10/5/82

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
COMMONWEALTH EDISON COMPANY	)	**Docket Nos. 50-454-OL**
	)	**50-455-OL**
(Byron Nuclear Power Station Units 1 and 2)	)	

ANSWERS OF ROCKFORD LEAGUE OF WOMEN VOTERS TO AMENDED SECOND ROUND OF INTERROGATORIES OF COMMONWEALTH EDISON COMPANY

Pursuant to the Memorandum and Order issued by the Licensing Board on August 30, 1982, Intervenor Rockford League of Women Voters herewith submits its answers to the second round of Interrogatories propounded herein by Commonwealth Edison.

Introduction

The answers submitted herein contain as much information as is available to the League as of the date of filing. However, document production by Commonwealth Edison Company ("CECO") has begun only very recently and has still not been completed. Additionally, as was noted at the August Pre-Hearing Conference in Rockford, Illinois, the League's expert witnesses were not expected to be and, in fact, were not available to the League during September except on a very intermittent basis. Consequently, they have not yet had an opportunity to examine any of the documents which have so far been produced. For these reasons and because the League's own investigation, which includes League-initiated discovery activities, is continuing, the League must state that additional facts and details may yet come to light. As these facts are uncovered, the answers herein will be elaborated upon by supplemental answers.

8210070129 821005
PDR ADOCK 05000454
G PDR

Interrogatory No. 1:

With reference to Contention 1A, (a) identify all instances demonstrating how Edison's quality assurance function is not independent of Edison's other departments; and (b) identify and produce all documents which support your answer to this Interrogatory.

Response to No. 1:

1(a) It is required that information in the Safety Analysis Report (SAR) pertaining to managerial and administrative controls be used to assure safe operation of the nuclear plant. Thus, as set forth in the "Introduction" to Appendix B to 10 CFR 50, Quality Assurance/Quality Control (QA/QC) requirements apply to a broad range of activities at Byron such as designing, purchasing, fabricating, handling, slipping, storing, clearing, erecting, installing, inspecting, testing, operating, maintaining, repairing, refueling, and modifying equipment, parts, and structures. Criteria I of Appendix B also requires, in part, that:

> ".....the persons and organizations performing quality assurance functions shall have sufficient authority and organizational freedom to identify quality problems; to initiate, recommend, or provide solutions; and to verify implementation of solutions. Such persons and organizations performing quality assurance functions shall report to a management level such that this required authority and organizational freedom, including sufficient independence from cost and schedule when opposed to safety considerations, are provided."

Contrary to these requirements, the Byron QA/QC program fails to provide the required organizational independence. For example, under the current QA/QC program, the CECO "Quality Control Supervisor" reports to the "Station Superintendent" through the "Administrative and Support Services Assistant Superintendent" (see Byron SER, Figure 17.1). Thus, the required independence from cost and schedule considerations has not been achieved.

Also, the results of a recent NRC Inspection conducted March 29-31, April 1-2, 5-9, 12-14, and May 11, 1982 document further violations of the independence requirements and demonstrate that despite the projected fueling date only one year away, CECO is still unwilling or unable to establish a proper QA/QC program. In the Inspection Report, the NRC cited CECO for failures to comply with language in both 10 CFR 50, Appendix B, Criterion 1, and the licensee's own topical report CE-1-A, Rev. 20, Section 1.A, and stated that contrary to those provisions:

> 1. On March 30, 1982 it was identified that the Quality Assurance Manager for Hatfield Electric Company, as shown in the Quality Assurance Manual, reports to the Vice President who is located on-site and has direct responsibility for cost and schedule;
>
> 2. On April 2, 1982 it was identified that the Quality Assurance Manager for Powers — Azco Pope — as shown in the Quality Assurance Manual reports to the Project Manager who has direct responsibility for cost and schedule;
>
> 3. On April 8, 1982 it was identified that the Project Construction Department of the licensee (CECO) is part of the approval chain regarding the hiring and promoting of contractor's quality assurance personnel;
>
> 4. On March 30, 1982 it was identified that the Hatfield Electric Company has been operating with a Quality Assurance Organization other than that described in their Quality Assurance manual;
>
> 5. On April 4, 1982 it was identified that Johnson Controls Inc. has been operating with a Quality Assurance Organization other than that described in their quality assurance manual;

Additionally, the organizational requirements for a QA/QC program for items "important to safety" but not "safety-related" (for definitions, see Denton's November 20, 1981 memorandum) as required by GDC 1 of Appendix A to 10 CFR 50 is not described in the FSAR by CECO or reviewed by the NRC in the Byron SER. This is a significant omission.

Finally, the Institute of Nuclear Power Operation (INPO), in a September 12, 1980 report summarizing its evaluation of CECO's site activities at Dresden, noted that there existed an opportunity for the improvement of a number of CECO management practices, including management's handling of the definitions of individual responsibilities and authority, its adherence to administrative-type procedure and industrial safety policies, the effectiveness of its administrative controls on instrument setpoints, and the effectiveness of its maintenance, surveillance, and records program.

Specifically, the INPO evaluation team identified two basic concerns. The first was that many of the findings showed a need for strengthened management control systems through adequate and clearly written definitions of lines of authority and responsibilities, and through additional written policies and procedures. The second was that a number of findings indicated the need for more management attention and vigor in insuring adherence to existing administrative policies and procedures.

