VOLUME 78
Number 2
June, 1988

Journal of the WASHINGTON ACADEMY OF SCIENCES

ISSN 0043-0439

Issued Quarterly
at Washington, D.C.

WASHINGTON ACADEMY OF SCIENCES 1898

Nuclear Radiation and Public Health Practices and Policies in the Post-Chernobyl World

A Symposium at Georgetown University

Proceedings Edited By: Dr. Irving Gray and
Dr. Kenneth L. Mossman

Washington Academy of Sciences

Founded in 1898

EXECUTIVE COMMITTEE

ACADEMY OFFICE
1101 N. Highland St.
Arlington, Va. 22201
Telephone: (703) 527-4800

The Journal

This journal, the official organ of the Washington Academy of Sciences, publishes historical articles, critical reviews, and scholarly scientific articles; proceedings of meetings of the Academy and its Executive Committee; and other items of interest to Academy members. The *Journal* appears four times a year (March, June, September, and December)—the December issue contains a directory of the Academy membership.

Subscription Rates

Members, fellows, and life members in good standing receive the *Journal* without charge. Subscriptions are available on a calendar year basis only, payable in advance. Payment must be made in U.S. currency at the following rates:

U.S. and Canada	$19.00
Foreign	22.00
Single Copy Price	7.50

Back Issues

Obtainable from the Academy office (address at bottom of opposite column): **Proceedings:** Vols. 1–13 (1898–1910) **Index:** To Vols. 1–13 of the *Proceedings* and Vols. 1–40 of the *Journal* **Journal:** Back issues, volumes, and sets (Vols. 1–75 1911–1985) and all current issues.

Claims for Missing Numbers

Claims will not be allowed if received more than 60 days after date of mailing plus time normally required for postal delivery and claim. No claims will be allowed because of failure to notify the Academy of a change in address.

Change of Address

Address changes should be sent promptly to the Academy office. Such notification should show both old and new addresses and zip number.

Published quarterly in March, June, September, and December of each year by the Washington Academy of Sciences, 1101 N. Highland St., Arlington, Va. 22201. Second class postage paid at Arlington, Va. and additional mailing offices.

CONTENTS

Nuclear Radiation and Public Health: Practices and Policies in the Post-Chernobyl World

Introduction

Under normal operating conditions, activities in the nuclear fuel cycle (including nuclear power plant operations) pose little hazard to public health. In fact, despite the large uncertainties in risk estimates, coal fuel power plants result in a greater cost of life and health than nuclear plants. However, unlike accidents which may occur in fossil fuel cycle activities, accidents in the nuclear fuel cycle, especially nuclear power plants, can have significant public health and environmental consequences. The accident at the Chernobyl nuclear power station in April 1986 has served as a stark reminder of the potentially disastrous consequences resulting from the uncontrolled release of nuclear radiation into the environment. This issue of *The Journal of the Washington Academy of Sciences* is devoted to a discussion of several important issues surrounding nuclear power technology which were of considerable concern in the aftermath of the Chernobyl accident. The papers presented in this issue are a result of a symposium held at Georgetown University in Washington, D.C., on September 18 and 19, 1987. The purpose of the symposium was to bring together noted experts to discuss various aspects of nuclear energy technology with Chernobyl as a springboard for discussion. The meeting was divided into four sessions, each concerned with a specific issue of nuclear power technology. Following each session there was a round table discussion among session speakers with questions and comments from the floor. These discussions are presented in their entirety, with a minimum of editorial changes, in order to represent fairly the spirited exchange of ideas and opinions which occurred at the meeting.

The first session was devoted to a discussion of the biomedical effects of nuclear radiation. At Chernobyl, 31 people were killed as a result of the accident and tens of thousands of others received radiation doses that may increase the risk of genetic effects and cancer. In this session, four distinguished scientists provide their views concerning what is presently known about the biological effects of nuclear radiation.

The second session focused on environmental and engineering issues. Following the reactor accident, significant concern surfaced about the reactor facility itself, what particular design characteristics were responsible for the accident, comparisons with American reactor designs and the possibility of a similar accident occurring in the United States. The environmental impact of the accident became almost immediately apparent with reports of contaminated milk and contaminated pasture lands in western

Russia and in several neighboring countries. The Chernobyl accident clearly showed that a major reactor accident cannot be expected to be confined to the "host" country but may have significant environmental, social, and economic impact on neighboring countries as well. In this session five nuclear technology experts discuss various environmental and engineering issues, including nuclear power safety and specific lessons learned in the Chernobyl accident.

The third session was devoted to communications. Following the Chernobyl accident, as in the case of the Three Mile Island accident in 1979, the print and broadcast media provided numerous technical reports and human interest stories. Did the print and broadcast media present technical issues fairly and accurately? Have the risks of radiations been overstated? These and other questions served as the basis for discussion of communications of nuclear technologies by noted authorities in the communications field.

The final session was devoted to public policy considerations. The Chernobyl accident clearly emphasized the potential difficulties in implementing effective medical management programs and emergency evacuation plans following nuclear accidents. These and other public policy concerns were discussed by leaders in the medical and nuclear technology fields.

This symposium was supported by the Departments of Biology and Radiation Science and the Office of the Dean, College of Arts and Sciences, Georgetown University, by the Institute for Health Policy Analysis, Georgetown University, and by grants from the United States Nuclear Regulatory Commission and the Department of Energy. The planning committee also gratefully acknowledges the assistance of Ms. Alexandra Bernstein for her time and effort in editing and preparing the discussion sections.

Kenneth L. Mossman, Ph.D.
Georgetown University

Planning Committee

Laurel Anderson
Research Associate
Institute for Health Policy Analysis
Georgetown University

Alexandra Bernstein
Symposium Coordinator
Institute for Health Policy Analysis
Georgetown University

Irving Gray
Professor, Department of Biology
Georgetown University

Stephen Klaidman
Associate
Institute for Health Policy Analysis
Georgetown University

David McCallum
Senior Fellow
Institute for Health Policy Analysis
Georgetown University

Kenneth Mossman
Chair, Dept. of Radiation Science
Georgetown University

This symposium was supported in part by:

Office of the Dean, College of Arts and Sciences, Georgetown University
Department of Biology, Georgetown University
Department of Radiation Science, Georgetown University
Institute for Health Policy Analysis, Georgetown University
Washington Academy of Sciences
United States Nuclear Regulatory Commission, grant No. NRC-04-87-422
United States Department of Energy

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 87–88, June 1988

Health Effects of Nuclear Radiation: Introductory Remarks and Overview*

Arthur C. Upton, M.D.

New York University Medical Center
550 1st Avenue
New York, New York 10016

The recent events at Chernobyl have demonstrated how catastrophic and far-reaching the consequences of a major nuclear reactor accident can be. The occurrence of early fatalities from radiation sickness among those on the scene, the necessity to evacuate entire communities in the surrounding area, and the increase in the risk of cancer and other late-occurring diseases posed to those residing many miles downwind exemplify the kinds and diversity of health impacts that may result from such an accident.

Because the health effects of ionizing radiation have been studied extensively for nearly a century and are better known than those of most other environmental agents, the potential impacts of reactor accidents have been estimated in detail. The public, however, is largely unfamiliar with reactor technology and radiation. Its views of nuclear energy include misconceptions about the pertinent risks and an exaggerated perception of the levels of uncertainty, confusion, and disagreement about the risks that exist among experts. Prevailing knowledge of the relevant issues within the health profession is substantially better, but few localities are equipped to cope with a major nuclear reactor accident. It is fitting, therefore to begin a symposium on "Nuclear Radiation and Public Health: Practices and Policies in the Post-Chernobyl World" with a review of the cogent biomedical issues.

Since the health effects resulting from a reactor accident can vary widely, depending on the amounts of radioactivity released, the numbers and ages of per-

* Preparation of this report was supported in part by Grants ES 00260 and CA 13343 from the U.S. Public Health Service and Grant SIG-009 from the American Cancer Society.

sons exposed, the doses of radiation that they receive, and other variables, the public health strategies that are called for vary accordingly. Each of the major types of biomedical effects that are relevant, their dose-effect relationships, and their public health implications thus deserve to be considered in some detail. To summarize the cogent information, this session is devoted to presentations by four noted authorities, whose discussions of the different issues follow.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 88–93, June 1988

Acute Radiation Injuries and Their Management

Niel Wald, M.D.

Dapartment of Radiation Health, Graduate School of Public Health,
University of Pittsburgh, Pittsburgh, PA 15261

ABSTRACT

The biological basis for injury produced by radiation lies primarily in its ability to kill cells or to inhibit their reproduction, leading to cell depletion and resultant malfunction of various organs, and, at supra-lethal exposure levels, to impairment of key organs directly. This leads to clinical manifestations of the acute radiation syndrome or to local tissue damage, usually from external irradiation sources. Radionuclide contamination may also produce acute local tissue and internal organ damage. Complicating factors include coexistent trauma or burns as well as manifestations of radiation-related psychological stress.

The Chernobyl accident provided useful information and raised new questions concerning mass triage, bone marrow transplantation indications, and our medical response capabilities in the unlikely event of a major accidental radiation release in the United States. Appropriate responses include an assessment of our current national medical radiation accident response resources of experienced personnel and pertinent facilities. Also, inclusion of the medical aspects of radiation accident management is proposed in the training and continuing education of medical specialists in occupational medicine, emergency medicine, hematology/oncology and nuclear medicine. With necessary federal support, this could provide a continuing cadre of physicians to maintain competences and facilities for a national medical response capability for radiation emergencies.

I. Introduction

The purpose of this presentation is to review briefly some key pertinent facts about the effects of radiation on cells and tissues, and to consider the resultant forms of clinical acute radiation injury and their medical care. Then, in keeping with the orientation of this symposium, attention will be focused on some exposure situations involving the general public, including the most recent one at Chernobyl in particular, to see what pertinent lessons have been or may be learned concerning radiation injuries and their management.

II. Biological Basis for Radiation Injury

Although radiation absorption in tissue produces many significant effects at the atomic and molecular level, time constraints require that we confine ourselves to its general effects on tissue cells. This can be a direct lethal effect on the cell or, at lower exposures, an impairment in the mechanism of normal cell division and replication. Although at supralethal levels of exposure there may be prompt functional failure of key organ systems, such as the neurovascular system, the usual effect is damage to the process of cell reproduction with resultant shortages of cells, particularly in organs that require high cell production rates. The clinical manifestations then depend on the temporary loss of key organ functions, with treatment being directed at supportive or more definitive replacement measures to enhance the likelihood of survival of such patients until cell repair and recovery of the damaged organs takes place.

A. Acute Radiation Syndrome

Three clinical forms of the acute radiation syndrome have been recognized as the result of the injury of certain key organs or systems, usually produced by whole body irradiation from an external source. These are the hematologic, the gastrointestinal and the neurovascular forms of the acute radiation syndrome. The magnitude of exposure determines the time of onset and the duration of the syndrome as well as the possibility of a successful therapeutic response. The syndrome can be diagnosed by some relatively simple nonspecific clinical indicators when the possibility of radiation overexposure is borne in mind.[1] An even simpler triage scheme based entirely on the time of onset of symptoms and the changes in the routine white blood cell analysis can be used to identify and predict the severity of radiation injury.[2]

B. Partial Body Exposure

Partial body exposure to external radiation sources causes a much more frequent type of radiation injury. This is seen in industrial radiographers in particular, with the hand being the injured tissue most often.[3] A sequence of changes which are rather similar to those of thermal injury or burns evolves over a time period usually of several weeks. Again, the time of onset and duration are related to the magnitude of the exposure and the depth of penetration of the particular type of radiation involved.

C. Radionuclide Contamination

The second major class of radiation accidents involves the deposition of the radioactive material itself on the surface of the body as well as its incorporation into the body by breathing or swallowing the material or having it deposited in an open wound. It is difficult to generalize about this form of potential or actual injury since each radioactive isotope has a different duration of activity, penetrating power in tissue, mechanism by which the body metabolizes the material in the specific compound in which it is present, and other variables. As a generalization, however, the effects can range from production of the acute radiation syndrome to only the slight enhancement of the statistical likelihood of developing a radiation related cancer decades later. As another generalization, the early management of such contamination is the separation of the individual from the radioactive material.

In the simplest case the separation is

effected by removal of the contaminant from the skin. A number of different methods are available for this purpose.[4] When the material has been inhaled there is a paucity of definitive measures for its removal. Lung lavage has been employed to wash radioactive material out of the lung when the material is large in quantity and is considered highly toxic.[5]

The passage of ingested or swallowed material through the gastrointestinal tract can be enhanced by the judicious use of cathartics, thereby minimizing the radiation exposure. In dealing with wound contamination it is necessary to perform the maximum removal of radioactivity feasible prior to conventional treatment of the wound. Of course, life-threatening bleeding or interference with breathing must receive the initial prompt attention because these are a greater threat to survival than radionuclide contamination.

Once the decontamination effort has been concluded, techniques are available for measuring the amount of residual radioactivity incorporated into the body of the injured person. These require the use of a highly sensitive low background radiation counting facility which can make measurements over part or all of the entire individual. The radioactivity excreted can be measured to determine the amount incorporated. If the radioactive material is sufficient in quantity and activity to produce a potential health hazard, there are a number of agents which are effective for one or another of the radionuclides which may be involved.[4] These can produce a marked reduction in the amount of residual radioactivity in many instances.

III. Complicating Factors

A. Multiple Injuries

The information presented thus far was derived primarily from situations in which radiation exposure was the only stressful agent. Unfortunately, in the real world there also exists the potential for events in which more than one injurious agent is involved. The mechanisms involved in such problems are less obvious and their management is clearly more complex. For example, in Hiroshima and Nagasaki, Japan, the atomic bombs produced not only radiation effects but also those of heat and blast. This resulted in patients with thermal burns and multiple traumatic wounds in addition to radiation injury.[6] Although the combined injury problem was recognized early in the use of radiation[7] and has been studied in experimental animal research[8] with the development of proposed approaches to its medical management,[9,10] it remains a difficult clinical situation, complicating diagnosis and prognosis as well as treatment.

B. Psychological Stress

At the Three Mile Island Nuclear Power Plant accident in Pennsylvania in 1979, another complicating factor became apparent in the occurence of the effects of perceived, but not actual medically significant radiation exposure. This is the problem of psychological stress and associated symptomatology in a population which, within 50 miles of the plant, received an average exposure of one or two millirems, or one hundredth of the annual natural background exposure which they continually receive. Due in part to the intense media coverage and the evidences of unfamiliarity with this type of accident on the part of government, industrial and regulatory personnel as well as health care personnel in the area, a significant proportion of the area's inhabitants developed the perception that enough radioactivity had actually escaped the containment of the power reactor to produce prompt harmful health effects. Psychological studies carried out early after the accident and thereafter have shown increased depression and anxiety lasting more than a year later in a portion of the population,[11] and occurring again at the time of the start-up of the adjacent reactor in 1985.[12]

Several considerations to reduce psychological stress in the management of patients or the public with actual or perceived significant radiation overexposure were suggested by these events. They included the need for one responsible individual to deal with communication with the exposed; a requirement of clear and open communication; the need for a credible and tested emergency plan to be in place in advance of such occurrences; and the necessity of adequate education concerning radioactivity and its effects for all of those who might become involved with this agent. This includes the general public whose education about radioactivity should be a part of the primary and higher education system.

IV. Biomedical Lessons From Chernobyl

A. Triage

The Chernobyl accident has taught us some new lessons. From the diagnostic standpoint, the validity of the type of triage scheme discussed earlier was borne out by its effectiveness in sorting out 203 individuals from the 135,000 living within a five-mile area as those in need of hospitalization and supportive or intensive treatment. In the absence of detailed physical dosimetric observations, it was the use of symptomatology, lymphocyte and neutrophil levels and chromosome damage that served to make these identifications which then were used as the basis for the treatment decisions.[13]

The clinical courses reported for the various patients in the four level classification used by the physicians in Moscow and Kiev[13] reinforced what earlier had been noted in Hiroshima and Nagasaki A-bomb patients;[6] that is, that combined injuries alter and increase the severity of the clinical manifestations expected from radiation overexposure alone. In particular, the occurrence of both thermal and radiation-induced skin burns over large portions of the body in the worker personnel was an important feature in all of the fatal cases.

B. Bone Marrow Transplantation

Since bone marrow transplantation was used rather unsuccessfully in 13 Chernobyl patients (11 deaths),[18] and fetal liver cells in 6 (6 deaths), we are left in uncertainty about the efficacy of this form of treatment for patients with equivalent radiation overexposure in the absence of the complicating injuries. In view of the only previous timely and successful application of this technique in an accidentally overexposed worker, who was fortunate enough to have an identical twin donor,[14] and in view of the 60-day radiation-related fatality rate of only 10% in several thousand leukemic patients treated with whole body irradiation of 1000 to 1500 rads in a brief exposure period followed by bone marrow transplantation,[15] it would be premature to discard this therapeutic approach on the basis of the complex exposure experience at Chernobyl.

C. U.S. Radiation Accident Response Capabilities

A third important issue raised by the management of acute radiation injuries that was performed so efficiently and effectively on the Chernobyl accident patients, is whether such rapid triage and treatment could be made available to a similar sized population with real or perceived radiation overexposures of the same magnitude in the United States. How quickly could the resources be mobilized to carry out all of the hematologic and other evaluation studies on 350 patients in a few days, including chromosome analyses in 154 of them?[13] How readily could we deploy 450 medical teams using local personnel augmented to a total of 5,960 health personnel (including 1,240 physicians, 920 nurses, 720 medical students, 360 physicians' assistants, and 2,720 aides) to carry out a screening examination of some 135,000 people evacuated from the 30 kilometer radius around a malfunctioning radiation facility?[16]

In the absence of federal support programs for the training and operational support of medical and other health personnel as well as for related facilities for the evaluation of acute radiation injury, combined with the paucity of actual patients due to the success of preventive efforts, are we prepared to manage a large number of people who are, or think they may be suffering from acute radiation injury?

V. Considerations for the Future

Most of the medical personnel with radiation accident training and experience obtained them under military and Atomic Energy Commission auspices in the period from 1940 until the moratorium on above ground nuclear weapons tests in 1960. This cohort is now rapidly being diminished by ageing, as one can observe in any current gathering of such personnel. The environmental movement of the 1960's, the cessation of successful marketing of nuclear power plants in the United States since the 1970's, the lack of federal training support in this area for more than a decade and the high frequency of civil litigation in cases involving allegations of radiation exposure have all discouraged new physicians from entering the field. Although the 108 nuclear power plants in this country with NRC operating licenses have all presumably identified the medical personnel and facilities that they would utilize in an emergency in order to meet NRC licensing requirements, and a list of nine definitive care centers was published by Linnemann in 1983,[17] the reality of these resources and their ability to deal with a problem in patient care approaching the magnitude of the one generated by the Chernobyl accident is not clear.

Although the design of reactors in this country and the preventive measures built into the NRC's regulatory requirements make the probability of needing such resources extremely low, it would be reassuring to have a better assessment of our state of preparedness. An initial measure to consider in this regard is the collection and analysis of data about the present personnel and resources committed to the maintenance of a capability to deal with patients with possible acute radiation injury stemming from organizations operating under Nuclear Regulatory Commission licensing.

Consideration should also be given to the incorporation of medical radiation accident management into the training of physicians preparing for medical specialties related to this problem. Specifically, this would mean that physicians in residency training in occupational medicine, emergency medicine, hematology-oncology, and nuclear medicine would be introduced to this subject because of similarities with the medical care of the patients in their chosen professional areas. This would provide a cadre of personnel familiar with the problems and treatment of radiation accident patients. With federal support, the development of the necessary teaching program, the maintenance of a roster of the resultant cadre and the provision for updated training as part of a continuing education program would be feasible. Federal support for the maintenance of appropriate specialized equipment, such as whole body radiation counters and wound radioactivity probes, would also serve to give reality to a necessary national resource for the clinical management of radiation emergencies.

VI. Summary

Some of the manifestations of acute radiation injury have been reviewed along with the radiobiological bases for their occurence. The impact and implications of the lessons learned from the medical management problems of such injuries, perceived or real, in large numbers of people have been considered with particular reference to the recent Chernobyl accident. Suggestions for maintaining the continued national availability of a cadre of medical personnel and facilities capable of participating in the competent and efficient management of such population exposures, however unlikely they may be, were provided.

VII. References Cited

1. **Wald, N.** 1983. Diagnosis and therapy of radiation injuries. Bul. N.Y. Acad. Med., **59:** 1129–1138.
2. **Thoma, G. E. and N. Wald.** 1959. The diagnosis and management of accidental radiation injury. J. Occup. Med., **1:** 421–447.
3. **Saenger, E. L., J. G. Kereiakes, N. Wald, and G. E. Thoma.** 1980. Clinical courses and dosimetry of acute hand injuries to industrial radiographers. In: The Medical Basis for Radiation Accident Preparedness. K. F. Hubner and S. A. Fry, eds., Elsevier/North Holland, New York, pp. 169–178.
4. **NCRP Report No. 65.** 1980. Management of Persons Accidentally Contaminated with Radionuclides. National Council of Radiation Protection and Measurement, Washington, D.C.
5. **Muggenburg, B. A., S. A. Felicetti and S. A. Silbaugh.** 1977. Removal of inhaled particles by lung lavage—a review. Health Physics, **33:** 213–220.
6. **Lewis, J. J., and H. A. Patterson.** 1959. Original signs and symptoms in patients surviving five years after atomic bomb exposure under 1,000 meters. Tech. Report 17-59. Atomic Bomb Casualty Commission, Hiroshima, Japan.
7. **Wintz, H.** 1923. Die vor- und nachbehandlung bei der Rontgenbestrahlung. Ther. Gegenw., **64:** 209.
8. **Messerschmidt, O.** 1986. Whole-body irradiation plus skin wound: animal experiments on combined injuries. Brit. J. Radiol. Suppl. No. 19: 64–67.
9. **Bowers, G. J.** 1987. The combined injury syndrome. In: Military Radiobiology. J. J. Conklin and R. I. Walker, eds., Academic Press, New York, pp. 191–217.
10. **Walker, R. I. and J. J. Conklin.** 1987. Mechanisms and management of infectious complications of combined injury. In: ibid, pp. 219–230.
11. **Bromet, E. J., D. K. Parkinson, H. C. Schulberg, et al.** 1982. Mental health of residents near the Three Mile Island reactor: a comparative study of selected groups. J. Preventive Psychiatry, **1:** 225–276.
12. **Dew, M. A., E. J. Bromet, H. C. Schulberg et al.** 1987. Mental health effects of the Three Mile Island nuclear reactor restart. Am. J. Psychiatry, **144:** 1074–1077.
13. **Linnemann, R. E.** 1987. Soviet medical response to the Chernobyl nuclear accident. J.A.M.A. **258:** 637–643.
14. **Gilberti, M. V.** 1980. The 1967 radiation accident near Pittsburgh, Pennsylvania, and a follow-up report. In: The Medical Basis for Radiation Accident Preparedness. K. F. Hubner and S. A. Fry, eds., Elsevier/North-Holland Inc., New York, pp. 131–140.
15. **Hahn, F., B. R. Scott, Wald, N., et al.** 1987. Early occurring and continuing effects. In: Health effects model for nuclear power plant accident consequence analysis (NUREG/CR-4214). J. S. Evans, D. W. Moeller and D. W. Cooper. eds., U.S. Nuclear Regulatory Commission, Washington, D.C., In press.
16. **U.S.S.R. State Committee on the Utilization of Atomic Energy.** 1986. The accident at the Chernobyl Nuclear Power Plant and its consequence. Annex 7. Presented at International Atomic Energy Agency Experts' Meeting, Vienna, August 25–29, 1986. Translation draft by U.S. Nuclear Regulatory Commission.
17. **Linnemann, R. E.** 1983. Systems approach to the initial management of radiation injuries. In: Systems Approach to Emergency Medical Care. D. R. Boyd, R. F. Edlich, and S. H. Micik, eds., Appleton-Century-Crofts. Norwalk, Connecticut, pp. 342–369.
18. **Gale, R. P.** 1987. Immediate medical consequences of nuclear accidents. J.A.M.A. **258:** 625–628.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 94–100, June 1988

Prenatal Effects of Exposure to Ionizing Radiation

Robert W. Miller, M.D., Dr.P.H.

Chief, Clinical Epidemiology Branch
National Cancer Institute
400 Executive Plaza
Bethesda, MD 20892

The Effects of Prenatal Exposure to Ionizing Radiation

Wilhelm Roentgen discovered x-rays in 1895. It was about 25 years later that a serious effect on the fetus was first recognized. Initially there were case-reports of mental retardation and microcephaly in children whose mothers had received therapeutic radiation early in pregnancy. Ionizing radiation was, in fact, the first environmental teratogen known to affect the human. Certain chemicals and viruses have since been identified as human teratogens. Ionizing radiation was also the first known human leukemogen. Interest began to develop in this relationship as a result of a review of case-reports in the literature in 1942.[1] A few chemicals and certain retroviruses have since been found to induce human leukemia. The first report suggesting the induction of leukemia and other forms of childhood cancer by in utero exposure to diagnostic x-rays was published in 1956.[2]

As laboratory techniques were developed for studying the number and morphology of human chromosomes in somatic cells, the effects of radiation as a clastogen were defined. How early in prenatal life this effect can be induced has been studied in the Japanese survivors of the atomic bombs.

Exposure to I-131 during intrauterine life has caused cretinism due to ablation of the thyroid gland.[3] Other findings from exposure of the fetus to ionizing radiation have been similar to those at other ages. Additional studies are needed as the in utero a-bomb survivors, now 42 years old, reach the age when the risk of cancer mounts rapidly.

Sources of Exposure

Knowledge of the effects of ionizing radiation on the embryo or fetus comes from studies of the atomic-bomb survivors, Marshall-islanders exposed to fallout from nuclear weapons tests and from persons exposed to radiologic procedures, therapeutic or diagnostic, from sources that were external or internal. There is no information from occupational exposures of pregnant women.

Embryotoxicity

Data on the group exposed in utero in Hiroshima and Nagasaki show a deficiency in the number of persons exposed who were under 4 weeks of gestational age. The only study[4] that has been made of perinatal loss was conducted in Nagasaki six years after the exposure, so the information depended on the accuracy of delayed reporting of miscarriages, stillbirths and neonatal or infant deaths. The study concerned exposure at any time during pregnancy. The results showed 43% of 30 cases had adverse outcomes among those exposed within 2000 meters of the bomb whose mothers had major radiation signs as compared with 8.8% of 68 cases in the same distance category whose mothers did not have major radiation signs. Another comparison group which was 4000–5000 meters from the bomb (ie, no radiation exposure) had adverse outcomes in 6.2% of 113 cases.

The deficiency in the number of people known who were exposed under 4 weeks of gestational age is relevant to current law suits in which it is claimed that birth defects were due to exposures at a time during pregnancy when the effect, if any, on the embryo is likely to be catastrophic. The stage of development is so early that damage to a single cell will affect all of the cells to which it gives rise as growth and differentiation progress. In accord with this reasoning are the results of a study not related to radiation exposure, in which human embryos from the general Japanese population showed no birth defects under 15–17 days of gestational age.[5]

Teratogenesis

A wide array of congenital malformations has been found in animal experimentation after intrauterine exposure to ionizing radiation. In the human the only excess in frequency has been in small head size and mental retardation. The first report of the Hiroshima group exposed in utero was by Plummer in 1952.[6] Since then improvements in scientific design or dosimetry have led to further reports.[7–11]

Until 1984 it was thought that ionizing radiation depleted the cells of the brain, which caused small head size, and when depletion was severe enough, caused mental retardation. Small head size occurred after exposure at 4–17 weeks of age. Severe mental retardation was defined as the inability to form simple sentences or to care for oneself. In 1984[12] it was pointed out that severe mental retardation occurred primarily after exposures at 8–15 weeks of gestational age, with a small excess at 16–25 weeks of age. The explanation, based on recent experimental studies was that at 8–15 weeks cortical neurons proliferate or migrate from areas near the ventricles to the cortex, and exposure to ionizing radiation impairs this cell proliferation or migration. Cells killed before this time apparently cause small head size without severe mental retardation, because cerebral histogenesis is absent then. Similar histogenesis occurs later in the cerebellum, but no dysfunctions such as incoordination, ataxia or abnormal eye movements have been observed among those at highest risk; namely those exposed between the 20th week of pregnancy and 1 year of age.

Small head size (2 or more standard deviations below the mean) is not so much a late effect of radiation as an immediate effect, recognition of which is delayed until it can be measured when the child is born. When it is said that as little as 1 cGy can double the frequency of severe mental retardation, it is not meant that a fetus destined to have an I.Q. of, say, 110, can be severely retarded by this exposure, but that a fetus destined to have a borderline IQ will fall just below this cut-off after such a small exposure.

Among atom-bomb survivors, the lowest dose at which small head size occurred in Hiroshima was 10–19 cGy in air in Hiroshima,[11] ie, before the dose was attenuated by passing through the mother's body. This estimate was based on the old dosimetry (T65), which has since been revised (DS86),[13] but with little change at this dose-level. According to the DS86 estimates, 82 percent of prompt gamma radiation would be transmitted through the unshielded mother's body to the fetus. The estimate for delayed gamma rays is 85 percent, and for prompt and delayed neutrons the estimates are 14 and 6 percent respectively.[13]

The lowest dose that might increase the frequency of severe mental retardation has been estimated by downward extrapolation to 1 cGy from intermediate and high doses at 8–15 weeks of gestational age. However, the numbers of cases by radiation exposure category were excessive only after 50 + cGy in Hiroshima and 200 + cGy in Nagasaki, where only 2 cases were observed.[9] Several persons exposed at 8–15 weeks of gestational in either of the two cities had mental retardation attributable to causes other than radiation exposure. Two of 4 exposed to 10–49 cGy had Down's syndrome, and 1 of 3 exposed to 1–9 cGy had had encephalitis.[14] Exclusion of these cases did not substantially change the regression coefficients in the analysis by Otake and Schull described above.[14]

Intelligence tests were performed at the Atomic Bomb Casualty Commission in Hiroshima and Nagasaki in 1955–56. For an analysis published in 1985,[15] Schull and Otake used the Koga intelligence test scores, and found a dose-related reduction in the mean IQ scores for the groups exposed at 8–15 or 16–25 weeks of gestational age. These findings are consistent with the occurrence of severe mental retardation (as a more extreme effect). In the report of a Task Group of the International Commission on Radiological Protection concerning the effects of radiation on the brain of the embryo and fetus,[14] it is said that "the statistical uncertainties in the data, and the known problems of obtaining a high consistency in intelligence testing, prevent quantitative statistical analysis of these data from refining these qualitative conclusions."

Sixty percent of children with severe mental retardation had small head size. Thus a substantial proportion were normocephalic. Conversely, 10 percent of those with small head size had severe mental retardation.[14] It was thought that small head size which occurred without mental retardation after exposure at 4–6 weeks of gestational age was due to loss of glial (support) cells, which does not seriously affect intelligence, as interference with the development of neurons does.

Head size was not standardized against body size, and indeed stature tended to be less than normal in the severely retarded, but not enough to be proportionate to the small head size.

The simplest most sensitive measure of a human radiation effect is small head size after in utero exposure. In Hiroshima 11 percent of those exposed under 18 weeks of gestational age to a dose of 10–19 cGy free in air were affected, as were 30 percent of those who were exposed to 20–49 cGy.[9] Small head size is detectable at birth and at any age thereafter. So it should have been sought among newborns exposed close to Chernobyl, in proportion to dose. All that is needed is a tape-measure. During a visit to Kiev almost a year after the reactor accident at Chernobyl, we learned that measurements had been made,[16] but apparently a relationship to dose had not yet been sought. The Soviets seemed to have looked instead for an excess of diagnoses, such as severe mental retardation, which did not occur (and would not be expected, given the number of conceptuses exposed). We hoped that after our questions, small head size without mental retardation would be evaluated, but have not heard that it was.

An extra dividend, should this information be available from the studies of those exposed at Chernobyl, would be to settle a lingering question about the possibility that radiation alone was not responsible for the in utero effects among atomic-bomb survivors. The possibility of an additive effect has been raised with regard to infections, the trauma of the bomb to the mother, nutritional deprivation and other stresses of war. If the same effect were found in the population at Chernobyl, one could be sure that the standards for radiologic protection, based on data from the in utero exposures at Hiroshima and Nagasaki, are appropriate.

Although a wide array of other congenital malformations has been induced by x-irradiation of experimental animals, none has occurred excessively in the human. Brent[17] believes that the interval of susceptibility in the human, from the 20th to the 32nd day of gestation, may be so short that not enough embryos were exposed to reveal the excesses. By contrast, the interval for inducing severe mental retardation lasts 8 weeks, and for small head size lasts 14 weeks. The situation is different in experimental animals: their susceptibility to radiation-induced small head size is of similar duration to that for the induction of other deformities.

Carcinogenesis: In 1958 Stewart and her associates[18] published the results of a comprehensive survey of childhood cancer deaths in relation to histories obtained from the parents concerning radiation exposure and other events during pregnancy. The radiation exposures were mostly late in pregnancy, for pelvimetry. Subsequent studies by Stewart showed that the number of x-ray films taken were related to the frequency of cancer, and that the relative risk of each form of cancer was increased 1.5-fold on the average. No concomitant variable could be found to account for the increase. At first the findings were supported in a study by MacMahon,[19] who linked records of childhood cancer patients with obstetric records in New England, but upon extending the study in time and geographically, the excess of cancers other than leukemia disappeared.[20] Other studies have not confirmed Stewart's work—in particular, studies of the Japanese atomic-bomb survivors exposed in utero.[21] In one large-scale U.S. survey, known as the Tri-State Study, an increase was found in the frequency of childhood cancer if the mother or the father was exposed before conception of the child.[22] This implies that a genetic effect due to very low doses was responsible, although no genetic effects have been detected by much more sophisticated studies of the progeny of atomic-bomb survivors.[23] When a recent study of cancer in twins was related to radiation exposures during gestation,[24] MacMahon wrote in an accompanying editorial, "It seems likely that the question of the association between fetal irradiation and childhood cancer will fade into medical history unresolved and remain a source of more confusion than enlightenment."[25]

Biologic plausibility is still another consideration. The data of Stewart and her co-workers show that each form of childhood cancer is equally increased by diagnostic prenatal exposures to x-irradiation, but why should this be when these neoplasms differ epidemiologically, etiologically and with regard to pathogenesis?[26,27] Also one wonders why the fetus, just before birth, should be so sensitive to radiation-induced cancer, when no such sensitivity is known in the infant?

Persons exposed in utero are now 42 years old, and are beginning to face a mounting risk of cancer with age. In particular the frequency of breast cancer in relation to in utero exposure to radiation will be of interest, because the rates are moderately higher in girls exposed to 50 cGy or more under 10 years of age (10 cases observed as compared with 2 expected) than in females who were older.[28] Breast cancer thus may have a long latent period after exposure early in life, and an effect after in utero exposure may be detectable.

Radioactive iodine has long been known to cause cretinism in children of women given this radioisotope therapeutically during pregnancy.[3] A similar effect was caused among infants in the Marshall Islands exposed to fallout from a nuclear weapons test in 1954, but not among the three children in utero on Rongelap, where the doses were heaviest. Two of the children were in the first trimester, before thyroid function is active. The third was in the twenty-second week of gestation, but did not suffer ablation of the thyroid, although the gland "was probably functioning sufficiently to have absorbed a significant amount of radioiodines from the mother."[29] This child and one of the two exposed in the first trimester have developed benign nodules of the thyroid, the latter presumably due to the external radiation exposure, estimated to have been 175 cGy.

Cytogenetics

Complex chromosomal aberrations were seen at about 20 years of age in peripheral lymphocytes in 15 of 38 persons who had been exposed in utero in Hiroshima or Nagasaki.[30] Three were in the first trimester. The estimated dose in air was 104–477 cGy. The complex aberrations included rings, dicentrics, fragments and translocations. The authors presumed that in the first trimester stem-cells for immunologically competent lymphocytes were present, and that the population resulting from the divisions of these stem cells apparently maintained the chromosomal aberrations through many cell divisions. A re-evaluation of the cytogenetics of in utero survivors at 40 years of age has been made at the Radiation Effects Research Foundation, but the results have not yet been published.

Sterility

Animal experimentation has suggested that exposure of male fetuses to ionizing radiation induces sterility,[31] but no such effect has been observed among the Japanese exposed in utero in Hiroshima or Nagasaki.[32]

Lens Abnormalities

Polychromatic granular plaques have occurred on the posterior capsule of the lens of the eye among those exposed in utero to the atomic bomb, as in other survivors.[33] Examination at the age of 17–18 years showed that the frequency of plaques among the in utero group increased as the dose increased. Uncertainty about the dosimetry when the study was made in 1968 prevented a comparison between Hiroshima and Nagasaki from being made. None of the subjects had impaired vision due to the plaques, and none had true cataracts.

The Future

The effects of exposure on the health of persons exposed in utero are continuously in need of reevaluation. The frequency of neoplasia will be of primary interest. Presumably the same cancers that have occurred with increased frequency in older cohorts of atomic-bomb survivors will occur excessively among those exposed in utero. Rates similar to those of older cohorts, will not support the claim that intrauterine exposure to diagnostic radiation increases the frequency of cancer in childhood.

Effects on intelligence of the group exposed at 8–15 weeks of gestational age need to be evaluated to determine if deficiencies less than severe mental retardation can be defined. The Koga intelligence test results from 1955 need follow-up by more sophisticated contemporary test procedures. If possible, new diagnostic imaging techniques should be performed on persons with severe mental retardation to determine if abnormalities occurred in accord with the current explanation for radiation-induced mental deficiency based on animal experimentation.

Head circumference, a most sensitive measure of an intrauterine radiation effect, is of great interest with regard to the exposure at Chernobyl. As yet the Soviets, who presumably made these measurements, have not made public their findings. If the dose was large enough (10–19 cGy) to compare with the findings in Hiroshima, and no effect was found in the Soviet Union, current standards for radiological exposure of the embryo or fetus will have to be reconsidered. A possible implication of a difference between the two studies is that other environmental circumstances in Hiroshima from the bomb or war combine with radiation exposure to produce an effect different from that in a medical radiology unit.

The study made in 1968[30] that showed chromosomal abnormalities even after first trimester exposure to the atomic bomb needs to be reevaluated using contemporary techniques. A wide array of other observations, too numerous to mention here, would also be informative as the in utero cohort moves through its full life-span.

References Cited

1. **Dunlap, C. E.** 1942. Effects of radiation on blood and hemopoietic tissues, including spleen, thymus and lymph nodes. Arch. Path. **34:** 562–608.
2. **Stewart, A., J. Webb, D. Giles and D. Hewitt.** 1956. Malignant disease in childhood diagnostic irradiation in utero: Preliminary communication. Lancet **2:** 447.
3. **Fisher, W. D., M. L. Voorhess and L. I. Gardner.** 1963. Congenital hypothyroidism in infants following maternal ^{131}I therapy. J. Pediatr. **62:** 132–146.
4. **Yamazaki, J. N., S. W. Wright and P. M. Wright.** 1954. Outcome of pregnancy in women exposed to the atomic bomb in Nagasaki. Am. J. Dis. Child. **87:** 448–463.
5. **Shiota, K., C. Uwabe and H. Nishimura.** 1987. High prevalence of defective human embryos at the early postimplantation period. Teratology **35:** 309–316.
6. **Plummer, G.** 1952. Anomalies occurring in children exposed in utero to the atomic bomb in Hiroshima. Pediatrics **10:** 687–693.
7. **Miller, R. W.** 1956. Delayed effects occurring within the first decade after exposure of young individuals to the Hiroshima atomic bomb. Pediatrics **18:** 1–18.
8. **Wood, J. W., R. J. Keehn, S. Kawamoto and K. G. Johnson.** 1967. The growth and development of children exposed in utero to the atomic bombs in Hiroshima and Nagasaki. Am. J. Public Health **57:** 1374–1380.
9. **Miller, R. W. and W. J. Blot.** 1972. Small head size after in-utero exposure to atomic radiation. Lancet **2:** 784–787.
10. **Blot, W. J. and R. W. Miller.** 1973. Mental retardation following in utero exposure to the atomic bombs of Hiroshima and Nagasaki. Radiology **106**: 617–619.
11. **Miller, R. W. and J. J. Mulvihill.** 1976. Small head size after atomic irradiation. Teratology **14:** 355–358.
12. **Otake, M. and W. J. Schull.** 1984. In utero exposure to a-bomb radiation and mental retardation: A reassessment. Brit. J. Radiol. **57:** 409–414.
13. **Roesch, W. C., ed. U.S.-Japan Joint Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki.** Radiation Effects Research Foundation, Hiroshima 1987, pp. 390–392.
14. **Task Group of Committee 1, International Commission on Radiological Protection.** 1986. Developmental effects of irradiation on the brain of the embryo and fetus. Ann. ICRP **49:** 1–43.
15. **Schull, W. J. and M. Otake.** 1985. The central nervous system and in utero exposure to ionizing radiation: The Hiroshima and Nagasaki experiences. In: *Epidemiology and Quantitation of Environmental Risk from Radiation and Other Agents.* A. Castellani, ed. Plenum Press, New York, pp. 515–536.
16. **Miller, R. W.** 1987. Radiation biology needs physicians. The Scientist **1:** 11.
17. **Brent, R. L.** 1979. Effects of ionizing radiation on growth and development. Contr. Epidemiol. Biostat. **1:** 147–183.
18. **Stewart, A., J. Webb, J. and D. Hewitt.** 1958. A survey of childhood malignancies. Br. Med. J. **1:** 1495–1508.
19. **MacMahon, B.** 1962. Prenatal x-ray exposure and childhood cancer. J. Natl. Cancer Inst. **28:** 1173–1191.
20. **Monson, R. R. and B. MacMahon.** 1984. Prenatal x-ray exposure and cancer in children. In: *Radiation Carcinogenesis: Epidemiology and Biological Significance.* J. D. Boice, Jr. and J. F. Fraumeni, Jr., eds. Raven Press, New York, pp. 97–105.

21. **Ichimaru, M., T. Ohkita and T. Ishimaru.** 1986. Leukemia, multiple myeloma, and malignant lymphoma. Gann Monogr. Cancer Res. **32:** 113–127.
22. **Graham, S., M. L. Levin, A. M. Lilienfeld, L. M. Schuman, R. Gibson, J. E. Dowd and L. Hempelmann.** 1966. Preconception, intrauterine, and postnatal irradiation as related to leukemia. Natl. Cancer Inst. Monogr. **19:** 347–371.
23. **Schull, W. J., M. Otake and J. V. Neel.** 1981. A reappraisal of the genetic effects of the atomic bombs: summary of 34-year study. Science **123:** 1220–1227.
24. **Harvey, E. B., J. D. Boice, Jr., M. Honeyman and J. T. Flannery.** 1985. Prenatal x-ray exposure and childhood cancer in twins. New Engl. J. Med. **312:** 541–545.
25. **MacMahon, B.** 1985. Prenatal x-ray exposure and twins. New Engl. J. Med. **312:** 576–577.
26. **Miller, R. W.** 1986. Genes, syndromes and cancer. Pediat. Rev. **8:** 153–158.
27. **Miller, R. W.** 1988. Epidemiology and environmental causes of childhood cancer. In: *Principles and Practice of Pediatric Oncology*. P. A. Pizzo and D. G. Poplack, eds., Lippincott. Philadelphia, in press.
28. **Tokunaga, M., C. E. Land, T. Yamamoto, M. Asano, S. Tokuoka, E. Ezaki and I. Nishimori.** 1984. Breast cancer among atomic bomb survivors. In *Radiation Carcinogenesis: Epidemiology and Biological Significance*. J. D. Boice, Jr. and J. F. Fraumeni, eds., Raven Press, New York, pp. 45–56.
29. **Conard, R. A., D. E. Paglia, P. R. Larsen et al.** 1980. *Review of medical findings in a Marshallese population twenty-six years after accidental exposure to radioactive fallout.* Brookhaven National Laboratory report BNL 51261. (Brookhaven National Laboratory, Upton, NY).
30. **Bloom, A. D., S. Neriishi and P. G. Archer.** 1968. Cytogenetics of the in utero exposed of Hiroshima and Nagasaki. Lancet **2:** 10–12.
31. **Rugh, R.** 1952. Fetal x-irradiation and fertility. Proc. Soc. Exp. Biol. Med. **80:** 388–395.
32. **Blot, W. J., Y. Shimizu, H. Kato and R. W. Miller.** 1975. Frequency of marriage and live birth among survivors prenatally exposed to the atomic bomb. Am. J. Epidemiol. **102:** 128–136.
33. **Nefzger, M. D., R. J. Miller and T. Fujino.** 1968. Eye findings in atomic bomb survivors of Hiroshima and Nagasaki: 1963–1964. Am. J. Epidemiol. **89:** 129–138.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 101–116, June 1988

Carcinogenic Effects of Nuclear Radiation

Gilbert W. Beebe, Ph.D.

Clinical Epidemiology Branch, National Cancer Institute,
Bethesda, MD 20892

ABSTRACT

The expanding knowledge base for radiation carcinogenesis derives from an extensive experimental effort and increasing attention to the importance of human epidemiologic studies. The relation between dose and carcinogenic risk is described by means of mathematical models without which low-dose estimates would be impractical. Aspects of the exposure situation that influence the dose-specific risk of cancer include dose-rate and fractionation, and the quality of the radiation. Organs and tissues vary widely in their susceptibility to the carcinogenic force of ionizing radiation, apparently without relation to natural incidence. The carcinogenic risk per unit of exposure also depends on a variety of host factors of which age at exposure is the most influential. Others include sex, race, genetic characteristics and, for breast cancer, reproductive history. Time after exposure dominates expression of radiogenic cancers. Typically there is a minimal latent period for a given type of radiation and site of cancer and a period of expression that may be modelled as a wave function for leukemia and as some multiple of natural incidence for most solid tumors. Although the evidence is limited there are a number of environmental influences and characteristics of lifestyle that may also affect the likelihood of cancer following exposure to ionizing radiation.

Introduction

Although ionizing radiation is capable of producing many, if not most, forms of cancer in man, there is no unique type of cancer so produced, and radiogenic cancers cannot be distinguished from normally occurring cancer of different etiology. The absence of a marker identifying the cancer as radiogenic forces investigators to employ statistical methods to determine whether a particular experience may have given rise to an excess that may be considered radiogenic.

Information on the carcinogenic effects of exposures to ionizing radiation is obtained from both experimental and observational studies. Experimental work involves chiefly mice, rats, dogs, and mammalian cells. Although the quantitative aspects obtained through animal experimentation may not be directly transferable to man, there is so much similarity between man and other mammals with respect to cancer that experimental research has made a great contribution to the understanding of radiation carcinogenesis in man.

The necessarily observational human studies are built on diagnostic and therapeutic exposures, occupational exposures, the bombing of Hiroshima and Nagasaki, fallout from nuclear weapons tests, and differences in natural background levels. Although the methods used in these studies may mimic those employed in experimental work, there is a vast difference between them in the degree of control exercised by the investigator over the material. In consequence, no single study of radiation carcinogenesis in man can be taken as definitive, and knowledge in the field grows only as different investigators gradually reach the same or similar conclusions.

The literature on radiation carcinogenesis is continually being reviewed by expert committees, especially those of the United Nations, the International Commission on Radiological Protection (ICRP), the U.S. National Academy of Sciences (NAS), the National Council on Radiation Protection and Measurements of the U.S. (NCRP), as well as other national and international bodies. The major reports that are current, and major updates in process, include:

- UN, Scientific Committee on the Effects of Atomic Radiation, 1977 (update expected in 1988)
- ICRP, Recommendations, ICRP 26, 1977
- NAS, Committee on the Biological Effects of Ionizing Radiation: 1980 BEIR III report on low-dose exposure (update in work); 1987 BEIR IV report on alpha radiation
- NCRP, Recommendations, Report 91, 1987 and other more specialized reports, e.g., Report 88 on radon, 1986

The relationship between exposure to ionizing radiation and cancer is not simply that the risk depends on dose. It also depends on other characteristics of the exposure, e.g., the dose-rate and the type of radiation, on various characteristics of the exposed subjects, on the organs exposed, on time after exposure, and on other risk factors that may be present in the environment or in the lifestyle of those exposed.

Characteristics of Exposure

How the carcinogenic response depends on dose is fundamental for prediction, and thus for radiation protection, and of some theoretical interest in regard to the nature of the carcinogenic process. Dose-response models have been proposed on the basis of microdosimetric considerations, but the response is probably determined by far more than the initial biophysical events.[1] Nevertheless, biophysical considerations have served to rationalize the use of linear and linear-quadratic equations that do fit much of both the experimental and the human data on dose-response. In addition, the frequent observation in mammalian experiments of a downturn in the dose-response curve at high doses has led to a general belief that cell-killing may be responsible. Figure 1, taken from the BEIR III report,[2] displays in the upper left-hand panel a general linear-quadratic model of dose-response modified by an exponential term to bring the curve down in the high-dose region. The other panels contain curves formed by dropping one or more terms from the general model. These models are especially important for low linear-energy-transfer (LET), low-dose risk estimation because low-dose risks are usually too small to be observed directly and must be estimated from an equation fitted to the relevant human data.

A crucial issue, not yet fully resolved, is whether there may not be a threshold dose below which the risk of at least some forms of cancer disappears. For some effects, e.g., sterility and cataracts, thresholds seem well established, but for cancer this is not the case and it is generally assumed, especially for purposes of radiation protection, that there is no threshold for cancer. Human data that suggest the possibility of thresholds for certain forms of cancer following particular types of radiation include the absence of skin cancer in heavily pigmented skin[3] and the absence of bone cancer following exposure

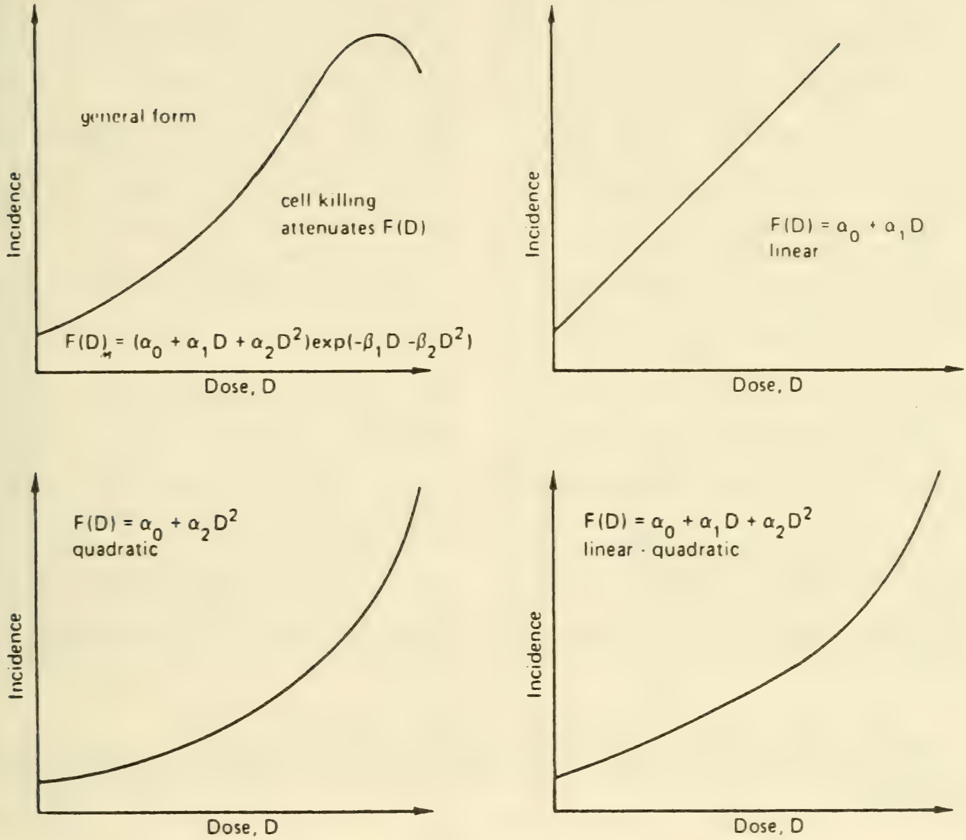

Fig. 1. Alternative Dose-response Curves. Source: BEIR III Report[2]

to low-LET radiation except in the high-dose range.[2] There must be negligibly small doses in the sense than any risk they may entail is quite small in relation to everyday risks assumed by most people without a second thought but, because both cancer and nuclear weapons are greatly feared, it is difficult for many to calibrate the risks from exposure to ionizing radiation. Many people fail to understand that they are exposed to ionizing radiation throughout life from cosmic and terrestrial sources, and even from radioisotopes within the body. The average exposure of about 0.002 Sv (0.2 rem) per year, or 0.15 Sv (15 rem) per lifetime is well within the range that many people anguish over and for which damage suits are brought against the Federal Government by people with cancer.

The lowest doses at which radiogenic cancers have been demonstrated statistically are 0.09 Gy (9 rad) to the thyroid gland in the Israeli tinea capitis series,[4] under 0.15 Gy (15 rad) to the breast in the Japanese A-bomb survivors[5] and, although this is less certain, a few rad to the fetus in large studies of x-ray exposure of the fetus during pelvimetry.[6,7] Upton has recently summarized the experimental evidence against the existence of a threshold dose for radiation carcinogenesis.[8]

There are many studies of the effects

of exposure in the low-dose range, studies undertaken for scientific, public health, or even political, reasons but, apart from the exceptions noted above, they have all failed to provide any firm basis for direct estimates of the risk at low doses.[9–19] Their necessarily inconclusive nature has, however, fueled the considerable controversy over the magnitude of that risk.

