in 10% to 15% of those examined, but there were no significant differences between exposed and control groups in history and physical findings, nutritional assessment, pediatric growth curves, or laboratory tests. The teams concluded that "reported adverse health effects attributed to radiation have not been substantiated either by those local studies which were adequately performed or by the studies under the Project" [67]. A statistically demonstrable increase in future childhood thyroid cancer was thought possible. Populations involved in the initial evacuation and specific liquidator populations were not included in the Soviet request for assistance and so were not examined.

Despite this careful work and its appropriate concerns about the social and personal costs of unwarranted fears and evacuations, the IAEA's perceived role in promoting nuclear power and its ties to central Soviet authorities appear to have tarnished the report's reception in the republics. While the report was in preparation, a Ukrainian opposition leader was quoted as saying, "[The IAEA report] is a script that has already been written. And if by some chance it is not, no one will believe it anyway" [2]. Romanenko and other authorities associated with IAEA lost a great deal of credibility in the first 3 years after the accident. For instance, Romanenko is still remembered in Ukraine for a television address in mid-May 1986 when he scolded the public for radiation phobia and displayed charts showing spots in Ukraine where radiation levels had actually *decreased* from baseline after the accident [62]. Marples discusses health problems from 1986 to 1989 in the Ukrainian district of Narodychi (to the west of the reactor but outside the controlled 30-km zone). Health complaints of the public were initially dismissed by Soviet and Ukrainian authorities as due to "natural conditions in that area." Subsequently, some areas in the district were found to have soil contaminated with cesium 137 at levels over 100 Ci/km^2, and about 15,000 people were hurriedly resettled in 1990 [55].

THE SOVIET AND REPUBLICAN HEALTH CARE SYSTEM AS OF DECEMBER 1, 1991

A major problem was that of the centralized economic and health care system itself. The Soviet health care system was severely underfunded, with public health expenditures per capita at only 30% to 50% of Western European levels. The dissolution of the Soviet Union in December 1991 has further eroded economic progress, with the gross national product predicted to fall at least 20% in 1992. Though formally health services have been free of charge and available to all, in reality class and political position were used as entrée to the higher tiers of medical care [118]. For all republics in the former Soviet Union, life expectancy lags five to eight years behind Western countries, despite high numbers of hospital beds overall [119]. These national statistics are influenced by the major inequalities of health care between the European and Asian republics and between urban and rural areas [118]. For example, infant mortality in Ukraine and Byelorussia is considerably better than in the union as a whole, with 1986 figures running about 14 per 1,000 live births, compared with 25 in what was the U.S.S.R. and about eight in Western Europe [119].

Physicians are very numerous within the former Soviet Union, but 40% work in clinics associated with various government departments. Distribution of physicians is poorer in neighborhood clinics and rural areas [119,120]. Practitioners typically complete their training at age 24 or 25, and training is often with outdated texts and materials. While efforts are being made to improve the training of physicians [121], salaries reflect their current lack of status. Average salaries for clinicians are about 200 rubles per month, about $4 at current official market exchange rates, and salaries many times this are being paid even to clerical staff in some newly emerging enterprises. An aphorism heard regarding a doctor's work was: "Work at one job—no money to eat; work at two jobs—no time to eat!" More talented and ambitious practitioners in Byelorussia appear to be seeking employment elsewhere, and several asked us about further training in the West. Other concerns are that talented students are increasingly looking to careers as "entrepreneurs" and are forsaking the medical field altogether.