In general, the underlying cause of identified QA/QC breakdown has been the failure of responsible management to properly emphasize the importance of compliance with the required QA/QC measures. This pattern of failure can be documented through NRC Inspection Reports as well as internal QA/QC audits and surveillances which reveal the root cause: a lack of proper management organization and attitude. The review of Byron audits, surveillances, and E & I reports is currently underway. Following this review, the answer to Interrogatory No. 1 may be supplemented with additional material.

1(b) Documents have been identified at the point of reference in this response, in previous affidavits, and in Interrogatory responses related to QA/QC breakdowns by Byron. All documents identified to date are publicly available, or if not, the documents have been provided by CECO. As additional documents responsive to this request are identified during the ongoing discovery process, this response will be appropriately supplemented.

Interrogatory No. 2:

With reference to Contention 8, (a) identify and produce the NRC studies, referred to in the second sentence of the contention, which have been carried out to identify "accident mechanisms, considered credible, which would lead to uncontrollable accidents and release to the environment of appreciable fractions of a reactor's inventory of radioactive materials;" (b) identify and produce the NRC studies, referred to in the fifth sentence of the contention, "which are not common public knowledge" but have cast doubt upon various conclusions of the Rasmussen report; (c) identify the specific conclusions of the Rasmussen report that have been questioned by the NRC studies referred to in subpart (b); (d) identify and produce a copy of the "secret NRC study" referred to in the contentions as the "unpublished document from Brookhaven National Laboratory"; and (e) identify the General Accounting Office report referred to in the contention.

Response to No. 2:

2(a) Studies which have been conducted by or for the NRC which identify "accident mechanisms, considered credible, which would lead to uncontrolled accidents and releases to the environment of appreciable fractions of a reactor's inventory of radioactive materials" include the following relevant to a PWR of the Byron design:

(i) WASH-1400, U.S. Reactor Safety Study.

(ii) NUREG-0400, Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission.

(iii) WASH-740, Theoretical Possibilities and Consequences of Major Accidents In Large Nuclear Power Plants.

(iv) Byron FES (Chapter 7 re Class 9 accidents).

In addition, Board Notification 82-75 presents the initial results of the NRC's Accident Sequence Precursor Program Report. The program was begun as a result of one of the Lewis Committee recommendations (see NUREG-0400) following their review of WASH-1400, the Reactor Safety Study.

The Precursor Program uses Licensee Event Reports to evaluate potential nuclear plant accident precursors occurring at operating reactors. These individual plant precursors are then summarized to evaluate the risk (for a particular time period) from all operating nuclear power plants.

The Report covers the period from 1969 to 1979, and the estimate is between 1.7×10^{-3} and 4.5×10^{-3} per reactor year. This estimate includes contributions from three major events: (i) the loss of feedwater and the stuck-open relief valve at Three Mile Island Unit 2 (which actually resulted in severe core damage), (ii) the loss of non-nuclear instrumentation at Rancho Seco, and (iii) the fire in the cable spreading room at Browns Ferry 1. The Report was released as a progress report with the expectation that some of its conclusions might need to be changed as the report undergoes continuing peer review and public comment. This information relates directly to issues on the probability of accidents for nuclear power reactors. Since it estimates the probability to be much higher than past studies, it appears to put a different light on the issue. The results of the Precursor Program are set forth in NUREG/CR-2497.

Furthermore, the plant specific Probabilistic Risk Assessments (PRA's) being prepared for the Indian Point and Zion plant sites appear to be relevant to Byron. Finally, the findings of the NRC's Interim Reliability Evaluation Program (IREP), TMI Action Plan Items II.C.1 and II.C.2, as well as the results of the risk assessment-systems interaction, TMI Action Plan Item II.C.3 appear relevant to identifying credible accident mechanisms. However, it should be noted that a Byron plant specific, site specific PRA and systems interaction study offers more potential insights for Byron than the generic PWR studies referenced herein. Such Byron site specific, plant specific studies should be provided by CECO to the Board, the NRC, and all parties in the OL proceeding prior to the completion of the operating license hearing.

2(b) See the documents referred to in the response to Interrogatory 2(a); see also the January, 1980 draft study performed by Sandia Laboratories for the NRC titled, "Effect of Liquid Pathways on Consequences of Core Melt Accidents."

2(c) The documents referred to in the responses to Interrogatory 2(a) and 2(b) are themselves the best source of the response to this Interrogatory. In addition, see the discussion at paragraphs 3.4.1 through 3.4.9 of the Affidavit of Richard B. Hubbard and Gregory C. Minor (a copy of which has previously been provided to Edison and the Staff) and see also NUREG/CR-0400; the NRC Statement of Policy issued on January 19, 1979 concerning the Risk Assessment Review Group Analysis of WASH-1400; NUREG-0642; and NUREG-0625.

2(d)(e) The League is endeavoring to locate, but has not yet located, its copies of the documents referred to in Interrogatories 2(d) and 2(e). The League will continue in its efforts and will produce the documents promptly when they are located.

