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Attachments

pp229extra

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Comment by Richard Wilson

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Comments by Richard Wilson on NRC-2012-0031-0002

Onsite Emergency Response Capabilities

The document on which comments have been requested is about the response of licensees. I will address those, and then much more importantly address the response of the NRC itself.

It has been said that "he who does not learn from history is condemned to repeat it. I therefore applaud any NRC regulation and action that asks licensees to modify procedures in the light of experience. This seems to be the purpose and thrust of the proposed regulations. The questions which NRC ask those who comment to address are all sensible but they are not fundamental enough.

There are two basic issues which NRC should have asked about. "Are the acceptable dose limits sensible or should they be changed? " and "Is the decision process on such matters as evacuation sensible or should it be changed? I argue that in each of these licensees should IMMEDIATELY change their position as soon as an untoward event takes place which is beyond normal operation. I fist address the issue of radiation exposure standards. I start with a decision process Risk vs Risk and Risk vs Benefit. We all make such comparisons all the time usually instinctively. In ordinary operation of a nuclear power plant it is cheap (in terms of radiation per KW-hour) to keep the dose low. Why not do so when the alternative is not expensive? The decision process is simpler if we ignore the alternates and depend only on ALARA. But in an accident situation or indeed any situation which goes beyond the previously instructions one should carefully consider alternate actions and perform a risk-risk or a risk-benefit calculation. Ideally the elements of this should be clear in advance so that other political pressures do not disturb an already difficult decision.

In particular the acceptable radiation standard should immediately be raised to 10 Rems (0.1 Sv) per accident or 80 Rems (0.8 Sv) if engaging in life-saving actions or if one is an Astronaut. By raising this automatically and immediately plant workers would be able to work more efficiently at mitigating the consequences of any accident. This was eventually done at Fukushima but there should have been no delay. The second feature that is important is that there should be a hierarchy of experts on call in any untoward situation and the operators be allowed, even ordered, to call them. At Three Mile Island, for example, the operators were out of their depth as early as 4:30 am in an accident that started at 4 am. Yet the operators did not call their supervisor until after the fatal shut down of the cavitating coolant pumps at about 5:40 am. As I read the history of the Fukushima accident with a number of contradictory emails, and responsible people "covering their asses" I am unclear what difference that would have made. But almost certainly some.

In many organizations from JP Morgan downwards there is a post mortem after an untoward event and the results of the post mortem used to guide the future. NRC could well

require that such a post-mortem be held by every licensee and the results be publicly available. But nothing in the proposed regulations suggests that this be applied by NRC to its own actions, whether collectively or individually by a commissioner or a staff member. Every organization should of course do this. Typically it should hold a post mortem after a challenging event, discuss went wrong and how to modify for the future. An admission of error if it occurred is crucial and essential for future credibility. In many cases failure to admit error may lead to legal liability.

In what follows I suggest that NRC lamentably failed to learn from an error in NRC procedure just after the accident at Three Mile Island (TMI) in 1979. I start by explaining why I know about the issue. I heard about the accident at approximately 11 am on the Wednesday, alerted by a telephone call from Dr Robert Budnitz, then Director of Research at NRC. For the next several days read what I could including the precise NRC press releases (which I note were almost all ignored by the press). From the power company I also obtained the telephone number of the TMI control room so I was able to find out directly what they knew. As a result of my knowledge and experience I was asked to head a small (3 person) unpaid committee to recommend to the Governor what the Commonwealth should be doing, I attach a copy of that report which include in an appendix a brief account of the accident. However we did not address the following unfortunate action by an NRC employee which had unfortunate consequences, I will call the NRC employee Dr X.

Any post mortem about TMI should show that there was almost certainly a hydrogen explosion inside the containment soon after noon on Wednesday. It should also show that after the coolant pumps were successfully restarted on the Wednesday evening that the basic problem was over. Yet the action which I assert was very unfortunate took place about 11 am on the Friday morning - 2 days later. The TMI operators noted that the pressure was rising in the containment and decided to vent the steam to the environment. They chose a suitable time when the wind was NOT blowing toward the city of Harrisburg. But a helicopter was overhead and the passengers (probably newspaper reporters) noted a sudden pulse of radioactivity which was reported to Dr X. Without any checking Dr X announced that he was recommending an immediate evacuation. This was on the radio almost at once. Among the people who heard this was the head of the Pennsylvania Department of radiation. He called the TMI control room (as I did 1/2 hour later) and was told that there was nothing unusual. Since the Governor's telephone line was busy he ran across Harrisburg to the Governor's office. But the damage was done. Governor Thornburgh was in a tight spot. He made a decision which was obvious for his own political survival. He had to show that he was in charge and had to "do something". The evacuation was partially ordered. He did not make a comparison of the effects on public health of "evacuation" vs "no evacuation". The inevitable adverse consequence took place. The stress of the evacuation took its toll. Although no numbers are in the Kemeny report, a member of the Kemeny Commission Dr Jacob Fabrikant MD insisted that the adverse effects of stress be mentioned and in many conversations thereafter Dr Fabrikant mentioned possible increases of

cancer up to 30%. There is of course huge uncertainty about this, but it seems certain that the adverse effects on health of evacuation exceeded the increase of cancer rate due to exposure CALCULATED to be less than one cancer. I can find no record in the NRC archives that the NRC carried out the post mortem on its own actions at TMI. If they had, it seems to this commentator inevitable that they would have incorporated into their own procedures a very strong statement that in any accident situation evacuation be only suggested by NRC after a comparison of the advantage of reduction of radiation exposure with the adverse effects of an unnecessary evacuation.

The document on which I am commenting is on discussion and possible modification of power company actions in the light of the Fukushima accident. As I discuss below the NRC Chairman Dr Gregory Jaczko, was apparently unaware of the simple fact above that history should have taught him, his colleagues and his staff. A simple analysis of the radiation measured at Fukushima, such as I carried out, using publicly available data, showed small radiation doses for the first few days until Tuesday March 16th and Wednesday March 17th when larger releases occurred. Even then a simple calculation told me, and should have told him as follows:

(1) It was obviously not an emergency in the USA and NRC need not have said anything.

(2) It was unlikely that anyone in the public would get Acute Radiation Sickness, so that an immediate action was not appropriate. Even if the event took place in the USA he should NOT have suggested such an evacuation.

(3) Any friend of Japan should of course respond to a legitimate question from Japan. But to recommend a 50 miles evacuation without such a formal request was inappropriate.

(4) This recommendation was repeated on Thursday morning and became a part of President Obama's message to Japan and an executive order to US citizens in Japan on the Thursday morning. After that many other actions took place. The president's recommendation was obviously news. The US news media amplified it, as is their wont, and neither the reports nor the letters editors were willing to explain that the measured doses did not justify such actions. The Japanese politicians and media amplified the problem still further. It was out of NRC hands. Interestingly, on the Wednesday night there was a meeting in the office of the head of DOE, Secretary Chu, and the President's Science advisor and other distinguished scientists. It is an open secret that President Obama had not discussed the matter with them.

In the document on which I am commenting the NRC are basically asking industry to tell them the results of an industry pro mortem. Very good. But I see no sign of such results among the list of questions nor on the list of NRC documents. I suggest that it is a matter of urgency for the NRC to carry out its own postmortem and to report to the public. I believe that any NRC post mortem would find that:

(1) No one in the public or plant worker got acute radiation sickness. Historical data suggest that evacuation can be delayed in such a case without much additional risk, and that gives the advantage of time to develop a more thoughtful response.

(2) There is plenty of evidence to suggest that the US media will amplify any dramatic suggestion by a US agency. This indeed was the case after Fukushima as it was after TMI. It was amplified further by politicians in Japan and elsewhere with no NRC input.

(3) The effect on the Japanese public was very large. It seems clear that the evacuation caused more harm than good. What should really happen in such a case?

(4) The report of a post mortem should honest and be public. I note that neither the statement on Wednesday 16th March nor the President Obama's statement on Thursday 17th March are mentioned in the documents upon which I comment. They are in the Federal Register but do not appear in the "list VIII Available Supporting Documents." They should so appear.

(5) I suggest that all concerned should apologize deeply to the Japanese authorities and of lesser importance to the colleagues and others in US who were misled by the unfortunate statements.

REFERENCES: 3 ATTACHMENTS

I recently published a requested review for physics teachers of the effects of radiation upon people. This was to provide a guide to the tens of thousands of papers on the subject. It is available at: "Resource Letter EIRLD-2: Effects of Ionizing Radiation at Low Doses," Am. J. Phys. **80**(1); 2011 [DOI: 10.1119/1.3661997]. Also available on the web at: http://physics.harvard.edu/~wilson/publicaions/ppaper925.html or ppaper925.doc

Some detail of the discussion about Fukushima is available in a paper "Evacuation Criteria" in "Dose Response" of which an electronic version has already been released to the public. http://physics.harvard.edu/~wilson/publications/pp932.doc

And my "1980 Report of the Advisory panel to the Governor (Edward King) of Massachusetts and cabinet Task force following the accident at Three Mile Island", R.Wilson (Chairman), G Rathjens and S.Wiltshire (January 1980): http://physics.harvard.edu/~wilson/publications/pp229extra.pdf

(Key words: radiation, cancer, doses, ionizing radiation, risk)
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Resource Letter EIRLD-2: Effects of Ionizing Radiation at Low Doses

Am. J. Phys. **80**(1); 2011.

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This Resource Letter provides a guide to the literature on the effects of ionizing radiation on people at low doses. Journal articles, books and web pages are provided for the following: data at high dose levels, effects of moderate to high doses (leukemia, solid cancer, lung cancer, childhood cancer and non-cancer outcomes), effects of dose rate, relationship to background, supra linearity and hormesis, and policy implications. [DOI: 10.1119/1.3661997]

Introduction

That ionizing radiation can have serious adverse effects on people was obvious to the first experimenters 110 years ago. The primary use of radiation was in the medical profession. The advantages of using an X ray for diagnosis is so great that the advantages outweighed the disadvantages. It took 50 years for the medical profession to realize that the disadvantages could be dramatically reduced (100 fold) by careful measurement and wise use of technology. This was the province of the new discipline of medical physics including radiation protection. There exist data on effects of high levels of radiation from excessive medical exposures, unwise use of radiation in treatment, and since 1945 from the effects of the atomic bombs at Hiroshima and Nagasaki and the effects of nuclear-power accidents at Three Mile Island, Chernobyl and Fukushima. This Resource Letter will mostly address what we can discern from direct epidemiological measurements upon people. There are a large number of references to data on the effects of radiation at high doses. These are mostly in books and compilations (refs. 1-37).

I. Journals are listed in the following order. General journals, Cancer and Environment journals, and Radiation specific journals. Many of the most important results are published in the general journals, but detail is usually found in the radiation-specific journals:

General

Nature
Lancet
Science
American Journal of Epidemiology
Journal of the American Medical Association
British Medical Journal

Cancer and Environment

Cancer Research

New England Journal of Medicine
Science of the Total Environment
Journal of the National Cancer Institute
Journal of Radioanalytical and Nuclear Chemistry

Radiation Specific journals

Applied Radiation and Isotopes
Health Physics
International Journal of Radiation Biology
Journal of Environmental Radioactivity
Radiation and Risk (from Obninsk, Russia)

Radiation Protection

Radiation and Environmental Biophysics
Radiation Research

II. Books and Major Compilations

Of the six books listed, the first is intended for physicians. Nonetheless, there is a lot of physics therein, and all can be read by physicists with great profit. The second is the classic text and the third a more recent text on radiation protection.

1. Medical Effects of Ionizing Radiation, edited by F.A. Mettler and A. C. Upton, 3rd edition (W.B. Saunders, Philadelphia, 2008). (I)
2. Principles of Radiation Protection, K.Z. Morgan and J.E. Turner (Wiley, New York, 1967). (E)
3. Radiation Protection: a Guide for Scientists and Physicians, J. Shapiro, 4th edition (Harvard University Press, Cambridge, MA, 2002). (E)
4. Radiation Carcinogenesis: Epidemiology and Biological Significance, J.D. Boice, Jr., and J.F. Fraumeni, Jr. (Raven Press, New York, NY, 1984). (I)
5. Health Effects of Low-Level Radiation, S. Kondo. (Kinki University Press, Osaka, Japan, 1993). (E)
6. Health Effects of Exposure to Low-Level Radiation, edited by W.R. Hendee and F.M. Edwards (Institute of Physics Publishing, Bristol, UK, 1996). (E)

The reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (abbreviated and pronounced UNSCEAR) are voluminous. They include reports on exposures from many countries and a summary of much of the scientific literature. Although in general the reader should look at the latest report first, they are not completely repetitive and earlier volumes contain some information not present in the later ones. In addition, a study of the changes helps the reader to follow the changes in scientific understanding.

7. Sources and Effects of Ionizing Radiation, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations, General Assembly Official Records: 13th

Session, Suppl. 17 (A/3838), (UNSCEAR, 1958). (I)
8. Effects of Atomic Radiation, United Nations Scientific Committee on the Sources and Effects of Ionizing Radiation, Report E. 77. (UNSCEAR, 1977). (I)
9. Atomic Radiation Sources and Biological Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Ionizing Radiation, Report to the General Assembly, United Nations, New York. (UNSCEAR, 1982). (I)
10. Genetic and Somatic Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with Annexes. United Nations, New York. (UNSCEAR, 1986). (I)
11. Sources, Effects, and Risks of Ionizing Radiation, , United Nations Scientific Committee on the Effects of Ionizing Radiation, Report to the General Assembly, United Nations, New York. (UNSCEAR, 1988). (I)
12. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, including annexes, United Nations, New York. (UNSCEAR, 1993). (I)
13. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with scientific annexes, United Nations Sales Publication E.94.1X.11, United Nations, New York. (UNSCEAR, 1994). (I)
14. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with scientific annexes, United Nations Sales Publication E.08.IX.6, United Nations, New York. (UNSCEAR, 2006). (I)
15. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with scientific annexes, United Nations Sales Publication E.10.XI.3, United Nations, New York. (UNSCEAR, 2008). (I)

The U.S. National Academy of Sciences has a Committee on the Biological Effects of Ionizing Radiation (abbreviated and pronounced BEIR) that regularly surveys the literature on the effects of ionizing radiation. In contrast to the UNSCEAR reports, which are mainly a compilation of data, BEIR reports are judgmental.

16. The effects on populations of exposure to low levels of ionizing radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR 1972) (National Academy Press, Washington, D.C., 1972). (I)
17. The effects on populations of exposure to low levels of ionizing radiation (BEIR III 1980) (National Academy Press, Washington, D.C., 1980). (I)
18. Health Risks of Radon and Other Internally Deposited Alpha Emitters (BEIR IV) (National Academy Press, Washington, D.C., 1988). (I)
19. Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V, 1990) (National Academy Press, Washington, D.C., 1990). (I)
20. Health Effects of Exposure to Low Levels of Ionizing Radiation Health Effects of Exposure to Indoor Radon (BEIR VI, 1999) (National Academy Press, Washington, D.C., 1999). (I)
21. Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR VII phase 2, 1996) (National Academy Press, Washington, D.C., 1996). (I)

The National Council of Radiological Protection and Measurements (NCRPM) has produced over 100 reports. Most are too detailed to be of general interest, but I list the following particularly useful

ones here.

22. Influence of Dose and Its Distribution in Time on Dose-Relationships for Low-LET Radiation, National Council on Radiation Protection and Measurements, Report No. 64 (NCRPM, Bethesda, MD, 1980). (I)
23. Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States, National Council on Radiation Protection and Measurements, Report No. 78 (NCRPM, Bethesda, MD, 1984). (I)
24. Induction of Thyroid Cancer by Ionizing Radiation, National Council on Radiation Protection and Measurements, Report No. 80 (NCRPM, Bethesda, MD, 1985). (I)
25. Ionizing Radiation Exposure of the Population of the US, National Council on Radiation Protection and Measurements, Report No. 93 (NCRPM, Bethesda, MD, 1987). (E)
26. Exposure of the Population of the US and Canada from Natural Background Radiation, National Council on Radiation Protection and Measurements, Report 94 (NCRPM Bethesda, MD, 1987). (I)
27. Risk Estimates for Radiation Protection, National Council on Radiation Protection and Measurements, Report No. 115 (NCRPM), Bethesda, MD, 1994). (E)
28. Research Needs for Radiation Protection, National Council on Radiation Protection and Measurements, Report No.117 (NCRPM, Bethesda, MD, 1993). (E)
29. Principles and Application of Collective Dose in Radiation Protection, National Council on Radiation Protection and Measurements, Report No. 121 (NCRPM, Bethesda, MD, 1995). (E)
30. Sources and Magnitude of Occupational and Public Exposures from Nuclear Medicine Procedures, National Council on Radiation Protection and Measurements, Report No. 124 (NCRPM, Bethesda, MD, 1996). (E)
31. Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection, National Council on Radiation Protection and Measurements, Report No. 126 (NCRPM, Bethesda, MD, 1997). (E)
32. Management of Terrorist Events involving Radioactive Materials, National Council on Radiation Protection and Measurements, Report No. 138 (NCRPM, Bethesda, MD, 2001). (E)

International Commission on Radiological Protection (ICRP). Although no specific reports are referred to here, this commission, started in 1928, issues many reports. There are also a number of books written by authors who think that effects of radiation are grossly underestimated. One of these by Gofman is in section F number 98.

III. Conference Proceedings

The International Atomic Energy Agency, a UN agency set up to promote peaceful uses of nuclear energy, and more recently to monitor (and aid in controlling) military uses, regularly holds conferences and issues a number of reports. The conference on low doses of radiation is particularly important since it contains reports from a number of people with divergent views.

33. International Conference: One decade after Chernobyl: Summing up the consequences of the accident, International Atomic Energy Agency, Vienna (1996). (E)
34. International Conference: Low Doses of Ionizing Radiation: Biological Effects and Regulatory Control, International Atomic Energy Agency, Vienna, IAEA-TECDOC-976, IAEA-CN-67/63, 223-226 (1997). (I)

35. "Chernobyl, 10 Years After: Health Consequences," Epidemiologic Reviews 19(2), (1997). (E)
36. Catalogue of studies on human health effects of the Chernobyl accident: 1995 update. In: WHO European Center for Environment and Health. Rome, Italy: World Health Organization (1995). (I)
37. "Radiation Research: State of the Service Science Twenty Years after Chernobyl," American Statistical Association Conference on Radiation and Health, Radiation Research 167, 338-360 (2007). (A)

One crucial feature of the data is that radiation does not seem to cause *any* medical or biological effect that cannot also occur naturally. It merely increases the probability of the effect. This fact is very important both for understanding possible dose-response curves and for deciding what if anything to do about radiation at low doses. It also leads us to ask a general question. Does radiation *add* an additional probability of developing cancer (an absolute-risk model) or does it *multiply* the probability that is there from natural or other causes (a relative-risk model). Although both are discussed in all the BEIR reports, it is noteworthy that the emphasis has changed from the *absolute* risk model in BEIR I (1970) to the *relative* risk model in BEIR III, BEIR V and BEIR VII.

IV. Websites

38. http://www.rerf.jp/index_e.html
Radiation Effect Research Foundation successor to the Atomic Bomb Casualty Committee (ABCC) with numerous reports.
39. http://www.iaea.or.at/ International Atomic Energy Agency (IAEA).
40. http://www.hpa.org.uk/Publications/Radiation/HPARPDSeriesReports/
Radiation Protection Division of the Health Protection Agency (HPARPI) is the successor to the National Radiological Protection Board (NPRB) in the UK.
41. http://www.elsevier.com/wps/find/homepage.cws_home
42. http://www.ncrponline.org/
These sites all have information on important reports and papers on radiation from RERF, IAEA, NRPB/HPARPD, ICRP and NCRPM respectively. Some of the more recent can be downloaded.
43. http://www.new.ans.org/pi/resources/dosechart/
The American Nuclear Society maintains this interactive webpage so that anyone may estimate his or her integrated dose. The author's dose in the previous 12 months was 2.4 Rems (0.024 Sv) mainly due to medical exposures.

V. What is the effect at moderate to high doses?

44. "Hazards of Ionizing Radiation: 100 Years of Observations on Man," R. Doll, Br. J. Cancer 72, 1339-1349 (1995). This very important review paper by the leading epidemiologist Sir Richard Doll discusses the effects that one might expect from general biological principles and the general status of the field. It is a good start to studying the subject. He asks several questions: (1) Does radiation exposure lead to cancer? (2) Does radiation exposure lead to heart disease? (3) Does radiation exposure lead to other diseases? (4) Does radiation exposure lead to genetic anomalies passed to following generations? (5) Does radiation exposure lead to birth defects?

Most of the studies address only (1) cancer, and the data do indeed suggest that cancer induction is the dominant adverse effect of radiation. The data are better than for the other outcomes largely because the observed effects are greater. Several groups of radiation-induced cancer can be distinguished with different characteristics.

A. Leukemia

Although there have been studies of the effects of radiation on people for 100 years, the most important are the studies of the consequences of the Hiroshima and Nagasaki atomic bombs. This study of the survivors has involved many good scientists, and considerable effort and expense. The exposures occurred over 66 years ago, but an increase in cancers over that expected in the general population is still occurring. Therefore, the most recent of these papers are the important ones to read. In addition, the radiation dose to which the population was exposed is uncertain. It was derived from measurements at other (similar) explosions, and for the neutron dose by measuring long-lived neutron induced, radioactivity in the region.

45. "Studies of the Mortality of Atomic Bomb Survivors Report 12, Part I. Cancer: 1950-1990," D.A. Pierce, Y. Shimizu, D.L. Preston, M. Vaeth, and K. Mabuchi, Radiation Research **146**, 1-27 (1996). (I)

Leukemia was the first cancer to be noticed in the atomic-bomb survivors. Leukemias began to appear 5 years after the exposure and continued to appear for another 20 years, after which the number of leukemias (almost) ceased. Radiation induces leukemias more readily than other cancers. Therefore, leukemias are often considered to be a "marker" for radiation effects. But the variation with age is clearly in great contrast to that of the "solid" cancers, and at old age even an "absolute-risk" model would over predict the number of leukemias.

A small increase of leukemia has been seen in children of workers near nuclear sites such as Sellafield (U.K.) and Douneray (U.K.). Although statistical significant, it is hard to reconcile the numbers with the measured doses. Reference 46 reviews the data. Kinlen found a bigger effect at Glenrothes new town north of Edinburgh (which has no nuclear facilities), and postulates that the observed effect is a viral effect of a new population.

46. "Epidemiologic Studies of Leukemia among Persons under 25 Years of Age Living Near Nuclear Sites," D. Laurier and D. Bard, Epidemiologic Reviews **21**(2), 188-206 (1999). (E)
47. "Evidence for an Infective Cause of Childhood Leukemia: Comparison of a Scottish New Town with Nuclear Reprocessing Sites in Britain," L. Kinlen, The Lancet **332**(8624), 1323-1327 (1988).

B. Solid Cancers (other than lung)

Also in reference 45 are data on cancers in tissues of the body (other than those connected with blood), hereinafter called solid cancers. These do not appear until 20 years after the exposure and have continued to appear for 50 years. The increase of cancer with radiation dose seems to follow a "Relative-Risk" pattern whereby the risk, after the latent period of 20 years, is increased

by a constant fraction relative to the background at that age.

48. "Solid Cancer Incidence among the Chernobyl Emergency Workers Residing in Russia: Estimation of Radiation Risks," V.K. Ivanov, A.I. Gorski, A.F. Tsyb, S.I. Ivanov, R.N. Naumenko and L.V. Ivanova, Radiation and Environmental Biophysics **43**, 35-42 (2004). (I)

For the considered dose interval (1-300 mSv) and for the period 1991-2001, the spontaneous incidence rate of solid cancer among emergency workers agrees, within confidence intervals, with that for the general Russian population. The presented estimates of radiation risk should be treated as preliminary because the follow-up period is rather short and the number of cases considered in the analysis is relatively small.

49. "The Chernobyl Disaster: Cancer following the Accident at the Chernobyl Nuclear Power Plant," M. Hatch, E. Ron, A. Bouville, L. Zablotska and G. Howe, Epidemiologic Reviews **27**, 56-66 (2005). (E)

C. Lung Cancers

Lung cancers have a special place because the lung is also the point of entry for a major exposure route. One of the surprises of the atomic age (i.e. since 1945) was that an excess of lung cancers appeared among uranium miners. In some of the early studies, they seemed to appear only among Caucasian miners and not among native Americans (Indians). There was some speculation of a racial difference in sensitivity. This speculation was rejected and the data somewhat resolved by further follow up, but also by the observation that there are fewer tobacco smokers among the Indian miners. Most analysts have assumed that the lung cancers are due to radon rather than to any other pollution in the mines (dust, etc.) although there is still room to question this. The main concern is that inhaled particles or radionuclides might cause lung cancer. For example, radon gas in uranium mines produces lung cancers by alpha particle irradiation to the lung. This is reviewed in references 18 (BEIR IV, 1988) and 23 (NCRPM, 1984).

The work in the following paper summarizes the evidence for the idea that radiation is synergistic with tobacco smoking, in that the effects *multiply* and do not merely *add.* This makes some intuitive sense since both smoke and radiation are highly irritant to the lung tissue. This idea can therefore be used to guide the questions that are asked of the data at low doses.

50. "Lung Cancer Mortality Among U.S. Uranium Miners: a Reappraisal," A.S. Whittemore and A McMillan, Journal of the National Cancer Institute **71**, 489-499 (1983). (I)

D. Childhood Cancers

Children in the age group 0-8 seem to develop leukemia naturally at a greater probability than children and adults a little older. It is usually accepted that these leukemias are caused by something that happened in utero. In the period 1940-1970 it was common to give an X ray to pregnant women to identify any problems with the infant fetus. This gave doses to the fetus approaching 1 Rem. This classic study (the Oxford study) showed that the probability of developing childhood leukemia increased with the number of X rays.

51. "Radiation Dose Effects in Relation to Obstetric X rays and Childhood Cancers," A. Stewart and G.W. Kneale, Lancet **295**, 1185-88 (1970). (E)
52. "Cancer Mortality Among Atomic Bomb Survivors Exposed in utero or as Young Children (1950-1992)," R.R. DeLongchamps, K. Mabuchi, Y. Yamamoto and D.L. Preston, Radiation Research **147**, 385-395 (1997). (E)
53. "Risk of Childhood Cancer from Fetal Irradiation," R. Doll and R. Wakeford, Br. J. Radiol. **70**, 130-139 (1997). (I)
54. "Childhood Leukemia in Belarus Prior and After the Chernobyl accident," E. P. Ivanov, G.V. Tolochko, L.P. Shuvaeva, S. Becker, E, Nikolla, and A.M. Kellerer. Radiat. Envir. Biophys **35**, 75-80 (1996).(E)

The Chernobyl accident is now 25 years old and childhood cancers (leukemias, reference 54, and thyroid, references 56 and 57) should have been seen within a few years. The lack of leukemias in the general population is consistent with a linear extrapolation from higher doses. Although the idea that X rays increase leukemia is generally accepted, it is still possible that causality works in the other direction, and that the reason for the X rays was a medical problem associated in some way with a latent leukemia. For that reason it is especially interesting to look at the pregnant women who were exposed at Hiroshima or at a radiation accident such as at Chernobyl. A small effect is seen. It is not larger than and could be smaller than the effect suggested by Stewart and Kneale (ref. 51).