The most recent systematic compilation of risk estimates for radiogenic cancer appears in the NIH report on the probability of causation,[20] from which Table 1 is an excerpt for cancers of particular concern. Note that these are linear absolute risk coefficients per 100,000 persons per year per 0.01 Gy (1 rad) suitable for calculations of cancer incidence following low-dose exposure. The rates that were excerpted all happen to have been up-dated from the 1980 NAS BEIR III report but others, not shown, were taken directly from that report.[2] All are linear coefficients; even when the linear-quadratic dose response model is considered more suitable than the linear model, it is only the linear coefficient of the linear-quadratic equation that is used for low doses. For some sites and ages at exposure within sites the NIH Working Group was unable to provide estimates. Note that it is only for the breast and the thyroid gland that the linear model was used in Table 1 and in the source table.

To the extent that risk coefficients have been based on the experience of the A-bomb survivors they will change as a result of the joint US-Japan effort to revise the applicable dosimetry.[21] The magnitude of the changes has become evident in recent months for leukemia and for all cancers combined except leukemia.[22,23] Figure 2 presents dose-response curves for leukemia contrasting the old (T-65D) and the new (DS86) dosimetries. The second T-65D curve for the DS86 cohort is included to show that the reduction in the original cohort necessitated by the lack of

Table 1.—Absolute Excess Cancer Incidence per 100,000 Persons per Year per Rad (Organ Dose), at Low Levels of Low-LET Radiation, by Site, Sex and Exposure Age, Averaged over the Specified Follow-up Period.

Site	Exposure Age	Years* Follow-up	Dose-response Model	Sex M	Sex F
Leukemia	0–9	5–26	Linear-Quadratic	.173	.110
(all types	10–19	5–26		.0854	.0543
except CLL)	20–34	5–26		.0846	.0538
	35–49	5–26		.105	.0670
	50+	5–26		.156	.0990
Lung	10–19	10–33	Linear-Quadratic	.030	.030
	20–34	10–33		.056	.056
	35–49	10–33		.086	.086
	50+	10–33		.120	.120
Breast	0–9	10–35	Linear	—	.38
	10–19	10–35		—	.76
	20–29	10–35		—	.49
	30–39	10–35		—	.49
	40–49	10–35		—	.13
	50+	10–35		—	.08
Thyroid	0–9	10–34	Linear	.15	.50
	10–19	10–34		.15	.50
	20–34	10–34		.05	.15
	35–49	10–34		.05	.15
	50+	10–34		.05	.15

*Observed years over which risk was averaged to produce the risk coefficients shown.
Source: Rall *et al.*[20]

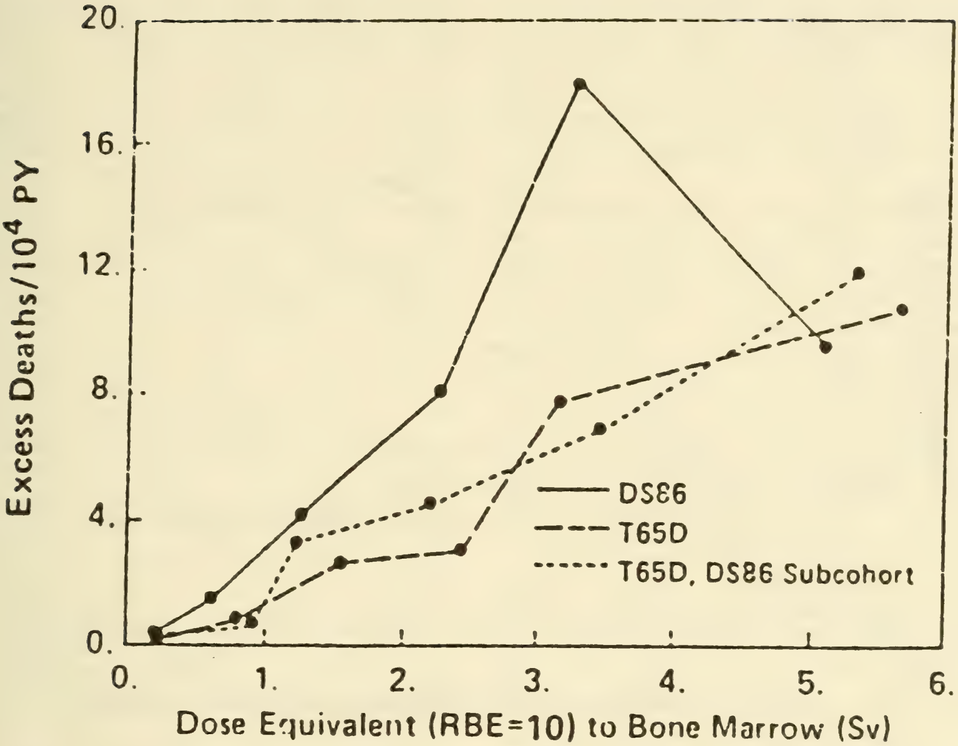

Fig. 2. Excess Leukemia Deaths per 10^4 Person-Years (PY), A-bomb Survivors, 1950–1985, by Dose-Equivalent, DS86 vs. T-65D.
Source: Preston and Pierce.[22]

DS86 estimates for some members of the cohort has little effect on the dose-response curve. These curves are based on the dose equivalent to bone marrow with the quality factor for fast neutrons set at 10. The overall effect of the adoption of DS86 doses is to increase the linear absolute risk estimate for leukemia by an average of 80 percent. Figure 3 provides parallel curves for all cancers except leukemia, but on a relative risk scale. Because individual doses had not yet been re-calculated for all organs under the DS86 system, the dose to the large intestine was used as a surrogate for the others. The average increase in risk on this basis is about 30 percent. If the quality factor for fast neutrons were set at 20, a value now recommended by the NCRP,[24] the average increases in linear risk coefficients above the T-65D estimates would be 136 percent for leukemia and 72 percent for all solid tumors combined. Those who may have been using risk estimates from the A-Bomb experience expressed in terms of rads, i.e., with an implicit RBE of 1, will see less change in the risk coefficients, the increase for leukemia being about 18 percent and that for all other cancers combined, −3 percent (22).

In experimental work the rate at which radiation is delivered to target tissue has a major effect on the resulting yield of tumor.[25] The 1980 NCRP report on the effects of dose-rate on the carcinogenic effect of low-LET radiation recommends that low-dose estimates based on linear dose-response equations fitted to largely high-dose observations be divided by a factor between 2 and 10.[26] The carcino-

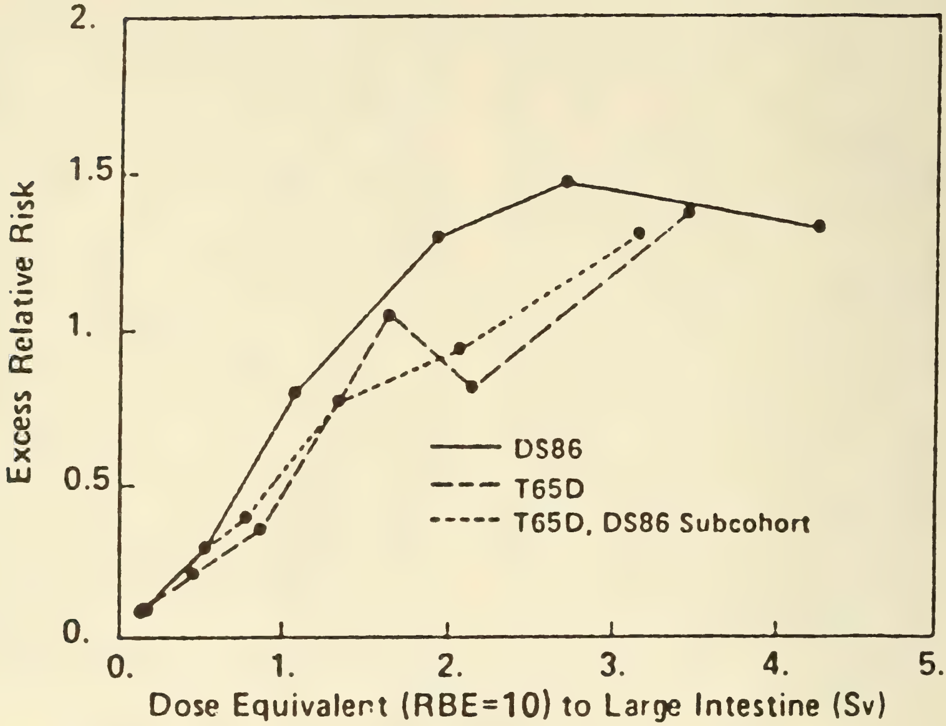

Fig. 3. Excess Relative Risk of Death from All Cancers except Leukemia, A-bomb Survivors, 1950–1985, by Dose-Equivalent, DS86 vs. T-65D.
Source: Preston and Pierce.[22]

genic effect of exposure to high-LET radiation is generally thought to be less dependent on dose-rate than exposure to low-LET radiation. Ullrich *et al.* have shown, however, that the influence of dose-rate on the effect of neutrons is mixed, depending on the target tissue and the size of the dose.[27] Human data provide little evidence of a dose-rate effect, although most non-medical exposure is of the low dose-rate variety and some of the medical exposure is fractionated. The data on female breast cancer provide the only substantial human evidence on the dose-rate effect, for similar absolute risk coefficients derive from the high dose-rate experience of the A-bomb survivors, the highly fractionated exposure of tuberculosis patients on collapsed lung therapy monitored by an average of about 100 fluoroscopic examinations, and the lightly fractionated exposure of mastitis patients treated by x ray.[28] Since the large difference in degree of fractionation of dose between the latter two U.S. series is accompanied by little or no difference in either absolute or relative risk, the fact that the relative risk is very much higher for the A-bomb survivors is of considerable interest but does not invalidate the conclusion that the absolute risk of breast cancer is insensitive to variation in dose-rate. The high relative risk among A-bomb survivors reflects the very much lower breast cancer incidence of Japanese women.

The apparently greater effect, per unit of absorbed dose, of high-LET in comparison with low-LET radiation has been amply demonstrated experimentally.[29,30]

Relative biological effectiveness (RBE) ratios not uncommonly range well above 10 in experimental studies. Also, since high-LET dose-response curves tend toward linearity, while low-LET tend toward curvilinearity, RBE ratios often increase with decreasing dose. Human data for estimating RBEs for neutrons are lacking, now that the new DS86 dosimetry for the A-bomb survivors has so downgraded the neutron component of dose in Hiroshima as to have effectively removed the possibility of any realistic estimation of the RBEs for neutrons on the basis of Hiroshima-Nagasaki contrasts.[22] There are both low-LET and high-LET data on lung cancer, but the high-LET risk estimates are in terms of Working-Level-Months (WLM) and it is doubtful that their conversion to estimates per rad of alpha radiation to lung tissue is reliable enough to produce trustworthy RBE estimates. Prevalent ideas about relative biological effectiveness ratios are illustrated by the quality factors (Q) recommended by the International Commission on Radiological Protection (ICRP) in 1977:

x rays, gamma rays and electrons	1
neutrons, protons	10
alpha particles	20

Further, as noted above, the Q factor for neutrons is being reconsidered at the present time and the NCRP has published a recommendation that it be increased to 20.[24]

Tissue Susceptibility

As was seen in Table 1, the absolute risk coefficients for even the organs most affected by radiation vary greatly. The reasons for this apparent differential sensitivity are not known and are little investigated. It is of more than passing interest that the variation among the sites for which estimates exist in no way parallels that for their normal incidence. Table 2 contrasts BEIR III average sex- and site-specific risk coefficients and average U.S. incidence taken from the Third National Survey by the National Cancer Institute.[31] Only for male lung cancer and female breast cancer are high risk coefficients matched by high incidence rates.

Differentials in tissue sensitivity can be demonstrated in comparisons of absolute risk, as in Table 1, where the risk coefficients for both breast and thyroid cancer are well in excess of those for leukemia, or in comparisons of relative risk where the risk coefficient for leukemia is well above those for breast and thyroid cancer. Thus the judgment as to differential sensitivity will sometimes depend on the definition of the measure of risk.

Omitted from the usual lists of susceptible organs are brain and ovary for both of which there is now evidence of some sensitivity to the carcinogenic action of ionizing radiation. Multiple myeloma occupies an uncertain position among the radiogenic cancers,[32] as do the lymphomas for which the NIH Working Group found insufficient data upon which to base risk estimates. Skin cancer has long been known to be radiogenic but the NIH Group also found insufficient quantitative data for risk estimation. If skin cancer could have been included in Table 2 it also would have been a marked deviant, with a high natural incidence and a low risk coefficient.

Cancers of a given organ are generally described in terms of their cellular origin. Only for leukemia are there reasonably adequate data on the risk by cell type, and it is notable that one form of leukemia, common at older ages, seems definitely not to be responsive to radiation, namely, chronic lymphocytic leukemia. Other forms of cancer that have not been found to be associated with radiation exposure include prostate, uterus, and small intestine. Nevertheless, it is generally suspected that, given sufficient dose, any form of

Table 2.—Average Linear Risk Coefficients for Various Forms of Cancer Induced by Low-LET Radiation and Average U.S. Incidence Rates, by Sex.

	Male		Female	
Type of Cancer	Coefficient*	Incidence†	Coefficient*	Incidence†
Leukemia**	3.1	.91	2.0	.57
Thyroid	2.2	.21	5.8	.50
Breast	—	—	5.8	7.4
Lung	3.6	7.2	3.9	1.4
Esophagus	.3	.57	.3	.16
Stomach	1.5	1.5	1.7	.70
Intestine	1.0	5.2	1.1	4.0
Liver	.7	.33	.7	.14
Pancreas	.9	1.2	1.0	.75
Urinary organs	.8	3.2	.9	1.0
Lymphoma	.3	1.2	.3	.79
Other	1.5	13.2	1.6	9.6
All sites	15.9	34.7	25.1	27.0

*Excess incident cases per million persons per rad per year, age adjusted, from BEIR III report.[2]
†Cases per 10,000 per year, age adjusted, from NCI survey.[31]
**Except chronic lymphocytic leukemia.

human cancer might be produced by irradiation.

Host Characteristics

Age at exposure and sex are both associated with differentials in risk estimates, but there is a paucity of information on the influence of other host factors, e.g., genetic constitution, immune competence, and hormone status, that might be expected to affect the risk of radiogenic cancer. Age at exposure exerts a particularly strong influence on average risk coefficients, as may be seen in Table 1. Those coefficients were calculated after excluding the first 5 or 10 years after exposure in recognition of the length of the minimal latent period. Since age at exposure apparently determines the minimal latent period before the radiogenic cancers first appear (Figure 4), generally at about the age when cancers normally begin to appear, the age-specific coefficients in Table 1 carry both the influence of the length of the minimal latent period and the intrinsic effect of age at exposure on risk. At a given age at death, as in Table 3, groups exposed at younger ages tend to have higher risk coefficients than older groups once the age is reached at which cancer normally appears.

For both leukemia and thyroid cancer there are significant sex differences in absolute measures of risk, males having the higher risk for leukemia and females for thyroid cancer. These sex differences tend to disappear, however, when relative measures of risk are calculated.

Race has not seemed to be an important factor in the carcinogenic response to radiation. The fact that Blacks in the New York University tinea capitis series did not suffer from skin cancer, while those with fair skin had a marked excess, especially in areas of the skin exposed to sunlight, suggests that ionizing radiation and ultra violet radiation interact to produce skin cancer in those whose skin is sensitive to ultra violet radiation.[3] The failure to find excess skin cancer among Japanese A-bomb survivors in the careful dermatologic survey in 1964–1966[33] may not depend on degree of pigmentation of the skin, for skin cancer has been reported following medical irradiation in Ja-

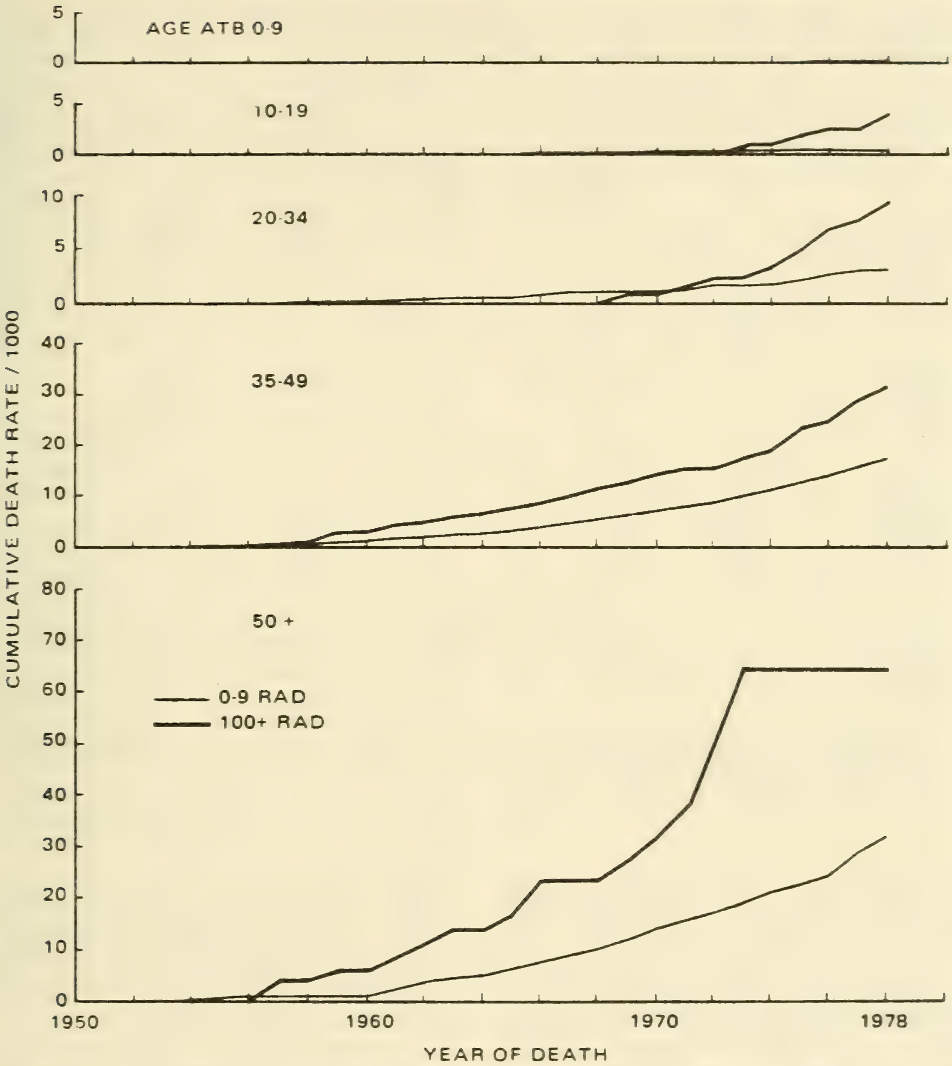

Fig. 4. Cumulative Deaths from Lung Cancer per 1,000 A-bomb Survivors 1950–1978, by Age in 1945 (ATB), Year of Death, and T-65 Dose.
Source: Kato and Schull.[41]

pan.[34] It may be explained in part by the apparently long minimal latent period for radiogenic skin cancer or, perhaps, by a higher threshold for radiogenic skin cancer among the Japanese.

Certain genetic diseases, especially the nevoid basal cell carcinoma syndrome and hereditary retinoblastoma, are known to predispose to radiation-induced cancer. According to the two-stage model of Knudson it is possible for the first, initiating, event to be an inherited defect and the second, promoting step, exposure to radiation.[35]

Maternal history of breast cancer and numerous inter-related characteristics of the reproductive history have been shown to influence the risk of breast cancer.

Table 3.—Absolute Risk* by Age in 1945, A-bomb Survivors, 1950–1978 by Type of Cancer and Age at Death.

	Age at Death					
Age in 1945	<30	30–39	40–49	50–59	60–69	70+
(a) All cancer except leukemia						
<10	1.22	4.35	13.41	—	—	—
10–19	—	1.72	4.62	20.69	—	—
20–34	—	—	1.01	7.97	10.25	—
35–49	—	—	—	−0.96	2.09	12.67
50+	—	—	—	—		18.31
(b) Stomach cancer						
<10	0.18	0.40	13.84	—	—	—
10–19	—	0.57	0.47	5.05	—	—
20–34	—	—	1.31	2.06	1.97	—
35–49	—	—	—	−1.20	−0.08	6.15
50+	—	—	—	—		8.82
(c) Breast cancer						
<10	—	−0.02	—	—	—	—
10–19	—	0.80	1.16	—	—	—
20–34	—	—	−0.18	2.27	4.49	—
35–49	—	—	—	−0.08	−0.10	−0.34
50+	—	—	—	—	—	0.38
(d) Lung cancer						
<10	—	−0.01	−0.45	—	—	—
10–19	—	−0.02	0.96	7.48	—	—
20–34	—	—	−0.23	1.73	3.34	—
35–49	—	—	—	0.59	1.19	4.72
50+						0.29

*Excess deaths per million persons per year per rad.
Source: Kato & Schull.[41]

Although these factors have not been extensively studied in relation to the risk of radiogenic breast cancer, in at least two independent studies there are indications that nulliparous women and those with delayed parity have a higher risk of radiogenic cancer per unit of exposure than do other women.[36] That hormonal factors influence the risk of radiogenic mammary cancer in experimental animals has been shown in a number of studies.[37]

Time-Response

The temporal distribution of radiogenic cancers is a matter of considerable practical interest and possible significance for a deeper understanding of the mechanisms of radiation carcinogenesis. There is, first, a latent period following exposure before expression begins. This has been reasonably well determined for leukemia following low-LET irradiation, and for bone cancer induced by Ra-224, as two to four years.[20] Following alpha irradiation from the administration of Thorotrast, however, the minimal latent period for leukemia is longer, 5–8 years.[38,39] For hepatic angiosarcoma following the administration of Thorotrast the minimal latent period, based on a compilation of several series, is about 16 years in comparison with 9 years following initial exposure to vinyl chloride.[40] The NIH Working Group modelled the latent period for solid tumors on the assumption that excess cancer begins 5 years after exposure and in terms of relative risk is fully expressed by 10 years after.

The duration of expression is clearly much shorter for leukemia than for the solid tumors. Although it is difficult to specify the point in time at which the excess reaches zero, observations on A-bomb survivors indicate that the duration of the leukemogenic response depends on age at exposure, with younger members of the study cohort showing no excess after about 20 years after the bombing, and older survivors showing a slight excess even 30–35 years after exposure.[41]

Since no large cohort has been followed to extinction there is some uncertainty about the length of the period of expression for solid tumors other than bone. The latest report on the British ankylosing spondylitis series has a substantial experience more than 35 years after treatment, 75 deaths having been observed for all causes vs. 66 expected at average national rates, but for all neoplasms combined there is no indication of an excess (14 observed vs. 17.4 expected). In the previous 5 years there were 68 observed vs. 57.6 expected, an insignificant excess.[42] Among the A-bomb survivors, on the other hand, survivors exposed to 100 or more rad (T-65D kerma) had 102 deaths from cancers other than leukemia vs. 63.8 expected in the 30–33 year interval after 1945, a highly significant excess.[41] For the 34–37 year follow-up interval parallel figures are not provided in the latest report, but it is clear that the excess continued to be a statistically significant one.[43] In the large international study of second cancers among women treated for cervical cancer the radiogenic excess is stronger at 30+ years after treatment than ever before.[44]

At present the investigation of time-response centers on the overall pattern of expression. The early experience of both the A-bomb survivors and the British ankylosing spondylitis patients revealed that radiogenic leukemia is expressed in a wave pattern, with a peak 6–8 years after exposure of the A-bomb survivors and 2.5–5 years for the ankylosing spondylitis patients. The NIH Working Group modelled the combined experience of the two series for chronic granulocytic leukemia, acute leukemias of all types, and all leukemias combined except chronic lymphocytic leukemia. Figure 5 exhibits its time-response model for acute leukemia by age at exposure.

In an early paper on breast cancer among A-bomb survivors McGregor *et al.* showed that the radiogenic excess is distributed over time in accordance with the age-specific pattern usual for this tumor in Japan.[45] This was followed by a paper by Land and Norman in which it was shown that radiogenic tumors of both breast and lung track natural incidence over time.[46] These developments led to the use of the "relative risk projection model" of the BEIR III Committee and its use of both an absolute and a relative risk model to predict the radiogenic excess beyond the period of actual observation, as in making lifetime estimates.[2]

In the 1950–1978 report on the mortality of A-bomb survivors Kato and Schull compared absolute vs. relative risk estimates over time within age-at-exposure groups (Table 4). This material has given considerable support to the hypothesis of a constant relative risk time-response function, i.e., a multiplicative risk model. It is by no means established, however, that a relative risk model need employ a constant ratio of radiogenic risk to natural risk. In the 1950–1982 report on the mortality of A-bomb survivors it is observed that relative risks have declined over the interval 1959–1982, but not to a significant extent.[43] More important is the conclusion of the BEIR IV Committee that the data from the various series of underground miners fit best a relative risk model that declines with advancing attained age, first at age 55 and again at age 65.[47]

Other Risk Modifiers

Epidemiologists have not wanted to overlook important interactions between

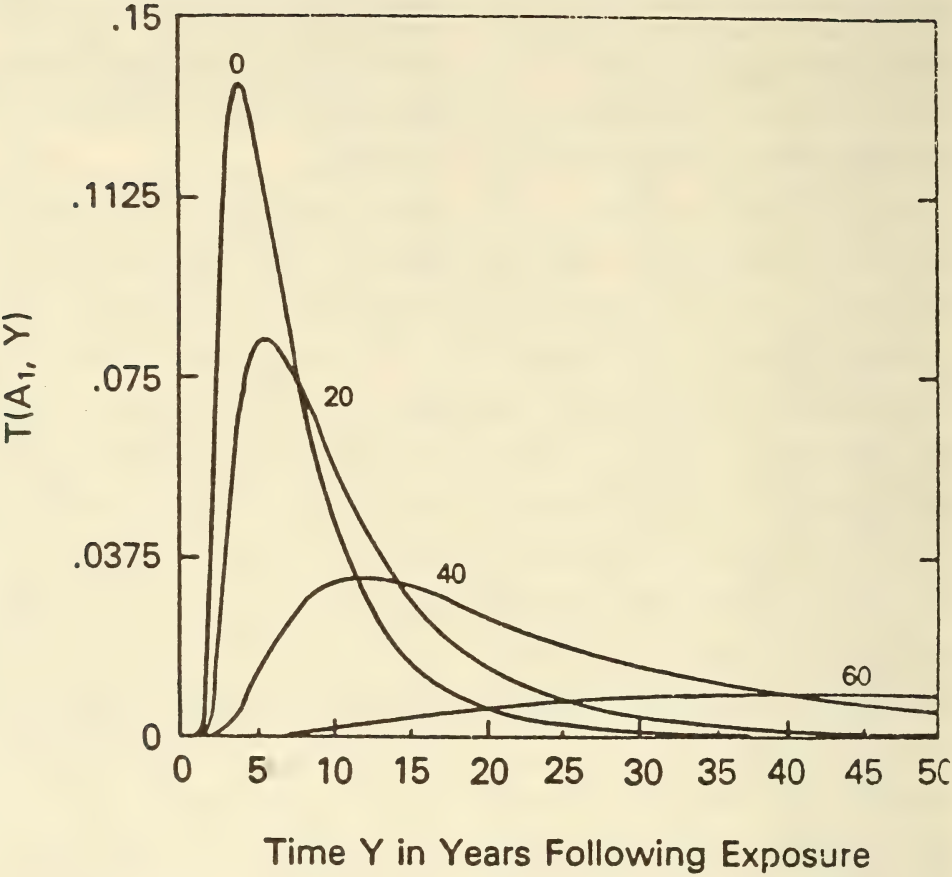

Fig. 5. Fitted Time to Tumor Model for Acute Leukemia Induced by Brief Exposure to Ionizing Radiation at Age A_1. $T(A_1,Y)$ is the probability of diagnosis within one year after time T. Lines within the graph represent the indicated ages at exposure.
Source: Rall *et al.*[20]

radiation and other risk factors for cancer but have mainly focused on smoking in relation to lung cancer, perhaps prompted by the example of asbestos and smoking and by the high prevalence of cigarette-smoking. Unfortunately the human data are not yet sufficiently robust to determine the role of even smoking when combined with exposure to radiation. Studies of lung cancer among the A-bomb survivors suggest that the risks may be additive[48] but those on underground miners have been interpreted as supportive of a multiplicative interaction.[47,49]

There may in time be a great deal more information about interactions between radiation therapy and chemotherapy for cancer from the follow-up studies designed to estimate the risk of second primary tumors, but at present such information is very fragmentary and provides little insight into the way in which chemotherapeutic agents and radiation therapy combine to enhance the risk of second tumors.

Investigators at the Radiation Effects Research Foundation (formerly the Atomic Bomb Casualty Commission)

Table 4.—Comparison of Absolute* and Relative† Risk Estimates by Age at Exposure and Age at Death, All Cancer except Leukemia, A-bomb Survivors, 1950–1978.

Age, in 1945	Type of Coefficient	Age at Death					
		<30	30–39	40–49	50–59	60–69	70+
0–9	Relative	15.1	5.0	6.8	—	—	—
	Absolute	1.2	4.4	13.4	—	—	—
10–19	Relative	1.0	2.5	2.4	8.2	—	—
	Absolute		1.7	4.6	20.7	—	—
20–34	Relative	—	1.8	1.9	2.0	1.6	—
	Absolute	—		1.0	8.0	10.2	—
35–49	Relative	—	—	1.2	1.1	1.3	1.4
	Absolute	—	—	—	−1.0	2.1	12.7
50+	Relative	—	—	—	2.2	1.0	1.4
	Absolute	—	—	—	—	—	18.3

*Excess deaths per million per year per rad.
†100+ rad vs. 0 rad.
Source: Kato and Schull.[41]

have collected a great deal of information on variables of epidemiologic interest in addition to radiation and the obvious demographic characteristics, e.g., on diet and socioeconomic factors, but thus far no environmental or lifestyle factor has appeared to interact with radiation so as to yield a risk greater than the sum of the risks normally attributed to the two factors acting independently. For example, Kato, in a recent review, reported that, although the risk of breast cancer increased with increasing socioeconomic status, there was no evidence of interaction.[50]

The most significant data in the epidemiology literature concern the relation between ultra-violet radiation (UVR) and ionizing radiation in inducing skin cancer. The New York University tinea capitis series not only has an excess of skin cancer among Whites and not in Blacks, but its distribution over the scalp, face, and neck is clearly related to the intensity of exposure to UVR.[3] The investigators believe their findings suggest that UVR exposure levels, or sensitivity to such exposure, interact with ionizing radiation in causing skin cancer among Whites. Analysis of the number of tumors per person suggested that there were subgroups of more and less susceptible individuals.[3]

Experimental investigators have paid considerable attention to the combined effects of ionizing radiation and other agents, especially chemicals, and have identified agents that may reduce, as well as agents that may enhance, the carcinogenic potential of ionizing radiation.[37]

Summary

An extensive experimental effort, coupled with growing epidemiological attention to radiation carcinogenesis, has created a large body of mainly descriptive information on the risk of cancer following exposure to ionizing radiation. A general outline of the relationship of radiation dose to the likelihood of cancer is well established, but empirical information is weak at the low-dose levels because the risks themselves are evidently so low; in general, estimates for the low-dose region can be made only by fitting simple mathematical models to data covering a range of dose that reaches into its higher levels.

In addition to dose other major factors influencing the magnitude of the risk of cancer include the target organ, age at exposure, and time after exposure. This is an area of active investigation that extends to host factors, elements of lifestyle, and environmental factors. The biologic basis for the highly variable sensitivity of various organs and tissues, apparently uncorrelated with natural incidence, awaits explication through more fundamental biologic knowledge.

There are several notable gaps and uncertainties in present knowledge:

- the magnitude of risk from low doses
- the effect of I-131 on the thyroid gland
- the RBE for fast neutrons
- whether fetal bone marrow is much more sensitive than that of infants and young children

Major problems impeding the accumulation of knowledge on radiation carcinogenesis include:

- limitations on the application of experimental findings to man
- lack of any specific marker identifying the cancer of an individual as radiogenic
- paucity of human radiogenic cancers in even the largest series, in the light of the complex relationships requiring exploration
- practical difficulties of combining datasets from different studies

Finally, there are powerful influences in the scientific community attempting to achieve consensus as the information on radiation carcinogenesis expands. National and international bodies of experts, stimulated in part by concerns about radiation protection, periodically synthesize the literature and, on occasion, re-analyse the larger series in combined fashion so as to achieve new integrations of existing data.

References Cited

1. **Storer, J. B.** 1986. Carcinogenic effects: An overview. In: *Radiation Carcinogenesis:* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 11–22.
2. National Research Council Committee on the Biological Effects of Ionizing Radiations. 1980. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980. National Academy Press. Washington.
3. **Shore, R. E., Albert, R. E., Reed, M., Harley, N. and Pasternack, B. S.** 1984. Skin cancer incidence among children irradiated for ringworm of the scalp. Radiat. Res. **100:** 192–204.
4. **Ron, E. and Modan, B.** 1984. Thyroid and other neoplasms following childhood scalp irradiation. In: *Radiation Carcinogenesis: Epidemiology and Biological Significance.* J. E. Boice, Jr. and J. F. Fraumeni, Jr., eds., Raven Press. New York, pp. 139–152.
5. **Tokunaga, M., Land, C. E., Yamamoto, T., Asano, M., Tokuoka, S., Ezaki, H. and Nishimori, I.** 1984. Incidence of female breast cancer among atomic-bomb survivors, Hiroshima and Nagasaki, 1950–1980. Technical Report 15-84. Radiation Effects Research Foundation. Hiroshima.
6. **Stewart, A. M. and Kneale, G. W.** 1970. Radiation dose effects in relation to obstetric x-rays and childhood cancers. Lancet **1:** 1185–88.
7. **Monson, R. R. and MacMahon, B.** 1984. Prenatal x-ray exposure and cancer in children. In: *Radiation Carcinogenesis: Epidemiology and Biological Significance.* J. E. Boice, Jr. and J. F. Fraumeni, Jr., eds., Raven Press. New York, pp. 97–106.
8. **Upton, A. C.** 1986. Historical perspectives on radiation carcinogenesis. In: *Radiation Carcinogenesis.* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 1–10.
9. **Mancuso, T. F., Stewart, A. and Kneale, G.** 1977. Radiation exposures of Hanford workers dying from cancer and other causes. Health Phys. **33:** 369–85.
10. **Caldwell, G. G., Kelley, D. B. and Heath, C. W.** 1980. Leukemia among participants in military maneuvers at a nuclear bomb test. J.A.M.A. **244:** 1575–78.
11. **Lyon, J. L., Klauber, M. R., Gardner, J. W. and Udall, K. S.** 1979. Childhood leukemias associated with fallout from nuclear testing. New Eng. Jour. Med. **300:** 379–402.
12. **Najarian, T. and Colton, T.** 1978. Mortality from leukemia and cancer in shipyard nuclear workers. Lancet **1:** 1018–20.
13. **Matanoski, G. M., Sartwell, P., Elliott, E., Tonascia, J. and Sternberg, A.** 1984. Cancer risks in radiologists and radiation workers. In: *Radiation Carcinogenesis: Epidemiology and Biological Significance.* J. E. Boice, Jr. and J. F. Fraumeni, Jr., eds., Raven Press. New York, pp. 83–96.
14. **Beral, V., Inskip, H., Fraser, P., Booth, M., Coleman, D. and Rose, G.** 1985. Mortality of employees of the United Kingdom Atomic En-

ergy Authority, 1946–1979. Br. Med. J. **291:** 440–47.

15. **Abbatt, J. D., Hamilton, T. R. and Weeks, J. L.** 1983. Epidemiological studies in three corporations covering the Canadian nuclear fuel cycle. In: *Biological Effects of Low-Level Radiation, Proceedings of an International Symposium on the Effects of Low-Level Radiation with Special Regard to Stochastic and Non-Stochastic Effects,* Venice, Italy, 11–15 April 1983. International Atomic Energy Agency. Vienna, pp. 351–62.
16. **Jablon, S. and Miller, R. W.** 1980. Army technologists: 29-year follow-up for cause of death. Radiol. **126:** 677–79, 1978.
17. **Wei, L.** Health survey in high background radiation areas in China. Science **209:** 877–80.
18. **Frigerio, N. A. and Stowe, R. S.** 1976. Carcinogenic and genetic hazard from background radiation. In: *Biological and Environmental Effects of Low-Level Radiation.* International Atomic Energy Agency. Vienna, pp. 385–93.
19. **Robinette, C. D., Jablon, S. and Preston, T. L.** 1985. Studies of Participants in Nuclear Tests. Medical Follow-up Agency, National Research Council. Washington.
20. **Rall, J. E., Beebe, G. W., Hoel, D. G., Jablon, S., Land, C. E., Nygaard, O. F., Upton, A. C., Yalow, R. S. and Zeve, V. H.** 1985. Report of the National Institutes of Health Ad Hoc Working Group to Develop Radioepidemiologic Tables. U.S. Government Printing Office. Washington.
21. **Roesch, W. C. (ed.)** 1987. U.S.-Japan Joint Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki. V.1. Radiation Effects Research Foundation. Hiroshima.
22. **Preston, D. L. and Pierce, D. A.** 1987. The Effect of Changes in Dosimetry on Cancer Mortality Risk Estimates in the Atomic bomb Survivors. Technical Report 9-87. Radiation Effects Research Foundation. Hiroshima.
23. **Sinclair, W. K. and Preston, D. L.** 1987. Revisions in the dosimetry of the A-bomb survivors at Hiroshima and Nagasaki and their consequences. To be published in the Proceedings of the Eighth International Congress on Radiation Research, Edinburgh.
24. National Council on Radiation Protection and Measurements. 1987. Recommendations on Limits for Exposure to Ionizing Radiation. NCRP Report No. 91. National Council on Radiation Protection and Measurements. Bethesda, MD.
25. **Ullrich, R. L. and Storer, J. B.** 1979. Influence of irradiation on the development of neoplastic disease in mice. Radiat. Res. **80:** 325–42.
26. National Council on Radiation Protection and Measurements. 1980. Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations. NCRP Report No. 64. National Council on Radiation Protection and Measurements. Bethesda, MD.
27. **Ullrich, R. L., Jernigan, M. C. and Storer, J. B.** 1977. Neutron carcinogenesis: Dose and dose-rate effects in BALB/c mice. Radiat. Res. **72:** 487–98.
28. **Land, C. E., Boice, J. D., Jr., Shore, R. E., Norman, J. E. and Tokunaga, M.** 1980. Breast cancer risk from low-dose exposures to ionizing radiation: Results of parallel analysis of three exposed populations of women. Jour. Natl. Cancer Inst. **65:** 353–76.
29. **Ullrich, R. L. and Storer, J. B.** 1978. Influence of dose, dose rate and radiation quality on radiation carcinogenesis and life shortening in RFM and BALB/c mice. In: *Late Biological Effects of Ionizing Radiation.* V.2. International Atomic Energy Agency. Vienna, pp. 95–111.
30. **Kellerer, A. M. and Rossi, H. H.** 1982. Biophysical aspects of radiation carcinogenesis. In: *Cancer, V.1, Etiology: Chemical and Physical Carcinogenesis.* F. E. Becker, ed., Plenum Press. New York, pp. 569–616.
31. National Cancer Institute. 1975. Third National Cancer Survey: Incidence Data. NCI Monogr. 41. U.S. Government Printing Office. Washington.
32. **Miller, R. W. and Beebe, G. W.** 1986. Leukemia, lymphoma, and multiple myeloma. In: *Radiation Carcinogenesis.* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 245–60.
33. **Johnson, M. L. T., Land, C. E., Gregory, P. B., Taura, T. and Milton, R. C.** 1969. Effects of Ionizing Radiation on the Skin, Hiroshima-Nagasaki. Technical Report 20-69. Atomic Bomb Casualty Commission. Hiroshima.
34. **Takahashi, S.** 1964. A statistical study on human cancer induced by medical irradiation. Acta Radiol. (Nippon) **23:** 1510–30.
35. **Knudson, A. G., Jr. and Moolgavkar, S. H.** 1986. Inherited influences on susceptibility to radiation carcinogenesis. In: *Radiation Carcinogenesis.* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 401–12.
36. **Shore, R. E.** 1986. Carcinogenic effects of radiation on the human breast. In: *Radiation Carcinogenesis.* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 279–92.
37. **Fry, R. J. M. and Ullrich, R. L.** 1986. Combined effects of radiation and other agents. In: *Radiation Carcinogenesis.* A. C. Upton, R. E. Albert, F. J. Burns and R. E. Shore, eds., Elsevier. New York, pp. 437–54.
38. **Faber, M.** 1978. Malignancies in Danish Thorotrast patients. Health Phys. **35:** 153–8.
39. **Van Kaick, G., Lorenz, D., Muth, H. and Kaul, A.** 1978. Malignancies in German Thor-

otrast patients and estimated tissue dose. Health Phys. **35:** 127–36.

40. **Spirtas, R., Beebe, G., Baxter, P., Dacey, E., Faber, M., Falk, H., Van Kaick, G. and Stafford, J.** 1983. Angiosarcoma as a model for comparative carcinogenesis. Letter to the Editor, Lancet **2:** 456.
41. **Kato, H. and Schull, W. J.** 1982. Studies of the mortality of A-bomb survivors. 7. Mortality, 1950–1978: Part 1. Cancer mortality. Radiat. Res. **90:** 395–432.
42. **Darby, S., Doll, R., Gill, S. K. and Smith, P. G.** 1987. Long term mortality after a single treatment course with x-rays in patients treated for ankylosing spondylitis. Br. J. Cancer **55:** 179–190.
43. **Preston, D. L., Kato, H., Kopecky, K. J. and Fujita, S.** 1987. Studies of the mortality of A-bomb survivors. 8. Cancer mortality, 1950–1982. Radiat. Res. **111:** 151–78.
44. **Boice, J. D., Jr., Day, N. E., Anderson, A., *et al.*** 1984. Cancer risk following radiotherapy of cervical cancer: A preliminary report. In: *Radiation Carcinogenesis*. J. D. Boice, Jr. and J. F. Fraumeni, Jr., eds., Raven Press, New York, pp. 161–179.
45. **McGregor, D. H., Land, C. E., Choi, K., Tokuoka, S., Liu, P. I., Wakabayashi, T. and Beebe, G. W.** 1977. Breast cancer incidence among atomic bomb survivors, Hiroshima and Nagasaki, 1950–1969, Jour. Natl. Cancer Inst. **59:** 799–811.
46. **Land, C. E. and Norman, J. E.** 1978. Latent periods of radiogenic cancers occurring among Japanese A-bomb survivors. In: *Late Biological Effects of Ionizing Radiation, Proceedings of the Symposium on the Late Biological Effects of Ionizing Radiation,* 13–17 March 1978. Vienna. V.1. International Atomic Energy Agency. Vienna, pp. 29–44.
47. National Research Council, Committee on the Biological Effects of Ionizing Radiation. 1987. The Effects on Populations of Exposure to Internal Deposition of Alpha-Emitting Radionuclides: 1987. Natl. Acad. Press. Washington.
48. **Blot, W. J., Akiba, S. and Kato, H.** 1984. Ionizing radiation and lung cancer: A review including preliminary results from a case-control study among A-bomb survivors. In: *Atomic Bomb Survivor Data: Utilization and Analysis.* R. L. Prentice and D. J. Thompson, eds., SIAM. Philadelphia, pp. 235–48.
49. **Whittemore, A. S. and McMillan, A.** 1983. Lung cancer mortality among U.S. uranium miners: A reappraisal. Jour. Natl. Cancer Inst. **71:** 489–99.
50. **Kato, H.** 1986. Cancer mortality. In: *Cancer in Atomic Bomb Survivors.* I. Shigematsu and A. Kagan, eds., GANN Mongr. on Cancer Research No. 32. Plenum Press. New York, pp. 53–74.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 117–121, June 1988

Genetic Effects of Nuclear Radiation

Seymour Abrahamson

Dept. of Zoology
University of Wisconsin,
Madison, WI 53706

When we consider genetic disorders, our concern lies specifically with the offspring of the exposed parents and their descendants. Once a newly introduced genetic change enters the germline of either parent it is subject to various selective forces such that the germ cell itself may be killed, or be less able to produce progeny cells or complete the maturation divisions required to transform it into a functional sperm or egg. Given that a successful fertilization has occurred the newly formed zygote is again subject to selective forces that may prevent successful gestation, usually the genetic imbalance leading to early abortion has caused such severe physical and or physiological abnormality that embryological or fetal development could not be sustained. Such disorders may well occur in at least 15% and probably closer to 35–40% of all conceptions normally. In other words nearly one out of every two conceptions are believed to be spontaneously aborted, most of these in the early stages of pregnancy and many go unrecognized. The next stage at which selection occurs is in the new born, and as the major infectious disease have been successfully eliminated we learn that the residue of neonatal deaths, about 1% of all live births, die from predominantly genetic or developmental abnormalities. Recent studies carried out in Canada have shown that genetic disorders account for the major portion of pediatric hospital stays through the first five years of life.

What is not generally realized by the public is that the current incidence of genetic disease in the live born population is estimated to be about 10% and is probably likely to rise as modern diagnostic tools continue to elaborate the previously unsuspected genetic involvement in a variety of diseases. We have used the National Academy of Sciences report on the effects of low level radiation on populations as one of the major reference sources. In addition The Nuclear Regulatory Commission report Nureg/cr-4214 Health Effects Model for Nuclear Power Plant Accident Consequence Analysis and the Department of Energy report on Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident, 1987 served as major sources of information for the estimates presented.

Table 1—Numbers of Naturally Occuring and Radiation-Induced Genetic Disorders In a Population of One Million, According to the BEIR III Report Analysis to the Present Analysis, Assumes a 0.01 GY dose.

		BEIR III Report[b]		This Study (Central Estimates)[c]	
Type of Disorder	Normal[a] Incidence	First Generation	All Generations	First Generation	All Generations
Single-gene	4800	3–30	20–100		
Autosomal Dominant				15	70
X-Linked				4	20
Irregularly Inherited	43200	—	10–400		70
Chromosome Aberrations	2880	<5	5		
Aneuploidy				4	5
Unbalanced Translocations				6	8
TOTALS	50900	—	—	30	175

[a] For a total population of 10^6 persons (16,000 live births per year) for 30 years (480,000 live births).
[b] Cases expected in each generation of children from a population of 10^6 persons each receiving a dose of 0.01 Gy. Assume 30 year intergenerational interval and birthrate of 16,000 per year per 10^6 persons, or 480,000 children per generation.

Broadly speaking we may classify genetic diseases into three bins; (Table 1) the first or monogenic disease, contains those resulting from the action of a defective gene as in the case of the dominant gene disorders, Huntington's chorea is an example, and the sex-linked disorders for example muscular dystrophy; or when both members of a pair of genes are defective in the case of recessive disorders such as sickle cell anemia. About 1% of all liveborn will suffer from these forms of diseases.

The second broad class of diseases involve changes in chromosome structure or number. In the former case the organization of one or more chromosomes of the set (23 chromosomes from each parent) may be altered such that large segments involving blocks of genes may be deleted, inverted, or reshuffled, so to speak, either within the same chromosome or between two different chromosomes (this is known as a translocation). All of these chromosomes derangements can lead to a wide range of genetic abnormalities in liveborn and may constitute a substantial portion of the abortus class. Numerical changes are more commonly known to the public. Down syndrome is the most famous example of this group, in which the child suffers both physical and mental deficiencies resulting from 47 instead of the normal 46 chromosomes. In this case chromosome number 21 is present three times. This particular disease is among the most common genetic disorders in the human population, about one in seven hundred live births are Down's children; and as is well known the frequency of the disease increases with the age of the mother, quite markedly after age 30. Some of the disorders associated with trisomies of other chromosomes are even more devastating to the health of the newborn and usually cause death within the first years of life. Many of the trisomies and the flip side, monosomies, where a complete chromosome is missing, however, are so severe that they contribute perhaps the largest component to the abortus class. Collectively chromosome aberrations of the types just mentioned constitute about 0.6% of all live births, based on the cytological analyses of consecutive births in major research centers in the world, with well over 50,000 newborns screened.

Finally the last category of genetic disorder is collectively known as the multifactorial class. As the name indicates these diseases result from a complex interaction of several to many different genes and environmental factors. This unfortunately to date is the poorest understood class with respect to mechanism. And since this category is also the largest class making up about 90% of all the genetic ill health we presently document and some will suggest even more, we are hard pressed to make sound estimates of risk with respect to mutagenic agents. Perhaps the only bright spot in this vale of ignorance is the likelihood that the induction of these events proceeds at a much lower rate and apparently will have less impact on offspring of the first several generations after parental exposure than do single gene mutations and chromosome aberrations, possibly providing the scientific breathing room necessary to unravel the host of factors involved in each of these many disorders.

It may not have been apparent from that which I have already said that not all genetic diseases become apparent at birth, in fact probably the majority begin to phase in after childhood and some only well after adulthood is reached. Though there is still more thorough work to be carried out I think it is fair to suggest that the impact of genetic disease is such that on average about 30 years of life expectancy is lost per genetic disease, this estimate also includes a component of disease severity and years so impaired. I recognize that years of life lost is a crude index of personal pain, family anguish and societal cost; however, it does permit a means of collectively weighing the diverse health effects of cancer, teratology and genetics. In terms of health effects it provides a better measure of the impact of the diseases than does simply a listing of cancer cases versus genetic disease cases or developmental abnormalities resulting from in utero injury.

When dealing with newly induced cases of genetic disease it is customary to establish a baseline population, for example one million people and a unit dose such as one rem (.01 Sievert) and describe the expected number of cases of each class. For example a population of one million persons composed of all age groups would be expected to produce about 480,000 offspring in a thirty year period (one generation). About ten per cent of these children would be expected to be genetically abnormal from natural causes and if this population had received an additional one rem exposure from a radiation source such as a Chernobyl accident, then among these 480,000 children in addition to the approximately 48,000 naturally affected children there would be approximately 20 children affected with dominant or sex-linked disorders such as hypercholesteremia, Huntington's chorea, hemophilia, muscular dystrophy the latter two are sex-linked and therefore would appear only in the male offspring of exposed mothers. Some additional 10–12 children might be affected with chromosomal defects about one-half from numerical changes and the remaining from structural unbalanced rearrangements. Thus about 30 cases would be expected in the first generation after an additional one rem exposure to one million people. Since the majority of the newly induced cases will persist for no more than five to six generations, calculations we have developed for the Nureg report suggest that somewhat less than four times the cases i.e. 120 additional cases will be distributed over those five generations.

The frequencies of these diseases are derived from experimental studies primarily on mice and then extrapolated

Table 2.—Collective Dose Projections External Exposure

Distance	Population Size	Ave. Individ. Dose Equiv. (Gy)
Pripyat	45×10^3	.033
3–15 km	24.2×10^3	.45
15–30 km	65.7×10^3	.053
Total	135×10^3	$\times .12 \cong 1.62 \times 10^4$ P-Gy
W. USSR	75×10^6	7×10^{-3}
E. USSR	400×10^6	4.5×10^{-4}
Asia	$2{,}350 \times 10^6$	3×10^{-5}
Europe	450×10^6	2×10^{-3}
USA	226×10^6	5.8×10^{-6}
Total N. Hemisphere	3.5×10^9	4.9×10^{-4}

using theoretical models based on experiments in a wide variety of animal, plant material and human cell cultures. In experimental test systems doses covering a wide range of exposures delivered at very low to very high dose rates have allowed us to demonstrate the shape of the dose response curve is a general phenomenon applicable to all animal and plant forms studied to date.

Clearly there must be uncertainty in extrapolating to humans in these situations, we however believe that the central estimates as presented are probably accurate to within a factor of three, that is to say the true values are likely to be no more than three times smaller or larger than those we present. Of course as newer information becomes available it should be possible to refine our estimates even further. It will be undoubtedly surprising for the lay public to learn that the Japanese A-bomb studies have to date provided no evidence for an increased frequency of genetic disorders in the offpsring of the exposed survivors who compose the ongoing study group. I do not mean to say that nothing was induced but that the size of the studied group some 17,000 children in the exposed parents sample and 35,000 in the unexposed group and their respective received doses were such that no more than 50–60 additional cases of disorder was to be expected and therefore they would remain undetectable relative to the natural occurring level.

With respect to Chernobyl we have de-

Table 3.—Estimated Increase in Genetic Disorders Approximately 1st Generation

Region	P-Gy $\times 10^3$ 1986 Dose Commitment	No. Induced
Chernobyl	16	60
W. USSR	220	660
E. USSR	76	230
Asia	22	70
Europe	330	nt 1,000
USA	0.37	~1
Total N. Hemisphere	640	1,900 vs. 180×10^6 Spont.
Future Dose Commitment	<1000	<3200

Natural incidence assumed to be 10.7% of live births. Expect $\cong 1.7 \times 10^9$ live births in next 30 years.

veloped global estimates on the impact of the radiation release from the Russian reactor (Table 2) for the three major health end points of concern namely cancer genetics and teratological effects. As can be seen in the (Table 3) the estimated number of induced genetic events will be literally swamped by the naturally occurring ones such that it will be highly unlikely that they can ever be detected. The exception to this statement may be a portion of the Chernobyl population which received an appreciable exposure of approximately 45 rem before evacuation. This group of 22,400 people of the 135,000 in the region is the most likely cohort to be followed for epidemiological studies. With respect to other populations the distribution of cases will be largest in European Russia and Western Europe but as shown in the table the number of cases expected relative to the population size is so small that it should go undetected. Let me express this statement in another way. Given that a child is born over the next generation with any form of newly arising genetic disease described in the preceding discussion we can ask the question: How likely was the radiation from Chernobyl to have been a contributory cause? The answer for all populations outside of the Soviet Union is much much less than one percent. Spontaneous mutation or other events will contribute over 99% the likely causation. Since for Western Europe the exposure generally amounts to an additional 100 millirem (.1 rem) it is equivalent to postponing reproduction by one year. For other parts of the western hemisphere the probability of causation from Chernobyl will be still smaller than for Europe.

Summary

We have presented the major genetic effects expected to be induced by high energy radiation exposure over the next five generations as well as the current natural incidence of those diseases. The estimated global distribution of doses were given with the expected number of genetic disorders resulting from the Chernobyl nuclear accident. These estimates suggest that it is extremely unlikely that the minute increases anticipated will be recognized by any epidemiological studies because they will be overwhelmed by the natural incidence cases. The only exception to this may be in the high dose subset of the Chernobyl population. We have also presented calculations regarding the probability of causation that radiation was responsible for any genetically diseased individual born subsequent to parental exposure.

