PEDIATRIC CT RESEARCH ELEVATES PUBLIC HEALTH CONCERNS: LOW-DOSE RADIATION ISSUES ARE HIGHLY POLITICIZED

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This article presents an analysis of issues related to low-dose radiation, with a focus on pediatric computed tomography (CT). It references several early studies that are seldom quoted in radiation research papers, then quantifies the excess lifetime fatal cancer yield attributable to an estimated 6.5 million pediatric abdominal CT scans. The authors highlight an important policy document issued jointly by the National Cancer Institute and the Society for Pediatric Radiology—specifically, its conclusion that a small dose from CT represents "a public health concern." Finally, the article identifies several contentious issues and proposes policy initiatives that, if implemented, could result in significant reductions of future radiogenic cancers and chronic injuries. The authors call for discussions between professional radiology societies and public interest health organizations, thereby involving *all* stakeholders.

There is no such thing as "safe limits" where exposure to X-ray radiation is concerned. Any X-ray exposure results in increased risk for disease.

Medical physicist Joel E. Gray, testimony before the
Minnesota Health Care Commission, June 18, 1997

The health effects of low-dose ionizing radiation have become highly politicized and risks are consistently understated. This article identifies several studies that seldom are referenced in the peer-reviewed literature. It then uses data from published works by radiation scholars to estimate the lifetime fatal cancer yield from pediatric computed tomography (CT) scans. We contend that unscientific attitudes and a culture of denial took root in skiagraphers' (photographers) X-ray

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clinics shortly after Roentgen's discovery in 1895—a defensive stance that resulted in an official cover-up of radiation research after Hiroshima that lasted throughout the Cold War. This review is based on a 2002 U.S. National Cancer Institute (NCI) and Society for Pediatric Radiology (SPR) *Guide for Health Care Providers* that contains this warning: "Because of the growing use of computed tomography (CT) and the potential for increased radiation exposure to children undergoing these scans, pediatric CT has become a public health concern" (1). The four-page pamphlet also notes that "major national and international organizations responsible for evaluating radiation risks agree there probably is no low-dose radiation 'threshold' for inducing cancers," and it calls for strategies "to minimize CT dose, disseminate relevant information, and clarify the relationship between CT radiation and cancer risk."

This NCI–SPR document stands in stark contrast to the conventional wisdom expressed over the past half-century by many leading health professionals and nuclear power advocates, who have operated on the belief that radiation exposures at low doses and slow dose rates have little impact on public health and safety. A classic example is contained in the 1996 Health Physics Society Position Statement, reaffirmed in 2004, which states: "Below 5–10 rem (which includes occupational and environmental exposures), risk of health effects are either too small to be observed or are nonexistent" (2). This premise was reinforced by a National Academy of Sciences panel: "On the basis of studies of radiation dose and risk in human populations, it is evident that ionizing radiation is not a potent cause of cancer" (3)—a highly selective reading of the evidence. The issue has become extremely politicized, with the nuclear power industry and its surrogates vigorously lobbying to relax radiation standards, while, at the same time, a growing number of federal and international agencies recommend more stringent regulation. The review of lifetime fatalities attributable to pediatric CT demonstrates the health risk from low-dose radiation and refutes claims minimizing risks. This article is an attempt to open a dialogue with those who seek an expansive search of the evidence.

HISTORICAL BACKGROUND: A MINDSET OF DENIAL

When Wilhelm Conrad Roentgen discovered X-radiation in 1895, its diagnostic qualities were instantly recognized, and skiagraphy clinics were quickly established in the United States and Europe. Medical journals and newspapers were flooded with ads proclaiming all manner of health benefits and cures, and laudatory commentaries heaped unqualified praise upon untested diagnostic and therapeutic procedures. In those early years there were numerous reports of serious skin burns to radiologists who used "the ray" with reckless abandon. Despite the death in 1904 of Thomas Edison's glassblower, Clarence Dally (the first attributable to radiation exposure), and the subsequent deaths of several prominent radiographers, few were willing to blame X-radiation since it had become a valuable tool for diagnostic and surgical procedures. Denial of low-level effects became an integral part of the medical community's armamentaria and even today plays a role in radiation policy and practice. There was little pressure to collect human data. In fact, skin dose was the only measure for almost half a century after Roentgen's discovery.

In 1926–1927, Hermann Joseph Muller performed his X-ray experiments on the fruit fly, *Drosophila*, proving radiation-induced mutation (4). His research was universally debunked or ignored, but that changed when the Nobel Committee honored him in 1946. He soon gained recognition as the Father of Human Genetics and was selected by the National Academy of Sciences as its first recipient of the annual Kimber Genetics Award (1955). In his acceptance address Muller cautioned: "No exposure is so tiny that it does not carry its corresponding mutational risk. It is well established that the overwhelming majority of mutations (more than 99 percent) are harmful, causing some functional impairment" (5). These early warnings, and the admonition *to first, do no harm,* were often disregarded. During the early developmental era, no public interest or medical groups had knowledge of radiation risk. Despite challenges to existing practices by prominent radiologists, indiscriminate use of X-rays and radium was widespread.