55. "Leukemia Following the Chernobyl Accident," G.R. Howe, Health Physics Society **93**(5), 512-515 (2007). (A)
56. "Chernobyl-Related Thyroid Cancer in Children of Belarus: A Case-Control Study," L.N. Astakhova, L.R. Anspaugh, G.W. Beebe, A. Bouville, V.V. Drozdovitch, V. Garber, Y.I. Gavrilin, V.T. Khrouch, A.V. Kuvshinnikov, Y.N. Kuzmenkov, V.P. Minenko, K.V. Moschik, A.S. Nalivko, J. Robbins, E.V. Shemiakina, S. Shinkarev, S.I. Tochitskaya and M.A. Waclawiw, Rad. Research **150**, 349-356 (1998). (I)

The childhood thyroid cancers from Chernobyl, while mostly non-fatal are numerous. They were a surprise although in retrospect they should not have been.

57. "Risk of Thyroid Cancer after exposure to 131I in Childhood," Journal of the National Cancer Institute **97**(10), 724-732 (2005). (E)
58. "Thyroid Cancers 60 years after Hiroshima and 20 years after Chernobyl," John Boice, Journal of the American Medical Association (JAMA) **295**(9), 1061-1062 (2006). (E)
59. "Radiation-induced Thyroid Cancer – What's New?," J.D. Boice, Journal of the National Cancer Institute **97**(10), 703-705 (2005). (I)

E. Medical Exposures

It might be expected that people already being treated with radiation would be examined more carefully than others. This makes a study of such patients particularly interesting. The following studies are typical. They are often interpreted as consistent with a linear dose-response relationship with a usual slope. But they can also be interpreted as showing evidence for a threshold. The

increase of heart problems after treatment for Hodgkin's disease is a particularly interesting (and troubling) effect.

60. "Mortality from Breast Cancer After Irradiation During Fluoroscopic Examination in Patients Being Treated for Tuberculosis", A.B. Miller, G.R. Howe, G.J. Sherman, J.P. Lindsay, M.J. Yaffe, P.J. Dinner, H.A. Risch, and D.L. Preston, N. Engl. J. Med. **321**, 1285-1289 (1989). (I)
61. "Radiation Induced Cancer and Leukemia Risk in Patients Treated for Cancer of the Cervix," J.D. Boice, M. Blettener, R.A. Kleneman, J. Nat. Cancer Inst. **79**,1295-1311 (1987). (I)
62. "An Affair of the Heart," J.D. Boice, Journal of the National Cancer Institute **99**(3):185-187 (2007). (I)

F. The Other Outcomes

Shimuzu et al. (ref. 63) found an increase in several other medical outcomes as a result of the lower levels of exposure. In particular, heart disease appears with a frequency about one third of the frequency of cancer. Boice (ref. 62) and references therein discuss how radiation for cancer treatment can cause cardiac problems.

63. "Studies of the mortality of A bomb survivors: non cancer mortality based upon revised doses DS86," Y. Shimuzu, H.Kato, W.J. Schull and D.G. Hoel, Radiation Research **130**, 249-266 (1992). (I)
64. "Cardiac Exposure in Breast Cancer Radiotherapy: 1950s-1990s," C.W. Taylor, A. Nisbet, P. McGale and S.C. Darby, International Journal of Radiation Oncology, Biology and Physics **69**(5), 1484-1495 (2007). (I)
65. "Cardiac Dose from Tangential Breast Cancer Radiotherapy in the Year 2006," C.W. Taylor, J.M. Povall, A. Nisbet, P. McGale, D. Dodwell, J.T. Smith and S.C. Darby, International Journal of Radiation Oncology, Biology and Physics **72**(2), 501-507 (2008). (I)

Careful search has been made in the Radiation Effects Research Foundation (RERF, ref. 38) data for genetic effects, which are so often portrayed in science fiction as dominant effects of radiation. Reference 66 shows that they are very small. Statistically significant effects are not observed.

66. "The Children of Parents Exposed to Atomic Bombs: Estimates of the Genetic Doubling Doses of Radiation for Humans," J.V.Neel, W.J. Schull, A.A. Awa, C. Satoh, H. Kato, M. Otake, and Y. Yoshimoto, Amer. J. Human. Genet. **46**, 1053-1072 (1990). (A)

One statistically significant non cancer effect has been found in the RERF data on children whose parents were irradiated while they were in utero. Those whose parents were exposed within 1500 m of the hypocenter of the Hiroshima bomb were on average 2.25 cm shorter, 3 kg lighter and 1.1 cm smaller in head circumference than those exposed farther away. This has not been seen in other data sets although there seems to have been no careful look.

67. "The Growth and Development of Children Exposed in utero to the Atomic Bombs in Hiroshima and Nagasaki," J.W. Wood, R.J. Hoehn, S. Kawamoto and K.G. Johnson, Amer. J. Public Health **57**, 1374-1380 (1967). (A)

Another effect that is perhaps associated with or a consequence of the reduction in head size is a statistically significant reduction in Intelligence Quotient (IQ) among children exposed in utero. In other cases, there is severe mental retardation. Although these effects are generally believed to have a threshold, the data on reduction in IQ are consistent with a linear relationship between reduction and dose.

68. "Threshold for Radiation-Related Severe Mental Retardation in Prenatally Exposed A-bomb Survivors: a Reanalysis," M. Otake, M.J. Schull and Lees Brit, J. Radiation Biology **70**(6), 755-763 (1996). (A)

V. The Effects of Dose Rate

From general principles one might guess that a high radiation dose given at a low rate over a period of years might have a different (probably smaller) effect them the same dose given in a short time, although the very use of a total *dose* summed over a long time period, of the order of a lifetime implies that the difference is unlikely to be large. Data from exposures of laboratory animals to radiation at varying rates shows that there is a reduction in cancers (for the same total dose) at low dose rates. A Dose Rate Reduction Factor (DRRF) is usually introduced to describe this. The following papers can be used to address this directly.

69. "Cancer Mortality Among Techa River Residents and Their Offspring," M.M. Kossenko, Health Physics **71**, 77-82, (1996). (E)
70. "Issues in the Comparison of Risk Estimates for the Population in the Techa River Region and Atomic Bomb Survivors," M.M. Kossenko, M.O. Degteva, O.V. Vyushkova, D.L. Preston, K. Mabuchi and V.P. Kozheurov, Radiation Research **148**, 54-63 (1997). (I)
71. "Studies on the Extended Techa River Cohort: Cancer Risk Estimation," M.M. Kossenko, D.L. Preston, L.Y. Krestinina, M.O. Degteva, N.V. Startsev, T. Thomas, V.P. Vyushkova, L.R. Anspaugh, B.A. Napier and V.P. Kozheurov, Radiation and Environmental Biophysics **41**(1), 45-48 (2002). (I)
72. "Protracted Radiation Exposure and Cancer Mortality in the Techa River Cohort," L.Y. Krestinina, D.L. Preston, E.V. Ostroumova, M.O. Degteva, E. Ron, O.V. Vyushkova, N.V. Startsev, M.M. Kossenko and A.V. Akleyev, Radiation Research **164**(5), 602-611 (2005). (E)

In 1955-56 radionuclides spilled from the reservoir in Lake Karachay into the Techa River in the Ural Mountains, Russian Federation. Villagers drank the water and ingested many radionuclides. For 40 years the health of 30,000 villagers around the Techa River has been studied. The exposures were mostly internal exposure from the bone seeker strontium 90. The doses can be moderately well determined by subsequent examination of radioactivity of teeth and other bones. This then enables a bone-marrow dose to be determined, which is the appropriate organ dose for describing leukemia incidence. In contrast, the "solid" cancers depend upon external doses which are far less well determined. There are fewer leukemias than suggested from a linear plot from the Hiroshima-Nagasaki data. This could be a DRRF of 3 with a large error band from 2 to 6 or a quadratic relationship of effect with dose. The dose-rate reduction factor for solid cancers is about 1 with a much larger error band.

72. "Radiation Doses and Cancer," A. Shlyakhter and R. Wilson, Nature **350**, 25 (1991). (E)

For many years it had been rumored that the workers at the MAYAK atomic bomb plant in the Urals received large radiation doses. Attempts from western countries to discover what they were fruitless until 1991 when a description was published in Russian in the journal Priroda. In this paper, these data are discussed and show that the cancer rate was less than suggested by the Japanese atomic-bomb data by a Dose Rate Reduction Factor of about 3.

73. "Verification of Occupational Doses at the First Nuclear Plant in the Former Soviet Union," A. A. Romanyuka, D. Regulla, E. K. Vasilenko, A. Wierser, E.G. Drozhko, A. F. Lyzlov, N. A. Koshurnikova, N. S. Shilnikova and A. P. Panfilov, Appl. Radiat. Isot. **47**(11-12), 1277-1280 (1996). (A)

74. "Mortality Among Workers with Chronic Radiation Sickness," N. S. Shilnikova, N. A. Koshurnikova, M. G. Bolotnikova, N. R. Kabirova, V. V. Kreslov, A F. Lyzlov and P. O. Okatenko, Health Physics **71**(1), 86-89 (1996). (A)

The doses to the MAYAK workers are in principle well determined by personal monitors. Personal monitors even at that early date were reliable in the USA. In principle it should be possible to determine a dose-rate reduction factor both for leukemia and for the principal solid cancers.

75. "Lung Cancer in Radiochemical Industry Workers," V. Hohryakov and S. Romanov, The Science of the Total Environment **142**, 25-28, Elsevier Science B.V. (1994). (A)

76. "Cancer Mortality Risk among Workers at the Mayak Nuclear Complex," N.S. Shilnikova, D.L. Preston, E. Ron, E.S. Gilbert, E.K. Vassilenko, S.A. Romanov, I.S. Kuznetsova, M.E. Sokolnikov, P.V. Okatenko, V.V. Kreslov and N.A. Koshurnikova, Radiation Research **159**, 787-798 (2003). (A)

An interesting subsidiary set of data comes from the MAYAK workers. This is because the workers were exposed to plutonium by inhalation and might be expected to develop lung cancer in the same way that uranium miners develop lung cancer from uranium. These are the *only* group of workers in the world exposed to plutonium (239 mostly) at doses high enough to have an appreciable incidence of lung cancer. While the first studies suggested that the dose-response relationship is quadratic with dose (in qualitative agreement with animal data) and therefore a low dose effect approaching zero seemed to make sense, a more careful look at the data suggests that a linear dose-response relationship fits the data better. However the doses are *not* low and a threshold or reduced effect at low doses is possible.

77. "Estimated Long Term Health Effects of the Chernobyl Accident," E. Cardis, G. Anspaugh, V.K. Ivanov, presented to the IAEA Conference: One Decade after Chernobyl: Summing up the Consequences of the Accident, International Atomic Energy Agency, Vienna (1996). (E)

VI. Low and Very Low Doses

A. The one-hit theory

The physicist Jeffrey Crowther produced the first theory of radiation-induced cancer of which this

author is aware. The idea is that when a cell was ionized by radiation it would initiate a cancer. The probability of ionizing a cell in a given time is clearly proportional to the radiation intensity and hence one gets a theory that cancer induction is linear with dose even at low doses. But this theory in its simplest form cannot be true. Cosmic rays and background radiation ionize millions of cells every day and yet lifetime cancer incidence is only about 30% in the U.S. population. Other effects must modify this idea drastically. Cells can be repaired; they can be excreted without leading to a cancer, and so on. Whether cancer incidence is linear with dose depends therefore on whether these important mechanisms are constant with dose or otherwise. The concept that even small amounts of radiation can induce cancer is deeply embedded in the public consciousness and influences public policy and legal actions. It is often called the One-Hit Theory. This claim cannot be tested directly and remains an unprovable hypothesis. But it is vitally important to realize that the inverse is demonstrably false. Every ionization of a cell does not lead to a cancer. It becomes necessary to discuss what is the lowest level that is known to cause increases in cancer.

B. What is low dose?

The concept of what constitutes a low dose changed after 1945. A typical chest X ray gave a dose of 1 Rem (0.01 Sv) and at least one jurisdiction (UK) went as far as to propose mandating such an X ray every year. (The bill died in the House of Lords because of the objections of the physicist Lord Cherwell.) In contrast, in 1987 a proposal of the U.S. Nuclear Regulatory Commission to call a radiation exposure that gave no more than 1 milliRem (0.00001 Sv) to any person "Below Regulatory Concern" was withdrawn after some vocal public opposition. Yet natural background exposures are a few hundred milliRems or 100 times this amount. Thus "low dose" now means doses as low as background dose, and usually well below background dose.

C. Variation of Cancer Incidence with Background Exposure

One way of attempting to understand the effect of radiation on people at low doses is to understand the variation of cancer mortality with natural radiation exposure. In many studies cancer mortality seems to be lower in areas with high radiation dose.

78. "Altitude, Radiation, and Mortality from Cancer and Heart Disease," C.R. Weinberg, K.G. Brown, and D.G. Hoel, Radiat. Res. **112**, 381-390 (1987). (E)
79. "Natural Background Radiation and Cancer Death in Rocky Mountain States and Gulf Coast States," J. Jagger, Health Physics **75**(4), 428-430 (1998). (E)

The radiation levels in the Rocky Mountain States are higher than in the Gulf States, yet the cancer rate is lower. This effect may be seen throughout the U.S. and Canada (see ref. 26), but confounding factors may exist. Many Mormons who live in Utah and mountain states do not smoke or drink alcohol or coffee and seem to have half the cancer rate of their non-Mormon neighbors. In New Jersey there also is much (presumably polluting) industry. Thus many analysts conclude that the only fact of importance from these studies of geographical variation is that radiation at these levels (a few hundred milliRems per year or 10 to 20 Rems per lifetime) is *not* an important factor in developing human cancers *compared to other factors*.

High background radiation in China does not seem to lead to high cancer rates. It is unclear how

much this is due to lifestyle factors or other pollutant effects.

80. "High Background Radiation Research in China," L. Wei, Atomic Energy Press, Beijing, China (1996). (I)

D. The Relationship of Low Dose Effects and Background - Cancer Modeling.

When doses were called *low* even when they were more than background dose, it was possible to discuss logically the effects of radiation independently of whatever causes the background. Now that *low* means radiation doses 100 times smaller than background it is necessary to consider them together. However, very few scientists and scientific papers do this logically. It is necessary to use theoretical models to suggest what the effects can be. The following discussion is primarily about cancer induction.

81. "Fundamental Carcinogenic Processes and their Implications for Low Dose Risk Assessment," K.S Crump, D.G. Hoel, C.H. Langley and R.Peto, Cancer Research **36**, 2973-2979 (1976). (E)

In the first of the following papers, Guess, Crump and Peto point out that whatever the basic biological process relating a dose to cancer, a differential linearity results provided that the radiation dose and the background act on the biological system in the same way. Indeed, this is implied in Doll and Armitage's well-known multistage theory of cancer. Since pathologists cannot distinguish the cancers produced by radiation and those produced by background, this is an assumption that has not been refuted. Crawford and Wilson went further and pointed out that the argument is a general one and can apply to other outcomes than cancer, and other causes than radiation such as respiratory problems caused by air pollution or cigarette smoking.

82. "Uncertainty Estimates for Low Dose Rate Extrapolation of Animal Carcinogenicity Data," H. Guess, K. Crump, R. Peto, Cancer Research **37**, 3475-3483 (1977). (A)
83. "Low-Dose Linearity: the Rule or the Exception?," M. Crawford and R. Wilson, Human and Ecological Risk Assessment **2**(2), 305-330 (1996). (E)

There is a possibility that the cancers from radiation and background can be distinguished, by DNA analysis, for example, in which case the above argument might not apply. Rowley and Le Beau (ref. 84) have shown that the chromosome structure of an Acute Myelogenous Leukemia (AML) occurring subsequent to and presumably caused by radiotherapy was appreciably different from those that occur naturally. If this turns out to be a general result, the low-dose extrapolation arguments of references 81, 82 and 83 must be drastically reconsidered.

84. "Cytogenetic and Molecular Analysis of Therapy-Related Leukemia," J.D. Rowley and M.M. Le Beau, Ann. N.Y. Acad. Sci. **567**, 130-140 (1989). (A)

E. Epidemiological studies of Low Dose Behavior

The following paper addresses the few epidemiological studies with a large enough data sample, and with systematic errors well enough controlled, that can be used to discuss directly the shape of the dose-response curve below a total dose of 50 Rems (0.5 Sv). The paper focuses on the data on atomic-bomb survivors.

85. "Threshold Models in Radiation Carcinogenesis," D. G. Hoel and P. Li, Health Physics **75**(2):241-250, (1998). (I)

There have been various studies of the cancer rates among workers in nuclear-power plants and other nuclear facilities. The most detailed study in the United States was in reference 87. But a more recent collaborative study in 15 countries (ref. 88) shows a small effect. This is not merely a "meta-analysis" of several papers but a combined study of those groups where the data are deemed reliable. The additional number of leukemias seen is consistent with an extrapolation from the number at higher doses (but the lower 95th percentile of the number is close to zero). The number of additional "solid" cancers is close to zero but the upper 95th percentile is close to the linear extrapolation from higher doses. Taken together these data suggest that much larger numbers suggested in references 88 and 89 can be excluded.

86. "A Mortality Study of Employees of the Nuclear Industry in Oak Ridge, Tennessee," E.L. Frome, D.L. Cragle, J.P. Watkins, S. Wing, C.M. Shy, W.G. Tankersley, C.M. West, Rad. Res. **148**, 64-80 (1997). (I)
87. "Cancer in Populations Living Near Nuclear Facilities: A Survey of Mortality Nationwide and Incidence in Two States," S. Jablon, Z. Hrubec and J. D. Boice, Jr., J. Amer. Med. Assoc. **265**(11), 1403-1408 (1991). (E)
88. "The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry: Estimates of Radiation-Related Cancer Risks," E. Cardis, M. Vrijheid, M. Blettner, E. Gilbert, M. Hakama, C. Hill, G. Howe, J. Kaldor, C.R. Muirhead, M. Schubauer-Berigan, T. Yoshimura, F. Bermann, G. Cowper, J. Fix, C. Hacker, B. Heinmiller, M. Marshall, I. Thierry-Chef, D. Utterback, Y.O. Ahn, E. Amoros, P. Ashmore, A. Auvinen, J.M. Bae, J. Bernar, A. Biau, E. Combalot, P. Deboodt, A. Diez Sacrista, M. Eklöf, H. Engels, G. Engholm, G. Gulis, R.R. Habib, K. Holan, H. Hyvonen, A. Kerekes, J. Kurtinaitis, H. Malker, M. Martuzzi, A. Mastauskas, A. Monnet, M. Moser, M.S. Pearce, D.B. Richardson, F. Rodriguez-Artalejo, A. Rogel, H. Tardy, M. Telle-Lamberton, I. Turai, M. Usel and K. Veress, Radiation Research **167**, 396-416 (2007). (E)

Only recently have there been studies of the effects of radon on people in residential situations. There are two types of study. One, an "ecological" study, compares the *average* lung cancer rate in a community with the *average* radon concentration in the houses of that community. There are several early studies but the most important and most careful are in references 89-97. The average lung-cancer rate falls with increasing radon concentration. It would be a logical non sequitur to derive directly from such a study the relationship of the probability of an *individual* person succumbing to cancer with the radon concentration to which that individual is exposed (the dose-response relationship). To draw such a conclusion is sometimes called "the ecological fallacy." However, Cohen argues that it is legitimate to compare *any* set of data with a theory and if the data do not fit, the theory must be wrong. In particular, he claims that the particular linear dose-response relationship espoused by the U.S. Environmental Protection Agency cannot be correct.

89. "Radon Levels in United States Homes by States and Counties," B.L. Cohen, R.S. Shah, Health Physics **60**, 243-259 (1991). (E)
90. "Relationship Between Exposure to Radon and Various Types of Cancer," B.L. Cohen, Health Physics **65**(5), 529-531 (1993). (E)
91. "Dose-response Relationship for Radiation Carcinogenesis in the Low-dose Region," B.L. Cohen, Int. Arch. Occup. Environ. Health **66**, 71-75 (1994). (I)
92. "Test of the Linear-no Threshold Theory of Radiation Carcinogenesis for Inhaled Radon Decay Products," B.L.Cohen, Health Physics **68**, 157-174 (1995). (I)
93. "Problems in the Radon vs. Lung Cancer Test of the Linear No-Threshold Theory and a Procedure for Resolving Them," B.L. Cohen, Health Physics **72**, 623-628 (1997). (I)
94. "Indoor Radon and Lung Cancer: Risky or Not?," J.M. Samet, J. Nat. Cancer Inst. **86**, 1813-1814 (1994). A distinguished epidemiologist challenges Cohen's studies and implicitly all other "ecological" studies. (E)

These are "retrospective cohort" studies in which a group of people is followed and the individual doses estimated. These are free from the ecological fallacy but there are no data in the low-dose region where 90% of Americans are exposed. It is important to realize that any conclusion about the risk at low doses (that is, doses below natural background) derived from these studies is dependent upon an extrapolation, which may not be in direct disagreement with the ecological study of Cohen.

95. "Residential Radon Exposure and Lung Cancer among Nonsmoking Women," M.C.R. Alavanja, R.C. Brownson, J.H. Lubin, J. Chang, C. Berger, and J.D. Boice, Jr., J. Natl. Cancer Inst. **86**, 1829-1837 (1994). (A)
96. "Lung Cancer Risk from Residential Radon: Meta-analysis of Eight Epidemiologic Studies," J.H. Lubin and J.D. Boice, Jr., J. Natl. Cancer Inst. **89**, 49-57 (1997). (I)

The following paper summarizes the evidence that suggests that the mining cancer data underestimate the risk of uranium miners. Such an underestimate would be even harder to reconcile with the data of Cohen.

97. "Radon-exposed Underground Miners and Inverse Dose-rate (protraction enhancement) Effects," J.H. Lubin, J.D. Boice, Jr., C. Edling, R.W. Hornung, G. Howe, E. Kunz, R.A. Kusiak, H.I. Morrison, E.P. Radford, J.M. Samet, M. Tirmarche, A. Woodwardand S.X. Yao, Health Physics **69**(4), 494-500 (1995). (A)

F. Larger effects than establishment

The following is the foremost and most logical of a set of claims that the effect of a low dose is greater than the "establishment" wisdom. At the time, the "establishment" used an absolute-risk model, which gives a smaller effect than the relative-risk model now accepted for solid cancers. But Gofman's estimate was still 5 times the relative-risk model. Although primarily concerned with radiation exposures from peaceful nuclear energy, Gofman is consistent in also pointing out high medical exposures although he is clearly less eager to oppose them.

98. Radiation and Human Health, J.D. Gofman, (Sierra Club Books, San Francisco, 1981). (I)

99. ECRR 2010 Recommendations of the European Committee on Radiation Risk The Health Effects of Exposure to Low Doses of Ionizing Radiation, C. Busby, R. Bertell, I. Schmitz-Feuerhake, M. S. Cato, A. Yablokov (Regulators Edition, Green Audit, August 2010). (E) This multinational group is the latest to advance the idea that the effect of the dose is undetermined.

The following paper discusses several claims that at radiation doses at or below the background cancers are produced. These reports often select data or otherwise fall into statistical "traps" or errors. Rarely (Gofman is an exception) is there a discussion of the effect of the background and why many more people are not dying naturally from cancer in high-radiation areas, which would be expected if their claims were true.

100. "Is there a Large Risk of Radiation? A Critical Review of Pessimistic Claims," A. Shihab-Eldin, A.S. Shlyakhter and R. Wilson, Environmental International **18**, 117-151 (1992). (E)

G. Is radiation good for you?

The idea that the effect of radiation is linear with dose at low doses dominates most discussions. But there is also a movement in the opposite direction, suggesting that radiation at low doses and low dose rates is good for you. The following paper is typical of several papers in this conference report that address this proposition. In addition, this view is strongly supported in reference 5.

101. "Health Effects of Low-dose Radiation: Molecular, Cellular, and Biosystem Response," M. Pollycove, and C.J. Paperiello, in: **Low Doses of Ionizing Radiation: Biological Effects and Regulatory Control**, International Atomic Energy Agency, Vienna, IAEA-TECDOC-976, IAEA-CN-67/63, 223-226 (1997). (A)

It is important to realize that there are many other possibilities. It is possible, for example, that radiation cures a commonly occurring cancer while increasing the less common ones. Although there are no good data on radiation effects this possibility has been suggested for the chemically induced effects. Also it is possible that radiation cures an infectious disease (such as by killing the bacteria) while increasing cancer. A clear example of a substance that is beneficial at low doses and very deleterious at higher ones is ethyl alcohol.

Alcohol is a substance that has been studied for a much longer period (millennia) than radiation. In the following paper Sir Richard Doll points out that at low doses it reduces the risk of stroke, while it is carcinogenic also (especially in conjunction with tobacco smoking) at medium doses, and at even higher doses the narcotic effects can cause many adverse effects such as car accidents. The implication here is that the same mixture of outcomes can occur with radiation.

102. "The Benefit of Alcohol in Moderation," R. Doll, Drug and Alcohol Review **17**, 353-363 (1998). (A)

H. Policy Implications: Man Rems (Person-Sievert) or Rems/man (Sv/Person)?

The first imperative in any policy discussion is to understand what question you are asking. The relevant policy may be different for different questions.

The following paper describes why health physicists often use collective dose. This was originally measured in Man Rems but allowing both for political correctness and also for a change in units, it is measured in Person-Sieverts. If a linear dose-response relationship is assumed, multiplying the collective dose by the slope of the dose-response curve (from BEIR VII Table 1) gives the overall calculated societal effect, which can be compared to other total societal impacts. However, this can also obscure the fact that an individual decision or decision of a small group, is best discussed using the individual dose.

103. "Principles and Application of Collective Dose in Radiation Protection, National Council on Radiation Protection and Measurements," Report No. 121 (NCRPM, Bethesda, MD, 1995). (E)

In 1978 Dr. Dunster while head of the Health and Safety Executive of the U.K. stated: "all politicians would prefer a dead body to a frightened voter." A dead body does not vote: a person who fears he may have cancer may vote. This dramatically brings out a potential bias in these discussions.