References Cited

NAS/NRC. 1980. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." Report of the Committee on the Biological Effects of Ionizing Radiations (BEIR) Nat. Acad. Sci, Nat. Acad. Press, Washington, DC.

NRC. 1985. Health Effects Model for Nuclear Power Plant Accident Consequences Analysis. NUREG/CR 4214. U.S. NRC Contractor Report (SAND.85-7185). U.S. Gov't Print. Office, Washington, DC.

1987. Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident. DOE/ER-0332. NTIS. US Dept. of Commerce, Virginia.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 122–124, June 1988

Round Table Discussion: Biomedical Issues

ELKIND: Mortimer Elkind, Colorado State University. I have a question for Dr. Beebe. I believe I understood correctly that the new dosimetry at Hiroshima/ Nagasaki showed a marked departure in incidence of leukemia as compared to the old dosimetry, in particular a peak ing at 300 rad, and for all other cancers a similar effect, but perhaps not as dramatic.

Do you have any comments about the change in the character of the curve, at least for leukemia with dose, which appears to be coming out; secondly, if in fact the quality factor for neutrons were 20 instead of 10, would that have any bearing on the character of the curve and in what way it would it be changed?

BEEBE: I think the full answer to that is, I don't know. I wished I did, but I really don't know.

PETERSON: Harold Peterson, U.S. Nuclear Regulatory Commission. I noticed one of the things Dr. Abrahamson showed as typical is that genetic effects are depicted as per unit live birth. That, of course, raises the possibility that there is a component there that is lost and obviously cannot be measured, which is the transformations that are fatal *in utero*. Has the reproductive capacity or the fertility of the Japanese shown any indication, perhaps of a drop, because I would suspect that was the only visible evidence, that the birth rate might drop a little.

ABRAHAMSON: In a sense, I am going to shift that over to Bob Miller in a moment, because Bob gave you some data that showed earlier on that there seemed to be a higher incidence in those who were exposed early in gestation for a drop in successful pregnancy. I know of no data from Hiroshima/Nagasaki that shows a signifcant increase in miscarriages or stillbirths, having been looked at for the multiple years.

My memory, if it is correct, says that in a Neal and Shull publication back in the early 1950s, there was, at first, an indication of an increase in stillbirths, and that disappeared with time.

Gil, you have much greater access to the Hiroshima data than I do.

BEEBE: You remember that in the early days, there was a difference in the sex ratio, and that disappeared. But there were six or seven or eight measures of genetic effects in the survivors of the atomic bombs. It began with simple observations of the frequency of malformations or stillbirths, neonatal deaths, body measurements, sex ratio, mortality after birth, and finally biochemical genetic studies. None of them show a demonstrable genetic effect among that population.

ABRAHAMSON: Another phase of the question I thought you were asking is, since I have only been concerned about genetic disorders among live born, you might ask me whether or not I would predict there were induced abortis-type situations occurring, and clearly yes, there can be quantitation for that as well. But since you do not know when they are dying within the first two, three, or four weeks of gestation, most of them would be in that first period, and they would go unrecognized to a great extent.

MOSSMAN: Ken Mossman, Georgetown University. Dr. Beebe alluded to several studies, purportedly showing that at low doses of radiation, one can demonstrate cancer in the Israeli children and in Alice Stewart's studies. I am addressing this to Dr. Puskin and the panel. In view of the concern about Radon exposure, are there similar studies which exist in which environmental levels of radon are also associated primarily with lung cancer?

BEEBE: As far as I know, our data line, the effect of radon in its quantitative adequacy is coming from the studies of underground miners, primarily uranium miners. Others may know of information I am not aware of, but I don't know of any environmental radon studies. Arthur, do you?

UPTON: Dr. Puskin, do you want to make a comment?

PUSKIN: There are a few studies that have been done, but they are certainly not definitive. In Sweden, there is an Island which has fairly high radon levels in one part of the island and not the other. A comparison of the groups living in the high-radon area and low-radon areas did show an excess of lung cancer, which to the first approximation is what you would expect based on the uranium miner experience.

There has been a lot of concern about the high levels in the Reading prong area in Pennsylvania, and people have looked for an excess of lung cancers in that area. In fact, you do not see a high rate of lung cancers in those counties as compared to the country nationwide.

Very recently, Dr. Archer has looked at this again, comparing the Reading prong counties with neighboring counties which had similar demographics and similar age structure. He found that there was an excess in the radon prong area. There are all kinds of potential confounders, but again to a first approximation, the excess is about what you would expect. This is still not shown definitively.

The biggest study underway is the one being conducted under the auspices of the Department of Energy, with Dr. Stebbings from Oregon as the principal investigator. He is going to look at lung cancers in eastern Pennsylvania, outside of Philadelphia. They are going to do a case controlled study, comparing radon levels in houses of people who have lung cancer against the control group. They are going to go back to try to measure radon levels in people's houses, going back in time, to try to get a lifetime exposure estimate.

EPA also has a study underway in the State of Maine to look at it. It's another case controlled study. I think there is also one in New Jersey. There are some things going on, and so far the evidence is just not there yet.

UPTON: Did you have a comment, Dr. Wald?

WALD: Yes. I was going to comment that the estimate I heard is that it will be about five years before we have any definitive results from the studies that are ongoing. So we really are not in a position at this point to make any conclusions.

MOSSMAN: I have another question for Dr. Abrahamson. I am not a geneticist, by any means, but I get a feeling from the genetics literature I have read that genetic effects, unlike carcinogenesis, are very wide-ranging. You can go from very subtle changes, which are by no means detrimental to the quality of life, all the way up to lethal changes. Is there research now underway to detect biochemical markers, so it would be easier for a geneticist to be able to identify genetic changes which would ultimately result in some alteration that phenotypically would be unrecognized but would allow you to make some type of risk estimate?

ABRAHAMSON: As you know, most of the early mouse radiation studies, or even chemical studies for mutagenesis, dealt with phenotypic markers—coat color, tail, hair shape, and things like that.

Over the last 15 years, extensive work has gone into developing both enzyme markers and other biochemical endpoints, and these are being used widely at major laboratories that are doing mammalian studies. They are also being done in cell culture work as well. The National Institutes of Environmental Health Sciences have a big project on contract with other people at Research Triangle Park, developing these biochemical markers. Oak Ridge is dealing with them. The large mouse research laboratory in Germany is also extending the number of locii that can be studied with biochemical markers. I think we are up to about 75 now.

WALD: Can I add, your question relates to the previous one that you asked, in that biochemical markers are also being used in epidemiologic studies for the early detection of precancerous changes. In fact, Dr. Luke Culler at the University of Pittsburgh is looking at bronchial cells' DNA content in high and low radon homes.

PUSHKIN: It may be noteworthy in this connetion to comment that at the radiation effects research foundation in Japan, efforts have been made to exploit biochemical markers to amplify what has not been found using phenotypic changes. As has been brought out, there really has been no definitive evidence for the transmission of inheritable damage to the children of A-bomb survivors.

The biochemical genetic studies utilized blood proteins as measures of mutational change, and as many as a million gene products have been examined without detection of a significant excess of phenotype variance among the children of irradiated survivors. The effort is now going into the use of recombinant DNA methodology to look for changes at the level of the genome itself, but I think this is an area that is developing.

There has been evidence for mutational change in the bone marrow cells of survivors, using another set of protein endpoints, glycoforin proteins, and the excess incidence of glycoforin mutants as a function of those seems to correlate very well with the excess of cytogenetic abnormalities.

WALD: Could I just add one thing? I think that many of the studies that just use simple, "Is the enzyme altered in its effectiveness by electrophoretic type studies?" with radiation may be doomed to failure. You need to have plus-minus markers. Is the enzyme product there, or is it not there. My bias is that most of the x-ray induced genetic events we call gene mutational and probably deletional, and therefore, if you delete a gene or a major part of it, you are not going to see a subtle change in electrophoretic markers. You are going to see the loss of the protein. That may be part of the reason we haven't been able to detect it in the past.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 125–130, June 1988

How Safe Are Nuclear Plants? How Safe Should They Be?

Herbert Kouts

Department of Nuclear Energy
Brookhaven National Laboratory
Upton, Long Island, New York 11973

We are becoming so accustomed to thinking about safety of nuclear plants in terms of risk as defined by the WASH-1400 study that some of the implications for the non-specialist escape out attention.

Even putting the question in these terms upsets many people. Many do not like to be reminded of their mortality, and they become frightened when it is suggested that some one thing can be singled out as possibly having a chance of ending their lives. This is especially true if that something is unfamiliar to them.

It gets worse when we start to discuss nuclear plant safety in probabilistic terms. Probabilities are not widely appreciated. Perceptions of probability are clouded by widespread belief in good luck and bad luck as an attribute of people or circumstances. It is usually not helpful to people who believe that big shifts in luck are commonplace to be told that some event has only a very low probability.

Yet we know that a rational program to understand safety, to identify unsafe events, and to use this kind of information or analysis to improve safety, requires us to use the methods of quantitative risk assessment. How can we make this process more understandable to a broader group of nontechnical people? And how can we develop a wider acceptance of the results of the process?

These are questions that have been struggled with for some time in the world of nuclear plant safety. The Nuclear Regulatory Commission examined them for several years as it moved toward developing a position on safety goals for nuclear plants, a requirement that had been assigned it by Congress. Opinion was sought from a broad spectrum of individuals, within the field of nuclear power and outside it, on the topic that was popularly called, "How safe is safe enough?" Views were solicited on the answer to the question and also on the way the answer should be framed when it was adopted.

A first workshop led to a coalescence of opinion that quantitative safety goals should be developed. Simplistically, these could be in the form that a nuclear plant should be so safe that the risk from accidents should not exceed x early fatalities and y late fatalities each year. Following these conclusions, it was pointed out that this would be interpreted by the public at large and even by political circles such as Congress that the Nuclear Regulatory Commission thought it would be all right if a nuclear plant killed x people outright and caused y fatal cancers each year. That spelled the end of strictly quantitative safety goals for nuclear power plants.

A second workshop was held. The conclusions changed. There was now a reasonably broad consensus that safety goals had to be qualitative; that they had to ensure safety of nuclear plants in the context of nothing being absolutely safe in this world, but nuclear plants being better than the rest.

After some deliberation, the Nuclear Regulatory Commission adopted this course last year. It adopted two qualitative goals. The first was that nuclear plants should not entail any significant additional risk to life and health. This goal limits the risk from nuclear plants relative to the risks from ordinary living.

The second safety goals states that the risk from a nuclear plant should be comparable to or less than the risks from viable competing technologies for generating electricity, and should not be a significant addition to other societal risk.

The goals when stated in these forms should be understandable to nontechnical people, though they do include a potential problem in that they use the word "risk" in its WASH-1400 technical meaning while seeming to substitute it for a word like "danger" for purposes of public interpretation.

Though the intention to state understandable goals was probably accomplished by this adoption, the goals were not very useful in this form for the regulatory staff. They were not a clear yardstick that could be used in determining when they were met or were not met. So the Commission also settled on what were called quantitative objectives, that restored some of the features of the quantitative goals that had been discussed in the workshops.

One of these referred to the early effects of potential accidents on people living near nuclear plants. It said that the risk to an individual living in the vicinity of a nuclear plant of being killed as the result of a reactor accident should not exceed one-tenth of one percent of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are normally exposed.

The second said that the risk to the population near a nuclear plant of dying from cancer caused by a nuclear accident should not exceed one-tenth of one percent of the sum of cancer fatality risks resulting from all other causes.

These quantitative objectives were augmented by what was called a "general performance guideline" to the effect that the chance of a reactor accident leading to a large release should be less than one in one million per year of reactor operation.

In adopting these goals, objectives, and the guideline, the NRC quietly overturned a position it had taken several years earlier when it attacked the concept of risk assessment generally and WASH-1400 in particular, and said that these methods should not be used in regulatory applications. This new policy on safety goals could not be implemented other than through use of risk assessment methods. In fact, the safety goals policy simply gave formal recognition to the reality that risk assessment by the best available means has turned out to be a powerful and even a necessary tool for ensuring and improving the safety of nuclear plants. It has put important new meaing into such time-honored phrases in nuclear safety as, "without undue risk to the health and safety of the public."

Let's now examine the implications of these positions taken by the Nuclear Regulatory Commission. The Center for Disease Control of the U.S. Public Health Service issues statistics on the causes of death in the United States. In the December 19, 1986 issue of the *Morbidity and Mortality Weekly Report* can be found statistics for the year 1984. Injuries or accidents accounted for 4.6% of all deaths.

According to the first quantitative safety objective, nuclear plant safety would therefore require that nuclear plants meet the criterion that nuclear plant accidents will not lead to a probability of accidental death greater than 4.6×10^{-5} for individuals at risk.

The same publication states the relative mortality rate from malignant neoplasms as 22.1%. The second quantitative safety objective therefore implies that for the population living near nuclear plants, these plants should not contribute more than a probability of 2.2×10^{-4} of incidence of fatal cancer over lifetime.

These are cold-sounding statistics, of the kind that have a tendency to disturb most people. They give an impression that nuclear power safety advocates first determine that there is a hazard attached to a nuclear plant, and then they say—go right ahead with it after all. There are plenty of unprincipled politicians ready to take advantage of this kind of public gut reaction, and the country is plentifully supplied with other individuals who are eager to take advantage of public fears to further their private objectives.

But I do not see how we could avoid use of such statistical methods if we are to improve safety of nuclear power plants, any more than we could avoid use of similar statistical methods to determine where to find the most urgent areas for research against mortality from disease, or to locate the region of the country most in need of improved measures for commercial air safety.

Other safety goals and safety criteria than the ones adopted by the NRC have sometimes been proposed, and some are incorporated in more or less obscure forms in some standards and regulations. One of the oldest is that nuclear power plants should not directly contribute to a time-averaged increase in radiation level by more than some factor times the natural rate. This has been the basis for some ICRP and NCRP standards and recommendations regarding radiation levels from normal operation of nuclear facilities. Another concept has been proposed to the effect that nuclear plant activities should contribute a time-averaged radiation level not exceeding the variability in radiation dose absorbed in connection with variability of choice by individuals. This is apparently the basis for the EPA regulation 40CFR190.

The former of the two criteria would lead to an annual average radiation level to an individual from all causes attached to operation of nuclear plants of no more than about 140 mR/year. A direct comparison between this and the NRC's safety objectives is not possible. For one thing, interpretation and use of the NRC objectives requires use of a dose response curve with inherent difficulties as to widespread acceptance and as to how to add long-term and one-time doses. For another, the annual dose limit of 140 mR/year would have to be added up over a lifetime to determine statistics. Naive use of the BEIR-3 value of LET dose per cancer at low dose, low dose rate implies that the 140 mR/yr value exactly coincides with the NRC delayed fatality safety goal for an individual exposed at this level for ten years of his life. The latter criterion based on the effect of variability in choice would be comparable to the NRC delayed fatality objective for an individual who spent his full lifetime at the 140 mR/yr annual radiation level.

I summarize all of this by noting that all of the objectives and criteria that have been discussed are in aproximate agreement. They are in much better agreement numerically than the uncertainties in the numbers themselves. Risk assessment is still an inaccurate science.

There are other interesting aspects to the question of how safe nuclear plants should be. Analysis of the source term of fission product release from postulated severe accidents to nuclear power plants of the type used in the United States now makes it clear that the off-site consequences of a severe accident would depend very strongly on the length of time the containment remained intact, holding in any fission products released from the reactor's primary system into the containment. If an accident were to lead to melting of the core of a reactor, if the fission products escaped from the primary system into the containment, and if the containment remained intact for a few hours longer, say more than three or four hours, the effects of plateout and of agglomeration and settling of aerosol particles would dramatically lower the amount of fission products available for release to the environment. It is found that almost all the contribution to risk is the result of severe accidents that could lead to early containment failure. Mechanisms for this have been identified, and recent NRC-sponsored research has addressed the probability of early containment failure and the effect on consequences of severe accidents.

It is found that the NRC safety goals and the numerical safety objectives are met if the probability of a severe accident with early containment failure is less than approximately 10^{-5} for an average nuclear plant. This finding has considerable uncertainty associated with it, much being the result of variation in meteorology, population distribution, design of the plant, and general difficulty in accurate analysis of risk.

This raises an important problem which will be solved only very slowly in the future. I referred a few moments ago to risk assessment as an inexact science. This leads to lack of ability to be absolutely sure if the goals and objectives are met. We are using a yardstick whose length is somewhere between one foot and ten feet.

This means that for the time being, at any rate, the ability to meet the Nuclear Regulatory Commission's safety goals can be only one index to the safety of nuclear power plants. It is widely accepted that these methods cannot be used to settle absolutely the question of adequate safety of a particular nuclear power plant. Probabilistic analysis has to be added to other methods to reach an overall conclusion based on many perspectives. Other kinds of questions that need addressing are: How well is the plant managed? What is its operating record? What is the character of the operating staff—how experienced are they? How well-trained? How well do they know their plant? How well do design and operation of the plant avoid potential problem areas that have come to be recognized over the years?

From answers to all of these questions can be developed a profile that can be used to identify weaknesses that might undermine the safety of a specific plant.

The safety goal structure of the Nuclear Regulatory Commission is more usable to assess the safety of the nuclear power industry, where the inputs from many risk assessment analyses should lead to some improvement of the statistical results and where an accumulation of historical information begins to be useful.

This leads us into the second of the two questions I want to explore. This is, how safe are nuclear plants? I want to consider this point from the standpoint of how well nuclear plants have measured up historically to the NRC's safety goals. This aspect of the question is especially important in view of the emphasis on Chernobyl in the title of this symposium.

But before we consider the implications and impacts of Chernobyl, let's concentrate on the United States, where nuclear plants very different from Chernobyl's RBMK design are used.

The United Staes has specialized in nuclear power plants with water-moderated and water-cooled reactors. All but two U.S. nuclear plants are of this general class; one of the exceptions is a small, demonstration size plant in Colorado using a gas-cooled reactor, and the other is a government-owned plant at Richland, Washington which produces plutonium for nuclear weapons and also supplies steam to turbine-generators operated by the Washington Public Power System.

As is well-known, the one substantial nuclear plant accident in the United States occurred in 1979 at the Three Mile

Island Unit 2 nuclear plant in Pennsylvania. This accident destroyed the reactor and led to permanent shutdown of Unit Number 2. Though hydrogen was generated as a result of extensive oxidation of the zirconium-based nuclear fuel cladding during the accident, and the hydrogen was released into the containment building where it burned, the integrity of the containment structure was preserved, and it was apparently not threatened. The only radioactive material released from the plant because of the accident consisted of the noble gas inventory and about 18 Ci of active iodine. Radiation levels outside the plant were far below life-threatening values and the total population dose was about 5000 man-REM. According to the BEIR-3 model this is assumed to be productive of a probable 0.8 cancers over the period of 30-50 years following the accident.

About 1000 reactor years of U.S. commercial water reactor experience have now been accumulated. A similar number of reactor years has been accumulated in other countries with nuclear plants of the same type. This is not enough for an adequate statistical basis for a test of meeting of the safety goals and objectives, but it is close. So far there have been no early fatalities in the U.S. or elsewhere as a result of accidents to water reactors, and an upper limit to the rate at which light water nuclear plants may have induced cancer is about 4×10^{-4} per operating year (we use the full 2000 reactor years of experience in deriving this number). There are now almost 400 light water nuclear plants in the world, so another 1000 reactor years of experience will be accumulated every 2-1/2 to 3 years. Thus accurate historical tests of the safety goals and objectives are almost at hand.

Let me recall that the second NRC safety goal compares electrical generation by nuclear plants against viable competing technologies. The principal competition is coal. To make a comparison between the two, I draw on some analyses made four years ago by Hamilton and coworkers. The comparison is made for the full fuel cycle, including not only electrical generation but also mining and transportation. It is seen that in all categories the risk from the nuclear option is lower than that for coal. The comparison is, however, not as reliable as one would like it to be. The range of the estimate of mortality from air pollution reflects the great uncertainty in use of a linear hypothesis for the effects of pollution at low doses. If anything, the use of this sort of hypothesis for organic pollutants and other components of smoke from a coal plant is more questionable than it is for effects of nuclear radiation.

To summarize, the safety goals and objectives estalished by the Nuclear Regulatory Commission seem to be met for nuclear plants in this country, for the industry as a whole. The statistical evidence supporting this conclusion is not yet adequate in some respects, but the statistical situation is improving rapidly.

These conclusions also seem to apply to other countries using water cooled and moderated nuclear plants of the western type.

What is the effect of Chernobyl on all of this? In the averaging process that tells the historical story of safety of nuclear plants, there is some temptation to add to the effects of TMI those from Chernobyl. I have thought about this possibility, and believe that for any international objectives that consider the effect of nuclear power world-wide, and that contemplate improvement of nuclear safety world-wide, there is some merit to this. But in doing so one should realize that any averages formed this way are taken over two very disparate distributions. The RBMK's in the Soviet Union are so different in their design and their safety features, and their mode of operation has been so singular, that averaging over the two sets loses a great deal of meaning. Certainly to form such an average would not improve our understanding of how safe U.S. types of nuclear plants are, when operated by U.S. practices.

The Soviet government gives all signs of believing that the past characteristics of RBMK's and their mode of operation at Chernobyl are not acceptable according to safety objectives of the Soviet Union. A number of physical changes are being made to RBMK reactors. New operational practices have been substituted for old discredited ones. Management personnel from Chernobyl have been subjected to criminal trials, found guilty, and are undergoing punishment. I believe that it would be wrong under the circumstances to use the historical record of RBMK's including the Chernobyl accident in evaluating the safety of these plants under present circumstances, and it would be even more wrong to apply such results to U.S. nuclear plants.

At the end of an analysis such as that preceding, I am left still unsatisfied as to the way the conclusions would be received by a broad public. The case for nuclear plant safety will probably have to become so clear that the analyst is obviously innocent of any charge of using numbers to obscure reality. Nuclear plants will have to show in real life a level of safety that reassures the public through pervasive excellence. I believe that it is not the function of the Nuclear Regulatory Commission to achieve this. They have developed a set of safety goals that I believe are rational and laudable, and which are suited to the responsibility of a regulatory body of this type. There should be no tightening of the screws by the NRC simply to reassure the public.

Achieving a level of excellence beyond that required by the regulators should be the responsibility of the nuclear industry. They are the only group able to do this, and they should do so as an act of social responsibility. If they are to have any sponsors and helpers in the Federal establishment in their enterprise, it should probably be the Department of Energy, which still has such a responsibility according to the Atomic Energy Act.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 131–138, June 1988

Chernobyl—Lessons Learned

William Kerr

Professor of Nuclear Engineering
The University of Michigan
Ann Arbor, MI 48109

ABSTRACT

Although the significant differences in design and in operating philosophy of the No. 4 reactor at the Chernobyl Nuclear Plant preclude the possibility of an identical accident at an operating US reactor there are lessons, applicable to US reactors, to be learned. The Soviet reactor had identifiable design weaknesses. Some US reactors have design features which, if improved, could eliminate or make less serious hypothesized accidents. The Soviets appeared to have become complacent because of a good operating record. There is evidence that some US reactor owners should be more aware of the potential for and methods for avoiding low probability severe accidents. It appears that Soviet operators found it easy to defeat a number of safety systems in the course of performing an unusual operation. We must continue to emphasize the importance of careful examination of possible consequences of abnormal operating modees. The Soviets had emergency plans which could not be followed in the actual accident. There is evidence that some of our own emergency planning needs reexamination in light of experience gained in emergency drills. Finally, since it is to be expected that severe accidents will occur infrequently, it is imperative that we continue to study this accident carefully in an effort to make serious accidents in operating US nuclear power plants less likely.

Prologue

Apprehension about the use of nuclear energy to generate electricity has a possible parallel in the fear associated with the application of steam power to transportation in the eighteenth century. Explosion of boilers on boats used in river transportation became frequent enough that several cities, including Cincinnatti, where one explosion took 150 lives, set up special committees to investigate the hazards of steam boilers, and to ask for legislation restricting their use. In 1832 a Select Committee of the twenty second Congress of the United States was convened to investigate the dangers. The opening passages of the committee's report bear a striking resemblance to some of the public concerns expressed today about nuclear power.

> "The distressing calamities which have resulted from the explosion and collapsion of the boilers of steam boats, the increasing dangers to which the lives and property of so many of our fellow citizens are daily and hourly exposed from this cause, unite in their demands upon that Government, possessing the competent power and authority, to

throw around the lives and fortunes of those thus exposed, all the safeguards which a wise and prudent legislation can give."

The Select Committee gathered a wide variety of testimony by distributing questionnaires and by advertising for information in newspapers. After considering the collected testimony, the committee reported "A Bill to provide for the better security of the lives of Passengers on board of vessels propelled in whole or in part by steam." The bill required periodic inspection of steamship boilers to ascertain that the boilers could withstand three times the pressure to be expected in normal operation. Passed in 1838, it did not prevent the further occurrence of boiler explosions. However it did set a precedent for government regulation of shipping in the interests of public safety.[1]

Today, the application of nuclear power is more closely regulated than any other energy source, and the excellent safety record is, to some extent, a reflection of this regulation. But, in spite of both public and private efforts to ensure safety, we cannot guarantee that serious accidents will not occur. In the US we have been able to accumulate a significant amount of operating experience with no accidents that have caused physical damage to the public. On the other hand, studies indicate that improvements in both design and in operation which should be achievable with an expenditure of modest resources, can decrease further the likelihood that serious accidents will occur.

The accident at the Chernobyl nuclear power plant has heightened public concern over reactors operating in this country. However after extensive studies by the nuclear industry, by the Nuclear Regulatory Commission, and by the Department of Energy, it has generally been concluded that, because of the differences in the design and of the operating characteristics of the RBMK 1000, and of the reactor power plants in operation in the United States, an accident of the kind that occurred at the Chernobyl plant cannot happen here. Nevertheless there are lessons to be learned from this accident, and since it is unlikely that many serious accidents will occur, it is important that we study this one carefully in order to make subsequent ones even less likely.

Introduction

Almost 18 months ago, the Soviet Union experienced, in one unit of a large nuclear power station, north of Kiev, the most serious power reactor accident that has yet occurred. Before the accident, details of the design of the RBMK 1000 reactor, and information on its operating experience, were not readily available in the West. Since the accident, the Soviets have been very open in making information available in both areas. Because of the wide dissemination of information on the causes and of the course of the accident, no effort will be made to duplicate that information in this paper.[2,3,4] However there are certain key elements of the accident from which useful information can be adduced.

Brief Comments on and Key Points in the Accident Sequence

In retrospect a number of factors appear to have contributed to the occurrence of and to the serious damage produced by the accident. Some of those considered most important are listed and discussed below:

a) *Design Weaknesses*—It is generally agreed that a major contributor to the onset of the accident, and to the seriousness of its consequences, was the existence of a positive coolant void coefficient of reactivity. It appears that the designers of the RBMK-1000 were fully aware of the positive void coefficient, and of its potential contribution to reactor instabilities. However because of economics (a lower fuel enrichment results in a larger positive void coefficient; greater enrichment increases fuel cost), because the technology for producing large pressure vessels was not available in the Soviet Union when the design was made some 25 years ago (the use of the pressure tube design requires a large amount of graphite in the core, and produces an over moderated system), and because they already had experience with this design (although this was not made explicit, this experience was probably gained with reactors whose principal purpose was plutonium production) they decided to use it for all of their early power producing reactors. The designers concluded that careful attention to operating procedures could ensure that the reactors operated safely.

Further, the design of the reactor control system reflects a different balancing of online availability and safety than is characteristic of US designs. Because of the importance of maintaining a reliable source of electric power, great emphasis is placed on high availability. In US reactors, rather small deviations from normal operating conditions produce rapid and complete shutdown (scram) of the reactor. The same set of conditions in this reactor would normally lead to a gradual control rod insertion, lowering power, in the expectation that whatever caused the transient could be corrected without taking the reactor off line. Automatic scrams for these reactors are extremely rare, and the reactivity control system is not designed for automatic rapid insertion of negative reactivity. Thus when operating conditions arose that produced a large, rapid insertion of positive reactivity, there was no mechanism for automatic insertion of negative reactivity to prevent the huge power surge that resulted.

b) *"If It Ain't Broke, Don't Fix It" Syndrome*—Significant successful operation of these reactors over an extended period had given those responsible for their operation an undeserved sense of security. The Soviet spokesman in Vienna commented that this power station had an unusually good operating record. Because of this the operating organization may have grown complacent. The Soviet team stated that after the TMI 2 accident they conducted a thorough review of the designs and operating procedures of their power reactors. For whatever reason, they missed some important accident precursors. One can hope that this accident has convinced them that a continuing careful search for other possible precursors of severe accidents is necessary if we are to avoid additional accidents.

There is evidence that before TMI 2 some US organizations had concluded that since no serious accidents had happened none could happen. Indeed there is evidence that a few organizations still retain this misapprehension. It is to be hoped that a third serious accident will not be required to bring them face to face with reality.

c) *Planning for the Unusual*—It is significant that this accident occurred in the course of an experiment, performed on a midnight shift, on a weekend, and after some twelve hours of delay (during which time a shift change occurred) in the planned schedule, caused by a load dispatcher's request for continuing power production during the daytime hours. To complicate things further, this experiment had been tried once before, with unsatisfactory results, and there was pressure to complete it during this planned outage. If this try was unsuccessful, the next opportunity was not to occur for more than a year.

One cannot identify any one of these factors as the major contributor to the accident. Nevertheless it is clear that each contributed to an unusual situation for the operating staff, and thus each deserved special care both in the planning and in the performance of a set of unusual operations. Available evidence indicates that a number of these contributors was not given adequate consideration in the planning and in the performance of the experiment.

d) *Adequate Safety Analysis of Unusual Operations*—US regulations require a detailed safety analysis, reviewed and approved by the NRC, before an experiment of the kind performed at Chernobyl, is undertaken. The Soviets reported that the station manager was responsible for the performance of such an analysis, and that one was performed. No additional detail was given, but it was implied that the analysis was inadequate, perhaps perfunctory. Remembering that this was the second time for this experiment, and that the first time the experiment was run the reactor was shut down when the turbine was tripped, it is plausible to suppose that, having performed a safety analysis for the first experiment, little attention was given to the additional risk associated with keeping the reactor operating after turbine trip had occurred. Indeed it is possible that, since the planned standby power was about 1000 Mwth, little or no consideration was given to the possibility of having the power go as low as it did (recall that it dropped as low as 30 Mwth, and was eventually stabilized at about 200 Mwth before the turbine was tripped). In any event the evidence available suggests that an inadequate safety analysis was performed.

It is worth noting that current practice of the Nuclear Regulatory Commission calls for a stepped ascent to full power operation for new plants coming on line, the philosophy apparently being that there is less risk in operating at low power than at full power. However there does not appear to have been any careful study of this question by either the NRC staff or by licensees. It would appear, in the light of the Chernobyl experience, that this question deserves some attention. Although the RBMK reactors have significantly different operating characteristics than US water reactors, the US reactors are designed and are analyzed primarily for full power operation. If they are to be operated for extended periods at low power, it would appear prudent to make a careful search for any unanticipated risk that might be produced thereby.

e) *Those Responsible for Plant Operation Were Not Aware of the Plant's Off-Normal Characteristics*—Even though the plant designers were aware of the instabilities that could occur at low power, those responsible for plant operation almost certainly were not. They surely did not understand the likelihood of a large rapid insertion of positive reactivity given the operating conditions that existed at the beginning of the experiment. Nor could they have been aware of the possible consequences. They also must have been unaware that with the control rod arrangement that existed at that time, not only was it impossible to achieve a rapid insertion of negative reactivity, but to make matters worse, the initial control rod insertion actually introduced positive reactivity! US experience, however, suggests that lack of communication between those who design reactor systems and those responsible for their operation is not unique to the Soviet system.

f) *It Was Surprisingly Easy for the Plant Operators to Defeat a Variety of Safety Systems and Operating Restrictions*—It appears that the planned experiment called for some of the normally operable safety systems to be made inoperable, and we assume, from the Soviet report, that there had been an analysis of the risk associated with this configuration. However, for unexplained reasons, during the entire 11 hours from the time when the experiment had been scheduled, to the time at which it actually began, the ECCS was disabled. Further, although some of the unusual safety system configurations may have been analyzed, the final configuration of control rods that existed at the time of experiment initiation almost certainly had not been, since it was arrived at during the course of attempting to reach a stable power level for the reactor during reduction from the 50 percent power at which it had been operating since early the previous afternoon to the planned level for the experiment. The Soviet spokesman commented that the normal complement of inserted rods was 30. That with specific approval of the station manager, this could be reduced, but to no less than 15. At that point, he said, "not even the prime minister could authorize any further reduction". (The number still in-core when the experiment began was reported to be as low as six!) During the Vienna meeting the Soviet spokesmen gave the impression that they could not understand how a decision could have been reached to go to that configuration. The implication was that the decision was made by the operators. Since then there are indications that the local plant manager is being blamed more than one might have expected from the reports made in Vienna.[5] A question was raised during the Vienna meeting about the advisability of automatic "stops" that would have prevented withdrawal of control rods beyond a certain point. The answer of the Soviets was that when this reactor system was designed it was concluded that humans were more reliable than the hardware available at that time!

g) *Emergency Plans Existed, but the Plans Had to be Revised Once the Accident Had Occurred*—Although emergency plans for accidents at the Chernobyl plant existed, they had to be revised once the accident occurred. For example, initial measurements in Pripyat indicated that evacuation would likely not be required. A day later, when the release mechanism had changed, and atmospheric conditions were different, measurements convinced those responsible that evacuation was required. However at this point, because local deposition of fission products had occurred, the original evacuation plans had to be modified significantly. The evacuation, when it did occur, apparently proceeded with dispatch. Further, the treatment of those injured during the accident, and the monitoring of those in the zone near the reactor, appears to have been carried on with remarkable efficiency. Several of those who listened to the description of how evacuation and treatment were conducted concluded that the Soviets must have had previous experience with some similar accident. (Indeed Dr. Sakharov is reported as having stated at a meeting in Moscow in February of 1987, that several hundred of those involved in an accident in the Urals about 1970 experienced extreme radiation sickness.[5])

h) *The Soviets Claim to Have Learned from TMI 2*—The Soviet team reported that after TMI 2 they reviewed their own reactor power plants and their operational program extensively and applied the lessons learned. Obviously they overlooked some important contributors to the TMI 2 accident that were clearly identified by several reviewers of that accident. Of special relevance to the Chernobyl accident were the recommendations of several of the various TMI 2 review groups that operational personnel be better trained to deal with the characteristics of the reactor systems in off-normal situations, and that more attention be given to risk produced by operating personnel in contrast to the emphasis that had been placed, up to that time, on risk produced by equipment malfunctions.

What Can We Learn From The Chernobyl Accident?

The philosopher Santayana is reported to have said that those who do not learn from history are doomed to repeat its mistakes. What can we learn from Chernobyl?

a) *We Cannot Have a Chernobyl Type Accident*—Many US commentators have assured us that a Chernobyl type accident cannot happen in US reactors because of the significant differences between the RBMK-1000 and US light water reactors. This is true. Nevertheless it is possible that US power reactors may be subject to some as yet not thoroughly evaluated abnormal situations that could cause serious difficulties. We should continue to look for them.

For example although the issue of Anticipated Transients Without Scram has been studied at length, and is now considered a resolved safety issue by the NRC, we nevertheless still depend heavily on a remarkably high estimated scram system reliability in our calculations of risk attributable to this transient. For existing reactors this situation may be tolerable because of the difficulty of making significant changes in reactors systems already in operation, but for reactors not yet constructed there are changes in design for both PWRs and BWRs that could, with modest cost, make this transient a much smaller source of risk, even if the scram system failed completely. Should we continue to use the same designs for future reactors just because our experience to date has been acceptable? The consequences of an unmitigated ATWS in some power plant systems could be very severe.[6]

b) *We Should Not Accept the Limited Positive Experience That We Have Had With Operating Plants as Adequate Assurance That no Further Serious Accidents Can Occur.*—Such accidents are not expected to occur very frequently. Furthermore experience on the part of those who have examined plant systems in detail (using, in most cases, Probabilistic Risk Assessment) has indicated that such a plant-wide examination, done systematically, frequently reveals weaknesses that are obvious enough when discovered that they are corrected without any formal action on the part of regulators. All nuclear power plant operators should perform at least a Class 1 PRA using, for the most part, their own staff. A similar thorough evaluation of containment system performance in severe accident situations should be performed. The results will be useful not primarily as a numerical indication of expected risk, but because of a better understanding of integrated system performance to be expected in both normal and abnormal situations. This understanding is most useful if it becomes part of the background of the permanent operating staff.

c) *Someone, Very Near the Operations Level, Should Have a Thorough Knowledge of the Off-Normal Behavior That Has Been Observed in US Nuclear Power Plants.*—Experiences, good and bad, should be shared freely. If the present regulatory system makes it difficult to be frank about some of the incidents that have occurred, as some have claimed, those responsible for plant operation should work to correct this situation. It appears, in retrospect, that if information, that already existed, on observed and expected behavior of B&W reactors had been available to the operators at TMI

2 this accident could have been avoided. But those responsible for safety should go beyond what has occurred. For example what instrumentation, not then available, might have either prevented or ameliorated the consequences of the TMI 2 accident? What would have been the consequences if the TMI 2 accident had been accompanied by loss of off-site power? What emergency measures could have been devised under those circumstances?

d) *Further Attention Should be Given to the US Practice of Testing Reactor Power Plant Systems While the Plant Is In Operation.*—Testing at power is now done presumably because such testing enhances system and plant reliability. Little or no attention is given to the possibility that such tests may introduce severe transients or accidents. Although no serious accidents have been initiated in the US by testing during operation, numerous examples exist of automatic shutdowns that have been caused by mistakes made during a test. The results of a recent study reported by the MITRE Corporation indicate that in the period 1984–1985 about 20 percent of the reactor trips, for which a cause could be identified, were due to errors made during testing and maintenance carried out during plant operation.[7] The Japanese, it appears, do not test plant systems during operation, but rather test during down time. The Chernobyl accident emphasizes the need for additional examination of this issue.

e) *Emphasis on Severe Accidents*—Since TMI 2 there has been a significant emphasis on dealing with severe core damage accidents. Further, most investigations of severe accident scenarios have assumed that once the capability to cool the core has been lost, the core will, in a very short time, become completely molten; and that all of the molten core, plus some fraction of the core supporting structure will penetrate the vessel and reach the containment floor (or alternatively will be sprayed into the containment atmosphere). Although such studies provide useful information, we may have, as a result of this emphasis, failed to place enough emphasis on prevention of core melt, and on the possibility of arresting, in-vessel, the progression of a core melt once it has begun. Experience at TMI 2 demonstrates that partial core melt does not necessarily lead to complete core melt, or to vessel penetration. Chernobyl has produced considerable discussion of containment performance. While there is general agreement in the US that existing power reactors should have containments, it is not clear that all of the existing US containments would have contained the Chernobyl accident. In any event it is clear that prevention needs continuing emphasis. What avenues should be explored? Studies should be made to determine which normal operations, and which emergency operations, now performed manually, should be automatic. Those that are now automatic should also be examined. (Incidentally whatever decision is reached must be carefully explained to the plant operators, since operators are ingenious in disabling or ignoring systems in which they have no confidence.) Some Japanese companies have already made progress in automating both operations and testing.[8]

f) *There Should Be Further Examination of Emergency Planning*—Much of the emergency planning in the US is based on the assumption that there will be evacuation beginning perhaps as much as two hours before any major release of radioactive material occurs. The experience at Chernobyl indicates that releases may occur without this warning time. The Soviets report that their plans for evacuation could not be used in a situation in which significant releases had occurred before evacuation began.

It is interesting that there have been recent studies in the US, making use of information collected from a number of evacuation drills held in connection with NRC requirements, which indicate that US officials are likely to be reluctant to order evacuation until a release begins. The studies indicate that under these circumstances immediate evacuation may not be the most effective method of protection of the local population. Under some circumstances sheltering, followed by later evacuation of selected fractions of the population, may be more beneficial.[9] Furthermore, our present emergency planning is not geared to an emergency of the magnitude encountered at Chernobyl. The formalized parts of the plans, the detailed planning and the drills do not consider such an emergency because of its small likelihood. The ability of the Russians to marshal the resources of material and manpower needed to cope with the Chernobyl accident is impressive. Some preliminary thinking about how we might approach recovery from such a disaster would be worthwhile. The disaster for which such planning might prove useful is unlikely to be a nuclear plant. But it would be worthwhile for some agency, probably FEMA, to give further thought to coping with large-scale emergencies. The Soviets apparently made considerable use of military personnel. In any event their ability to coordinate such a large effort rapidly and efficiently deserves serious study on our part.

Conclusions

Although it is generally agreed that an accident similar to that which occurred at Chernobyl cannot happen to a US reactor, there are features of the accident from which US plant operators can learn. Since serious nuclear power plant accidents occur infrequently, it is incumbent upon us to learn as much as possible from those that do occur in order that the likelihood of future accidents be made low. Lessons learned can contribute not only to public safety, but also to a more reliable source of electric power, and to the financial stability of utilities which operate nuclear power plants.

References Cited

1. Editorial Comment from "Nuclear Powered Ships", *Phoenix,* University of Michigan Memorial Phoenix Project, 1962.
2. "The Accident at the Chernobyl' Nuclear Power Plant and Its Consequences", *USSR State Committee on the Utilization of Atomic Energy,* Vienna, Austria; August, 1986.
3. "Report on the Accident at the Chernobyl Nuclear Power Station", *NUREG-1250, US Nuclear Regulatory Commission,* 1987.
4. "Report of the US Department of Energy's Team Analyses of the Chernobyl-4 Atomic Energy Station Accident Sequence", *DOE/NE-0076, US Department of Energy,* 1986.
5. **R. Wilson,** Private Communication.
6. See, for example, M. K. De and W. Kerr, "ATWS: A Retrospective"; *Proceedings of ANS Topical Conference on Anticipated and Abnormal Transients in Nuclear Power Plants;* Atlanta; April, 1987.
7. **S. Seth, R. Lay, G. Malone;** "Balance-of-Plant Transients: A Review of Recent Experience"; *Proceedings of ANS Topical Conference on Anticipated and Abnormal Transients in Nuclear Power Plants;* Atlanta, Ga.; April, 1987.
8. **M. Makimo and T. Watanabe;** "Operational Experience of Human-Friendly Control and Instrumentation Systems for TOSHIBA BWR Nuclear Power Plants"; *Proceedings of ANS Topical Conference on Anticipated and Abnormal Transients in Nuclear Power Plants;* Atlanta, Ga; April, 1987.
9. **Frank R. Rowsome,** "Assessment of the Effect of Evacuation on Risk for Indian Point", enclosure in a letter dated July 28, 1987, Rowsome to Thomas E. Murley, Director Nuclear Reactor Regulation, USNRC.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 139–142, June 1988

Somewhere Between Ecstasy, Euphoria and the Shredder: Reflections on The Term "Pro-Nuclear"

Peter A. Bradford

Chairman, New York State Public Service Commission
Albany, NY 12223

In devising sensible nuclear regulatory policies for a post-Chernobyl world, it is important to try to identify the significance of Chernobyl. You are hearing from others better qualified than I am on the subjects of radiation effects and accident sequences. I will address the regulatory environment and, with some hesitancy, the broader political and governmental environment.

In these contexts, Chernobyl accelerated forces that were already in motion, and it may have made irreversible some trends that were dominant in any case. It has certainly made life more difficult for those who would license Seabrook, Shoreham or the other plants remaining under construction, but I don't think that it has produced a fundamental realignment of forces in this country. Let me explain.

Nuclear power in this country has never stood lower in public esteem. The polls are clear on this point, and Maine voters may well this November vote to close a nuclear power plant that they have twice in this decade voted to keep open. Seabrook and Shoreham together have $10 billion invested in them, and I have yet to hear even one among the dozen presidential candidates urge that they be operated. Nor do any urge that more plants be built.

The nuclear industry in the late 1970's blamed its declining fortunes in substantial part on an "antinuclear" president and on "antinuclear activists" at the Nuclear Regulatory Commission. Indeed, the President of the Atomic Industrial Forum said that the nuclear industry's reaction to President Reagan's 1980 victory was "somewhere between ecstacy and euphoria."

Well, we are now seven years into the most "pro-nuclear" presidency in our history. Yet the nuclear achievement of the 1980's is closer to Ralph Nader's agenda than to Ronald Reagan's.

—The Clinch River Breeder is gone.

—So is reprocessing.

—The waste repository program is stalled and mired in nationwide con-

troversy. The target date has slipped a year for each year of the program's existence.
—No new plants have been ordered since 1977.
—Every plant ordered since 1975 has been cancelled.
—Legislation to "streamline" the licensing process for new plants has gone nowhere in twelve straight Congressional sessions.

At the bottom of this collapse is a decline in public trust almost without parallel in industrial history. I suppose that one could argue that the Hindenburg was to dirigibles what Three Mile Island and Chernobyl were to nuclear power, but air travel has seen worse accidents since, and—in recent months at least—highly publicized near misses and ineptitude. Yet many people opposed to nuclear power still fly; a lot of them sit in the smoking section.

To judge from the operating record in the U.S. to date, nuclear power is a relatively low risk public health proposition. It's impact on public health has almost certainly been better than coal to say nothing of the automobile.

Still, the public does not trust it— and endorsements of all sorts from scientists and public health officials through the years haven't changed that situation. Nor has the enthusiasm of a popular president or the adoption of reasonable safety goals.

Unlike most NRC commissioners, I have lived for most of the last 15 years within a fairly short distance of an operating nuclear power plant, one whose operating history and economics have been favorable, one that may well not obtain majority support this November in a state where 95% of the electorate lives beyond the 10 mile zone.

I have friends who are long term opponents of the plant and friends who have come recently to that view, as well as some who still support keeping it open, as I did in the two earlier referenda. I can tell you with some confidence that the concerns of those who oppose it will not be met by some new way of presenting the data or by a public relations campaign. The matters that dismay them about nuclear power do not reach them on that level. They include the following:

First, Three Mile Island and Chernobyl caused a massive discrediting of the "experts," a discrediting that has in any case been going on throughout our society since Vietnam and that has recently been embodied by the Challenger, by the Iran/Contra affair, by Bhopal, by disillusioning conduct among Fundamentalist ministers and by Gary Hart. For each of these events you can find many people saying, "I used to believe in [fill in the blank], but I don't any more."

This destruction of misplaced faith is basically healthy, but a craving for faith remains. If that craving is filled by the casual embracing of yet another unreliable creed, the inevitable cycle of betrayal can only lead to levels of cynicism and apathy that threaten democracy itself. The alternative of a more active and informed citizenship is one about which nuclear proponents have at best been schizophrenic, and their tolerance for those among them who would frustrate or dismiss public inquiry has bred wide distrust among people who know little about man rems or defense-in-depth or safety goals.

Second, the failure to achieve a waste program concensus is deeply perplexing to anyone inclined to believe that nuclear power is in good hands. To state that the waste problem is largely political is not to discredit those concerned about it. Indeed their concerns, nontechnical though they may be, are not an irrational response either to the general decline of faith in expertise or to the specific self-destruction of the Nuclear Regulatory Commission's public position.

Of that, more later. I cannot leave the nuclear waste issue without remarking on the devastating counterproductivity of last year's maneuverings regarding the second round repository sites. If the Department of Energy had set out to undermine its own position, it could not have done so more effectively.

The choice of several of the second round sites was ill-considered. One of the two in Maine was relatively highly populated, an area heavily dependent on tourism, an area dominated by Sebago Lake, which is the City of Portland's water supply. DOE's effort to defend the choice only made things worse. It is this venture even more than Chernobyl that has put the Maine Yankee referendum in doubt.

To make matters worse, the Administration then, for political purposes, withdrew the entire second round process, infuriating the first round states without improving its position in the second round states, who were further dismayed when DOE moved gingerly to reinstate the program after the 1986 elections, which went against Administration candidates in every state in which the wastes were a serious issue. So transparent were the political motives in these wrenching changes of course that those in charge lost all claim to being in pursuit of the technically optimal solution.

Now the intractability of the waste problem is cited to explain the political opposition while the political opposition is cited to explain the intractability of the waste situation.

Those who urged a decade ago that we pay more attention to the wastes and less to the breeder, to reprocessing and to accelerated power plant licensing were regarded (and disparaged) by the industry as being antinuclear. In hindsight, the sincere ones appear to have been among nuclear power's last real friends.

Meanwhile what of the NRC? Given the source of my invitation, it would be impolite for me to dwell on that subject at length. The recent Union of Concerned Scientist book *Safety Second* says about what I would (or, in some cases, did) in any case.

I will, however, spend a moment on lessons that I think the Administration, the NRC and the industry need to learn about the consequences of excessive zeal in the setting of public policy. These lessons are not unique to nuclear power; indeed they emerge just as clearly from our recent exposure to Iran/Contra policymaking, with which our nuclear experience shares the following:

First, both sets of policies have lavished discredit on their intended beneficiaries and goals, beneficiaries and goals that may at one time have deserved better fates.

Second, both sets of policies have been driven by obsession and ideology in directions directly contradictory to fundamental and bi-partisan American principles.

Third, the label "national security" has been so abused in both contexts that its repetition has come to warn of skulduggery rather than justify the policy.

Fourth, funds have been channeled—publicly when possible, clandestinely when necessary—in ways inconsistent with professed policies ("no dealing with terrorists" in the one case, "noninterference in the free market" in the other).

Fifth, in both cases we have assisted foreigners in travelling roads that the Congress, public opinion or other forces constrain the U.S. government from travelling itself (reprocessing and breeder reactors in the one case; grants of money for arms through Switzerland and Costa Rica to the Contras in the other).

Sixth, both sets of policies have been promoted in the U.S. by private groups spending large amounts of privately raised money but coordinating closely with the relevant agencies of the federal government.

Seventh, in both programs lack of accountability, easy access to too much money and a pervasive mistrust of the American public has furthered interests inclined in any case toward arrogance and self-enrichment.

Finally, in a bizarre irony, both sets of policies have benefitted the Ayatollah immeasurably. In the one case we have undermined our domestic energy policy in ways that have tended to support the price of his oil; in the other we allowed his agents to ensnare us in a vat of global humiliation whose bottom is not in sight.

So what does it really mean to be "pro-nuclear" or "pro-Contra?" If one believes that the answer to Harold Denton's earlier question is that reactors are a "good bet," what to do about their manifest unpopularity?

At the very least, a pro-nuclear policy would have the following characteristics:

First, it would take the public and our democratic and federal/state systems of government as a given, not something that can be manipulated to private ends. Engineers who know perfectly well that the boiling point of water at given pressures cannot be manipulated much seem unwilling to learn that the public also inevitably boils over (granted that the precise moment cannot be predicted) in the face of accumulated disillusionment on a threatening topic.

Obvious or gauzy though this first principle may sound, it cannot be said to underlie the preemptive features of the Atomic Energy Act or the NRC's proposed rule on emergency planning, to name two examples.

Second, a truly "pro-nuclear" policy would accept "no" for an answer at some sites. It is one thing to preempt on-site safety findings to the federal level. It is another to require states to operate the plants in the face of their own adverse off-site emergency planning conclusions. The issues of fairness to investors and impact on rates are much more familiar to the states and to the courts than they are to the NRC, and they should be left there.

Third, the next few years must be accepted as a time of consolidation. Expedited licensing should be explicitly disavowed. The operating plants and the wastes should be the sole focus of attention. Public opinion should be allowed to follow performance.

Fourth, the industry must realize that it can only lose public trust when it demands that Jim Asselstine not be reappointed to the NRC while maintaining a dignified silence about conduct—and I have in mind shredding or other loss of documents relating to an investigation—elsewhere on the NRC, an event for which any utility would have to sack its own vice president for nuclear operations. This is, I know, superficially impolite to say, but no safety goal, no statement of good intent can transcend a lack of public confidence in those who must enforce it. For the industry to accept such conduct because it comes from someone whom they have labeled "pro-nuclear" is, in fact, profoundly anti-nuclear conduct.

Finally, to decompress a bit, nuclear plants in the future must expect to compete on a levelized per kilowatt hour and per kilowatt basis with other sources of electricity. Otherwise no state commission will certify them.

I don't know that the public will ever be willing to accept more nuclear units. What I have tried to outline are some of the conditions under which they might, though not soon. If these conditions are unacceptable to the industry, if the industry response continues to be—as it was in the 1970s—that such conditions would mean an end to new nuclear units, then I do know the outcome after all.

It is not necessarily the wisest public health outcome measured in terms of environmental impact, but an energy source that has as a precondition the belief that the public's concerns must be "streamlined" away will not be judged on environmental impact alone.

More importantly, the fortress mentality that goes with such conduct will ultimately encourage unsafe practices that will vitiate safety goals, safe designs and years of safe operations. That is the cycle that led to Three Mile Island, if not Chernobyl. In this cycle, Chernobyl has deepened a downswing that it did not initiate.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 143–147, June 1988

Industry Evaluation and Response

Byron Lee, Jr.

President and Chief Executive Officer, Nuclear Management and Resources Council, Inc. Washington, DC 20036

I am pleased to be a participant in this important symposium. It is clear that the speakers include some of the top radiation health experts in the country. My intention this afternoon is to summarize the results from the U.S. nuclear power industry evaluation of the Chernobyl accident, and to describe to you the manner in which we responded and how we communicated our conclusions. I will share some thoughts on my favorite (and now well rehearsed) topic, the near term future of nuclear power and how NUMARC will help shape that future. I will then close with some thoughts on radiation health—not as a scientific expert, but as an individual representing the corporate executives in this country who are entrusted with the safe operation of nuclear power plants, and who must apply the research and wisdom of radiation physics and medical experts to the public health aspects of safe nuclear operations in and around our plants.