Interrogatory No. 3:

With reference to Contention 19, (a) identify the "[r]ecently developed information" referred to in the first sentence thereof; (b) identify the "Information" referred to in the third sentence thereof and which allegedly shows that "evacuation regarding Byron in an acceptable time cannot be accomplished;" (c) identify the "other emergency measures" referred to in the eighth sentence of Contention 19; and (d) identify and produce all documents which constitute, refer or relate to the "information" identified in your answers to subparts (a) and (b) of this Interrogatory.

Response to No. 3:

3(a) See NUREG-0625. As is apparent from NUREG-0625, the siting of Byron within 17 miles of the City of Rockford mandates sound and effective emergency evacuation procedures for the reasons noted therein, as is the case with a number of other plants for which construction permits were issued prior to the recent intensive NRC review — supported by (among others) the ACRS — of siting policy. In this regard, see also pages 15-17, 38-40, and 76-77 of the Kemeny Commission Report and pages 129-30 and 133 of the NRC Special Inquiry Group Report concerning the TMI-2 accident and the deficiencies revealed in then-existing emergency planning and evacuation criteria.

3(b) The Byron Station Emergency Plan Annex clearly documents the fact that, based simply upon population size and location as well as the availability of possible escape routes, Byron and its environs could not possibly be evacuated in a time period which could even approach being considered acceptable.

There are a total of five recreational areas to be found within Byron's three-mile Low Population Zone ("LPZ") alone. Thus, this comparatively small region may at times contain a total permanent and transient population of up to 13,000 people. Similarly, the ten-mile evacuation zone ("EZ") may itself contain a permanent and transient population numbering as high as 68,000 people. Byron Station Emergency Plan Index, p. BYA 1-7.

Page BYA 6-9 of the Byron Station Emergency Plan Annex contains a map of the ten-mile evacuation zone. This map shows only two thoroughfares, German Church Road and Highway 2, which have been designated escape routes for the 68,000 people potentially within the zone at the time of an emergency requiring evacuation. Both designated escape routes are winding, two- ‹e roads, and many of the turns along Highway 2 are not even banked.

Obviously, a large number of vehicles would be traveling these two roads during any evacuation. It therefore becomes inevitable that a traffic accident, a mechanical breakdown, or even a simple flat tire would substantialy disrupt or halt altogether any attempted evacuation under even the best of circumstances.

Furthermore, based upon the history of emergency planning, it is unlikely that the best of circumstances will obtain during an evacuation insofar as having a prepared citizenry is concerned, despite the language of Byron Safety Evaluation Report ("SER"), Appendix D, p. D-21, sub-paragraph 10.

Sub-paragraph 10 states "within one year before the issuance of the operating license for full power operation [Commonwealth Edison ("CECO") must] successfully complete a full-scale [evacuation] exercise." Yet, when the first emergency preparedness drill was conducted at the Zion station in July, 1981, Mr. Chuck Jones of the Illinois Emergency Safety and Disaster Agency stated, "It would be detrimental to have a large-scale evacuation [drill]. People would panic, there would be traffic accidents. We don't have the manpower here to handle that sort of evacuation. This is a controlled group and what we're testing are the agencies involved...." "Nuke Accident Planned for Byron," Rockford Register Star, August 2, 1981. To further compound the problem, there is no indication on the designated escape routes, German Church Road and Highway 2, of potential bottleneck locations, steep grades, restricted bridges and roads or possible hazards caused by the adverse weather conditions which are known to occur in the Byron area such as floods, ice, snow and fog.

Even the notification system proposed for use in an emergency situation is insufficient and would only further exacerbate the evacuation problem. CECO has indicated in a January 18, 1982 letter to the Nuclear Regulatory Commission Staff that the planned notification system consists of a combination of fixed and mobile sirens. CECO anticipates notifying those people within a 10-50 mile radius of Byron with either (1) existing or additional sirens or (2) mobile sirens/public address systems. Yet the Rockford metropolitan area lies within the 50-mile ingestion zone and clearly the proposed notification system would be woefully inadequate in reaching the approximately 204,000 people living in that metropolitan area. Furthermore, the southern portion of Rockford whose population will be "notified" in the same manner as other areas, lies within the possible plume pathways which could extend 15 miles according to Byron FES Appendix F, p. F-2.A. Only one hour delay time is proposed for notification according to Appendix F.

Furthermore, CECO has yet to "establish formal letters of agreement with appropriate agencies and organizations including law enforcement, ambulance services, medical and hospital support, fire departments, and state and local authorities responsible for implementation of protective measures for the public. Byron SER, Appendix D, "Emergency Preparedness Evaluation Report," p. D-20. The implementation of an acceptable evacuation plan is simply impossible without agreements — including, because of Byron's geographic location, interstate agreements with Wisconsin — which specify the emergency measures to be provided the Licensee.

Finally, the conclusion section of the Byron SER, Appendix D, lists 11 improvements which the NRC Staff <u>itself</u> believes are necessary to meet the planning standards of 10 CFR 50.47(b) and the requirements of 10 CFR 50, Appendix E.

3(c) Ideally, foremost among "other emergency measures" should be additional containments such as a vented, filtered containment, or other applicable design changes necessary to reduce the magnitude of the release or to lengthen the time over which a release might occur.