In this category are recommendations by the International Atomic Energy Agency (IAEA).

One criterion is for external acute exposure of 2.5 Gray at a depth of 0.5 cm in tissue. This criterion is more applicable to a localized radioactive-source accident than for the effective whole-body dose applicable to a nuclear reactor or RDD device and must be used with caution.

104. "Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency General Safety Guide," Series No. GSG-2, International Atomic Energy Agency, Vienna Austria (March 17, 2011) Table 2. (E)
105. Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, Environmental Protection Agency (EPA), May (1992). (E)

These guides have been the basis for action by other agencies including the U.S. Nuclear Regulatory Commission.

There are few discussions, and none in the regulatory arena yet, of how such important individual decisions or decisions of small groups work in practice. Obviously a sensible decision involves careful balancing of alternative non-radiation hazards. Three examples are:

106. "A Nuclear Explosion in a City or an Attack on a Nuclear Reactor," R.L. Garwin, The Bridge **40**(2), 20-27 (2010). (E)
107. Analyzing Evacuation Versus Shelter-in-Place Strategies After a Terrorist Nuclear Denotation, L.M. Wein, Y. Choi, S. Denuit, Society for Risk Analysis (2010). (E)

108. "Medical Preparedness and Response to Nuclear Terrorism," G.C. Benjamin, The Bridge **40**(2), 39-44 (2010). (E)

It is surprising that even 66 years after the detonations at Hiroshima and Nagasaki, mankind still has not come to grips with what might happen in another nuclear explosion. The above papers argue that an explosion at ground level, rather than the 500 feet altitude at Hiroshima and Nagasaki will increase the number of radiation casualties. They also argue that merely running directly away from the site may be the wrong thing to do. Sheltering in place can cut our exposure for the first day, and when the direction of the wind-blown plume is known, walking sideways from the plume is the best response.

There is much confusion in many public discussions between an explosion of a fission device and dispersal of a large radioactive source. There is a difference of roughly a factor of 10,000 in the amount of radioactive products released. While calculation and experience with the theft and accidental dispersal of a source at Goiania, Brazil, suggest that the immediate casualties in such dispersal are small (less than 10) there is no consensus on when to reenter a contaminated area.

109. "Management of Terrorist Events Involving Radioactive Material," National Council on Radiation Protection Measurements, Report No. 138 (NCRPM, 2001). (E)
110. "Health Aspects of a Nuclear or Radiological Attack," T.S. Tenforde, D.A. Schauer, R.E. Goans, F.A. Mettler Jr., T.C. Pellmar, J.W. Poston Sr., and T.P. Taylor, The Bridge **40**(2), 50-57 (2010). (E)

The following report discusses the evacuation decision at Fukushima and argues that it was deleterious to public health. It points out that as soon as there is an important adverse effect of any action then a risk-benefit comparison must take this into account. The IAEA and other guidance in the above references omit this in their documents and may therefore be deleterious to overall public health.

111. "Lessons from History of Radiation Use and Nuclear Accidents particularly Fukushima," R. Wilson, The 44th Seminar on Planetary Emergencies, World Federation of Scientists, Erice Sicily (August 20th, 2011). To be available in a full volume of the papers of the seminar at World Scientific. (E)

In 1985, the U.S. Congress requested a set of tables to determine the probability that a person's cancer was due to his radiation exposure. These tables assume a linear dose-response relationship. The dose for which the probability of causation is greater than 50% (and therefore compensable by ordinary legal rules) is very high and very few people will receive it. However, there is a complex procedure with a computer calculation that claims to be reliable, administered by the U.S. Department of Labor. While nominally it is based on scientific principles, a close examination shows the scientific basis is flawed. For example, a worker who was a heavy cigarette smoker and developed lung cancer is more likely to be compensated than a worker who did not know his smoking history.

112. Report of the NCI-CDC Working Group to Revise the 1985 NIH Radioepidemiological Tables, U.S. Department of Health and Human Services (2003).

In accordance with current knowledge of radiation health risks, the Health Physics Society recommends against quantitative estimation of health risks below an individual dose of 5 Rems (the Rem is a the unit of effective dose; in international units, 1 Rem = 0.01 sievert (Sv)) in one year or a lifetime dose of 10 Rems in addition to background radiation. "Risk estimation in this dose range should be strictly qualitative, accentuating a range of hypothetical health outcomes with an emphasis on the likely possibility of zero adverse health effects. The current philosophy of radiation protection is based on the assumption that any radiation dose, no matter how small, may result in human health effects, such as cancer and hereditary genetic damage. There is substantial and convincing scientific evidence for health risks at high dose. Below 10 Rems (which includes occupational and environmental exposures), risks of health effects are either too small to be observed or are non-existent."

113. Policy Statement of the Health Physics Society, 1313 Dolley Madison Boulevard, Suite 402, McLean, VA 22101. (1996). (E)

The policy recommendation of the International Commission on Radiological Protection (ICRP) dating back to 1928 is that it is prudent to assume that a risk remains at low doses and that no exposure should be accepted without expectation of some benefit. This has led to the principle of ALARA - that doses should be reduced to As Low As Reasonably Achievable (economic and other factors taken into account). The following report outlines suggested procedures and on page 25 suggests that if doses can be reduced at a cost of $10 - $1,000 per man Rem or less ($1000 - $100,000 per person Sv) that should be done. The Nuclear Regulatory Commission in 1975 had already suggested a number at the high end, $1,000 per Man Rem, for nuclear activities under their purview. The NRC since updated this to $200,000 per person Sievert. Firstly the number is doubled for inflation, and secondly for political correctness. This is approximately $6,000,000 per cancer (calculated with a linear dose response) and is consistent with a US EPA figure of $6,000,000 per "Statistical life." It is noteworthy that although for almost all individuals medical exposures are a large fraction of a person's individual dose, these are not under the purview of the Nuclear Regulatory Commission and there is no reliable monitoring of these medical doses.

114. "Implementation of the Principle of As Low As Reasonably Achievable (ALARA) for Medical and Dental Personnel," National Council on Radiation Protection and Measurements, Report No 107 (NCRPM, Bethesda MD, 1990). (E)

This reference also recommend a *de minimis* level for an individual dose of 1 milliRem (100 m Sv). Another suggestion was to note that the difference in radiation exposure of about 50 mRem/year (0.5 MSv/year) between sea level and in the Rocky Mountains due to cosmic rays and increased terrestrial radioactivity is generally accepted without question. Although the first was proposed by the NRC, there were public political objections and the proposal was not finalized. Many scientists believe that their time and that of the public is better spent in insisting that these guidelines be followed (and not exceeded) with a coherent risk/cost/benefit analysis rather than addressing the possibility of a threshold at low doses that may be impossible to prove rigorously.

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EVACUATION CRITERIA AFTER A NUCLEAR ACCIDENT: A PERSONAL PERSPECTIVE

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D In any decision involving radiation a risk-risk or risk-benefit comparison should be done. This can be either explicit or implicit. When the adverse effect of an alternate action is less than the planned action, such as medical use of X rays or nuclear power in ordinary operation, the comparison is simple. But in this paper I argue that with the situation faced by the Japanese in Fukushima, the assumption that the risk of an alternate action is small is false. The risks of unnecessary evacuation exceeded the risk of radiation cancers hypothetically produced by staying in place. This was not realized by those that had to make a decision within hours. This realization suggests important changes, worldwide, in the guidelines for radiation protection in accident situations.

Key words: Evacuation, Nuclear, accident, radiation, risk.

BACKGROUND

There is an extraordinary large literature on the effects of radiation on health but surprisingly little on the effect on public health of an accident or of deliberate sabotage or terrorist attack. For example there is no discussion at all in the radiation protection handbook in Harvard University (Harvard 2002). Yet a proper understanding is crucially important for public acceptance of nuclear technologies. In this paper I examine some historical experience of radiation use and various accidents to show that the recommendations are overly complex and ignore problems other than radiation. I summarize from the enormous data pool at our disposal the facts that I consider to be important. The reaction to the Fukushima accident was incorrect and detrimental to sound public health. In this I use the perspective of a Risk-Benefit analyst who constantly compares the risks of an action (or inaction) with risks of alternative actions or inactions.

MEDICAL USE OF X RAYS

Very soon after Roentgen's discovery of X rays in 1895, physicians used them for diagnostic purposes. Although very early it was realized that they caused skin and other lesions, the fantastic ability to see within

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the body was so important that physicians correctly argued that the benefits of the X ray use overshadowed any harm. But this only addressed one part of the risk-benefit calculation. Others, physicists in particular, pointed out that the same benefit could be achieved with far less harm by more careful use of shielding, more sensitive film and so forth.

In the 1920s there was more interest in controlling the use of radiation. In 1927 the International Commission on Radiological Protection (ICRP) was formed. This is a non governmental body but most governments heed its recommendations. But the advice of ICRP and physicists was not fully heeded till about 1970. In 1961 for example I had an (unnecessary) chest X ray at Stanford University and measured my dose. About 1 rem. Now the same X ray would take 7 mrem. But a CAT scan today is nearly 1 rem (0.1 Sv). In addition the US Environmental Protection Agency (EPA) realized that there is a risk posed by a number of radioactive materials in the environment. I found that the justification for the regulations they proposed was not well argued and in my public comments I proposed a justification based upon the health effects data (Wilson 2000a,b).

HIROSHIMA AND NAGASAKI: DISTINCTION BETWEEN ACUTE PROBLEMS AND CHRONIC PROBLEMS

The studies find a crucial distinction between the results of radiation exposure in a short period (integrated over a week or two) and the acute effects that it causes, and radiation over a long period of a few years and the chronic effects that causes. The acute effect of Acute Radiation Sickness starts with a reduction in white blood cell counts and can then lead to tissue damage. It is generally accepted that this occurs at radiation levels above 100 rems (1 Sv) with an LD50 (least dose at which 50% of people die) if 400 rems (4 Sv), (formerly believed to be 250 rems) which can be extended to 500 rems (5 Sv) by a blood transfusion. The first major example of a death from Acute Radiation Sickness was Dr Harry Daghlian who was exposed on 21 August 1945 in a nuclear criticality accident and died some days later. It is not always realized but prompt evacuation is only needed to avoid Acute Radiation Sickness (sometimes Acute Radiation Syndrome) (CDC 2011).

Hiroshima and Nagasaki provide the data from which effects of radiation are usually determined. As occurs with all chronic effects, they are determined at a high radiation level and a model is used to describe what happens at the lower level. A discussion of the underlying toxicology and the models it suggests was made in 1980 (NCRP 1980). But the usual (conservative) model suggests low dose linearity. This comes from the realization that if a medical outcome of a pollutant or action is indistinguishable from one that occurs naturally, any addition to natural incidence is proportional to the dose at low doses (Crump *et al.* 1976; Guess *et al.* 1977; Crawford and Wilson 1996). Indeed this is also a consequence of the usual application of the multistage theory of cancer as described over 50 years ago (Armitage and Doll 1954). Scientists tend now to recognize a more general statement: Understanding

effects at low doses cannot be separated from a general understanding of what causes the "natural" levels of cancer. It is vitally important for perspective to realize that this argument also applies to cancers caused by chemical pollutants also, and even to lung problems caused by air pollution - a fact not realized by most of the public and not incorporated into regulations (Crawford and Wilson 1996).

But there are assumptions and approximations. In the justification I used the word "indistinguishable". They must be biologically indistinguishable and not merely that a pathologist cannot distinguish. There is only one paper to my knowledge on this fundamental point. Cancers that occur after radiation therapy have a different DNA structure (Le Beau *et al.* 1986). Unfortunately there seems to be no interest in exploring this further either for radiation cancers or chemically produced cancers. The coefficient of the linear term is determined from data at high doses. Also the dose in Hiroshima and Nagasaki was over a short period and it is probable that doses over a long period produce smaller effects. There are animal studies that suggest a factor between 2 and 10 but only two data sets. The occupational doses at Ozerk in 1948 as the Russians were rushing to make a bomb before the "wicked Americans" killed them, (Shlyakhter and Wilson 1991; Shilnikova *et al.* 2003) and the Russians exposed at Techa River (Burmistrov, *et al.* 2000; Krestinina *et al.* 2005), after the waste pond overflowed. A detailed discussion of how toxicologists considered other dose response models can be found in an NCRP report (NCRP 1980) and in an ICRP report (ICRP 1990).

According to the above theoretical model, if someone gets a dose just below the LD50 he can still get chronic problems of which the most important is cancer. At an integrated dose of 200 rems there is a 10-20% increase in cancer probability. This depends upon a dose integrated over a long time - of the order of years. It can therefore rise well above 200 rems without causing Acute Radiation Sickness. The natural incidence of fatal cancers is about 20% so that no one who gets less than 100 rems will double his natural incidence and he cannot rightly claim that it is "more likely than not" that his cancer is due to radiation. Low dose linearity was used in the BEIR VII report to the US National Academy of Sciences/National Research Council (NRC 2006). Here I simplify their Table 1 as my Table 1. At 100 milliSievert, 0.1 Sv or 10 rems the increase in fatal cancer probability is 4% or 20% of the natural fatal cancer rate. The number of digits in each entry is high but they are not significant. Alas there is no easily available table where age is broken out.

TABLE 1. The table shows the estimated number of cancer and deaths calculated to result in 100,000 persons (with an age distribution similar to that of the entire U.S. population) exposed to 100 mSv (10 Rems). The estimates are accompanied by 95% subjective confidence intervals shown in parentheses that reflect the most important uncertainty sources including statistical variations, uncertainty in adjusting risk for exposure at low dosed and dose rates, and uncertainty in the method of transporting data from a Japanese to a U.S. population. For comparison, the number of calculated deaths in the absence of exposure is listed in Table 1; BEIR VII (NRC 2006).

	All Solid Cancer		Leukemia	
	Males	Females	Males	Females
Excess deaths from exposure to 100 mSv (10 Rems)	410 (200-830)	610 (300-1200)	70 (20-220)	50 (10-190)
Number of deaths in the absence of exposure	22,100	17,500	710	530

The radionuclides that are produced by nuclear fission are well known, as are their melting points and boiling points. A listing can be found, for example in Table 2 of the report of a study Severe Accidents at Nuclear Power Plants that was carried out for the American Physical Society (Wilson *et al.* 1985) reproduced here as Table 2. Most of the entries in this table are barely relevant to this argument. But I call attention to the isotopes of iodine and of cesium. The former is normally gaseous and is easily released and the latter, although normally solid, is soon evaporated in an accident. Only in the high temperature of a nuclear explosion would it be likely to emit large quantities of strontium, uranium or plutonium. Cesium unlike these chemicals, does not stay in the body and irradiates it roughly uniformly which simplifies the understanding. The last column of this table tells us the amount in the first 7 days after an accident. Unfortunately, although reporting on avoiding nuclear accidents, that committee did not explain how this table should be used in practice.

NUCLEAR POWER - NORMAL OPERATION

Physicists and engineers have for decades been urging careful use of radioactive materials. A modern nuclear power station emits very little radioactivity. Indeed it is often stated (correctly) that a coal fired power station in its particulate emissions emits more. Also the exposure to the plant workers can be kept low without sacrificing performance. Health physicists have set standards which are low and can be met with little cost. The benefit of a low radiation exposure is not limited by a high cost to the consumer of electricity. This leads to a very simple risk benefit calculation. Likewise the risk benefit calculation for laboratory use of radioactive materials is governed by such a simple risk benefit calculation with a reduction to a level "As Low as Reasonably Achievable" (ALARA) first

TABLE 2. Radioactive inventories and whole-body dose conversion factors (3200 MW_PWR) (Table II.B.3; APS 1985).

Radionuclides	Half-life $t_{1/2}$ (days)	Shutdown inventory (10^6 Ci)	Cloud D_c/χ_0 (rem m^3/Ci s)	Inhalation, κ_i (rem/Ci inhaled) (0–50 yr)	Ground D_g/S (rem m^2/Ci)
Noble gases					
Kr-85	3950.0	0.56	0.475E −03	0.310E +00	
Kr-85m	0.183	24.0	0.364E −01	0.260E +00	
Kr-87	0.0528	47.0	0.181E +00	0.100E +01	
Kr-88	0.117	68.0	0.467E +00	0.230E +01	
Xe-133	5.28	170.0	0.906E −02	0.700E +00	
Xe-135	0.384	34.0	0.567E −01	0.120E +01	
Iodines					
I-131	8.05	85.0	0.872E −01	0.600E +03	0.708E +03
I-132	0.0958	120.0	0.511E +00	0.700E +02	0.107E +03
I-133	0.875	170.0	0.154E +00	0.200E +03	0.311E +03
I-134	0.0366	190.0	0.533E +00	0.300E +02	0.414E +02
I-135	0.280	150.0	0.419E +00	0.150E +03	0.285E +03
Cesiums and rubidiums					
Cs-134	750.0	7.5	0.350E +00	0.470E +05	0.369E +04
Cs-136	13.0	3.0	0.478E +00	0.590E +04	0.410E +04
Cs-137	11 000.0	4.7	0.122E +00	0.360E +05	0.131E +04
Rb-86	18.7	0.026	0.207E −01	0.660E +04	0.185E +03
Telluriums and antimony					
Te-127	0.391	5.9	0.936E −03	0.340E +02	0.813E +00
Te-127m	109.0	1.1	0.110E −02	0.240E +04	0.584E +02
Te-129	0.048	31.0	0.147E −01	0.980E +01	0.198E +01
Te-129m	0.340	5.3	0.783E −02	0.300E +04	0.246E +03
Te-131m	1.25	13.0	0.314E +00	0.550E +03	0.960E +03
Te-132	3.25	120.0	0.475E −01	0.150E +04	0.308E +04
Sb-127	3.88	6.1	0.151E +00	0.790E +03	0.920E +03
Sb-129	0.179	33.0	0.268E +00	0.110E +03	0.104E +03

defined numerically by the Nuclear Regulatory Commission in 1975 to cost less than $1000 per man rem (NRC 1975a, b) (This was upgraded recently both for inflation and political correctness to $20 per person Sievert). NCRPM also suggested a number 100 times smaller for occupational doses.

But when the situation in a power plant is not normal all changes. The habits, rules, customs about radiation exposure should change accordingly and the change should be automatic and instantaneous and therefore prepared in advance. Advance preparation would have avoided a problem stated in about 1979 by John Dunster when head of the UK Health and Safety Executive; "There is no politician who would not prefer a dead body to a frightened voter". There was obviously no advanced preparation at Fukushima. The need to balance risks is similar to the physicians' situation in 1900-1970.

WINDSCALE, THREE MILE ISLAND AND CHERNOBYL

There were three reactor accidents from which lessons can be learned. At Windscale in 1957 a plutonium production reactor caught fire and iodine was released. Short-lived radioactive iodine (^{131}I with 10 day half life) can make the major immediate hazard with a well-known chain. Iodine can fall to the ground and be eaten by cows where it concentrates in the milk and babies drink the milk and concentrate the iodine in the thyroid. This has been realized for 60 years and at the Windscale accident in the UK in 1957 the government impounded and bought all milk downwind for a month (McGeoghegan *et al.* 2010; Wakeford, 2007). (Curiously the cows produced twice as much as usual, although this increase is not usually attributed to radiation!)

No one knows exactly how much iodine was ingested at Chernobyl, but a lot. 2,000 children got thyroid cancer of which 20 have died. No one need have got thyroid cancer if it were not for secrecy. There are anecdotes (which I believe) that a school teacher near Hohnichi (Belarus) and an army general in eastern Ukraine were reprimanded by the KGB for advising children not to drink milk for a month (the half life of the iodine is 10 days or so) and thereby causing a panic (Shlyakhter and Wilson 1992). This was, and is, far less likely to happen in an open society in Japan.

There is disagreement about the effects of potassium iodide. If ingested before radioactive iodine exposure it can reduce the ingestion of the radioactive substance. But there are suggestions that if taken after exposure to radioactive iodine it can lock in the radioactive iodine already taken. Moreover, there are other side effects particularly for pregnant women so it is wise not to take it unnecessarily.

At Three Mile Island (TMI) in 1979 there was a partial meltdown but mostly contained. I can find no report of what happened to the iodine, but believe that it combined with water to form HI which was pumped out of the containment into the turbine building where it stayed quietly on the floor.

After Chernobyl in 1986 scientists confirmed that the important releases for the long term effects are ^{134}Cs (two year half life) and ^{137}Cs (30 year half life). The measurements of radioactivity deposition confirms that deposition and therefore emission of ^{90}Sr and the transuranic elements was much less, even though the initial explosion dispersed them locally. The subsequent graphite fire must have reached thousands of degrees and almost all the cesium was evaporated, and that the radiation from the ground deposition is the important pathway with ingestion only about 25%. Evacuation from Pripyat was delayed 36 hours and Chistallogovka 3-4 days. This delay raised public criticism. But prompter evacuation would not have changed the integrated dose much. Only at Chernobyl, and in the plant, did anyone get Acute Radiation Sickness. No one in the general public did.

One important feature for perspective and public understanding is that the effects on health of these low levels of radioactivity are calculated, and not measured. The calculated number is too small to be directly measured. Indeed the number might be zero if the radiation cancers are not identical with those occurring naturally or might even be less than 0 (beneficial). This is described by the word hormesis. There is no hormesis for those washed out to sea in the Tsunami. Those who wish to dramatize the effect tend to stress the total number of calculated fatal cancers. Typical numbers discussed are 4,000-8,000 in the Ukraine, Belarus and European Russia countries and 20,000 worldwide. The latter is to be compared with the billion or so naturally occurring cancers in the world in that time period. But when an accident has occurred, and in discussion of how to manage its consequences, the dose to each individual is appropriate.

FUKUSHIMA: ADVERSE EFFECTS ON HEALTH OF DISLOCATION OR EVACUATION

It has been noted in the medical community for many years that there are stresses and problems associated with relocation that can lead by themselves to adverse effects on public health. In 1975 I saw figures of a 5% increase in cancer probability. I note that in an accident situation this would only be a calculated increase but in that sense is directly comparable to any increase in cancer rate due to radiation. It is hard to find good numbers and I merely refer to a recent review (Uscher-Pine 2009). She opined (Uscher-Pine 2009): "Despite the frequency of post-disaster relocation and evidence of its effect on psychological morbidity, there is a relative paucity of studies; the few examples in the literature reveal weak study designs, inconsistent results, and inattention to physical health impacts and the challenges facing vulnerable populations. Further research guided by theory is needed to inform emergency preparedness and recovery policy."

In the 1980s Dr Crouch and I were interested in the comparison of carcinogenic potency of animals and men. We looked at the unexposed "control" rats and mice from the US National Toxicology program. The rate of cancer varied many percent. For example we found that in some experiments the lights in the cages were on continuously and these were rodents with an elevated "control" rate. In the large study of 30,000 mice at the National Center for Toxicological Research (NCTR), the ED01 or "Megamouse" study (Littlefield and Gaylor, 1985; SOT 1981) there was a variation in response according to where the cages were. Those on the top shelf got tumors later than those on lower shelves. I presume that is because their stress was less. But what counts as stress for a mouse is unclear.

Similarly stress from divorce and separation, or even merely lack of a partner, has been blamed for a 15% increase in the probability of cancer fatalities (Kravdal 2001). I take 5% increase in cancer probability from relocation as a reasonable "lower limit" to the increase of cancer with the stress of evacuation.

The "official" Kemeny report (Kemeny *et al.* 1979) after the TMI accident stated (inter alia): "We conclude that the most serious health effect of the accident (for any reason) was severe mental stress, which was short-lived. The highest levels of distress were found among those living within five miles of Three Miles Island and in families with preschool children."

Anecdotes in Japanese media have noted unexpected deaths in the elderly who have been evacuated. Significant numbers of the elderly in shelters have died unexpectedly. Maybe the calorie intake is below starvation level and not all have three meals a day. Lack of hot food, running water, crowding, poor toilet facilities and lack of water for cleaning people and locations, lack of fuel and lack of hospitals to accept admissions, ambulances or medical services except what appear to be medical personnel who are themselves local victims. Yet there is no indication that these possibilities were considered by those ordering an evacuation! A simple calculation shows that this can far exceed any benefit evacuation may bring. A recent unconfirmed and therefore anecdotal news report that 300 people have died from the Fukushima accident from non-radiation causes in two townships emphasizes the possible problems.

DOSES FROM FUKUSHIMA

Armed with this information I looked at the measurements from Fukushima Daiichi. I first looked at the data on the radiation spike measured at the gate of the Fukushima complex and integrated it (Fig. 1) (GRS 2011). The releases on Friday, Saturday, Sunday and Monday were not serious. Indeed, associated with these early releases was a publicly shown photograph of the explosion showing that the wind was blowing out to sea. This by itself suggests that attention be given to careful timing of gaseous releases. The big doses were on Tuesday, 15 March 2011 and Wednesday, 16 March 2011. The spikes were probably doses from noble gases. The integrated dose was large enough for concern - 0.02 Sv (or 2 rems). But even this is less than one year of normal occupational dose and it should not have prevented a radiation worker from going to or being near the plant. Indeed the report to International Atomic Energy Agency (IAEA 2011) states that the average for all power plant workers as of 23 May 2011 was only 7.7 mSv or 770 mrems, which is about the amount of a CAT scan.

Starting on Thursday, 16 March 2011 the reactors and the spent fuel pools were being cooled by seawater, and there has been no comparable release since that time. Taking the usual decay of ^{134}Cs and ^{137}Cs into

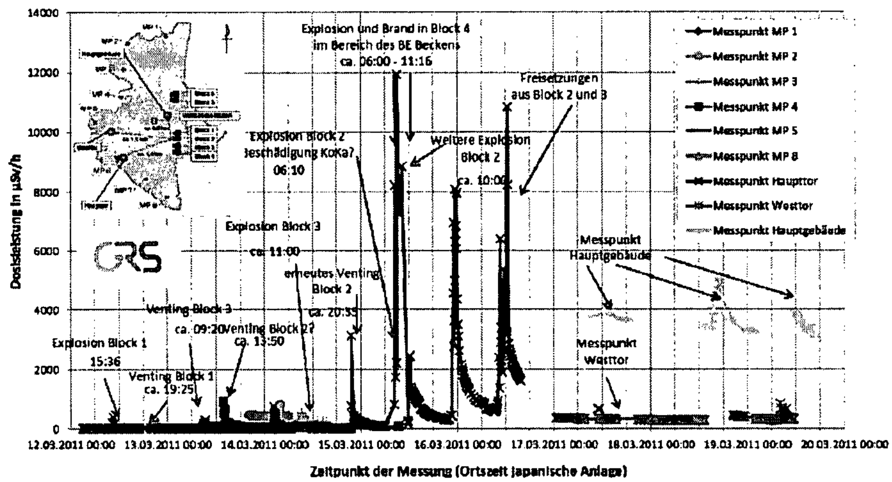

FIG. 1. Dose rates measured at main gate of Fukushima Daiichi (Figure 1; GRS 2011).

account one would expect an immediate drop, and my estimate would be for about 0.06 Sv (6 rems) at the main gate for the first year and falling more slowly thereafter. At three miles (5 km) this would be down a factor of 10. Although the details of who did what and why are confused, a fair independent source of information is available (INPO 2011)

I next looked at doses in the various other locations noted in the map of Fig. 2 They were listed by the Japanese Atomic Industrial Forum but the plots of the doses at these locations (Figs. 3 and 4) come from MEXT (2011) The newspapers emphasized the doses in the Ibaraki region on the way to Tokyo. The abscissa in that plot is μSv per hour. But the dose seems much smaller when the doses in the Ibaraki prefecture are plotted with a different abscissa and ordinate (Fig. 5). One μSv per hour, kept up for a year, would give 8,760 μSv, or 8.76 mSv or 876 mrems. What does this mean?