This afternoon's session speakers are well qualified to discuss the environmental, engineering and political implications of the Chernobyl accident. All have been deeply involved in assessing Chernobyl or in leading teams of experts charged with responsibilities for evaluating the accident. I was asked by the Utility Nuclear Power Oversight Committee (UNPOC) to chair the Industry Technical Review Group on Chernobyl in May 1986. The Group consisted of thirty industry leaders who shared the tremendous resources they represented to study the accident. They represented nuclear utilities, nuclear steam supply vendors, architect engineer firms, universities, and industry organizations such as the Institute of Nuclear Power Operations (INPO), the Electric Power Research Institute (EPRI), the Atomic Industrial Forum (AIF), the American Nuclear Society (ANS), and Edison Electric Institute (EEI). Our Group had three objectives:

1. To learn as much as possible of the causes of the accident as well as the post-accident response and recovery experience;
2. To identify whatever lessons there may be for U.S. reactor design, construction and operation; and
3. To give direction to the response from the legitimate questions raised by this event.

In my opinion, the industry responded quickly and effectively to the Chernobyl accident. We conducted extensive reviews of Soviet documents to understand the design and operation of RBMK reactors.

A number of U.S. industry representatives participated in the post-accident review meeting held in late August 1986 to receive and analyze the Soviet written report of the Chernobyl accident. We conducted a significant amount of independent analyses of the Chernobyl accident, which generally agreed with analyses by our U.S. government agencies and by foreign countries. We helped write the U.S. "Report on the Accident at the Chernobyl Nuclear Power Station" (NUREG-1250) which was a joint report prepared by the NRC, DOE, FEMA, EPA, and two industry-sponsored organizations, EPRI and INPO. Hundreds of industry personnel have conducted briefings for local, state, and federal officials, as well as the general public, on the Chernobyl accident.

The Industry Review Group on Chernobyl prepared two documents: *The U.S. Nuclear Industry Position Paper on the Chernobyl Nuclear Plant Accident in the Soviet Union,* and *The U.S. Nuclear Industry Plan of Response to the Soviet Nuclear Plant accident at Chernobyl,* both dated February 2, 1987. The "Position Paper" reviewed the Group's assessment of the accident, including the consequences and the causes of the accident, and has been given wide distribution. Our general conclusion was that the accident was the result of significant design weaknesses coupled with several human factor breakdowns by management and the operators of the Chernobyl Nuclear Power Plant. It was the consensus of the Group that one cannot be separated from the other, but that the "root cause" of the event was design weaknesses.

As we became more familiar with the Soviet RBMK reactor design, we recognized how difficult it is to make direct comparisons between the Soviet RBMK and the U.S. LWR. The differences were so great that a strong consensus began to emerge from the technical experts in the industry that this accident had little direct relevance to U.S. light water reactors. Nevertheless, we were committed to a thorough search for any possible lessons or insights. Our conclusions compared well with the conclusions drawn by the NRC, DOE, Congress, the national laboratories, and the mainstream of the U.S. scientific and academic communities. The Industry Position Paper presented three major conclusions that emerged from our analysis:

1. The design and institutional differences between the Chernobyl-type, water-cooled graphite reactor and U.S. light water nuclear power plants are so fundamental that the Soviet accident should not impact the processes of design and regulation of U.S. nuclear reactors. The accident does point up the importance of the emphasis that the U.S. plants place on high quality training and procedures, and strict adherence to administrative controls.
2. The Chernobyl accident confirms U.S. choices in nuclear technology, supported by our public regulatory program. A very deliberate determination was made at the foundation of the U.S. nuclear industry that we could not tolerate the same risks as other industries. From the beginning, conservative reactor plant and containment designs, high safety standards, defense-in-depth, and operating discipline were imposed. Our record of protecting the public is an affirmation of our safety philosophy.
3. Comparisons made between the Soviet accident and the less severe Three Mile Island accident led to very important observations. The TMI-2 accident caused no physical harm to the public or the plant's workers, primarily due to defense-in-depth design features including a full containment. However, the TMI-2 accident identified weaknesses in U.S. reactors and their methods of operation. Major industry-initiated self-improvement efforts were made as a result, which are continuing to this day.

As I mentioned, our group also prepared a "Plan of Response" to Chernobyl. This document covered efforts already taken and those that we believed needed to be considered more thoroughly by the industry for future action. You should all recognize that the plan is a roadmap for a comprehensive search for lessons to be learned from Chernobyl. Even though many of us had high confidence in our own technology and standards of operation, we felt that as a responsible industry we must undertake our own review to satisfy ourselves that potential lessons were learned and applied.

The Plan is broken into three levels of response. Level I covers the evaluation of the accident and the identification of findings. Many different industry organizations were asked to help complete the reviews called for by the industry plan. These efforts are proceeding well and are essentially complete.

Level II addresses the challenges to U.S. nuclear safety in light of the Chernobyl experience. Most are not a result of any specific findings from Chernobyl, but more a result of issues raised by public concerns, NRC, and the media following Chernobyl. In addressing these challenges, the industry has conducted, and will continue to conduct, a thorough search as more information becomes available for potential applications of the Chernobyl experience to our reactors.

Our level II efforts are leading to conclusions that generally dovetail with existing safety initiatives. We are finding that the lessons of Chernobyl either confirm actions already taken or add further confirmation that ongoing efforts are appropriate. No situation has been found that indicates a blind spot in our own designs, regulations, or operational practices. Rather, we are finding a few areas that need to be reemphasized, reprioritized, and in some cases expanded to take advantage of new insights.

These results appear to be completely consistent with my reading of the NRC's recently released draft NUREG-1251: "Implications of the Accident at Chernobyl for Safety Regulation of Commercial Nuclear Power Plants".

The NRC has concluded in their report that "No immediate changes are needed in the NRC's regulations regarding the design or operation of U.S. commercial reactors." The NRC has also determined that: "The *most important lesson* is that [Chernobyl] reminds us of the continuing importance of safe design in both concept and implementation; of operational controls, of competence and motivation of plant management and operating staff to operate in strict compliance with controls; and of backup features of defense in depth against potential accidents."

I agree wholeheartedly with those statements and am confident that the entire leadership of the nuclear industry supports them also.

Level III of the Plan suggests an increased participation by the U.S. industry on the international nuclear scene. The industry has been involved in international activities through EPRI, INPO, AIF, ANS, and individual company contacts, but has had no comprehensive or coordinated international program. It was the consensus of our group that a more coordinated and involved industry presence is required.

The Chernobyl accident has provided this industry with a vivid case study in the results of complacency in reactor operations and a reason to continually strive to improve our operational performance. I would like to briefly review for you some of our actions to demonstrate our own commitment to operational excellence. To fully appreciate industry actions to improve operational safety, we need to consider briefly what has happened since the TMI accident.

In the early days after TMI, the Institute of Nuclear Power Operations (INPO) and the Nuclear Safety Analysis Center (NSAC) were created. The Significant Event Evaluation and Information Network (SEE-IN) program was developed, and operating experience and safety information was shared on the "Nuclear Network" electronic mail system. INPO began setting standards of excellence in nuclear operations through a variety of assistance, evaluation, and monitoring programs.

The National Academy for Nuclear Training was formed in September 1985. Over 600 nuclear training programs were completed at our operating nuclear plants and made ready for accreditation by the end of 1986.

The industry, through INPO, developed a set of performance indicators over four years ago. The program was refined in 1985, and ten overall indicators now provide an important management tool for monitoring plant performance. Trends over that four year period show significant progress by the industry in most of these areas.

The utility industry has not rested on its record and is looking to the future. It has developed, with the help of EPRI, nuclear suppliers and architect-engineers, an advanced light water reactor program drawing on our experiences that should provide extremely safe standardized reactor designs available to meet the increased base load demands of the mid and late 1990's. These designs emphasize operational simplicity and human factors engineering.

A detailed study of the industry's activities was initiated by the utility leadership which resulted in the publication in August 1986 of a report entitled "Leadership in Achieving Operational Excellence: The Challenge for All Nuclear Utilities," better known as the "Sillin Report." The authors were three gentlemen with vast experience in nuclear power—Lee Sillin, Marcus Rowden, and Dennis Wilkinson. The report proposed recommendations in three major areas:

1. Improving operational performance of nuclear power facilities.
2. Improving the nuclear utility interface with the NRC.
3. Establishing a unified nuclear utility industry organization.

When the Sillin Report recommended the establishment of a unified nuclear utility industry organization that would interface with the NRC, many in the industry felt we already had the basic element that was needed in the Nuclear Utility Management and Resources *Committee* formed in 1984. For three years the NUMARC executives had been interfacing frequently with the NRC staff to identify areas in our industry where improvements could be made. A positive course of action had been taken on a number of issues. We believe that through this process an increased sense of cooperation and trust has developed between the NRC and the industry. We view our new organization, the Nuclear Management and Resources *Council,* as an opportunity to build further upon the successes this process has achieved.

The Nuclear Management and Resources Council, retaining the acronym "NUMARC," was established to provide a unified nuclear power industry approach on generic regulatory and technical issues. Our responsibilities include coordinating the combined efforts of licensee utilities, and other industry organizations that are NUMARC participants, in all matters involving regulatory policy issues, and on the regulatory aspects of operational and technical safety issues.

NUMARC serves as the industry's principal mechanism for conveying our views, concerns, and policies to the NRC and other government agencies as appropriate. We will also initiate industry self-improvement efforts when deemed necessary, and direct attention to and act on regulatory issues the NRC considers important.

We carry out our responsibilities by drawing upon the knowledge, operational and technical experience, and safe operational responsibility of the entire nuclear industry. We seek to improve the industry's effectiveness in developing and analyzing information concerning generic regulatory technical and operational issues and to improve the quality and constructive character of contributions made by the industry to the evolution of regulatory analyses and decisions.

NUMARC must work closely with the industry and with the NRC—the two major repositories of nuclear operational safety expertise—to further enhance the industry's pursuit of operational excellence. NUMARC is dedicated to improving communications between the industry and NRC. We believe very strongly in the publicly controlled regulatory process. We believe that process best serves the public if the regulator and the regulated industry treat each other with openness and respect, and always exercise technical objectivity. This formula has worked in other U.S. industries and in the nuclear industries of other nations such as France, Japan and Canada. Here in Washington this professional approach is periodically branded as "Coziness." A few real or perceived abuses of open communications have preoccupied the thinking on the NRC/industry interface to the exclusion of the thousands of sound technical interfaces that occur each year. They also cause us to forget the overwhelmingly positive safety and economic benefits to the American people from a less adversarial approach.

It is the same spirit of cooperation and professional exchange that I wish to offer to the medical and health physics community. Our industry respects the responsiveness and technical objectivity of the U.S. experts on radiation health effects who have contributed to the body of knowledge and public awareness since Chernobyl. I would encourage you to continue to help in the important effort of educating the public and the media on radiation health effects. The public needs sound scientific estimates of the real risk associated with radiation exposure. They have become confused by bounding or conservative upper limits. The public particularly needs help understanding the uncertainty in health effects predictions for very low doses of radioactivity to large populations.

Much of the confusion and debate on nuclear issues are not based on legitimate technical arguments. In many cases, these situations have been exacerbated by false claims in the media that a Chernobyl-type accident could happen at these reactors. These situations have been exacerbated by a lack of public understanding of the nature and relative importance of radiation health risks, and the level of emergency planning in place in the U.S. in the unlikely event of nuclear accident. The future of the nuclear option will depend on educating the non-technical policy makers and the majority of the public on the benefits and risks.

I think it is important that we focus our educational efforts toward three groups: first the broad medical community, particularly the younger generation of medical students and professionals; second, our public and private schools as they are gearing up with renewed interest in the sciences; and finally the media, who desperately need more expertise in this field.

I am optimistic about the future role of nuclear power in this country. I believe the nuclear option can be improved significantly by improving the credibility of the regulatory environment. That is one of NUMARC's objectives.

In closing, I would like to stress that our industry has made a substantial investment in reviewing and assessing the implications of the Chernobyl accident. We have determined the responses needed and are taking action toward improving our operational performance. We at NUMARC are dedicated to doing our share. We must all work together to ensure the continued viability of nuclear power in the energy needs of our nation.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 148–157, June 1988

Round Table Discussion: Environment and Engineering

DENTON: Getting back to the new dosimetry estimates from Hiroshima/Nagasaki, I was at the ICRP (International Committee on Radiation Protection) meetings in Lake Como last week, and the new papers by Preston and Pierce would indicate that the cancer risk from that radiation probably will go up by at least a factor of five. It may go up less. It may go up more, but right now the factor of five increase in cancer risk seems to be where it is going. This would then mean that the health effects to workers in the field may have to be adjusted by that factor of five; it may or may not be that.

The last speaker, Mr. Lee, was saying that in fact you now have excluded workers from having in excess of 5 rem per year, but there is still a reasonably large group, I would think, perhaps 8 or 10 percent of the tail of your population of exposures, that may be getting between 1 and 5 percent. I think about 90 to 95 percent get under 1 rem, if I'm not mistaken, in the point of .6 or 600 mg.

These points may in fact require increasing the safety components to still lower than 1 to 5 rem exposure. Will industry be prepared to do so?

LEE: After all the technical experts in the world analyze that information, and if the conclusion is indeed that is a fact and that the risk is considerably higher, I think we will work on trying to reduce the exposure limits at our facilities. As you point out, for the vast majority of our employees, the levels are extremely low in comparison to the standards.

We have been working with the efforts here to keep moving that down, and that will continue to be our goal. But again, this is where we have to rely on the experts. We have to avoid jumping into doing things hastily before we have some kind of a conclusion from the experts, but I'm sure if that's the fact, we will respond accordingly.

DENTON: Dr. Wald, how do you see that data? Would you like to comment?

WALD: I haven't really seen the data either. I think it's probably premature to say what it will do.

KERR: Refresh my memory. I thought I remembered that the BEIR III reports (Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences) that we are still not certain that a one-time exposure of 10 rem has any significant harmful effects. Isn't that the case?

SPEAKER: BEIR III says the epidemiological data cannot prove below 10 rem whether or not there is a cancer effect because you don't have a population size large enough to make that study. BEIR III also says there are three potential ways of doing risk estimates: the linear, the linear quadratic, and the quadratic. BEIR III chose the linear quadratic as its most reasonable way of recommending risk estimates.

I think the present NCRP/ICRP risk estimates—and I'm not sure now whether

EPA adopts this—generally internationally suggested that 1 rem of exposure had a probability of inducing one cancer per 10,000 people, one rem exposure to a population. What I'm saying now is—and BEIR probably adopted a number of about 1.7—that number is up by a factor of five, if you look at the new dosimetry data and recalculate the cancer incidence in Hiroshima/Nagasaki. That is essentially what Gil Beebe was referring to this morning, but he didn't have the final data.

KERR: It seems to me what you were referring to is not really calculating the risk estimates for large populations but, rather, dealing with fairly small populations of people who work in nuclear power plants. My next question was going to be, if my memory was correct, and I wasn't sure it was, Is the next edition of BEIR III going to make about that same statement?

SPEAKER: BEIR V is now in preparation. In fact, Arthur Upton is chairing the BEIR V committee. It expects to have its report completed, I believe, by September of 1989. So both BEIR V and the newest UNSCR will be coming out within six months of each other. They will have this new data. But neither the BEIR committee nor the UNSCR Committee make recommendations with respect to risk limits. All they do is provide the risk estimates that are used.

KERR: I recognize that, but it seems to me, it's one thing to predict estimates of populations, which one does in determining risks to large populations, and it's another thing to deal with a fairly small population of people in nuclear plants in a situation in which, if I interpret the BEIR III report correctly—and I may not; I'm certainly not a radiation biologist—there is uncertainty as to whether low levels of radiation have any significant effect, which is what I am interpreting that statement to mean.

SPEAKER: That is one interpretation. It is not the one that would be used by most radiobiologists. I think we would argue that the linear quadratic model best fits the data, although we do not have a population size that would permit an epidemiological study at the levels of 10 rem or below at this point.

KERR: I do not know what radiation biologists use or what they use it for, but when they tell me, as a possible user, "We don't know whether 10 rems of exposure to an individual has any harmful effect," I guess I do not know what they mean if they don't mean that this has some significance.

SPEAKER: I think you took that out of context. They gave you a risk estimate down below 10 rem. They give you a risk estimate per rem, but say they cannot accurately—which is obviously true—make an estimate below 10 rem that they have great confidence in. It could be zero. The report that was just quoted by Marv Goldman on the DOE report says that the number of cancers induced by Chernobyl could equally be zero or 28,000. That number now could go from zero to 85,000 with the new risk estimates, but very few radiobiologists would accept the value of zero, although it is not impossible.

YANIV: Shlomo Yaniv, Nuclear Regulatory Commission. As far as BEIR III is concerned, BEIR III did not give risk coefficients for single exposures below 10 rem or 20 exposures below 1 rem per year. They made a statement which was in BEIR I, repeated in BEIR III, that they do not know whether the level of exposure of those that are 100 mg per year are detrimental or not.

With regard to Hiroshima/Nagasaki, I have seen the Preston paper, and as far as the dosimetry impact itself, it is depending upon the RBE chosen for neutrone. It is on the order of two, not five, based on the paper. That does not imply that the risk coefficient that might come out of the deliberation and combination of the new radioepidemiological data and the dosimetry might not be higher, the reason being that it has to do with temporal projection of risk beyond the period of observation.

ICRP-26, which has a risk coefficient

of 1.25 times 10 to the minus 4 per rad in little cancers is based upon absolute risk projection UNSCR-77. A new UNSCR already has come out, which basically endorses a relative risk projection model. The new radioepidemiological data support a relative risk projection model for most of the solid tumors, and that, in combination with a much higher relative risk observed dose irradiated young in life, will lead to a higher risk coefficient than presently is given in ICRP-26.

HERN: John Hern. I have a question for Byron Lee. I have read the Sillen report. You talked a little bit about outliers, and as I recall the report, one of the recommendations was that the nuclear industry identified publicly those outliers, those companies or plants that really were not performing well. What is the industry doing about that recommendation?

LEE: That was one of the recommendations of the report. That was considered by the INPO Board, which I am not a part of, and the INPO organization has been re-reviewed several times. Their decision is that at the present time, they don't think that is in the best interest of the effort to achieve excellence.

We kind of beat ourselves very badly in this country in the media as it is. The old saying of taking somebody to the woodshed and beating them works on a rare occasion and in a really extreme case, but I don't think, the industry does not think, INPO (Industrial Nuclear Power Organization) does not believe, that is the way to solve our problems; to expose to the public who happens to be the worst case.

Georgetown is a good example. The worst student in the class obviously is above the level to get in here, but he is still the worst student. So you have to put it in perspective, and it's like this radiation issue. The public does not read that situation. The headline will be, this is a plant that the industry thinks is bad. If the industry thought it was bad, they would take some dramatic actions, and you would know about it if they thought it was an unsafe plant.

DENTON: Perhaps some other panelist would like to comment?

KERR: I cannot speak for the industry, obviously, but one of the concerns I have had about INPO—and I have asked this question of INPO people on a number of occasions—is that I think they have a good mechanism for identifying problems, but I have not been able to discover a mechanism for dealing with recalcitrant organizations. There may be one, and if there is, I would feel better about INPO's influence.

SPEAKER: I don't want to speak here for INPO, but I will have Zach Peyton or somebody else give you a contact on it. I think there are mechanisms that are in place to deal with it.

BRODSKY: Allan Brodsky, Georgetown University. I would like to get back to talking about something like preparations for something like Chernobyl or TMI, along the line of what Neal Wald alluded to this morning a little bit. In a moment, I am going to introduce another young friend, Dr. Ken Inn from the National Bureau of Standards to say something along these lines because he wants to talk.

Going back to the days of Three Mile Island, and we have seen some of the things after Chernobyl, there was a clamor to find out how much radiation exposure these people got, not only the workers but the public. I have heard a lot about, "We don't know what the doses to the workers were at Chernobyl." I think we have a better handle on what the doses to workers were at Three Mile Island, in terms of the external exposures, because they wear badges.

But I happen to know that in terms of estimating internal exposures, we were not prepared very well to examine what happened to some of those people immediately after the accident. You know that Three Mile Island called in a whole body count, two of them, about seven or eight days after the accident, and it took them a little while to set up. One of them got contaminated and had various calibration difficulties.

This shows, in the event of this rare incident of an accident in a nuclear power plant, that people do clamor to know what the exposures are in the first place, before you estimate what the risk are. In fact, how low are some of the exposures? This is something we have to be able to prove also.

Neal Wald alluded to the fact that you have to do some planning for the internal exposures months and years in advance. I think he has to be given some credit for that kind of insight 20 some years ago, when he built a whole body count without any funds from the nuclear industry. Because it was there, a number of very important radiation incidents were handled without too much information in the news media, among non-nuclear, but materials facilities.

Although these things were rare, we realize that they were important in context, because each individual who gets 20,000 or 50,000 rem becomes a very important case. It's important from both aspects, both to take care of the individual and from the standpoint of the government officials who were very interested at that moment—they were all over the place after each one of these accidents—to be able to show that they were not only concerned about the individual, but they have been prepared to take care of that individual and follow up appropriately on each one of these cases.

I don't want to over-emphasise this matter because I also believe that the probability of further accidents at nuclear power plants injuring any member of the public is extremely rare. But of course, we believed that before Three Mile Island, and it occurred. It turns out that after Three Mile Island, one of our colleagues published articles saying that Dr. Allen Brodsky, an expert from the Nuclear Regulatory Commission, has said that the internal exposures of people around Three Mile Island were 130 times what they have reported. They were telling false information. I have copies of this headline: The government may be lying.

Friends of mine called me up all over the country and said, "Brodsky, are you crazy, supporting that?" I said, "He didn't even consult me before he published that." He pulled something out of context from the literature, where I calculated something for a full fission product release. Seven or eight articles came to me around the country about that. I couldn't refute it. First of all, the media were not interested in publishing what I said at the time. I had gotten on a couple of programs, but that wasn't adequate.

But more importantly, when I ran into my colleague one day, he pulled out the item he found, but there were no specific measurements of the public that I could use, if I had to, to show how low some of these claims were. So it leads to a question for Byron Lee.

In looking at the emergency planning again, from the lessons learned at Chernobyl, from the lessons learned at TMI, did you look at the possibility that for a relatively small sum of money compared to what we have been spending on emergency evacuation and planning and what else, did you look at the possibility that one could fund the training and the setup of some centers, such as Neal Wald did on his own, in at least a few places around the country so they would be ready in case another accident occurs?

LEE: That is one of the things that Roger Linneman has been talking to the industry about; some increased capabilities to respond not to the public situation but to the internal situation. I think there is a possibility: We have all had in our plans, the capability to respond to one, two, or three individuals who were overexposed.

The question becomes, When you get a combination of an accident—steam burn situation is the most likely thing that would occur in the plants, we think—and low-level contamination, possibly, are we capable of handling that? We are. The industry has been taking a look at that. I know he has looked at the possibility of developing some major centers. But I think the conclusion they came to is that the capabilities already exist. There are some major medical centers that are capable. You may disagree with that, but the feeling was that there are.

In fact, I think Commonwealth Edison was one of the first, with Dr. Bud Main, to have a whole body counter at all of our plants, probably way back in 1970 or something like that.

SPEAKER: Neal, I think, was correct in asserting that an accident the size of Chernobyl would tax our medical system. It's remarkable how the Soviets were able to assemble so many resources so quickly, and he has made a number of proposals to the government that, so far, have not been acted upon, but that whole area is always worth considering.

WALD: I'm Neal Wald, University of Pittsburgh. The question of the medical preparedness and the emergency preparedness to deal with medical problems is one that has, as Mr. Denton suggested, been occupying us for quite awhile. Our concern really is not with the Chernobyl size population problem, because we do agree that it is less likely because of our reactor designs and our operations.

On the other hand, somewhere between the individual worker who is injured at the plant and the 135,000 people that are predicted—even if you follow WASH 1,400 for some small or moderate sized accidents. The problem that concerns us is that if 50 people come to a hospital for attention, and the hospital is fully occupied, as they are, with their own problems and their own commitments to incoming patients, even though you think you have in your plan, and every one of the 105 operating reactors has a plan, we are not quite sure that the reality behind the plan is what we think it is.

We have been proposing to the NRC, to FEMA, to the Department of Energy that the database should be compiled. I've never seen a listing by NRC of the 105 hospitals which are involved. I know you could probably dig this out in the public document room, but I don't think we have looked behind the paper to any great extent to see whether this is real.

I point out, hospitals have a liability which requires them to take care of the patients in house. The fact that a hospital says it will handle a problem at a local plant does not mean that it can, willy nilly, dispose of the other patients or close down the emergency room without being at moral as well as legal risk. So the reality of some of these things in our medical system is a little different than it is in the U.S.S.R.

I am not advocating changing the system to accommodate this particular unlikely problem, but I think we ought to at least compile a database to see what resources we really have in hand. I know of several institutions which come to everyone's mind as being available. I also know that the head of one of these became professor emeritus at the beginning of this month, and this kind of thing, as I suggested in my talk, is going on. So what is listed now as being available on the basis of a look two or three years ago may not really be there.

This is something we finally have been talking to EPRI (the Electric Power Research Institute) about, and I think EPRI is interested in the possibility of pursuing it. We will see.

SPEAKER: Dr. Wald is certainly correct that we don't have the capability, and almost heroic measures of this kind will be necessary to get it to us. I would like to hark back to the years 1950 to 1955, when there was a very strong civil defense effort in this country. It was policy to alert hospitals to the requirements that radiation cases be dealt with and to inform the staff at hospitals how to do this and to tell what facilities had to be acquired at hospitals so as to take care of radiation cases that might arise as a result of civil defense requirements.

That was a period when this capability that we see present in the Soviet Union now was present in the United States. The Soviets were able to take care of Chernobyl principally because they have never relaxed in their civil defense efforts. They have maintained training of a large corps of physicians in civil defense activities associated with radiation injury, and drew on this to a substantial extent.

Not only was this true in the medical capability that they drew on, but the actual physical response to the cleanup process took advantage of a great deal of thinking which had gone into civil defense. The activity that in fact was used to restore the Chernobyl area to some accessibility—to the degree that allowed them to restart Chernobyl I and Chernobyl II and to get ready to restart Chernobyl III later this year—that massive effort was incredible. It is something that we, in this country, are not capable of mustering on short order.

BURLEY: Gordon Burley, the Environmental Protection Agency. I would like to pursue this question of lessons learned a little bit further. The general consensus after Chernobyl seemed to be that this was the type of accident that just couldn't happen with our types of reactors. With the exception of some Department of Defense reactors, that certainly seems to be true. However, Dr. Kerr also indicated that there are some things that we might want to look at outside of the hardware. One thing that comes to mind is the commonality of human errors. What I would like to know is, what has been done, in the light of Chernobyl and all the other reactor operating errors, to again look at this human factor from the broader perspective of preventing these major accidents?

SPEAKER: I guess I'm not so sure how to respond to that very broad question. All I can say is that since Three Mile Island, that has been our major effort; to look at improving the operating capabilities, the capabilities of people to respond to events beyond what we had normally been training people for, to the emergency cases, maybe not as far as some people at this point believe we should. That is still one area that we are looking at and will have to look at.

When you say the commonality of cause, I guess I am not sure what you are talking about. Human error is something that we understand is going to happen. I think we don't give any credit on the other side for the human intervention. From an old operating standpoint, I would say that there are probably five cases where operators have prevented something for each case where they have caused something. You never hear about that. There are all kinds of examples, like Brown's Ferry that he referred to, although not that extreme, where operators have done things.

People are ingenious, if they understand the plant and the circumstances, and you give them the ability to respond and to act on their own, not to follow prescriptions come Hell or high water. It's amazing what good, trained, qualified people can do. That's a key, and that's what we're trying to do: to get people to better understand. One of the things they looked at in one area, and they will look at others, is symptom-based. It's kind of like the physician: don't just have prescriptive rules to follow; look at symptoms and have enough knowledge to understand or at least guess where you should go from that.

INN: Kenneth Inn, National Bureau of Standards. The Chernobyl incident has sparked renewed radioactivity measurements in Europe. The Radioactivity Group at the National Bureau of Standards is interested in providing standards which may make a positive contribution to needs you see as necessary, given the Chernobyl experience—for example, radioactivity in foodstuff standards.

I would like to ask the panel and the audience for suggestions as to what kind of standards you feel would be nice to have, good to have, necessary to have, so that we will be prepared in the future.

PUSKIN: Jerry Puskin, E.P.A. After the Chernobyl accident, everyone might recall that in Europe there was a lot of confusion and inconsistency about levels that should be allowed in food. Some countries set their levels practically to zero and others followed ICRP (International Committee on Radiation Protection) recommendations. That got us to thinking in this country too, because we really didn't have that much of a problem here with respect to radioactive contamination. The simplest thing to do was to say, "Let's follow the FDA Protective Action Guides," which allowed, depending on the situation, one-and-a-half rem or 15 rem to the thyroid and one-third of that to the whole body.

That is a nice marker, but these guides were devised for an accident that was acute, in terms of it happened immediately and you don't have too much time to respond, and people have to eat. I think both Chernobyl and TMI point up the fact that nuclear accidents, and releases particularly, often could be spread over time and you have plenty of time to respond. There may be cases where an area has its milk contaminated to a level which is lower than allowed by PAGs, but people could very easily obtain other milk which was essentially free of radioactive contamination. It wouldn't make sense for them to drink that milk.

The FDA guides actually allow for this, and the States have the ultimate responsibility for setting these. There are States like Oregon which recommended you not drink the rain water at that time. We need to think about setting levels, to use a dirty word in some quarters, on a LARA type of basis: we should set them as "low as reasonably achievable" given the circumstances. We need better guidelines, depending on the circumstances and how acute it is, as to what is an acceptable level of contamination in food and milk.

LEE: I guess I am not sure how you apply "as low as reasonably achievable" to an accident event, if that is what you were inferring. From an industry standpoint, again, I think we have to turn to the experts in the field. We do need some kind of a number that is a reasonable number, that allows some safety factor in it. But again, I think we have the public confused.

We deal also in the electric utilities business with PCBs and all of the other toxic substances. It's not just radiation. It's the same issue: what is a safe level?

I live southwest of Joliet. It's in a very high-limestone area. The radiation levels in the wells there—I remember at our Dresden II hearings, Meryl Eisenbud came out and testified that what we ought to do is spend our money working on the well water in the town of Joliet, rather than trying to take the squeal out of the pig coming out of the plant.

I get a little thing in the mail that says, "Your water is above the safe guidelines for radiation, but don't be concerned. We are working on it." That, to me, is crazy. I get that about every six months from my water company because they are required to do that. That is not the kind of thing we need to do. I think we have to do something better than that, or the public is not going to believe any of us.

SPEAKER: I would like to comment a little further on the earlier question about what is being done about human contributions to risk, because I personally think it is an extremely important question. Indeed, I would say that perhaps if we are going to make any significant improvement in risk, I think the risk is already clear, we probably should concentrate on that area rather than on equipment.

If you will recall, most of the investigating groups that looked at the TMI-II accident did recommend that more emphasis be placed on human contribution. The human contribution, as Byron has said, can be both positive and negative, and we don't know very well how to describe it quantitatively. But experience certainly does indicate that not only licensed operators but people who do maintenance construction, people who work throughout the plant can contribute both positively and negatively to a trouble-free plant operation.

I am trying to speak in terms of the industry, and I do not represent it very well, but it seems to me that most of the people involved in developing the nuclear industry up to now have been people with technical backgrounds—engineering, scientific—and they therefore feel more comfortable working on what one might call scientific, technical or equipment problems. They are not trained and do not understand very well how to deal with some of the human problems about which we need to know more than we now know in order to train people better, select people better, motivate them better, manage them better. All of those things clearly contribute to not just safer but more reliable and more economical nuclear power plants.

Anybody who has seen power plants in operation, who has observed a number of them, who has compared them, knows how important these things are. But very few people, I think—maybe nobody—has a good recipe that says, "This is the way you produce an organization that does a good job." I certainly don't know how to solve the problem, but I think we need to give it continuing attention. It is receiving some attention, both on the part of industry and on the part of the regulatory agency. But from my view, the results are still rather sparse and the study is in its infancy.

SPEAKER: I would say that in all of these areas, the industry has put a lot of emphasis in the last few years. It is a growing area. Human factors, before Three Mile Island, was a hardly recognizable term in this country. It has expanded and grown considerably. EPRI and INPO are working very diligently in those areas trying to develop programs to meet the concerns that Bill just expressed.

We talked about one of the responses, I think, after Three Mile Island was in the human factors area. If you had asked at that point of time of the utilities, "Did you apply human factors engineering to your control room?" the answer would have been yes. That is true. We did. We applied what was in those days human factors terms, but we were applying it toward normal operation as such. We had not really thought about the transience condition, and that was a major lesson that was learned at Three Mile Island. A lot of the instruments were behind the board and around the corner, and they weren't in a location that the operator or the supervisor or some person could quickly get a glimpse of the critical parameters that were required. That was a major change that was made.

CONWAY: My name is Kathleen Conway. I am a sanitary engineer, and I expect that, given the illustrious and experienced company in this room, I am probably the closest thing you have to the great unwashed public. I would like to share a couple of experiences with you and then address some of the comments you made today.

In the early 1970s, I went for a tour of the Pilgrim Nuclear Power Plant with a group of engineers. To my great embarrassment, one of the engineers in the group asked why you cooled the water down after it goes through the blades of the generator. My embarrassment at his feeling the need to ask that question was overwhelmed by my shock when the guy from the power plant did not know the answer. That was kind of a surprise to me.

I was sent for a health physics course this spring. We had a mix in the class of about one-third Canadians and two-thirds Americans. Most of the people worked at nuclear power plants. There were a few people like myself who were coming in for crash training. Most of them had been working for years in your areas. I found the discussions that the Canadians and the Americans would have about how their plants were managed and operated to be simply fascinating.

The Canadians clearly were far more interested in training. They would tell stories of having to go to six weeks of health physics classes before people were allowed to push a broom through the plant, being five or six deep in the number of people who could handle a particular job at a plant. The Americans would tell stories that, although they had educational requirements, they did not appear to be as demanding. It struck me that they were often only one or two deep for certain tasks, often had to rely on traveling gypsy bands of atomic workers. It seemed to be a different situation.

In my work, I come across other risk numbers. I don't find the ones that you present particularly frightening. I find your comparison to the coal industry very interesting. I find your track record as an occupational group looks pretty good. I think a lot of people in the public are capable of looking at numbers, comparing them, and deciding whether they look big or not. I think they are also capable of looking at people and saying, "Would I buy a used car from this person?"

I was not impressed at that power plant when that spokesperson could not answer a very simple question that really did not even relate to nuclear operations but just to the whole business of using steam to drive a turbine. I was impressed by the Canadians.

I would have been very impressed, Mr. Lee, had you given Dr. Kerr's speech. I found some of the comments about the confused public to be insulting. I am not sure that when the public does not agree with the position taken by an industry that it is because the public is ignorant or confused. I found Mr. Bradford's arguments very sympathetic. I know that this would not be the place for you to be supporting those arguments. I trust that there are places where you can make some of those arguments effectively.

I think if you are to restore the credibility in this country of the technology which actually holds promise—I mean, the Canadians seem quite happy with it, and the French seem quite happy with it, and indeed, as I said, I was impressed by the Canadians in this group—I think you are going to have to consider some of the things that Mr. Bradford said this morning and take a slightly different path. I know this is a little bit off what you were talking about earlier, but you had mentioned the public a number of times, and I just thought I should give you that feedback.

SPEAKER: I was on a team that visited Canadian plants recently in an attempt to become more international in our outlook, and they do operate their plants very well.

SPEAKER: I would be the last person to try to justify ignorance as a recipe for operating a nuclear plant or anything else. Certainly, the accident at Three Mile Island had as one of its major ingredients a lack of understanding of the physics of fluids associated with the way things were going on in that plant. On the other hand, I would like to point out that this is not the only thing you have to take into account, and the Chernobyl accident I think was perhaps one of the strongest sources of recognition of this point.

The Soviet attitude toward operators in nuclear plants is extremely different from that in the United States. It's almost at the opposite pole. To be an operator in the Soviet Union, you have to be a licensed engineer. You are a graduate engineer from a university. You go into an apprenticeship program for five years before you can become a licensed operator at a nuclear plant, and then you have to pass the examination on your understanding of the plant. After some additional period—and I'm not sure what it is; I think it's something like three years—you can advance to the next level of operator in the nuclear plant, and so on up the stage until you become a supervisor. It's a very strongly structured program to emphasize training and understanding of the way things go on in these plants.

The Soviet scientists in Vienna last year told us that this was the key to why the accident actually took place. They said these individuals thought they were so good that they could do anything to that plant and get away with it. They did do some things, and they didn't get away with it.

The only lesson I could draw at the moment is that you have to balance your understanding of the plant with this concept that we have pushed in the United States, that Byron Lee talked so much about, and that is defense in depth. Defense in depth is a management concept. It is a technical concept. It's a thing you draw on to structure your defenses against mistakes that people make, mistakes that mechanisms make, and that still provide you safety back-up when you get failures of any of these kinds.

The difficulty that occurred at Chernobyl was that there was not a defense in depth. At least there was not a defense solidly in depth, so that certain things could happen and did happen to the plant that could not be taken care of by the structure of the plant. This is the additional ingredient that I think certainly took care of Three Mile Island and prevented widespread public disaster at that place and, I would hope, would do the same if we ever got into such a fix again.

SPEAKER: Can I respond to one comment that was made about the confused public, versus the ones that disagree with me. I did not consider the people who disagree with me confused. I was talking about the masses: people who do not disagree with me or agree with me. I was talking about what I think. We dealt, in my business, with a lot of people. They were all our customers, the 7 million people. We met with them and talked with them and did a lot trying to educate. That is what I was basing it on, not the people who disagreed with me.

STANGLER: Arnold Stangler from FEMA. I just wanted to comment on the medical services capability. As a result of some Atomic Licensing and Safety Board hearings, some Atomic Safety and Licensing Board Appeal Board hearings, and I believe a court decision involved U.S. Guard versus NRC and SONG's facility, the San Onofrey Nuclear Generating Station, there has been an effort over the last nine months to reassess and reevaluate and improve the medical capability at all the operating plants.

I believe there is a requirement placed on all utilities to respond roughly a month ago with their assessment. This included the requirement for a minimum of a primary hospital, one backup hospital minimum, and minimal medical and nursing staff to handle radiologically injured as well as contaminated individuals. All State plans also have an annex that would include the medical facilities. There is a requirement for letters of agreement for both the hospitals, the transportation capability with ambulances, et cetera. So I think it would not be too much trouble to look these annexes up and assess the number of facilities.

In the case of the San Onofrey facility, I believe there is like a dozen hospitals within 15 miles but outside 10 miles of the nuclear power plant that have letters of agreement and have agreed to take care of injured personnel.

SPEAKER: As part of our program—I cannot speak for all of the programs—we did work with those hospitals at least once a year to review the programs. It really was a training, drill kind of a program that we went through.

STANGLER: Right. There is a requirement for an annual medical drill, minimum, for each hospital also.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 158–166, June 1988

Fear and Trembling and The Dog That Didn't Bark: Policy and Science

Keynote Address

John F. Ahearne

Vice President, Resources for the Future, Washington, DC 20036

I. Introduction

I start by quoting from an economist:

". . .I'd just like to offer a few thoughts about the future, looking ahead. . . .I see the potential of big changes coming about in the future. . . .there are smart people everywhere. And there are people all over this world that are working very hard along with their smarts. So that this spread of capability and capacity is going to change the structure of the world economy and the strategic situation, and we have to try to understand it. There is, I think, a gigantic amount of change in technology to go with this. . . .It's a cliche to say that it's a small world but it is a small world. We are a big part of it. There is no way that we can, once again, as we did after World War I, sort of remove ourselves from the world—it is impossible. The only question is how effectively are we going to engage. . . .And one of my fears right now is that somehow as we look at all of the difficulties and some of the things that you have brought out that there will be a tendency for people to throw up their hands and say, 'Stop the world. I want to get off.' We can't get off, we have to be engaged."

Those are final remarks of Secretary of State Schultz, at the recently completed Iran/Contra hearings.[1] I think they characterize the view of many people that technology is here, it is changing our life, it is changing the world. My comments address what role will technologists have?

This evening I wish to address a range of attitudes about technology. I will focus on what has been called the hazards, or risks, of technology.

By the phrase "policy *and* science," you should suspect that I am concerned whether policy and science go together. I believe they can, but often they conflict. Tonight I will address some problems in the application of science to policy in general, and to radiation safety policy in particular.

I speak as one who has had the advantage and the disadvantage of spending almost twenty years in Washington. This city has been described as a bottleneck for information. The government and its associated support groups produce volumes, tons, of information, much of which does not seem to pass beyond the local area (usually described here as "inside the Beltway"). The other difficulty is that the vast amount of knowledge, opinions, concerns, outside the Beltway seldom seem to penetrate effectively into Washington. The bottleneck works both ways.

I will make three principal points tonight. First, I will remark on a particular argument in the area of technological risk, how safe is safe enough. Second, policy in the area of technology is strongly affected by three major groups. I will describe at length one of the groups and some of the concerns I have with them. And third, how can technologists become more effective in developing policy, or affecting policy? My comments are intended to apply more broadly than to radiation safety policy. I intend them to apply across the spectrum of technological safety issues currently being addressed in the United States.

Before I go much farther, I will identify the sources of my title. I have taken it from two literary allusions. *Fear and Trembling* is the title of a book by Kierkegaard, a Danish philosopher writing in the mid-nineteenth century.[2] The book is based on a subject—appropriate at Georgetown—from the Bible, the Old Testament: how far can faith take a believer. The second is from a story by Arthur Conan Doyle, "The Adventure of Silver Blaze."[3]

II. How Safe is Safe Enough?

A debate that has particular significance to this conference's topic is on the question: How Safe is Safe Enough? In recent years, the EPA has tried to apply cost-benefit analysis to answer this question for some of the activities regulated by that agency. This approach has been criticized on many grounds, including the inappropriateness of applying economics to safety, the absence of ethical considerations, and an over reliance upon technical experts.

However, economics as a conceptual approach is based on rational analysis. Economic analysis does use what are called utility functions. But it is incorrect to infer that such a definition of utility is restricted to what can be bought and sold. Utility can include non-market goods, such as the value of unsullied mountain slopes, clean air at the Grand Canyon, and other environmental amenities. It can also include what might be called psychological satisfaction.

Some discussions imply a confusion between technology and the application of technology. This leads to the argument that a technology is unethical. Most technology is neutral. I grant there are exceptions: most would grant that poison gas is ethically negative. But usually, ethical issues are introduced in addressing how technology is used, under what constraints or controls, but not the technology per se. The aspect of the debate which directly involves the role of the technical expert involves a specific issue, that underlies all Federal safety regulation: What is an acceptable risk, or, how safe is safe enough?

This issue has been argued for decades. In a famous—to those in risk analysis—series of papers in 1975, published in *The George Washington Law Review,* Harold Green, an eminent jurist, and Philip Handler, a research biologist then president of the National Academy of Sciences, engaged in a discussion of—in Green's term—the risk-benefit calculus used in safety determinations.[4] The debate is over ten years old—but is still fresh.

Green wrote:

"Whether or not something is acceptably safe usually requires consideration of two aspects: an identification of potential injury and an assessment of the quantum of injury, and an identification of potential benefits and an assessment of their magnitude and importance. . . .

"Scientists and engineers have an important role to play in the making of safety determinations. Representatives of these disciplines are obviously better equipped than others to identify and quantify potential risks and to identify potential benefits." Here, Green hits on the sore point for experts. "It is questionable, however, whether they have special competence to quantify benefits in a manner that can be regarded as authoritative in the formulation of public policy. No elite group of experts, no matter how broadly constituted, has the ability to make an objective and valid determination with respect to what benefits people want and what risk people are willing to assume in order to have these benefits."

Handler countered: "The principal difference between my approach to the subject of 'safety' and 'risk' and that of Professor Green is that I insist on quantification wherever possible whereas Professor Green appears more comfortable with 'perception,' 'values,' 'order of safety,' 'judgment,' etc. This is made explicit, for example when [Professor Green] states that 'safe is rarely defined in the real world in terms of a one-in-a-million chance of an accident, except, perhaps, as a standard for assessment chosen by experts.' " Handler then asks: "What other choice is there?"

". . .government regulation of technical products and processes must rest on a rational and sufficient scientific base. Everyone has gained heightened awareness of the natural and man-made hazards to our environment. Governmental regulations or programs intended to combat those hazards must, as a minimum, rest on detailed appraisal of the nature and magnitude of those risks, of the monetary and other costs of measures intended to reduce the severity of each risk, and of the nature and magnitude of the benefits involved in the process or product under consideration. If those in public office choose to flaunt such data, let that then be clear."

Green had a different conclusion: "Even though a scientist may not regard a safety determination as incorrect, he feels uneasy. . .when the decision is not rooted in an assessment of soundly presented scientific fact. In this view, where the ultimate decision turns upon scientific questions, scientific fact should dictate the ultimate decision, or, at the very least, should define the factual predicates on the bases of which value conflicts are resolved. To the lawyer and the politician, on the other hand, facts (including scientific facts) exist to be used selectively and with variable weight as tools for framing positions in an adversary context and for making decisions of a practical, utilitarian nature. To the scientist, truth, objectivity, and accuracy are the ultimate *desiderata;* to the lawyer and the politician, the ultimate goal of public policy decision-making is the optimum resolution of conflict, and achieving this goal may require the symbolic acceptance of something as true which in fact is untrue or only partly true. This is not to say that truth is or should be cynically sacrificed at the altar of expediency; it is merely to recognize that decision-making in a democratic society almost always involves compromising, and temporizing, and therefore error, and that a democratic society can tolerate error in the expectation that ultimately truth will prevail. . . .Scientists are newcomers to the area of public policy decisionmaking. . .and [must] develop the capability of functioning within the institutional framework in a manner consonant with the basic principles of our forms of democratic society."

The Green-Handler debate has not been resolved, and technologists are still uncomfortable in public policy debates.

The groups most influential in determining public policy in the area of hazard management are technologists, managers, and concerned citizens. Here I will address the first.

III. Technologists

I will describe weaknesses in the approach many in this group now take, but in a short talk I can only sketch the problems. In my concluding remarks, I will describe how scientists and engineers can better affect the policy process.

I want to separate the general body of scientists, engineers and technologists into three subgroups:
(1)those who really know science and technology, (2) those who know a lot but are not experts, and (3) those who operate high technology systems but do not really understand the technology they are using.

A. The first group contains those who really do know the science or the technology—the true experts. Unfortunately, many cannot communicate their knowledge. They are not able to reduce their discussion to a level that can be translated by the media or understood by lay people. In some cases, this lack of communication is not due to an inability, but rather to a belief that it is not worth their valuable time. Perhaps there are none such here tonight, but I have met scientists who believe that writing for the general public is a waste of their time, that it is of little professional benefit, and that it also does little good. However, in the area of hazards and management of risks, it is critical for the experts to take time to communicate well. Doing so reduces the possibility and, for complex issues, the high probability, that technical accuracy will be lost in the translation to lay language. In addition, there is a point made by Robert Samuelson:[5] "It is not an onerous requirement that when writing about risk assessment to make the assessment intelligible to the people who might be exposed to that risk."

I grant that many good scientists do try hard but have difficulties dealing effectively with the media. Many scientists correctly are reluctant to say more than they know. Journalists have a tendency to treat this as equivocation, and so describe it to the public. Many lay people believe that when a scientist refuses to be definitive, it is equivocation, or, at least, indicates the scientist does not know much about the area. Many lay people believe that if you know something, you should be positive about it. Unfortunately, what a scientist can be positive about is often not what the lay person is interested in. This is a difficulty that will face all technologists who try to deal with the media. I encourage you to be patient with this problem, and to work with the media. I have found that most representatives of the media are willing to take the time to try to understand what you are describing, if it is obvious that you are making an effort to help them understand.

My hypothesis is that when an expert is not communicating effectively, that usually is due to inability or unwillingness. There are other reasons that I will mention in connection with my second subgroup.

B. The second sub-group of technologists are those who are well-informed about the science and technology, but do not really have a complete understanding. They are not what we would call experts. Unfortunately, they often believe they are. These take a paternalistic or maternalistic attitude towards the public: "Parent Knows Best."

This subgroup can be split into two further subgroups: Those believing the solution is education, and those believing the solution is trust. I recognize there are many experts who will also fall into these categories in the sense that they share the problems that I will now identify.

(i) Those who believe the problem is education. Their attitude is that if only the public were educated, they would agree with us. Although I do not imply Chauncey Starr does not fully understand technology—he is an expert—many of Starr's writings have this flavor. They importune the public to understand. Starr was one of the first to attempt to classify what he would probably call true risks and to rank such true risks relative to each other. This approach has not been abandoned, and was recently demonstrated in an article by Bernard Cohen in which he criticized what he sees as the irrational spending on cost per life saved in the United States. He wrote, "With any reasonable consideration. . .we are spending the equivalent of innumerable billions of dollars per life saved in our radioactive waste management programs." He also estimated that ". . .[the] NRC program of regulatory racheting [has led to] . . .an average of at least $1.6 billion extra [for each nuclear plant], for a total cost of $100 billion in an effort to save. . .fifty lives." He then commented, "Why is this insanity taking place?. . .the problem is that public concern is driven by media coverage rather than by rational scientific analysis. The media have driven the public insane over the fear of radiation and of nuclear power accidents."[6]

The attempt to address risk management by ranking risks from different hazards has led to an attempt to define acceptable risk. I can sympathize with this attitude. For many years, I shared it. When I was on the Nuclear Regulatory Commission, I tried to get the National Academies to undertake a study of the comparative risks of coal and of nuclear power, believing that the development of an objective view by a credible organization would significantly help the debate on the risks of nuclear power. However, I am now shifting to agree with the position of some who have concluded, "The acceptable risk formulation has provided increasingly elaborate and precise answers to the wrong question."[7] It is the wrong question because it is not linked to participation by and dialogue with the concerned public.

A similar conclusion, that education is necessary to resolve risk controversies, is seen in a recent study examining whether the sources of environmental conflict can be explained by the characteristics and views of the participants in the conflict. The researchers polled a variety of people as to what are the most important causes of environmental conflict. Nearly three-quarters of those polled labeled "public misunderstanding" as a major source. But those polled did not agree on what the public did not understand. The respondees whose educational background was in "hard expertise [viewed] environmental conflict as scientific rather than political, while those. . .individuals educated in the humanities or social sciences reject knowledge differentials as a major source of controversy. . . .Physical scientists, as expected, endorsed knowledge differentials, and reject value differences."[8]

As a technologist, I must admit I do lean towards what may be a biased interpretation of those results. I read the results as showing that those who understand technology see the conflict being between those who understand technology and those who do not. However, those who do *not* understand technology, do not see understanding as important. Unfortunately, this is a weakness, I believe, in many non-technologists, i.e., they do not believe understanding the technology is important to understanding risks of technology. I will return to this point.

These attitudes can also be seen in nuclear industry comments on the TMI and Chernobyl accidents. I ascribe this industry attitude as seeing the accidents as the "dog that didn't bark." You may recall that in the Sherlock Holmes' story, Holmes commented that the unique feature that led him to the solution of the case was that the dog didn't bark.[9]

Some of the nuclear industry have pointed to TMI and Chernobyl in a similar way. Three Mile Island destroyed a major reactor. It nearly bankrupted a major company. The cleanup has been underway for nine years, is still not completed, and the costs of cleanup will be about a billion dollars. But the health studies done by the Pennsylvania State Department of Health and the United States Health and Human Services Department indicate there were no significant adverse *physical* health effects associated with that accident and there are unlikely to be many. The Chernobyl nuclear accident, the worst accident known at a power plant, led to thirty-two deaths, several hundred people hospitalized, and a high radiation exposure to many thousands of the Soviet public. Nevertheless, the immediate deaths in the surrounding vicinity were much less than estimated by some previous studies from such a massive release of radiation. Consequently, some members of the nuclear industry have said TMI showed how well-built reactors are and Chernobyl showed that the worst accident would not be a calamity. In other words, the dog didn't bark. This argument, while perhaps scientifically correct, should not lead to the conclusion that nuclear power is now acceptable. The flaw in the conclusion is that it avoids addressing the public. And therefore, I included this attitude in the category: if the public were only educated, they would agree with us.

(ii) The second subgroup are those whose attitude is "trust me, I know best." This is characteristic of the approach that the U.S. Federal government has taken to deciding the location for nuclear waste sites, starting with the Atomic Energy Commission approach in Kansas, continuing with the Energy Research and Development Administration approach in the Midwest, and now seen for many years with the Department of Energy. This has led the chairman of a mid-West compact commission to describe the current situation for the case of low-level radiation waste siting as "the lines are clearly drawn: it is a battle between the technocrats and the public over whose values the technology will ultimately reflect."[10] "Trust me" is still used as the principal answer to "why are you doing that?"

Nuclear power has been afflicted with this approach. Many early advocates of nuclear power convinced electric utility executives of the advantages of nuclear power. These executives went ahead—aggressively—with ambitious nuclear programs. Much to the chagrin of later executives, who have found public opposition being reflected in adverse public utility commission rulings on rates. The latest trials facing such utility executives are prudency hearings. Essentially these are public utility commissions examining many years after a plant construction began whether the electric utility was wise to have built the plant. Frequently, the commission decides "no," and consequently the rate payers do not get charged for the plant. The President of the Edison Electric Institute earlier this year said, "Technology was the Siren who beckoned us to nuclear power—power that was supposed to be too cheap to meter but turned out to be too expensive to bill."[11] Thus it is not only the general public who are now skeptical of technologists who present an argument based on "trust me, I know best."

C. The third technology group are those who are engaged in operating high technology systems without really understanding them. Perhaps these should not really be characterized as technologists, but for the purposes of this talk I am lumping large groups of people into simple structures. In some cases, people in this group have had significant technical training, while in others, part of their problem is they have had too little. But, nevertheless, they use and therefore are strongly associated with high technology systems. The major weakness represented in this group is complacency.