Additionally, there should be studies conducted and any resulting recommended measures for sheltering exposed and potentially exposed victims should be implemented. These measures should include the following:

1. The distribution of potassium iodide pills ("KI") to all families living within the 10-mile EPZ, and the stockpiling of KI within the 50-mile ingestion zone. The value of KI as a blocking agent has long been recognized. Some 15,000 pills were distributed by the Illinois Department of Nuclear Safety in the areas around four nuclear power plants in Illinois during 1981. The FDA has recommended that KI be stockpiled near all nuclear reactors in the United States, and Great Britain has stockpiled KI around its reactors for years.

Such stockpiling is necessary to ensure rapid distribution in the event of an emergency because KI must be taken before or at the time of exposure for it to be effective in blocking the uptake of radioactive iodine into the thyroid gland. Consequently, the stockpiling would have to be organized in a manner which would allow supplies to be located within a half-mile of all individuals living or working within the 50-mile ingestion zone. The cost of such a program has been estimated to be only $.05 per person with the assumption of a three-year shelf life and an average residence occupancy figure of three persons. Many utilities now store KI on site in order to comply with the requirements of NUREG-0654;

2. All hospitals, parks, nursing homes, and recreational centers within the EPZ should have available on-site equipment capable of measuring radiation levels exceeding the standards listed in 10 CFR, Part 20. This equipment should include filter samplers, film badges, electronic dosimeters, and alarms activated by a prescribed radiation level;

3. All hopsitals, nursing homes, schools and other public buildings, as well as workplaces within the EPZ, should be equipped with radiation sensors which would automatically disconnect the air-conditioning system when radiation levels exceed prescribed limits;

4. All hospitals and other health facilities within the 50-mile ingestion zone should be equipped with decontamination facilities. Mobile decontamination facilities should be provided for large-scale accidents, which regular facilities would be unable to handle;

5. All recreational and outdoor areas within the 10-mile EPZ should be equipped with sheltering facilities capable of providing stores of non-radioactive food and water;

6. Radiation levels should be measured on-site and off-site by monitors linked to an on-site computer which would determine when an emergency situation had occurred based on the measured levels of radiation. The computer would then automatically notify every radio and television station within the 50-mile EPZ so that the media could, in turn, alert the populace;

7. Carefully planned, comprehensive educational material should be distributed before an emergency occurs. This material should include a map such as was suggested by the United States Environmental Protection Agency in the Byron FES, Appendix A, p. A-21;

8. Transportation problems with the 17 schools located in the EPZ should be carefully planned because the available school buses serve more than one school and provisions would have to be made for the parents to pick up their children.

Other measures may be identified once the integrated CECO on-site and local (county and State of Illinois) off-site Emergency Plans are completed and available. However, as noted in Section 13.3 of the Byron SER, the "off-site state and local entities within the emergency planning zones have not submitted their plans." Discovery and the League's own investigation are continuing and as more facts are ascertained, the answers to Interrogatory 3 may be expanded by supplemental answers.

3(d) The following documents constitute, refer or relate to the "information" identified in the answers to subparts (a) and (b) of Interrogatory 3, and all have been previously furnished to or by CECO or are in the public domain:

Byron Station Emergency Plan Annex;

Byron SER, Appendices A, D and F;

"Emergency Planning for Reactor Accidents," Jan Beyea, BULLETIN OF THE ATOMIC SCIENTISTS (December, 1980);

Letter from Eric Jones, Director of Illinois ESDA to Robert Ryan, Director, Office of State Programs, NRC;

"Nuke Accident Planned In Byron," Rockford Register Star, (August 2, 1981);

Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency; Changes to Labeling Guideline, Food and Drug Administation, 44 Fed.Reg. 48237 (1979);

Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency; Draft Recommendations on Use, Food and Drug Administration,. 46 Fed.Reg. 38, 189 (1981);

Potassium Iodide as a Thyroid Blocking Agent in a Radiation Emergency, 43 Fed.Reg. 58798 (1978);

"State Hands Out Disaster, Four Nuclear Areas 'Dosed'," The News-Sun (January 5, 1982);

"Emergency Plans Made Mandatory After Three Mile Island," Education Week (April 14, 1982);

NUREG-0553, Beyond Defense in Depth;

NUREG-0654, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Nuclear Power Plants;

NUREG-0696, Functional Criteria for Emergency Response Facilities, Final Report;

"Nuclear Power and Nuclear Safety: Illinois Style," Illinois Dept. of Nuclear Safety, News Release (January 7, 1982);

"Public Citizen Calls for Immediate Stockpiling of Potassium Iodide to Protect the Public in the Event of a Nuclear Accident," Public Citizen;

"Stockpiling Potasium Iodide for Radiation Emergencies," Comments of Public Citizen Critical Mass Energy Project and Public Citizen Health Research Group on FDA's Draft Recommendations.

Interrogatory No. 4:

With reference to Contention 22, (a) identify all other plants where there presently exists an "extremely serious problem" of degradation of steam generator tube integrity and describe the specific nature of the "problem"; (b) for each of the plants identified in your response to part (a) of this Interrogatory, identify both the differences and the similarities between the identified plant and the Byron plant, in relation to (i) materials in the secondary system; (ii) secondary water chemistry control, and (iii) operating procedures; (c) identify each fact which would tend to indicate the "serious problem" referred to in the first sentence of the Contention is "likely to occur at CE's Byron Plant"; (d) identify what would constitute an adequate resolution at Byron of the problem referred to in the last sentence of this Contention; and (e) identify and produce all documents which support your answers to parts (a), (b), (c) and (d) of this Interrogatory.