Many actions can give anyone a dose of 876 mrems:

- A single chest X ray in a major hospital as late as 1960.
- A CAT scan today.
- Seven months allowable occupational dose.
- 1/5 of what a Chernobyl clean up worker (liquidator) got.
- 1/100 of an astronaut's allowed dose.
- About the dose I got in 1991 from a day at Chernobyl mostly from inside the sarcophagus.

Any serious student should evaluate his own lifetime dose for comparison. I have been officially a "radiation worker" since 1946. Yet my integrated dose is almost all due to medical X rays – and I have no record of

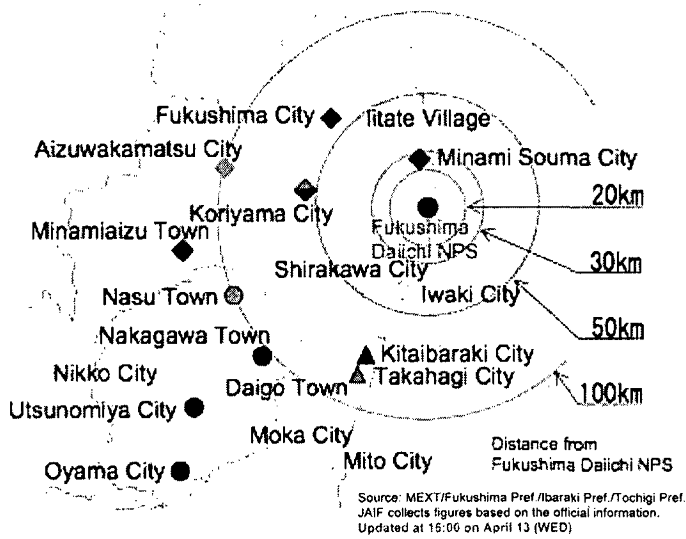

FIG. 2. Locations where Radiation Exposure was measured around Fukushima Daiichi NPS (MEXT 2011).

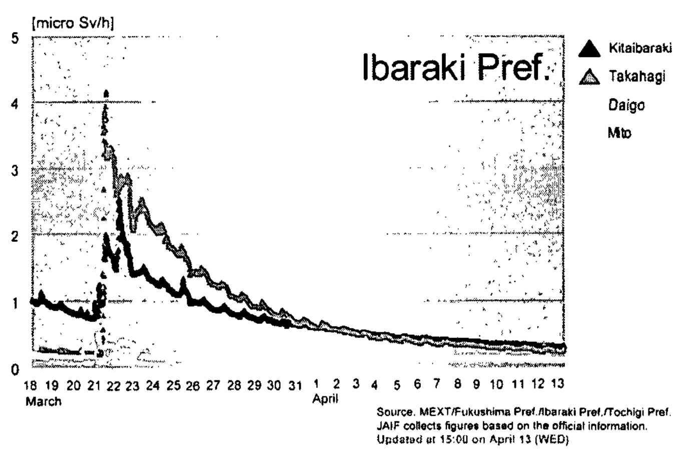

FIG. 3. Dose rate vs. time in Ibaraki prefecture (MEXT 2011).

these for the first 20 years and even now I have to keep the record myself. The American Nuclear Society has a website which enables a good estimate to be made online (ANS 2011). Ideally there would be such a program with the fatal cancer rates at different ages.

In the last year I received 2.4 rems (0.02 Sv). I believe it is absurd to evacuate to avoid this small a dose. Certainly evacuation should not be mandatory. Of course if we go further and consider age, evacuating an 85 year old for anything except Acute Radiation Sickness is really stupid. The graphs (Fig. 2, 3 and 4) from MEXT (2011) of radiation releases suggest

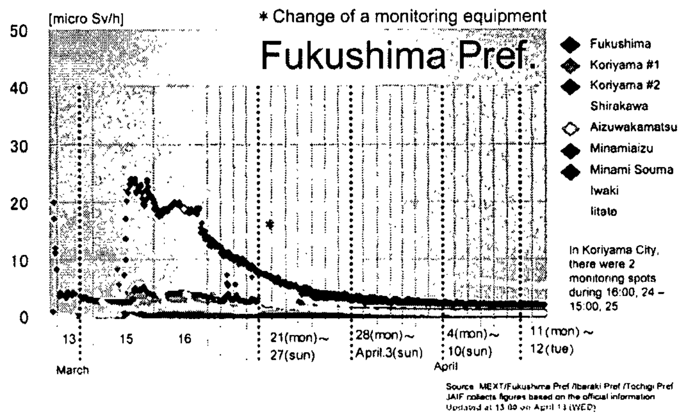

FIG. 4. Dose rate vs. Time in Fukushima prefecture (MEXT 2011).

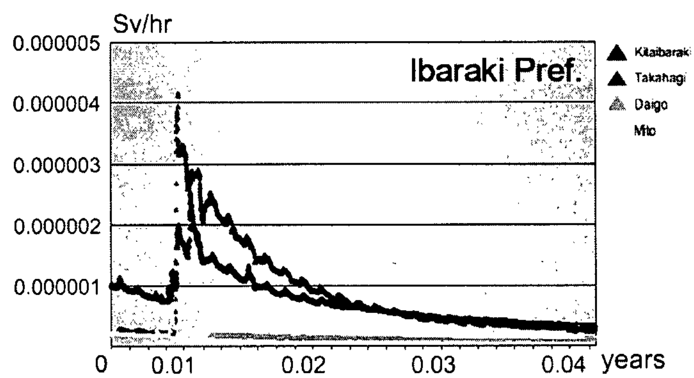

FIG. 5. Dose rate vs. time in Ibaraki prefecture with different ordinate and abscissa.

that no one in the Tochiki or Ibaraki prefectures should be concerned but naturally they will be interested.

For the area NW of the plant, the best description of the doses comes from the Ministry of Education, Culture, Sports, Science & Technology (MEXT 2011) in Japan.

Their map (Fig. 6) shows that the major deposition was to the NW of the plant toward Fukushima itself. MEXT integrated the doses to March 2012 using the usual model, giving the results shown in Fig. 6 and Table 3. The integrated doses are in milliSievert (mSv). The high-integrated doses are all in the Furaha County. Only one is higher than 0.2 Sv (20 rems) integrated to March 2012. These are for continued occupancy in the open. It can clearly be reduced by being indoors and by avoiding high dose hot spots. The lack of important doses in the south and southwest is clearly apparent.

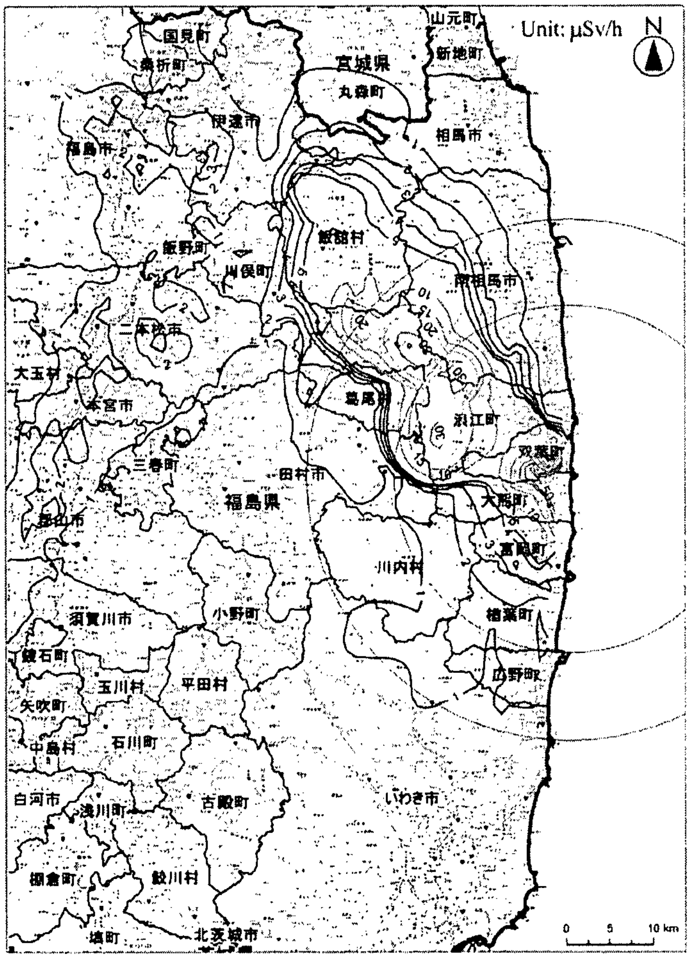

FIG. 6. Integrated radiation dose map of the area NW of the plant, in April 2011 (MEXT 2011).

For comparison 20 rems was the official dose allowed for the "liquidators" (clean up workers) after Chernobyl. According to the studies of effects of radiation (Table 1) this can add 1% or so to cancer probability. This is well below the variation in natural cancer incidence (up to 30%) from unknown causes.

There is no indication of any large deposition of either strontium or transuranic elements, which evaporate at a higher temperature, suggesting that the internal deposition by these elements can be ignored. From this MEXT used a theory to estimate the integrated dose to March 2011 shown in Table 3.

TABLE 3. Measurements at some specific locations with high exposures (MEXT 2011)

Location	From Fukushima Dai-ichi NPP		Estimates of Integrated Dose	Latest Readings (Average)	Estimates of Integrated Dose as of March 11, 2012 (mSv)
	Direction	Distance	mSv	mSv/h	
Akogi Kunugidaira, Namie Town, Futaba County	Northwest	24km	68.2	0.0374	224.9
Akogi, Ishigoya, Namie Town, Futaba County	Northwest	30km	37.1	0.0158	103.1
Akogi Teshichiro, Namie Town, Futaba County	Northwest	31km	32.9	0.0163	101.0
Onami Takinoiri, Fukushima City	Northwest	56km	3.8	0.0018	11.4
Aza Kitaaramaki, Hisanohama Town, Iwaki City	South	31km	1.0	0.0002	1.6
Takahagi, Ogawa Town, Iwaki City	South-southwest	36km	0.6	0.0002	1.4

THE EVACUATION DECISION

The question the Japanese faced was whether and how much to evacuate. This decision had to be made within hours. They had not thought in advance. Then they panicked. It is unclear whether the evacuation was ordered by the government or merely suggested. But it was without analysis. But this is clearly understandable and forgivable given the history of radiation effects in Japan and the failure of the world community to provide guidance. Indeed for 30 years the world community has set guidelines which, I argue, are stupid.

They should have asked the questions:

- Is there an immediate reason to evacuate to avoid Acute Radiation Sickness? The measured doses give the answer NO. Indeed a subsequent independent report by INPO (2011) shows that the highest exposed worker received a dose 1/6 of the LD50.
- Would there be an appreciable increase in long term radiation dose by waiting a few days to analyze? Again the realization that Cesium was the problem would demand the answer NO.
- In retrospect was it sensible to evacuate people beyond three miles from the reactor, bearing in mind the competitive risks? I submit that here again the answer is NO.

- Would it have been wise to inform everyone and prepare for a voluntarily evacuation for those who wished it, which preparation could avoid the chaos that occurred in New Orleans after Katrina? Here the answer is definitely YES.
- Is there an adverse effect on health in evacuation? Here the answer is definitely YES although such effects are often ignored.

The answers at the end of each question are my own personal answers. I submit that the whole world nuclear power and safety community, including semi-political agencies like IAEA and the politicians themselves ponder the above.

American friends of the Japanese people should ask themselves the following questions:

- What is the role of friends who believe they are experts?
- Careful analysis along the lines of the early part of this report?
- Off the cuff remarks at a Senate budget hearing?

Dr Gregory B. Jaczko, Chairman of the Nuclear Regulatory Commission, gave the following testimony Jaczko to the US Congress on 17 March 2011: "Recently, the Nuclear Regulatory Commission (NRC) made a recommendation that based upon the available information that we have, that for a comparable situation in the United States, we would recommend an evacuation to a much larger radius than has been currently been provided in Japan. As a result of this recommendation, the ambassador in Japan has issued a statement to American citizens that we believe it is appropriate to evacuate to a larger distance up to approximately 50 miles." (Jaczko 2011)

This was repeated by President Obama, on Thursday, 17 March 2011, with the following news release: "President Obama made remarks from the White House Rose Garden on the nuclear crisis in Japan shortly after paying an unannounced visit to the Japanese Embassy. After expressing condolences to the Japanese people, the president confirmed calling for an evacuation of U.S. citizens within a 50 mile radius of the reactors in northeastern Japan." (Obama 2011)

These were unfortunate. I so stated in a formal *fax* to Dr Jaczko as soon as I saw the transcript but got no response I have been told that Jaczko was merely following an NRC rule: Keep the dose less than 500 mrems in the immediate accident and < 2 rems over the first year. I argue that the events at Fukushima demonstrate clearly how stupid, and counterproductive to public health, that rule is, and it becomes a matter of urgency to modify it.

RADIATION ACCIDENT MANAGEMENT

At Fukushima there was no proper management of radiation doses immediately the reactor situation was out of control (immediately after the tsunami). There seems to have been no realization in Japan, and probably no realization anywhere else, of the fact that radiation management after an accident should, even must, must differ from radiation management immediately before the accident.

Before TMI (before 1980) it was generally accepted that there were certain radiation levels that should not be exceeded. After TMI, and even more after Chernobyl the recommended levels were reduced. While it makes some sense to keep, for example, to 5 rems/yr (0.05 Sv/ yr) for a nuclear power worker in ordinary operation it is, I believe desirable to return to the higher figures as soon as an accident goes beyond normal operation. Thus it should be allowed for a worker to plan for 20 rems (0.2 Sv) for the whole accident, and indeed at Chernobyl 100,000 or more workers got this dose of 20 rems as "liquidators" (clean up workers). A one time dose of 80 rems (0.8 Sv) was allowed for an astronaut and for a rare individual "to save lives" 80 rems was allowed. It is reported that at Fukushima workers were pulled off the job in Sunday and Monday in the Fukushima accident before the Japanese belatedly restored the pre-1980 levels. This probably delayed a proper technical response to the accident. Although at all ages it is important to keep the radiation dose below that giving Acute Radiation Sickness, full use of older workers, particularly volunteers, should be taken. A person over 70 years old with a high accumulated radiation dose will develop cancer only after 20 years and then it is the least of his worries. (e.g. Harding *et al.* 2011)

It is unclear whether my recommendation of an immediate reversion to the pre-1980 radiation safety levels would have enabled the Tokyo Electric Power Company (TEPCO) to control the reactors any better in the crucial first day. I think they would and that is implied in INPO (2011).

A LESSER ISSUE: RESPONSIBILITY OF THE MEDIA.

News media have been the principal method of communicating with the public, and even with experts. At Three Mile Island, at Chernobyl and at the Tokyo incident the US media failed miserably and forgot their duty. Not one newspaper, nor Associate Press quoted the precise NRC press releases. None of the major newspapers even got the units correct. The Internet has improved this. Experts can find information directly. But there is still a responsibility to inform the public, and in particular to explain what the radiation dose levels mean, in terms of public health and to discuss the harrowing decisions those on the spot must make. In that I find the media lacking.

I next turn to accident prevention. The aim is to prevent the undesirable fission products ever coming into contact with the public. There are several barriers:

1. The fuel is in zirconium pellets with are in a zirconium tube. Although design criteria allowed 0.1% of these tubes to leak, probably none did.
2. If the first barrier fails, there is a pressure vessel which should hold them.
3. If the pressure vessel fails there is a containment vessel.

But, we must emphasize the importance of keeping barrier one intact if possible. Of course it is always important to stop an untoward event as early in the chain as possible. It is especially important because failure here makes it harder to control. In a Boiling Water Reactor (BWR) one can be close to the reactor in operation as I personally have been - one is shielded by the water in the pressure vessel. Once the first barrier fails, doses are higher outside the pressure vessel increasing radiation doses for a worker and making subsequent fixes harder.

MAN REMS (PERSON-SIEVERT) OR REMS MAN^{-1} (SV PERSON^{-1})?

In the preceding paragraphs I have emphasized the dose per person (rems man^{-1} or Sv per person) because that matches the decisions that I was discussing. Rosalyn Yalow, who won the Nobel Prize in medicine for radioimmunioassays repeatedly emphasized this in her lectures "Radioactivity in the Service of Man". But radiation protection experts frequently calculate the collective dose in Man-rems (or Person-Sieverts) because when using a linear dose response relationship and multiplying by the appropriate slope (coefficient) this gives the total societal impact. I do this for the next section on comparing disasters and also take a more optimistic slope allowing for a dose rate reduction factor.

COMPARISON TO OTHER WORLD DISASTERS

The effects of evacuation or not evacuating should be compared to 15,000 dead, and 15,000 missing direct, measurable and definite "dead bodies" from other earthquake and tsunami problems (Table 4).

My rough guess is that one can calculate (but never measure) 500 fatal cancers from radiation from Fukushima (originally my incorrect prediction was close to zero. But it could be zero or even slightly negative.). However Richard Garwin has recently calculated a figure of 5000 worldwide.

I emphasize that the calculated cancers are within the fluctuations of the natural cancer numbers and cannot ever be directly measured.

TABLE 4. Estimated Number of Deaths Compared to Other World Disasters.

Cause and Event	Estimated Number of Deaths
Fatal Cancers from Natural Background Exposures [1]	10,000,000 per year 300,000,000 in average half lifetime
Arsenic Poisoning in Bangladesh [2]	500,000 from exposures 1970 to date
Earthquake in Haiti	200,000
Earthquake and Tsunami in Japan [3]	30,000
Fatal Cancers from Chernobyl in the Next 60 years [4]	7,500 in Belarus, Russia and Ukraine 20,000 – 30,000 worldwide
Fatal Cancer from Three Mile Island [5]	0.7 total
Adverse Health Effects Due to the Evacuation Around Fukushima	0 – 5,000

[1] Including medical exposures; on a worldwide basis.
[2] Assuming everyone have pure water.
[3] Prompt deaths.
[4] Calculated excluding effects of stress.
[5] Calculated for the Kemeny Commission.

MY RECOMMENDATIONS FOR STUDY OF RADIATION EMERGENCIES

I have argued since 1980 that there should be detailed study of a number of fundamental issues. (These should be for other pollutant substances and actions also.)

1. Before 1980 the US Nuclear Regulatory Commission asked for an "Emergency Planning Zone" (not an evacuation zone) of 10 miles diameter. After TMI this became an "evacuation zone" without the detailed discussion such a decision requires. I, personally, was opposed to this implication for automatic evacuation, and testified to the Ontario Royal Commission and others that it was a mistake. I strongly urge the International Community to reexamine this requirement.
2. One should similarly reconsider the requirements for reentry into an area with higher than usual radiation levels after an accident.
3. Are cancers caused by radiation truly indistinguishable from naturally occurring cancers? Or is it just that a pathologist cannot distinguish? (use DNA analysis). Even if this were only done for another pollutant such as arsenic there would be an increased understanding of low dose effects.
4. What is the effect of dose rate? (I urge a careful look at such data as the Techa River and the Mayak workers)
5. What is the effect of disaster stress on cancer? In people? In animals?
6. Can one design a fuel cladding which does not oxidize and therefore does not release both hydrogen and energy?
7. Scientists must continually remind the public and public policy specialists about the effects and lack of effects about radiation. 40 years ago as nuclear power began to enter the world energy system, anti-nuclear activists took the stage. Their dramatic assertions of utter disas-

ter tend to dominate the media. It is important to publish detailed refutations of their extreme arguments. Ideally newspapers would do this but they do not. An example is the paper by Shihab-Eldin *et al.* (1992).

IMPLICATIONS FOR THE FUTURE

The need to reconsider the change the procedure in a risk analysis for the consequences of a serious accident after it has taken place should clearly be part of the training of every person operating a nuclear power reactor and health physicists on duty. But there is another implication. The world is concerned about possible release of a dirty bomb or radioactive dispersal device (RDD) or even a nuclear bomb itself by a terrorist, whether a state actor or non state actor. If it can be made clear to the public, including potential terrorists, that the effects of radiation release can be limited, such a procedure and target can be less attractive to a terrorist. It is also vital that every group of first responders have AT LEAST one person who understands radiation and is not afraid of entering a high radiation area.

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This paper is expanded from a report given to the 44th seminar on Planetary Emergencies, held in Erice, Sicily. The proceedings of that seminar are being published by World Scientific. I have had useful comments from Dr Joseph Ring, Director of Radiation Safety at Harvard University and Dr Robert Budnitz, University of California, Berkeley. I also give my thanks to Ms Jostine Ho who has painstakingly assisted in this preparation.

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January 1980

Advisory Panel to the Governor and Cabinet Task Force On Nuclear Safety Following the Accident at the Three Mile Island Nuclear Power Station

Commonwealth of Massachusetts

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Contents

1. Introduction

All of the United States was shaken by the reactor accident at Three Mile Island, near Harrisburg, Pennsylvania on the morning of Wednesday, 28 March 1979. The reactions of the power company, the neighborhood, the state and federal governments, the regulatory authorities, and the media (newspapers, radio, and TV) in the following days showed major deficiencies in preparedness for a major nuclear accident.

It is essential to learn what we can from the accident at Three Mile Island to help prevent a future accident with more grave consequences. Several studies and investigations have already been initiated. A committee appointed by President Carter and chaired by John G. Kemeny, President of Dartmouth College, has reported to the President; the Nuclear Regulatory Commission (NRC) is conducting on-going detailed reviews; and the Electric Power Research Institute (EPRI), the research arm of the electrical utility industry, has set up a Nuclear Safety Analysis Center which makes and publishes reports and analyses.

Each state which has or contemplates a nuclear power plant also has a responsibility to address the problems of public safety raised by Three Mile Island. In this context, Governor Edward King of the Commonwealth of Massachusetts established a Special Nuclear Cabinet Task Force to review the situation. The Cabinet Task Force is composed of the heads of the state agencies which have responsibility in the area: the Executive Office of Human Services, the Executive Office of Public Safety, the Executive Office of Environmental Affairs and the Massachusetts Office of Energy Resources.

Governor King also appointed this three person panel stating in a press release:

> "The reason for creating this panel...is to assess those reactor safety issues that will have an impact on the future of nuclear energy in Massachusetts...
>
> "No region of the country is more dependent on nuclear energy, and no greater potential exists for stabilizing our costs than the nuclear option. In fact, nuclear energy provides us with one third of our electricity needs and has saved New England consumers $500 million and 80 million barrels of high-priced residual fuel oil since its inception. The benefits are worth pursuing as long as the general public is confident that this technology does not pose unacceptable risks to our public health and welfare...
>
> "However...in light of the Three Mile Island incident, any further actions with regard to this state's involvement in licensing new reactors should not occur until we are certain

that every measure involving public safety and health, which could have precluded the incident in Pennsylvania, is in place in Massachusetts...

"As a result, I have appointed this distinguished panel and asked them to review the NRC's investigation of the Three Mile Island incident and report their findings to the Legislature and the Cabinet-level task force that I have appointed as soon as possible."

Discussions with the Governor, and with the Energy Committee of the Legislature, made it clear that the panel was to be independent of the legislative and executive bodies; and, that, within the broad responsibilities outlined in the Governor's press statement, the committee was to determine its own frame of reference. The panel regarded its responsibility as a task of prime importance.

As in the Kemeny study (report page 4) we did not attempt to reach a conclusion as to whether, as a matter of public policy, the development of commerical nuclear power should be continued or should not be continued. That would require a much broader investigation involving economic, environmental, and political considerations. This panel did not review the general status of nuclear power in Massachusetts. We felt that that larger question also involved too many issues for us to consider properly.

Because 33% of electric power in New England is now generated by nuclear plants we did make an initial assumption that nuclear power is likely to continue as a source of electricity in this state. In addition we proceeded on a premise that the generation of electricity by nuclear power involves a potentially dangerous technology which requires continuous and rigorous care in its use. If in the course of our deliberations we had felt it was clear that the necessary care would be impossible, that the nuclear hardware would be so liable to failure that it should not continue to be used, or that human beings are so fallible that they could not operate this technology, we would have said so. Without going this far, we do say that people can be careless, that equipment may fail and that bad judgements are sometimes made. Our task was to point out approaches which might minimize the number of failures by people or machines and prevent the results of any failure from causing harm to the citizens of the Commonwealth.

Since the panel had limited personal time and no funding or staff, it was not realistic for us to undertake the thorough independent review necessary to certify the adequacy of various state and utility actions and programs. Rather it was decided that the most useful contribution we could make within our resources would be to provide advice to the Cabinet Task Force about their

work and additional actions which could be considered.

To carry out this task the panel met with the Cabinet Task Force on May 15, 1979 and July 14, 1979, had three open public meetings on October 12, 1979, November 19, 1979 and December 14, 1979 as well as several other working meetings. We have reviewed a number of documents and solicited aid and clarification from state agencies, power companies, and the general public. A review and list of these documents and a list of letters are in the appendices.

Although many officials in the responsible state agencies have been working diligently to upgrade the preparedness of the Commonwealth for nuclear emergencies, the decision making level of the Cabinet Task Force is still in the early stage of its work. Therefore, in most cases our recommendations form a work program for the Cabinet Task Force.

We believe that the Commonwealth in its accident prevention management plans and evacuation plans must act in a prudently cautious manner and assume that accidents such as Three Mile Island can lead to meltdown and under some circumstances meltdown can lead to release of an appreciable fraction of the radioactivity in the core.

Finally, we wish to stress that nuclear safety demands continuous vigilance. It should not take a Three Mile Island in Massachusetts to ensure that the problem is treated with the needed urgency.

2. Summary of Principal Recommendations

The panel has reviewed the report of the President's Commission on the accident at Three Mile Island (Kemeny Commission) and agrees with its recommendations almost in their entirety.