Complacency can be reflected in many ways: a lack of recognition by management that increased attention need be given to technologies which have the potential of serious consequences; inadequate attention by operators, based upon a belief that the technology is so well developed that monitoring is not really needed; a belief it is not important to understand the technology; and a lack of attention to mundane matters, such as regular maintenance.

Aircraft accidents and near accidents have been attributed to complacency in the cockpit. These include a 1978 crash of a DC-8 in Portland, Oregon, when the plane ran out of fuel. The plane circled the airport while the crew tried to solve a landing gear problem. The flight engineer mentioned the plane was running out of fuel, but apparently the captain and co-captain did not hear, or did not react to the message, and the plane crashed. In 1978, a plane crashed three miles short of landing in Pensacola, Florida. An automatic warning device for rapid descent sounded, but was disarmed by the crew, which continued the descent to impact. This complacency could also be seen in the airline pilot who cut all engines during a recent takeoff from Los Angeles International Airport. The most recent example, which has not yet been resolved, is the apparent failure of the crew in Detroit to extend flaps during takeoff.[12]

The Challenger shuttle disaster led to a major review chaired by William Rogers.[13] The report makes interesting reading for those concerned with the effect of complacency. The complacency problems surfaced between the lower levels of NASA and its contractors and the top of the agency.

The Rogers report described the pressures on NASA which followed the announcement that the shuttle was fully operational. The Rogers report states: "From the inception of the shuttle, NASA had been advertising a vehicle that would make space operations 'routine and economical.' The greater the annual number of flights, the greater degree of routinization and economy, so heavy emphasis was placed on the schedule."[14]

". . .resources were strained to the limit, strained by the flight rate itself and by the constant changes it was forced to respond to in that accelerating schedule."[15]

". . .arguing in support of the space station [in September, 1983], [NASA Administrator] Beggs said, 'We can start anytime. . . .the shuttle is now operational.' "[16]

However, "according to Astronaut Henry Hartsfield:

'Had we not had the accident, we were going to be up against the wall. . . .somebody was going to have to stand up and say we have got to slip the launch because we are not going to have the crew trained.'[17]"

"As [Shuttle] Program Manager, Arnold Aldridge reported to the Commission: '. . .intentional decisions were made to defer the heavy buildup of spare parts procurement in the program so that the funds could be devoted to other, more pressing activities. . .' "

"Those actions resulted in a critical shortage of serviceable spare components. To provide parts required to support the flight rate, NASA had to resort to cannibalization. Extensive cannibalization of spares. . .became an essential *modus operandi* in order to maintain flight schedules."[18]

Thus, underlying the problems that led to the Challenger disaster, was simply a disbelief that this technology was really hazardous—complacency by those who did not really understand their system. Many reports on the Three Mile Island accident showed that a lack of operator understanding was a precipitator of the accident. With appropriate understanding by the operators the accident probably would never have happened.

Similarly, the reviews of the Chernobyl accident illustrate the complacency which had afflicted the crew of this plant, because it had been operating so well. The judge who recently sentenced the plant director to ten years in a labor camp said, "There was an atmosphere of lack of control and lack of responsibility at the plant," adding that "workers on duty played cards and dominoes or wrote letters."[19]

IV. Conclusion

What can be done if anything to address these problems. I will only speak to technologists and scientists, because I believe they are the heart of the problem. Now, what can they do:

1. They can understand the technology that they deal with. They should be alert to surprises. Anyone growing up with an understanding of the many scientific discoveries that were the result of intelligent observation of experimental accidents should not misunderstand that lesson.
2. They must be alert for signs of complacency.
3. They should listen and discuss with the public. It is the public's lives that will be affected. It is both right and, since we are in a democracy, the only constitutionally valid approach to use.

And, you may learn something important. Uneducated does not mean not insightful.

This listening must be a true dialogue. Public hearings should be hearings, not, as was recently mentioned in a description of a New York City Board of Estimates' meeting, only "public talkings."

4. You should push for competence in government. You understand technology. You should not allow superficial treatments of technology to pass for understanding on the part of government officials. Scientists involved in making science policy, however, often have not demanded competence on the part of government officials. Worse, they themselves demonstrate a willingness to use less than their normal standards of professional behavior. Harvey Brooks pointed out: "Scientists inexperienced in the political arena, and flattered by the unaccustomed attentions of men of power, are often inveigled into stating their conclusions with a confidence not warranted by the evidence and. . .not subject to the same sort of prompt corrective processes that they would be if confined within the scientific community."[20]
5. In the U.S. all controversial issues seem to end up in court. "Expert" witnesses proliferate—and disagree, often strongly. I believe that we should establish a system of "friend of the court." The professional societies, American Chemical Society, American Physical Society, etc., should develop *pro bono* experts. A panel from the Society could use consensus agreement to address issues that courts need addressed. These "friends of the court" should be paid through the court system. Then if in a significant court hearing a scientist is needed to address a scientific issue, or an engineer is needed to address a technical issue, one of these friends of the court would appear to discuss the scientific or technical issues. If a scientist or an engineer wanted to appear for one of the sides in the case, the technologist could not appear as an "expert" witness, but as an "advocate" witness. This would address a major reason for a growing disbelief on the part of the public in what scientists and technologists say.

The public is not fooled by the disputes between scientists, or expert witnesses. Rather they are beginning to become skeptical of the objectivity of science and technology. A recent controversy with regard to whether the large funds spent on cancer research have done much good led to charges being thrown back and forth, heating up the pages of *Science* and the general press. Daniel Greenberg wrote about this controversy: "When scientists become abusive, pay attention. The departure from professional decorum means something important is at stake."[21]

We scientists and technologists have not been much help in developing rational policy in the areas of hazards. We share significant responsibility for what Bill Clark has described: "Society's attitudes towards risks such as cancer and nuclear reactors are not readily distinguishable from its earlier fears of the evil eye."[22]

Each time a technological disaster occurs, TMI, Challenger, Bhopal, Chernobyl, meetings like this one are held. Unfortunately, the general descriptions of the problems and the recommended solutions are uncomfortably similar. Progress is *not* our most important product.

References Cited

1. **Schultz, George P.,** testimony, Iran-Contra Hearings (pp. 51-1 to 55-1 transcript text). July 24, 1987 (pm).
2. **Kierkegaard,** *Fear and Trembling,* Penguin Books, Ltd., 1985, p. 18.
3. In the *Complete Illustrated Sherlock Holmes,* **Arthur Conan Doyle,** Castle Books, Secaucus, New Jersey, 1977.
4. **Green, H.** "The Risk-Benefit Calculus in Safety Determinations," 43 *Geo. Wash. L. Rev.* 791, pp. 796–807 (1975). Handler, P. "A Rebuttal: The Need for a Sufficient Scientific Base for Government Regulation," 43 *Geo. Wash. L. Rev.* 791, pp. 808–813 (1975).
5. "A Reporter's and Father's Perception of Risk," The Colloquium by and for Regulatory Analysts," 24 March 1986, Washington, D.C.
6. "Insanity in Action; Reducing the Hazards of Nuclear Power," Bernard L. Cohen, *Physics and Society,* Volume 16, No. 3, July 1987.
7. "Beyond Acceptable Risk: On the Social Acceptability of Technologies," Harry J. Otway and Detlof von Winterfeldt, *Policy Sciences* 14 (1982), p. 255.
8. "Defining Conflict as a Means of Legitimizing Resources," Thomas Dietz, Paul C. Stern, and Robert W. Rycroft, unpublished manuscript, July 1987.
9. "Inspector: Is there any other point to which you wish to draw my attention? [Holmes], "To the curious incident of the dog in the nighttime." [Inspector] "The dog did nothing in the nighttime." "That was the curious incident," remarked Sherlock Holmes. (pp. 196–197) ". . .significance of the silence of the dog. . . he had not barked enough. . ." (p. 199). "The Adventure of Silver Blaze," *op cit.*]
10. "Issues in Radioactive Waste Management," Clark W. Bullard, Chairman, Central Midwest Compact Commission for Low Level Radioactive Waste Management, Oak Ridge National Laboratory, April 30, 1987, p. 13.
11. Speech by Jerry Geist, 55th Annual EEI Convention, June 8, 1987.
12. "Automation, Routine Can Produce Cockpit Inattentiveness," Douglas B. Feaver, *Washington Post,* 8/23/87, p. A1.
13. *Report of the Presidential Commission on the Space Shuttle Challenger Accident,* June 6, 1986, Washington, D.C.
14. *Ibid,* p. 164.
15. *Ibid,* p. 164.
16. *Ibid,* p. 165.
17. *Ibid,* p. 170.
18. *Ibid,* pp. 173–4.
19. "Chernobyl Officials are Sentenced to Labor Camp," *The New York Times,* July 30, 1987, p. A5.
20. **H. Brooks,** "Expertise in Politics: Problems and Tensions," Proceedings, American Philosophical Society, **119:** p. 259, 1975.
21. Quoted in *The Public Interest,* No. 88, Summer, 1987, p. 151.
22. "Witches, Floods, and Wonder Drugs," William C. Clark, R-22, Institute of Resource Ecology, University of British Columbia, January, 1980, p. 11.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 167–172, June 1988

The Media's Coverage of Radiation Risks

David M. Rubin

Center for War, Peace and the News Media, New York University,
New York, NY 10003

In 1979, I was the head of the Task Force on the Public's Right to Know for the President's Commission on the Accident at Three Mile Island. One of the opportunities of that experience was that I had a chance, with my group, to practice journalism with subpoena power. I have practiced journalism with subpoena power, and journalism without it. Let me tell you, having subpoena power is the only way to go, if you can get it. But it's the only time I've had it.

As a result of the Three Mile Island experience, I was able to reach some tentative conclusions about why mistakes were appearing in the news media during the first really difficult week of that accident. We examined what utility officials, the NRC officials, and state government officials were saying to the press and the public, and we identified where the bottlenecks in communications occurred. We made recommendations in that report to the utility companies, government officials, and the press on how better to perform their jobs in emergency situations.

Fortunately, there has been no comparable test in the United States since Three Mile Island to determine whether any of the procedural problems we identified have been solved, or whether any of the specific recommendations have been adopted.

The accident at Chernobyl in April and May of 1986, however, provided the American press with a second opportunity to report on a serious power plant accident. As a co-director of the Center for War, Peace, and the News Media, at New York University, which looks at how the media cover U.S.-Soviet relations and the arms race, I examined American and European coverage of the Chernobyl accident during the first three weeks, when events were quite confused. I was able to draw some comparisons between coverage of the Chernobyl accident and Three Mile Island.

There are enough similarities in coverage of the two events that I have now reached some tentative conclusions about how journalists operate—indeed, must operate—during events of this type. Because of the way journalists in the United States work and the pressures they work under, and because of the nature of the events themselves, I fear it is inevitable that critics of journalism will say that coverage of serious power plant accidents is "sensational" or "inaccurate," for lack of better words. Further, there may be little that journalists can do to head off these charges.

Having studied these two accidents, I am, therefore, going to offer you "Rubin's Four Rules" that govern media coverage of serious, or seemingly serious, nuclear power plant accidents. I admit that concerning the Chernobyl accident, I was unable to answer many questions about information flow in the Soviet Union, so I had to make some educated guesses about who knew what, and how much was being communicated by Soviet officials. I obviously have much more detail about TMI than Chernobyl.

With that caveat, let me offer these four rules. By the end of the presentation, you will see that criticism of press performance is probably inevitable.

Rule No. 1: Big stories demand lots of space in newspapers and lots of air time on television and radio, because that is what signals they are big stories. Once those who determine news play have committed to the notion that a story is "a big story," then they signal their readership or viewership that this *is* a big story, not just by the positioning of it on the front page or at the top of the newscast but also by the amount of space that they choose to give it. Once editors have committed all those column inches and all that air time, they must fill it with words or images, even if there is little hard, confirmed information to report.

I wouldn't quibble with editors who decided that both TMI and Chernobyl were "big stories." Both clearly fit the definition of "news." TMI was a potentially serious nuclear power plant accident. It was ongoing; that is, it was not over by the time the press found out about it, which meant that journalists could get to the scene and actually witness it as it was playing out. There was evacuation potential, which meant that large numbers of people might be involved. The location was near enough to major media centers—New York, Washington, Philadelphia, Pittsburgh—so that many journalists could get there quickly. It was not clear how serious this accident was going to become. All these factors made it a "big story."

Chernobyl evinced some of the same "big story" features, as well as others. First, it happened in the Soviet Union. From an American perspective, that immediately makes it news. The United States was still very much in the grip of an "evil empire" view of the Soviet Union. The accident was viewed as a test of "glasnost," Soviet Communist Party leader Mikhail Gorbachev's policy of openness; how would it apply to this accident? This was a test of Soviet secrecy. It was also unclear how serious the accident was, although from the beginning it was correctly viewed as more serious than TMI, and probably more serious than any other past accident. And like TMI, it was ongoing.

The "big story" rule really gets the ball rolling toward charges of media sensationalism and inaccuracy. Once the press is committed to the notion of the big story, it must fill a lot of space to prove it.

This leads to Rule No. 2: Newspaper space and television time will be filled with *something,* for better or worse. Editors cannot signal that TMI or Chernobyl is a big story and then say, "We don't know anything else" and provide only two or three paragraphs. The large news hole must be filled. The question is, "How?"

In reporting such stories, journalists are essentially captives of their sources. Good journalists will try to contact those sources they believe are in the best position to know what is happening at a particular point in time. Sources, of course, vary in quality. Good journalists will bring to the interviewing process sufficient knowledge of the subject so that they know what to ask sources, and how to evaluate the answers by comparing them to what they are hearing from other sources.

If journalists cannot interview the sources they want on a story like this, they do not have the option of saying to their editors, "I can't speak to any of the people who really know what is going on. I don't have a story." Editors expect stories. They need to fill space. Journalists will have to seek alternative sources to report some sort of story.

If one examines the inaccurate, speculative or sensational information reported during TMI and Chernobyl, it almost always appeared because journalists were forced to rely on sources who were themselves uninformed, speculative, or sensational.

For example, during Chernobyl, some of the most incendiary information came from foreign ham radio operators, whose broadcasts were picked up. In one case, this resulted in a story that thousands were dead as a result of the accident, and that they were being buried in mass graves.

Should those ham radio operators have been credible sources? Some media accorded them more credibility than did other media. Those wild estimates of the number dead received bigger play in some media than in others. But at root, it was the lack of information from key Soviet sources that permitted those ham radio operators to gain any credibility at all.

Similarly, many journalists resorted to interviewing Ukranian Americans about what they were hearing from relatives living close to the accident. Many of these interviewees were strongly anti-Soviet and prepared to believe the worst about what was happening. Much of what they said appeared in newspapers that serve large Ukranian-American communities, such as Chicago or Cleveland, as well as in New York and Washington.

A lack of sources also produces "man in the street" coverage. A reporter may legitimately want to plumb reactions of local residents, but there is also pressure to do that if one is having difficulty getting information from other sources. Such "man in the street" information can often be wildly inaccurate as to what is happening, and it can even be an inaccurate indication of what the community is in fact thinking.

Citizen activists—in the case of nuclear power, generally opponents of the technology—often receive much attention in the press during an accident, because journalists know who these people are. They have their phone numbers. They know how to reach them. During Three Mile Island, some came to the plant site to be available to journalists. These activists know how the journalism game is played. They are aware that they can get their views into the press at that time. It is another way for reporters to fill space. Some citizen activists have technical expertise and can provide a useful perspective. Others offer a political perspective on these questions.

All these groups are alternatives to the kinds of sources journalists would prefer to have during such accidents; that is, sources who are on scene, fighting the emergency, who can explain why it happened, what the status of the reactor is, when it is likely to be under control, and the amount of radiation released.

Rule No. 3: In any nuclear power plant accident, there is built-in controversy. Conflicting charges and counter-charges are inevitable. A power plant accident is a disaster like no other. As a news story, it cannot be compared to a hurricane, an earthquake, a flood, or any other kind of disaster. One reason for that is the large number of groups in the United States well-organized in opposition to the technology. There are no strong citizen groups in opposition to hurricanes, earthquakes or floods.

In addition, journalists have come to the conclusion there are no neutral sources on nuclear power plant accidents. This is not the case concerning sources of information on hurricanes, floods, fires, famines and so on. On nuclear power, sources are on one side or the other. Therefore, reporters can and do pit sources against each other. This creates conflict in news stories, and conflict is one important element of journalism. This also helps to contribute to what appears to be sensational or inflammatory news coverage.

Journalists have by now decided on the likely bias of potential sources in the nuclear power area, and they therefore approach those sources with certain assumptions. For example, most journalists assume that utility officials are pro-nuclear power; that they are, in whatever they say, protecting their own careers and the technology to which they are committed; that they are unduly optimistic about what is happening at the plant during an accident; and that whatever they say needs to be discounted or played down in light of that. Journalists also assume that most NRC officials share the bias of utility officials, largely because NRC officials have the same stake in the safety of the technology that utility officials have and, therefore, they would prefer to see the optimistic aspects of an accident emphasized, as opposed to the worst-case fears.

On the other side of the ledger, journalists believe that most citizen activists are opposed to the technology and are, therefore, grinding an ax. Academicians fall on both sides: some are well known to support the technology, and others are well known to oppose it. Journalists know which are which, and they seek them out precisely to elicit contending, conflicting views.

One of the few groups that journalists might concede is neutral or unbiased in this area is meteorologists, who will discuss wind currents and possible patterns of radiation dispersal. A second group might be persons gathering data about radiation releases. During Chernobyl, for example, Swedish and Finnish meteorologists and radiation experts were accorded high credibility with the worldwide press corps, although I do not believe Soviet scientists from the same disciplines would have been believed by American journalists, just as they mistrust utility officials in the United States.

It is still possible that State government officials—in the case of TMI, Pennsylvania—maintain a reputation for honesty with the press and are viewed as sources who have no ax to grind.

It should be added that I do not believe journalists themselves are objective about this story, given its emotional content and history. Journalists have views. They bring to stories all kinds of baggage. They are now suspicious of any story that deals with radiation releases or nuclear power, in part because of the past history of governmental secrecy in this area. The constraints on information concerning matters nuclear have made journalists rightfully suspicious of whatever is said about the technology. They are also suspicious of utility cover-up, because the utility has the most to lose during an accident. Indeed, they are now suspicious of the entire nuclear power plant program of the last 35 years because of the manner in which it was oversold to the public. Journalists do not like to be used in a public relations program.

During Chernobyl, American journalists were, of course, also suspicious of the Soviet government. Almost every Soviet statement during the first three weeks was greeted with great skepticism, even though many turned out to be accurate, if woefully incomplete and late.

Finally, in reporting any serious accident, journalists are going to look for blame. This element is absent in coverage of a hurricane, earthquake or flood. Looking for blame automatically injects controversy and sensationalism into a story. All of these suspicions and biases which journalists bring to nuclear accident stories serve to heighten controversy and create the appearance of sensationalism.

Rule No. 4: Journalists care more about the future than about the past. One might even go further to say that they care more about the future than the present. Look, for example, at the coverage in September 1987 of the agreement in principle with the Soviet Union to sign a nuclear weapons treaty. The most interesting questions are what this will mean for President Reagan's influence on Capitol Hill, for his ability to conclude future treaties, for Mikhail Gorbachev's power in the Soviet Union, for future agreements between the two countries.

It is amazing how much of the information does not deal with what happened yesterday, or what it says about the relationship between the two countries over the last six years, but rather is speculative. This is a key reason journalists write all the worst-case scenario stories, or ask the what-if questions that utility and NRC officials hate and fear. Such questions force them to lay before the public the worst possible consequences of an accident, consequences they feel will not happen and which they honestly feel are irresponsible to discuss. People read their responses, become alarmed, and then blame the press for sensational coverage. This phenomenon is also related to the difficulty of discussing risk during an accident. It is hard to put risk into a proper perspective when one is asked these what-if questions. The press asks them, in part, because they are interested in the future, but also because the press feels it has a responsibility to protect the public.

On this score, the American press and the Soviet press disagree on how best to protect the public. The American press does not want to be in the position of having underestimated the risk. If the American press were to cover an accident in a fairly low-key and reassuring manner, and then something terrible were to happen, the press would be seen as having been in league with those who were giving an optimistic view of the accident and would be blamed for it. The American press very much wants to avoid that. In the Soviet Union, it is just the opposite. The press does not want to alarm the public. It played down the seriousness of the accident at Chernobyl so as not to alarm the public. One could debate which method is more responsible and which better serves the public. But there is that difference.

As a result of these four rules, should another serious power plant accident occur anywhere in the world, certain aspects of the coverage can be predicted.

First, a wide variety of sources will be consulted because of the need to fill space. Sources will vary widely, and wildly, in their credibility and in the quality of information they have. Second, as a result, there will be many mistakes in the coverage—some of them big, most of them small—because the sources themselves are incorrect. They have false information, or they have old information, or they are shading the truth, or they are lying. Third, journalists will be under deadline pressure, and many will be underprepared. They will hear what they want to hear and see what they want to see. They will bring some of their own baggage to the story. Journalists will inevitably charge officials with covering up or lying. Often, these words are an exaggeration. In most cases, sources simply do not know. But reporters cannot be in the position of saying "We don't know." They have to fill that space. As a result, reporters press for answers from whoever can supply them. Often those answers turn out to be incorrect.

As a result, there will inevitably be public confusion. The public will proclaim a continuing erosion of confidence in the media. There will be much breast-beating about press performance. If one goes back to examine press coverage of both Three Mile Island and Chernobyl—particularly Chernobyl—it is surprising how much of the information reported at the time was fairly accurate. If one had thoroughly read three or four different newspapers, and watched all three television networks, it was possible to get a good picture of what was going on. But then not many people in the audience do that.

Many in this audience are persons who function as sources for journalists and who would like to make this process work better. There are some things they might do to improve the situation.

First, the Denton-Blix approach. Harold Denton, on the third day of the accident, was sent to Three Mile Island as a sort of information czar to bring order out of the chaos, to provide regular briefings, and to become a central source of accurate information for the press, so journalists would not have to keep scurrying around to alternate sources collecting misinformation. That system worked pretty well at Three Mile Island. It finally worked at Chernobyl, where Hans Blix of the International Atomic Energy Commission was a much more credible source than anyone the Soviets could have provided.

If government and utility together can designate a Denton or a Blix early in the accident, and set him up in a place where the press had gathered, this will reduce the press' need to go to alternate sources to fill space. A Denton or Blix might provide so much information that reporters would have little—or less—need to go to outside sources. While journalists will always go to some outside sources as a check on what they are hearing at the site, the more information the utility and the government provide to the press, the more space they will fill. The more space they fill, the less need journalists will have to consult other sources.

One risk with a Denton-Blix approach is that if the press ever catches the information czar in a lie, then the game is over. Reporters will never forgive an information czar in whom they have placed that kind of trust for misleading them. A Denton or Blix must be selected very carefully. An examination of Denton's performance at Three Mile Island indicates that he did a very good job, particularly since he did not know he was going to be playing that role, had never done it before, and was really improvising when he did it. While he wasn't totally candid, the press didn't find him out at the time. That was key. Had he been found out at the time, even more serious information problems would have ensued.

Also required is that the information czar have a support group of other people available to provide information across a range of topics right at the site so the press need not go to other sources. Any source caught in a situation like TMI should not lie, and should attempt not to provide old or outdated information. Journalists, if they are given outdated information, and then hear newer information, are likely to assume a coverup. They are less likely to assume that a source had old information. It is also advisable not to be too optimistic during an accident, because journalists are suspicious of such optimism.

In conclusion, however, do not be surprised if coverage of the next TMI or Chernobyl is just as controversial as it was in 1979 or 1986. This is a situation beyond remedy so long as the press in the U.S. works under the pressures that it does.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 173–177, June 1988

Covering Radiation Risks and Benefits

Richard D. Smyser

Editor, The Oak Ridger, Oak Ridge, TN 37831

Preparing for this talk and going through my large, if not well organized, accumulation of newspaper and magazine articles related to nuclear power, I discovered that I have a collection. Well, not a collection, but at least the start of, an idea for a collection. Until a better name occurs, I shall call it my collection of "Obligatory Skeletons."

Could I have the first slide please:

(Slide of ad in the Philadelphia Evening Bulletin promoting a coming series of articles on nuclear wastes. Ad features a large skeleton.)

This is an ad from the Philadelphia Evening Bulletin, or I should say the late Philadelphia Evening Bulletin. It died in 1982, like so many metropolitan afternoon newspapers have died.

Next slide, please.

This is an illustration in Deadline, a publication with which a fellow speaker, David Rubin, of New York University, is associated. The skeleton here, you will note, is digging his own grave while the Chernobyl Nuclear Power Plant, I presume, looms in the background. These are the only two "obligatory skeletons" I have now in my collection but I know that in time I'll locate many others that have appeared as illustrations with nuclear articles. I call them "obligatory skeletons" because, on this subject, it seems they are expected, required.

Next slide, please.

(Slide of Washington Post special section cover showing cooling towers.)

And if not a skeleton, then some menacing cooling towers, either conceived by an artist to suggest something other than benign energy or taken by a photographer with a telescopic lens so that they loom, loom, loom.

Next eight slides please, somewhat slowly, with pauses between.

(Early man lying in shadow of cooling tower);

(Cooling tower with "What if?");

(Cooling tower with question mark);

(Cooling towers presented as grotesque heads);

(Cooling towers in vivid purple and pink);

(Russian bear emanating from cooling tower);

(Wash flapping in foreground, cooling tower in background);

(Cooling towers belching smoke and fire).

Now just a few more from my very beginning collection:

Next slide please:

(Slide of vivid yellow radiation hazard symbol with headline "Deadly cargo.")

Plutonium has inspired many newspaper graphic artists too. Next slide please:

(Slide of another page from Anchorage Daily News.)

Stories on the possible preservation of foods by radiation still further inspire both artists and photographers. Next slide please:

(Slide of page from Charlotte Observer.)

This appeared just two weeks ago in the Charlotte Observer. It's a presentation on the pros and cons of food irradiation, although I tend to doubt the objectivity of the photo editor at least.

So much for my beginning collection. I'll welcome contributions.

I have just a few more slides on a somewhat different aspect of my subject. Next slide please:

(Slide showing nuclear story on inside page of paper.)

Note that all of the stories I have marked on these pages are, on any relative scale, positive stories about nuclear power. Note also that they all appear on inside pages of the newspapers—not on page one. Now all but the last slide please.

(Pause for comments on appropriate slides.)

And here's some interesting media risk analysis: A trace of radiation exposure is given greater, if not really much greater, prominence than the evacuation of 5000.

I could, of course, have shown an equal number of front pages featuring, with quite large headlines, first reports on the nuclear accidents concerned here, chiefly Chernobyl, but you are all well aware of those.

Let me have the last slide, please, one that is somewhat out of sequence but I show it now rather than interrupt again.

(Slide of The Oak Ridger's weekly "Radiation Report" included with the other weather information.)

This is something my paper has been doing since the summer of 1979, just after Three Mile Island. We may be unique.

The slides I have shown make it clear that the emphasis of media coverage on nuclear power is negative—significantly more negative than is the emphasis on most other subjects.

Why? Because nuclear is a terribly flawed and deadly technology? Or is it some sort of liberal media or subversive plot?

I don't really know why the emphasis is so negative, although I do know that it is not a media plot, nor do I think it is a subversive plot. For myself, in the very final analysis, I reason that any technology that we learn about first in terms of the deaths of hundreds of thousands of people, even though they are hundreds of thousands of people in an enemy country during a terrible war that has killed millions—any technology born in the public consciousness in this context is going to have a lot of trouble developing a positive image. Nor do subsequent events like Three Mile Island or Chernobyl help.

But I don't really want to talk today about why nukes get such a bad press. I want to suggest instead some things that all of us might consider toward giving the public, through the press, a fuller, fairer base of information on which to evolve future judgments of nuclear technology.

I have separated my suggestions into three parts:

First, what we of the media might do;

Second, what you of science, technology and government might do;

Third, what we all might do together.

I have oversimplified the separation as I have oversimplified, for the sake of time, many of my suggestions.

First, the media:

Process reporting: News is not just a succession of events. Most things don't just happen—they evolve. Events are news, but so are processes and especially the process of the development of technologies.

Media suggestion number two: Do we tend to report so heavily on the potential dangers of nuclear power plants because these dangers have been so widely assessed and extrapolated? Are the "worst case scenarios" that have been developed for nuclear power plants a weakness or a strength of the technology?

Joe Kramer, in an article in the March issue of Quill, writes of the "sixth w"—"What if?" Have we done so much "what if?" reporting of nuclear power because, other than Three Mile Island and now Chernobyl, we have had no specific examples? Have we "what iffed" any other story so constantly, so thoroughly?

Let's reexamine our use of words. Have we developed some cliches? Does radiation always spew? Is plutonium always deadly? Was Darrell Eisenhut, member of the NRC staff in 1979, really "big-boned, square-jawed, wire-rimmed, blond—the compleat nuclear man," as the Philadelphia Inquirer described him? Is there no one on the NRC staff who looks like Woody Allen?

Relatively recent surveys show that 40 percent of the public still believes that a nuclear power plant can explode like a nuclear bomb. It is not taking sides in the nuclear power debate to try to correct that wrong impression.

We should recognize that on this issue—in fact on most issues in these times—pro and con is not enough. There are not just two sides in many of the disagreements. There are, instead, three, four, five different positions. Let's make sure we present them all.

And still more suggestions for us of the media:

Develop not just a passion for accuracy per se, but also for context, qualifiers, perspective, background.

Is nuclear really so "Dr. Strangelove"? Or it is something very much of nature—of this earth? How many newspapers have written about the natural chain reaction that occurred 2000 years ago in uranium deposits in Gabon, Africa—a natural reactor that, over eons, disposed of its own nuclear wastes too?

Let's report the total energy story. Put nuclear power into the context of the "greenhouse effect" and the Persian Gulf.

My suggestions for science, technology and government:

Help us to do process as well as event reporting. Be available to explain your processes as well as your events. Appreciate that the public is capable of understanding the uncertain, the incomplete, the ongoing.

Work to still further eliminate elitism and clubbiness within science. The value of peer review notwithstanding, develop an equal respect for public review.

Stop making lepers out of those injured in radiation accidents. (And stop calling those accidents incidents.) Report the names of victims of these accidents as you report the names of other accidents—vehicles, falls, fires.

Aside: I suggest that Charley Foust is a hero of sorts in the cause of public acceptance of nuclear power. Charley works at Oak Ridge National Laboratory and he suffered a small exposure in an accident there in early 1986. Charley didn't actually aggressively announce himself as a victim, but when he was quoted anonymously and incorrectly in another newspaper about the accident and then was contacted by us, because we had learned his identity unofficially, he did not object to our use of his name to correct the misquotation. And soon after that, another of our Oak Ridge nuclear workers, L. D. Conger, of the Y-12 Plant's Metal Preparation Division, suffered an exposure and specifically asked that his name be used. Nor have either Foust or Conger been shunned or otherwise abused by the public.

Still more suggestions for you of science, technology and government:

Work to get the NRC to open all of its hearings, meetings.

Stop comparing nuclear power risks to highway fatalities and airline crashes. It's boring.

Combat the kind of mentality that was apparent when, after Chernobyl, DOE slapped a gag rule on its scientists and engineers—the people most capable of intelligent comment and reaction.

Watch your jargon: You know what the "BEIR report" is, but I had to spend more time than I should have spent to find out that it's the 1972 report of the Committee on Biological Effects of Ionizing Radiation of the National Academy of Science.

And heed this advice from Elizabeth M. Whelan in her book "Toxic Terror," as adapted for the December 1985 Quill:

"Obviously, all scientists and health professionals can't be expected to ditch their careers in favor of media tours, but it seems reasonable to ask some of them, particularly academic physicians, to make themselves available to the media from time to time, and to learn to present their messages with a proficiency comparable to that of the average quack.

"All health professionals, however, should make a point of keeping track of the current fads and frauds being promoted by the media. Even if they never go on the air, health professionals can exert some social and economic pressure by praising those stations that are fair and responsible in their coverage of health topics. . .

"Physicians and scientists should not deny or fight the power of the media; they should join it. If a charlatan is in town, a qualified professional should be demanding a debate. To stand back is to permit facts to be distorted—a dangerous error of omission."

These are things we need to work at together:

How can we make the public more aware that the effects of low level doses of radiation are simply not yet substantially known and will not be known for who knows how long?

Can't we find some way to make the language of radiation exposure measurements simpler, more consistent—as simple as temperature and barometer readings? My own newspaper's regular printing of the background radiation readings in our community is an indirect effort toward that end. Rads, rems, body rems, man rems, milirems, person rems, becquerels, rutherfords, curies, roentgens, coulombs: Help! High level scientific committees have been formed to attack many other problems. Why not a blue ribbon group from the National Academy of Sciences to simplify the language of radiation exposure: Two dental X-rays, membership in a Frequent Flyer club, sleeping with your spouse, sleeping with your spouse in a masonry building?

Let's work together toward mutually agreeable guidelines for check backs, read backs on sensitive stories. I emphasize mutually agreeable. There are very good reasons why we of the media are cautious about read backs.

Work together also to develop lively, colorful, but accurate and fair analogies. Like this one: Fusion scientist describing problems of dealing with exceedingly high temperatures: "It's not something we can fan with a hat;" a nuclear reactor engineer describing a long since abandoned reactor concept, the homogeneous reactor: "It's a soup instead of a Swiss watch."

Work together to make organizations like Scientists Institute for Public Information (SIPI) work better: scientists and engineers by adding their names to the tens of thousands already listed for all-hours availability for media inquiry; media people by spreading the word about and using SIPI.

And that NAS committee seeking a simplified language for radiation exposure measures might do at least beginning work on developing a scale for measuring all risks. We tossed this around in the editorial columns of my paper and got some interesting suggestions. What about saying that such and such a risk is so many "cigs"—for cigarette—or so many "Naders" for you know who? Or, more specifically, my Oak Ridge friend John Haffey suggested: "Why not evaluate risks in relation to their known record and potential benefits, hazards and consequences on three major areas: Lifespan (health and mortality), livelihood (jobs and economics) and lifestyle (environment and quality of life)?"

Further, let's agree on what "meltdown" means—literally.

The word has now entered the language in the figurative sense. We now have all sorts of meltdowns—stock market meltdowns, Chicago Cubs meltdowns (when they let the Phillies score seven runs in the seventh inning Wednesday night). But what does a reactor meltdown really mean? Now that it has been established that the core did indeed melt at Three Mile Island but that all but only infinitesimal amounts of radiation were contained, is that a meltdown, or must there be devastating effects on the public—a China Syndrome?

And perhaps most important of all, in conclusion, let us guard against becoming preoccupied with—hung up on—each other: Government and scientists vs media. We need to communicate with each other, but only because we both need to communicate with the public—and a very smart public—a public that, like the late Raymond Clapper told us many years ago, "knows only half as much as we think it knows but is twice as smart as we think it is."

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 178–185, June 1988

Non-Media Communications

Karl Abraham

Senior Public Affairs Officer
Office of Governmental and Public Affairs
U.S. Nuclear Regulatory Commission,
King of Prussia, PA 19406

ABSTRACT

People who are very worried about the effects on themselves of the various uses of radioactive materials and radiation will tell you they are less interested in statistical or technical discussions of relative risks than they are in obtaining some practical advice that recognizes their own desires and fears and that is given in a language with which they are comfortable.

People will call up a government information officer and ask questions that they feel are too delicate to be asked of their family physician. They will, in the most hushed, discreet-sounding tones ask for financial information that they believe to be too sensitive to be anything but "insider" information. They don't know that it is locatable at any time in Standard & Poors. They will try to get from you a special dispensation to wear radioactive jewelry a week after every newspaper in the country has carried NRC warnings against it because "it's just so very, very beautiful. It was the last present my sister ever gave me. I promised her I'd wear it always." We "negotiated" that she could wear it to dinner on her late sister's birthday (for about three hours, once a year) on the theory (altogether lacking any proof) that the small exposure probably would do her less harm than feeling guilty about it all the time by never wearing the keepsake at all.

Many people, most of the time, aren't sure how to even ask questions about the nuclear business. They will begin by explaining that they have an open mind and don't want to be labeled either "pro-nuclear" or "anti-nuclear." They don't want to sound "ridiculous" or "ignorant" and often will begin by saying "this may sound like a dumb question, but . . ." to which I always reply that there are no dumb questions, only dumb answers.

In my schooldays, somebody told me that there were only seven great plots in all of fiction, and all the others that we found in literature were variations and elaborations on these basic seven plots. When it comes to the asking of questions about radiation, whether the questions are asked by members of the news media or by the non-media public, I think there are only two basic questions: first, how much radiation am I going to get from this [source, procedure, experience, etc.] and, second, what will that dose do to me?

All of the questions I get from the public boil down to that. Sometimes there is a reasonable answer to the first part, but there hardly ever is a good answer to the second one.

People who aren't either occupationally involved with large radiation sources, or getting radiation treatments for extremely serious illnesses, stand only the remotest chance of getting a serious radiation exposure—one serious enough so that the experts can agree, within narrow limits, on what the consequences will be.

The radiation incidents that most people worry about fall between an exposure from a real or imagined source that is a small fraction of their annual natural environmental exposure, on the low end of the scale, and an exposure that at the high end is still less than 10 rem.

Even nuclear industry workers very rarely get exposures of more than 10 rem in a year. In the NRC's last published annual report on such exposures covering the year 1984,[1] out of about 195,000 workers, only 24 had exposures of more than five rem that year, and only two of these were more than 10 rem.

It isn't common experience of individual radiation exposures that makes most people so afraid of radiation. It is, rather, the vivid memory of large-scale events, like the accident at Three Mile Island, and the one at Chernobyl. And it is the invisibility of radiation. If only we could give it a bad smell, the way the gas company does with otherwise equally invisible natural gas, attitudes would change a great deal. When people smell gas, they go make a telephone call, with some urgency, but usually not in panic. It is the invisible presence in our midst, and the common knowledge that in large enough amounts it can kill or make its victims seriously ill, that makes most people willing to accept some other, potentially much more imminent, dangers while wanting to be spared even the slightest radiation exposures. And, the discovery that naturally occurring radon gas has been building in concentration in many American homes, unsuspected and until a couple of years ago a matter of academic interest rather than public health concern, that has alarmed the public, in this instance for good reasons.

When the National Academy of Sciences published the report popularly called the "BEIR-3,"[2] what it said in the Summary and Conclusions section at the front of this 524-pager was that the increase in lifetime risk of getting cancer and dying from it for somebody who had absorbed a dose of 10 rads at one time was 0.5 to 1.4 percent of the naturally occurring rate among people who had not absorbed such a dose. They estimated that people who had a continuous lifetime exposure at a rate of 1 rad per year would have a 3 to 8 percent higher rate of dying of cancer. Then the committee said that it did not know whether getting an additional dose of gamma or X-rays comparable to what many Americans get as an annual natural environmental exposure—100 millirads per year—was detrimental. I am advised that there is a "BEIR 4" in preparation, but I don't know whether it will help with this problem of putting low exposure "in perspective."

Of the many hundreds of questions I get in a year from people who are worried about a possible radiation exposure, 99 percent, or more, concern exposures that are a small portion of that 100 millirad. Everything that passes in our conversation between the asking of the question and the giving of the only entirely accurate and honest answer I could give, which is "I don't know and I doubt anybody anywhere else does either" is an attempt on my part to figure out if the caller wants the truth, or a comforting answer. Put that bluntly it sounds tactless, even arrogant, and begging for the retort, "well, if you don't know send me someone who does!" If the caller is quite insistent, I do send them elsewhere. Clearly there are people with really impressive expertise in the NRC, and I don't doubt for a second that they could give a thoroughly correct answer with very formidable technical rigor. But, a great many intelligent but technically undereducated people find the technical discussions quite emotionally unsatisfying. Sometimes the people who press hardest for numbers, end up confessing that they don't really understand probabilities couched in decimal fractions amply sprinkled with zeroes. The world is filled with people who elected to take biology in high school or college in the belief, sometimes true, that this was the way to avoid having to deal with scientific notation, also called exponential numbers. Some of these generally well educated people think that writing a number as a single digit followed by the capital letter "E" and another one or two-digit number must be some secret code used only by people who have security clearances. My most-frequently asked question is, "what is my chance of being killed by an accident at the nuclear plant near me?" Answer: "Well, it's about one in a million, and that estimate may be as much as ten-to-a-hundred times too low, or ten-to-a-hundred times too high." Retort: "what is that supposed to mean?" I thought you wanted a number. "Yes, but is there any other way to describe it? Is there no way you can describe it in ordinary words?" Well, yes, I can. Your chance of being killed by a nuclear power plant accident is a lot less than your chance of being killed by an automobile accident but its a lot more than your chance of being killed by a falling meteorite while engaged in an act of love in a gondola on a canal in Venice.

There may be a few of you who can tell right off, at the very beginning of a conversation, what kind of a person you have at the other end of the phone, but I'm not one of them. I used to think I had developed a kind of sixth sense about the credibility of the people I talked to, after 20 years as a newspaper reporter, but I was cured of that delusion by a grandmotherly sounding lady in New Jersey. She had begun by writing me letters, to express her concern over non-radiological environmental damage caused by a nuclear power plant on her much-beloved Jersey Shore. The damage was real enough and so were the steps the NRC was taking to help bring the problems under control. She enclosed a newspaper clipping that had triggered her concern. I sent replies to the street address on her envelope, and we exchanged about four letters. Eventually I had a telephone call from her. Her speech was deliberate, calm and she asked me a question to which I didn't know the answer, so I asked to call her back. "Please give me your telephone number, and I'll call you some time tomorrow," I said. She gave me an area code and telephone number, and I ended the call. A little later, I realized that "tomorrow" was going to be a Saturday. That apparently had not occurred to her, either. I tried to call her back, but the phone rang a long time without being answered, and I gave up. At mid-morning Monday, I placed the call again. It must have rung eight or nine times, and then a young man answered. I asked for her. He said she was not able to come to the phone. "When will it be convenient for me to call her again," I asked. "You can call any time you like," he said. "Can I leave a message to have her call me back," I asked? "No, I don't think so," he said, and then politely said "goodbye" and hung up. I thought that was very odd and my curiosity led me to exercise some slightly rusty reporting skills to identify the location of her telephone number. I found out that it was a pay phone in one of New Jersey's larger mental institutions. So I called the head of the place and asked about the name that the woman had called herself. She had given me her correct name. She had been institutionalized for many years, was very old, indeed, had only rare moments of lucidity, in which she wrote letters to all kinds of people. She had money, her relatives brought her stamps, and she had a telephone credit card for which the relatives also settled the bills. I asked why she couldn't have her own phone in her room. "We tried that, but most of the time she would just sit and listen to it ring, so we finally took it out. She never complained about that either," said the director. A few days later I decided to write another letter, giving her the answer to her question. I never heard from her again. If people who have the unimpaired use of their mental faculties are sometimes worried, alarmed or frightened by something they have heard or seen about radiation and its practical uses, imagine the terror in those who believe that extraterrestrial beings are using nuclear radiation to inflict pain on them, or that our government is using it to spy on them, and would it help if they papered their bedroom walls with aluminum foil? The Northeastern United States is filled with lonely people who have discovered that their local telephone book blue pages contain government telephone numbers where collect calls are accepted, and so they call. I've never thought that my appointment to federal service qualified me to practice electronic group shrinkery, or any other kind of shrinkery. But who is to say that graduate students anxious to complete a class paper by deadline or elected officials who want to appear to be well informed when meeting with their constituency are entitled to have their anxieties relieved with a little bit of conversation, but people who wear hats festooned with old radio tubes and Tarot cards are not?

In the last week of August I had a phone call from a woman who started right out by asking me, "How dangerous is it to have a CAT scan?" I explained that medical X-rays from machines like CAT scan equipment do not come under NRC jurisdiction. I suggested she call her state health department. She appealed, "Won't you please just try to answer my questions." Well, I began, there are three answers: (1) under some circumstances a lot less dangerous than not having one; (2) not very dangerous at all if the exposure is accurately planned and the administration carefully controlled; (3) have you asked the doctor who told you to have one?" It isn't me, it's my husband. He has these headaches. How much radiation would he get from a CAT scan?" she asked. "Let me think about it," I stalled. I remembered in the middle 1970's playing a very minor role in helping the Philadelphia Food & Drug Administration to put a South Jersey practitioner out of the business of giving people a large dose of X-rays over a period of many weeks or months, as treatment for all kinds of minor complaints for which X-rays were so inappropriate as to constitute medical quackery. "Your husband's doctor recommended the CAT scan?" I asked. "Yes." Well, I suggested, if you have some doubt about the validity of that recommendation, why not get a second medical opinion on whether the CAT scan is really needed for a diagnosis. There may be a medically sound alternative. "No," she said, "I've already gone to four other doctors and they all say he has to have the CAT scan. Well I said, the amount of exposure really depends to some extent on the location they want to look at. If it is deep beneath bony structures, they may need to use more radiation than if they are looking just through soft tissue. One of the basic benefits of the CAT scan technique, in addition to giving a clearer picture of a possible problem area is to distribute the exposure of the overlying tissues by rotating the beam around the body. "You're not answering my question," she said. "How does it compare with a single chest X-ray? How much radiation do you get from a single chest X-ray?" "If it is a well calibrated and well colimated machine, and the techician has been trained to use the minimum exposure for the tissues involved, probably between 20 and 40 millirem, and possibly less than that with the latest fastest films." "And how much from a CAT scan?" Well I finally confessed that I've had three of them, one of my head and two of my abdominal area, and after the second one I browbeat the radiation physicist into calculating my exposure, and it was in the neighborhood of 2,500 to 3,000 millirem. "That sounds like really a lot," she said. "That's all relative," I said. I explained that NRC regulations allow a nuclear industry worker to receive up to that much radiation exposure to his whole body in a 13-week period, but that we try to get employers to keep worker exposures well below that. I think you might try to weigh the potential benefit against the potential risk. For the industry worker it's his weekly paycheck. For me it was the peace of mind that came from finally knowing, after the CAT scan, that I didn't have a tumor.

By now you should have caught on to the idea that I don't think it's right for people in my position to try to talk the public into either ignoring their concerns or ignoring the risks, though they often are small risks. I think it's more appropriate to try to nudge them along the road to confronting their fears and recognizing their doubts, and getting them to make one more try at getting a medically competent opinion that they will accept as good advice.

I have read some of the studies that have been done on the health effects of exposures to low levels of ionizing radiation, and they all have two things in common: They make enough points with statistical analysis to be persuasive, if not convincing to practitioners of the scientific method, and they are uniformly lousy in helping the layman understand the relative risks he assumes in enduring a radiation exposure in any terms other than numerological. Numerology is what I call lists of numbers that compare the risk of dying of cancer from the routine radioactive emissions of nuclear power plants to the risks associated with smoking some trivially few cigarettes per year, or to taking a few canoe rides, or crossing streets against the light, etc., etc. Good scientific statistics do not always make for useful human communication.

Sometimes people will ask you the wrong question because they misunderstand the real problem. It isn't because they are dumb, but most often because they have become so afraid of one thing, and are so intensely focused on that concern, that they have altogether overlooked the real danger, which sometimes hasn't much to do with radiation at all.

At the beginning of June, 1979, when my calls about the consequences of the accident at Three Mile Island were still running 20 to 30 a day, I had a call from a woman who said she lived in a far northwestern suburb of Harrisburg, maybe 25 miles from the cooling towers seen 'round the world. "Please tell me how dangerous the radiation from TMI still is?" she asked. After some preliminary discussion, it boiled down to her being worried about radiation at her home. I said I doubted that there would have been any measurable amount at that distance and in that direction. The wind was blowing away from her nearly all the time, not from TMI toward her, at the times when significant radiation releases were coming out of TMI-2. I injected a lot of long silences into the conversation and finally she got down to her real worry. For many years, she said, her married sister, who lived in the Miami area, escaped the broiling Florida summer by visiting her in Harrisburg. She was scheduled to come up early in July and stay all summer. But, she had just called. She had heard about the TMI accident, and within the past week had learned she was pregnant. Was it really safe for her to spend the summer in Harrisburg, just 25 miles from the accident. "She says she is worried about her baby." Have you ever spent the summertime in Florida? I asked. "No." Well, this is a very good year to go and be there with your sister. "Oh, you think the reactor is still that dangerous?" No. Not at all, but you are worrying about the wrong thing," I said. Suppose your sister comes up here, has a wonderful summer, and then goes back to Florida and next spring delivers a baby with a gross birth defect. There is no way in the world anyone will ever be able to prove that the defect was caused by radiation from TMI, nor could anyone prove that it was not. But just the suspicion that it could have been avoided will poison your relationship with your sister forever. About one out of every thousand babies is born with a serious birth defect, even in places where there have been no nuclear accidents, even where there are no nuclear reactors, even in times long before mankind ever discovered radioactivity. Your sister runs that risk, even in Florida. She might already be carrying a fetus with a genetic or environmentally caused birth defect. She might already be the one-in-a-thousand mother unfortunate enough to deliver such a baby. There is nothing much the mother can do about that risk, after she's made up her mind to follow the best pre-natal care advice any modern obstetrician would give her. But there is something you can do about the risk of having later regrets. Avoid that risk, go to Florida this summer, wear a big hat when out in the sun and enjoy the peace of mind.

In the early 1980's New York City discovered the ionization chamber smoke detector (ICSD) . . . I mean DISCOVERED! Between reporters wanting to know all about how they worked, and which type was the best, and other people wanting to know how much radiation they emitted and how dangerous they were, and public officials debating the best places to mount them in a home, and how many, there was a period of about three months when, it seemed, all other radiation risks were forgotten. Of course, many local firemen across the country did the best job of putting the health problems into perspective when they advised parents that their children ran a far greater risk of death by smoke inhalation or burning than the risk of death from smoke detector radiation. That simple statement, and the many instances of local government enacting ordinances requiring smoke detectors in new residential construction, have undoubtedly saved many, many lives. At the beginning of the controversy, I sent some copies of NUREG 1156[3] to people in the New York area. I had skimmed the book, and it all seemed to be there. Then, one day, a man from somewhere in Nassau County called up to ask if I could translate some of it for him. He had asked me on the phone a few days earlier how much radiation he would get from the smoke detector, and I had told him the answer was in this book I would send him. Now, he began to read from the second page of the Executive Summary of the report. "The use of Am-241 ICSD's does result in exposure of people to low levels of radiation. Analysis shows that the manufacture, distribution, normal use, and disposal of 14 million Am-241 ICSD's each containing 3 uCi of Am-241 will result in a collective total body dose of 1100 person-rem. The useful life (of the ICSD) is assumed to be ten years. Disposal is by either sanitary landfill or incineration. Fourteen million ICSD's will service about 21 million people. Analysis also shows the risk to the exposed population is about 0.1 fatal cancer." The report went on to say that in this same group of 21 million people, about 35,000 would die each year from cancers. It is really just an average high school algebra problem, I said. Let's see if I can remember how to do it. If you have a dose of 1100 person-rem spread out among 21 million people, the average dose per person is 1100 divided by 21 million, or about one-twentieth of a millirem. Out on Long Island, you probably get about 1,500 times more than that a year from natural background radiation. Since finding out that you may become the possessor of a 0.1 fatal cancer is not exactly a self-explanatory fact, what is one supposed to think that means? I have a lot of trouble putting "0.1 fatal cancer" into meaningful words. It's sort of like having a 0.1 pregnancy. Does it mean that after the fourth week you're suddenly not pregnant anymore . . . is a 0.1 cancer death one that is cured nine times out of ten, before it kills you? Or does it mean that if there were ten times as many people at risk, say 210 million instead of 21 million, that among the 350,000 yearly cancer deaths there would be one cancer death that could be blamed on exposure to radiation from a smoke detector? Of course there would be no way of telling whose cancer death it would be. It reminded me of the old story of the firing squad commander giving out nine live rounds and one dummy so that no one soldier would know for sure if his was the fatal bullet, but all could believe it was not theirs if they wished. I doubt that this kind of statistical blizzardry will cause anyone to believe or disbelieve in the much publicized dangers of radiation. NUREG 1156 contains a kind of cost-benefit approach that might arouse some people's sense of self-interest enough to help them manage their fear of very, very small exposures to radiation, if they have one. The report points out, and I read to my caller, that "The ratio of potential lives saved to the possible fatal cancers due to the use of ICSD's ranges from 15,000 to 51,000." There was some silence, and the man asked, "Based on what statistics?" So I read from the first page: "Between 7,500 and 12,000 lives are lost in fires every year with 70 percent of these occurring in residential fires . . . Based on theoretical studies and case histories, the estimated percent of residential fire-related deaths that smoke detectors could save is between 41 and 89 percent," and I added, that's between 3,075 and 10,680 lives saved per year, compared to one cancer death in ten years. There was another long silence, and then the man said, "That's all very well, but you still haven't told me how much radiation I am going to get from the smoke detector if I put it up in my house." Ah, I said, you should look on page 3-23. After taking into account your picking up the smoke detector, transporting it home, installing it on the ceiling, testing it with its test-button, doing periodic dusting or other maintenance, such as changing batteries, and then letting it operate while you walk under it so many times a day, and making a few assumptions about how people do these steps, the study arrived at an average annual exposure of 9.3 urem (microrem) per year, which is a figure much smaller than the earlier one I gave you because that one included the exposures of people who handle the radioactive americium-241 material during its manufacture and during the smoke detectors' manufacture, and while their exposure is higher than the average exposure of the consuming public, it is still a small fraction of the occcupational exposure limits in NRC regulations.

Now if that all sounded quite reasonable, and I think it is, then it should also have sounded quite unsatisfying. There is another answer, probably more accurate, and also bordering on rudeness. "Mr," I could have said, "get a notebook and count the number of times each day that you walk under the smoke detector, and how much time you spend in a chair or a bed or standing by a telephone, and how far those locations are from the detector. Then hire yourself a competent health physicist to measure the radiation from the device to wherever you are for how long you are there, and he will give you a reasonably close figure of your annual exposure." At which point my caller would say, "is that what I pay taxes for, for advice like that?" Actually, in trying to give him the best approximation to a precise answer that the documentation suggested, I had simply exhausted his interest, or his patience, or both. In a quite flat tone, he said "Thank you very much" and hung up.