Response to No. 4:

4(a) A detailed summary of steam generator problems and failures through November 1981 can be found in NUREG-0886, Steam Generator Tube Experience (Feb. 1982). Byron is to be equipped with Westinghouse Model D steam generators and a list of problems arising specifically with Westinghouse steam generators is contained in NUREG-0886 under Table 1, "Operating Experience With Westinghouse PWR Steam Generators Through November 1981." Additionally, definitions of these problems and further details of each reported failure are also contained in NUREG-0886 at pages 1 to 28.

Problems which have been experienced with foreign pressurized water reactor steam generators, including 19 units of Westinghouse design, are detailed in Table 4 of NUREG-0886. Table 4 contains the same kinds of information as Table 1 of the report.

The nature of the problem experienced at each of the plants listed in Tables 1 and 4 is clearly identified in those tables. The reported problems consist of wastage or other wall thinning, steam corrosion cracking initiated from the inside diameter at the u-bends, fretting and denting.

4(b) The Byron steam generators are described in the FSAR, Section 5.4.2 and the NRC's review is documented in the Safety Evaluation Report, pages 5-19 through 5-22. The Byron steam generators are specified to be Model D. Tube material is Inconel-600. The secondary water chemistry control at Byron is to be all volatile treatment (AVT). The League does not currently have access to the Byron operating procedures but will be obtaining whatever is available at this time through discovery.

The steam generator model numbers, secondary water chemistry control, and tube material for all of the steam generators listed in NUREG-0886 are identified in Table 1 and/or Table 4. This material covers the steam generators associated with 53 Westinghouse units.

4(c) The fact that steam generator problems have been, currently are, and will continue to be serious problems at Westinghouse pressurized water reactors is well evidenced by the NRC's designation of this problem as an "UNRESOLVED SAFETY ISSUE". This is discussed in the Byron SER Appendix C at C-9 and 10. Further extensive discussion of this problem is contained in A February 18, 1982 memorandum by William J. Dircks (NRC Executive Director for Operations) identified as SECY-82-72 to which was attached a February 1982 Steam Generator Status Report. This information was previously provided in response by LWV to the first round of Interrogatories of Commonwealth Edison Company.

Numerous discussions of this problem and information were filed by the parties in conjunction with CECO's Motion for Summary Disposition on DAARE-SAFE Contentions 9(a) and 9(c). Affidavits were filed by CECO and by the NRC Staff as well as the Intervenors. This information discusses the problems currently being experienced and investigated on Westinghouse Model D steam generators with respect to the phenomenon of bubble collapse water hammer and with flow induced vibration and tube wear. The Board's findings that the Westinghouse Model D problems are to be further considered is certainly indicative that this is considered to be a "serious problem" and certainly not one that can be dismissed at this time. Extensive documentation exists in the industry literature discussing these problems, all of which literature is readily available to CECO.

4(d) An adequate resolution of the problem of steam generator tube degradation would necessarily be one which reached the root causes of the problem. However, such "[a]n effective solution would require major changes in S.G. mechanical design, thermal-hydraulics, material selection, fabrication techniques and changes in the secondary design and operation... There are no simple corrective actions." February 1982 "Steam Generator Status Report," an attachment to February 18, 1982 Memorandum by William J. Dircks, NRC, SECY-82-72.

The discovery process and the League's own investigation of the subject areas of Interrogatory 4 are continuing. As additional facts are ascertained they will be supplied by supplemental answers to this Interrogatory.

4(e) In addition to the FSAR and the Byron Safety Evaluation Report the folowing documents are relevant to and support this Contention:

NUREG-0886, Steam Generator Tube Experience

February 18, 1982 Memorandum by Wiliam J. Dircks, NRC, SECY-82-72 with Attachment February 1982 Steam Generator Status Report

NUREG-0909, NRC Report on the January 25, 1982 Steam Generator Tube Rupture at the R. E. Ginna Nuclear Power Plant, April 1982

NUREG-0523, Summary of Operating Experience with Recirculating Steam Generators, January 1979

NUREG-0571, Summary of Tube Integrity Operating Experience with Once Through Steam Generator, March 1980

November 24, 1981 Memorandum from W. J. Dircks, SECY-81-664

NUREG/CR-0175, Investigation of the Influence of Simulated Steam Generator Tube Ruptures During Loss of Coolant Experiments in Semi-scale MOD1-1 Systems, May 1978

All other reports and documents referenced in LWV's Response to First Round of Interrogatories of Commonwealth Edison Company with regard to Contention 22.

Other documents yet to be obtained through discovery.

All of the above referenced documents are in the public domain and quite likely already in the possession of Commonwealth Edison Company. Any documents not available to CECO will be supplied on request.