In most cases, our recommendations are based on the Kemeny recommendations pointing out those actions appropriate to the Commonwealth. After each recommendation, we note the section in which the subject of the recommendation is discussed in the detailed report which follows. The order in which our recommendations are listed follows the order of the Kemeny report.

1. The Cabinet Task Force should find out what actions the Nuclear Regulatory Commission (NRC) is taking in respect to Kemeny Commission recommendations A4a (P. 63) and C2 (P. 70) that the NRC operator and supervisor licensing functions be upgraded. The Cabinet Task Force should decide in the light of this information whether or not to support the proposal of the Department of Public Safety to widen the scope and increase the frequency of state licensing examinations. Our reading of the Kemeny recommendations and the present NRC role is that the NRC examinations will cover the nuclear aspects of the power system. If that is the case, the state examinaation emphasizing ordinary steam power operations is not a duplication and might therefore usefully be retained and strenghtened. Possible use might be made of the large reservoir of talent in the Boston area to help in these examinations. (Section 4 of this report.)

2. The Cabinet Task Force should satisfy itself that the Energy Facilities Siting Council of the Commonwealth has the competence to address the siting issues discussed in Kemeny recommendations A6 (P. 64). The Kemeny report recommends that to the extent feasible, reactors be located remotely from concentrations of population. The existing reactors in Massachusetts were "grandfathered" (previous approval not re-examined) when the Siting Council was established. The Pilgrim II site was also grandfathered as an adjunct to Pilgrim I. However, Pilgrim II was not grandfathered under NRC rules and although testimony has been closed in the N.R.C. hearing, the Cabinet Task Force should consider whether the Siting Council or other agencies of the Commonwealth should take a position before the N.R.C. hearing board if this issue is reopened. (Section 13 of this report.)

3. The Cabinet Task Force should take a hard look at the

Kemeny recommendation A10a (P. 65), that duplicate consideration of issues be avoided whenever possible, and see to what extent the issues of importance to the Commonwealth can and should be considered at the same time, possibly in a simultaneous hearing with the considerations of those issues by the NRC.

4. The Cabinet Task Force should satisfy itself that Kemeny recommendations A11 a and b (P. 66) that there be systematic safety evaluation and assessment of experience in existing reactors, are being properly implemented. On paper these programs were already taking place before Three Mile Island, but the experience of Toledo Edison Co. in September 1977 which might have prevented mistakes by the Three Mile Island operators was not adequately used. If the Task Force is not satisfied, it should take further action--such as including these matters on the agenda of an independent safety committee established by the Commonwealth (see recommendation 6 below).

5. The Panel notes that the two nuclear power plants in the Commonwealth, Yankee Rowe and Pilgrim I, as well as Vermont Yankee, have separate safety groups reporting to high level management as recommended by Kemeny B2 (P. 68). We recommend that the committees include members with different training and background than normally found in utilities--such as a physicist and a chemical engineer and include members who obtain no more than 20% of their salary from the nuclear industry so that there can be no reasonable doubt about their independence. (Section 5 of this report.)

6. The Cabinet Task Force should review the safety committees noted above, and if they consider them inadequate should set up a Commonwealth safety committee. This committee should be a professional committee with adequate compensation. If Kemeny recommendation A3b (P. 62) is implemented, that the Advisory Committee on Reactor Safeguards (ACRS) of NRC not review individual reactors, this review could be a charge to a Commonwealth Safety Committee. (Sections 3 and 5 of this report.)

7. If a safety committee is set up by the Commonwealth it should include in its review the issues of recommendation B5 d of Kemeny (P. 69) that the utilities and suppliers systematically resolve safety questions in plant operations.

8. We particularly endorse the Kemeny recommendations B 3 (P. 69) that there be clearly defined roles and responsibility both during ordinary operation and during an emergency, and that the responsibility for operations during an emergency rests with the utility company. The Cabinet Task force should satisfy itself that these recommendations are implemented and that the rules and responsibilities be not merely defined but also written down, agreed to and understood by each and every person who is likely to be involved in an incident or its aftermath, including not only utility company employees but also the employees of every agency of state government concerned. (Sections 8, 9 and 10 of this report.)

9. The Cabinet Task Force should satisfy itself that the rate setting board of the Department of Public Utilities is allowing reasonable safety related charges to be reflected in the rate base.

10. The representatives of the utility companies informed us that they are improving operator training in accordance with Kemeny recommendation C 3d (P. 71) by increasing the frequency of simulator training from once a year to twice a year and by having accident scenarios incorporated in the simulator. We urge continued attention to this aspect of operator training. (Section 4 of this report.)

11. The Commonwealth, through its Department of Public Health and the Advisory Council on Radiation Protection should maintain its capability to monitor the exposure to radiation of various population groups in addition to the research proposal recommended by Kemeny (E1c, P. 74) to be coordinated by the National Institutes of Health (Section 7 of this report).

12. The Cabinet Task Force should determine whether there is adequate training for health professionals and emergency response personnel in radiation problems in the Commonwealth as recommended by Kemeny E3 (P. 74) and whether the personnel in the Nuclear Incident Advisory Teams (NIAT) are adequately trained and their level of training is known to those who would be in command in a nuclear incident. (Sections 6 and 9 of this report.)

We recommend that this program of education also be extended to those employed in the industry. In particular, employees should be altered to the ways they can reduce their own exposure, for example, by avoiding high radiation areas, and this awareness should be

reinforced regularly. (Section 7 of this report.)

13. The Commonwealth should verify that the monitoring of radiation is adequate in all circumstances as recommended by Kemeny E4 (P. 75). We are particularly concerned that the present stack gas monitors will overload during accident conditions (E4a). (Section 6 of this report.)

14. We recommend the Commonwealth obtain a supply of potassium iodide (or other thyroid blocking agent) and decide where it should be located (Kemeny recommendation E5, P. 75). Note should be taken of the fact that although potassium iodide has been approved as a drug by FDA, it should not be taken unless necessary because possible side effects are unknown. (Section 6 of this report.)

15. The emergency plans of the Commonwealth have recently been revised in accordance with Kemeny recommendation F1 (P. 76). The panel urge particular attention to clear and consistent delineation of the actions public officials and utility company officials should take. This delineation should also be well advertised so that the coordination recommended in F1c can be achieved. We also recommend that the Department of Public Health, clearly identify the criteria suggested in Kemeny F2a and that the Cabinet Task Force review that effort. (Sections 8, 9 and 10 of this report.)

16. We have some reservations about the practicality of Kemeny recommendation G1a (P. 78) that the utility company be responsible for the dissemination of information during an emergency. The utility company has the responsibility to determine the status of the power plant, whether, for example, a meltdown is possible or likely. However, even if information should be disseminated clearly by the highest possible technical official of the company, we are concerned about whether or not the information will be accepted as reliable due to the present lack of public confidence in utility companies. We anticipae that, as at Three Mile Island, an NRC official may have more public credibility, but in any case we do not feel there is a major role for the Commonwealth in dissemination of information about the status of the plant itself. (Section 10 of this report.)

17. In respect to recommendation G1b, we believe that everyone concerned in the Commonwealth should be clear in advance who should provide the information about radiological releases and evacuation plans. Several times in this

report we suggest circumstances where one or another agency of the Commonwealth--usually the Department of Public Health, should be officially designated the lead agency.

18. We concur in the recommendation of Kemeny F4 (P. 77) that the public must be informed about nuclear power. At present public information is often unreliable and incomplete. The principal role we see for the Commonwealth in this is education about emergency and public health planning and we applaud the actions already being taken by the Civil Defense director and the Department of Public Health in addressing public meetings, responding to questions and providing information. (Section 10 of this report.)

We feel it is a general responsibility of technically informed people to share their information with others and encourage them to do so.

19. We concur with the recommendation G3 (P. 79) of Kemeny, that the newsmedia should improve their ability to cover a nuclear emergency in accordance with their responsibilities. In addition to the detailed list in Kemeny, we suggest that the media should be asked to print verbatim the official press releases of NRC and state officials as well as any interpretations the media may wish. The official releases are likely to be more complete and easily understood by the technical public than the press interpretations. The general public will turn for information analysis to those technical individuals in whom they have confidence, and the supplying of reliable and detailed information to the technical community is an important part of dissemination of information. (Section 10 of this report.)

20. We recommend, in the event that Pilgrim II is licensed, that the Cabinet Task Force consider whether the Department of Public Safety should be asked to inspect the work in progress as the D.P.S. suggests. (Section 13 of this report.)

21. The Cabinet Task Force should examine the relationship of the Commonwealth with the adjacent states (in particular, Vermont) in which a nuclear power plant exists. We have no good way of judging the existing situation with respect to emergency responses, operator training, and reactor safety, but what we have heard suggests that the interests of the Commonwealth may be served by a cooperative effort

to improve safety. (Sections 4 through 12 of this report.)

22. In view of the hearing of the U.S. Department of Transportation scheduled for February 1980, we are disappointed that the relevant agencies in the Commonwealth, the Department of Public Health, the Department of Transportation and the Massachussets Turnpike Authority do not appear to have made an effort to resolve differences they have with respect to a nuclear transportation policy. We are encouraged however, by the statements of December 14, 1979 that they will now meet and try to arrive at a common approach. We suggest guidelines for this in Section 11 of this report.

23. Under current practice spent fuel is being stored at the reactor site and will remain there until there is a plan to reprocess the fuel or store the fuel elsewhere. This is a situation not envisaged in the original plans. We recommend, therefore, that the Cabinet Task Force reexamine the situation to see whether the consequences of any possible accidents at these pools should be included in emergency planning. (Section 12 of this report.)

24. Although not directly related to reactor safety, the panel notes that the Commonwealth is at the mercy of decisions made by others when it sends wastes to repositories in other states. We accordingly recommend that the Cabinet Task Force consider whether it is appropriate to develop a repository within the state or region for low and/or medium level wastes--mostly hospital and laundry wastes with half lives less than 100 years. The analysis might be carried out in conjunction with the consideration of toxic waste disposal now in progress by the Executive office of Environmental Affairs. (Section 12 of this report.)

25. The Cabinet Task Force should review the problems of theft and sabotage at the nuclear reactor sites and the recommendations about this of the RathJens committee. (Section 13 of this report.)

26. The Cabinet Task Force should consider whether a stack gas monitor be installed to read directly into a state building to give an immediate indication of problems. (Section 6 of this report.)

3. The Kemeny Report

The Kemeny Report, on which we have based most of our recommendations should be carefully read by all those in the industry and state government who have the responsibility for nuclear safety.

We note that the report emphasizes the human element at Three Mile Island, The statements by Herbert Diekamp, President of General Public Utilities, that the operators and staff at Three Mile Island were trained as well as any in the industry seem to be true as far as paper qualifications are concerned. However, the repeated statements of these same operators to the Kemeny Commission that they did not understand what was going on in the first 3 hours of the accident are a damning indictment of the training. We discuss this further in section 4 on operator training.

Among the many comments on regulation in the Kemeny report, it was noted that both in industry and in the NRC there is a preoccupation with meeting regulations, rather than addressing the safety issues directly.

The panel saw this clearly in its open meetings, as both industry and NRC representatives kept discussing whether or not the regulations had been met before and even instead of addressing the safety issues themselves. This is a dangerous trend but to a very considerable extent it is inevitable. One consequence of this method is the insistence on incorporating any safety idea into a regulation, before acting upon it. Writing a regulation and establishing its legality and workability, and abolishing or modifying regulations when appropriate are necessary and appropriate activities. However in this process both regulated and regulators may tend to forget the original objective of the regulation. We see a very useful role for the Commonwealth here, both in the licensing hearings and in continuous review subsequently. That is: to be certain the objective of public safety is not lost in the maze of procedure but is constantly used as the standard for measuring any action or regulation.

It appears to this panel that an independent review of crucial issues by a committee appointed by and responsible to the Commonwealth suggested in recommendation 6 above may be useful even when changes in regulations are not an issue. We envisage activities similar to those of the Advisory Committee on Reactor Safeguards (ACRS) of the Nuclear Regulatory Commission. In contrast to the ACRS, a state committee would be expected to act on matters specific to one particular nuclear facility rather than on generic issues, and primarily to address those areas over which the state has some jurisdiction. The committee members should not be full time state employees, but drawn from the larger pool of talent available in Massachussets and they should be recompensed for their

services in the same way as federal government advisors.

4. Operator Training

The Kemeny Commission emphasizes the human errors involved in the Three Mile Island accident. We note here that Dr. Herbert Diekamp, President of General Public Utilities, in a press statement commenting on the Kemeny report noted that the operators were trained as well as any in the industry. This statement is based on examination performance in the Nuclear Regulatory Commission examination.

It is, of course, conceivable that the operators and staff in the utility companies in Massachusetts are better trained and better qualified than those at Three Mile Island. It appears to us to be a role of the Commonwealth to ensure that this is true. Already, Massachusetts has a separate examination for power plant operators. The Department of Public Safety; which is in charge of this licensing, emphasized to us that accident prevention depends upon good training in steam systems and not specifically on nuclear matters. This is not extensively covered in the federal licensing process. While this distinction is to a large extent true, there is no analogue in a coal fired power plant to the necessity of keeping the core covered at all times. Before the accident at Three Mile Island, the Massachusetts operators were trained in unusual operating conditions but not in accident conditions. This is done on a computer simulator at Morris, Illinois for Pilgrim I and Vermont Yankee and at Keyesport, Pennsylvania for Yankee Rowe; Seabrook will have its own. The staff for Pilgrim are trained with their own computer code to reflect the particular plant they have.

Only since the accident at Three Mile Island have accident scenarios been placed on the simulators. Kemeny noted that failure of a pressure relief valve to reseat was only put on the Babcock and Wilcox simulator in April 1979, after the Three Mile Island Accident. The panel was informed that some of the accident sequences in the Rasmussen report (see Appendix II) are now on the General Electric simulator. We recommend that they all be on the simulator as soon as practical.

We note and applaud the fact that the American Nuclear Society is upgrading its recommendation on administrative control procedures, operator selection, and simulator training.

The nature of operator training in the neighboring states of Vermont and New Hampshire is unclear. we recommend that the Commonwealth make common cause with Vermont and New Hampshire, possibly with common testing procedures.

If, as we believe is the case, operator licensing in Massachusetts should continue, then the examiners themselves should be trained on the simulators, and the Commonwealth should appropriate funds for that purpose.

The Executive Office of Public Safety has drafted a bill to improve the state licensing procedure and we recommend that the Cabinet Task Force consider it seriously.

We recommend that the Executive Office of Public Safety consider making use of the large reservoir of independent talent in Massachusetts to help structure a rigorous testing procedure. Although our detailed recommendations are open for discussion, we suggest that this could include:

1. review of the 80 odd event tree sequences for serious accidents, such as those outlined in the Rasmussen report and review of the operator actions necessary in these cases.

2. simulator training on these and other accidents.

3. oral examination in which the operator explains safety to an independent expert.

5. Accident Prevention

The Kemeny Commission recommended that each utility company have a safety review group reporting directly to top management. The panel in its open meeting on November 19th, 1979 ascertained that both Boston Edison and the Yankee Atomic group have such review groups and details of their composition were given to us.

We recommend that these groups should each include one or two members with a wider range of expertise than normally found in the utility companies--such as a chemical engineer or physicist.

It is also important that the safety groups include among their membership some persons who derive less than 20% of their salary from the nuclear industry to assure there can be no reasonable doubt about their independence.

We are concerned that there be such safety groups for reactors close to Massachusetts borders: Vernon, Vt. and Seabrook, NH. Although these are now part of the Yankee Atomic group, the situation is in a state of flux, and we are concerned that if they become totally independent they may have too little internal expertise to draw on. The adequacy of these in house safety groups should be reviewed by the Cabinet Task Force as suggested in recommendation 6.

We suggest that the Commonwealth consider establishing a safety review committee of competent professionals able and willing to work hard. The prototype for this committee would be the Advisory Committee for Reactor Safeguards (ACRS) to the Nuclear Regulatory Commission. This committee has a high reputation. (recommendation 6)

We make a suggestion to the Cabinet Task Force not covered by the Kemeny Commission that they consider establishing an anonymous letter office associated with this review committee for safety questions.

We are fully aware of, and share, the deep and natural repugnance of Americans for anonymous letters which question the honesty and competence of individuals, private citizens, public officials or politicians. But in the matters of public safety we feel there might be some modification of this absolute stand. It should be made clear that any letter will be transcribed before being passed on; that no attempts will be made to locate the sender, but that the contents may be acknowledged in the public press. Of course, anyone violating the anonymity should be subject to appropriate civil penalties.

6. Radiation Monitoring

The Nuclear Regulatory Commission reports, especially NUREG 0558, indicate that the amount of radioactivity released to the public at Three Mile Island was not large, and it was released through filters out of a tall stack, and dispersed throughout the surrounding area.

As a result, the effects on public health are predicted to be miniscule. While this is very reassuring, we asked the following questions of the power plant operators in Massachusetts and of the agencies of the Commonwealth:

1. Is monitoring adequate to ensure understanding of the small releases of radiation in ordinary operation?

2. Is the monitoring adequate to make an ex post facto measurement of radiation dose in the event of an accident in which the releases are the size of those at Three Mile Island?

3. Is the monitoring adequate to measure radiation releases in real time, so that indications can be given of whether and how to evacuate?

On October 12, 1979 at an open meeting, the panel discussed these questions with representatives from the power companies, the NRC, the Department of Public Health, the Department of Environmental Quality Engineering, the Department of Public Safety and the Advisory Committee on Radiation Protection.

It seemed clear that most of the monitoring is geared to releases in ordinary operation and that a good job can be done under ordinary conditions.

In accident conditions the situation is likely to be less satisfactory. At Three Mile Island the stack gas monitor saturated, and as the incident progressed no one was able to tell how much radioactivity was being released. This could only be deduced from meteorological calculations and doses measured in the field. Although doses in the field are in the final analysis what we need to know, this leaves out an important piece of information which would be particularly useful for immediate prediction of hazard in the event of an accident to aid a decision about whether or not to order an evacuation.

We were told that it would take over a year to install equipment at Boston Edison Co. Pilgrim Reactor that would not saturate under accident conditions, i.e., instruments capable of indicating the levels of radiation that might be expected in the event of a serious accident. While we believe that this may be

true for a bureaucratically acceptable monitor--one which has been approved in advance (on paper), is fireproof, and so on--it seems to us that a temporary one that could measure the unusually large amounts of radioactivity in an accident could and should be available in a week. We urge that such a monitor be obtained promptly and that the Department of Public Health assure itself that this did take place.

Although the 2 nuclear plants in the Commonwealth are no better equipped to measure stack gas effluents during an accident than were those in the State of Pennsylvania, they have been better equipped to measure releases at distances remote from the plant in the event of an accident and the provisions have been recently improved. Detailed plans exist to use the results from ground base monitoring to quickly estimate the magnitude of the radioactivity release. Twice as many radioluminescent dosimeters are now in place around Pilgrim I as were around Three Mile Island. The company, the NRC and the state separately maintain dosimeters which are checked against each other.

When it comes to on-line monitoring the situation is less clear. No stations exist with continuous recording monitors. Monitoring depends upon radiation monitoring teams which can be sent out at the first sign of trouble.

This ensures that calibrated monitors are used, but it depends entirely on word of mouth for immediate feedback. In retrospect this worked at Three Mile Island, but we have some misgivings about whether the feedback is adequately prompt and whether radiation survey teams will be sent out early enough.

At Three Mile Island the operators realized there was trouble by 6 a.m., the radiation level in the containment went up to 25 mr/hr, more than fifty times normal, at 6:35 a.m., but not until 6:54 a.m. was a site emergency called and radiation monitoring teams dispatched. By this time the radiation level in the containment had risen to 400 mr/hr (it rose to 100,000 mr/hr [= 100 R/hr] by 7:20).

Although the nuclear engineers at Three Mile Island (incorrectly) measured a high dose of 40 R/hr in the containment at 6:55 a.m. and calculated a dose in Goldsborough of 40 R/hr due to the presence of noble gases, it was not until 7:48 a.m. that accurate measurements were made confirming a low dose. Part of the delay was in checking equipment--which could have been checked anytime in the previous 3 hours if the monitoring teams had been alerted.

Although we questioned the power company representatives, it is not clear to us that if an emergency occurs in Massachusetts there will be any more rapid response. We were not told of the existence of procedures which identify specific events that would

lead to:

1. Summoning a radiation survey team to the site

2. Checking instruments and ensuring that a vehicle is available

3. Sending out radiation survey teams

We recommend that this aspect of emergency readiness be clarified and improved. A suggestion was made to us that a stack gas monitor be installed to read directly into a state building, so that there is immediate indication of problems. Such a readout may be useless unless it has well defined points which trigger a response. The power companies argue that the information supplied could be misused by an overly exuberant public relations official. Yet it would be a safeguard against failure to obtain adequate information from the reactor operators. This might occur, for example, if sabotage and terrorism were the cause of the accident. We urge that this question be re-examined by the Cabinet Task Force.

At the present time, the Department of Public Health is responsible for emergency monitoring while the Department of Environmental Quality Engineering reads some of the thermoluminescent dosimeters for the Department of Public Health. This we believe to be a sensible and proper arrangement. The Department of Public Health has monitored radiation devices for many years and has expertise and staff who routinely monitor radiation sources such as medical x-ray equipment, and thus their skills and equipment are kept up-to-date. All of their staff is available in any emergency.

The reasons for the assignment of this responsibility to the Department of Public Health may not be obvious to the executive and legislature in the future and we recommend that the Department of Public Health be formally designated the lead agency to avoid possible confusion.

We note that there are a number of personnel throughout the state who have training in radiation monitoring who can be called upon, some of whom form the NIAT teams discussed earlier. However they may not be present during the critical early stages of an accident.

We note that in a major nuclear accident, the total quantity of the noble gases and also a large fraction of the iodine, tellerium or cesium present as fission products in the fuel might be released. It is these last three elements that account for estimates of large possible hazards to public health, since they are absorbed by the human body and iodine concentrates in the

thyroid. Although it is reassuring that at Three Mile Island only 15 curies out of 30 million curies of iodine present were released, (because of chemical plate-out and because of filters) it is possible that in a major accident such filtering processes would be rapidly saturated.

The iodine which has a half life of 8 days can be an important contributor to the short term hazard and the possibility of its release would dominate any evacuation plans. This is made very clear in a report for the Council on Environmental Quality by Dr Jan Beyea of Princeton, and in a 1978 NRC report (NUREG CR-1131) by Aldrich et al of Sandia laboratories.

Tellerium and cesium are particulates and to be released require evaporation of core products. Their release is less likely than the iodine releases but they are also important and are a longer term hazard.

For purposes of judging evacuation plans, therefore, a rapid measurement of iodine and particulate releases seems to be very important. This is not made clear in the N.R.C. guides on emergency planning. There are presently no adequate monitors which distinguish these releases, although we were told that they are forthcoming, and the important distinction between releases with and without particulates is not included in any of the emergency plans presented to us. We recommend that all personnel involved with measurement of radiation, and with possible evacuation, learn and understand the distinction between the effects of noble gas release, iodine release and particulate release.

Two mitigating features are worth noting. First, if people are exposed to iodine, some of the effects can be reduced by taking medication--such as potassium iodide--that blocks the uptake of iodine in the thyroid. The Commonwealth should ensure that in the case of accident it has access to an adequate supply of such medicine within 24 hours.

Second, the cesium and tellurium release is a long term hazard for which prompt evacuation is not essential. Evacuation and/or decontamination subsequent to the accident can prudently be postponed until radioactivity levels are actually measured.

7. Pilgrim I Operating Staff Radiation Exposures

There has been some discussion about unusual levels of exposure of workers to radiation at Pilgrim I.

Cobalt steel in a reactor vessel becomes radioactive as a result of neutron bombardment. Some of it leaches into the reactor coolant system and is conveyed to all parts of the reactor. This radioactivity should be removed by filters, but it appears that these filters were clogged in the first year of operation of Pilgrim I and radioactive cobalt, half life of 10 years, was deposited on many parts of the reactor coolant system. This produced unnecessary radiation exposure to the reactor staff. This was clearly a major error on the part of the Boston Edison Company.

A graduate student at Harvard, Mr. Huffman, has measured radiation at several places near the reactor and confirms that indeed it is dominated by cobalt 60. We are informed that over the past two years a massive effort has been in progress to identify, replace, or shield radioactive piping.

The occupational radiation dose, added up over all employees, was 2800 person rems in 1977, and this fell to 800 person rems in 1979. The original high radiation doses were a sign of sloppy management. However the doses have remained within the standards recommended by the International Committee on Radiological Protection and have now been reduced. We urge continued efforts in this direction. In addition to cleaning and replacing pipes, we urge that the operating staff continue to pay attention to the level of their own exposure to radiation. Staff members can reduce their own exposure levels, by careful avoidance of places with high radiation levels but Boston Edison must provide the framework in which this can take place.

8. Accident Management

At Three Mile Island an incident was allowed to escalate into an accident. Everyone seems to agree that operator training is the primary cure and improved plant control design a secondary cure; we address at this time a third issue of responsibility during the accident.

Mr. Olson, of the Department of Public Safety, told us that the law is clear. General Law 146 of the Commonwealth states that the shift engineer has complete responsibility and in his absence the shift supervisor, and then the most senior operator takes over. If they think it is appropriate, they can ask for anyone present to leave the control room.

If an accident develops, additional personnel are sent to a technical support center, separate from the control room. When radiation is released, an emergency control center is established and it is to this center that radiation monitoring teams report and where a Department of Public Health official goes.

We are concerned that not everyone is clear on the chain of authority. In view of what happened at Three Mile Island we believe this can be a very serious problem. We understand the authority and responsibility to be as follows.

To operate the reactor the chief engineer or his delegate as above. To measure radiation: whoever is in charge at the emergency control center; to assess radiation and whether to recommend an evacuation: the Department of Public Health through its representaive at the emergency control center. To carry out an evacuation: Civil Defense from an emergency control center in town.

A reactor operator at Three Mile Island decided to release radioactive gas out of a storage tank at 9 a.m. on Friday, March 30th to prevent a more serious situation from developing; it was his authority to do so, but he did not inform those monitoring radiation to expect a sudden increase, causing unnecessary alarm. If a reactor operator in Massachusetts decides to initiate such a release he should discuss it with the representative of the Department of Public Health and to give as much warning as possible to avoid confusion, although he is not required to do so.

We recommend that procedure relative to chain of command during an accident be clarified and that it be made known to all who might be involved. In our meeting of November 19th we were not convinced that everyone agreed to who has authority for what. In our view this is inexcuseable and we call it to the attention of the Cabinet Task Force.