As the firestorm consumed Hiroshima and Nagasaki, the Atomic Genie rose from the smoldering ashes, ushering in an incendiary paradigm that found its sustenance in a protracted Cold War, breeding fear and suspicion and throttling open debate. A Brookings Institution study noted that the Atomic Energy Act of 1946 included provisions whereby radiation studies were "born secret," to be tucked away under their RD (restricted data) labels (6). Operating under this cloud of secrecy, the Department of Defense initiated a series of human radiation experiments involving soldiers and cancer patients. An executive order finally ended official secrecy in 1992. None of the professional medical or radiation organizations protested the use of the atomic bomb, none protested official secrecy, none protested the human radiation experiments, and none supported the Linus Pauling petition, signed by thousands of physicians and scientists, that led to a 1963 ban on testing of nuclear weapons.

LOW-DOSE RADIATION STUDIES

Alice Stewart was the first to conduct an epidemiological study on low-dose radiation in humans, the Oxford Survey of Childhood Cancer (7). Her study found that in utero exposure to one or two X-rays—10 to 20 mSv (millisieverts)—in a pregnant woman increased by about 50 percent the incidence of cancer and leukemia in the child by age 10. This was the first definitive human evidence linking diagnostic X-ray to these health risks. Cancer "experts" reacted with derision and disbelief, claiming Stewart's retrospective research was unscientific. But four years later, MacMahon at Harvard conducted a prospective study confirming her work (8). This evidence was followed by publication of at least eight other epidemiological low-dose radiation studies disproving threshold theories (9–16), including the important tinea capitis (a fungal infection of the scalp) study by Modan, which found thyroid cancers in children at exposures of 60 to 90 mSv.

A major project on radiation health effects commenced in 1963 when John W. Gofman, associate director at Lawrence Livermore National Laboratory, received a grant from the Atomic Energy Commission to establish the Biomedical Research Division for the express purpose of investigating radiation health risks. In a paper presented at the Institute of Electrical and Electronics Engineering Nuclear Science Symposium in 1969, Gofman (17) warned of low-dose radiation health hazards and called for a five-year moratorium on construction of nuclear power plants. The Atomic Energy Commission was not pleased. Gofman lost his funding at Livermore and then established the Committee for Nuclear Responsibility (his board members included four Nobel laureates—Linus Pauling, Harold Urey, George Wald, and James D. Watson) and authored five books on the health effects of low-dose radiation, containing 1,916 references (18–22). Two eminent medical physicists reviewed his 1990 book, *Radiation-Induced Cancer from Low-Dose Exposure* (20), along with the National Research Council's *BEIR V Report* (discussed later in the article), stating that they contain "substantial areas of agreement" and both books are "strongly recommended" (23).

A decade later, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) issued a report confirming Gofman's "no safe dose" theory: "Breakage of both strands of the [DNA] duplex may be achieved by the traversal of a single ionizing track and does not require multiple track action. . . . A fraction of radiation-induced double-strand damage will be repaired efficiently and correctly, but error-free repair of all such damage, even at the low abundance expected after low-dose exposure, is not anticipated" (24).

In 1997, a paper by Doll and Wakeford (25) basically supported the conclusions of Stewart's in utero studies. Six years later, 15 cancer experts published a review that concluded there is good epidemiological evidence for increased cancer risk at a 10 to 50 mSv acute dose and 50 to 100 mSv protracted exposure (26).

CT WARNING SIGNS

When a team of Columbia University scientists published a paper in 2001 estimating 500 future excess cancer deaths resulting from 600,000 pediatric CTs (27), shock waves reverberated among radiologists and clinicians in the wider medical community. This was the first attempt to quantify CT-induced fatalities, and it reopened the contentious low-dose radiation debate. On August 18–19, 2001, the Society for Pediatric Radiology convened the ALARA (as low as reasonably achievable) Conference, attended by many of the major players. The entire April 2002 issue of *Pediatric Radiology* was devoted to summary statements of many participants. Some extracts follow (28):

> Don Frush:
> I would like to challenge the audience that we've used the *optimal image quality* a lot, and I argue that that's not what we need to do. We need to look at *acceptable image quality*.
>
> Ed Nickoloff:
> The radiation doses throughout the [acrylic] phantom are nearly uniform for the small sizes, and the dose at the center is approximately 50% of the surface dose for the adult size.
>
> Tom Slovis:
> The consensus among pediatric radiologists is that somewhere around 30% of CTs are unnecessary.