Interrogatory No. 5:

With reference to Contention 32, (a) specify what would constitute "adequate qualification methods with which to satisfy the objective of the requirement that all safety-related equipment conform to the requirements established in IEEE Standard 323-1974"; (b) identify and produce all documents which support your answer to subpart (a) of this Interrogatory; and (c) identify each factual issue which this Contention purports to raise which is not encompassed within Contentions 61 or 77.

Response to No. 5:

5(a) The concern for the qualification of safety-related equipment is broader than just that equipment be subject to IEEE 323-1974. The issuance of IEEE 323 highlighted the qualification problem for Class IE electrical equipment and the definitions and provisions in the IEEE Standard do serve to describe the scope and methods which are possible. However, the list of methods is not an exhaustive one because there is no single answer applicable to the qualification of all equipment.

IEEE 323 sets out the overall goal of equipment qualification within the very definition of the term: "Equipment qualification. The generation and maintenance of evidence to assure that the equipment will operate on demand, to meet the system performance requirements." IEEE 323-1974, p. 8.

Following this definition is the non-exclusive list of qualification methods.

> Qualification may be accomplished in several ways: type testing, operating experience, or analysis. These may be used individually or in any combination depending upon the particular situation. In the first, it is expected that the equipment will be subjected to the environments and operating conditions for which it was designed and its performance measured. In a test program, it is usually practical only to simulate environments and operating conditions. The limitations in such simulations, the abbreviation of exposures permitted by increasing the severity of the environment, and the validity of data extrapolations must be taken into account in the design of the test. IEEE 323-1974, p. 8.

Meeting these qualification requirements for Class IE equipment has always been a problem, as was noted by the NRC while designating it generic safety task A-24 in NUREG-0410 and still later in NUREG-0371, Rev. O, November, 1977, TAP A-24, wherein the NRC stated:

> It is the NRC position that construction permit applicants for which a Safety Evaluation Report was issued after July 1, 1974, are required to qualify all safety related equipment to the requirements established in IEEE Standard 323-1974, IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations..
>
> From the conception of the standard, industry has been developing methods that will be used to qualify their equipment in order to satisfy the objectives of the standard. Certain proposed concepts and methods used by industry in addressing equipment qualification, such as testing margins, aging effects on materials and equipment, and adequacy of testing simulators, which simulate the worst case environment for the equipment have not yet been resolved.

Unfortunately, the issue of what constitutes proper qualification methods is stil not fully resolved and the implementation of a resolution of A-24 is still incomplete.

One example of the problems with the current methods of qualification is the issue of aging. In order to account for the aging of equipment, the effects of aging must be qualified and the qualified life must be defined. The industry has had difficulty in obtaining a clear indication of "qualified life" and the methods for assessing aging effects are still being studied. Two recent reports highlight the problem of the aging of electrical insulation in radiation and temperature environments. These reports indicate that there may be a greater effect on the insulation due to long exposure to low level radiation than to short exposure to high levels of radiation. NUREG-

CR-2156: Radiation-Thermal Degradation of PE and PVC: Mechanism of Synergism and Dose Rate Effects, Sandia Laboratories, June 1981; NUREG-CR-2157: Occurrence and Implications of Radiation Dose-Rate Effects for Material Aging Studies, Sandia Laboratories, August, 1981. Thus the expected reduction of qualified life due to aging effects may be greater than had been previously thought.

Additionally, the resolution of the environmental qualification issue may take longer than expected. The previous deadline for complying with qualification requirements in CLI-80-21 and NUREG-0588, Interim Staff Position on Environmental Qualification of Safety-Related Electric Equipment, July 1981 was June 30 1982. The NRC issued a rule on June 30, 1982, 47 Fed.Reg. 28363 (June 30, 1982) which withdrew the deadline of June 30, 1982. This issue is further complicated by a proposal to extend the deadline to March 1985. However, the Union of Concerned Scientists has taken the NRC to court asking that they reinstate the previous deadline (Nucleonics Week, September 23, 1982, p. 6, 7.).

Finally, there is a growing uncertainty as to whether all the necessary equipment is being qualified. The NRC in a recent memorandum established a new category of equipment called "important-to-safety." This now exists in addition to the old category of equipment called "safety-related." See Denton Memo, November 20, 1981, Subject: Standard Definitions for Commonly-used Safety Classification Terms. There is no assurance that Byron has classified and qualified the equipment for both the important-to-safety and safety-related classificatins. Given the newly-differentiated terms, the words of Contention 32, the related qualification contentions should have been written and should now be construed to cover all important-to-safety equipment.

As discovery and the League's own investigation continue, additional material on Interrogatory no. 5 may be supplied by supplemental answers.

5(b) The documents used and referenced in response to Part (a) of Interrogatory 5 are all in the public domain and most are available directly from the NRC.

5(c) Contentions 32, 61 and 72 are related but not identical. Where 61 references the TMI experience as an indication of a particular problem in the environmental range used in the qualification of equipment, and 77 refers specifically to the problem with aging and related seismic requirements, the issue in 32 is much broader in that it includes the entire issue of qualification methodology and its timely application for Byron.

Interrogatory No. 6:

With reference to Contention 34, (a) identify each inadequacy in the provision for overpressure protection at Byron; and (b) identify and produce all documents which support your answers to subpart (a) of this Interrogatory.