Our recent visit to Byelorussia in June 1991 was sponsored by a nonsectarian religious charity, Citihope, and included an internist, a pediatric hematologist/oncologist, and an oncology nurse. These personnel had been invited by the charity to assess the health needs in Byelorussia in an independent manner, gaining information for the provision of more effective aid. Over the past year, this group had accompanied many tons of medical equipment to Byelorussia and placed dozens of children in the U.S. for medical treatment and respite from the contaminated zones. In the process, ties had been established with many of the key players in the Byelorussian Chernobyl relief organizations, both communist and republican. These contacts permitted visits to a variety of health care institutions in Byelorussia, both referral sites and local clinics in contaminated areas. These included the separate oncologic (Fig 5) and hematologic institutes in Minsk, the three-year-old "anti-Chernobyl" center and the radiation medicine institute, known as the "Fireman's Hospital," in Asakovshina, and finally a small regional hospital in Narovlia. This city is on the edge of the highly contaminated zone, that is, with ground cesium 137 contamination above 40 Ci/km^2. The clinics visited were involved with care of the local population, referral cases from within the republic, and, in the case of the anti-Chernobyl center and Fireman's Hospital, liquidators involved in the cleanup of the stricken reactor during and after the accident in 1986. Over a week's time, a number of patients, both adult and pediatric, were examined and their medical records reviewed.

The medical needs are great indeed. Institutions were busy, and hospital beds were full because of the longer hospital stays for diagnostic work and recuperation typical in the Soviet Union. Buildings were similar to aging American urban county hospitals, with the exceptions of the anti-Chernobyl center, which had received lavish attention, and the radiation medicine institute, which had been a party clinic until 1988. An individual nurse typically cared for 30 to 40 patients. Medical records were fairly cursory by American standards. Laboratory reports were handwritten and typically included blood counts and a few chemistries. Imaging studies were usually limited to basic radiography, and computerized tomography was available, but on a limited

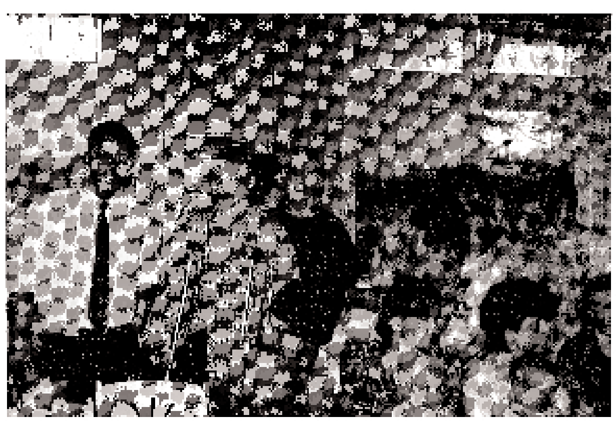

FIGURE 5. The author at the oncologic center in Minsk in June 1991. Physicians in Minsk were convinced of an increase in cancer as the result of the accident at Chernobyl though their registry data were more ambiguous.

basis. For example, a 12-year-old boy with brain cancer and hemiparesis had a computerized tomographic study and then received radiation therapy, but no follow-up studies were done. The scarcity of modern medical supplies, from basics such as syringes, sutures, and pharmaceuticals to essential laboratory and clinical equipment such as centrifuges and laboratory analyzers, has been well described in the West.

The uneven supply and quality of Western aid was an important issue. Most institutions presented us with a "wish list" of needed medicines and equipment. Medical supplies from Germany, France, Switzerland, and Japan were encountered. Difficulties come from small quantities, unfamiliar and incompatible medicines, medical equipment, technical support, and spare parts. Therapeutic improvisation is a way of life, as physicians cobble together available intravenous equipment and medicines. Physicians were also somewhat cynical about the frequency with which outdated medicines were brought in by aid groups, preceded by flourish and favorable press in the originating country. Jealousy exists between institutions, with particular concern over siphoning of Chernobyl aid to other institutions or areas of the country with "blat" (clout).

Also relevant are historical factors in Soviet medicine. Genetic counselors are in very short supply, in part because of the legacy of Stalin and Lysenko, who suppressed for political reasons the teaching of Mendelian inheritance. Similarly, the sad heritage of the use of Soviet psychiatry as an instrument of state oppression has made individuals reluctant to seek psychological counseling for stress related to Chernobyl. This in turn has increased the pressure on clinicians to provide organic diagnoses for stress-related symptoms.