Two months after the ALARA Conference, the U.S. Food and Drug Administration (FDA) issued a Public Health Notification, warning that "children less than 10 years of age are several times more sensitive to radiation than middle-aged adults" (29). It recommended methods to optimize CT settings, including a reduction in tube current, using a table of tube-current settings based on patients' weight; reduction of multiple scans with contrast material; and elimination of inappropriate referrals.

REASSESSMENT OF PEDIATRIC CT DATA

Here we review recent data from authoritative sources, use estimates from the atomic bomb survivors Life Span Study (LSS), make several assumptions, and construct an easy-to-understand formula to estimate the excess lifetime fatal cancer yield (FCY) attributable to pediatric (age 0 to 14) CT body scans in the United States.

Methods

Defining Radiation Dose. There is much confusion throughout the radiology community in defining and quantifying dose. At the November 2002 National Conference on CT Dose Reduction, Cynthia H. McCollough, a Mayo Clinic medical physicist, observed that "we have too many concepts, terms and trade names. In particular, we need to agree on how to define or describe CT dose and agree on the terms used for such units. . . . Perhaps we should declare a moratorium on any new dose concepts and terms until we can sort out what we have now" (quoted in 30). The sievert (Sv) is now universally accepted.

Abdominal CT Examinations in the United States. To quantify the number of pediatric CT scans, we begin with studies that estimate the total of CT examinations in the United States. A 2000–2001 FDA survey of CT facilities in 39 states revealed at least 50 million CT exams. It also found a 3:2 body:head scan ratio, with effective dose from abdominal CTs averaging 10 mSv per scan (20 mSv in children) and 1 death per 1,000 (31). According to the FDA, body scans are on the increase. Many experts now estimate at least 75 percent of all exams are abdominal scans (we use 70%).

During the final draft of this article, we viewed a press release on the IMV Ltd website (imvlimited.com, November 6, 2006) describing its current survey conducted by the company's Medical Information Division. It counted all CT examinations at one-third of hospital and non-hospital CT sites (2,565 of 7,650 facilities) during the February–August 2006 study period and estimated there were 62 million CT exams. This represents at least a 25 percent increase over the past four years. At the November 2002 National Conference on Dose Reduction in CT, chairman Fred A. Mettler, Jr., stated that "CT now represents the largest single source of medical exposure and its use is increasing rapidly. In some university departments CT scanning has grown to be about 15% of the total number of examinations but now accounts for about 70% of the dose delivered. CT procedures could account for as much as 60% of manmade radiation exposures to Americans" (32).

In the 1998–1999 study year, Mettler and colleagues reviewed 33,713 consecutive CT examinations and then gave a more thorough analysis of 2,000 of these. They found 11.2 percent in the pediatric age band and concluded: "Our data are derived from only one hospital, but we believe that the findings are broadly representative of a large portion of radiology practice in the U.S." (32).

Based on the rapid increase in CT utilization, we conclude that pediatric CT now accounts for at least 15 percent of total examinations, or 9.3 million in the pediatric age band; 6.5 million (70%) are body CTs, the base used in Table 1. Note that this conservative estimate does not include multiple scans.

Pediatric CT Body Dose. Using acrylic phantoms, medical physicist Edward Nickoloff calculates the typical pediatric CT body dose at 29 to 68 mSv when scanned at 100 to 300 mAs (milliamp seconds), and he observes that "as the diameter of the phantom decreases to a small size, the dose at the center is nearly the same as the surface" (33). Nickoloff indicates that his lab scans at 60 to 80 mAs, with an energy dose of 10 to 30 mSv to the internal organs (34).

On the basis of the FDA estimate of 20 mSv for an internal organ dose (31) and the estimate by 15 cancer experts that an average abdominal pediatric CT dose is 25 mSv (26), we use 20 mSv as the typical pediatric CT body dose and a calculated mean dose of 28 mSv to the internal organs (Table 1). This review would be incomplete without an analysis of the multiplier effect and the relative biological effectiveness of X-ray.

Multiplier Factors. When the Mettler team examined 2,000 consecutive CT folders, they produced evidence of multiple CT scans in four categories: 59 percent of CT patients had one or two scans; 30 percent, three or four scans; 7 percent, five to eight scans; and 4 percent, nine or more. Their study found that 96 percent of all patients had more than one scan sequence on the same day (32).

We use the mid-point at each level (9+ becomes 10 scans)—1.5, 3.5, 6.5, and 10—as multipliers to determine the total number of scans per number of patients in each category.

Radiation Effects Research Foundation (RERF) DS 86 Dosimetry. This study references the RERF DS 86 Dosimetry "Estimation of Lifetime Fatal Cancer-Yield for the United States' Population," as reproduced in Gofman's book (20) from the LSS diskette. The same age bands (0–9, 10–19, 20–34, 35–49, 50+) are listed, five each for males and females, with a conversion factor as applied to the age-sex distribution in the 1978 U.S. population for a sample of 10,000 persons per cSv (centisievert) of exposure.