Response to No. 6:

6(a) The primary inadequacy identified to date is CECO's apparent failure to fully classify the pressurizer relief valves (PORV) as components important to safety in all respects. This makes the two PORV's used for low temperature overpressure protection of the reactor coolant system susceptible to a potential common mode failure. This susceptibility is described in the SER Section 5.2.2.2, Low Temperature Operation.

CECO has proposed to overcome this inadequacy by use of required operator action following receipt of alarms indicating an overpressurization event. Operator action following receipt of alarms could be required within 10 minutes if a steam bubble is present within the RCS and would be required in lesser periods of time if the system is water solid. We believe this situation is representative of an inadequate design and should be rectified by design changes which would obviate the common mode failure susceptibility.

The second inadequacy in the overpressure protection system is the reliability of PORV's during operational transients. This concern was thoroughly discussed in LWV's Response to CECO's First Round of Interrogatories under Contention 34 and the information contained therein is adopted here by reference. The issues basically center around poor reliability of PORV's, failure of CECO to classify the PORV control system as safety-related, and the failure of CECO to fully perform the testing of safety relief valves and to qualify them under plant specific conditions as required by NUREG-0737.

6(b) As discovery and the League's own investigation continue, material under Interrogatory 6 may be supplied by supplemental answers. All documents currently being relied on are identified in LWV's earlier response to CECO First Round of Interrogatories, Contention 3. Those responses are incorporated herein by reference. All should be available to CECO. Copies will be furnished to CECO if they are not.

Interrogatory No. 7:

With reference to Contention 39, (a) identify each deficiency alleged to exist in the method of evaluating and analyzing radionuclide sediment transport through the hydrosphere in the Environmental Report for Byron; (b) identify the relationship, if any, between the "serious and unresolved problem" referred to in the last sentence of this Contention and the findings required by 10 CFR Sections 50.57(a)(3)(i) and 50.57(a)(6); and (c) identify and produce all documents which support your answers to parts (a) and (b) of this Interrogatory.

Response to No. 7:

7(a) The fundamental deficiency which is currently identifiable in the evaluation of radionuclide transport at Byron is the complete lack of any effective, field-tested methodology with which to analyze the problem. Of course, such methodology would also have to be adaptable for site-specific use which in the instant case would mean being capable of being made Byron site-specific. Without the creation of this methodology, no effective safety measures can ever be instituted, particularly since none of the numerous conditions unique to the Byron site would ever be accounted for in the measures which might be planned. Ironically, this is true despite the fact that interdictive measures are not only feasible (see "Effect of Liquid Pathways on Consequences of Core Melt Accidents," Scandia Laboratories [January, 1980] [Draft]), but are also absolutely necessary for the safe operation of the Byron plant. Unfortunately, with current construction methods and technology, once the plant is completed it may be too late to implement any of the available safeguards.

This lack of a proper hydrogeologic analysis was discussed in the League's Answers to CECO's First Round of Interrogatories in response to an Interrogatory also dealing with Contention 39. That discussion is incorporated herein by reference.

Obviously, since no effective, field-tested methodology exists, CECO's current analysis of the Byron hydrogeologic situation is deficient, both in its theoretical basis and in the application of the theory to the on-site conditions. The theoretical basis fails because, as was noted in the League's earlier answer, CECO's "treatment" in the Byron FES of the hydrogeologic situation was not based upon conditions at the Byron site, but upon NUREG-0440 which was, in turn, not based upon conditions of any real site. The FES did explain that NUREG-0440 had relied upon the "Rasmussen Report" (WASH-1400) which had been at least partially discredited, but then the FES failed to note that the portion of NUREG-0440 on which CECO was basing its analysis of the Byron water pathways problem was one of the precise portions which had been premised on the discredited findings of the Rasmussen Report.

Specifically, the relevant fault lay in the Rasmussen Report's analysis of the effect of a meltdown on a river. The Report concluded that a meltdown would not result in a significant release of radioactivity into a river with a flow of 13,000 CFS. Yet the Report's own data show that the release of radioactive strontium, the isotype which poses the greatest hazards, would be 7.4 times greater than the federal limits on routine emissions allow.

In addition to the inadequacies of NUREG-0440 resulting from its reliance on the Rasmussen Report, NUREG-0440 was also written before the events at TMI-2 and thus its conclusions were founded on the assumption that a very severe core melt accident was unlikely, an assumption now demonstrably incorrect. Given these "deficiencies" in NUREG-0440, it is clear that even the cursory handling of the Byron water pathways problem which has been indulged in by CECO is flawed at its very foundation. Not only does CECO lack a site-specific model for Byron, but the generic model on which CECO has relied is virtually useless.

Even assuming the theory itself had been sound, those significant conditions which are unique to the Byron site rendered the NUREG-0440 small river evaluation inapplicable to any analysis of the Byron site. See Byron FES, Appendix A, p. 21, USEPA Comments, Accident Risk Impact Asssessment. These site-specific conditions include the rate of flow of the Rock River, which is less than that of the river analyzed in NUREG-0440.

Additionally, this rate of flow is variable. There is a dam on the river several miles south of Byron at Oregon which slows its flow and the occurrance of ice jams, drought conditions, and pools in the river where fish kills have occurred also alter the rate of flow and could result in the accumulation of sediment and radionuclides.