MEDICAL CARE IN A CONTAMINATED REGION

Dr. Adam Nikonchuk, a general surgeon for 28 years and the chief physician in the Narovlia district, described to us major losses of personnel over the past several years. The district hospitals and clinics have a total of 210 inpatient beds and a normal complement of about 52 physicians. Although partially balanced by the evacuation of the more heavily contaminated villages in the district, their complement fell to 24 physicians in 1990, and they expected to lose an additional seven in July 1991. In this latest group they will lose such key specialties as anesthesiology, endocrinology, and dermatology. This loss of much-needed specialists was usually attributed to concerns of the physicians about the effect of radiation on the health of their families. Transfers have usually been within the republic and are slowed by the difficulty of finding new housing, with delays of over a year common.

Dr. Nikonchuk has seen no increase in colon, thyroid, or lung cancers in his own practice but does describe a clear increase in ulcers and, to a lesser extent, in asthma. He is involved in disability evaluations in association with the referral centers in Minsk and finds that this takes an increasing portion of his time. Physicians in general describe the demoralizing effects of the polarized opinions about the seriousness of the radioactive contamination and its health effects, though Nikonchuk is more worried about acquiring the human immunodeficiency virus (HIV) in surgery than about radiation. The well-publicized problems of needle sterilization with transmission of the virus during inoculation programs, as well as the poor performance of Soviet HIV diagnostic kits, even when available, give substance to his concerns. Feshbach reports that up to 85% of eligible children are not receiving the diphtheria vaccine. This is occurring in part because parents and physicians fear transmission of the HIV virus. A number of physicians are also concerned by reports that some vaccine lots are of low potency and that some are contaminated by mercury [122].

Cases encountered during the visit by the group from Citihope were challenging by any standard and included recurrent throat and breast cancer, pyogenic liver abscess, sarcomas, and chronic abdominal pain. Many clinicians perceive an increase in several types of cancer, especially leukemia and thyroid cancer, as well as other less well-defined types of radiation illness. Most of the physicians we encountered were aware of the recent IAEA-sponsored International Chernobyl Project, based on 1,300 health surveys in contaminated and uncontaminated areas of Byelorussia, Ukraine, and the other republics in 1990. Across the political spectrum, we found essentially unanimous disagreement with its cautious dismissal of widespread, radiation-induced illness. A frequent comment was that the group's brief stay and technocratic focus had blinded the group to the obvious illness confronting seasoned clinicians in their daily clinics.

The most consistent claim was for an increase in thyroid cancer, with insistence that this disease had virtually not been seen previously. For instance, at the Research Institute of Radiation Medicine in Minsk, we were given a conference abstract that reported 42 cases of thyroid cancer from 1986 to 1990, compared with 17 from 1975 to 1985. We had little success in our attempts to establish histologic classifications and referral patterns before and after 1986 and to determine whether since 1986 clinicians had become more aggressive in case-finding, biopsy, and thyroid resections. This is relevant because of the frequent presence of occult papillary thyroid carcinoma in world autopsy series [122a]. Awareness of recent Western research on radiogenic thyroid cancer [122b] was generally limited among clinicians.

Our initial review of a general cancer registry provided by staff at the central Byelorussian oncology referral center demonstrated a diffuse 15% to 50% increase in tumors from 1980 to 1986, compared with the second half of the decade. While some increase seemed to have occurred in leukemia, most of the increase appears to have occurred in unspecified and less common types of malignant tumors. In general, the incidence of various cancers per 100,000 population was only now approaching baseline Western figures, suggesting previous underascertainment as a significant factor in rising cancer statistics.

Our examinations did give a sense of the issues facing clinicians. Several children presented with mild anemia, slight perturbations of the leukocyte count, and modest adenopathy. Given the small size of most families in this area (few have more than two children) and the doting with which parents traditionally treat their children, the degree of parental and physician attention is not hard to understand. We also encountered a 39-year-old coal miner from Donetsk who had worked to tunnel under the Chernobyl reactor while it was still burning. He was troubled with nonspecific leg and abdominal pains that had not been present before the accident. He, and perhaps his physicians, attributed these to his 65-rad dose, though such symptoms are difficult to explain by traditional radiobiological precepts. He had made repeated diagnostic visits and felt that his symptoms merited a higher level of disability.