For the purposes of our study, the 10 to 19 age band is halved (to 10 to 14) to conform to the pediatric age band, and we find 16.57 (our calculation uses 16) deaths per 10,000, or one fatality for every 625 persons in the pediatric age band.

Note that the National Research Council's Committee on the Biological Effects of Ionizing Radiation *BEIR-V Report* concluded that "if 100,000 persons of all ages received a whole body dose of 0.1 Sv (100 mSv) of gamma radiation in a single brief exposure, about 800 extra cancer deaths would be expected to occur during their remaining lifetimes" (35). To arrive at these numbers, BEIR-V uses the previously accepted dose reduction factor of 2 (used by the International Commission on Radiological Protection (ICRP) and UNSCEAR), which divides risk rates by 2 when estimating cancer risk at low dose, but the report also indicates that the mortality risk for children is double the risk for the entire population. The basic equation is:

$$800 = r\,(100{,}000)\,(0.1\text{ Sv})$$

where r is the rate of cancer deaths per exposure. Thus:

$$\begin{aligned} r &= 800/[100{,}000\,(0.1\text{ Sv})] \\ &= 8/[1{,}000\,(0.1\text{ Sv})] \\ &= 8/(1{,}000 \times 100\text{ mSv}) \\ &= 8/(10{,}000 \times 10\text{ mSv}) \\ r\,(10{,}000)\,(10\text{ mSv}) &= 8 \end{aligned}$$

This is equivalent to a lifetime fatal cancer yield of 80 per 10,000 persons exposed to a 100 mSv whole-body dose, or 8 FCY per 10 mSv exposure per 10,000—and double this number in the pediatric age band. (BEIR III Chairman Edward Radford was ostracized for 10 years after stating that low-dose radiation from manufactured sources posed a health risk, and he clashed with those who claimed there is a threshold.)

Relative Biological Effectiveness (RBE). In 1986, the International Commission on Radiation Units and Measurements recognized that gamma rays received by A-bomb survivors were only half as effective as orthovoltage X-rays (36), thereby doubling the risk estimate for X-rays—or an RBE factor of 2 when using the DS 86 Dosimetry gamma data in determining the mortality rate from X-rays. This factor may be on the low side. In 1995, Tore Straume, working at the Lawrence Livermore National Laboratory, authored a paper indicating that 250 kVp (peak kilovolt) X-rays have an RBE of 4 when compared with an equal mSv dose of gamma received at Hiroshima (37). We use RBE × 2 to arrive at the total lifetime FCY, as shown in Table 1.

Table 1

Pediatric CT lifetime fatal cancer yield (FCY)

a. 6.5M CTs × .59 (1–2 scans) × 1.5 avg. scans per child	5,752,500
b. 6.5M CTs × .30 (3–4 scans) × 3.5 avg. scans per child	6,825,000
c. 6.5M CTs × .07 (5–8 scans) × 6.5 avg. scans per child	2,957,500
d. 6.5M CTs × .04 (9+ scans) × 10 avg. scans per child	2,600,000
Total number of scans per child at 10 mSv per scan	18,135,000
Mean number of scans per child	2.8
Mean organ dose at 10 mSv per scan	28 mSv
FCY based on DS 86 Dosimetry ratio of 1:625 gamma dose of 10 mSv in pediatric age band: 18,135,000/625	29,016
Conversion factor from gamma to X-ray (RBE 2)	58,032
As percent of 6.5M pediatric body scans	0.9%
FCY based on body dose of 20 mSv	116,064
As percent of 6.5M pediatric body scans	1.8%
FCY based on mean organ dose of 28 mSv	162,490
As percent of 6.5M pediatric body scans	2.5%
As percent of 9.3M pediatric scans in 2006	1.7%
FCY based on mean organ dose of 5 mSv per scan	29,016

Note: Calculations based on 6.5 million body CTs, Mettler et al. (32), DS 86 Dosimetry, and organ dose of 10 mSv per scan in 2006.

Results

This reassessment of the data finds that a 10 mSv dose of ionizing radiation from a single CT examination is a potent mutagen, wreaking havoc in a child's internal organs and bone marrow, with a direct link to more than 58,000 excess lifetime fatal cancers among the 6.5 million pediatric patients in the United States who received some 18.1 million separate doses from multiple abdominal scans during CT examinations in 2006. A typical organ dose of 20 mSv results in 116,064 FCY, whereas the mean dose of 28 mSv results in a lifetime FCY of 162,490—or 2.5 percent of all pediatric CT abdominal scans (6.5 million). In analyzing DS 86 Dosimetry A-bomb survivors' data, it came as no surprise to find that 64.7 percent of the lifetime FCY is in the 0 to 14 age band, and 77 percent within the 0 to 19 age bracket (20).