It appears that at Three Mile Island the operators were

reluctant to call in help. In our meeting of November 19th it became clear that most operators would be so reluctant--indeed it is a natural human characteristic which can be found in other situations. It was represented to us that after a transient the operators must first bring the reactor to a stable condition before reporting the situation, that the solution to the operator errors at Three Mile Island is better operator training and that after such training, operator judgement will be as good as that of a supervisor. We are reluctant to accept this.

That 5 operators, in a time of stress should all make the same incorrect diagnosis for 2 1/4 hours does not surprize us since they were working together in the same situation. It is possible, although far from certain, that another person coming in fresh to the situation and possibly with a different training could find their error.

We find it strange that an operator can turn off an emergency system (the HPCI) without immediately calling his supervisor, or maybe his supervisor being called automatically. This type of practice needs reexamination and we recommend a procedure whereby supervisors would be immediately called without judgement on the part of the operator under certain circumstances.

9. Emergency Plans

The panel met with the Civil Defense Director and his staff, together with representatives of Boston Edison Company, the Department of Public Health and the Department of Public Safety, at the Civil Defense headquarters in Framingham, Mass. on 16th of July and with representatives of the power companies, the Civil Defense Director, the local communities, NRC and the state agencies (Department of Public Health, Department of Environmental Quality Engineering and Civil Defense) on Friday, October 12.

On brief examination it appears that Massachusetts has a good general emergency plan which has been well tested. There have been four recent incidents in the Commonwealth involving evacuation. These are:

1. Blizzard in the Boston area February 6 and 7 1978

2. Hurricane Belle in Cape Cod and the Islands, Aug. 9 and 10, 1976

3. Chlorine tank car overturned in Western Massachusetts, March 9,1966

4. Propane tank accident at Tewksbury, Feb 9,1972

During Hurricane Belle, 17,000 people were evacuated within 4 hours from the initial decision. Prompt evacuation after hurricane warnings has saved many lives in the U.S. in the past.

Although the situations are similar, there are important differences. In the case of hurricanes there is advanced warning of the storm and the decision to evacuate will not normally catch people unaware. Of course, this need not happen in a nuclear incident. It is reasonable to expect at least 2 hours notice of a major radiation release, and limited windspeeds can provide more time. At Plymouth the local authorities feel they can alert everyone within 10 miles within one hour, with a street by street, home by home, notification. The vast majority of people would be notified within a shorter time.

This suggests that evacuation can be complete before high radiation doses occur, provided that the initial warnings based either on radiological measurements or reactor operation from the reactor staff are prompt and provided that people are adequately informed in advance about what action to take.

There is a problem with evacuation in nuclear incidents which we feel has not been adequately addressed; psychological concern for nuclear events is far greater than that for other events of similar calculated risk. We have only to compare the casual media coverage of the Canadian evacuation of 250,000 from a region of a

spilled chlorine tank car to the coverage of the Three Mile Island incident to know that there will be more trauma in the nuclear incident. This may hinder evacuation.

The panel asked for detailed reports on each of these incidents with a discussion of the successes and failures of the plans. We were disappointed that we only got press summaries of some of them, although one was more thoroughly reviewed.

The Cabinet Task Force could ask that the Civil Defense authorities carry out postmortems on each evacuation incident and on the practice drills and we recommend that the power companies be asked to include these post mortem reports im personnel training. Although they can then be accused of merely being ready to fight the last war, that is better than not being ready to fight a war at all.

In general we found the written emergency plans to be incomplete and lacking in detail. Our confidence that they will be adequate stems more from oral discussion than from the written submissions. Since personnel may change and can only be expected to read the written words and not the minds of their predecessors, written plans are important.

We have been informed that evacuation plans are now being rewritten to integrate all aspects of emergency planning in one document, listing clearly the assigned responsiblities. We hope that this plan will answer these concerns. The Cabinet Task Force should satisfy itself that this document is complete.

10. Review of the Communications in the Event of an Accident.

One of the major problems in the Three Mile Island accident was informing the public. There were failures by the power company, the Nuclear Regulatory Commission and of the press and media generally.

Power company press releases were not sufficiently detailed. Press statements were made which appeared to be contradicted by NRC officials on the spot and in the Bethesda headquarters, and there was a lack of understanding by the press, radio, and TV.

In retrospect the official press releases of the Nuclear Regulatory Commission were good. They were brief, precise, and accurate. But they were hard to obtain. The public would have been well served if the press had printed them verbatim. One of the recommendations, then, of this panel is that the press be requested, in an emergency, to print official press releases verbatim (and make whatever additional comments they choose to make separately).

Also, it is important that the power company have a procedure for giving adequate press releases and not merely leave this to the Nuclear Regulatory Commission since the power company is responsible for the plant, not the Nuclear Regulatory Commission.

The Kemeny Commission recommended that in the event of an accident, the utility company should continue to have responsibility for operation and for dissemination of information to the public. In principle we agree, but have some qualms about the ability of the utility company to properly inform the public. Accordingly we recommend that the responsibilties of public communications be handled by persons more technically qualified than the usual public relations staff. This person or persons should be technically competent, have access to all information, know the special skills of each member of the Nuclear Safety Advisory Center set up by the Electric Power Reseach Institute, and develop an ongoing rapport with the press.

In the days subsequent to the Three Mile Island accident, the issue that caused the most confusion and panic was that of the gas bubble (or bubbles) in the reactor vessel.

At about 5 p.m. on Wednesday, March 28, the reactor was repressurized and shortly thereafter the reactor coolant pumps were restarted. The reactor pressure did not rise instantaneously as water was added showing the presence of a gas bubble. The gas was slowly bled from the relief valve at the top of the pressurizer, but even when all available gas had been bled, measurements of the change of pressure with amount of liquid showed a residual bubble.

On Thursday, March 29, the chairman of the Nuclear Regulatory

Commission, Dr. Joseph Hendrie, asked a series of reasonable and proper questions. What is the gas? Could it be hydrogen? Could it be an explosive mixture of hydrogen and oxygen, disassociated from water by radioactive bombardment? We now know that it could not have been hydrogen and oxygen, but do not know whether the gas was hydrogen or steam or in what proportions.

The NRC staff, under Dr. Roger Mattson, made calculations, and said that the bubble could be composed of hydrogen and oxygen. This led to consideration of the possibility of an explosion in the reactor vessel, large enough to crack the containment vessel. There was a flurry of activity at NRC which got their contractors to calculate ab initio the probability of each of these.

Not until Sunday, April 1, was it clear to the NRC staff that they had made a mistake in the calculation; that a mixture of hydrogen and oxygen could not have been present; that if it had ignition was in any case unlikely, and that an explosion consuming all the gas would not have cracked the containment. In subsequent congressional hearings, the NRC staff and in particular Dr. Roger Mattson apologized for the error. Meanwhile on Friday, March 30, the Governor of Pennsylvania and his staff were in confusion, not knowing what to do or whether to order an evacuation. Some citizens were close to panic.

In retrospect also, an examination of the calculations in the NRC report of Aldrich et al already referred to, which was already available in 1978, suggest that even if a complete core meltown, with containment violation, had occurred on Friday March 30th, no immediate evacuation beyond 2 miles would have been called for. The short lived radioactive elements had decayed, and since Three Mile Island II had only operated at full power for three months, the long lived ones had not built up.

What should we hope for in these circumstances? We want to encourage those we charge with protecting us to ask reasonable and proper questions. The answers will not always be accurate. But there were men at Babcock and Wilcox, at the Electric Power Research Institute and Metropolitan Edison Co. who had thought through the problems before and knew the right answers. Some others steadfastly maintained (correctly) that there was no problem. Moreover some of the NRC contractors knew the answers.

This panel does not know whether, how soon, and in what way the right answer was given to NRC by Babcock and Wilcox and the Electric Power Research Institute. The answer may have been too brief and without the backup necessary to be believed or it may have reached an overly tired or pugnacious NRC staffer. It seems to us, however, that in these days of telephones, TV and jet aircraft, that 3 days is too long a time for this and that there was a communications foul-up of major proportions. The primary responsibility must lie with the utility company, the president of

Metropolitan Edison Co., who was in charge of the reactor and did not ensure that technical questions got adequate technical answers including sufficient detail to ensure acceptance.

11. Transportation of Radioactive Materials

There are several "levels" of radioactive waste which must be shipped:

1. High level waste--mostly spent fuel from reactors which is to a large extent a future problem.

2. Low level waste--e.g. workers' clothing with small amounts of radioactivity.

3. Transuranic wastes where the level is low but the half-lives are long.

Radioactive sources for medical and industrial use are also shipped in the Commonwealth and have characteristics similar to 2 and 3 above. The rules for transportation of these sources are, and probably should continue to be, the same as those for transportation of waste.

The high level wastes are the ones which represent a potential major hazard. These wastes contain the fission products and the transuranic elements from fission.

High level shipments that can be foreseen in and through the Commonwealth of Massachusetts are of complete spent fuel rods. These will contain all the waste inside the zircalloy tubes under normal circumstances. The spent fuel will not move from the reactor site for many months--or even years--after removal from the reactor, and much of the short lived radioactivity (particularly the gaseous iodine 131 and xenon) will have decayed. However the regulations should anticipate that if there is a reactor accident where the fuel rods are cracked open as at Three Mile Island, earlier transportation may be desireable. In the event of a transportation accident, most of the material may be expected to stay in place, with a possible exception of cesium isotopes. Transfer of radioactivity to the biosphere might take place as a result of dissolving in water, or airborne dispersion by means of an (externally caused) explosion and fire.

To guard against such events, unlikely though they may be, the high level wastes, including fuel rods, must be transported in specially designed containers which are not likely to break in the event of collisions, dropping, immersion in water or fire. The specific criteria are spelled out in rules of the U.S. Department of Transportation.

The U.S. Department of Transportation rules also specify that the shipment shall travel by a route that avoids population centers as much as possible. This is an obvious rule to avoid problems in the event of an accident. The problems could be of two types: a

real spillage--an event considered to be very unlikely; or an accident where the truck is destroyed, but the shipping cask remains intact. It is important to realize that even in the latter case, there will be considerable disturbance before it is ascertained that no radioactivity is spilled. Thus in either case it is desirable to take a route which minimizes the accident probability. More than one designated route is necessary to allow for closed roads and so forth.

At the present time, the Department of Public Health is informed of every shipment involving nuclear fuel and medium or high level wastes (but not including the numerous shipments of low level medical wastes.) In the event of an accident it is then prepared to send the appropriate personnel and monitoring equipment to check for spillage of radioactivity.

A public hearing of the U.S. Department of Transportation has been scheduled in early 1980 to discuss this matter further. It seems likely that the preference for direct routings will be confirmed. Some shipments (from the University of Lowell and MIT reactors) will probably be made within a year thereafter.

A question about direct routings arises because the Massachusetts Turnpike is privately owned. The Turnpike Authority feels an obligation to bondholders not to allow any cargo to travel along the Turnpike for which there is not adequate liability insurance.

About 5 years ago, subsequent to the licensing hearings on Maine Yankee Atomic Power Plant, the Maine Turnpike agreed to allow shipments of waste on a regular basis along the Maine Turnpike from Brunswick to Kittery. This was at the request of the state, made through its Attorney General and with an understanding that the state would provide all necessary police escort and reimburse the turnpike authority for any clean up expenses and any lost revenue in case of an accident. This was based on a business judgement; not only is the frequency of road accidents on the Turnpike less than on city roads, the clean up costs in the countryside are less than in a city.

About five years ago also, the New Hampshire Turnpike made a similar arrangement, and Dr. Alan Altshuller, then Secretary of Transportation in the Commonwealth of Massachusetts made representations to the Massachusetts Turnpike Authority. We have no record of the result, but in 1975, MIT had to ship spent fuel from its reactor along route 20 instead of the preferred route, the Massachusetts Turnpike. In 1975, the committee set up by Governor Sargent, and reporting to Governor Dukakis (the RathJens committee) also recommended that the Turnpike be used when it is the most direct route.

Mr. Driscoll of the Massachussets Turnpike Authority raised the question of liability to bondholders both in writing and orally at our December 14th meeting and commented that his insurance costs would increase were radioactive shipments to be permitted. We have sympathy with the problems of the Turnpike Authority, but are concerned that it has no positive suggestions about how these concerns might be resolved. The Massachussets Turnpike Authority has some obligation to the residents of the Commonwealth in return for the undertaking of the legislature not to permit a competing east west freeway.

While the Price-Anderson Act specifies that there shall be $560 million in insurance to cover accidents to life, limb and loss of property. Whether lost revenues would be recovered will be determined in the courts as various claims resulting from the accident at Three Mile Island are litigated. A question has been raised by the Massachussets Turnpike Authority and the Massachusetts Department of Transportation, whether $560 million is enough to cover costs of a severe transportatoion accident.. The accident with the most severe consequences would probably be one resulting from sabotage, with an explosive fragmentation of the load. It seems probable that this would be less severe than the most serious reactor accident since only a few percent of the total fuel inventory would be carried at any one time, and then usually only many years after removal from the reactor. Issues such as this, should be raised in the forthcoming hearing of the U.S. Department of Transportation.

Most of the above discussion is specifically relevant to the transportation of high level wastes. In our view the same criterion, avoiding populated centers when possible, could well apply to all radioactive material, including radioactive sources for use in medicine and industry.

It is important that at the forthcoming hearing of the U.S.Department of Transportation, that the agencies of Massachussets should speak with a united voice if possible and if not that each has a thorough understanding of the concerns of all other state agencies involved. At our December 14 meeting, Dr. Parker for the Department of Public Health,Ms Murray for the Department of Transportation, and Mr Driscoll for the Massachussets Turnpike Authority agreed to try to develop a common approach.

We recommend that a listing of these recommended routes be kept in the appropriate state offices to avoid the cofusion now created by the circulation of inaccurate private lists.

12. Waste Disposal in the Commonwealth

A large amount of radioactive waste is generated in the Commonwealth; although the focus is primarily on the waste generated by the power plants, there is a significant amount generated by hospitals and research laboratories.

The classification of waste by radioactivity--high, medium, and low-- corresponds approximately to a classification by half life. The medium and low level wastes are usually fission products of half lives less than 20 years, whereas the high level wastes contain also some transuranic elements with half-lives of thousands of years.

At the moment, the high level waste is retained, in fuel rods on the site of each power reactor (the fuel of the research reactors at MIT and Lowell University are transported out of state). Although some of the low level waste is kept on reactor site for a while, most is transported to a federal repository, and all the medical and research waste is so transported.

Originally industry planned to remove the fuel to a central reprocessing plant to extract residual uranium and useful plutonium, and to leave separated wastes for ultimate burial. The desire to limit the free availability of plutonium, and financial constraints have led the U.S. Government to forego this procedure until adequate safeguards against theft of plutonium and international guarantees against proliferation of nuclear weapons are available. Until there is reprocessing or provision for permanent disposal, the fuel rods will probably not be removed from the reactor spent fuel pits and this method of storage will continue to be permitted for as long as the reactor site remains operational.

Since this was not the scenario planned for when the plants were built we recommend the Cabinet Task Force satisfy itself that adequate attention has been given to the safety implications of the change in plans.

The relationships between Massachussets and other states would be much improved if Massachussets had its own storage site located within the state or region for low level waste, which are mostly of half lives less than 100 years. Accordingly we concur in a recommendation of the Advisory Council on Radiation Protection, that the Commonwealth explore, probably in concert with neighbouring states, the setting up such a repository. This could be done in conjunction with toxic waste disposal which is now being considered by the Department of Environmental Affairs.

13. Suitability of Plymouth as a Site for Pilgrim II

One obvious question which is raised as a result of the accident at Three Mile Island is whether Plymouth is a suitable site for a second reactor. The proposal to build this plant was made several years ago, and although a construction permit has not yet been issued by the Nuclear Regulatory Commission, the licensing hearings has already been the longest licensing hearings in history.

Many issues are brought out clearly by the "Proposed findings of fact and conclusions of law" submitted by the Attorney General's office of the Commonwealth of Massachussets on November 5th 1979.

These issues are:

I. Financial qualifications of Boston Edison Co. to construct a power plant.

II. The adequacy of the quality assurance of the Bechtel Corporaton and of Boston Edison Co.

III. The need for power.

IV. Alternative energy sources.

V. Alternative sites.

VI. Risks of theft or sabotage.

Issues on which no testimony has been submitted:

VII. Emergency planning.

VIII. Cost benefit analyses.

IX. Safety issues subsequent to Three Mile Island. (The numbering I-VI is that of the Attorney General, and VII-IX is ours.)

The panel feels a duty to comment on those aspects which have a bearing on safety.

On issue I, the Attorney General noted that the Boston Edison Company does not have cash in hand to complete Pilgrim II, and depends with some optimism on cash becoming available. The safety concern is that a company which is short of cash might be tempted to cut corners and to rush to commence operations before it is proper.

We recommend that the Commonwealth exercise due vigilence, probably through the Department of Public Safety, to ensure that no corners are cut if Pilgrim II is licensed. The Cabinet Task Force should review the suggestion of the Department of Public Safety

that they intensify their inspection efforts in this eventuality.

The issue II on quality assurance is much more serious. The past performance of Bechtel Corporation and of Boston Edison Company which between them constructed Pilgrim I, must be considered in speculation about their possible future performance for Pilgrim II.

There is no doubt that both Bechtel and Boston Edison Company made mistakes.

One of these we noted in section 10 on Radiation at Pilgrim I. There have been several violations of regulations, for one of which the Nuclear Regulatory Commission fined Boston Edison Company $12,000.

We hope that both Bechtel and Boston Edison have learned from their mistakes. If Pilgrim II is licensed this should be watched carefully by the Department of Public Safety.

Issue III the need for power, and issue IV alternative energy sources, have in our view little direct impact on the current safety of nuclear power and we chose not to discuss them. To satisfactorily discuss these questions we would have to consider the growth of electricity consumption both in the Boston Edison region and in the whole New England power pool (NEPOOL). We would have to consider the desireability of replacing imported oil, the possiblity of importing hydroelectric power from Quebec and whether and how soon renewable energy sources such as solar power and wood can be used. We would also have to take into account the safety and health effects of each of alternatives.

Issue V on alternitave sites and issue VII on emergency planning are very much the direct concerns of this panel. We have in section 9 of this report discussed the emergency planning for Pilgrim I. Pilgrim II is planned to have twice the power of Pilgrim I.

Whether another site would be preferable for Pilgrim II is a more complex question. There are many aspects of site selection and the possibilty of a severe accident is only one of them, although it is the one we consider here. Would the choice of another site be significantly better in the event of an accident?

It was already clear from a close study of appendix VI of Rasmussen's report, and is underlined by the more recent work of Beyea and of Aldrich referred to earlier, that in the event of the most severe accident, there would be fewer fatalities around some sites than others. The reactors at Indian Point N.Y. and Zion, Illinois are close enough to the population centers of New York and Chicago respectively that an accident during a northerly wind could cause many more than the number of latent cancers calculated by

Rasmussen for an average of the 50 reactor sites used in 1974. On the other hand, the nearest population center to Maine Yankee is Bath, and even with a northeast wind the latent cancer rate would be 10 times less than average.

The Plymouth site lies inbetween these extremes, and the results of Rasmussen apply almost directly to it. The principal concern is the large population that lies to the northwest. A great deal of attention has been focused recently on the question of siting as a safety issue. We urge the Cabinet Task Force to follow the discussin closely.

Issue VIII has no direct safety coneauence, and issue IX is discussed extensively throughout the rest of this report.

The question of sabotage and theft of nuclear materials which is the substance of issue VI, remains very important. The Rathjens Committee of a few years ago made recommendations on these subjects, which we call to the attention of the Cabinet Task Force and the Utility companies. Professor Rathjens testified on this subject at the Pilgrim II licensing hearing. We were pleased to be told that the Department of Public Health has studied these questions, and has been briefed, in secrecy, by the Nuclear Regulatory Commission. We suggest that this also be reviewed by some members of the Cabinet Task Force.

Appendix I. The Three Mile Island Accident

To determine which state actions are now appropriate it is useful to follow in some detail the course of events between 4 a.m. on Wednesday, March 28, 1979 and the following Sunday, April 1, 1979. There are several voluminous reports on this, and we condense from these a simplified account. This summary is intended not to replace these more comprehensive and, therefore, more accurate accounts, but to place in clear language the problems as they arose so that the reader of this report can see the perspective of the recommendations.

Three Mile Island is 20 miles south of Harrisburg in the middle of the Susquehanna River. Two nuclear power plants are located there, Three Mile Island 1 and Three Mile Island 2. The nuclear steam generating systems were in each case designed by Babcock and Wilcox Co. The reactors are pressurized water reactors and the relevant parts are shown in a simplified diagram in figure 1.

The nuclear reactor core consists of about 30,000 fuel rods about 1/2 inch in diameter and 16 feet long; each rod is a tube of zirconium alloy (zircalloy) filled with many ceramic pellets of uranium oxide, 1/2 inch in length. During operation nuclear fission takes place within the fuel rods, releasing energy within them. The zircalloy tubes are filled with helium under pressure and sealed to contain the radioactivity. The whole is surrounded by water. Neutrons from the nuclear fission escape from their tubes, are slowed down by collision with the water, and the slow neutrons reenter the tubes where most start a new fission in new uranium nuclei.

The fuel rods heat up as a result of the nuclear reactions producing a total power of 2772 megawatts maximum and water flowing around the rods is heated by them to 600 F; the water is pressurized to 2155 pounds per square inch (psi) (150 atmospheres) to prevent boiling. The water is pumped to a heat exchanger, called a once through steam generator (OTSG) where much of the heat in the water is removed. The water then passes back to the bottom of the reactor vessel. There are two such reactor cooling loops, each with 2 pumps. All of this is inside a concrete containment vessel designed to contain any radioactivity that would be released if the barriers of the zircalloy fuel rod and the reactor cooling system were to break.

Steam is produced in the steam generators, where the water is at a lower pressure of 900 psi, and passed to the turbine, where it is used to generate electricity. The steam is condensed back to water in the condenser, and flows through the condensate pumps and the feedwater pumps back to the steam generator. These two "secondary" loops pass through a penetration in the containment vessel to the turbine room.

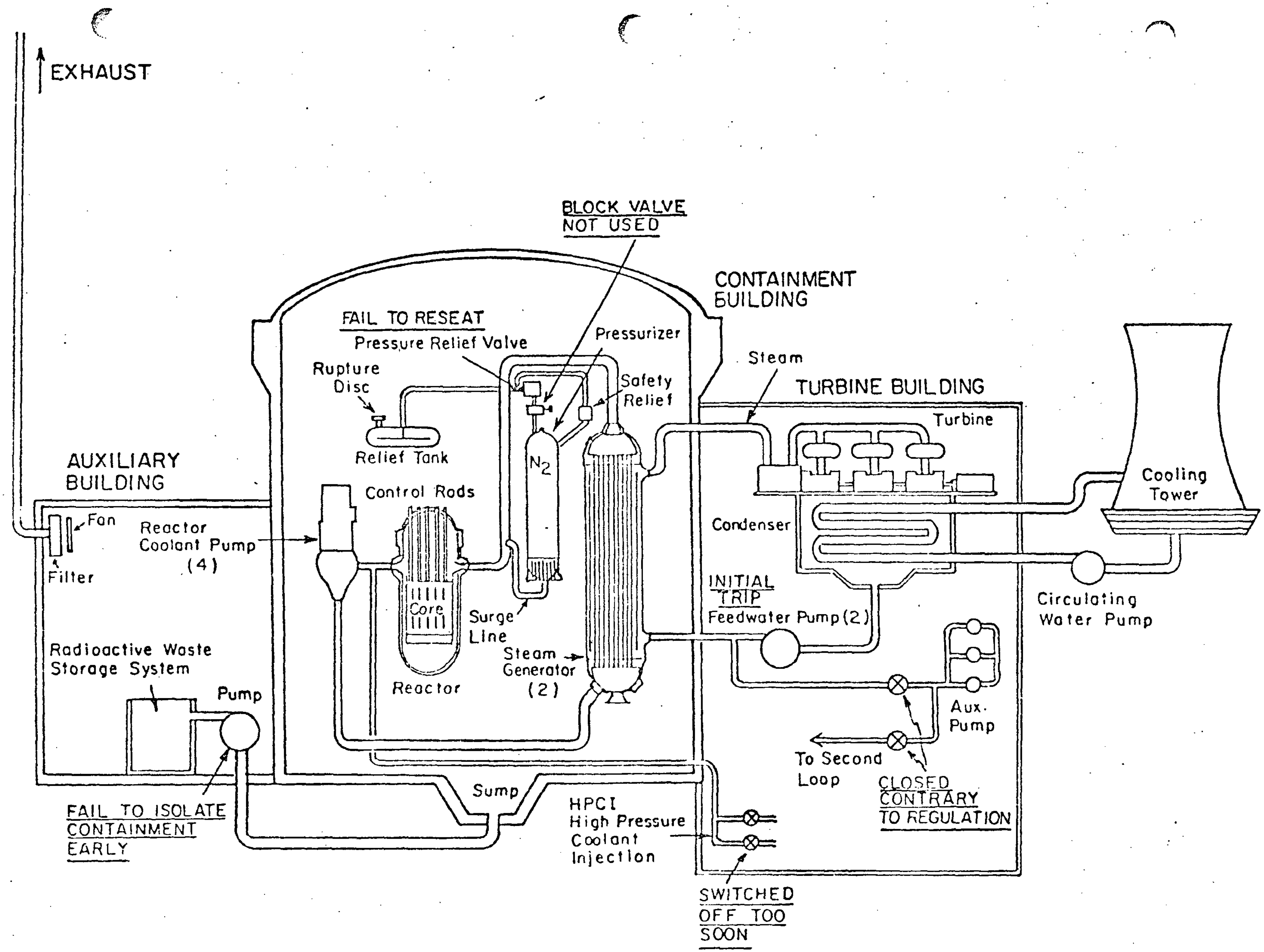

EXHAUST
BLOCK VALVE NOT USED
CONTAINMENT BUILDING
FAIL TO RESEAT
Pressure Relief Valve
Pressurizer
Rupture Disc
Safety Relief
Steam
TURBINE BUILDING
Turbine
Relief Tank
N_2
AUXILIARY BUILDING
Control Rods
Cooling Tower
Fan
Reactor Coolant Pump (4)
Condenser
Filter
INITIAL TRIP
Feedwater Pump (2)
Circulating Water Pump
Core
Surge Line
Radioactive Waste Storage System
Steam Generator (2)
Reactor
Pump
Aux. Pump
To Second Loop
CLOSED CONTRARY TO REGULATION
Sump
HPCI High Pressure Coolant Injection
FAIL TO ISOLATE CONTAINMENT EARLY
SWITCHED OFF TOO SOON

Figure 1

Various safety systems exist to insure that the radioactivity always stays within the fuel rods; this is done by ensuring that the generated heat is always removed and the fuel does not crack or melt. To shutdown the nuclear reaction (SCRAM the reactor) boron shutdown rods can be rapidly inserted into the reactor core; this can happen either manually or automatically.