Given a setting marked by bitter controversies between central and local health authorities, new laws urging further evacuation, and a siege of journalists and Western scientists, it is hardly surprising that "radiation illness" has become a default diagnosis for the myriad of symptoms individuals have every week. In the West, headaches, fatigue, and musculoskeletal aches are often attributed to "a virus," though the precise documentation is usually lacking for a given encounter even in the most affluent of medical systems. Longer-lived symptoms may be attributed with little more evidence to hypoglycemia, chronic mononucleosis, or chemical sensitivities [123,124].

There was frequent reference to compromise of the immune system, especially of children, by radiation [125]. Some reports claim implausibly precise correlations between ground contamination with cesium 137 and medical conditions such as tonsillitis, cholecystitis, and iron-deficiency anemia, with correlations ranging from 0.6 to 0.93 [126]! Another study compared the symptoms of 220 children aged 7 to 14 years from Pripyat with the symptoms of 170 children of the same age from other areas of serious radioactive contamination. The symptoms of the Pripyat group were dominated by "headaches, dizziness, and car sickness," while the other group had predominantly stomach aches [127].

In view of the fact that most patients we saw had had only quite basic laboratory testing, at least some of these impressions seem to be based on subjective observation and sampling biases. Several local research studies documented perturbations of immune function in exposed patients, though the reports we saw lacked controls and clear associations with clinical illness [127,128]. In adults, it appears that disability is freely granted to ill liquidators, even those with confirmed exposures under 5 rem. One study reported on a group of 90 liquidators who had had their cases reviewed by an expert Byelorussian disability council. Although nearly 70% were under the age of 40, over 90% were granted disability of some form. Disabling diagnoses included "biliary tract disease," "cerebral circulatory disorder," and diabetes, among others [129].

It was not clear that the compensation paid for living in contaminated areas, the "coffin supplement" [62,130], or housing benefits were a source of exaggerated patient complaints. For one, the supplement was a modest 30 rubles per month, and benefits tended to go to nearly everyone in an area. Some community conflicts arise when preferential treatment is given for resettlement, such as to World War II veterans. However, resettlement villages were not always desirable. Villagers who had returned to the officially evacuated village of Gridney, even with small children, described life there in very positive terms and denied medical concerns. As one elderly woman put it, "I never saw a physician before Chernobyl—why should I see one now?"

WESTERN ENVIRONMENTAL AND CHARITABLE GROUPS

The political dissolution of the Soviet system and collapse of the ruble have led to the loss of traditional medical suppliers. It was reliably estimated in June 1991 that the Soviet Union would supply only 20% of needed pharmaceutical supplies in the 1991 calendar year [122]. Soviet medicine is dependent on herbs as sources for 40% of its drugs, given the traditional use of galenicals. The breakdown of the Soviet system's discipline and economy has also led to the pilfering and diversion of relief shipments to the black market.

There is now vigorous competition between republican and party Chernobyl aid groups to be seen as doing the most for accident victims. This includes securing foreign medical visitors and sending children abroad for medical treatment and for respite from what is perceived as a seriously contaminated environment [41]. Western environmental, religious, and charitable groups are thus finding a warmer welcome as republican leaders turn to the West for publicity and aid [131–133]. The new atmosphere of religious tolerance has encouraged missionary work in the Eastern bloc and republics, particularly by evangelical Christian groups. The levels of radiological expertise in the republics and in these more recently involved groups are uneven, and some may be tempted to overstate the health effects to increase donations.

There are important risks in overstating the danger individuals face because of radiation exposure. To the extent that alarmist reports appear about the people of Chernobyl, this important story gains more attention and support, at least in the short run. However, the ultimate cost may be high in terms of undermining the confidence of people in their own medical care, even when it is adequate, and misdirecting scarce social resources to alleviate radiation health risks, which for most are probably small in comparison with basic medical needs. Exaggeration may also promote continued flight of medical personnel, delay child-bearing, lead to unnecessary abortion, and contribute to the demoralization clearly felt by some. As one of our group members was scornfully asked by an individual in the contaminated territory, "so are you here to see the freaks?"