Discussion

The National Cancer Institute and Society of Pediatric Radiology guide (1) provides the frame of reference for this study. The principles listed below justify the claim that low-dose exposures and pediatric CT represent a public health concern and should be the subject of an ongoing discussion at medical conferences and grand rounds:

- CT use (all ages) increased about seven-fold between 1993 and 2002.
- Epidemiological studies demonstrate a much greater sensitivity to radiation in the pediatric age band than in adults.
- Lifetime risks are significantly increased when children are exposed to radiation.
- There is probably no low-dose threshold for inducing cancers.
- Unnecessary exposure is associated with unnecessary risk.
- Minimizing dose will reduce the projected number of CT-related cancer deaths.
- Physicians who prescribe pediatric CT should continually assess its use on a case-by-case basis (1).

We concur with the NCI–SPR observation that multiple scans present a particular concern, and medically irradiated populations demonstrate small, but significant, increases in cancer risk even at the low levels of radiation associated with pediatric CT scans. In fact, the mean dose of 28 mSv from multiple scans (see Table 1) is a very low exposure, and the 2.5 percent mortality rate demonstrates a small and significant risk.

Note that there are no studies showing age distribution in the pediatric age band, and thus we have to make certain assumptions. Based on the referenced studies, 10 mSv per abdominal scan represents a conservative approach. Some critics may cite a reduced mean dose, based on lower settings and new equipment.

Potency of Ionizing Radiation. Ionizing radiation is the world's most effective mutagen, but the RERF Life Span Study used by international standard-setting agencies seriously understates the risks. In her 1998 testimony before the U.S. Senate Committee on Veterans' Affairs, Bertell describes serious flaws in the LSS, beginning with errors in the doses. Research dose categories are based only on the immediate flash of gamma radiation from the bomb explosion, and the "exposed" or study group is limited to those within one kilometer of the hypocenter at time of detonation. Other people, not included in the study, were subjected to radiation doses from fallout, ingestion of contaminated food and water, and ground shine from radioactive ground cover, and a large cohort in the control group (judged to be uncontaminated) who assisted in the cleanup were also exposed to low doses delivered over time. These people were not monitored, nor were radiation exposures indicated as a possible cause of subsequent cancers. Moreover, medical X-rays received as part of the follow-up research—and not homogeneously distributed among the study population—were ignored in the main analysis. The LSS controls were matched by age and sex distribution to the "exposed" cohort, but no correction was made for the "healthy survivor effect," which could have been determined. Also, persons with a calculated dose of less than 10 mSv were placed in the control group (unexposed), approximately 34,000 of the more than 80,000 in the entire cohort. These errors in research design raise questions about the validity of the data.

A large body of low-dose radiation research has demonstrated a statistically significant effect on childhood cancer, leukemia, and noncancer diseases. For example, Gofman (22) cites a study by John F. Ward that demonstrates the special potency of ionizing radiation and its unique property to deliver so much extra energy, all at once, to very small regions of a cell. Five studies prove a "doubling dose" (the amount of radiation that adds a rate equal to the effect's preexisting rate, similar to the rate attributable to natural background radiation) for structural chromosomal mutations in the range of 20 to 200 mSv (38–42). And nine other studies demonstrate that genomic instability could be induced by ionizing radiation from X-rays, gamma rays, and alpha rays (43–51).

Two papers on the "bystander" effect were published in 2001, both of which indicated that current risk estimates may be seriously understated (52, 53). In their review of this phenomenon, Mothersill and Seymour provide a broad definition: "the detection of responses in unirradiated cells that can reasonably be assumed to have occurred as a result of exposure of other cells to radiation" (52). Citing literature going back to 1954, these authors indicate that studies with microbeams now being conducted at Columbia University and at the Gray laboratory (U.K.) will advance our understanding of the microdosimetric aspects of the bystander effect, and they note that direct irradiation of cells is not required when accounting for perpetuation of radiation-induced genomic instability and transgenerational effects. Zhou and colleagues discovered that "cells irradiated with a single alpha particle can induce a bystander mutagenic response in nonirradiated neighboring cells through a process of gap junction cell-cell communication whereby irradiation of 10% of a population resulted in a mutagenic yield that was similar to the yield when all of the cells in the population were hit" (53). This team also found evidence that bystander effects are involved in malignant transformation of mammalian cells in vitro. Genomic instability implies that this impact results in vulnerabilities to further assault by radiation and other carcinogens in the environment. These factors, not used in our study, provide further scientific evidence of undercounts in cancer incidence and mortality.