I don't think the way that researchers are accustomed to phrasing applied research results and publishing them necessarily lends itself to use in public information. I have become quite shy about quoting studies, setting aside for now the question of their intrinsic merit, in the areas of biological effects of low level radiation and in the area of nuclear power plant probabilistic risk assessment.

I am amazed by people I know who sometimes are so inattentive when driving that they go through a red light. You would think that they would become absolutely paralyzed a few blocks down the road, when they realize what a huge risk of automobile accident fatality they have just taken. But, the incident quickly slips from their mind. Yet they fight bitterly with their dental hygienist to avoid the small added risk from having a mouthful of asymptomatic, probably unnecessary X-rays. I know there are people like that, because I'm one of them.

Maybe it isn't so much that we don't know enough about the effects of low-level radiation exposures as that we just don't know enough about human nature and the perception of risk. I've read a couple of luxuriantly statistical studies on that also. They didn't do much for my perception of perceptions of risk, except to make me accept their seemingly infinite variability as a fact of life.

References Cited

1. **Brooks, B. G.** 1986. Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities 1984. U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (NUREG-0713, vol. 6) pp. 1–9.
2. **Committee on the Biological Effects of Ionizing Radiations.** National Research Council. 1980. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation:1980. National Academy Press. pp. 2–3.
3. **Belanger, R., Buckley, D. W., and Swensen, J. B.** 1979. Environmental Assessment of Ionization Chamber Smoke Detectors Containing Am-241. Science Applications, Inc. U.S. Nuclear Regulatory Commission (NUREG/CR-1156) Executive Summary.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 186–189, June 1988

Policy Perspective on Communications Issues

Frank E. Tooper

Office of Nuclear Energy
U.S. Department of Energy
Washington, DC 20585

It seems as though whenever two or more parties with diverging viewpoints need to communicate an issue arises. That leaves the topic of my talk open to a wide array of discussion points. Therefore, today I will offer a communications issues perspective in the context of the future of commercial nuclear power.

The prospects for nuclear power and attendant communications issues associated with the formulation and adoption of policy in the United States after Chernobyl can best be gauged by examining the conflict between two competing forces:

- The emergence of nuclear energy as a vital and growing source of electricity worldwide which is inextricably tied to energy security, and
- Anti-nuclear strategies which are focussed on altering the political climate in Western countries thus making policy decisions regarding the deployment of nuclear power unrelated to need or economics.

Nuclear Power is Vital to Energy Security

Since the Atoms for Peace Initiative of 1954, nuclear technology has been transformed from a scientific curiosity to an economic powerhouse. By any measure the commercial introduction of nuclear power has to be one of the great success stories of this century. Consider the role of nuclear power in reducing worldwide dependence on oil. Nuclear power currently offsets the equivalent of about 8 million barrels a day of oil in the United States. It has been a potent force to break the grip of OPEC and restoring energy security.

Moreover, the transition to an electricity intensive economy powered by nuclear energy has been a principal element of national policy in countries such as Japan and France. In those countries, and others, nuclear power continues to be cheaper and more viable than other forms of electricity supply. An economic edge in the price of power production brings benefits beyond energy security.

Nuclear power construction worldwide has almost reached the end of its first phase—that of replacing fossil supplies.

Nuclear power is now entering a phase of lower growth—competing for a share in meeting new electricity demand.

The sharp reduction in the rate of electricity growth that took place in the United States due to the 1970's recession caused an unforeseen shakeout in the U.S. nuclear industry. What occurred in the United States presaged the more general shakeout that is now taking place worldwide. The prospects for new orders are much lower than some projected a decade ago. Nuclear vendors and suppliers are leaving the scene. In the meantime, the shakeout is putting great strain on the U.S. nuclear industry.

Overlay this reduced demand for new construction with institutional and political forces that tend to further curb the prospects for new nuclear powerplants and you have the ingredients for energy security concerns—even without Chernobyl.

Opposition to Nuclear as an Effective Political Tactic

The level of rhetoric concerning anything nuclear is very high. Public officials have the ability to hold up construction projects in ways that are qualitatively different for the nuclear option as compared with coal, oil, natural gas, or doing without. Some Federal officials have regarded nuclear as an option of last resort. Many equate civilian nuclear power programs with concerns about nuclear weapons.

In large measure, the sophistication and complexity of nuclear technology is such that public acceptance of nuclear power involves an act of faith and trust. Those unalterably opposed to nuclear power have, over the years, attempted to undermine confidence in nuclear power. A host of strategies have been used to discredit the industry and challenge the effectiveness of the agency charged with assuring good industry practice.

The strategies find special fuel in events such as Chernobyl. When Chernobyl occurred, some were quick to sound the theme that nuclear technology is fundamentally unsound—claiming that Chernobyl proved their point.

The fact is that nuclear power can and does come in all shapes and sizes. A designer of a nuclear powerplant can choose from among several fuel types, coolants, and nuclear moderators. These choices can be configured to optimize fuel economy, power output, assured safety, ease of construction, or some other set of performance values.

The Soviets, at the Chernobyl Post-Accident Review Meeting of August 25-29, 1986, went to some lengths to explain the rationale for selecting the Chernobyl type design. Features were selected that reflected the particular circumstances of the Soviet system—such as their inability to manufacture the large thick-walled vessels needed for light water reactors. The result was a design that was unstable at low power, operators who apparently did not understand the safety weaknesses of their machine, and a management system which did not encourage open discussion of safety issues.

The weaknesses in the Soviet technology and the susceptibility to human error have been used by some to criticize U.S. technology and practices. The truth is that the Chernobyl accident has little or no bearing on the commercial technology deployed in the United States except to the extent that it reenforces what we already knew—that these machines should be as resistant as possible to human error, and that safety in design, construction, and operation are of paramount importance.

Communications Issues

There is an old adage that truth is the best policy. I firmly believe in this. The truth, however, sometimes takes some interesting turns between the source and the receiver. This may result from the receivers level of understanding, preconceived notions or biases, or the number of intermediaries between the source and the receiver. Viewing the general public as a receiver it is not surprising how public perception can become distorted.

History shows that public policy and public perception ultimately converge. Therefore, communications issues associated with the formulation and adoption of sound public policy must be addressed, hand-in-hand, with issues associated with prevailing public perception.

The ability to communicate effectively among parties with diverging viewpoints and the general public will ultimately shape policy and public perceptions in the future. As we look to the future, I believe it is time to leave ideologies such as pronuclear and anti-nuclear behind us. We need nuclear power for energy security and economic growth. It is time for responsible parties truly concerned about nuclear safety and economics to start effective and constructive communications for the benefit of the general public.

I have observed a considerable amount of counterproductive and wasted effort between pronuclear and antinuclear forces in the United States. In the meantime, other nations move ahead and we stagnate. For example, electricity demand in the northeast is growing at a rate of six to seven percent annually. That region of the United States needs new central generating capacity that can only be provided from coal or nuclear. However, the investment risk for these types of plants is too high for utilities in that region to entertain new construction requiring large capital commitments over an uncertain period of time. Recent experience, specifically regarding nuclear powerplants already completed yet not operational, demonstrates the magnitude of the investment risk. What is happening in the Northeast may presage what will happen in the rest of the country in the future when new large capacity additions are required.

Canada, observing these trends, built nuclear powerplants near our border with the specific intent of selling power to the United States. This is a disturbing situation, particularly when we have the technology, and the diverging forces that come to bear in our system derive the nation of the benefit of using it appropriately. Communication is a key to correcting this situation.

Health, Safety, and Economics

In the past, health and safety are issues have been discussed apart from considerations of economics. This is consistent with the philosophy adopted in the United States long-ago that safety comes first at any cost. However, in the wake of TMI, the U.S. Nuclear Regulatory Commission promulgated many additional requirements aimed at enhancing the safety of reactors in operation and those under construction. The cost of implementing these requirements was enormous. In retrospect, while most of these requirements were advantageous from a safety standpoint, some requirements may not have been. From a consumer standpoint, some retrofits may not have been cost/effective. Thus, it brings into question whether the regulatory process should enable determinations whether or not a proposed safety improvement is worth the money. Generally speaking, experience shows there is a point of diminishing returns in increased safety for capital spent.

Pragmatically, it seemed this experience should lead to the formulation of an improved regulatory policy that allows the cost of a safety improvement to be judged in the context of the benefit derived. While this may sound reasonable and serve to lend stability to the regulatory process, it did not win unanimous support.

The proposed policy evoked a response that it was intellectually inconsistent with regulatory responsibilities. Cost should not enter into safety considerations, particularly those which involve backfitting operating plants or those under construction. Backfitting, by definition, requires additional expenditures and contributes to the cost of the power produced by the plant in most cases. Thus, the cost of nuclear plants is an open question. A utility never knows when the plant is completed.

The point here is not whether the policy was right or wrong, but rather that the process of attempting to develop and adopt seemingly better policy provided an arena that resulted in miscommunication to the public. The intent of the NRC, and basis for that intent, was never communicated to the public. Instead, the public heard that the NRC held industry interests as a priority over public safety. This is one example of how the truth takes many turns.

Relative Risk and the Perception of Risk

Many ardent supporters of nuclear power have tried in many ways to communicate to the general public the relative risk of nuclear power. Lists showing the risks due to smoking, flying in airplanes, driving automobiles, and many other every day activities purport to illustrate how acceptable the risk is from nuclear power. While many people who already view nuclear power as essential find these comparisons convincing or enlightening, these comparisons are, for the most part, irrelevant.

Generally individuals can and will accept almost any risk as long as they are in control of that choice. However, if an individual feels they have no control over a particular risk, real or otherwise, then it is unacceptable. This response to risk is true for all electricity generating technologies. However, perceptions of the risk from nuclear power appear to be more acute.

The communication issue at hand is how to increase public understanding of relative risk and what constitutes levels of acceptable risk.

In summary, key communications issues are:

- How to communicate the need for nuclear power as a vital and growing part of our electricity supply mix for energy security and economic growth?
- How to leave the ideologies of pro- and anti-nuclear behind, and move toward timely and constructive dialogues among responsible parties having diverging viewpoints regarding the safety and economics of nuclear power?
- How to communicate that societal risk is unavoidable and, as far as electricity technologies go, the health risk from nuclear power is relatively small—acceptably so.

As I mentioned before, truth is the best policy. It is a fact that only coal and nuclear can provide large central supply capacity increases for meeting anticipated electricity demand in the foreseeable future. Conservative estimates of electricity demand to the year 2000 indicate about 100 GWe of additional capacity will be needed over and above that which is currently planned or under construction. Gas and renewables will play an important role in adding relatively small increments of supply. However, we are going to need further contributions from nuclear power if energy security and economic objectives are to be met. Communications issues must be faced squarely and now.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 190–204, June 1988

Round Table Discussion: Communications

RUSSELL: Before we open the panel to discussion, we are going to have a few comments from Robert Alvarez, who is here as a discussant. He is with the Environmental Policy Institute, a Washington group that is often referred to by the media as a watchdog group. The Environmental Policy Institute has been around since the early 1970s, and Bob's group was among the groups that has monitored Three Mile Island and other nuclear problems.

ALVAREZ: I would like to discuss just two basic issues here: one is, what has been the impact of media coverage as a result of the Chernobyl accident and the issue of risks.

I think that Mr. Smyser has raised a very important point which I want to expand upon. I think a lot of public perception of atomic energy does stem from its birth during World War II and the detonation of atomic bombs over Japan. I think, moreover, the impact of the media relative to the Chernobyl accident has been more profoundly felt on our nuclear weapons program than commercial nuclear power, and that this media coverage has implictly cast the long shadow of the nuclear weapons program over our commercial nuclear power industry.

About four or five years before Chernobyl, several of the regional dailies—Oak Ridge, Knoxville, Cincinnati, South Carolina and Georgia papers, Colorado papers, Washington State papers—began to publish stories about largely the legacies of the Department of Energy nuclear weapons industry and certain things that were coming out. Over the years, these papers in a sort of mosaic form presented a picture of a technology or an industry which has depended very heavily on the use of air, soil, water, ground waters as disposal media for some of the world's most dangerous pollutants.

For example, at the Hanford Plutonium Works, before the Three Mile Island occurred—several months before that, probably about a year before that—it was reported that approximately 200 billion gallons of radioactive and hazardous contaminated liquids were deliberately dumped into the soil there, using the soil as a disposal medium. This is roughly equivalent of creating a lake the size of Manhattan to a depth of 40 feet.

By the time Chernobyl came, the regional media were primed. I recall two or three days after the accident was reported, the first serious reporting in this country started on Monday, I believe, from the weekend. A gentleman from Oak Ridge National Lab was on CBS Evening News and made the point that our commercial nuclear power plants are much different from that of Chernobyl largely because they contained these containment shields, these concrete, steel domes that are there to prevent the escape of radioactivity as a final safety backup in the case of a severe accident.

However, this gentleman failed to note that the Department of Energy, who was his employer, has been running several reactors without containment shields for decades. This point was eventually made known, largely because of the "hysterical environmentalists."

What has resulted of this knowledge is that the regional dailies essentially provided a groundswell for national media to draw attention to the most dangerous aspects of the nuclear industry in this country, which are their military applications. This has resulted in some very significant impacts.

Ask yourself, How many commercial nuclear power plants have been shut down or had their activities curtailed in direct result of Chernobyl? I cannot think of one example. However, if you asked that question in regard to its impact on the Department of Energy's nuclear arms program, the Hanford N-Reactor, which has general design similarities to that of Chernobyl—in fact, the Soviets more or less stole their reactor designs from those developed at the Hanford Plutonium Works—is now shut down. The Senate Armed Services and Appropriations Committees have just recently voted to put it on permanent standby status.

The reactors at the Savannah River plant facility, which also produced nuclear explosive materials, are of a different design, but it has been discovered that they have been operating under conditions with inadequate safety systems, and they are running at much lower capacities. At the Oak Ridge facility, several "Class A" reactors, the DOE's largest reactors, have been shut down because of age and fatigue, and there is some question as to when or if those reactors are started up. In essence, the impact of public awareness about our nuclear weapons program provided by the media has sharply curtailed the production of nuclear explosives in this country and is leading to a reevaluation of that.

Also, it has drawn attention to the fact that the nuclear weapons program is far more dangerous but yet controls most of the information upon which we determine the risks. For example—this is something that has been reported off and on but more people are becoming aware of this, largely because of the media—the Department of Energy funds over 60 percent of all radiation health effects research, and most of this research is derived from activities stemming from the production or deployment of nuclear weapons. The baseline epidemiologic information upon which we determine our radiation risks are derived from the health and mortality experience of the Japanese A-bomb survivors. The other data that are now being generated are those derived from the studies of workers who helped make the nuclear arsenal possible. So there has been a very prominent role which the nuclear weapons program has played in things concerning nuclear power.

Now in terms of modern times, there is also the situation of the declining budgets in the Energy Department's civilian nuclear R&D program for actual civilian application and the increased spending for military uses. What this means is that the Department of Energy is taking money away from developing advanced reactors which could be used for commercial use or to improve the safety of existing reactors in order to enhance the use of reactors for military purposes, mainly for Star Wars. You merely have to study the Energy Department budget to figure this out.

To reiterate what I said before, I think media coverage has had a more profound effect on our military program than the civilian.

Now in terms of the issue of risks, first, there is the risk of the accident, which has been characterized in terms of the method that has been used to portray this risk, which is probabilistic risk assessment. This is a method that is widely used by the chemical and nuclear industries. The gist of how the method works is that it compares the probability of failure from events which occur fairly frequently, which have small consequence, to the probability of a failure of events that are very infrequent and that have, nonetheless, a catastrophic consequence.

This is very much like comparing the risks of getting AIDS from unscreened blood from the risk of catching a cold by going to work in the wintertime. If this were adopted as a public health policy, it would be advised that people can receive unscreened blood because the risk of getting AIDS compared to that of getting a cold is so small that the screening of blood is not warranted.

This particular method is shunned by an industry whose business is risk assessment, which is the insurance industry. No insurance company will use a method to provide an insurance policy to an activity that could ultimately lead to catastrophic consequences, with a very small probability that it would bankrupt that insurance company. This is why, historically, the insurance industry has not been willing to assume full liability for nuclear power and why the government contractors who operate nuclear weapons factories refuse and are fighting adamantly in the Congress this year to not accept any form of financial responsibility for catastrophic accidents which they may cause from their own negligence and misconduct in the nuclear weapons program.

This is one of the problems. Any risk assessment where you are involving a catastrophic event, where the potential is quite severe, there has to be a major element of risk assessment, and it has been basically excluded.

In terms of the biological risks of radiation, as we have been told and as we probably know, radiation has been one of the most studied phenomenon in the world. To the credit of our government nuclear program, this is the only industry I am aware of where, since its inception in World War II, there were conscientious people who had access to very large resources who were able to set up a system where, one, the workers in these facilities are individually monitored, and two, the environment is monitored. There is no industry in the world that has ever done this, or even does this to this day, with the kind of detailed practice that occurs in our nuclear program. When you deal with asbestos, for example, in terms of estimating doses from asbestos, it is more of a hand-waving exercise as opposed to dealing with the radiation risks, because there is a record there.

But at the same time, the irony of this is that it's true we know very little about the biologic effects of radiation, but we also realize that there are still very great uncertainties about the nature of these risks when you start to get down to the almost invisible level of the single cell. What is really going on there? This is where the debate is going on relative to the risks of low-level radiation.

You have heard various risks presented to you, in terms of your risk of getting cancer versus this. First of all, I have heard no discussion about fetal risks. The fetus is considered the most sensitive form of human life to ionizing radiation.

The fetus, it has been discovered, is very sensitive to radiation, and I just draw your attention to two types of studies, one dealing with cancer and the other dealing with teratogenic problems.

The studies dealing with cancer are those which are derived mainly from the study of children who were x-rayed *in utero* during pregnancy. Those studies generally suggest that a single x-ray can initiate a childhood cancer. Now, childhood cancer, as some of you may know, is the single biggest cause of death by disease in this country for children. Yet, the Nuclear Regulatory Commission, after 30 years, is finally producing a standard to protect pregnant working women many years after these data have been made known.

The notion of risk, in terms of radiation, is rarely ever presented in terms of range of risk. It's always given as a certain figure. Your risk of developing cancer versus your risk of cancer from smoking cigarettes is x, y and z. But I think that the risk has to be portrayed in the true reflection of its uncertainties, and I do not see that happening. This leads me to some other basic issues.

When you have this kind of uncertainty, upon whom does the burden of proof rest? For example, the Energy Department is consistently saying that their practice of dumping large amounts of radioactive and toxic materials into soils poses no hazards to people. Well, how do they know that? They do not even have standards for soil contamination or ground water standards. This obviously puts the burden of proof on the people who stand to be contaminated by this.

First of all, the way the burden of proof has been portrayed, for example in the Three Mile Island accident, there has been a lot of paper and a lot of information generated about Three Mile Island, but empirical evidence? Thirteen monitors. The stacks went off scale. They do not know exactly what went out of the reactor itself. There is a tremendous amount of uncertainty, despite the reassurances of small amounts of radiation released. There is no empirical evidence to support that. There is a lot of extrapolation from a small amount of evidence to that effect.

Let me give you an example of how extrapolations are used. At the Savannah River plant and at nuclear power plants, the way doses are estimated to members of the public is by extrapolation. In other words, a number, which represents the amount of radioactivities being released from a point source, a stack, is then put into a rather elaborate computer model, which takes into account the weather conditions and the distance from people and other variables. Then a number comes out.

At the Savannah River Plant, the model suggests that the radiation being emitted from their two reprocessing plants which are in the middle of the site are so dilute by the time they reach the plant boundary, they cannot be measured. Well, according to a study done by the Energy Department, the Air Force, and the Weather Service, they tracked a Krypton-85 plume, just a radioactive gas that comes out of one of these reprocessing plants, and discovered that it was 10 times more radioactive at several hundred miles than what the model said it would be at the plant boundary.

The models that you are looking at, in terms of these risks, basically have not been validated by empirical evidence. The monitoring systems around commercial and civil facilities are not designed to validate these models. I was told by Dr. William Mills many years ago in writing, who was with the EPA and then joined the NRC and I believe has retired now, that monitoring around nuclear power plants are for public reassurance. This is what we are dealing with, the uncertainty of risk.

I think that when you are getting into the uncertainty of risk, there are two basic principles you have to operate under. One is conservatism. When you do not really know what the nature of the risk is with any precision, you have to assume the worst can happen. And two, there is a question of trust. For example, the Energy Department, it has been revealed over the years, has released very large amounts of radiation deliberately in order to produce nuclear weapons and never told anybody about it. I served as a panel member for the Centers for Disease Control, looking into matters concerning Hanford. The CDC in the State of Washington estimated infant thyroid doses in 1945 which were on the order of 2,950 rem. Nobody was told about this. Can you trust the people who are doing the pollution to tell you the truth.

I say that we need better forms of independent regulation, and we need to be more conservative.

LIDSKY: I'm Larry Lidsky from M.I.T., and that has something to do with what I am going to say. M.I.T. is in Massachusetts. We have a State lottery. The chances of winning the State lottery are somewhat less than 1 in a million. Everybody in the State buys a ticket, and everyone is surprised when they do not win the next week. One in a million to the public, if you are concerned about the answer is sort of 50/50. So you have a real problem with that number.

The other real problem you have in communicating risk is a point that was just raised. That is the risk of serious exposure due to an accident in a nuclear plant is calculated by the engineers working on the plant. At the end of that process, they say, "The risk of a serious exposure is 1 in 10^7. And I calculated this, doing a very careful calculation. I am a scientist. Trust me." The public says, "I don't trust you anymore."

So you have two problems. One is that 1 in a million is not a real number to the public. But more to the point, and I think deservedly so, the public does not trust you—the scientist or the industry or the government—to tell them what the risks really are. I think that is the fundamental problem in communications we have now. It may well be that the communications have been accurate.

ABRAHAM: I think that is an extremely important issue. I do not think it is, however, a large mystery. The public does not trust scientists because some of them have lent their pedigrees and credentials to commercial enterprises that have disillusioned kids who learned in school that a scientist, like a physician, was somehow on a higher moral plane. I do not know how scientists will solve that problem, but I do know that the public will not solve it.

The government is not trusted because some people who have been in the government in the past have shown themselves to be underserving of the trust that was placed in them. There is no point in my reeling off names. You read them all in the newspapers. I think the biggest surprise I got when I left the newspaper business, where I had a fair amount of credibility, and I joined the Federal Government in the fall of 1973, was to find overnight and even more so in the next couple of years that there was a wide mistrust of me that had nothing to do with my personal reputation. That is another fact of life that we have to deal with.

I think the mistrust of the industry comes from the industry using the same mechanism for product advertising that it uses for communication with the public on public interest issues. I do not believe that the stereotype of the public relations guy in the movie *The China Syndrome* was, until very recently, very widely true. It is a problem that the industry would have to solve. I do not think that the solutions to the problems are going to come from anybody else. I think they are very serious problems. You cannot help people if they do not trust you. The physician cannot help a patient if the patient does not trust the physician.

SPEAKER: We are talking about public perception. I think we tend to internalize too much about industry having to do this, to improve public perception, and the government needing to do this, and the credibility source.

There was a study that did what I consider to be an interesting survey of TV programs and how movies and TV programs treat scientists and engineers versus the doctor. The large majority, something like 9 out of 10 programs that dealt with problems pertaining to scientists and engineers portrayed them as ogres, they do more harm to the public than they do benefit. However, the same fraction, 9 out of 10, of the medical programs, they were all doing good. They were all saving people and that type of thing.

Now you talk about public perception, think of the impact the media in that regard has on nuclear power and coal and the preconceived notions and biases of the general public. That is what I do not know how to address, and that is where our media professionals have to help us.

SMYSER: I would just say something that I have said many times to my fellow newspapermen. There has been some trend in the media in more recent years, and I am generalizing now, to get away from old fashioned type of reporting. In many ways, I think that has been good; we need some innovations. But I think it has been bad, particularly to the extent that there has been some tendency to think that local government matters are boring to people and that we shouldn't report them in the detail that we have in many years past.

I think public trust only comes—We of the media only create public trust by this kind of day-in/day-out coverage. J. Ed Murray, who was a Knight Ridder editor and publisher for many years, a very thoughtful man, speaks of what he calls a reinforcing redundancy in our coverage. I think this is really the only way, and this is what I was trying to say when I referred to process reporting. I think this is the way that we of the media can help nuclear power to become better trusted. Day-in/day-out, over and over again type of coverage that you can help us do.

HENDEE: I'm Bill Hendee from the American Medical Association. All the panelists today have identified the nuclear power issue as one of the most contentious and polarized technological issues in our society, and there have been various reasons for that. Among those reasons are that it was born of the Hiroshima/Nagasaki explosions. Therefore, the public has a certain perception of it that is unlike any other technology and is something very hard to overcome. There are many other reasons for that, too.

But Mr. Abraham brought up an issue that seems to me to be a more fundamental issue that may be very difficult to deal with, no matter how hard we try to establish communication between those who understand radiation, nuclear power, and the public. And that is the issue that radiation is something different, because it is intrinsically mysterious and difficult to understand. It is subtle; the senses are not sensitive to it. And therefore, it is unlike the other types of technologies we deal with where we have more of a sense of their significance.

If that is true, if that is one of the fundamental issues that confuses and confounds the problem of communicating with the public about radiation, then my question is simply, What can we do to try to provide better public education and understanding of that issue when it is so mysterious and subtle and so intrinsically difficult to talk about?

SPEAKER: I sometimes think that we are not aware, we do not think about gravity until we drop a bottle of milk or somebody falls out a window. It isn't the underlying theory of the law of gravity that people need to understand in order to stay away from falls. It isn't the underlying research or the techniques of research about the effects of radiation that people need to understand the way scientists and technologists think they understand it.

I do not know what it is that people need to understand to take something for granted, but people take a lot of things for granted that they do not understand. They are not willing to take radiation for granted. They are not willing to take a doctor's word for the fact that a casual contact will not communicate AIDS to you. If I was going to suggest research, I think it ought to be on why that is.

ALVAREZ: In following up on why that is, I think the research could look very closely at recent history, starting with World War II. Indeed, the perception of radiation, in terms of what you would call the cultural or collective memory, certainly has its origin from the devastation it caused in Japan. But also following that, there was the atmospheric weapons testing program, and the conduct of the U.S. Government, the claims made by the U.S. Government about the insignificant dangers of testing, which were in effect repudiated by the signing of a test ban treaty.

To a large extent, government credibility has never recovered from that and it has washed over into the nuclear power debate. We have to live up to these legacies. Now why does this continue? It is not just a matter of, how do we better educate the public but looking more seriously at the roots of this problem. From my point of view, it has been an historical isolation of the radiation biological research program from the mainstream of public health science. This has been a discipline that has been dominated largely by the military nuclear bureaucracy until recent years. It is still funded very heavily by the military program. You have to understand that you cannot ignore that infrastructure.

If you were to transfer the research authority for radiation health effects to public health agencies and open that up to those processes and to deal with that, you would get more at the root of the problem.

ABRAHAMSON: I am Seymour Abrahamson, Professor of Zoology and Genetics at the University of Wisconsin.

One of the points I wanted to make was with respect to the last point Mr. Alvarez made. I have been a radiation geneticist since 1950, working on just these issues of health effects. In the 1950s and early 1960s, my research was funded almost exclusively by NSF. By the mid-1960s, the chairman of that program called me to say, "I think you ought to go to DOE. We don't have enough funds to support basic research. That's the organization that should be supporting your studies." For 10 years, DOE did support the studies. NIH has picked up some of it. But in fact, within the interagency government research funding programs, DOE was the source of most of the research, and almost all the basic research in radiation came out of that set of programs.

I do not know how you can knock it: if they were the ones giving out the money, and that is where it came from, and nobody else wanted to do that funding. That is the way it was, as far as I am concerned.

I have a couple of other points. One is a point of correction to Mr. Abraham, who said that when he informs people that 1 in 1000 is the chance of a congenital child defect, you are inaccurate because it is closer to two-and-a-half percent. So you are giving them wrong information. I just wanted to correct the communicator on that. We know that 1 in every 750 kids born is mentally retarded just from Down's Syndrome alone, and there are all sorts of other child defects.

You made the point in your discussion, Mr. Abraham, that in general only a very few people at nuclear power plants get over 5 rem exposure. I have forgotten what the number was, but it might have been 24 or something in that range. Are you using only the numbers of the workers who are employed in the plant exclusively as those who are monitored, or is that number also including those who were brought in as contractors to do cleanup work and then moved out?

One of the major problems in the estimation of what risk is that a large-dose exposure was possible for those workers, boilerplate makers, and what have you, who came in, unbolted some of the units, got 5 rem, and then were moved out, but were never part of the monitoring system of the individual plants. Do you have any information on that?

ABRAHAM: Yes, I have it with me. I will show you the book. It is published annually, I think for the last 17 years. Brooks at NRC is the author. If my memory serves me correctly, the table from which I got the numbers has in it all people who are badged. People who come into nuclear power plants are badged. Their radiation is tracked. When they leave, I think the company has—I forget whether it's 30 or 90 days—to send them a letter and tell them what their exposure was. I occasionally go on tours of plants. I get letters like that routinely. They always say zero.

The system should embrace everybody who comes to work in a nuclear power plant that gets a badge. All the plants that I am familiar with in the Northeast, nobody walks in without getting a pocket dosimeter and a badge. So I believe all that data are reported to us. I will let you look at the book and find out whether or not I'm interpreting that correctly.

ABRAHAMSON: This is to Mr. Tooper. You were lamenting the fact that we are not putting up nuclear power plants in the northeast sector of the country for the future growth and the needs of the future, and that Canada might be putting up plants in that area to supply the future needs of our country. I think that was the point you were making.

TOOPER: I wasn't lamenting the need. We are not doing it. I am lamenting the situation, the process that we have in the United States.

ABRAHAMSON: As a member of DOE, I guess my question to you would be, until DOE and the public can get their act straight on high-level waste repositories, should we be putting up any more nuclear power plants when the NIMBY syndrome exists throughout the entire United States, and we haven't really gotten a high-level waste repository acceptance at this stage of the game?

TOOPER: Clearly, the waste issue, particularly high-level waste management, is an issue that has to be addressed hand in hand, but I do not tie it with the deployment of nuclear power plants. For example, if we did not deploy any more nuclear power plants, we would still have the waste issue. By deploying what I call a robust redeployment or revitalization of nuclear power with, say, 30 plants, that is not going to significantly contribute to our waste management problem.

So, no, I do not tie the deployment of nuclear power plants in the foreseeable future to the waste management problem, albeit it clearly impacts the public perception that we do not have a tangible solution to waste management at hand, and that is the subject of another debate.

BRODSKY: I am Allan Brodsky from Georgetown University. Up until a year ago, for 11 years, I was back with the government's Nuclear Regulatory Commission. I guess I should point that out, but my remarks are as an individual.

My question will be, what can be done to interest the media in seeking further the truth, plus a true perspective of scientific opinion in their reporting?

RUBIN: What is the truth? You, I gather, have a notion in your mind as to what you think the truth is, but as far as I can tell, this subject is sufficiently complicated that reasonable people will disagree on the truth. To expect the press to tell the truth, you are going to have to somehow demonstrate that there is a truth to be told, and what areas of this subject need to be told.

Beyond that, the press does not work that way anyway. The press does not write stories each morning in which they say, "Now the truth about this subject," and then talk about nuclear power; and "Now the truth about that subject," and so on through the list of various controversial issues in society. The press in this country is very much tied to the reporting of specific events. It is event-pegged. Very much of what you see in the press is dictated by events that are out of the control of the press. Either they are like TMI and Chernobyl, which are out of the control of everybody, or they are controlled by government, in that government creates events that it wants the press to cover.

The time at which the press spends the most attention on discussing "the truth" about nuclear power is during accidents like TMI and Chernobyl, which I would say is probably the worst time to attempt to discuss the truth. It is the period in which the truth, whatever it may be, is most elusive, passions are highest, people are most confused, and the audience is most concerned and ready to believe the worst.

So one really needs to understand better how the press works when it is going to cover events, and also not to expect that the press is in any way the ultimate arbiter of truth, although I think the ultimate truth of what Three Mile Island has meant as an accident, slowly and through the accumulation of stories, as Dick Smyser points out, is now available. It was not a very serious accident in public health terms, it was a very serious accident in economic terms for that utility, and it was a very serious accident in public relations terms for the industry. So what is the truth of the importance of that accident? It depends where you sit?

SMYSER: There is a marvelous quote by Walter Lippman. The effect of it is that really the function of the press, the media, is not so much to presume to give you the truth as it is to signal some directions for you in which you, as a reading public, might seek out the truth yourself. I think that is a very accurate description.

I have been many times distressed about something in my paper, maybe something that I have written and sometimes written under pressure and in a hurry and without as much research as I should have. I have been concerned because maybe there have been some nuances of it that really are not quite correct, and I worry. But then sometimes I satisfy myself, "Well, perhaps it wasn't precisely right, but at very least it called to the attention of our readers some area which they should know about that they might not otherwise have known about, even though maybe I called it to their attention in a flawed fashion." I think Lippman's quote is helpful.

RUSSELL: Time is very important. In the accidents that we are talking about, both Three Mile Island and Chernobyl, often there was not much time to get a lot of perspective. Initially, at the time of the event, what you are really looking for is information. What has happened in both of these incidents is, there is often a lack of information, and therefore you are forced to get more opinion, and sometimes the opinion is very polarized.

I was very concerned as a reporter and also as a member of a journalistic organization with Chernobyl, where not only were we impeded in getting information because the accident did not happen here, and the Soviets were not very informative about what was happening, but in that case, again with all the problems we had in getting accurate information, we had problems with the government in getting to the sources of information.

There was an attempt basically to try to centralize information, which is a good idea in theory so that everybody is not making contradictory statements. But in doing so, there was a sort of strangling of information that was available. Fortunately, it was a temporary problem. But there was a lot of concern by journalists about that because we couldn't get information, and we were forced to get more opinion. I would be interested in a comment from Mr. Tooper about this question of access to information during a crisis and how we can improve getting information from the people who really know.

In that case, at Lawrence Livermore Lab in California, there was a group very experienced in tracking radiation that had information that might have been helpful and valuable for us to get. Suddenly, they were precluded from providing that information. In my own instance, I called in the morning and was told that I'd get a call back. I missed the call because I was on another call. By the time I called them back, they said, "We are not allowed to talk. Call Washington."

TOOPER: Again, it is a matter of perspective. At TMI, there were so many sources of information, they appeared to be conflicting; the media journalists unfortunately had to go to more and more sources, and no one really had a straight story. So therefore, the lesson we learned from TMI was that we really need a single source, like a Harold Denton or a Hans Blix. That works very well.

On the other hand, you are espousing that the media is not too content just having one source of information. They really want to have several sources of information so that they can get an objective viewpoint. Well, it seems to be a bit contradictory, in terms of objectives and how to best serve the public. I think that DOE, viewing the team I experienced, had a multigovernment agency involvement, in terms of accumulating all the information, albeit through DOE contractors, through EPA contractors. They were all focused as a single unit, coming through Lee Thomas of the EPA as the spokesman. It was our attempt, to the best of my recollection, to focus all the credible sources of information into a coherent package that the media then could take and run with. We have to move toward the development of the credible source, and this all loops back to DOE trying, in addition to the other government agencies, to establish their credible source.

There was an interesting point in the Kameny Commission report that the media perhaps failed in some regard because they did not have the level of technical engineering expertise unto themselves, or they did not bring it with them to be able to interpret the story.

RUSSELL: With all of these things, it's a question of time. By the time you get all organized, it may be several days after the story has unfolded.

TOOPER: The issue that I have is the issue to serve the public and convey the information at hand and the implications thereof, or is the issue to be able to discuss implications prematurely before the answer is available.

ABRAHAM: Because of my grim experiences at Three Mile Island, when the Chernobyl accident happened, I read almost all the stories only for that aspect that Christine talked about: how was the information being made available, where was it coming from, and who knew what they were talking about or appeared to.

I have clipping services and things that allow me to read a large cross-section of newspapers every day. It seemed very obvious to me that there were some things going on that had nothing to do with the accident or the availability of a spokesman per se. There was an enormous reluctance on the part of anybody in this country to get involved in saying something outrageous that would be construed as an anti-Soviet opportunistic slap at the Russians, because everybody on both sides I think was trying to improve relations. We can look now in hindsight at what other things were going on.

I think people who might otherwise have been willing to speculate, because they are high enough in the scientific pecking order or the governmental pecking order, realized that if they really blew it, the Russians could easily later prove it was false and accuse us of doing it for malicious reasons. But a government official or a high person in a research center that gets privileged information, I think they would recognize immediately it would be the end of their career to scuttle a summit or to do any one of a number of things.

Those were never considerations at the time of Three Mile Island. I think some of the news media gradually caught on to the fact that the Americans were laying back a little bit in their information because there were other things at stake. I just recognized that as a fact of life.

KASPERSON: I'm Roger Kasperson from CENTED at Clark University. Several aspects of the communication problem have not been dealt with very much and deserve mention. First, communication is a two-way process. If there has been a major failure in this area, it seems to me to be on the listening side rather than on the communicating side or on the portrayal of information. If one goes beyond noting that communication ought to be two-way and really try to address what those listening problems are, and the kinds of impediments that exist in institutions, or the fact indeed that if you do communicate accurately, risk perceptions that are often fundamentally different than the technical assessments, what are you going to do with the information that you have gathered? How are you going to internalize it in the institutional structure of the way that regulatory agencies operate? What role, for example, should it play in definitions of safety goals for nuclear power, licensing of nuclear power plants, implementation of the LARA and so on? That is one problem.

The second problem related to that is

this: If we are smart enough or clever enough to find out how to do the communication, the presentation-of-information job to the public in a really good way that would capture the public's attention, get them to listen, get the right information to them, that we would get different kinds of decisions and response to the public.

There is now a substantial body of accumulated social science research on why the public responds to hazards in the way that they do. Basically, most of that work suggests that is probably not the case. We now know that when the public assesses nuclear hazards, for example, it comes out to very different kinds of perceptions than the experts do because they do it in fundamentally different ways, considering fundamentally different properties of the hazards, as well as the risk process that delivered the hazard.

One of the questions is, When we are done with the job of conveying all the information well, and we still have this major difference in assessment, do you think that perhaps the problem is in the inadequacies of the technical assessment that fails to capture what is of concern to the public and what is certainly relevant to the public interest, rather than in the kinds of responses that are occurring in the public?

ALVAREZ: In regard to your latter question about the technical aspects, I think that the clarification of technical aspects again falls on access to information. In the previous discussion from the previous question, we were talking about getting access to information in the wake of an accident, but I think more importantly is the problem of getting information before an accident occurs, especially information that deals with what if an accident occurs. That is a very serious problem, in terms of getting data out of the government, both the Nuclear Regulatory Commission and the Energy Department, from my perspective as a public interest advocate.

For example, we were very interested and have been for many years in studying the nuclear waste management aspects of the Savannah River Plant in South Carolina and were only able to obtain the safety analysis report that had been classified secret after we went to court and forced them to give it to us. So we wrote a report, which we issued last year, and the Dupont Corporation, with the sanction of the Energy Department, issued a reply based on a new safety analysis report, of which they released the results but not the method.

By not releasing your method, you can juggle your stuff in secret, and there is a definite lack of scientific integrity. You need to have access to good technical information on a regular basis, and there should be an open policy about this. But that has been a problem. I think is a real stumbling block in dealing with the thorny technical problems.

MOSSMAN: Ken Mossman, Georgetown University. I wanted to just make a few comments about the peculiar characteristics of radiation. The panel has already alluded to the unusual history, the images of disaster that one thinks of with atomic bombs and mushroom clouds, and the history of nuclear testing, and Three Mile Island and Chernobyl. I just wanted to bring up a couple of others for possible comment.

One, of course, is that the public is very confused about radiations. They are used in different ways. For instance, 500,000 people per year in this country are treated for cancer by radiation. So a lot of people know or know about either family, friends, or relatives who have been treated. Perhaps they have seen some of the adverse effects that may come about from the radiation treatment, and they may incorrectly compare those kinds of things with what goes on with radiation accidents such as at Chernobyl and at Three Mile Island.

Another situation in which I was personally involved was during Chernobyl. I was asked a number of times to make the comparison between the radioactivity released at Chernobyl with the radioactive releases which occurred during the nuclear testing in this country. Really, that is not a very fair comparison because, of course, it implies that Chernobyl was like a bomb going off. A lot of people have these kinds of misconceptions, and it is the kind of thing that I think journalists ought to address, because it's one of the serious problems in the knowledge array that the general public has.

One last thing. If you look at the radon problem, where we are talking about pico curie levels in the environment of radon, and following Chernobyl, the release of 100 million curies of radioactivity into the environment, you are talking about a 20 orders of magnitude range of radiations. To my knowledge, I do not know of any agent—chemical, physical, or otherwise—for which one has to deal with the public in which one has such a very wide range of concentrations of some particular kind of agent, trying to explain away that perhaps at the very low end you do not have very many effects, but in the treatment of cancer you may have some very serious side effects to deal with. So I think the public is very confused about it, and it is because of these problems that I have identified.

SPEAKER: I think something that certainly adds greatly to public confusion about radiation is the scattered and fragmented nature of regulation itself. I recently had to do some work to look at this problem and try to quantify just how scattered it is. Really, you have several different players at the federal level. You have 50 States imposing some form of regulation. When you get into the Energy Department, they have site-specific regulations; there are no uniform standards whatsoever. And you have double standards: if you live near a DOE facility, particularly in terms of soil dumping of liquids, you are allowed to receive 20 times more radiation than if you are living near an NRC facility. Then you have the Food and Drug Administration involved in the contamination of food and medical advices. Then you have several different advisory committees giving different kinds of advice to the agencies.

This scattered and fragmented program of radiation protection really encourages a dangerous form of self-regulation. Without uniform and conservative standards that the general public can understand, it is just going to add to confusion.

RUSSELL: I think some of the confusion results from there being so many different terms and so many different sources. When you are trying to make these analogies and you go to different experts, many of us will go to someone in nuclear medicine—so there is a natural tendency to compare it to x-rays.

It is fascinating, on the radon question, why the public alarm has not been as high about that as it might be about something that was nuclear power related. As journalists, we are always struggling with what would be the right analogy to really make people understand it. I think some simplification of terms by professionals and some attempt to work out some analogies that might be more apt would be helpful. I think that professionals have trouble explaining it to us, and we then have trouble explaining it to the public. In any case, none of us is out there holding the hand of the person reading the newspaper and helping monitor why they are reacting to it. That is a whole different question.

SHARP: My name is Daniel Sharp, and I am a health physicist at the National Bureau of Standards.

With reference to Karl Abraham's talk, I do not work with the public. I work in a large laboratory with hundreds of people. At least half of my work is exactly like his work. I give psychological counseling to people, even though I am not a psychologist. A lot of the damage that radiation does is psychological, and I consider that a real, valid injury. I have never read anything in any book or heard any lecture or talk like Karl Abraham's. To me, that is about the most meaningful talk I have ever heard in five years of this work.

The second comment is related to something that Alvarez said, that the root of the problem is in the psyche of people. If there is a root of the problem, it is not just that people do not understand all the details. It is that there is a real psychological problem entrenched in people's minds, and there is no communication that is going to change that.

The next comment is that people do not evaluate risk-to-benefit, they just consider benefit. So there is no risk so great that will be ignored if they want to ignore it, and there is no risk so small that it would be the biggest thing in the world if you do not want to accept it. All people examine is benefit. So there will be a time when people's washing machines and dishwashers and television sets, vacuum cleaners, and air conditioners will not work because there is no power, and they will want nuclear power.

But I do not believe it is the place of the government or of any big corporations to try to force people to want things that they do not want, especially in a democracy. I believe you could have a whole civilization filled with cheap power and all the nuclear power plants to supply all the energy everybody could ever need, but the quality of life is not going to be very high if everybody is super neurotic about the radiation.

ABRAHAM: I will just mention in passing that one of the issues the federal court had to deal with in deciding some compensation cases in connection with Three Mile Island was the issue of psychological damage. Everybody says there was some and then finally agreed that the scientific community that has the expertise in looking at psychological damage did not have a really good way of measuring it. There was no really good way of coming to grips with what you would call damage and what you would say was happening to people who had a predisposition to be alarmed. Some very nasty talk went around in the popular press on the issue, but it is one area where everybody who tried to deal with it in connection with those lawsuits realized that we do not have institutions, either legal or scientific, that can effectively deal with psychological stress from being afraid that you might get a very high radiation dose and then it turns out there is no really high radiation dose.

SPEAKER: One quick comment pertaining to the government and industry forcing nuclear power. One has to recognize that government's concerns are associated with the fact that you are not building a nuclear power plant today and we are probably not going to build any in the very near future. The industry as industry is not something you turn on and turn off. It goes away. People go on to other activities, other portions of the private sector. The concern is, if indeed you are going to need significant additional amounts of electricity generative capacity, and coal and nuclear are your only choices, then what do we do in the meantime to keep nuclear as a viable choice. It is not a matter of forcing. It is a matter of minimizing the risk and being able to have that capacity available when needed.

FINUCANE: I'm Jim Finucane from the Department of Energy, but my comments or questions are specifically as an individual. I observed, as I guess we all have, that the good news appears on page 46 with the used car ads and the bad news on the front page. Because of my interest in the subject, I did watch very carefully the Chernobyl reporting. I found it rather uniformly bad, with the exception of public television.

Mr. Rubin, to whom my question is specifically addressed, alluded to the ham radio operator and the 3,000 deaths that were reported almost universally throughout the media the first week after the accident. By the middle of the second week, at least the New York Times reported, again on page 46, a fairly detailed analysis of clues to the credibility of that source, but I never say in any of the media, written or electronic, any formal statement or retraction of the 3,000 immediately dead. The 20,000 in a mass grave, I think people would dismiss out of hand from the *New York Post,* but the remainder of the media never got up and said, "Hey, this was a mistake."

RUBIN: I am glad you raised that. We cannot let the *New York Post* stand for American journalism. The way the 20,000 deaths report from the ham operator was really in fact covered by the elite media was, I think, with a lot of responsibility.

I do not know what your memory of this is, but *The Washington Post* ran that report in a box, a small box, and made it clear that it was unconfirmed. It was not in any headline. It had none of the prominence it had in the *New York Post.* When UPI admitted, as they did on their wire, that they were wrong, the retraction appeared. *The New York Times* ran it in a single paragraph within a much larger story and also indicated that there was no confirmation for this.

In fact, the *New York Post*'s running of it was completely atypical of the way American journalism handled the 20,000 death figure. It is unfortunate that the *New York Post* is in New York. It is unfortunate that it exists, period, but that it is in New York gives it greater prominence. People assume that these kinds of headlines were typical across the U.S. The Soviets use the *New York Post* to indicate the way in which the capitalist press was bashing them over the head inaccurately.

But I simply urge you to remember that Murdoch is not American journalism.

RUSSELL: I just second that. Often, even in the discussion today, we use the word "press" and "media" as if it is a monolithic institution with one single voice. All reporters are not alike, all newspapers are not alike, all television is not alike, all scientists are not alike. It is dangerous to generalize in the same way about good news and bad news.

MOORE: Scott Moore, U.S. Army. The title for this discussion, part of it, "In the Post-Chernobyl World," indicates an international flavor to the discussion. This is directed at the journalists. How would you characterize relationships between, say, the Japanese press and the Japanese general public, the French press and the French general public? Is there anything we can learn from these other nations and their presses?

RUBIN: Let me only speak about the French press, because that is the only one that I am slightly competent on. The French press is much less aggressive in challenging its government and its policies than our press is in challenging its government. Since the French government seems fairly set on this particular course, the French press does not challenge it. It has not and is less likely to than is ours. So that if you are a champion of press/government cooperation in order to further public policy, the French model would appeal to you.

D'ARRIGO: My name is Diane D'Arrigo. I am with the Nuclear Information and Resource Service. We are a public interest group which provides information to the public and sometimes to the media on nuclear power and waste questions. One of the things that I found distressing in a lot of the reporting after accidents is that there can be a short or a long article, but it always ends with "and there was no risk to the public."

It makes me not even want to give any credibility to almost the rest of the report because every amount of radiation has some risk. It may be a very minute risk. I sympathize with the reporters because it is very difficult to present that risk to the public. That is what this whole thing is about today, how do we explain what the risk is and how do people perceive it and so on. But to give a blanket statement at the end that there is no risk, and a lot of times it is quoting someone from the Department of Energy or the company that had the accident or the release, it is a real conflict of interest. There is not going to be trust from that. The Department of Energy is an advocate, even though the people within the agency themselves are honest and have integrity. The agency's mission is to promote nuclear technologies, and people are not going to believe when the promoter turns around and says that there is no risk, because they are the ones that are promoting.

If I was looking back at a lot of the coverage, I was struck really, a little bit in contrast to what some of our speakers have said, that a lot of the stories that I was reading emphasized uncertainty and said the risk was unclear and said there did not appear to be an immediate risk. Particularly with Chernobyl, there was a worldwide question of risk. So I think there is not a single generalization about how risk was covered, but I think a lot of the coverage did make a single-bullet statement.

ALVAREZ: Briefly, I think your point is a very good one concerning coverage of the plant before the accident. We found in our TMI report, we looked at coverage of the plants while they were being constructed, and we found that there had been lots of little incidents. Typically, the press release from the utility was that there was no danger to the public, which may be true or may not be true, but the local press printed the press releases as received. They did no investigation of their own. They just took it at face value. The effect of that is that the public is lulled into thinking that there is no problem and that there will be no problem. Then when there is a problem, as there was, you then have the credibility issue which lingers.

So in the short term, I suppose, it is smart for the utility to take that position. In the long term, if you have an accident, you have real credibility problems.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 205–209, June 1988

Physicians, Physicists, and Radiation Accidents

William R. Hendee, Ph.D.

Vice President for Science & Technology
American Medical Association
Chicago, Illinois 60610

ABSTRACT

Emergency planning for radiation emergencies has been a long-standing activity of regulatory agencies and medical institutions in the United States. This activity has been re-evaluated following the Chernobyl accident, with the result that several changes have been identified as desirable in current emergency planning measures. Among these changes is the need for closer involvement in emergency planning by physicians and health physicists available in communities where nuclear facilities are present. This involvement requires increased education of these individuals on a variety of topics associated with radiation. One model effort to provide this education has evolved from an International Conference on Radiation Emergencies sponsored last fall by the American Medical Association. This effort is designed not only to enhance professional knowledge about radiation accidents, but also to facilitate communication of this information to the public sector.

The topic of preparing for and responding to radiation accidents is not a new issue. Physicians and health physicists have had a long standing commitment to emergency preparedness and the design of plans for responding to radiation accidents. Ever since the dawn of the nuclear age, we have understood that radiation accidents can happen, and over the past four decades such accidents have happened. It would be foolhardy to believe that they will not continue to happen, especially with the increased use of nuclear energy in defense and for production of electricity, and with the ever-growing use of radiation sources in industry and for diagnostic and therapeutic purposes in medicine. These uses require that radiation sources are handled by technicians, transported from one site to another, and shipped to remote sites for storage and disposal. Under these circumstances, accidents involving nuclear facilities and radiation sources are bound to occur, and then physicians, health physicists and representatives of the media have major responsibilities. Physicians are responsible for caring for persons injured during the accident and for those possibly exposed to radiation. Health physicists are expected to prevent or minimize exposures to individuals wherever possible, and to control the environment to prevent the spread of radiation and radioactive contamination. And the media is expected to provide factual information about the accident that is as objective as possible and not slanted to either increase anxiety about the accident or underestimate its possible consequences.

Responsibilities assigned to physicians, physicists and media representatives during a radiation accident are reflected in emergency plans required of hospitals by various agencies, including the Joint Commission on the Accreditation of Healthcare Organizations, the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the Federal Emergency Management Agency. They are also encompassed in plans for radiation accidents developed by state agencies responsible for radiation safety. In most communities these plans have been in effect for some period of time. Occasionally these plans have been implemented for events other than radiation accidents, including natural disasters and industrial and transportation accidents involving hazardous substances other than radiation sources. In fact, there are only two major differences between radiation accidents and other types of emergencies for which accident plans are useful. These differences are the long-term consequences of radiation sources released to the environment during a radiation accident, and the exaggerated perception of risk whenever radiation is involved.

Today there is renewed interest in emergency planning for radiation accidents. This interest is a reflection of the accident at Three Mile Island, and, more recently, the accident at Chernobyl in the Ukraine. For example, the present symposium is a direct result of the accident at Chernobyl.

Although the management and public information aspects of the Chernobyl accident left much to be desired, the medical response was excellent as demonstrated by the fact that only 31 persons died, and fewer than 200 persons are estimated to have been exposed to doses exceeding 100 rams. It has also been stated by the Soviets that the medical response to Chernobyl exhausted the resources of that country to deal with a radiation accident.

Since the Chernobyl accident, there has been much soul searching in the United States about this country's ability to respond in similar fashion to a radiation accident, both medically and as a society. In particular, there has been much discussion about whether our professional teams would respond as well, and the public reaction would be so controlled, given our free press and delegation of responsibility of decision making more to the individual and less to a bureaucracy. These questions are reflected in the many phone calls that I and many others received immediately after Chernobyl from physicians and representatives of medical societies inquiring into their responsibilities following a radiation accident, and their feelings of inadequacy in meeting those responsibilities. These phone calls were part of the stimulus for development of the International Conference on Non-Military Radiation Emergencies that was held last November in Washington, D.C. The purpose of this conference was to examine the current status of emergency planning for radiation accidents, and the existing and desired roles of the medical community in planning for such accidents, educating physicians and the public about radiation accidents, and responding to them should they occur.