CONCLUSIONS

As seen in the preceding discussion, drawing reasonable assessments of the consequences of Chernobyl is far from simple. Independent tallies of the health effects of Chernobyl are now being collected in the republics, and, now that they have become politically independent of Moscow, wide dissemination of these findings is certain. As an aid to interpretation of new data, the following points highlight some areas where data appear well-grounded and indicate other areas where the literature is more silent.

Acute Deaths

The official Soviet toll of 30 or 31 deaths (two from trauma and burns and 28 or 29 from complications of radiation illness) is widely disputed as an underestimate, with competing figures running from 250 [134,135] to even 10,000 [136]. A key here is that nearly all the deaths in the official tally include only patients evacuated to Hospital #6 in Moscow during the first 48 hours. Personal protection was largely lacking during the initial week of response to the disaster, and at least 3,400 persons took runs across the roof of the Chernobyl machine hall with radiation fields in some areas exceeding 10,000 rad/h [37]. Soldiers were described as picking up pieces of nuclear fuel and radioactive graphite with their bare hands [47]. Thousands of coal miners, many from the Donetsk region of Ukraine, were involved with the digging of tunnels to cool the reactor and support the sarcophagus structures [57]. Some of these workers may well have received lethal doses but were cared for in military or district hospitals where their illnesses were either misdiagnosed or covered up. Gale notes "perhaps 40" cases of probable acute radiation sickness that he has become aware of through conversations with clinicians outside of Moscow and Kiev but knows of no deaths in this group (R.P. Gale, personal communication, August 15, 1991).

Ukraine reported 187 cases of acute radiation illness among liquidators at an IAEA-sponsored conference in May 1991, but again deaths, if any, were not discussed [115]. The lack of early deaths in patients with milder acute radiation syndromes (doses of 80 to 250 rem) is consistent with the clinical course of such cases, even without the benefit of hospitalization. Disposal of heavily contaminated debris and equipment likely explains the 1,000 cases of radiation burns in a registry of 129,000 Ukrainian liquidators [115]. Further information on the health of the early liquidators (especially from the military) will be of great interest. As noted previously, however, detailed and complete records are unlikely to be produced.

There is more information about liquidators not directly involved in early activities at the reactor complex. These liquidators participated in the decontamination of buildings, vehicles, and roads and the clearing of vegetation and topsoil, as well as evacuation, medical care, and other logistical support. Annual doses for a small group of liquidators working in the field away from the reactor were reported to be 20 rad for 1986, 12 rad for 1987, and 2 rad for 1988 [137]. However, other reports suggest that cleanup workers were assigned to a variety of zones in the contaminated regions, that logistical exigencies kept them in some areas longer than official guidelines would permit, and that dosimetry and protective gear were often absent [3]. Notwithstanding these obstacles, the World Health Organization has begun a study of 227,000 cleanup workers [138].

In contrast to the well-documented deaths over the first three months of ARS patients hospitalized in Moscow, most of the deaths in the first few years are more difficult to attribute directly to the radiation. Causes may include pre-existing illnesses, trauma, and early cardiovascular mortality [139]. Careful dose reconstruction and documentation of the causes of death will be vital in making sense of reports that allege hundreds or thousands of short-term fatalities. Setting aside the mortality issues, there appears to be significant disability among some groups of liquidators; conditions include impotence, thrombosis, and immune dysfunction [115]. While attributability to radiation is again uncertain, the importance of such morbidity should not be overlooked in the debate over "body counts."

Birth Defects and Perinatal Mortality

Many abortions were induced because of fear of radiogenic malformation, with early estimates exceeding 100,000 across Europe [140]. While some research suggested an increase in preterm deliveries with malformations [141], neural tube defects [142,143], spontaneous abortion [144], and low birth weight [145], expert consensus is that no conclusive increase in frequency of adverse pregnancy outcomes caused by Chernobyl radiation has been demonstrated to date [143]. Some increase in childhood leukemia from previous fetal exposure is possible, though the vast majority of fetal exposures are likely to have no adverse consequence [146]. A recent study by Gardner et al. [14] has raised the possibility that gonadal exposure to low-dose ionizing radiation can contribute to leukemia in children subsequently conceived. This conclusion has been questioned [15], in part because data from Hiroshima, Nagasaki, and animal studies suggest that the gonadal exposure needed for clear evidence of mutational effects, the "genetic doubling dose," lies around 2 Sv (200 rem) for acute, high doses and at about 4 Sv for cumulative long-term, low-level exposures [147].