Although the nuclear reaction can be (and was at Three Mile Island) shut down in less than a second, the radioactive fission products continue to provide some heat (decay heat). Immediately after shutdown this is almost 8% of full power or 200 megawatts at Three Mile Island.

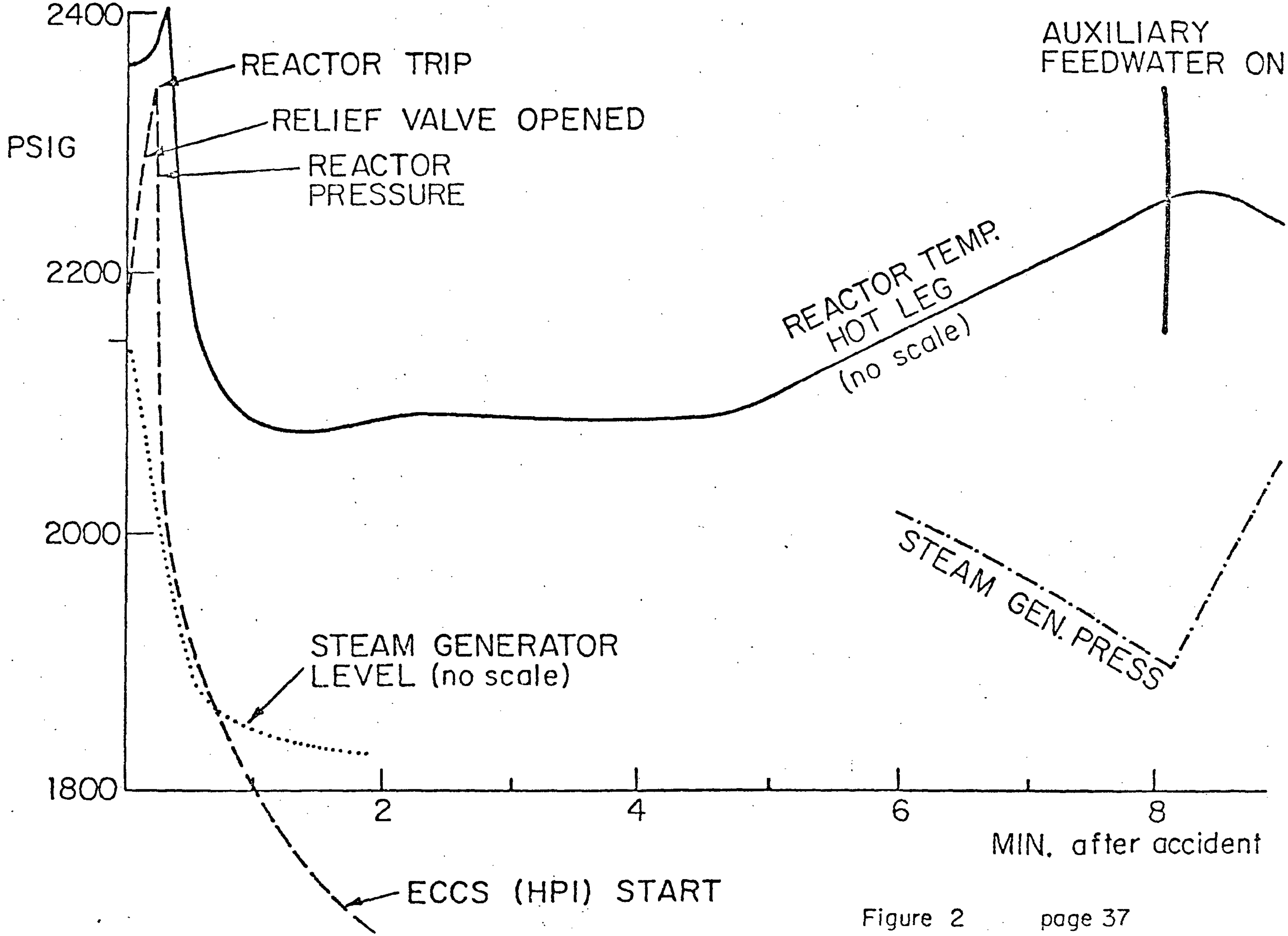
If the main feedwater pumps fail, there are 3 auxiliary pumps to provide water to the steam generators. Two are electrically controlled, and one is operated by the steam turbine. If the reactor pressure gets too high, there are pressure relief valves; one can be controlled from outside the containment (electromagnetically operated relief valve EMOV) and two others which cannot be operated from outside the containment vessel are set at a slightly higher pressure in case the first fails to operate.

If the water in the reactor evaporates so that cooling slows down, a number of emergency core cooling devices exist to put water back in the core. This water is borated to ensure that the nuclear reaction ceases.

On March 28, 1979, just before 4:00 a.m., Unit No. 2 at Three Mile Island was operating at 97% of full power, under automatic control and had been for three weeks. Three of the operating crew of 4, the shift foreman and two operators, were engaged in transferring resin from a condensate polisher tank to a regeneration tank, and produced a block in the transfer line.

Probably as a result of action to clear the resin blockage, the plant suffered a total loss of feedwater, which automatically triggered a turbine trip, (i.e. a switch off of the turbine) at 04:00 and 37 seconds. All emergency feedwater pumps started, as they were supposed to do and this starting was noticed by the operator. The reactor continued to operate at full power, and since the heat was no longer being taken away as rapidly as normal, the reactor operating temperature and pressure rose. So far, the response to the transient was as anticipated.

The subsequent behavior can be seen most readily by examination of several figures and tables. In Figure 2 are the outputs of several strip chart recorders during the first 10 minutes after the transient. In figure 3 these and other recorders are shown over a period of 16 hours, and both figures show times of crucial events.



2400
2200
2000
1800
PSIG
REACTOR TRIP
RELIEF VALVE OPENED
REACTOR
PRESSURE
AUXILIARY
FEEDWATER ON
REACTOR TEMP.
HOT LEG
(no scale)
STEAM GEN. PRESS
STEAM GENERATOR
LEVEL (no scale)
2
4
6
8
MIN. after accident
ECCS (HPI) START

Figure 2

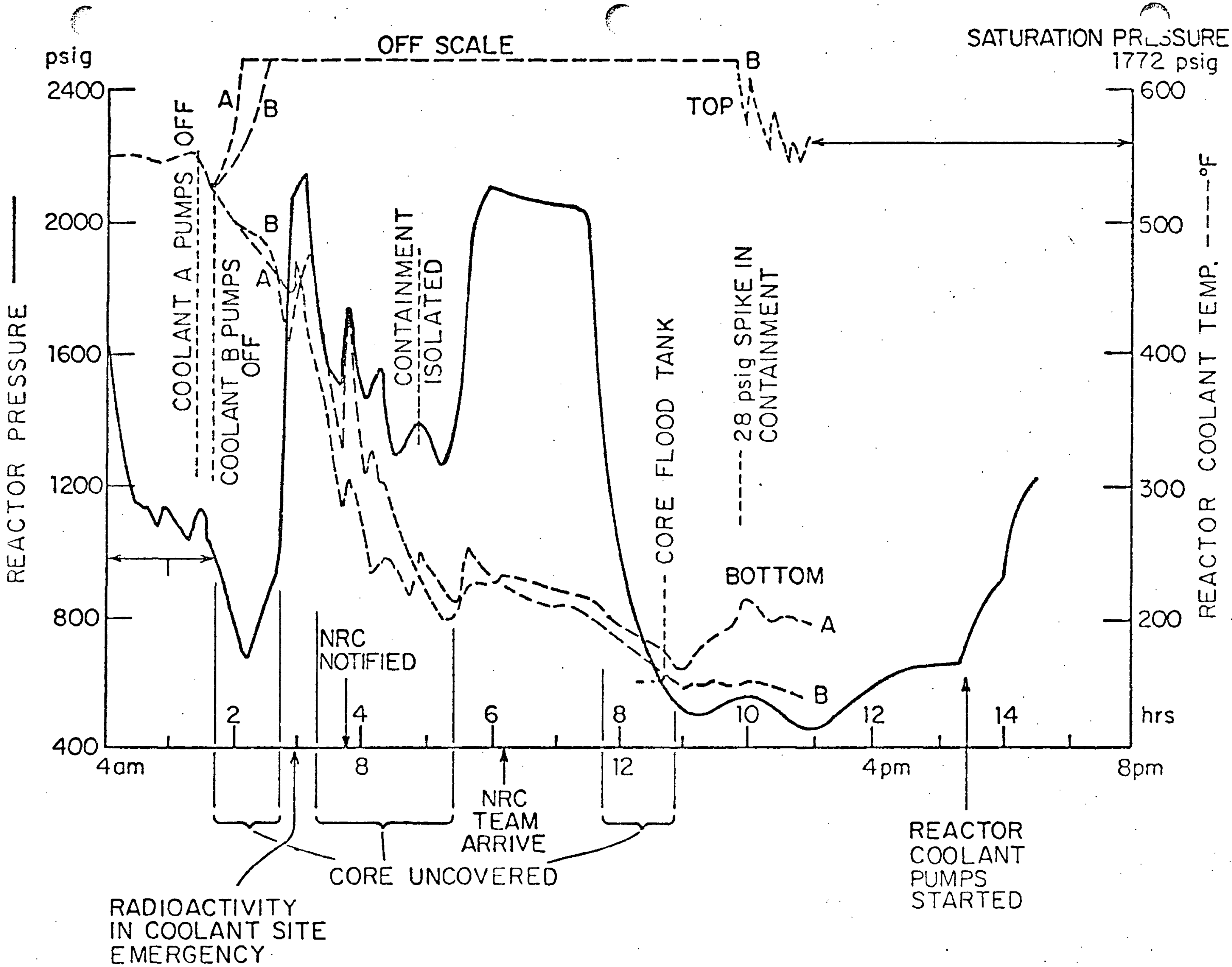


Figure 3 page 37

Approximately 8 seconds after the accident, the electromagnetically operated pressure relief valve (EMOV) opened, at a set point of 2255 psi to relieve the pressure. The reactor system pressure continued to rise, until the set point of 2300 psi was reached when the reactor tripped according to design and the control rods were injected, stopping the nuclear reaction.

We pause and note some problems that had developed. For safety, it would have been desireable (and possible) to have the reactor trip in the event of feedwater interruption. Were this the case, in many incidents the relief valve would not need to operate (although in this particular incident it would have).

After the reactor tripped, reactor system temperature fell; the pressure fell as steam was vented through the relief valve. The relief valve was supposed to close again as the pressure fell to 2100 psi (13 seconds after the accident) but it failed to do so. This failure was unnoticed by the operating crew, because falling temperature also leads to a drop in pressure (although a slower drop).

The reactor pressure continued to fall and when it reached 1600 psi (after 2 minutes) emergency pumps (high pressure core injection or HPCI) started to inject more water into the reactor. If this had been allowed to continue the reactor would be intact--and probably operating--today.

Unfortunately the operators were watching another indicator--the pressurizer level. The pressurizer is a small tank, normally half filled with reactor water, and covered by pressurized nitrogen gas. This gas enables the system to cope with small volume changes without large pressure changes. The operators are trained not to allow the pressurizer to be completely filled with water for this normally indicates that no gas is present. Control of the reactor is difficult in that case. (This is referred to as a "solid" plant.) The pressurizer began to indicate a high level of water, because of a combination of release of gas from it through the relief valve and formation of steam voids elsewhere in the reactor system. These steam voids formed because the pressure became low enough for the water to boil. The operators mistakenly thought that the reactor system had too much water and made the terrible mistake of turning off the emergency pumps which add water to the system; these pumps were turned on and off throughout the day, actions which showed a complete lack of understanding of the status of the reactor. It appears that this lack of understanding has been widespread throughout the nuclear industry. Naval reactor operators also are taught to follow the pressurizer level.

At 8 minutes into the accident, an operator noticed that the steam generators were dry of water on the secondary side, although the auxiliary feedwater pumps had been seen to start. The operator found that these pumps had been isolated from the system by closed

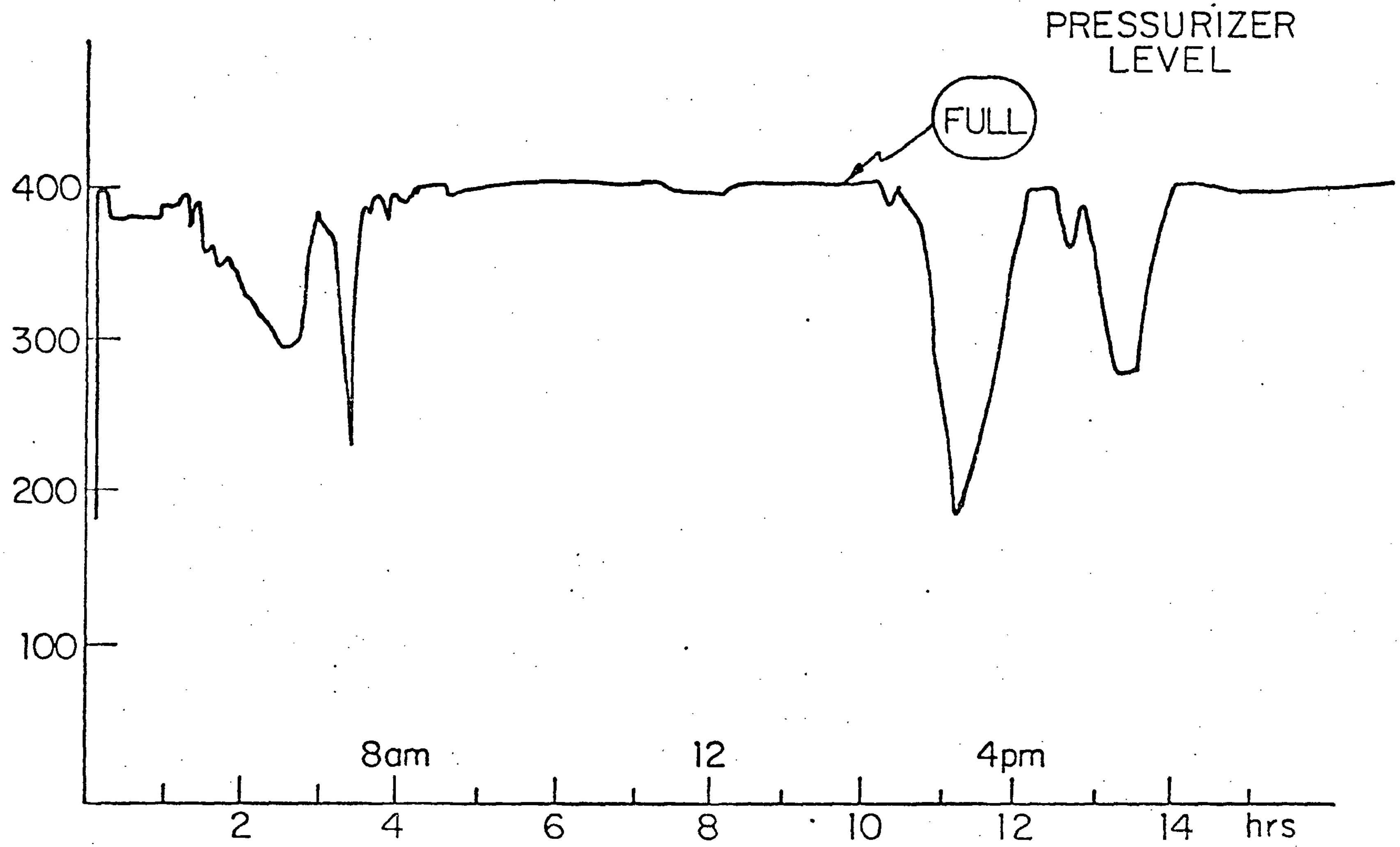


Figure 4 page 38

block valves, and the operator opened these valves. It still appears to be unclear why these valves were closed, and how long they had been closed. Although it was initially thought that this was a major contributor to the accident, it contributed nothing directly except added confusion. It misled the operators into false actions in the first minutes of the accident.

The reactor system temperature and pressure appeared to stabilize between 4:20 A.M. and 5:14 A.M.; this is because the water was boiling and the steam was going out of the relief valve. The reactor system was by this time rapidly filling with steam and emptying of water, and the circulating pumps were pumping a steam/water mixture.

This steam/water mixture was still adequate to maintain adequate cooling of the fuel rods, but the coolant pumps are not designed to pump steam and began to be noisy (cavitation). The operators turned off the pumps, one set at 5:14 a.m. and the other at 5:41 a.m. expecting that natural circulation would occur. Natural circulation would indeed have occurred if the reactor system had been filled with (subcooled) water. But since it was filled with a boiling water/steam mixture the decision led to a disaster. The water settled to the bottom and the steam rose to the top, making circulation impossible. Only the bottom 2 feet of the core was covered with water and the top part of the core was cooled only by steam.

Immediately after the pumps were turned off, the thermocouples measuring temperature in the coolant loops showed that the core was uncovered but the operators did not interpret them correctly. The temperature of the hot leg (top) went off scale, the temperature rising to a point that at that pressure could only indicate that the thermocouple was in pure steam, and the cold leg cooled down showing that circulation had stopped.

The operators had created serious problems, although they still did not know what the problems were or how they had created them. For about 1 hour--5:40 to 6:40 a.m.--the top of the core was uncovered and undercooled. Subsequent detailed calculations show that the temperature in the top of the core rose to 2000°F. At this temperature two phenomena occurred; the steam interacted chemically with the zirconium fuel rod cladding, oxidizing the cladding and releasing hydrogen:

$$Zr + H_2O \rightarrow ZrO + H_2$$

The fuel rods, by then brittle, cracked open and released the gaseous fission products (xenon, krypton, and iodine) to the reactor coolant water whence some left via the relief valve to the containment vessel and some to the outside environment through leaks in the primary coolant system. Rising radiation levels were observed as early as 5:20 a.m., a site emergency declared at 6:35 a.m. and a general emergency at 7:24 a.m.

Fortunately, at 6:18 a.m. an operator noticed that the tail pipe temperature on the electromagnetically operated relief valve was 35 F higher than on the adjacent safety valves, indicating steam flow. Why this was not noticed earlier, at 5:20 a.m., when the computer printed out this information on operator request, (the temperature difference was then 65 F) is not clear. However, the block valve was closed at 6:18 A.M., isolating the electromagnetically operated relief valve and ending the uncontrolled loss of coolant. The reactor began to repressurize and continued partial use of the emergency water injection system recovered the core by about 6:45 p.m.

Attempts soon after to restart the circulation pumps failed because the pumps were filled with steam. The reactor for the next 11 hours was cooled by the boiling of water to steam which left by the electromagnetically operated pressure relief valve.

There was still not complete understanding of the situation. The emergency coolant water was again turned off at 7:30 A.M.. and the reactor was partially depressurized twice more in attempts to get a stable situation, until at 2:28 p.m. the temperature in the hot leg of coolant loop A came on scale again. The reactor pumps (A) were finally operated again at 7:50 p.m. and the reactor core temperature and pressures stabilized.

The incident was over, although that was not clear for many more days.

The Hydrogen Bubble

As the reactor was being repressurized about 5 to 6 p.m. on Wednesday, March 28, 1979, it was noticed that although water was being rapidly fed into the reactor, the pressure rose only slowly. This was evidence that there was a gas bubble in the reactor coolant system. Moreover the bubble wasn't steam or it would have condensed.

The questions then arose:

1. Where was the bubble?

2. What was the composition of the bubble? Hydrogen (From zirconium and water reactions)?

3. Or was the hydrogen/oxygen mixture from a photodissociation of water present?

The location of the bubble was quickly determined; it could only be gas trapped in the head of the reactor vessel, where it could not be vented by remote control.

The composition of the bubble was originally assumed to be

condensible steam, then hydrogen, but on Friday morning, March 29, Dr. Joseph Hendrie, Chairman of NRC, asked his staff the third question. He got the (incorrect) answer that it could be a hydrogen/oxygen mixture. This, if true, could be alarming because hydrogen and oxygen can be ignited producing an explosion. No one was quite sure whether that would a) destroy a pump or b) open the reactor coolant system boundaries or even c) crack the containment vessel. It was feared that a) or b) could lead--even at this late stage of the accident--to a complete meltdown of the core. Not until Sunday afternoon, April 1 were definitive answers available. By then it was understood that:

a) The photodissociation of water to hydrogen and oxygen does not take place under these conditions. On the contrary, they recombine to form water (in ordinary operation hydrogen is added as a scavenger for oxygen to prevent corrosion). It was not however obvious that it is also true when fission product gases are in the waters as they were by 8 a.m. on Wednesday morning, but it transpires that it was the case.

b) Subsequent calculations made for NRC suggest that an explosion would not have broken the coolant system boundary anyway.

The question with the incorrect answer and the failure of industry to get the correct one rapidly to the right place, caused great confusion and even panic from Friday to Sunday, March 30th to April 1.

The release of the fission product gases to the primary reactor coolant systems also allowed the release of some fission product gases to the containment vessel--via the open pressure relief valve. Various small leaks in the piping allowed radioactivity releases to the other buildings, whence some were released through a filter to a stack and the atmosphere. Short lived radioactive isotopes had mostly decayed before release, or before passing over population centers. The dominant radioactive element released was xenon 133 with a half life of 5.27 days which emits a beta ray with maximum energy of 0.35 mev, average 0.17 mev, and a gamma ray of 80 kilovolt energy in the case of almost every disintegration. This is not a very high energy compared with some other radioactive decays. Most of this xenon was released within the first few days, before much had decayed. Xenon is a noble gas which for all practical purposes is chemically inert. The radiation from the xenon 133 is easily absorbed. This isotope was the dominant contributor to the radiation hazard. Most of the radioactive iodine either plated out on metal surfaces or was trapped in filters. In all it was estimated that of 2,000,000 curies of radioactive iodine (I 131) in the main building and 40,000 curies in the auxiliary building only 15 curies were released to the environment, but that 10,000,000 curies of noble gas, mostly xenon 133, were released in the period March 28-April 30, 1979, 2/3 of it in the first 36 hours.

The following agencies cooperated in radioactive monitoring:

The Department of Health, Education and Welfare (Center for Disease Control and the Food and Drug Administration)

The Department of Energy (Brookhaven National Laboratory)

The Environmental Protection Agency

The Metropolitan Edison Company

The State of Pennsylvania (Bureau of Environmental Health)

Their preliminary findings are given in a preliminary report, (with authors from several of these agencies who appear to be in agreement), and a final report is in preparation.

The preliminary report states that no one person in the general public received a dose (exposure) of more than 100 millirems. If the dose is added up over all persons within a 50 mile radius, the preliminary report showed an integrated dose of 3500 ±1500 man x rems. Later correction is made for the facts that:

1. Xenon 133 is a favorable isotope and that response of people to xenon 133 is less than thermoluminescent dosimeters suggest
2. People were shielded by clothes and buildings
3. Many people moved away

This brought down the estimate of total population dose to about 2000 manrems or less.

The significance of these doses can be seen by comparison. Eighty millirems is an average yearly background radiation dose at sea level. Assuming a proportional relation between dose and response and based on observation, 5000 man rems leads to one cancer according to the BEIR (I) report.

Accordingly, the Three Mile Island accident will add less than 1/2 to the expected number of cancers among the population within 50 miles of the site of the power plant. This is an increase from the normal number of cancers expected in the area of approximately .5--from 350,000.0 to 350,000.5. The meaning of the fraction 0.5 is statistical; it is clear that it it will never be possible to determine whether the accident at Three Mile Island produced an additional cancer.

It is virtually certain that the Three Mile Island accident did not and will not cause many cancer cases, although we believe

it is irrelevant to this panel's work, since the main issue is whether the Commonwealth is prepared in the event of an accident with more serious results.

How Close Was the Three Mile Island Accident to a Disaster or Serious Accident?

The concern over Three Mile Island is for us not the accident itself but the perspective on accidents that it provides. Does it mean that serious accidents are more probable than previously supposed?

A class IX accident is defined in the Federal Register (10 CFR 100) as one in which the radiation exceeds 100 mr/hr at the site boundary which dose was not achieved at Three Mile Island. However the Nuclear Regulatory Commission has stated that as far as core damage is concerned, the accident was large enough to be considered a class IX accident.

The "waiver of defenses" clause in the provisions of the Price-Anderson Act takes effect at about this level.

In answering the question, are serious actions more probable, we will first discuss intermediate questions. How close did the reactor come to a meltdown of the fuel? How close did the reactor come to a breach of the containment vessel and liberation of radioactivity?

The answers to these questions will be discusssed in voluminous reports and hotly debated over the next several years. However some features seem definite.

1. The reactor came closer to a meltdown than any previous commercial reactor accident in a light water reactor.

2. It is not easy to say how close, for two reasons. On the one hand human failure was present in a way that had not been previously taken into account--the operators, by reasoning incorrectly, intensified the accident by a series of incorrect actions. The statistical question becomes: if we imagine 1000 independent accidents proceeding as happened at Three Mile Island up to 6:10 a.m. in how many of them would the operators have noticed the leaking relief valve--and if they had, would they therefore taken correct action? These questions are hard to answer. Secondly, there is disagreement over what would have happened to the reactor core if they had not acted correctly. It seems that the cooling of the top of the reactor from 5:30 a.m.--when it first became uncovered--to 7:00 a.m. when it was covered again, was greater than had been feared. This has led some to claim that a small loss of coolant accident could never lead to a meltdown since convective steam cooling may be adequate.

3. The probability of violating containment may still be small after a meltdown occurs. In reactor safety studies

a probability of 1/10 has been estimated.

4. All the radioactivity will not be released even if the containment is violated. Particularly critical are the chemical elements iodine, tellurium and cesium; if released they interact chemically in the body whereas xenon does not. Filters and plate out mechanisms kept the iodine release low at Three Mile Island, but in a serious accident these filters might be overloaded; they were in fact not as effective as they should have been at Three Mile Island because they had become saturated in previous use.

Acceptability of Accidents and Their Consequences

The panel made no attempt to decide whether one particular accident is publicly acceptable or unacceptable. The Kemeny Commission made a point that the present level of safety--which includes the accident at Three Mile Island, must be improved.

> "To prevent nuclear accidents as serious as Three Mile Island fundamental changes will be necessary in the organization, procedures and practices--and above all in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions are typical of the nuclear industry."