Another study of very low-level X-ray risk was presented by University of Washington researchers who found low birthweight (<2,500 g) in infants born to mothers who had received a single dental exam that exposed the thyroid to a 0.1 to 1.0 mGy (milligray) dose during their pregnancies (54). A recent National Center for Health Statistics report found an "unexpected increase" in infant deaths per 1,000 live births, from 6.8 in 2001 to 7.0 in 2002, "the first increase in the U.S. infant mortality rate since 1958" (55). It identified low birthweight as one of the three leading causes of infant death, along with congenital malformations and sudden infant death syndrome. Radiation from atmospheric atomic bomb tests in Nevada, in addition to radiation exposure to the hypothalamus-pituitary-thyroid axis in pregnant women, may be implicated, but its role needs to be researched and quantified. Additional evidence of childhood risk comes from the August 2001 ALARA Conference Executive Summary conclusion: "Children are more sensitive to radiation than a middle-aged adult by a factor of 10" (56). This sensitivity factor suggests that in utero exposures may be much greater than supposed and indicates a heightened sense of urgency for research on these risks to the unborn.

Low-Dose Radiation: Postmortem. In addition to the work cited above, there is a large and growing body of scientific human evidence confirming the primary role of low-dose ionizing radiation in the multistage process of mutagenesis and a recognition that the rapidly increasing number of pediatric CT scans, and corresponding steady rise in diagnostic radiography and fluoroscopy over the past quarter-century have resulted in a statistically significant increase in cancer mortality and noncancer effects. The recent *World Cancer Report* completely ignores the role of radiation, stating that "the most important human carcinogens include tobacco, asbestos, aflatoxins, and ultraviolet light" (57, p. 304), a conclusion promoted by the major cancer prevention organizations. There is no mention of X-radiation, or emissions and waste from nuclear power reactors, or additive and synergistic effects with chemicals—an omission that calls into question the validity of the entire report.

In 1994, Nussbaum and Kohnlein identified a number of unsettled questions and suggested a look beyond the cohort of A-bomb survivors (used internationally as the "gold standard") to numerous unrefuted studies "that are inconsistent with traditional notions and, therefore, have been rejected, ignored, or glossed over in purportedly comprehensive reviews of the field" (58). They issued a call for new research and "an urgent need for the formulation of novel, guiding questions that need to be translated into testable hypotheses."

Historically, there has been strong opposition to independent scientists and their investigations into low-dose radiation, particularly those studies that conclude there is no safe dose (threshold). In her award-winning book *Betrayal of Trust: The Collapse of Global Public Health,* investigative journalist Laurie Garrett identifies, in a single paragraph, the root cause of this hostility toward those who challenge the status quo (59, emphasis added):

> The Eisenhower Administration veiled all radiation research in secrecy and disinformation. And, in 1955, with the creation of the first nuclear power plant, it extended that veil to cover the civilian sector. For nearly four more decades all information regarding the public health impacts of radiation would be rife with critical flaws. The Atomic Energy Commission and its descendant, the Nuclear Regulatory Commission, would hide—literally—mountains of data and obfuscate or distort the information that was released. Employees of both government and civilian industries would be compelled to sign secrecy agreements, violations of which would constitute grounds for prosecution on charges of treason or espionage. *Scientists who independently studied the human health impacts of low-level radiation would be vilified, their reputations smeared*.

Karl Z. Morgan, for 29 years the health physics director at Oak Ridge National Laboratory, was one of the founding members of the Health Physics Society and its first president, but in later years he became distressed with its support for the nuclear power industry and was treated with open hostility when he warned of low-dose risks. In his memoir, Morgan expressed his displeasure: "The once noble profession of health physics that I helped create over fifty years ago, and that was infused with high professional and scientific stature, has sunk to a new low" (60).

PUBLIC HEALTH INITIATIVES

Because of the high dose level of CT compared with conventional X-ray, the focus on pediatric CT is a legitimate public health concern, but it should be viewed in the context of a more comprehensive public policy discussion.

Strategies to Minimize Radiation Exposures

More than five years have passed since the NCI and SPR issued the *Guide for Health Care Providers,* listing a series of strategies—as yet unrealized—designed to reduce the radiation dose from CT exposures. These strategies include: (*a*) to educate through journal publications and conferences within and outside radiology specialties; (*b*) to adopt pediatric CT protocols; and (*c*) to disseminate information through health-related organizations, including the American Academy of Pediatrics and the American Association of Family Physicians.

- Professional radiology associations should invite representatives from independent nongovernmental organizations (NGOs) to participate in strategy conferences on a broad spectrum of controversial issues, with plans to greatly reduce the number of unnecessary radiological procedures as the first priority.
- Pediatric protocols should be based on high-yield criteria—that is, give higher priority to pre-CT symptoms that yield information vital to treatment, and require sign-offs by two radiologists for CTs in cases that fail to present high-yield symptoms.
- Significant reductions in CT radiography could be accomplished by following the Canadian CT Head Rule, Canadian CT Head Rule (children), Canadian C-Spine Rule, Ottawa Knee Rule, and New Orleans Criteria. Reduction estimates with these criteria run as high as 30 to 40 percent.