A study done at the Research Institute of Radiation Medicine in Minsk did find an increase in structural birth defects during the periods 1982 to 1985 and 1987 to 1989 but was unable to correlate these increases with average population radiation exposures [148]. Alternative causes of reproductive abnormalities pertinent to these populations include nonradiological environmental toxins, alcohol intake, stress, and dietary deficiencies in nutrients such as folate. The relatively high infant mortality and patchy baseline statistics and registries will make definitive findings more difficult.

Longer-Term Effects

The issue of long-term deaths has in part become a proxy for the scientific, political, and ideological struggles being waged over the "truth" about the Chernobyl accident. It is almost certain that more cancers will be found in patients exposed to Chernobyl fallout; what is not clear is whether this increase will be due to radiation exposure. Competing hypotheses would include better ascertainment through better diagnostic and community vigilance, an improvement over previously incomplete cancer registries, more frankness on the part of clinicians in informing their patients about a cancer diagnosis, stress [96], poorer nutrition, and other environmental infectious and toxic agents [17,149,150].

The best analyzed estimate of eventual Chernobyl radiation-induced cancer in the northern hemisphere may be Anspaugh's 1988 "central" figure of 17,400 [66]. Other estimates are closer to 2,500; the lower estimates are based in part on adjustment for Soviet overestimation of doses, especially internal, to the general public. As is stated repeatedly in radiation protection documents, the true cancer toll "may be zero" because a low-dose threshold may exist, and animal data and some human data suggest a reduction in carcinogenic potency for low-dose, low-dose-rate radiation [151]. However, these assumptions are strongly contested by some [152], and BEIR V found "no departure from linearity for solid tumors" [5]. Further, lifetime excess cancer risk estimates were raised from BEIR III to BEIR V by factors of 3.4 to 18.3, with somewhat higher increases for the continuous smaller exposures (1 mSv/y or 100 millirem/y), which are most relevant for the great majority of those significantly exposed [5].

Whether the correct toll is 2,000 or 300,000, these cancer deaths will be extremely difficult to identify and document as Chernobyl-related in the sea of "spontaneous" cancers, which will number over 120 million over the next 50 years, in the former U.S.S.R. and elsewhere in Europe. This leads to a public health paradox for individual practitioners counseling individual patients exposed to radiation. As horrendous as any of these collective tolls are, even the highest doses will increase lifetime cancer risk for individuals by only by a few percent (most by a small fraction of 1%) compared with the "natural" cancer mortality of about 20%. Roughly 25% of these collective cancer deaths will be due to leukemia [18]. Given the latency of radiogenic leukemia incidence (onset at two to three years, peaking at seven to eight years, and elevated, but trailing off, over at least 35 years) and of solid tumors (which typically begin after 10 years and have continued to increase in the atomic bomb survivors for 40 years), the threat of cancer likely will hang over individuals in exposed populations for life.

However, for most the increase in risk of cancer is probably small relative to that stemming from health behaviors such as excessive alcohol consumption, faulty diet, and smoking. Understandably, this explanation typically meets with outrage from individuals who are at risk from Chernobyl radiation exposure, since this exposure was not a matter of personal choice.

The understanding of ways in which experts and lay persons perceive and evaluate risk is a subject of growing study, but it is very clear that these processes encompass much more than simple mortality figures. Factors include outrage, controllability and familiarity of the agent, effects on children and future generations, and trust in institutions [153]. The Chernobyl disaster encompasses all of these negative factors, and tens if not hundreds of thousands of persons have been exposed to potentially serious levels of radiation. It is unlikely that an ivory tower approach will be respected in any Byelorussian quarter if it requires rigorous proof of a statistically significant increase in radiogenic illness in advance of any action. It is also unlikely that any set of actions will completely reassure the public. After all, there remains significant bitterness among some "hibakusha" about similar symptoms, now 50 years after the atomic bombings in Japan. The A-bomb studies themselves remain controversial, even though hundreds of millions of dollars were spent to meticulously gather and analyze data at a time when doctors were trusted and in a country where conditions favored complete medical follow-up.