It also note (P. 32 paragraph 16) that implicit among the calculations in the Rasmussen Report is an estimate of frequency of accidents similar in size to Three Mile Island. This frequency is one in several hundred reactor operating years. We have now had nearly 500 reactor operating years and one accident of this magnitude. Although the accident at Three Mile Island was not predicted by Rasmussen it was not in itself contrary to the probability estimates therein. Since Rasmussen and colleagues, and many of those who have read and understood the report, believe the results, if correct, were acceptable, it seems to us that this assumption of the Kemeny report represents a significant departure from those past beliefs and needs examination. This is particularly true when we realize that the main public criticisms of nuclear reactor safety and Rasmussen's report in particular, have been based on a disbelief in the numbers--not declared statements that even if the low accident probability estimates are correct, reactors are still unacceptable. Discussion by individual critics and the public seem not to have considered adequately whether the results in Rasmussen's report would be acceptable if true. However the nuclear industry and the Nuclear Regulatory Commission proceeded as if it were.

Kemeny doesn't address this discrepancy.

Appendix II. Review of Available Reports

Members of the panel reviewed a number of reports. The most relevant are discussed below.

a) The adverse effects of exposure to low levels of radiation and to levels of radiation likely as the result of an accident.

There have been many reports on this topic. Of these, we note in particular the reports of the Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences, particularly the first of these in 1972 (BEIR I) and the most recent (1979) of which only a draft is available (BEIR III).

We note that the members of the BEIR III committee are presently disagreeing on whether the incidence of cancer in a population is proportional to exposure, or whether this is an overestimate of the number at low doses and therefore an overestimate of the risk. However we also note that there are a few scientists (e.g. Karl Morgan of Oak Ridge National Laboratory) who believe the linear hypothesis understates the risk by a factor of about 5.

Until this is settled we believe it is reasonable to assume that radiation exposure causes cancers in a population in proportion to the exposure.

Accepting this and the estimates given in the BEIR I report, the expected number of cancers expected in the event of an accident is

$$\# c = \frac{\sum^{N} D_i}{5000}$$

where the summation is over the whole population exposed (N people) and D is the exposure of the individual in rems.

b) The Rasmussen Report had flaws, some of which we list:

1. It is not very readable

2. The executive summary does not summarize the report

3. The discussion of common mode failures where several safety systems fail simultaneously from the same cause is not always correct. The best known example is the incorrect calculation of the probability of core melt arising from an anticipated transient without scram (ATWS) for a boiling water reactor.

4. The uncertainties in the numbers are larger than Rasmussen

states.

This study was overly praised by NRC and industry and overly damned by critics. Subsequently, the NRC expressed reservations about it. It was misused, including in Congressional testimony by its authors, but insofar as we know neither it nor the methodology used in it has been used to improve safety.

We agree for the most part with the conclusions (which include some of the above) of a committee set up by NRC at the request of Representative Udall and chaired by Dr. H. Lewis. We agree that the basic methodology of event tree analysis is useful. We agree with Dr. Lewis also in his testimony subsequent to Three Mile Island that this methodology can and should be used in licensing reactors, and training and licensing of operators.

In particular the Lewis review report said:

1. The [Rasmussen report] was an essential step beyond earlier attempts to estimate the risks of nuclear power.

2. The report attained a far reaching objectivecation of safety assessment, introduced a workable accident classification, and presented a methodology for the quantitative determination of risks.

3. The event tree/failure tree procedure, together with an adequate data base, has proved to be the best available tool for the quantification of the occurrence of low probability accidents.

4. The importance of late fatalities and property damage was recognized besides that of early fatalities although this is not apparent from the summary report and was not reflected in many of the statements purporting to have been based on the report, including those by the authors, about the risks of nuclear power.

The occurrence of an accident at Three Mile Island does not "invalidate" the general conclusions of the Rasmussen report or any of these reports. Rasmussen's general point that an accident falling just short of a meltdown is likely once every few hundred reactor years, but that other defenses will in the vast majority of cases prevent anything more serious, is not altered although not necessarily correct. Indeed the accident itself suggests the desirability of using the methodology for plant design and training purposes. The specific conclusions of this report applied only to two specific reactors--the Surry plant in Virginia (for which Westinghouse Electric Corp. provided the nuclear steam supply system) and Peach Bottom in Pennsylvania (a General Electric

plant). Rasmussen did not analyze a Babcock and Wilcox reactor, and if he had one so, it is possible that he would have realized that the accident sequence that took place at Three Mile Island was more probable than acceptable.

A more recent reactor safety study in Germany, chaired by Dr. Birkhofer of Munich is now available and the panel had a copy of the summary. While overcoming some of the defects in presentation of the Rasmussen report, it comes to similar conclusions.

c) The reports of NRC on the details of Three Mile Island accident and the radiation measurements thereat are thorough, seem very factual and show no bias that we could discern.

d) The best known general reports on comparative risks of nuclear and other power sources include the Ford-Mitre study; a report of a subcommittee on CONAES (Committee on Nuclear and Alternative Energy Sources of the National Academy of Sciences), the risks associated with nuclear power; and a report from Canada by Inhaber. The last of these, by Inhaber, is so full of errors that it is useless for policy purposes.

These reports put a large uncertainty on the comparison of nuclear power with the most obviously comparable alternative--coal (coal because its price is comparable, it is best burnt in large power plants, and there is plenty of it). But they all agree that unless the uncertainties all conspire to favor coal, and so against nuclear, nuclear power is probably safer. It is important to note that this argument depends upon a belief that the question of disposal of nuclear wastes can be safely dealt with. The responsibility for the resolution of this question lies with the federal government rather than an individual state.

Staff Report on the Generic Assessment of Feedwater Transients in BWR's and PWR's, NUREG-0560, May 1979.

Investigation into the March 28, 1979, Three Mile Island Accidnet, Office of Inspection and Enforcement, Nuclear Regulatory Commission, NUREG-0600, August 1979.

TMI-2 Lessons Learned Task Force, Status Report and Short Term Recommendations, NUREG-0578, July 1979.

Analysis of Three Mile Island Unit 2 Accident, Nuclear Safety Analysis Center, NSAC-1, July 1979, P.O. Box 10414, Palo Alto, California 94303.

Indexed Bibliography of TMI-2, NSAC Bib, August 1979.

Population Dose and Health Impact of the Accident at Three Mile Island Nuclear Station, NUREG-0558, May 1979.

The Effect On Populations of Exposure to Low Levels of Ionizing Radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR I), NAS/NRC, Nov. 1972.

The Effects on Populations of Exposure to Low Levels of Ionizing Radiation (BEIR III) Draft Report, NRC/NAS May 1979.

E.J. Sternglass--extensive list of references in BEIR report.

Mancuso, Kneale and Stewart, Radiation Exposures of Hanford Workers Dying From Cancer and Other Causes, Health Physics, 33:5, p. 36 (1977).

Mortality From Leukemia and Cancer in Shipyard Nuclear Workeers, T. Najarian and T. Colton, Lancet 1:8072, 1018 (1978).

Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, 'The Rasmussen Report', WASH 1400, NUREG 75/014, October 1975.

Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission, H.W. Lewis; et al., NUREG/CR-0400.

Population Dose and Health Impact of the Accident at Three Mile Island Nuclear Station, NUREG 0558, May 1979.

The German Risk Study--Summary, Gesellschaft fur Reaktosicherheit (GRS) mbH, Glockengasse 2, 5000 Koln 1, Germany, August 15, 1979.

Jan Beyea, Some Long Term Consequences of Hypothetical Major Releases of Radioactivity to the Atmosphere from Three Mile Island, Princeton, N.J., Draft, Sept. 7, 1979.

D.C. Aldrich, P. McGrath, N.C. Rasmussen, Examination of Offsite Radiological Emergency Protective Measures for Nuclear Reactor Accidents for Questioning Core Melt; NUREG /CR-1131 or SAND 78-0454

J.G. Kemeny, B. Babbitt, P.E. Haggerty, C. Lewis, P.A. Marks C. Marret, L. McBride, H.C. McPhersoan, R.W. Peterson, T.H. Pigford, T.B. Taylor, A.D. Trunk; Report of the Presidents Commission of the Accident at Three Mile Island. November 1979

Demographic Statistics pertaining to Nuclear Power Reactor Sites, NUREG 0348 October 1979.

Massachusetts Commission on Nuclear Safety (Rathjens report) Department of Public Health, Commonwealth of Massachusetts September 1975

Title list, Publicly available documents Three Mile Island Unit 2, Docket 50-320 Cumulative to May 21 1979 NUREG 0568

NIAT (Nuclear Incident Advisory Team) Handbook (draft) Department of Public Health, Commonwealth of Massachusetts June 1979

New England Interstate Radiation Plan; New England Radiological Health Committee, March 1979

Commonwealth of Massachusetts Comprehensive Emergency Plan, Civil Defense Agency and Office of Emergency Preparedness January 1979

Areas around nuclear facilities should be better prepared for Radiological Emergencies. Report to the Comptroller General of the United States Congress. EMD -78-110 March 30,1979

Planning basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants NRC, EPA NUREG -0396 (EPA 520/1-78-016)

Protection of the Thyroid Gland in the Event of Releases of Radioiodine; National Council on Radiation Protection and Measurements NCRP report 55

Regulatory guide 1.111 Methods for Estimating atmospheric transport and dispersion of gaseous effluents in routine releases from light water cooled reactors NRC Rev 1 July 1977

Risks of Energy Production; H. Inhaber; AECB 1119/Rev 2 Nov 1978

Appendix III. Meetings

The following persons were present at meetings of the panel; the meetings of October 12, November 19 and December 14 were open. Formal presentations were made by Mr. Lydon of Boston Edison and Paul Cahill of the Civil Defense Agency on June 25. Informal discussions and response to the questions of the panel were the format of the last 3 meetings. Any person present was able to present his views and on December 14 a written submission from the South Shore Chamber of Commerce was made.

Many written and oral responses to our questions were supplied by the utility companies and state agencies.

We are grateful to all of these participants for sharing with us their views and thereby helping us to form our recommendations.

The list of attendees at the meetings follows.

June 25, 1979, Civil Defense Facility, Framingham

Richard Wilson, Harvard University

Susan Wiltshire

C.D.W. Thornton, Executive Office of Environmental Affairs

Al Comproni, Massachusetts Department of Public Health

John K. Olsen, Dept. of Public Safety

George Surteli, Massachusetts Department of Public Health

Edward Howard, Boston Edison Company

James Lydon, Boston Edison Company

William J. Bell, Mass. Dept. of Public Health (Radiation Control Program)

John Clement, Mass. Dept. of Public Health (Div. of Hazardous Materials)

Bernard Holan, Mass. Civil Defense Agency

George H. Tully, Asst. Sec., Executive Office of Public Safety

Lillian Morgenstern, Mass. Office for Energy Resourses

Paul Cahill, Mass. Civil Defense Agency

October 12, 1979, Saltonstall Building, Boston

Frank Congel, Nuclear Regulatory Commission

Ed Wojnas, Mass. Civil Defense Agency

Bernard V. Holan, Mass. Civil Defense Agency

Robert H. Cunningham, Director, Mass. Civil Defense Agency

Robert Boulay, Mass. Civil Defense Agency

John Louerins, Mass. Civil Defense Agency

Gerald Hayes, Plymouth Civil Defense

Tom Sowdon, Boston Edison Company

Harrison Balfour, Boston Edison Company

Fred J. Mogolesko, Boston Edison Company

Christine E. Bowman, Boston Edison Company

Robin R. Shult, Boston Edison Company

Edward Karaian, Mass. Institute of Technology

James F. Wright, Dept. of Public Safety, Div. of Inspection

Joel Brown, Consultant to Boston Edison Company

R. Merlino, Consultant to Boston Edison Company

Frank Archibald, Mass. Dept. of Labor and Industries

Lewis Draffer, Dept. of Environmental Quality Engineering

Al Comproni, Mass. Dept. of Public Health

William J. Bell, Mass. Dept. of Public Health

Patrick Coggio, Mass. Institute of Technology

James A. MacDonald, Yankee Atomic

David E. McCurdy, Yankee Atomic

Thomas C. Elsasser, State Liaison Officer, U.S. Nuclear Regulatory Commission

Ronnie Lipshutz, Union of Concerned Scientists

V. Carlisle Smith, Dept. of Public Safety, Rep. on Governor's Council on Radiological Protection

John H. Clement, Mass. Dept. of Environmental Quality Engineering

George Swible, Mass. Dept. of Public Health

C.J. Maletskos, Advisory Council on Radiation Protection

L. Morgenstern, Mass. Office of Energy Resources

J.S. Fitzpatrick, Director, Mass. Office of Energy Resources

Judy Shope, Mass. League of Women Voters

Mary Gorham, Senator Sharon Pollard

Andrew C. Kadak, Yankee Atomic

Efford H. Pierce, Rowe Civil Defense Dept.

Joseph Mowe, Monroe, MA 01350

Richard Wilson, Harvard University

Susan Wiltshire

George Rathjens, Mass. Institute of Technology

November 19, 1979, McCormack Office Building, Boston

Lillian Morgenstern, Mass. Office of Energy Resources

John Olsen, Dept. of Public Safety

George Swible, Mass. Dept. of Public Health

C.J. Maletskos, Advisory Council on Radiation Protection

J.S. Fitzpatrick, Director, Mass. Office of Energy Resources

G. Parker, Dept. of Public Health

F.S.W. Wright, Attorney General's Office

Several representatives from Boston Edison

Several representatives from Yankee Atomic

Helen Woodman, State House News Service

George Rathjens, Mass. Institute of Technology

Susan Wiltshire

Richard Wilson, Harvard University.

plus many others.

December 14, 1979, State House, Boston

Gerald Parker, Mass. Dept. of Public Health

C.J. Maletskos, Advisory Council on Radiation Protection

George Swible, Mass. Dept. of Public Health

Bob Cunningham, Civil Defense

Jerry Ackerman, Boston Globe

Andrew C. Kadak, Yankee Atomic

Lincoln Clark, Jr., Mass. Institute of Technology (Reactor Laboratory)

Edmund C. Tarnuzzer, Yankee Atomic

Larry Carpman, Mass. Office of Energy Resources

Frank Archibald, Dept. of Labor and Industries

Helen Woodman, State House News Service

James W. Gosnell, Boston Edison

W.R. Griffin, HMM Associates, Consultant to Boston Edison

James F. Wright, Dept. of Public Safety

William H. Dormer, Jr., Dept. of Public Safety

John K. Olsen, Dept. of Public Safety

Harrison R. Balfour, Boston Edison Co.

John Murphy, Boston Edison Co.

Pat Granahan, 36 Croydon Rd., Hingham, MA

Joy Augenstern-Stuart, 883 Nantasket Ave., Hull, MA

Joe Baerlein, New England Council

Elizabeth Murray, Executive Office of Transportation Construction

Lillian Morgenstern, Mass. Office of Energy Resources

Richard Wilson, Harvard University.

Susan Wiltshire

George Rathjens, Mass. Institute of Technology

Appendix IV. Glossary of Terms

Auxiliary building. A structure housing a variety of equipment and large tanks necessary for the operation of the reactor. These include make-up pumps, the make-up and waste gas decay tanks, and the reactor coolant hold-up tanks.

Babcock and Wilcox (BW). The company that designed and supplied the TMI-2 reactor and nuclear steam supply system.

Background radiation. Radiation arising from natural radioactive materials always present in the environment, including solar and cosmic radiation and radioactive elements in the upper atmosphere, the ground, building materials and the human body.

Beta particles. High-energy electrons; a form of ionizing radiation that normally is stopped by the skin, or a very thin sheet of metal.

Boston Edison Company. A local utility responsible for the operation of Pilgrim and other nuclear power reactors in the New England region.

Caesium or Cesium. A chemical element produced in fission. Cesium of isotope 137 has a half life of 10 years and has a gamma of 600 kev.

Chain reaction. A self-sustaining reaction; occurs in nuclear fission when the number of neutrons released equals or exceeds the number of neutrons absorbed plus the neutrons which escape from the reactor.

Cladding. In a nuclear reactor, the metal shell of the fuel rod in which uranium oxide pellets are stacked.

Collective dose. The sum of the individual doses received by each member of a certain group or population. It is calculated by multiplying the average dose per person by the number of persons within a specific geographic area. Consequently, the collective dose is expressed in person-rems. For example, a thousand people each exposed to one rem would have a collective dose of 1,000 person-rems.

Condensate booster pumps. Three pumps located between the condensate polisher and the main feedwater pumps.

Condensate polisher. A device that removes dissolved minerals from the water of the feedwater system.

Condensate pumps. Three pumps in the feedwater system that pump water from the condensers to the condensate polishers.

Condensers. Devices that cool steam to water after the steam has passed through the turbine.

Containment building. The structure housing the nuclear reactor; intended to contain radioactive solids, gases, and water that might be released from the reactor vessel in an accident.

Control rod. A rod containing material that absorbs neutrons; used to control or halt nuclear fission in a reactor.

Core. The central part of a nuclear reactor that contains the fuel and produces the heat.

Critical. Term used to describe a nuclear reactor that is sustaining a chain reaction.

Curie. A unit of the intensity of radioactivity in a material. A curie is equal to 37 billion disintegrations each second.

Decay heat. Heat produced by the decay of radioactive particles; in a nuclear reactor this heat, resulting from materials left from the fission process, must be removed after reactor shutdown to prevent the core from overheating. See radioactive decay.

Emergency core cooling system (ECCS). A backup system designed to supply cooling water to the reactor core in a loss-of-coolant accident.

Emergency feedwater pumps. Backup pumps intended to supply feedwater to the steam generators should the feedwater system fail to supply water. Also called auxiliary feedwater pumps.

Feedwater pumps. Two large pumps capable of supply TMI-2's two steam generators with up to 15,500 gallons of water a minute.

Feedwater system. Water supply to the steam generators in a pressurized water reactor that is converted to steam to drive turbines; part of the secondary loop.

Fission. The splitting apart of a heavy atomic nuclus, into two or more parts when a neutron strikes the nucleus. The splitting releases a large amount of energy.

Fission products. Radioactive nuclei and elements formed by the fission of heavy elements.

Fuel damage. The failure of fuel rods and the release of the radioactive fission products trapped inside them. Fuel damage can occur without a melting of the reactor's uranium.

Fuel melt. The melting of some of the uranium oxide fuel inside a reactor.

Fuel rod. A tube containing fuel for a nuclear reactor.

Gamma rays. High-energy electromatic radiation; a form of ionizing radiation, of higher energy than x-rays, that penetrates very deep into body tissues.

General emergency. Declared by the utility when an incident at a nuclear power plant poses a potentially serious threat of radiation releases that could affect the general public.

General Public Utilities Corporation (GPU). A utility holding company; parent corporation of the three companies that own TMI.

Genetic defects. Health defects inherited by a child from the mother and/or father.

Half-life. The time required for half of a given radioactive substance to decay.

Health physics. The practice of protecting humans and their environment from the possible hazards of radiation.

High pressure injection (HPI). A pump system, capable of pumping up to about 1,000 gallons a minute into the reactor coolant system; part of the emergency core cooling system.

Iodine-131. A radioactive form of iodine, with a half-life of 8.1 days, that can be absorbed by the human thyroid if inhaled or ingested and cause non-cancerous or cancerous growths.

Ionizing radiation. Radiation capable of displacing electrons from atoms; the process produces electrically charged atoms or ions. Forms include gamma rays, x-rays, and beta particles.

Isolation. Condition intended to contain radioactive materials released in a nuclear accident inside the containment building.

Isotope. Two nuclei of the same chemical element but different mass.

Krypton-85. A radioactive noble gas, with a half-life of 10.7 years, that is not absorbed by body tissues and is soon eliminated by the body if inhaled or ingested.

Let-down system. A means of removing water from the reactor coolant system.

Loss of coolant accident (LOCA). An accident involving a broken pipe, stuck-open valve, or other leak in the reactor coolant system that results in a loss of the water cooling the reactor core.

Make-up system. A storage tank in the auxiliary building which

provides water for the make-up pump.

Meltdown. The melting of fuel in a nuclear reactor after the loss of coolant water. If a significant portion of the fuel should melt, the molten fuel could melt through the reactor vessel and release large quantities of radioactive materials into the containment building.

Metropolitan Edison Company (Met Ed). Operator and part owner of the Three Mile Island nuclear power plant.

Millirem. 1 one-thousandth of a rem; see rem.

Natural cooling. The circulation of water without pumping by heating water in the core and cooling it in the steam generator.

Neutron. An uncharged particle found in the nucleus of every atom heavier than ordinary hydrogen; neutrons sustain the fission chain reaction in nuclear reactors.

Noble gases. Inert gases that do not react chemically and are not absorbed by body tissues, although they may enter the blood if inhaled into the lungs. These gases include helium, neon, krypton, xenon, and radon.

Nuclear Regulatory Commission (NRC). U.S. agency responsible for the licensing and regulation of commerical, test, and research nuclear reactors.

Nucleus. The central core of an atom.

Person-rems. See collective dose.

"Poisons". Materials that strongly absorb neutrons; used to control or stop the fission reaction in a nuclear reactor.

Pilot-operated relief valve (PORV). A valve on the TMI-2 pressurizer, designed to open when steam pressure reaches 2,255 pounds per square inch.

Potassium iodide. A chemical that readily enters the thyroid gland when ingested. If taken in a sufficient quantity prior to exposure to radioactive iodine, it can prevent the thyroid from absorbing any of the potentially harmful radioactive iodine-131.

Pressure vessel. See reactor vessel.

Pressurizer. A tank that maintains the proper reactor coolant pressure in a pressurized water reactor.

Pressurized water reactor. A nuclear reactor system in which reactor coolant water is kept under high pressure to keep it from

boiling into steam.

Primary system. See reactor coolant system.

Radioactive decay. The spontaneous process by which an unstable radioactive nucleus releases energy or particles to become stable.

Radioactivity. The spontaneous decay of an unstable atom. During the decay process, ionizing radiation is usually given off.

Radiolysis. The breaking apart of a molecule by radiation; such as the splitting of water into hydrogen and oxygen.

Reactor (nuclear). A device in which a fission chain reaction can be initiated, maintained, and controlled.

Reactor coolant pump. One of four large pumps used to circulate the water cooling the core of the TMI-2 reactor.

Reactor coolant system. Water that cools the reactor core and carries away heat. Also called the primary loop.

Reactor vessel. The steel tank containing the reactor core; also called the pressure vessel.

Rem. (Roentgen equivalent man) A standard unit of radiation dose. Frequently radiation dose is measured in millirems for low-level radiation; 1,000 millirems equal one rem.

Respirator. A breathing mask that filters the air to protect against the inhalation of radioactive materials.

Safety-related. The NRC employs several broad definitions for this concept. By one, safety-related items are "structures, systems and omponents that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public." However, the NRC has no specific list of safety-related items. The licensee designates what in its plant is considered safety-related. If the NRC disagrees, the question is negotiated. Safety-related items receive closer quality control and assurance, maintenance, and NRC inspection.

Saturation temperature. The temperature at which water at a given pressure will boil; the saturation point of water at sea-level is 212 F.

Scram. The rapid shutdown of a nuclear reactor, by dropping control rods into the core to halt fission.

Secondary systems. See feedwater system.

Site emergency. Declared by the utility when an incident at a

nuclear power plant threatens the uncontrolled release of radioactivity into the immediate area of the plant.

Solid system. A condition in which the entire reactor coolant system, including the pressurizer, is filled with water.

Steam generator. A heat exchanger in which reactor coolant water flowing through tubes heats the feedwater to produce steam.

Steam table. A chart used to determine the temperature at which water will boil at a given pressure.

Tellurium. A chemical element produced in fission. Solid under ordinary conditions.

Thermoluminescent dosimeter (TLD). A device to measure nuclear radiation.

TMI. Three Mile Island; site of two nuclear power reactors operated by Metropolitan Edison Company.

Transient. An abnormal condition or event in a nuclear power system.

Trip. A sudden shutdown of a piece of machinery.

Turbine building. A structure housing the steam turbine, generator, and much of the feedwater system.

Uranium oxide (UO). A chemical compound containing uranium and oxygen that is used as a fuel in nuclear reactors.

Waste gas decay tank. One of two auxiliary building tanks in which radioactive gases removed from the reactor coolant are stored.

Xenon-133. A radioactive noble gas, with a half-life of 5.3 days, that is not absorbed by body tissues and is soon eliminated by the body if inhaled or ingested.

Yankee Atomic Group. A company formed by several New England utilities to build the nuclear power plant at Rowe, Mass. Now also an engineering service organization for the New England utilities.

Zircaloy-4. A zirconium alloy from which fuel rod cladding is made.

Appendix V. List of Letters

7/10/79 and 8/2/79--J.T. Driscoll, Mass. Turnpike Authority, Use of Turnpike with enclosures.

7/19/79--L.E. Beghian, University of Lowell, Shipment from the University of Lowell Reactor.

7/23/79--L. Clark, Mass. Institute of Technology, Shipment from the MIT reactor.

8/13/79--G.E. Parker, Department of Public Health, Funding for DPH work with enclosures.

8/6/79--R.H. Cunningham, Civil Defense Agency, Emergency plans

12/14/79--R.F. Frazier, South Shore Chamber of Commerce, Need for Pilgrim II.

8/31/79--M.B. Meyer, Attorney General's Office, Pilgrim II hearing.

9/4/79--J.M. Lydon, Boston Edison, Response to questions

10/3/79--J.M. Lydon, Boston Edison, (A) Management of unusual events (B) radiation exposure (C) communication flow paths.

8/30/79--N.M. Haller, NRC, response to questions with enclosure NUREG-0578.

9/10/79--D.E. Vandenburgh, Yankee Atomic Electric, response to questions with enclosure.

10/11/79--C.J. Maletskos, Advisory Council on Radiation Protection, report on emergency plans with enclosure.

10/12/79--J.M. Lydon, Boston Edison, Oyster Creek incident.

11/1/79--J.C. Brooks, Boston Edison, response to questions.

12/14/79--G.E. Parker, Department of Public Health (handed to Richard Wilson), list of TLD's.

12/17/79--J. Driscoll, Mass. Turnpike Authority, use of turnpike.

Several letters from Mr. Harold Rafton, 9 Alden Road, Andover, MA concerning work by the Union of Concerned Scientists and nuclear power in general.

Mr. Dave Miner (undated), a letter concerned with sabotage of nuclear reactors.

Rulemaking Comments

From: Gallagher, Carol
Sent: Wednesday, June 13, 2012 3:59 PM
To: Rulemaking Comments
Subject: Comment on Proposed Rule - Onsite Emergency Response Capabilities
Attachments: NRC-2012-0031-DRAFT-0010.pdf - Adobe Acrobat Pro.pdf

Attached for docketing is a comment from Richard Wilson on the above noted proposed rule (77 FR 23161; April 18, 2012) that I received via the regulations.gov website on June 13, 2012.

Thanks,
Carol