Scientific Obfuscation

As of late 2006, none of the radiology organizations have developed CT protocols, nor have the American Academy of Pediatrics and American Association of Family Physicians provided position statements for their members. Professional organizations have remained silent on the impact of medical X-rays, nuclear power reactors, atmospheric atomic tests, occupational exposures, nuclear accidents, and weaponized depleted uranium, and scientists who dissent from official radiation-protection recommendations are seldom quoted in other radiation studies. How can radiation-protection organizations claim there is a consensus among experts while ignoring a significant body of peer-reviewed work?

When the Health Physics Society set a 10 rem threshold, it referenced only a single 1997 National Council on Radiation Protection and Measurement (NCRP) report to support its policy statement, and it urged risk assessors to acknowledge the possibility of zero health effects at low dose—thus disregarding the mounting human evidence and ignoring the fact that diagnostic X-ray examinations fall under this standard. Also, most clinicians are confused by the proliferation of specialized terminology promulgated by medical physicists, who use such terms as gray, sievert, rad, rem, relative biological effectiveness (RBE), roentgen, dose and dose-rate effectiveness factor (DDREF), and so forth, without adequate explanation. We provide an equivalency chart (Table 2) to assist in bridging this linguistic gap.

- Radiologists should explore the widest possible range of published studies in the low-dose range. A terminology conference should be organized with the express purpose of developing a list of standardized terms to be used by both medical and health physics professionals.

Table 2

External radiation equivalencies

Gray	Sievert	Rad	Rem
1,000 mGy	1,000 mSv	100 rad	100 rem
1 Gy	1 Sv	100 rad	100 rem
1 cGy	1 cSv	1 rad	1 rem
10 mGy	10 mSv	1 rad	1 rem
100 mGy	100 mSv	10 rad	10 rem
1 mGy	1 mSv	100 mrad	100 mrem
0.01 Gy	0.01 Sv	1 rad	1 rem

Note: Internal alpha emitters: 1 rad = 20 rem = 200 mSv.

The Ethical Imperative and Informed Consent

Writing in the *British Medical Journal,* clinical cardiologist Eugenio Picano noted that patients undergoing radiological and nuclear medicine examinations receive no or inaccurate information on risk. He claims that physicians do not communicate radiation risks to the patient because they are ignorant of those risks, and "that may be why 30 percent of all radiological examinations are inappropriate" (61). In response to Picano, Ehrle asks, "Why should X-ray exposures be immune [from informed consent] when ionizing radiation health effects have been measured and proven at very low dose?" (62).

- Every medical association should take a strong position on the issue of informed consent by adopting policies respectful of the mandates in the Nuremberg Code, which states, in part, "The voluntary consent of the human subject is absolutely essential. This means that the person involved should have legal capacity to give consent; should be so situated as to be able to exercise free power of choice, without the intervention of any element of force, fraud, deceit, duress, overreaching, or other ulterior form of constraint or coercion."
- Medical schools should require readings on radiation theory and practices.
- Clinicians should be urged to observe the "Precautionary Principle" and their oath "to first, do no harm," and they should provide patients with more definitive risk/benefit comparisons.

A Cancer Pandemic

Cancer incidence in the developed countries continues to rise and is projected to increase 50 percent by 2020, as indicated in the 2003 *World Cancer Report* (57).

In the United States, cancer deaths accounted for more than 24 percent of all deaths in 2004, but this figure understates the problem because of the low rate of autopsy (<6%).

- Medical associations, societies, and academies should petition the National Cancer Institute to sponsor regional cancer prevention symposia *involving all public health policy stakeholder NGOs,* to more fully comply with the Congressional statute in U.S. Code Title 42, Part C, Sec. 285a, mandating that "the National Cancer Program shall consist of an expanded, intensified, and coordinated cancer research program . . . including an expanded and intensified research program for the prevention of cancer caused by occupational or environmental exposure to carcinogens."

Conflicts of Interest

The nuclear industry prospered during the Cold War, and conflicts of interest in academia and government agencies became systemic. Safety considerations were a low priority. Three radiation-"protection" bodies have particular problems: the U.S. National Council on Radiation Protection and Measurements, the U.K. National Radiological Protection Board, and the International Commission on Radiological Protection. These are self-appointed and self-perpetuating bodies, allowing no peer review of their documents by outside stakeholders. The ICRP's radiation threshold is 10 rem per year, the same as the Health Physics Society standard.

These criticisms also apply to the BEIR-VII 2005 Committee (63). Its charge was to examine the health risks from low-dose radiation, a task that took more than seven years to complete (several sessions were closed to the public). At least 10 low-dose radiation experts nominated by nonprofit organizations were kept off the panel, an issue that resulted in unsupported and unscientific conclusions, as indicated by this representative sample (all quotations are from BEIR-VII):

1. BEIR-VII defines low dose as "exposures up to 100 mSv" whereas UNSCEAR 2000 cites a range of 0 to 200 mSv (24), a calculated attempt to ignore health effects within these low ranges. We consider health effects at all levels to be of valid concern.