Chernobyl as Paradigm

The Chernobyl experience cannot be dismissed as irrelevant to the West or as a peculiar function of Soviet engineering and medical incompetence amidst a crumbling and discredited political and economic system. For example, there are powerful and troubling parallels between this experience and that of American communities downwind of Hanford and near toxic chemical sites. Although the scales of the incidents are not generally comparable, the public reaction to a careless, secretive bureaucracy and to deliberate deception is very similar. A few excerpts from newspaper articles about U.S. nuclear weapons plants in 1988 and 1989 and one from a book on the Love Canal toxic chemical dump serve to illustrate this point.

On the accidents:

> [They] included the melting of fuel and extensive radioactive contamination [154]. . . memo[s] describe

a striking complacency . . . numerous procedure violations were made . . . failure to disclose the problems illustrated a deeply rooted institutional practice [155]

On the public response:

"We know what caused all this It was the government. They never told us so we could protect ourselves" . . . "no one knows what our prospects are in the future. First our thyroids. Then cancer? . . " Mothers describe the horror of losing infants to unexplained illnesses. Husbands grow tearful remembering young wives who died from cancer, blood disorders, and other diseases . . . numerous studies have been conducted on these (exposed) groups, and the conclusions conflict substantially [156].

On the response of authorities:

Energy Department officials say that while the anecdotes are compelling, they have not been confirmed scientifically . . It is unlikely, they say, that such small doses could have significantly altered the health of residents. And health specialists under contract to the Energy Department have suggested that the real culprit might be the agricultural pesticides . . . [156].

On Love Canal:

Because [New York State Department of Health] officials did not pay serious attention to the task of providing information to them and working through the implications of the information, the residents felt that they were being treated not as rational, respected adults, but rather as though they had somehow lost their mature good sense when they became victims of a disaster they had no way of preventing [157].

Scientific uncertainty is inescapable in disasters such as Chernobyl, especially when attempts are made to estimate adverse health effects due to lower levels of exposure far into the future. Organizations and governments around the world have traditionally responded to this uncertainty (and to military and industrial self-interest) by concealing information from the public. Few technological disasters occur without prior warnings that corners have been cut, that systems are awry, that safety has been sacrificed for goals such as production, profit, or pride The assessment of when too much risk has been taken with too little regard for safety often has a strong ideological component [158,159], but, when whistle-blowers are ignored and even rudimentary public awareness of a technological hazard is squelched, corrective actions may come only after disaster has struck [160]. In Eastern Europe relative to the U.S., these technological risks are perhaps clearer because of their degree, and wide consensus exists that the safety of the remaining reactors in the former Soviet Union should be aggressively addressed and other environmental problems investigated.

Turning again to the health consequences of Chernobyl, sustained efforts toward achieving a few basic goals may be the most useful approach for clinicians and public health workers. Health habits and the health care system in general need to be strengthened. Public confidence in the safety of the food is essential. Clinicians should keep an open heart and mind about the nature and etiology of individual symptoms and should respond to well-documented medical and emotional illness of any cause. Patients should be provided with the best possible information about the risks of cancer and genetic damage when significant exposure to radiation has occurred and should be encouraged to remain active and integrated with their communities.

Honest and detailed records, open to review by the public and outside investigators, should be gathered and research supported with a focus on the integrity of the data, rather than on building a case for or against nuclear power. Completion of these studies will require considerable resources, persistence, and imagination. Communicating and applying the findings, in appropriate balance with economic development and other social needs, will demand great political skills. The struggle to accomplish these goals in circumstances of economic, social, and political upheaval will be daunting, even assuming major contributions from the West. Chernobyl will continue to challenge us for decades to come ❧

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