Several recommendations evolved from the International Conference on Non-Military Radiation Emergencies. It is clear that significant engineering differences exist between the RMBK-1000 graphite moderated reactor that caused the accident at Chernobyl, and the reactors in the United States that are used to generate electricity. These differences provide assurance that an accident of similar magnitude in this country is unlikely to occur. Nevertheless, radiation accidents involving nuclear power facilities can occur, as can accidents involving other sources of radiation. Adequate preparedness for such accidents, and education of professionals including health physicists and physicians, are absolutely essential if the likelihood of these accidents is to be minimized, and the consequences are to be controlled when they do occur.

The planning effort should include objective risk assessment of environmental hazards in general and sources of nuclear energy and radiation in particular. Risk assessment is especially important with regard to nuclear energy used to generate electricity. We have too long tended to separate this issue into two camps. One camp, the advocates of nuclear power, tend to trivialize the risk, saying that an accident simply can not and will not occur, and that even if it did the consequences would be minimal. On the other side are the opponents of nuclear power who tend to exaggerate the risks and claim that nuclear energy is the most hazardous force ever unleashed upon mankind. At present, the opponents are ahead in this debate, as evidenced by the fact that no applications for new nuclear power stations have been filed since 1977.

This country needs a renewed effort to understand, appreciate and expand the nuclear contribution to electricity generation and increased attention to ways to achieve that contribution at minimum risk to individuals and society. Shortly after Chernobyl, a Gallup poll showed that 70% of those questioned opposed the siting of a nuclear power station within five miles of their residences, in spite of overwhelming evidence that a nuclear station in this country does not pose a significant risk to individuals in the vicinity. A major public education effort is needed about the risks and benefits of nuclear energy applied to the generation of electricity. This educational effort requires the participation not only of representatives of the print and electronic media, but also of health physicists and physicians serving as community resources knowledgeable about the benefits and hazards of radiation in general and nuclear power in particular. Similarly, the disposal of radioactive wastes is an issue that demands understanding leading to resolution in our society.

Several other issues evolved from the International Conference on Non-Military Radiation Emergencies. An international notification system for announcing the occurence of a radiation accident of substantial proportions is essential, and appropriate response mechanisms for addressing the consequences of a radiation accident are needed. The international notification system agreed to recently by the Soviet Union, the United States, and several other countries as a result of the September meeting of the International Atomic Energy Agency in Vienna is a good beginning to meeting the first need. Improved engineering and safety inspections of nuclear power facilities are needed at an international level. The program on safety inspections and planning efforts for criticality scenarios recently made available through the International Atomic Energy Agency are a promising start toward addressing these needs.

Both Three Mile Island and Chernobyl have enhanced the appreciation of the role of human error in radiation accidents. Improved training and testing of radiation workers are needed to reduce the potential of human error. Improved vigilance against complacency and increased attention to education and training of health physicists and physicians, as well as the public, about radiation and radiation accidents are needed. These needs should be matched with improved understanding of ways to mobilize the medical and health physics communities in the event of an accident, and with improved planning for radiation accidents at the community level.

The medical community needs to be better educated about radiation and the appropriate mechanisms of response in the event of a radiation accident. Forums for professional education on issues involving radiation need to be established, so that physicians can better understand:

1. Radiation exposure and radioactive contamination.
2. Pathophysiology of exposure and contamination.
3. Physical and physiologic behaviors of sources of radiation.
4. Responsibilities of professional groups in the event of accidents, including their obligations to respond and the limitations intrinsic in their response.
5. Role of medical schools and professional organizations in providing the necessary education and training.
6. Existing response mechanisms (eg. the U.S. Nuclear Regulatory Commission Radiologic Assistance Plan, and the Radiation Emergency Assistance Center and Training Site (REAC/TS) in Oak Ridge).

An improved understanding of levels of risks is needed, together with a greater recognition of the obligations of physicists and physicians to respond to a radiation accident if one should occur. These issues need to be worked out before, not after, an accident has occurred. We have assumed for too long that professionals would respond appropriately in the event of an accident, without questioning whether this assumption is reasonable. We also have to wonder about the responsibilities of physicists, physicians and others, whose homes and families are threatened by a radiation accident and yet whose professional obligations require them to be present at the accident scene or health facility. And, last but not least, we need to examine carefully the role and responsibilities of the electronic and print media in the event of a radiation accident, and of those individuals who have responsibility for interfacing with the media.

Three major actions resulted from the international conference. The first was a demand of the participants to publish the proceedings of the conference. The proceedings are currently in press, and should be available in a few weeks. The second action was a request that communications be established between the American Medical Association and the various federal agencies involved in emergency planning and public education about radiation accidents. These communications were, in part, to express the willingness of physicians to become more involved in these issues, both proactively and reactively. I have communicated this offer of help to a number of agencies, including the Environmental Protection Agency, the Nuclear Regulatory Commission, Department of Energy, Federal Emergency Management Agency, and others, and have found a receptivity to the involvement of physicians and health physicists in emergency planning. I plan to continue this effort.

The third major action of the conference was to establish an improved dialogue between representatives of agencies operating nuclear power plants and contractors for DOE facilities, and physicians, other health providers, health and medical physicists, and hospital administrators in communities where such facilities exist. In response to this directive, we have focused initially on improving the dialogue in two states, Illinois and Pennsylvania. In Illinois, we are developing a model program for improved dialogue in communities around nuclear power facilities, starting with a meeting last week hosted by the Will-Grundy County Medical Society. This meeting focused on radiation accidents and involved representatives from Commonwealth Edison and physicians, physicists, technologists and administrators from the community. We plan to hold similar meetings in other parts of the state where nuclear facilities are present, with the intention of developing a model program that can be exported to other states. We are pursuing a similar approach in Pennsylvania, where Pennsylvania Power and Light is already involved with the medical community in a series of public forums about radiation and radiation accidents.

There is one remaining issue that deserves mentioning as part of this presentation. That issue is the current public perception and misperception of risks, both individual and societal, and how the applications of risk assessment and risk management techniques can be made more objective and more efficient as viewed from the public sector. There is considerable information available about the processes of risk assessment and risk management, and more is becoming available as time goes on. These processes pertain to, but certainly extend beyond, the specific issues of radiation, radiation accidents and nuclear energy. This past week the American Medical Association held a teleconference on risk assessment and risk management that was broadcast to over 900 hospitals across the country. We are also attempting to develop educational materials for school-age children on risk assessment and management from both a personal and a community level. In helping the public gain a more objective view of risk assessment, factual, succinct and understandable information about these processes is needed. In addition, a mechanism of transfer of this information from credible sources to the public needs to be available at the community level. This latter need is the one that could be met by health physicists, physicians and other health providers working as resources in their community. These individuals are knowledgeable, or with education can be made knowledgeable, about risk and risk assessment. Certainly they are credible sources of information, and they are available in communities around the country. We need to develop ways to mobilize this resource of information providers, and use it to provide education and guidance at the community level about environmental and personal risks.

One mechanism to mobilize this resource is through state and county medical societies working in concert with medical specialty chapters, chapters of groups like health physicists and medical physicists, and others. I have discussed this approach with several federal agencies, and have uncovered a lot of interest. We are actively pursuing this approach with the intent of mobilizing health providers and other knowledgeable individuals in communities around the country to help improve public perception of risks.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 210–225, June 1988

Emergency Planning for Nuclear Accidents: Contentions and Issues

John H. Sorensen

Oak Ridge National Laboratory* Oak Ridge, TN 37832-6206

and

Barbara M. Vogt

University of Tennessee

ABSTRACT

The purpose of this paper is to identify and discuss issues that have been raised concerning emergency planning for nuclear power plants. The extent to which these issues can be eliminated or dismissed on the basis of current physical and social science knowledge is important for assessing the viability of emergency planning as a form of human protection. Where an issue is valid, it is important that emergency planning incorporate knowledge concerning those issues.

The results of the analysis indicate that the critical point for changes made in planning requirements was the TMI accident. Current plans, as a result of these changes are far too complex, bureaucratic and rigid to permit flexibility in managing emergencies. Having an adaptive and flexible organization is a key factor in having effective emergency management response.

Many of the issues in nuclear power plant emergency planning are derived from behavioral intent surveys. Research based on these methods which concludes people will behave in certain ways in a future emergency is largely invalid and should not be the basis for developing emergency plans. The basis for plans must be developed on existing knowledge, not on speculative or inaccurate assumptions.

Based on the analysis three recommended actions are proposed:

1. Revise radiological emergency planning frameworks in a manner which promotes more flexibility in response procedures and which is more responsive to local factors such as unique topography and population distributions.
2. Develop policy positions on various issues including the validity of various contentions and the conditions under which the contention are or are not valid.
3. Give local and state governments more legal responsibility for developing emergency plans for nuclear power plants while placing the burden of proof on all parties.

Introduction

The purpose of this paper is to identify and discuss issues that have been raised

operated by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract No. DE-AC05-84OR21400 concerning emergency planning for nuclear power plants. Some issues have been raised by researchers and the scientific community, others by concerned publics, and still others by critics using emergency planning issues as a means to address other social controversies. Some have generated significant public concern and debate while others have been academic issues. These issues and beliefs are important because they represent challenges to the feasibility and efficacy of emergency planning and some can potentially provide the means to improve emergency plan implementation if properly addressed.[9] The extent to which these issues can be eliminated or dismissed on the basis of current physical and social science knowledge is important for both assessing the viability of emergency planning as a form of human protection and eliminating unneeded research.[44] Where an issue is valid, it is important that emergency planning incorporate knowledge concerning those issues.[77] The extent to which an issue is unresolvable is also important for establishing agendas for new research on emergency planning. Where invalid, examination of the issues is important to prevent erroneous issues from interfering with sound decision making or even from leading to poor emergency plans.

Contentions and Issues

The issues identified in this paper come from a variety of sources, including research reports, critiques of emergency planning, editorials, transcripts of hearings, litigations and newspaper articles. Issues were initially summarized in a point form for each hazard. A conceptual typology of major issues was induced from these lists and a hierarchy of issues was specified under these five categories. The major categories of issues and their definitions are as follows:

Physical Hazard: the nature of the threat including the definition of areas at risk, lead time, location, magnitude, probability, and type of hazardous products.

Warning: the nature of the information dissemination process including the ability to notify and provide a warning message, the quality of the information, and timing of the message delivery.

Social: the pre-emergency population attributes including psychological, demographic and social characteristics.

Organizational: the attributes of emergency preparedness and response organizations.

Response: the behavior of people and organizations in an emergency.

1. Physical Hazard Issues

Definition of Impacts

The area at risk for a nuclear power plant accident is a function of source term and meteorological conditions.[1] Considerable research has been conducted on establishing accident risk levels.[79,82,83] There is great controversy at present about the size, composition and release characteristics of source terms and the areas they would effect. Research conducted on the Three Mile Island (TMI) accident has been interpreted in divergent ways. The nuclear industry contends that TMI did not demonstrate the need for evacuation planning.[27,28] Research conducted since the accident demonstrated that source terms were smaller than expected and thus the emergency planning zones for detailed evacuation plans should be lowered to 1 or 2 miles. The Nuclear Regulatory Commission (NRC) maintains, however, that research has not

*This paper is drawn from a report prepared for the Federal Emergency Management Agency: J. Sorensen, B. Vogt, and D. Mileti. 1987. *Evacuation: An Assessment of Planning and Research,* ORNL-6376. Oak Ridge National Laboratory.—The findings and conclusions are those of the authors and not of FEMA.

reduced the uncertainties sufficiently to change the Emergency Planning Zone (EPZ) concept.[11] Intervenors argue for an expanded plume exposure zone because accident that exceed the Protective Action Guides (PAG's) beyond 10 miles are possible.

The accident at the Chernobyl reactor in the Soviet Union (1986) raised different issues about areas at risk because the area impacted was much larger than expected and the risk from exposure did not decline in a linear fashion with distance from the reactor. The Chernobyl accident also pointed out the critical role that rainfall plays in particle deposition.

Uncertainty in Ability to Detect

Inability to recognize that a threat exists makes it more difficult to issue a protective action warning or prompt people to move away from the threat. That one cannot see it, smell it, taste it hear it, or feel it is a popular "battle cry" of nuclear power opponents. Critics of nuclear power hold that because radiation is invisible, the public at risk will not see the approach of the hazard and therefore will not take protective action. An additional issue is that people who do evacuate will not know where radiation exists and may be exposed during an evacuation.

Physical cues are important determinants of evacuation behavior.[39,41] It is easier to achieve high levels of evacuation when cues are present to aid detection. Substitution of visual cues in the warning process may help overcome this constraint but the specific impacts of variation in the style and content of warnings on propensity to evacuate is largely unknown. At TMI attempts to educate the public to use monitoring equipment met with mixed results.

Planning Increases the Risk of an Accident

Critics have argued that planning changes the likelihood of nuclear power accidents. It has been reasoned, albeit in a somewhat tautological fashion, that emergency planning, because it sanctions the operation of a plant, and because it rests on the assumption accidents will occur, increases the likelihood of an accident.[25] A related issue that is more relevant and of greater importance is whether emergency plans increase the threat or consequences of a hazard if it occurs because it creates a false sense of protection should the threat actually occur.

There is no research which proves or disproves the validity of this issue. Logical arguments can be formulated to support opposite positions or a "no effect" conclusion. The motivation for preparing such arguments is largely ideological or political in nature and further research is unlikely to change the arguments.

2. Warning Issues

Uncertainty in the Ability to Alert

The speed of onset of some hazards dictates that warnings be issued in short time frames. Critics of emergency planing claim that the warning systems will not provide timely information and therefore evacuations are not feasible. According to federal regulations, 100% of the public within 5 miles of the plant must be alerted within 15 minutes following a decision to warn and the rest of the public, including those not receiving the initial alert, within 10 miles must be warned in 45 minutes.[80] Nuclear power plants have developed systems that can theoretically provide quick alerts, but the systems remain questionable as to their ability to perform under emergency conditions and to provide instructional information about protective actions.[58] Additional research is needed on how to improve planning for issuing warnings within short time frames to support evacuation efforts as well as other forms of protective action. The current methods for evaluating alert systems fail to provide data for addressing this particular issue.

Public doubts have surfaced about the persons and organizations involved in the warning process withholding information from the public. Litigation has arisen over whether or not utilities would try to cover up an accident instead of reporting it to local officials or would delay the communication until the problem was corrected. The rationale is that because of their vested interest in keeping the plant operating if would be advantageous to under-report risk. Poor abilities to communicate also constrain issuing warnings for protective actions such as evacuation or sheltering. Public doubts do arise about persons and organizations involved in the warning process withholding information for a variety of reasons. Anecdotal evidence from case studies indicates that, on occasion, some warning or parts of a warning to support an evacuation are indeed withheld from the public. Often this is done by rationalizing that the public will panic, that the evacuation will be expensive or that it will be a false alarm. Research does not indicate how prevalent the problem of deliberate withholding of information is in reality. Furthermore, the conditions under which information is withheld have never been systematically identified or analyzed, but doing so is unlikely to result in improved emergency planning.

In some cases inadequate organizational communications have led to poorly implemented warnings.[2,57,66] Such was certainly the case at TMI.[17,18,68] Sufficient organizational research exists to demonstrate that communications are major determinants of organizational effectiveness in emergencies.[16,15,67] While poor communication does impede effective evacuation it does not preclude successful evacuation. The conditions that lead some organizational systems to good versus poor communications in emergencies are not well understood. Hypotheses based on organizational theory could be developed and tested to improve our understanding of communication failures.

Another issue centers on transient populations. Transients are defined as people in an area at risk that generally live somewhere else. Typically, transients are people travelling through an area or vacationers in an area of risk for a short period of time. Litigation over nuclear power plants such as the Seabrook Nuclear Power Plant in New Hampshire has focused on the issue of the difficulty in warning people in recreational areas as well as alerting seasonal tourist populations. Transient populations do present difficulties in evacuation warnings. Anecdotal information suggests that problems have occurred in notifying vacationers of hurricanes. Warning campers in recreational areas to evacuate has been a problem in several flash floods. Little systematic data exists on the receipt of warnings and evacuation behavior of transient populations.[56] Research on this topic could be valuable in developing evacuation plans in areas with large transient populations exposed to threats.

Another issue concerns conditions under which sirens would not be heard by people at risk. At the Shearon Harris Nuclear Power Plant intervenors maintained that sirens cannot be heard at night by people inside residences when air conditioners are operating. Considerable research has been done on receipt of warnings in general and some on the receipt of warnings made with siren systems.[32] This research suggests that a contagion or confirmation process accounts for much of the early notification in disasters.[58,60] In addition much is known about how people can be warned effectively and the problems involved in issuing warnings.[35,41,42]

Information Constrains Protective Action Implementation

People may receive a warning but the information in that warning may not lead them to evacuate or go to the best location for safety. One issue is over the adequacy of messages to get people to evacuate from hazardous areas. Intervenors charge that sample messages prepared by planners for nuclear power accidents are inadequate. Inadequate message content does constrain evacuation. The problem exists, however, in defining what is adequate. At this point research has outlined what is believed to be necessary, but that base of knowledge can be improved.[63] Additional research on effectiveness of alternative message content could help to fine tune warning message content. Implementing what is currently known into practice is the second issue of great importance. The state of knowledge about effective warning content is not reflected in practice in many evacuation situations.

A second issue involves credibility. This issue questions whether people will believe warnings from organizations with low credibility and take the protective response needed. It has been argued by intervenors that companies that operate nuclear power plants are not a credible source of warning information. If the public perceives the information is not credible then people will ignore it, fail to follow it, or deliberately engage in a different course of action. It is well known that credibility of information affects its use by potential evacuees. Research has shown that credibility is an important factor in evacuation decisions and has illustrated some of the ways it may constrain evacuation efforts. Some ideas exist on how to deal with credibility problems that have been induced from general knowledge. Knowledge also exists regarding how emergency warnings can be made credible.[64] The precise ways in which credibility effects evacuation decisions have not been sufficiently researched to understand when credibility specifically interferes with evacuation behavior.

A third issue concerns the impact of false alarms on subsequent evacuation behavior—the "cry-wolf" syndrome. The false alarm issue has also been raised for a number of other hazards including hurricanes, earthquakes, tsunamis, and tornados. The basic issue is that people who keep hearing false alarms due to inadvertent warnings will not respond to a real warning. Contrary to popular belief, false alarms have not been a constraint in getting people to evacuate in events subsequent to the error. This conclusion is largely based on anecdotal evidence from recent hurricanes but is also supported by experimental research. If people understand the uncertainty and basis for the false alarms, issuing a warning is less likely to pose problems when a subsequent event occurs. Further research on this topic could be conducted in a field setting if a series of false alarms do occur.

3. Social Issues

Social Factors Color Risk Perceptions

A major social issue concerns the effects that pre-emergency risk perceptions have on human evacuation behavior in an emergency. Nuclear power evacuation planning critics feel that radiation is a unique threat and because of the public's great fear of radiation people would behave differently when warned to evacuate in the event of a radiation emergency.[30,31,85] The differences cited have included panic, a psychic numbing rendering people incapable of evacuation, and, conversely, chaotic flight behavior. Yet such problems did not occur at TMI and would not likely occur in a future accident.[69]

Social Factors Color the Ability to Receive Warnings

Another issue is whether social characteristics affect the way in which people interpret a protective action warning message. One major issue is that warnings are not geared to ethnic, racial, or non-English speaking groups, but to the dominant population or political groups. As a result, minority groups are more vulnerable to the risk because they are less likely to evacuate or less likely to receive or understand a warning message. There is sufficient knowledge on the behavior of ethnic groups in disaster situations that this should not be an issue in emergency planning.[48,49,50] Research shows that members of societies with distinct cultural characteristics are less likely to evacuate for several reasons including language, isolation from authority, beliefs and risk perceptions.

A second issue is that some people distort or do not understand the nature of risks from nuclear power plant accidents, even when told of the risks in a warning message. A consequence of not understanding would be to delay evacuating and remain at an area of risk. There is little evidence to suggest that fear of radiation will constrain evacuations by causing panic or massive population moves.[47,51,65] This knowledge, however, is based on a limited number of observations. In a situation where a very large amount of radiation is released we can only hypothesize that human behavior would be similar to those incidents experienced to date where this did not occur. Additional research on human evacuation in radiological accidents should be conducted following any future events.

Social Factors Affect the Ability to Evacuate

The basic issue is that certain population characteristics constrain peoples' ability to evacuate even if they are adequately warned. The major issue centers around whether special populations and institutional populations can be effectively evacuated. The key parameters include identifying the particular problems of these populations and what the different groups or institutions need to be told to evacuate effectively. The ability to develop and implement plans for institutional facilities and special populations has been questioned. This issue also concerns whether or not detailed plans are needed to evacuate individuals within the general population such as the hearing impaired or mobility impaired, as well as institutional populations such as schools, hospitals, nursing homes, or correctional facilities. Second, if these plans are lacking, what information the plans need to cover. The third concern is whether or not resources will be available to evacuate these individuals or facilities during an emergency.

The issue of institutional populations is a valid and important one in evacuation planning. There are special populations and institutional populations that require specialized warnings and assistance to evacuate. The key issue is identifying the particular problems and establishing what the different groups or institutions need to evacuate effectively. Some research has been done on this topic and current work is addressing some additional groups.[23] Overall, however, the knowledge base to plan for such groups is lacking and needs to be improved.

4. Organizational Issues

Planning Elements Are Inadequate

A series of issues have been raised about the scope and content of emergency planning. Planning for evacuations and other forms of protection is done by separate jurisdictions and different levels of government. The overall question is whether or not these plans are coordinated and, if not, if the absence of coordination will lead to ineffective evacuations. The issue of coordination of plans has developed in nuclear power plant planning where local governments have refused to participate in planning efforts for that specific hazard.[25]

Two shelter issues have emerged for radiological emergency planning. First is the ability to evacuate people to decontamination shelters in the event of contamination from radiation. It is known that people go to a variety of different destinations in an evacuation—friends, relatives, motels, hotels and so forth. The portion of people who would go immediately to a decontamination site largely depends on how information in warning messages is distributed at the time of the event.

The second issue concerns the adequacy of mass care shelters. Sufficient research has been conducted on the provision of temporary shelters for evacuees.[52] The problems in operating centers are largely understood and documented. Demand for shelters or expected use by evacuees is also known. However, it is an issue as to whether this knowledge is being utilized in evacuation planning by the agencies responsible for evacuation planning. The evidence on that front tends to suggest that shelter planning for most evacuation situations is adequate.

Definition of emergency planning zones has been a hotly debated issue at nuclear power plants. At issue is whether the size of the planning zone covers the true area at risk (see above) and if evacuation is feasible outside the detailed planning zone because of the lack of detailed evacuation studies. The nuclear power industry maintains that detailed planning within a ten mile radius provides the basis for expanding the areal coverage if protective actions are needed beyond ten miles. An EPZ is mainly developed on the basis of the physical impact area of a hazard, the resources at risk, and the protective action feasibility. It is beyond the scope of this research to determine if the distance of ten miles for a nuclear power plant EPZ is correct. The research reviewed does suggest, in a different light, that the definition of an EPZ is not critical and may obscure the important point that evacuation plans must be flexible to handle a range of scenarios. Those scenarios not only include disasters which extend beyond the EPZ but emergencies that affect only a small part of an official planning zone.

Another issue concerns emergency planning for nuclear power accidents that occur because of another hazard such as an earthquake. Opponents of the Diablo Canyon plant in California argued that emergency planning needs to factor in the occurrence of an earthquake that would disrupt communication capabilities, hinder evacuation efforts and disrupt other emergency response functionings. Anecdotal case studies suggest that evacuation plans for secondary hazards are inadequate. Notable situations include volcano-induced mudflows and floods, ashfall, sunny-day dam failures, flash floods during tornado episodes and seismic-induced landslides. This points out a need for research that can better support the development of flexible emergency plans for multiple or concurrent hazardous situations.

Training of Workers

Evacuations are supported by a variety of emergency personnel who often perform different tasks than normal during an emergency including warning, transport, traffic control, and law enforcement. The issue has been raised at nuclear power plants that these types of workers have not been adequately trained to support an evacuation effort. Better training will likely improve evacuation planning and execution. This is a problem of organizing existing knowledge into training courses and then providing all emergency personnel with training. It is not a research issue because knowledge exists to do this type of training. It is mainly a problem of implementation, resource allocation and political priorities.

The Technical Basis for Planning

Another set of issues regarding planning is the lack of data or information on which to base the planning. A major issue concerns the accuracy of evacuation time estimates. A variety of models exists to estimate the time it takes to evacuate geographical areas.[5,38,43,61,70,71,72,75] Different model types are used for different locations. Issues have been raised about which models are appropriate to use and whether or not the results are valid. Many of the issues regarding validity are over the assumptions used in the models. Some of the major assumptions that have been challenged include mobilization time, departure time, road capacity estimates, impacts of bottlenecks, number of vehicles used per household, impacts of accidents, route selection, and effectiveness of traffic control. A variety of models exist to estimate the time it takes to evacuate specific geographical areas. The models are definitely useful in evacuation planning and likely provide better estimates than seat-of-the-pants guesses. How accurately they predict actual evacuation times is a valid issue.[12] Assumptions in the models require closer scrutiny.[84] There is a need to conduct empirical research to fine tune and validate the models to provide more accurate and certain estimates of evacuation times.

5. Response Issues

Physical Factors Constrain Evacuation

Many people have questioned the ability to evacuate large densely populated areas such as New York City, Long Island or other major urban areas near power plants in a timely or orderly fashion. Problems cited include lack of transportation for large numbers of evacuees, inadequate road capacity, traffic jams and the litany of issues associated with large-scale evacuations. Anecdotal information exists from case studies regarding the ability to evacuate some densely populated areas but not extremely large populations. Such evidence comes from studies of war time evacuations, events like the large-scale Mississuaga evacuation, or during Gulf and east coast hurricanes.[7,37,59,76] Additional knowledge has come from modeling studies but the results have been questioned regarding their assumptions. It is unclear, therefore, how long it would take to evacuate large and densely populated cities or regions and further investigation is needed.

The ability to relocate tourist and permanent populations in areas with large seasonal populations has been raised at several nuclear power plant sites. Questions have been raised regarding the organizational ability to warn vacationers, transients' knowledge of evacuation routes, sufficiency of shelters, behavior of transient evacuees, timing of evacuation, and traffic congestion. Near Seabrook as many as 40,000 people may occupy coastal beaches during peak tourist season. The ability to evacuate tourist populations from areas subject to nuclear power plant accidents is a valid issue. Questions regarding knowledge of evacuation routes, use of shelters, behavior of evacuees, timing of evacuation or the potential problems of traffic congestion should be addressed in emergency plans. There is not a great deal of research to support analysis of these issues. Anecdotal experience provides some information, but even good case studies are lacking Behavioral research has not focused on studying tourists as a population so behavioral knowledge is poor. Traffic modeling studies provide data on the length of time to evacuate some areas and are useful within the bounds of uncertainty governing those studies. Application of general knowledge does not suggest traffic simulation models are not feasible, but additional knowledge would improve planning to implement evacuation plans effectively.

Critics of nuclear power evacuation planning have said that traffic accident rates will increase in an emergency evacuation and this will cause excessive accidents that will tie-up traffic trying to leave. There is no research to date that suggests traffic accidents are more likely in an evacuation. Limited research and observation suggests there are lower accident rates during evacuations.[4,24,56] This may be due to increased driver vigilance and lower vehicle speeds.

Public Behavior

These issues relate to people responding in a way that will jeopardize the effectiveness of evacuation. Evacuation shadow is a point of litigation at nuclear power plant hearings. Based on the experience at TMI, critics charge that people will evacuate from far larger areas than are officially advised.[6,10,19,20,21,33,86] Because plans do not exist to handle this withdrawal phenomenon, the contention is that evacuations will fail. The evacuation shadow exists by definition either spatially or demographically. A shadow is judged retrospectively and often with an arbitrary indicator of who or what area was ordered to evacuate.[62] As such, the definition of shadow ignores the social processes in disaster.[13,14] Research has shown that perceived personal threat or risk at the time of the disaster is a central reason for persons evacuating.[48,65] Research also shows that evacuation declines as the perception of threat decreases and distance from the threat increases. Even if one accepts the validity of the shadow concept, it can be concluded that it has been poorly studied. Behavioral studies have either failed to include a variety of risk areas in investigations or have inadequately sampled the alleged areas of shadows.

Panic is defined as acute fear of entrapment coupled with attempted flight behavior.[53] Critics maintain that people will exhibit this type of response to an earthquake, nuclear power accident or nuclear crisis warning. This panic behavior will lead to increased traffic accidents and dysfunctional behavior. The conditions under which panic occurs are well understood. Panic rarely occurs in evacuations because the conditions for panic are not likely to occur although not impossible.[54,55] One problem regarding the panic issue is that officials and the media often mislabel some behavior as panic and thus the myth is perpetuated. No further research on panic is needed unless a situation does occur in which panic actually does take place.

Spontaneous evacuation is commonly defined as leaving an area before the warning to evacuate is given as an official order.[8] The claimed impact is increased congestion on roadways. Another proposed problem of spontaneous evacuation is that it makes zonal or staged evacuations (eg. evacuating a two mile radius, then the five mile and so forth) infeasible. As for shadow, this concept of spontaneous evacuation exists by definition. The issuance of an official order is an arbitrary yardstick by which individual behavior is judged. Other types of information, including messages that an evacuation is likely or that an unofficial evacuation is recommended, will cause some people to evacuate. The reasons why are more speculative. Anecdotal information suggests that it is due to avoiding having to evacuate when officially ordered and erring on the side of caution.

Aberrant behavior includes looting, anti-social aggressive acts, or other criminal acts. Some believe that this type of behavior increases during emergencies and would be more prevalent in the event of a nuclear power plant accident or nuclear crisis situation. The research evidence against aberrant behavior of evacuees is fairly overwhelming to the contrary. Hostile behavior, particularly to emergency workers does not occur during evacuations. Looting occurs, but is extremely rare. Crime rates are believed to decrease during evacuations and the demand for police services for non-evacuation or emergency functions decrease. Aberrant behavior is typically a myth that tends to be perpetuated by the media which covers isolated instances, misinterprets behavior, or falsely associates an unrelated incident with an emergency.

Traffic time estimates and planning assume that people will use certain optimum traffic routes. Critics content people will not use those routes and therefore the evacuation will not be effective. Furthermore, congestion will occur on the routes that people will try to use or routes will be used that place evacuees at higher risk. No one has investigated the actual routes which people use when evacuating with any specific detail. Thus it remains a major issue with traffic time estimation models. The most reasonable assumption is that people will use routes they normally use except if the routes are blocked or if evacuees are specifically directed by law enforcement personnel to use different routes.

Another contention is that people won't obey officials managing an emergency. The issue centers around the belief that people will disregard traffic control guides or warning instructions while evacuating. Critics also argue that people will disregard traffic signals or roadblocks. There is considerable amount of anecdotal evidence which suggests that a very small percentage of the public will disobey official orders. Part of the problem in addressing this issue is the definition of an official order which ranges from recommendations to evacuate to active attempts to get people to leave designated areas. In other words, this problem is related to the strength and perceived credibility of the official orders. Much is known about how to increase evacuation rates.[45,46] In high risk situations where door-to-door evacuations are ordered, 98 to 99 percent of the population under threat will likely evacuate. In less forceful situations the number evacuating can be substantially lower, but it would be improper in those situations to define that behavior as being disobedient.

Another issue raised is that people will not go to designated host or reception areas. Evacuation planning at some sites assumes people will go where they are told. This issue raises the point that people will go to areas other than what the evacuation plans dictate. By implication this makes traffic time estimates and resource availability analyses inaccurate. In most evacuations people are usually not told to go to designated areas. (This is different from going to assigned shelters.) When instructions are absent, research has shown the destinations people choose when evacuating. Research does not exist to infer how many people would go to a designated host area if instructed to do so by a credible source given adequate warning. In part, the number of evacuees going to assigned shelters would be determined by the information provided and the degree to which transportation movements are controlled.

Emergency Worker Behavior

This set of issues contend that emergency personnel will engage in behaviors counter to evacuation goals.[25,29] Role abandonment is conceptualized as emergency workers leaving their jobs to perform other roles. The main issue is over how many workers will engage in this behavior. A secondary issue is whether this will constrain an evacuation. Role abandonment has also been a controversial issue for other hazards. Research suggests that total role abandonment has not been prevalent in disasters and certainly has not been dysfunctional in organizational behavior.[40] Some people have hypothesized that role abandonment would be greater and likely problematic in a nuclear power plant accident or during a nuclear war threat. This remains somewhat speculative. Research suggests that in the former case there may be an increased potential for conflict and role strain but emergency functions would not be threatened. In the latter case the issue is highly uncertain. Additional research on role conflict would be confirmatory but is not of high priority.

Larger Issues

1. TMI And Emergency Planning

The accident at TMI continues to be the dominant reference for emergency planning issues around nuclear power plants.[73,74,78,81] Drastic changes were implemented on the basis of that experience. There is little doubt that if an accident similar to TMI does occur in the future, the response will be greatly improved. Accidents, by definition, include a host of unanticipated events. There is no guarantee that research to date has identified the next accident sequence or scenario. Witness the Chernobyl accident. The U.S. response was that it cannot happen here. This is probably correct, although not provable. A more important issue is that does this country have its Chernobyl class accidents. The answer is likely yes.

The changes in emergency planning due to TMI are a prime example of crisis management. A crisis occurs and changes are made which will improve response given that set of historical conditions. Yet science is not that deterministic. Rarely do scientists in either the physical and social fields make conclusions based on one data point. Yet our current plans are based on that single point.

The accident at Ginna Nuclear Power Station in New York involving a steam tube rupture provides a second data point. This accident involved a release of radiation, led to activation of the emergency warning system and caused a precautionary early dismissal of area schools. People did not spontaneously evacuate. There was no shadow, panic, aberrant behavior, role abandonment, etc. Several interpretations exist. First is that the accident demonstrated that changes in emergency planning solved the problems that occurred at TMI. Better, more certain, and credible information was given to the public. Second is that the Ginna utility plays a much different role in the local community than the one at TMI and it's integration into the structure of the community led to a good community response. A third assessment was that a snowfall on the day of the accident acted as a constraint against spontaneous evacuation. In reality it was a combination of factors that help explain this different pattern of response. The emergency planning changes that occurred since TMI cannot take full credit for the improved management nor should the lack of spontaneous evacuation be attributed to the fact it was snowing. As a competing hypothesis the snow explanation, like snow, does not hold much water.

The critical point is that the dramatic changes made in planning requirements because of TMI do not insure good responses to a future event. Elsewhere we have argued that the plans are far too complex, bureaucratic and rigid to permit flexibility in managing emergencies. At one reactor site alone we have identified over one hundred separate plans for the utility, government and private facilities. The sheer number makes consistency among the plans unlikely. Even if the plans were consistent, the problems of continued coordination during planning and in an actual emergency are immense. Yet having an adaptive and flexible organization is a key factor in having effective emergency management response. The current plans do not promote flexibility. If a future accident does not fall within the confines of the plans, the ability to adapt to problems posed by an accident may be constrained by the structured plans. If the Chernobyl accident had occurred in the U.S., current plans would have been of little utility in guiding response. The extent to which the planning process had facilitated inter-organizational coordination among the appropriate people and the extent to which organizations could adapt plans to the differing situation would be critical factors in determining the effectiveness of response.

2. Use of Behavioral Intent Studies

One of the ways suggested to resolve these contentions involves the use of behavioral intent studies for future events. For many of the contentions the burden of proof involves the use of behavioral intent studies. However, most behavioral intent studies rest on the results of survey research. For example, several studies have polled emergency workers and asked them about role abandonment.[29] In a study of school teachers at the California Diablo Canyon nuclear power plant teachers were asked: "Assuming the Diablo Canyon Nuclear Power Plant is licensed and begins to operate, we are interested in knowing what you think you would do if there was an accident at the plant on a school day during normal operating hours. Everyone living within ten miles were advised to evacuate. Teachers were expected to help evacuate school children. What do you think you would do first?

1. Help with the evacuation of school children outside of the designated danger zone; or
2. Go to make sure family members were safe; or
3. Leave the evacuation zone to make sure you were in a safe place; or
4. Do something else."

The results of the survey, at face value, indicate that only two-thirds of the teachers would perform their specified emergency roles. Several specific problems exist with this literal interpretation of the research. First, the researcher failed to provide a realistic set of responses to the teachers that encompassed all possible behaviors and categories that were mutually exclusive. Adding a catch-all category does not alleviate this problem. No attempt was made to provide a response category that includes checking on the safety of family while performing an emergency role. Secondly, the wording of the responses were unclear. One may well interpret the first option as evacuating children who are located in schools outside of the 10 mile radius. Certainly a teacher inside the ten mile zone would not choose this option. Third, the question forces the assumption that all teachers have emergency roles that last the duration of an evacuation. This is likely to be unrealistic. Thus a teacher who does not have a specified role could legitimately answer with responses two or three. Nevertheless, a response of 61% of teachers to perform emergency roles for the duration of the emergency is likely to be more than sufficient to effectively evacuate the schools. Even this interpretation of the results were taken at face value, it is unwise to believe that this estimate is an accurate predictor of actual behavior.

This research is problematic for several other general reasons. First, polls are premised on the notion that statements about current attitudes or thoughts about future behavior can be used to predict actual future behavior. This assumption is wrong when that behavior concerns a future emergency situation. Most social scientists would say that people's attitudes and their speculation about future behavior are imperfect predictors of behavior except when that behavior is frequent and repetitious. Asking a person to make a "cold" judgement about how he or she might hypothetically react in a complex future situation for which they have had no previous experience, and giving him or her a few seconds to answer, is not a good predictor of future behavior. Behavior in an emergency is a social process and is situationally determined. In that process notions about appropriate ways to act emerge based on the information being disseminated at the time.

The factors that influence human response to emergencies are relatively well-known and accepted as valid by most scientists in this area. These factors can be addressed in an emergency plan to help achieve the desired response when the plan is put into operation. An attitude or opinion profile or a catalogue of behavioral intentions would not appreciably help address these factors in planning or upgrade good organizational or public response when the plan is activated. In fact, a compilation of behavior intentions—which is certain to be wrong when compared to actual emergency behavior—could hurt planning efforts because plans would be based on incorrect assumptions about behavior.

Consequently, research which asks teachers or school bus drivers what they would do in an emergency is not a good way of predicting nor understanding role conflict issues. Research based on these methods which concludes people will abandon their roles is largely invalid and should not be the basis for developing emergency plans. The basis for plans must be developed on existing knowledge, not on speculative or inaccurate assumptions.

Conclusions and Recommendations

In conclusion we make three recommendations for changes in policies regarding emergency planning for nuclear facilities.

1. Revise radiological emergency planning frameworks in a manner which promotes more flexibility in response procedures and which is more responsive to local factors such as unique topography and population distributions.

This change would re-orient planning guidelines to encompass a broader range of accidents than current plans describe. Additionally, this concept involves changing the structure of planning regulations to encourage a more adaptive and flexible approach by emergency organizations. While flexibility can be considered as a trade-off with the formalization of procedures, the current planning philosophy only emphasizes a strict implementation of narrowly-defined tasks. Therefore, the policies, and hence planning regulations, need to encourage a different approach to emergency planning. The regulations should be changed to encourage adaptivity to local situations, while at the same time giving guidance on how to manage the hazard in question. The greatest consequences of not adopting this approach is that organizations will not be effective in an anomalous situation and that local organizations will concentrate plans around the wrong accident scenarios.

2. Develop policy positions on various issues including the validity of various contentions and the conditions under which the contention are or are not valid.

It is the basic responsibility of the NRC to license nuclear power plants. As part of that procedure the NRC should develop consistent positions on common contentions. At present, the NRC attempts to avoid committing to a position on many contentions. This stance allows the process of licensing to be judged on the basis of a comparison of the ideologies of experts representing the intervenors and those of the experts representing the utility. A set of guidelines based on scientific evidence and previous Atomic Safety Licensing Board (ASLB) rulings should be established for all major contentions. This should not exclude litigation over any issue, but make the resolution of these contentions more consistent. In time this should decrease the time spent in resolving generic issues.

3. Give local and state governments more legal responsibility for developing emergency plans for nuclear power plants while placing the burden of proof on all.

Currently local and state government can hold hostage utilities seeking a license for nuclear plant. The local decision about nuclear power should be made at the siting stage. Subsequent actions to negate a poor siting decision should not centrally involve the procedure of emergency planning; albeit the contents or effectiveness should be addressed. If analysis are done which conclusively demonstrate that emergency plans cannot mitigate accident consequences, then a siting decision should be reconsidered. If analyses are done that suggest improvements in the emergency plan can reduce risk or consequences, those changes should be adopted. Emergency planning has become a means of fighting other issues. This is a problem in that it detracts from the goals of planning. We hope that such issues are refocused and the legitimate aspects of emergency planning are brought forward instead.

References Cited

1. **Aldrich, D., D. Alpert, J. Sprung and R. Blond.** 1982. Recent developments in reactor accident offsite consequence modelling, *Nuc. Safety* **23:** 643–652.
2. **Anderson, W.** 1969. Disaster warning and communication processes in two communities, The *J. of Comm.* **19:** 92–104.
3. **Bartlett, G. S., P. S. Houts, L. K. Byrnes and R. W. Miller.** 1983. The near disaster at Three Mile Island, *Int. J. of Mass Emerg. and Disasters* **1:** 19–42.
4. **Bastien, M. C., M. Dumas, J. Laporte and N. Parmetier.** 1985. Evacuation risks: A tentative approach to quantification, *Risk Anal.* **5:** 53–61.
5. **Belardo, S., A. Howell, R. Ryan and W. Wallace.** 1983. A microcomputer-based emergency response system, *Disasters* **7:** 215–220.
6. **Brunn, S., J. Johnson and D. Ziegler.** 1979. *Final Report on a Social Survey of Three Mile Island Residents.* East Lansing, MI: Department of Geography, Michigan State University.
7. **Burton, I.** 1981. *The Mississauga Evacuation, Final Report.* Toronto: Institute for Environmental Studies, University of Toronto.
8. **Chenault, W., G. Hibert and S. Reichlin.** 1979. *Evacuation Planning in the TMI Accident,* PCPA01-78-C-01-93. McLean, VA: Human Sciences Research Corp.
9. **Cutter, S.** 1984. Emergency preparedness and planning for nuclear power plant accidents, *Applied Geog.* **4:** 235–245.
10. **Cutter, S. and K. Barnes.** 1982. Evacuation behavior at Three Mile Island, *Disasters* **6:** 116–124.
11. **Denning, R. S., P. Cybluskis and R. DiSalvo.** 1987. Changing perspectives on severe accident source terms. In *Proceedings of the American Nuclear Society Meeting Radiological Accidents—Perspectives and Emergency Planning,* pp. 67–72.
12. **Desrosiers, A. E., M. Moeller, M. McLean and T. Urbanik.** 1984, Sensitivity and benchmark study of the CLEAR evacuation time estimate code, *Transactions of the American Nuclear Society* **46:** 325.
13. **Drabek, T. E.** 1969. Social processes in disaster: Family evacuation, *Soc. Prob.* **16:** 336–349.
14. **Drabek, T. E.** 1983. Shall we leave? A study of family reactions when disaster strikes, *Emergency Management Review* **1:** 25–29.
15. **Drabek, T. E.** 1986. *Human System Response to Disaster: An Inventory of Sociological Findings.* New York, NY: Springer Verlag.
16. **Dynes, R.** 1970. *Organized Behavior in Disasters.* Lexington, MA: D. C. Heath.
17. **Dynes, R. et al.** 1979. *Report of the Emergency Preparedness and Response Task Force, Staff Report to the President's Commission on the Accident at Three Mile Island.* Washington, DC: U.S. Government Printing Office.
18. **Fisher, D.** 1981. Planning for large-scale accidents: Learning from the Three Mile Island, *Energy* **6:** 93–108.
19. **Flynn, C.** 1979. *Three Mile Island Telephone Survey: A Preliminary Report.* Washington, DC: U.S. Nuclear Regulatory Commission.
20. **Flynn, C.** 1982. Reaction of local residents to the accident at Three Mile Island, pp. 49–63 in *Accident at Three Mile Island,* edited by D. Sills and others. Boulder, CO: Westview Press.
21. **Flynn, C. B. and J. A. Chalmers.** 1980, *The Social and Economic Effects of the Accident at Three Mile Island.* Tempe, AZ: Mountain West Research, Inc. with Social Impacts Research, Inc.
22. **Fritz, C. E. and E. S. Marks.** 1954. The NORC studies of human behavior in disaster, *J. of Soc. Issues* **10:** 26–41.
23. **Gant, K., M. Adler, J. Sorensen.** 1987. *Experience Pertaining to the Protection of School Children.* Draft report. Oak Ridge, TN: Oak Ridge National Laboratory.
24. **Hans J. and T. Sell.** 1974. *Evacuation Risks—An Evaluation.* Las Vegas, NV: U.S. Environmental Protection Agency, National Environmental Research Center.
25. **Herr, P.** 1984. Small town nuclear emergency response, *Small Town* **14:** 4–10.
26. **Houts, P. et al.** 1984. The protective action decision model applied to evacuation during the TMI crisis, *Mass Emerg.* **2:** 27–39.
27. **Hull, A. P.** 1981. Critical evaluation of radiological measurements and of the need for evacuation of the nearby public during the Three Mile Island incident, pp. 81–96 in *Current Nuclear Power Plant Safety Issues,* Vol. 2. Vienna: International Atomic Energy Agency.
28. **Hull, A. P.** 1981. Emergency planning for what? *Nuc. News* April: 61–67.
29. **Johnson, J.** 1985. Role conflict in a radiological emergency: The case of public school teachers, *J. of Env. Sys.* **15:** 77–91.
30. **Johnson, J.** 1983. Planning for spontaneous evacuation during a radiological emergency, *Nuc. Safety* **25:** 186–193.

31. **Johnson, J. and D. Ziegler.** 1984. Distinguishing human responses to radiological emergencies, *Economic Geography* **59:** 386–402.
32. **Lachman, R., M. Tatsuoka and W. Bonk.** 1961. Human behavior during the tsunami of May, 1960, *Sci.* **133:** 1405–1409.
33. **Lindell, M. and R. Perry.** 1983. Nuclear power plant emergency warnings: How would the public respond?, *Nuc. News*: February: 49–57.
35. **Lindell, M., P. Bolton, R. Perry, G. Stoetzel, J. Martin and C. Flynn.** 1985. *Planning Concepts and Decision Criteria for Sheltering and Evacuation in a Nuclear Power Plant Emergency.* Bethesda, MD: Atomic Industrial Forum.
36. **Lindell, M., P. Moeller and M. Renner.** 1984. Off-site response considerations for appropriate protective actions, *Trans. of the Am. Nuc. Soc.* **46:** 322–323.
37. **Liverman, D. and J. Wilson.** 1981. The Mississauga train derailment and evacuation, 10–16 November, 1979, *The Can. Geog.* **25:** 365–375.
38. **McLean, M., M. Moeller, A. Desrosiers and T. Urbank II.** 1983. CLEAR: A model for calculation of evacuation time estimates in Emergency Planning Zones, pp. 58–63 in J. Carroll ed., *Computer Simulation in Emergency Planning,* La Jolla, CA: Society of Computer Simulation.
39. **Mileti, D.** 1975. *Natural Hazard Warning Systems in the United States.* Boulder, CO: Institute of Behavioral Science, University of Colorado.
40. **Mileti, D.** 1985. Role conflict and abandonment in emergency workers, *Emerg. Man. Rev.* **2:** 20–22.
41. **Mileti, D. S. and J. Sorensen.** 1987. Why people take precautions against natural disasters in N. Weinstein ed., *Taking Care: Why People Take Precautions.* Cambridge: Cambridge University Press.
42. **Mileti, D., T. Drabek and J. Haas.** 1975. *Human Systems in Extreme Environments.* Boulder, CO: Institute of Behavioral Science, The University of Colorado.
43. **Moeller, M., T. Urbanik, A. Desrosiers.** 1982. CLEAR: *A Generic Transportation Network Model for Calculation of Evacuation Time Estimates,* NUREG/CR-2504. Washington, DC: U.S. Nuclear Regulatory Commission.
44. **Olds, F. C.** 1981. Emergency planning for nuclear plants, *Pow. Eng.* August: 48–56.
45. **Perry, R. W.** 1979. Evacuation decision-making in natural disasters, *Mass Emerg.* **4:** 25–38.
46. **Perry, R. W.** 1979. Incentives for evacuation in natural disaster—Research based community emergency planning, *J. of the Am. Plan. Ass.* **45:** 440–447.
47. **Perry, R. W.** 1985. *Comprehensive Emergency Management: Evacuating Threatened Populations.* Greenwich, CT: JAI Press, Inc.
48. **Perry, R. W. and A. Mushkatel.** 1984. *Disaster Management: Warning Response and Community Relocation.* Westport, CT: Quorum Books.
49. **Perry, R. W. and M. Greene.** 1982. The role of ethnicity in the emergency decision-making process, *Soc. Inq.* **52:** 309–334.
50. **Perry, R. W., M. K. Lindell and M. R. Greene.** 1982. Crisis communications: Ethnic differentials in interpreting and acting on disaster warnings, *Soc. Behav. and Pers.* **10:** 97–104.
51. **Perry, Ronald W.** 1983. Population evacuation in volcanic eruptions, floods and nuclear power plant accidents: Some elementary comparisons. *J. of Comm. Psych.* **11:** 36–47.
52. **Quarantelli, E. L.** 1982. *Sheltering and Housing After Major Community Disasters: Case Studies and General Conclusions.* Columbus, OH: Disaster Research Center, Ohio State University.
53. **Quarantelli, E. L.** 1954. The nature and conditions of panic, *Am. J. of Soc.* **60:** 267–275.
54. **Quarantelli, E. L.** 1957. The behavior of panic participants, *Soc. and Social Res.* **41:** 187–194.
55. **Quarantelli, E. L.** 1960. Images of withdrawal behavior in disasters: Some basic misconceptions, *Soc.Probs.* **8:** 68–79.
56. **Quarantelli, E. L.** 1980. *Evacuation Behavior and Problems: Findings and Implications From the Research Literature.* Columbus, OH: Disaster Research Center, Ohio State University.
57. **Quarantelli, E. L.** 1983. *Evacuation Behavior: Case Study of the Taft, Louisiana Chemical Tank Explosion Incident.* Columbus, Ohio: Disaster Research Center, Ohio State University.
58. **Rogers, G. and J. Nehnevajsa.** 1987. Warning human populations of technological hazard, in *Proceedings of the American Nuclear Society Meeting Radiological Accidents—Perspectives and Emergency Planning,* pp. 357–362.
59. **Rogers, G. and J. Nehnevajsa.** 1984. *Behavior and Attitudes Under Crisis Conditions.* Washington, DC: U.S. Government Printing Office.
60. **Rodgers, G.** 1985. *Human components of emergency warnings.* University of Pittsburgh, Center for Urban and Social Research.
61. **Sheffi, Y., H. Mahmassani and W. Powell.** 1982. A transportation network evacuation model, *Transp. Res.* **16:** 209–218.
62. **Sorensen, J.** 1987. Evacuation behavior in nuclear power plant emergencies, in *Proc. of the Am. Nuc. Soc. Meeting Radiological Accidents—Perspectives and Emergency Planning,* pp. 351–356.
63. **Sorensen, J. H.** 1984. Evaluating the effectiveness of warning systems for nuclear power plant emergencies: Criteria and Application, pp. 259–277 in M. Pasqualetti and K. Pijawka eds. *Nuclear Power: Assessing and Managing Hazardous Technologies.* Boulder: Westview Press.
64. **Sorensen, J. H.** 1984. Public confidence in local management officials: Organizational credibility and emergency behavior, *Proceedings of a Conference on Evacuation Risks in Nuclear*

Power Plant Emergencies. Penn State University.