2. "Most of the studies of populations living around nuclear facilities have not included individual estimates of radiation dose and have therefore not provided an estimate of disease risk. Three case-control studies found no increased risk of disease associated with radiation exposure" (63, p. 372). These studies understate risks and are refuted by Beral (64), Bertell (65), Busby (66), Burlakova (67), Gardner (68), Sternglass (69), Schmitz-Feuerhake (70), and colleagues, none of whom are referenced in the BEIR-VII report.

3. "Although there is now good scientific evidence that an excess of thyroid cancer has occurred in highly contaminated areas, there is still very little information regarding the quantitative relationship between radiation dose to the

thyroid from Chernobyl and the risk of thyroid cancer" (63, p. 392). Several groups of scientists have published extensively on the increased noncancer risks, including Bandashevsky (71), Goncharova (72), Mangano (73), and colleagues, again unnoticed by the BEIR-VII committee.

4. The report has a pie graph estimating "worldwide background radiation exposure at 2.4 mSv per person" and another graph that shows that this per year level represents "82% of all exposures in the U.S., with only 14.2% [0.55 mSv] attributed to nuclear medicine and medical X ray." The source for these data is an obsolete 1987 report (no. 93) issued by the NCRP. The 2003 International Agency for Research on Cancer report (58) shows the same 2.4 mSv background dose, or 60.6 percent of the 3.96 mSv total dose per person worldwide. It also puts all medical X-rays at 39.4 percent, an exposure level of 1.56 mSv, almost triple the NCRP estimate. The 1987 NCRP report does not support the claim by the National Research Council that BEIR-VII develops "the most up-to-date and comprehensive risk estimates for cancer and other health effects from exposure to low-level ionizing radiation."

5. "There have been few incidence or mortality studies of solid cancers other than the thyroid cancer in populations exposed to radiation from the Chernobyl accident" (63, p. 399). This statement is disputed by the European Committee on Radiation Risk (ECRR) report that critiques the ICRP methodology (which was adopted by BEIR-VII). The ECRR report documents indices of somatic illness (13 in number) in adults and adolescents in five control areas of the Brest region in Belarus and a similar comparison in the same region for 10 childhood noncancer illnesses. The ECRR also identifies three types of internal exposures that could lead to a high probability of two hits in the low-dose range, occurring during the cell replication cycle over a period of several hours: (*a*) immobilized sequential emitters such as strontium-90/yttrium-90 and tellurium-132/iodine-132; (*b*) immobilized, insoluble "hot particles" or aggregates of uranium oxides or plutonium; and (*c*) tritium, the very-low-energy beta emitter (74).

ECRR editor Chris Busby was also on the U.K. Department of Environment's Committee Examining Radiation Risk from Internal Emitters, and he and his coauthors noted in the Minority Report that "since the ICRP view is almost exclusively derived from acute external irradiation, applying it to calculate numbers of cases expected following chronic internal irradiation is deductive logic (i.e. reasoning on the basis of theory or assumption) whereas classic scientific method requires inductive reasoning according to which observations of excess disease in populations exposed to internal radionuclides must be taken as evidence of a causal link" (75).

6. "No excess risk in thyroid cancer was found in residents exposed to radiation from Hanford, and the slight excess risk of thyroid neoplasms associated with radioiodine exposure from the Nevada test site in Utah residents was based on small numbers" (63, p. 414). In the Utah Thyroid Cohort Study of 4,000 Nevada test site "downwinders" by University of Utah researcher Joseph Lynn Lyon and

colleagues, preliminary results show more than "the slight excess risk of thyroid neoplasms" (76). Despite a dosimetry that is used throughout the world, the Centers for Disease Control defunded the study in March 2005.

7. IN 2006, U.K. physicist Chris Busby and Russian ecologist Alexey Yablokov edited *Chernobyl: 20 Years On,* which contains scores of references to Russian scientific papers on the cancer and noncancer effects after Chernobyl (free full text at euradcom.org). Busby is the Scientific Secretary of the ECRR, sponsor of the 2006 report. Despite the fact that the World Health Organization, International Atomic Energy Agency, and ICRP had copies of the Russian studies, they had refused to translate them. Dr. Bertell, author of the book's final chapter, estimates future fatal cancers directly attributable to the Chernobyl accident in the range of 899,000 to 1,786,000 (uncertainties due to the mutation rate and use of different models). This estimate stands in stark contrast to the 2006 Report of the U.N. Chernobyl Forum Expert Group "Health" estimate of 5,000 (full text online at who.int/ionizing_radiation/Chernobyl).

- Medical associations, societies, commissions, and government agencies whose mission is to protect the public health, promote patient safety, or develop radiation-protection measures should take immediate steps to investigate relevant low-dose radiation studies. They should also adopt conflict-of-interest and radiation policies based on guidelines proposed through a process of joint discussions and workshops involving *all* stakeholders, with the goal of depoliticizing the low-dose radiation issue.

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