65. **Sorensen, J. H. and B. Richardson.** 1984. Risk and uncertainty as determinants of human response in emergencies: Evacuation at TMI reexamined, *Proceedings of the Society of Risk Analysis Annual Meeting,* Knoxville, TN.
66. **Sorensen, J. H. and D. S. Mileti.** in press. Decision-making uncertainties in emergency warning system organizations, *Int. J. of Mass Emerg. and Disasters* March, 1987.
67. **Sorensen, J. H., D. S. Mileti and E. D. Copenhaver.** 1985. Inter and intraorganizational cohesion in emergencies, *Int. J. of Mass Emerg. and Disasters* **33:** 27–52.
68. **Special Inquiry Group of the Nuclear Regulatory Commission.** no date. *Three Mile Island: A Report to the Commissioners and the Public.* Washington DC: U.S. Nuclear Regulatory Commission.
69. **Stallings, R.** 1984. Evacuation behavior at Three Mile Island, *Int. J. of Mass Emerg. and Disasters* **2:** 11–26.
70. **Tweedie, S. W., J. R. Rowland, S. Walsh, R. R. Rhoten and P. L. Hagle.** 1986. A methodology for estimating emergency evacuation times, *The Soc. Sci. J.* **21:** 189–204.
71. **Urbanik, T.** 1981. *An Analysis of Evacuation Time Estimates Around 52 Nuclear Power Plant Sites,* NUREG/CR-1856, Vols. 1 and 2. Washington, DC: U.S. Nuclear Regulatory Commission.
72. **Urbanik, T., A. Desrosiers, M. Lindell and C. Schuller.** 1980. *Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones,* NUREG/CR-1745. Washington, DC: U.S. Nuclear Regulatory Commission.
73. **USFEMA.** 1980. *Report to the President, State radiological emergency planning and preparedness in support of commercial nuclear power plants.* Washington, DC: Government Printing Office.
74. **USFEMA.** 1982. *Planning Guidance for the preparation of the Federal Radiological Emergency Response Plan, Final Draft #4.* Washington, DC: Government Printing Office.
75. **USFEMA.** 1984. *Application of the I-DYNEV System,* FEMA-REP-8. Washington, DC: FEMA.
76. **USFEMA.** 1984. *Transportation Planning Guidelines for the Evacuation of Large Populations,* CPG2-15. Washington, DC: FEMA.
77. **USGAO** (United States General Accounting Office). 1984. *Further Action Needed to Improve Emergency Preparedness Around Nuclear Power Plants,* GAO/RCED-84-43. Washington, DC: Government Printing Office.
78. **USNRC** (United States Nuclear Regulatory Commission) 1981. *Report to Congress on Status of Emergency Response Planning for Nuclear Power Plants,* NUREG-0755. Washington, DC: Government Printing Office.
79. **USNRC and USEPA.** 1978. *Planning basis for the development of state and local government radiological emergency response plans in support of light water nuclear power plants,* NUREG-0396, EPA 520/1-78-016. Washington, DC: Government Printing Office.
80. **USNRC and USFEMA.** 1980. *Criteria for preparation and evaluation of radiological emergency response plans and preparedness in support of nuclear power plants,* NUREG-0654, FEMA-REP-1, Washington, DC: Government Printing Office.
81. **USNRC.** 1979. *Beyond Defense in Depth,* NUREG-0553. Washington, DC: Government Printing Office.
82. **USNRC.** 1979. *Examination of off-site radiological emergency protective measures for nuclear rector accidents involving core melt,* NUREG/CR-1131, SAND-78-0454. Washington, DC: Government Printing Office.
83. **USNRC.** 1981. *Emergency Action Levels for Light Water Reactors, Draft,* NUREC-0818. Washington, DC: Government Printing Office.
84. **Walsh, S., R. Rhoten, S. Tweedie, J. Rowland and P. Hagle.** 1983. Applications of population projections and remote sensing for nuclear power plant licensing, *The Soc. Sci. J.* **20:** 89–102.
85. **Ziegler, D. and J. Johnson.** 1984. Evacuation behavior in response to nuclear power plant accidents, *Prof. Geog.* **36:** 207–215.
86. **Ziegler, D., S. Brunn and J. Johnson.** 1981. Evacuation from a nuclear technological disaster, *Geog. Rev.* **71:** 1–16.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 226–239, June 1988

Reactor and Nuclear Waste Siting: Problems and Prospects

Richard J. Bord

Associate Professor of Sociology
Department of Sociology
The Pennsylvania State University
University Park, PA 16802

ABSTRACT

It has become virtually impossible to site risky waste disposal facilities or waste treatment facilities, especially those handling radioactive wastes. A growing army of experts has joined the fray with suggestions for solving the impasse. Three of the more popular proposed solutions are: improved risk communication; improved disposal or treatment technology; and the provision of incentives and assurances to affected communities. This paper argues that these proposed solutions ignore fundamental realities. The proposed solutions are juxtaposed with the realities facing those responsible for siting. These include: the popularization and democratization of risk; a host of problems associated with risk information and communication; problems with improved technology including its cost, the inability to create anything foolproof, and the issue of adequate management; the inability of incentives to address health and safety questions and the legal and practical limits to assurances. In addition, the fundamental political dimensions of the problem are addressed and future prospects explored.

Introduction

Effective opposition to risky facilities has assumed the dimensions of a significant social problem. The growing familiarity of the neologisms "LULU" (Locally Undesireable Land Use) and "NIMBY" (Not In My Back Yard) reflect the reality of effective pubic opposition to many types of unwanted facilities. Facilities bearing the burden of the label "radioactive" appear to generate even more intense negative emotions and have the distinction of being targeted by professional opposition groups.[1] This paper constitutes an evaluation of the problems facing those responsible for siting hazardous facilities, with an emphasis on radioactive waste treatment and disposal facilities, and a brief assessment of currently proposed solutions.

The evolution of the siting problem has witnessed the co-evolution of a number of proposed solutions. Experts of many persuasions have leaped into the fray in the hope of providing techniques which will result in successful siting. This paper examines each of these proposed solutions in light of the network of problems which presently characterize radioactive facility siting. It concludes with a discussion of likely paths that future siting attempts may take.

Siting Risky Facilities: The Search For Solutions

Before discussing specific siting difficulties it is necessary to set the general problem within its cultural context. There exists a matrix of common understandings, conditioned by our unique liberal democracy, which shapes the nature of the problem and the search for solutions. It is this culture which makes it highly unlikely that solutions which are successful in other countries can be transferred here with similar results.

Public participation is part of our Jeffersonian heritage. The American Revolution, the Civil War, and the Westward expansion have institutionalized a general lack of respect for constituted authority and that tendency persists. It is commonly understood that the citizen should not be timid in fighting "the establishment." In the decade of the 1960's, public participation in decisions involving the siting of risky facilities was mandated by law. These legal innovations have made it possible for citizens, even small groups and individuals, to delay or stop the implementation of many risky technologies. From this perspective opposition should be expected because the socio-political system encourages and reinforces it. Furthermore, since the nuclear industry, both private and public, depends on capital intensive technology which is managed by large organizations and regulated by the Federal government, it is easy to construe the situation as one of the powerless individual and/or community against the mobilized forces of corporate wealth and political power.

An understanding of this cultural context highlights the limitations of many attempts at solution presently being pursued. A problem which is inherently political in nature tends to be treated primarily as a problem in attitude change.[2] A basic argument in this paper is that approaches emphasizing attitude change have little chance of success because they fail to address to real issues. Other approaches have a higher probability of success but the magnitude of that probability is open to considerable debate.

Various experts have promoted basically three classes of solutions to the siting problem:

1. improved risk communication;
2. improved disposal or treatment technology;
3. and, provision of the opportunity to negotiate incentives and assurances to affected communities.

Each of these proposed solutions, and their limitations, will be discussed in turn.

Improved Risk Communication as a Solution

Those favoring improved risk communication as a solution to public intransigence view the problem as one of correcting errors in perception and judgment. The assumption appears to be that if the public only understood the problem as the experts, at least those experts involved in the siting process, understand it then fear and resistence would diminish. An excellent example of faith in improved risk communication is provided by EPA administrator, William Ruckelshaus in a speech delivered before the National Academy of Sciences at the beginning of his second term. Quoting Jefferson, Ruckelshaus stated:

> "If we think (the public) not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it from them, but to inform their discretion."[3]

Unfortunately, less than two years later Ruckelshaus was having second thoughts about the sentiments expressed in that quotation.

Two issues are viewed as keys to understanding the limitations of improved risk communication:

1. the popularization and democratization of risk;
2. and, problems associated with the risk information itself.

While there are excellent review articles detailing problems in risk communication,[4,5] they do not generally address the first issue to be discussed.

The Popularization and Democratization of Risk

Concern with risk is certainly not an invention of modern technological societies. It can be argued that the major function of religion and law has been risk control or avoidance. All religions include rituals through which spirits can be invoked to protect person, family, and property. Law focuses on the social control of risk and risky individuals and what is considered as the equitable distribution of risk in a society.

However, concern with risk in modern, democratic society has become fine-tuned. There are now hosts of professionals devoted to discovering new risks, more accurately estimating known risks, better communicating risks, and more adequately controlling risks. Risk has become big business. In fact, risk discovery, estimation, communication, and control is fast becoming a somewhat independent academic discipline embracing natural and social-behavioral scientists of many persuasions and even publishing its own professional journals.

While this growth of the risk establishment has much to commend it, there may be unexpected consequences which have not been adequately addressed. Consider that it is now virtually impossible to escape news of the latest "significant" risk on an almost daily basis. Newspapers, television news and advertising, government pronouncements, and popular books and magazines provide constant reminders that life is one constant flirtation with disaster. Questions about fiber, fat, alcohol, sugar, and caffeine in the diet, the relative safety of flying congested airways with a suspect population of air traffic controllers, the possibility of terrorism abroad, the need to get more (or less) exercise, the threat of the AIDS virus, the latest crime statistics and so on ad infinitum create a climate in which attention to risk may have become almost pathological. While the mental and behavioral outcomes of constant attention to risk are debatable, there has been virtually no research on that specific topic, there is little reason to believe that lowered anxiety or a willingness to assume greater health risks are among them.

Another historical dimension of risk is that it is seldom distributed equitably. The poor generally bear greater burdens of risk than do the rich. Modern studies demonstrating that the poor breath fouler air, experience more occupational hazards, and tend to live nearer to environmentally risky facilities should come as little surprise.[6] The more affluent have always had greater opportunity to relocate to areas of less risk, to purchase more adequate diets, and to assume safer jobs. However, contemporary ". . . features of environmental risk seem so ubiquitous . . . that even the wealthy and the powerful are becoming anxious."[7]

Risk experts have made it clear that environmental pollutants in the air, soil, water, and food chain are no respectors of social status. Nor is it possible for most people to geographically relocate to escape the more common environmental hazards. Modern surverys of environmental attitudes, especially attitudes toward risky facilities, tend to demonstrate no consistent pattern for social class variables such as education, occupation, and income.[8] One resonable interpretation of those results is that everyone is frightened or anxious to some degree. The only consistently discriminating demographic variable is sex: women demonstrate higher levels of concern than do men and, at least in my data on LLRW siting, proclaim themselves as unequivocal "NIMBY's" more often than do men.[9] In this context it is worth noting that emergent local opposition is often lead by middle to upper-middle class women.[10]

Sensitivity to a wide range of risk has been popularized and democratized. The risk enterprise continues to document possible health hazards and the various information media helps keep the general public aware of the latest health threat fad. The ubiquitousness of modern pollutants insures that everyone shares in exposure to some degree. Heightened anxiety and avoidance is a reasonable response.

Paradoxically, while we may be the healthiest and long-lived peoples to ever inhabit the planet we may also be the most concerned with issues of health and safety. It makes little sense to label this a phobia or some other mental health aberration. There is a dense network of organizations whose major goals include keeping the public concerned about their health. That is how one garners contributions to health organizations, how numerous magazines and newsletters are promoted, how exercise equipment and health foods are sold, how careers in various health organizations are maintained, and how a plethora of health and beauty aids are marketed. Promoting anxiety about health is a very profitable enterprise.

Problems Associated with Risk Information

Much has been written about the rationality or irrationality of the public's response to risk information, especially risk information dealing with radiation hazards.[11,12] The more technically minded tend to see the problem as one of properly educating the masses so that decisions are made which allow the utilization and further development of the technology. However, judgments of rationality-irrationality are clearly value based. The more pertinent question is exactly how do people process risk information and what is the probability that their judgments can be modified. Three issues are crucial:

1. how is risk information processed;
2. what information is available for processing;
3. and, who provides the information with what effect.

Problems in Risk Information Processing

Three interrelated aspects of risk information processing are central to this discussion:

1. the importance of attention selectivity;
2. the perceived voluntariness of the risk;
3. and, the issue of generalizing risks.

"People's perceptions of risk . . . are influenced by the memorability of past events and the imaginability of future events. As a result, any factor that makes a hazard unusually memorable or imaginable, such as a recent disaster, heavy media coverage, or a vivid film, could seriously distort perception of risk."[13] Cognitive pyschologists agree that attention selectivity is a key issue in information processing. The more vivid or dramatic the event the more likely it will garner attention. That is why advertisers employ unusual scenes, loud and rapid sounds, brilliant colors, sex, and other attention-getting devices. It is worth noting that information about a plane crash which kills 200 people is attention getting, information about the hundreds of planes which fly daily across the country is not.

Related to the issue of attention selectivity is the fact that people seldom accurately interpret information based on probabiliites.[14] While this tendency is sometimes used as a example of irrationality it may be more pertinent to ask why anyone, except a scientist doing impersonal analysis, should pay any attention to probabilities. From an attention getting perspective, news that something in drinking water increases the incidence of annual cancer by one in ten-thousand is simply news that the cancer rate has increased. The "red-flag" is more cancers.[15] The one in ten-thousand is personally irrelevant. After all, the individual either gets cancer or does not get cancer, he or she cannot experience a probability.

The perceived voluntariness of the assumed risk is close behind attention selectivity in importance. People routinely assume all sorts of risks on a voluntary basis. They do so because the risk taking provides benefits such as easier living, personal satisfaction, ego-enhancement, or simple physical pleasure. Comparison of this type of risk taking with living next to waste disposal or power generating facility is futile. They are not comparable within any reasoned frame of reference. However, the involuntariness per se is not the critical issue. Involuntariness arouses public ire when it is imposed by some person or agency who is perceived as occupying a position of power.[16] Recall the discussion of our historically based cultural hostility toward authority viewed as arbitrary. In addition, there are enough examples of corporate, industrial, and governmental insensitivity which results in significant negative outcomes to justify suspicion and hostility toward those who would impose unwanted risks.

Finally, the current state of risk estimation is greatly deficient in one aspect of central concern to many citizens, the ability to estimate the cumulative effect of exposure to many environmental hazards. The person who is informed about the increased risk posed by a particular substance quite logically wonders about how it interacts with all the other hazards being ingested, inhaled, or absorbed. This is especially the case in our highly charged risk information society. While the EPA is presently considering a "total human exposure" methodology, useful information will not be forthcoming soon.[17] Furthermore, it should not be assumed that once this information is made available that it will diminish public anxiety. The accuracy of the information can always be challenged, its sources impugned, or it can result in increased fear and a more militant avoidance response, a frequent result of risk information campaigns. A typical reaction to such news is, "My God I didn't know thing were so bad."

The Availability of Information

The importance of selective attention has been established. It now becomes important to explore what kinds of risk information is readily available to the general public. In my own research on public attitudes toward a proposed LLRW volume reduction facility and a LLRW disposal facility[18,19] several events are frequently mentioned: Love Canal, Three Mile Island, nuclear bomb testing, and the movies "Silkwood" and "China Syndrome." These examples are used by people to illustrate the perceived seriousness of the risk, the callousness of government and industry, and the reason why no governmental regulator or facility manager can be trusted. In other words, these events appear to be part of a common culture through which related pieces of information are filtered. If indeed these are elements of a coherent cognitive system they may have the same effect as any deeply held belief system: they are virtually impossible to change.

Exploring my own "memory dump" of fairly recent related bits of information produces the following: the infamous garbage barge looking for a home; an article in an outdoor magazine advising that if you must hunt waterfowl make sure you only eat one a month because of PCB and EDB contamination; a similar advisory on fish from the Great Lakes and bottom feeders from the Atlantic; a local advisory on fish from my favorite fishing lake; the Bhopal tragedy; Chernobyl; the death of porpoises off the east coast being tied to possible offshore chemical dumps; and the recent discovery that our local water supplies have unacceptably high levels of PEC's.

I am sure the reader can supply their own shopping list of environmental horrors which would vary in specifics but not in general impact. Whether the items in any particular shopping list are truly environmental disasters is not the issue. The fact is they are dramatic, frightening, and frequent. That is, they embody all the criteria for attention getting stimuli and they do remain in memory. Even if people were regularly exposed to more objective information, which they are not, it could not hope to compete with that information which is already stored and which comprises daily risk information fare.

However, perhaps the single most vexing issue facing those who favor more objective risk information as a palliative to public opposition is the lack of certitude which plagues risk estimates. For example, the problems with low dosage radioactive materials is that they carry some degree of risk but the magnitude of that risk is largely conjecture and open to challenge:

> "There appears little consensus among scientists over the health effects of exposure to low-level radiation. In an extensive study done by the Committee on the Biological Effects of Ionizing Radiation issued in 1980, the authors reported that health risk estimates are based on incomplete data and involve a large degree of uncertainty, especially in the low-dose region."[20]

The kind of uncertainty permits British anti-nuclear activist Dr. Alice Stewart to predict a "hidden epidemic" as a result of the Chernobyl accident.[21] Hidden epidemics tend to be more frightening than those whose effects are easily observable. Uncertain information invites challenge and encourages rejection among those who are not experts in the field. It seems a reasonable response to assume that if the experts cannot agree why should anyone tolerate it.

Finally, the argument has been effectively made that the selection of risks to evaluate, the methodologies employed in determining risk, and the selection of data all embody values and baises. As in most important policy arenas, it is extremely difficult to separate fact from value in the great risk debate. The issue of a possible underlying ideology is another barrier to public acceptance of information provided by experts they do not trust.

The above discussion naturally leads to consideration of who does, and does not, provide that risk information which elicits attention.

Who Provides the Risk Information

Although there is a relative paucity of research on the subject there is general consensus that the media sets the agenda for risk perception[22,23] and that media provided risk information is highly distorted.[24] One of the obvious reasons for this bias is that attention-getting news sells papers. News of human tragedies, failed technologies or management systems, or of a powerless public being bilked by some powerful industrial or government giant is "juicy" fare. This phenomenon helps explain the public's keen interest in a policitician's sex life and relative indifference to his views on important policy issues.

However, the issue of media bias is more complicated than simple over-attention to the dramatic. Rothman and Lichter provide provacative data indicating that journalists who write on scientific matters are: (a) more likely to attend to the writings and pubic statements of antinuclear scientists; and, (b) are strongly influenced by their political beliefs. That is, ". . . key science journalists are far more skeptical of nuclear energy than are scientists" (p 51) and therefore more attuned to the pronouncements of anti-nuclear activists such as those affiliated with the Union of Concerned Scientists, Ralph Nader, and Dr. Ernest Sternglass. Also, the more liberal the journalist, both science journalists and others, the more antinuclear: "The best predictor of opposition to nuclear energy is the belief that American society is unjust" (p 51).[25] It is likely that this bias generalizes to risks other than nuclear energy. It is true that many environmental problems are tied to the operation of large, for-profit organizations and are regulated by government bureaucracies which are viewed as being allied to the for-profit industries. It is easy for a journalist, or anyone, concerned with social justice to view this as another case of the helpless individual against corporate and government giants. Apparently that is the definition promoted by the media and accepted by much of the general public. The "us little people versus them powerful, insensitive bureaucrats" theme recurred frequently as unsolicited comments on my LLRW survey. This also explains how nuclear technology evolved into a liberal-conservative issue.

While the media, with its biases, is the most prevelant source of risk information there has been an interesting development in the evolution of nuclear experts who offer their services on the information market. Risk information experts traditionally are affiliated with government, industry, and educational bureaucracies. Within the past several months, however, anti-nuclear activist Marvin Resnikoff has begun advertising as a "second opinion" resource to state and compact officials. His "Radioactive Waster Management Associates" provides an attractive and convincing brochure which touts the professional qualifications of he and his staff. In addition, Resnikoff's former organization, the "Radioactive Waste Campaign," is under new leadership and is advertising "Living Without Landfills" to state officials, radwaste generators, and other interested parties. "Living Without Landfills" provides state or compact officials with detailed information on how to calculate ". . .total radioactivity and radioactive hazard over the lifetime of waste generated in a State or Compact region." This professionalization and improved marketing strategy of anti-nuclear activists should increase their influence with the general public and, perhaps, with state and local officials. In the LLRW survey mentioned previously, respondents were asked who they trusted as sources of information on LLRW. Anti-nuclear activists scored very low in terms of public confidence while any source which had the term "expert" appended to it elicited high votes of confidence.

Finally, information regarding risky technologies is not provided solely by formal sources such as the media or professionalized interest groups. Information, and its meaning, is usually filtered and negotiated through informal networks of co-workers, friends, and relatives. Little is presently known about the role of informal information sources on the formation of attitudes toward risky facilities. It does appear that negative attitudes are relatively easy to mobilize. Siting campaigns that start on a positive note frequently turn sour once the information is more widely distributed in the community. The source of this opposition probably lies in informal opinion leaders and the negotiation of meaning in the context of small, informal groups.

Improved Disposal and/or Treatment Technology as a Solution

Improved technology proponents tend to originate from two quite disparate sources: environmental activists and waste technology developers. Environmental activists, particularly the Sierra Club and East Coast anti-nuclear groups such as the Radioactive Waste Campaign, have publically disparaged landfill disposal since the passage of the 1980 LLRW Policy Act. Their preference is for high-integrity, above-ground storage which would allow constant monitoring and the possibility of material removal should problems develop. A number of compacts, recognizing the poor reputation of landfills, have officially opted for engineered containment. Waste technology companies have recognized that the development of high-integrity, easily monitored, containment, along with volume reduction technology, can have substantial payoff and have been developing competing versions in an effort to capture a viable market share.

While this solution to the problem of public intransigence has substantial support among diverse constituencies it is still not known whether other sectors of the public, particularly the communities targeted to host risky sites, can be convinced of its relative merits. Above-ground storage, in particular, has its detractors in terms of costs, overall safety, and worker protection. In my Pennsylvania survey, a substantial majority of the general public did not view above-ground storage as significantly safer than traditional landfills. They did clearly prefer below-ground disposal with engineered barriers. The problem is that environmental activists can, and will, challenge any below-ground facility on the basis that it is technically impossible to guarantee zero migration of radionuclides into the soil and eventually the water. This is especially likely in regions of high rain and snowfall. Given previous arguments, it can be expected that the local news media will focus on controversy of this sort and this may further erode public confidence in the viability of a technical fix.

Furthermore, attempts at technological fixes will be very expensive. It appears that many decision-makers have decided that the costs can be passed on to the consumer with relatively little effect.[26] However, this may be a dangerous attitude in the sense that once the public is made aware that they are again being asked to pick up the tab for for a technology that was once touted as producing electricity at a rate "too cheap to measure", their opposition may escalate. While decision makers may not think the per capita cost is excessive, the public will have to be convinced.

Finally, there is a growing recognition that beyond the issue of the scientific and technical integrity of a given technology is the question of management: can it be operated safely on a routine basis over long periods of time. The Bhopal, India disaster provoked the following comment:

> "What truly grips us in these accounts is not so much the numbers as the spectacle of suddenly vanishing competence, of men utterly routed by technology, of fail-safe systems failing with a logic as inexorable as it once was . . . indeed, right up until that very moment-unforseeable. And the spectacle haunts us because it seems to carry allegorical import, like the whispering omen of a hovering future."[27]

News of mismanaged high tech is increasingly common. For example, it is well known that managemet decisions were somewhat responible for the space shuttle disaster, TMI, Chernobyl, and cases of failed waste sites. Male respondents especially, in my LLRW survey and a survey dealing with a volume-reduction facility, spontaneously mentioned the high probability of human error as a reason for their opposition to siting. They view Murphy's Laws as alive and well in high tech industries.

Negotiation for Incentives and Assurances as a Solution

First, it must be made clear that incentives and assurances are distinct entities and vary considerably in their degree of attractiveness to various communities and people within communities. Incentives, or concrete material rewards, are generally viewed in the context of restoring equity. It is reasoned that a risky facility is a common good distributing benefits widely but concentrating costs locally. The key to public cooperation is viewed as some sort of concession which raises the reward value of the facility and thus makes the costs less onerous. Material rewards appeal to pecuniary motives, are more attractive to financially strapped communities, and are subject to being labeled as crass payoffs by the opposition.

They do not address issues of fear and distrust.

Assurances, on the other hand, are typically in the form of options which provide the community with some means to protect itself and to check on the data provided by experts and site operators. Assurances provide some measure of power sharing and do directly deal with issues of fear and distrust. Their major shortcoming is that whatever assurances are offered can always be defined as insufficient by those dedicated to stopping siting.

Again, in my 1985 survey on Pennsylvanians' attitudes toward various policy issues connected with LLRW siting, respondents were asked to evaluate material incentives and assurances. The incentives included guaranteed property values, local tax relief, a surcharge on the waste to be returned to the community, and local hiring and buying agreements by the site operator. The assurances included community control over who operates the site, the provision of resources to hire independent experts as checks on industry and government experts, the provision of resources to train locals to monitor the site and local power to shut down the site should malfunctions occur. Each of these options were presented in two formats. First, the respondent was asked how important they thought it was to provide a community with the particular option. Then, they were asked if they thought that the provision of that option would encourage community cooperation. In addition to the general public, these same questions were put to a small sample (38) of state level heads of environmental, civic, and public health associations.

The results of these surveys indicated that the public thought that affected communities should receive both incentives and assurances but a solid majority expressed little confidence in material incentives, except guaranteed property values, as means to promote cooperation. Large majorities (80% and above) chose the options providing control to the community. This is simply a reaffirmation of the primacy of health and safety concerns.

However, in responding to the same items, major decision makers demonstrated the opposite tendency. They tend to overchoose the material incentive options. During interviews they often expressed the opinion that "money talks." The exception to this generalization was those leaders of environmental activist organizations. Their responses paralleled those of the general public. That is, options granting local control were viewed as much more crucial than simple material incentives. This gap in perception between the public and decision makers highlights the different basis from which each is making their judgments. For the public, personal protection is paramount. For most decision makers, siting is paramount. Since incentives are easier to manipulate than shared power options they are likely to be favored by decision makers.

If shared power is to be taken seriously then what form can it assume given the existing legal and institutional infrastructure? Providing grants to communities to hire independent experts and to pursue site monitoring are manageable options and are presently being written into siting legislation in various states. No means presently exists to allow communities to control site operations. While grants to hire independent experts and to monitor the site are welcome assurances they may not be enough. For example, the community could hire independent experts who they know will challenge government and industry data.

A related issue is who does the community trust to represent them to the siting agency. Communities are never homogeneous on issues such as this. Some members will favor siting, some will be on the fence, and many will be opposed. To be viewed as a legitimate exercise, the negotiation process will have to include community members who enjoy trust and credibility. In the same study referenced above, respondents were asked who they trusted to represent the community. Surprisingly, local and county officials elicited very low votes of confidence. Higher confidence was expresed in locals elected to a committee, referenda, or general town meetings. Of course each of these options could be used to effectively stifle the siting process.

Somewhat complex incentive and assurance packages are currently part of all serious attempts to site nuclear facilities. The Texas low-level radioactive waste campaign is a good example.[28] Their degree of success will have to be evaluated post hoc.

Note that most of the issues discussed above focus on changing individuals. Little systematic attention has been given to crucial political aspects characterizing this problem. The reason for this relative lack of attention may lie in the fact that solutions aimed at individuals are consistent with our democratic beliefs and our faith that reasoning will win out. Attention to political issues are certain to mobilize deeply held passions.

Political Dimensions of the Siting Problem

Three issues will be discussed in this section:

1. the decline of the notion of "common interest;"
2. the political rewards for being "anti;"
3. and, the multiple publics and overlapping jurisdictions involved in our fractionated waste policies.

Decline of the Notion of "Common Interest"

The perception of events from an individualistic perspective mitigates against definitions of common interest. "Support—even identification-of the common interest becomes elusive under conditions of extreme normative dissensus."[29] While "doing your own thing" is in some respects an admirable philosophy of individualism it tends to collide with the social realities of teenage pregnancies, the spread of lethal diseases, highway shootings, insider trading on the stock exchange, and homeless hazardous waste.

This fragmentation of the common interest favors the political activities of sectarian voluntary associations. Groups favoring extreme positions and simple solutions will tend to dominate when government is too weak or divided to provide legitimate leadership. The absence of a notion of common interest favors confrontation and conflict over compromise.[30] From this perspective it should come as no surprise that risky waste siting has foundered on the shoals of interest group, local, and sometimes state intransigence. Furthermore, since there is no developed notion of common interest there is no incentive for a politician, or an aspiring politician, to take up the banner of safe siting "somewhere."

The Political Rewards for Being "Anti"

All the above arguments foster the conclusion that political hay is to be made by being anti-siting: not anti-siting in general, but certainly in particular. If the public does not trust the technology, the waste industry and its regulators, or state and local government to adequately represent their interests on this issue then the only popular role for a politician is to favor safe siting in principle but to quash any siting attempt that might impact on his or her consituency. Since the issue tends to be defined in terms of the little person versus the powerful bureaucracy, the politician is in somewhat the same position as the journalist. To side with the waste industry or government is to ally with evil against good. Like journalists, politicians can be expected to publically place more credence on the pronouncements of those who appear to represent the "little people," that is, environmental and anti-nuclear activists. In private, of course, the politician has the unenviable task of negotiating around a number of state and federal agencies and trying to reconcile official views with interest group and local citizen perspectives. Decisive pro-siting political leadership is a highly improbable outcome.

The Problem of Multiple Publics and Overlapping Jurisdictions

Unpopular political issues become footballs. They get tossed around in the hope that someone will be able to solve the problem. In the process of being tossed around they pick up more and more players who want to get into the game. Eventually, the resulting chaos practically insures the game will never get played. Although there are numerous examples, one will suffice to make the point. The economically strapped town of Edgemont, South Dakota viewed a LLRW disposal site as a source of jobs and revenue. The town had been a uranium mining and milling town and its familiarity with radioactive materials translated into less fear. Almost 70 percent of the county and 80 percent of Edgemont's citizens voted in favor of the proposed disposal facility in June, 1984. However, anti-nuclear activists forced the issue to a statewide referendum in which a majority of the State's voters favored statewide approval before South Dakota could enter into a nuclear waste compact with another state and approval by a majority of voters before any private industry could be licensed to open a disposal site.[31] The result was no site.

When the Federal Government threw the LLRW problem to the states in 1979 they hoped that they had taken the initial steps toward a solution of a political crisis. However, the requirements of interstate cooperation, intrastate approval, the meeting of both federal and state regulatory guidelines, the burden of obtaining local cooperation, and pressure from various interest groups has made the entire process something of a nightmare. This multi-group involvement highlights the limitations of all the proposed solutions. A siting project can be scuttled at a number of junctures by a host of different actors, not the least of which is the court system which has been very sensitive to citizen and interest group arguments on environmental issues.

Discussion and Conclusions

We are now in a better position to understand the limitations of currently proposed solutions to siting problems.

More technically adequate risk communication has little chance of successfully competing with the daily "scare fare" which greets us over our morning newspaper or television news program. It is unlikely to command attention, to be given adequate coverage by the media, or to be trusted as objective. In focused settings, such as a local community facing siting, it may be possible to get some people to carefully digest this kind of information. However, they will certainly be a minority and will be very constrained by social pressures from neighbors and counterarguments from visiting "anti's". Should the entire community be convinced that siting is safe then opposition can still emerge at the regional or state level.

Since the source of opposition to siting is fear and distrust there are no compelling reasons why equity solutions should promote acceptance. Compensation and incentives simply do not address these issues. It may be difficult to find a large enough "carrot" to overcome public fear and distrust. The search for a high-level radioactive waste site is now facing this problem.

A more thorough involvement of the affected public in the siting proces could have some effect *IF* it is acknowledged that the goal of that participation is to put some real power in the hands of the locals. Control is clearly what locals see as a prerequisite to any serious consideration of siting. However, it may be practically and legally impossible to give them the degree of control necessary to establish trust. Furthermore, even if a local involvement or an incentive program is successful the project can be halted by other levels of government. This is exactly how a proposed Monitored Retreivable Storage facility was recently stopped in Tennessee. "The siting process was stopped by extensive state-wide opposition resulting in legal challenge by the state and vetoes by the governor and state legislature."[32]

Improved siting technology certainly has a chance of winning some converts. However, like risk estimates in general, debates can go on interminably over whether the new technology is truly more safe or safe enough. Containers fail, monitors malfunction, operators doze off and come in hungover, water infiltrates, storms threaten, terrorists could blow it up, and government regulators never have large enough budgets to do a thorough job of regulating. The success of improved technology depends on establishing trust. That will be difficult to accomplish.

All the above paints a grim picture for hazardous facility siting and may lead the reader to the conclusion that all that is left is to pack up and go home. However, the waste issue must be solved. I will end by briefly discussing what I think those concerned with siting will try to do, what will actually happen, and what could happen.

Clearly, there will be ongoing attempts to meet the legal guidelines established in the amended LLRW Policy Act and the legal amenities demanded for the siting of other risky facilities. Combinations of all the solutions discussed above will be employed. Some successes will certainly occur and it is possible that a few successes will stimulate other compacts and states to "bite the bullet." No one should be surprised, however, if many states do not have operating sites by the prescribed deadline. Any chance for success of a high-level waste facility in the next two decades will likely depend on a volunteer state. This conflict has been referred to as a second "Civil War" and a go-very-slow approach can be expected. The further establishment of nuclear power plants is likely to depend on geo-political events beyond anyone's immediate control. The difficulties in solving the radioactive waste issue has provided a back-ended rationale for holding the line on more nuclear power plants. Anti-nuclear activists have high stakes in seeing to it that this issue is not resolved soon. However, another international oil crisis could change the perceived reward-cost ratio for nuclear power.

In the meantime, waste will continue to be generated. At present there are strong pressures to reduce waste volumes, not only through treatment technologies and more efficient practices, but through redefining what is hazardous enough to require special treatment. In order to solve their waste problems the medical community may take steps to redefine much of their waste so as to separate it from reactor waste. Suggestions to this effect were made at the recent American Chemical Society meetings. If this happens then anti-nuclear activists will be free to more vigorously attack reactor waste. Since low-level radioactive waste has been a combination of reactor, industrial, and medical wastes there has been some constraints on an all-out attack. No one wants to be accused of threatening public health by hampering nuclear medicine. It is likely that more materials will find their way into solid waste landfills and more will be stored on site. The pressures for on-site storage may eventually redefine the entire problem. In line with what environmental activists are proposing, much waste may eventually be stored in expensive, above-ground facilities on-site. In other words, there will be a great deal of "muddling through" to invent solutions to the continued waste problem. None of the solutions are likely to be optimal either from a safety or a cost perspective.

However, it should be made clear that

the bottom line to risky facility siting is, and will remain, public fear and distrust along with political timidity and favor-seeking. Public health and safety and economic efficiency are the major issues. Many analysts are optimistic that the existing piecemeal approach will, in the long run, favor improved safety while promoting democratic ideals.[33] However, a viable counterargument can be made that a solution involving the long term interests of the public and industry requires planning, negotiation, compromise, and especially leadership from the highest levels of government. National mobilization similar to that experienced during wartime may eventually be necessary. Given continued lack of progress, we may be forced to question whether our present course is a optimal one or whether the long-term impact is simply more economic and health liabilities forced on our progeny.

References Cited

1. **Freudenburg, W. R.** 1985 Waste not: the special impacts of nuclear waste facilities. In: R. G. Post, ed., *Waste Isolation in the U.S., Technical Programs and Public Participation*, Proceedings of the Symposium on Waste Management, Vol. 3, Tucson, Arizona.
2. **Douglas, M.** 1985. *Risk Acceptability According to the Social Sciences*. Russell Sage Foundation, New York, NY.
3. **Ruckelshaus, W. D.** 1983. Science, Risk, and public policy. *Science*, 221: pp. 1026–1028.
4. **Covello, V. T., P. Slovic, and D. von Winterfeldt.** 1987 Risk Communication: a review of the literature. Unpublished Manuscript. p. 79.
5. **Con, W. D. and N. R. Feimer.** 1985 Communicating with the public on environmental risk: integrating research and policy. *The Environmental Professional*, 7: pp. 39–47.
6. **Epstein, S. S., M. D., L. O. Brown, and C. Pope.** 1982. *Hazardous Waste in America*. Sierra Club Books, San Francisco.
7. **O'Riordan, T.** 1983. The cognitive and political dimensions of risk analysis. *Journal of Environmental Psychology,* 3: pp. 345–354.
8. **Douglas,** Ibid.
9. **Bord, R. J.** 1985 Opinions of Pennsylvanians on policy issues related to low-level radioactive waste disposal. Institute for Research on Land and Water Resources Report. The Pennsylvania State University.
10. **Schnaiberg, A.** 1987 Economics of environmental regulation: the impact of environmental protest dynamics. Paper delivered at the annual meetings of the American Association for the Advancement of Science, Chicago, Ill.
11. **DuPont, R. L.** 1981. The nuclear power phobia. *Business Week.* September 7: pp. 14–16.
12. **Mitchell, R.C.** 1984. Rationality and irrationality in the public's perception of nuclear power. In: W. R. Freudenberg and E. A. Rosa, eds., *Public Reactions to Nuclear Power: Are There Critical Masses?* Westview Press, Inc., Boulder, Colorado.
13. **Covello, et. al.,** Ibid.
14. **Slovic, P., B. Fischhoff, and S. Lichtenstein.** 1982. Facts versus fears: understanding perceived risk. In: D. Kahneman, P. Slovic, and A. Tversky, eds., *Judgment Under Uncertainty: Heuristics and Biases.* Cambridge University Press, Cambridge.
15. **Conn and Feimer,** Ibid.
16. **Douglas,** Ibid., p. 34.
17. **Yosie, T. F.** 1987. EPA's risk assessment culture. *Environment, Science, and Technology,* 21: pp. 526–531.
18. **Bord, R. J., P. J. Ponzurick, and W. F. Witzig.** 1985. Community response to low-level radioactive waste: a case study of an attempt to establish a waste reduction and incineration facility. *IEEE Transactions on Nuclear Science,* Vol. NS-32, December, pp. 4466–4471.
19. **Bord, R. J.,** Ibid.
20. **Eisenbud, M.** 1984. Radioactivity and you. *Environment,* 26: pp. 6–33.
21. **Horneday, A.** 1986. Straight about Chernobyl. *MS Magazine,* IV: pp. 83–86.
22. **Freimuth, V. S. and J. P. Van Nevel.** 1981. Reaching the public: the asbestos awareness campaign. *Journal of Communication,* 31: pp. 155–167.
23. **Pfund, N. and L. Hofstadter.** 1981. Biomedical innovation and the press. *Journal of Communication,* 31: pp. 138–154.
24. **Covello, et. al.,** Ibid., p. 27.
25. **Rothman and Lichter,** Ibid., p. 51.
26. The Radioactive Exchange. 1987 *Low-Level Radioactive Waste Management: Facing the New Realities.* A Briefing book Presented to Participants of the Third Annual Decisionmakers Forum Sponsored by the Radioactive Exchange, June 16–19, Traverse City, MI.
27. Editorial. 1985. *The New Yorker.* Feb. 18, Reported in Covello, et. al., Ibid, p. 25.
28. Texas Low-Level Radioactive Waste Disposal Authority. 1985 *Siting a Low-Level Radioactive Waste Disposal Facility in Texas: Local Government Participation, Mitigation, Compensation, Incentives, and Operator Standards.* Texas Advisory Commission on Intergovernmental Relations, Austin, Texas.
29. **Short, J. F.** 1984 Toward the social transfor-

mation of risk analysis. *American Sociological Review,* 49: pp. 711–725.
30. **Short,** Ibid.
31. **McCaughey, J.** 1985. South Dakota town dreams of its own nuclear waste dump. *The Energy Daily,* 13: pp. 1 and 4.
32. **Peelle, E.** 1987. Innovative process and inventive solutions: a case study of local public acceptance of a proposed nuclear waste packaging and storage facility. *Symposium on Land Use Management,* Praeger Press, New York, NY.
33. **Bullard, C. W.** 1987 Issues in Radioactive Waste Management. Paper Presented to the National Advisory Committee of the Institute of Government and Public Affairs, University of Illinois, Champaign-Urbana, June 15.

Journal of the Washington Academy of Sciences,
Volume 78, Number 2, Pages 239–244, June 1988

Round Table Discussion: Policy Considerations

McGUIRE: Steven McGuire, Nuclear Regulatory Commission. This is for Dr. Bord.

You expressed the opinion that improving technology would not help siting. In view of the last talk, covering state-of-the-art technology, what comment would you make?

BORD: As a citizen, I was very excited about the information that was provided in the last talk. I think that kind of dramatic improvement might have some effect. Now, what would happen, and it is predictable, you would go on 60 Minutes, and someone would try to demonstrate that there are problems with this. There are anti-nuclear activists who, I am sure, would dig up something. But I think we have to look at the whole issue of what reasonable people can agree on. If we can invent a technology that is powerful enough that we can make opportunistic politicians not look so good by opposing it, we will be in better shape. I think that the information provided in the last talk gave some realm of hope in that line.

There is one other point there where the technology does interact with institutional problems. The question came up here, How does this affect the waste disposal problem, because it certainly makes the siting problem easier. There are two features that need to be considered.

One of the things that has happened in the last bit of time is that the waste disposal problem is being treated very differently than it was early on in the fission program. When you believed the nuclear power was very cheap, if you spent any money at all in disposing the waste, you really affected the cost of nuclear power at the front end of the system. Now, luckily, nuclear power is very expensive. You can spend fortunes disposing of the waste, and it will hardly affect the cost of power at all.

That lets us begin technologically to consider lots of things we couldn't consider before. It also lets us consider, because uranium is so available, just throwing the stuff away without ever reprocessing it. If you do that for the sort of reactor that I spoke most about here, the trick is, you take the fuel as it exists, and if it is capable of surviving in the center of an operating uncooled reactor without relinquishing its waste, it is as beautifully packaged as you could possibly imagine to put it somewhere else in a hole in the ground where those conditions are not there. So the fuel comes prepackaged for disposal, and it does become a lot easier. Proving that it survives in one condition makes it a lot more plausible that it survives in another.

SORENSON: I like tech fixes, too. I think the public ultimately would want a tech fix for the nuclear power. But I believe the social and institutional process by which the public gets involved in these new technologies and independently comes to accept them as safer is as important as having the safe technology itself. It's like the government saying, "Trust me. We have this new reactor. It won't fail" will not solve the problem, but it's the whole social process that must take place as well.

BRODSKY: Allen Brodsky, Georgetown University. I was impressed by Dr. Lidsky's presentation. I think maybe if we can get some of these ideas across, that would be great, but I still go back to worry about how the media might present it anyhow. We might find new methods that are safer, and this is very good, but if the kinds of myths that have been propagated are dreamed up against the new technology, the same thing could happen again.

I believe that the public can understand this aspect of chance. Somebody mentioned today that you could not say 1 in 10,000, that it is meaningless. I would like to question that word "meaningless." Our only hope is to get the public to think in terms of chance and quantitatively about risk.

We have to devise ways of doing it and we have to get it to them, not only by person-to-person contact, which I think is important, but we also have to try to get it on the media, and I think there are possibilities of doing that, too.

BORD: In this public education/information program I was on for about three years, we spoke to League of Women Voters and all kinds of civic groups around Pennsylvania. We were very successful in having them sit there and listen to us and afterwards agree that it was a wonderful presentation, they had much better understanding of radioactive waste issues, and they thought everyone should hear this presentation.

I would ask them, "All right. Does that mean that you would be more supportive of a waste site near you?" And they said, "No."

MARKS: Franklin Marks from the U.S. Public Health Service, in the Office of Emergency Preparedness. My office deals a lot with coordinating Public Health Service efforts to combat disasters of one sort or another, often helping work on nuclear power plant problems. Two of the agencies we have worked with often are the Nuclear Regulatory Commission and the Federal Emergency Management Agency.

Earlier in Mr. Sorenson's talk, he was talking to some extent about evacuations, moving people out if necessary. We at some times have had to pay attention to some of the specifics of that, and you can quickly run into some pretty thorny questions. One of them is, How to get people out of an area you want to evacuate if you are talking about patients in a hospital or, secondly, patients in an old age home, or something like that.

Then we often have people raise the issue, What about individuals who don't have cars? Of course, one answer can be mass transit, but that has to be worked out well. Sometimes it even gets a little comical, but it isn't really funny. What about all the people with cars who obviously from time to time will need some gasoline? Will the gas stations be open? If not, you may run into a number of cars running out of gasoline.

Of course, where do all the people go? Presumably some miles away, but where do they wind up staying? Is it friends, big mass area, or what have you. Could you address some of these issues, please?

SORENSON: Certainly I cannot address them in a depth to which we have knowledge on them, because there exists a considerable amount of information on how publics behave in evacuations. To date, we have maybe 15 detailed empirical studies of different evacuation situations that document those kinds of problems, and we are in the process of developing a lot more information on some of the specific topics that you raise, such as how are hospitals and nursing homes being evacuated?

We have a study going on now, funded by FEMA, with Oak Ridge and the University of Tennessee, to address those kinds of issues. By and large, the record of information to date indicates evacuations occur with surprisingly few great logistic problems, in situations in which warning information gets out to the public in sufficient time for them to take action. People adapt to the amount of time they have available to respond to the hazards.

Evacuations prevent a considerable number of deaths and injuries every year from a variety of hazards. So you are faced with a litany of problems. Yet, when you look at the actual record, you find that somehow people are pretty good at taking care of themselves in emergencies, adapting and helping each other to overcome those kinds of problems that you raised.

BRODSKY: I do think people need to understand. People get turned off at the end of all these things when the announcement to the public is, "There is no danger." You cannot say that anymore, because people have heard about the no-threshold concept. They have heard people like Art Upton get up in public and say, "Any level of radiation is dangerous." What people have to realize is that the question is not, "Is radiation dangerous" The question is, "How much radiation is how dangerous?"

McCALLUM: I think it is interesting, and I would like to move us back to the positive side of this. I liked Mr. Sorenson's comments about needing the sort of social machinery to look at evaluating new technologies and dealing with that and, ultimately, achieving the benefits of them. I also wonder if Dr. Lidsky could talk a little bit about research policy and the kinds of things that ought to be considered in the area of research policy to try to move in some of these directions and some of the potential problems, in terms of either economic or political or other kinds of disincentives to evaluating and trying new technologies that might throw some roadblocks in the way.

LIDSKY: That is an immense area of discussion you have opened up, of course. It involves the politics of large commercial organizations interracting with the government, politics that are implicit in people making policies that are wide-ranging, long-lived, and possibly not being as productive as they thought, and all those other issues that I think it is almost hopeless to open up here.

Large research programs develop in their wake. Large research organizations are very hard to turn around quickly, for all sorts of reasons. The nuclear industry in this country, for example, is not going to save itself. The idea is to find some trick. In some ways, I took Mr. Sorenson's comment very much to heart also, because it does not just do to have the technological fix available, especially after I have been advocating that you match your technological fix to what society needs. You also have to do some degree of institutional karate, and it happens differently, in different ways.

It turns out, in this particular case, the particular reactor I was looking at—and here again, each particular case is *sui generis*. You have to tailor it. I did not mention—although not for reasons of hiding it but because I spoke too quickly—that in building a reactor with Level 1 properties, it must be small. If you make it big, it can heat itself up. It took a long time for people to perceive that this was okay. If we believed that big ones were cheaper than small ones, and if we believed in economies of scale, then there was no sense in building a small one.

If you also believed, as everyone did

for a long period of time, that existing reactors were safe enough, then having a reactor that was so much safer was just a marginal inconsequential benefit. It is only recently that people perceive small size being a good thing as far as utilities are concerned—it means they are smaller, they are cheaper and easier to manage; it is easier to build one and test it. But other perceptions come along also.

The institutional karate that is used in this particular case comes about because a reactor of small size, if it is going to meet large power needs, is going to have to be built in very large quantities. People who are interested in building small things in large quantities jump at something like this. I discussed this reactor in Japan, and they have difficult siting problems. They have used up their whole sea coast. They have to move everything else inland, in smaller quantities and closer to cities. They need to have demonstrable safety. They are also very used to building things in large quantity, for their own use and for export use. It turns out, my research now is going to be supported by Japan for the next two years. That is a specific answer, but it is meant, again, to illustrate a general point.

When it comes to technologies, there is no overriding way to do this, because you are trying to match some very difficult constraints that come from different angles. The trick is to find out if you can. It is not always true that you can do it.

BURLEY: Gordon Burley, Environmental Protection Agency. I would like to pursue that same question of alternative technologies just a little bit further. I started work modeling of severe reactor accidents in 1967 when I was with the old Atomic Energy Commission. We also at that time recognized that there were safer reactors. The German pebble reactor was one. I think you did not mention the molten salt reactor. All of these were killed effectively by fiat early on, and some other technologies, evolving technologies, the liquid metal fast breeder reactor, was also killed at about the same time.

We have to put this in the context of the time. We did not have any real antinuclear sentiment in the country at that point. The decisions that were made by the Atomic Energy Commission effectively held. So we went with the light water reactors, which has been indicated are 15 seconds away from disaster. The thing is that we are heading into an era now where the fossil resources are beginning to diminish. We are going to have to go to alternative energy sources. The question is, how does one introduce a change of policy at this point into the thinking process so that there is adequate funding. One is talking about lead times of 15 and 20 years on evolving technology. These decisions cannot be made 15 years from now when we are down the road.

The question is, What should be done at this point to start moulding public opinion to either accept the light water reactors with all their warts or try to get some funding for these alternative technologies which might provide a safer environment.

LIDSKY: Here again, you have come right to the heart of the institutional issue. This country does not have a long-lasting well-thought-out energy policy. Electricity is made by a number of utilities which work in more or less autonomous fashion. Some are very large and very well run. Some are very large and very poorly run. And there is a whole gamut of utilities. That is one of the differences between this country and almost every other, except Germany, by the way, which has a system very much like ours and has a very successful nuclear program going. They do not have quite the choice we have, and they have somewhat different incentives.

Unless you want centralized government planning—and what you have just done is given me an example of a case where centralized government planning did not work. In fact, if the AEC had had its way, we would have many more of the sort of reactors we are finding we wish we did not have right now. So the natural antipathy to centralized planning of that sort in a place where you have a choice is very valid. The thing you have to do is find a way to make things attractive to the system we have, to the utilities we have.

If they are working in a capitalistic system, as most utilities are, then you find a way that makes it attractive for them to put the power they need on line, cheaper and easier than any other way. That is going to be some entity making reactors of this sort, which can be done now by a single entity because they are small and selling them.

Absent that, what we will do is what I said we will do. Each utility will respond individually in a way that makes most sense for them, and that is to put on gas plants and then coal plants. Though I sit in the middle of a nuclear engineering department, I cannot really claim that is going to be a great tragedy for this country. Even as we think about that, and the difficulty I have in developing nuclear reactors that will win, you can build coal plants now that are many times better than existing ones, many times better than we dreamed they could be, in terms of clean emissions, efficient use, small size, and lots of other things. It is not a panic issue in this country, and it may well be that this time we take the time to do the job right.

McCALLUM: Is there a way, from your experience in dealing with waste siting problems and other general issues, to focus the public debate on trying to see things in the context of a larger energy policy and to look at a variety of options and choices. That is a fairly complicated thing to get political force behind, but do you see hopes or have insights into how something like that might work?

BOND: I think that we have not failed in communicating with the public so much in the sense that we have not gotten them to understand probability. I think we failed in getting them to understand programs and international competition. It may well be that certain geopolitical events could occur that would tip the balance of costs and rewards and refocus public attention on some other things.

Specifically with the problem of the NIMBY syndrome, I do not know. I wish I could be more optimistic about that. But right now, I think we would have to come up with an amazing technology to get people to accept it, to show some enthusiasm for it. We cannot site incinerators, we cannot site chemical plants. We are fighting that battle right in my home county with solid waste in Pennsylvania right now. The courts have given the public the power to say no, and that is what they are saying.

I think that in line with some of the remarks that have been made, perhaps eventually in order to deal with the problem, the change will have to occur in the institutions and in the infrastructure. I really do not want to predict how I think that might go.

LIDSKY: There is an aspect of the technology that has been described by our last speaker today that has great appeal from a social policy issue. There are scholars who interpret the controversy over nuclear power in a public reaction against largeness and large scale technology, large scale organizations and the like. There is this resentment among the American public against things that they perceive are out of their control. The idea of a small reactor brings the technology back down in scale to which the individual may feel like they have more opportunity to control the management of that technology.

I think at one point the idea of a neighborhood nuclear power plant would have been very facetiously received, but the idea has inherent merits on its own.

KASPERSON: Perhaps the Chair could add one note of optimism on the radioactive waste siting situation. I have been struck by the experiences of a number of countries in their programs for radioactive waste siting. Sweden is in the process of solving their radioactive waste siting program. They are solving it in a country that has a strong tradition of environmental movement. It has had an active debate over the situation of nuclear power. The institutional situation is that in Sweden there is a local veto right over any industrial plant or waste facility to be located in the community.

Sweden has successfully sited several radioactive waste facilities. They have done it partly by locating the facilities at existing nuclear sites, which may indicate some reason for optimism. That may yet be managed with a monitored retrievable storage facility if we build it at Oak Ridge, so DOE may have been at least partly on track with that particular approach.

But also in Sweden they are not trying to fine-tune the safety of the facility which is rather critical to this process. The approach in Sweden is that they are going to make the facilities so super safe that they are going to win over the broad consensus of expert and even environmental opinion about that. They are not going to try to hedge on the safety issue.

By the way, I wish we could convince the American institutions to do that because the process costs in this area are so enormous compared to the substantive costs of putting the issues to bed that it does not make any sense to get in long protracted siting fights and debates if you can overwhelm the problem by additional investment.

Sweden has also reached something of a societal consensus on the future of nuclear power. If you can do that, some of your problems go away in the siting of facilities.

I think that if you look at the international experience, appreciating the fact that cultures are different—and in Sweden, if you make a decision, basically everybody feels it is their obligation to pull together and make it work; we do not have that luxury—there are important clues as to how this problem can be managed. I think we have gone about it poorly, and we have made a lot of mistakes along the way, but I really do not believe that it is not a manageable problem.

QUESTIONER: Under the present social and political climate of wanting the United States' high technology to be competitive, do you feel that the new technology proposed by Dr. Lidsky would find sympathetic avenues for significant development?

SPEAKER: Viewing the utilities as effectively independent entities whose job is to make money, the answer is yes, if you can make a buck on it. The trick in that case is to find someone to build the first one. It may be possible to do it here, and if it does not happen here, it will be built elsewhere sooner or later. Eventually, if it is built elsewhere and found successful, it will be imported into this country. So the answer is that in the long term, very definitely yes.

In the shorter range, only if one sees a way to make a relatively clear profit on it. Again, time scales in this country being what the are, to make that relatively clear profit in the relatively short period of time. That requires a lot of things to happen just precisely right, and I am not about to predict that that will happen. There are ways in which it might happen.

McCALLUM: This was a very exciting panel. I like the idea of extending this debate to other fora and other places. The panel this afternoon also suggests new ideas and new things that could be included in those discussions that could be very exciting and very useful. There are things we have talked about before, trying to find ways to get more people involved in it and looking at whether or not, in some of the siting debates or in some of the emergency exercising around existing nuclear facilities might be used as focii for attention to get discussion of some of these broader issues when the awareness or the attentiveness of the public has been enervated because of special events. I think that the conference has done what we wanted it to do, which was to produce some new ideas and some things that can be applied in the future.

DELEGATES TO THE WASHINGTON ACADEMY OF SCIENCES, REPRESENTING THE LOCAL AFFILIATED SOCIETIES

Washington Academy of Sciences
1101 N. Highland St.
Arlington, Va. 22201
Return Requested with Form 3579

2nd Class Postage Paid
at Arlington, Va.
and additional mailing offices.

DR. HARALD A. REHDER
5620 OGDEN ROAD
BETHESDA, MD
20816 F