Furthermore, there is a toxic waste site already in existence at the Byron site and there has been no analysis of the possible synergistic effects which could result from a combination of radionuclides and the on-site toxic pollutants in the groundwater. See FES, Appendix A, p. A-40, "Letter from Office of Nuclear Reactor Reg."; Ill.EPA, Div. of Water Pollution, An Intensive Water Quality Survey of the Rock River from Rockford to Byron, Illinois (May-October, 1978) (see particularly the information on the unnamed tributary 5.2 miles upstream from Byron).

NUREG-0440 pointed out that the existence of cavernous limestone under a nuclear plant could affect the rapidity of contamination of groundwater by radioactive releases. The Byron plant rests upon porous fractured limestone. CECO has attempted to grout the site in an apparent attempt to slow the dispersal rate, but no study has been done of the long-term effects of this process. Despite these uncertain and potentially disastrous conditions, no groundwater model has been constructed according to the Environmental Statement, p. 25, 2-5; See FES, Appendix A (USEPA Comment on need to assess drinking water pathway status).

The related question of flooding was discussed in both the FES and the SER, and both admitted that flooding could present problems at Byron. However, no analysis has been performed of any combined flooding and seismic event, either with or without an accident.

From the above discussion, it is clear that no worthwhile study of the water pathways issue at the Byron site has been or can be performed. Such an analysis would require, in addition to the inclusion of the conditions detailed above, an accounting for sediment interaction, residence time in water, sedimental patterns and rates, biota present and bioaccumulation, shoreline data and seasonal data. Until such a study is completed, no effective measures can be taken to eliminate the spread of radionuclide sediments through the Byron water pathways.

7(b) The "unresolved problem" refered to in Contention 39 is the lack of any field tested radionuclide/sediment transport model with which to determine the effect of sediment and aquifer materials on radionuclide transport through the hydrosphere. More particularly, there is no Byron site-specific model.

As stated in the answer to part 7(a), without such a model no proper assessment can be made of the full extent and the true nature of the problem at Byron. As a result, no adequate preventative measures can be adopted prior to the completion of construction which will block the release of radionuclides into the hydrosphere.

Both 10 CFR Section 50.57(a)(3)(i) and Section 50.57(a)(6) require that the plant be shown to be operable without endangering the health and safety of the public. The relationship which exists between the "unresolved problem" and these statutory provisions is simply that without the construction of a proper analytical model of the problem and without the resulting adoption of appropriate countermeasures to enable to plant to fully operate within the parameters of Section 50.57, the plant may never be licensed. This situation obtains because once the plant is completed and is ready for final licensing, it may be too late to implement the necessary safety features, even if they were to be ascertained, in order to prevent hydrospheric contamination and, hence, the plant may be forever unlicensable.

7(c) All documents used in this answer are referenced at the appropriate points in the text. These documents are all in the public domain or were originally furnished by CECO or the NRC and are, therefore, available to CECO.

The League's investigation and the discovery process continue. Additional facts may be supplied in response to this Interrogatory or supplemental answers.

Interrogatory No. 8:

With reference to Contention 41, (a) identify each safety related water supply at the Byron Station which is subject to ice build-up; (b) with respect to each safety related water supply identified in response to subpart (a) of this Interrogatory, identify the manner in which such water supply would be affected by ice buildup; (c) identify what would constitute an adequate resolution of the problem referred to in the last sentence of this Contention; and (d) identify and produce all documents which support your answers to parts (a) and (b) of this Interrogatory.

Response to No. 8:

8(a)(b) The concern for ice build up is with the make up sources. Specifically, this refers to the river, the intake canal, and screen house where make up water is obtained. In view of the low flow in the Rock River, serious ice build-up is conceivable and recent winter weather conditions have demonstrated long periods of cold weather are quite probable in the area of the plant site. The on-site wells would be less subject to icing as would the cooling towers.

8(c) Resolution of this problem for Byron would include insuring that the requisite days supply of make-up water was available independent of predictable natural phenomena.

8(d) The documents referenced are all in the public domain, available through the NRC or already in the possession of CECO.

Interrogatory No. 9:

With reference to Contention 42, (a) identify the new information on low-level radiation effects referred to in this contention and (b) identify and produce all documents that refer to and support our contentions.

Response No. 9:

9(a) New information on the effects of low-level radiation exposure is contained in the following recent publications by Dr. Karl Z. Morgan:

1. Morgan, K.Z., "The Need for Radiation Protection," RADIOLOGIC TECHNOLOGY 44, 6, 385 (1973).

2. Morgan, K.Z., "Yes is the Answer to Question of R.H. Thomas and D.D. Rusick, 'Is It Really Necessary to Reduce Patient Exposure?'", AM. INDUSTRIAL HYG. ASSN. J. 37, 665 (1976).

3. Morgan, K.Z., "Cancer and Low Level Ionizing Radiation," THE BULLETIN OF ATOMIC SCIENTISTS 34, 7, 30 (September 1978); also Proc. 4th International Summer School, Dubrovnik, Yugoslavia.

4. Morgan, K.Z., "The Non-Threshold Dose-Effect Relationship," given before Academy Forum of the National Academy of Sciences, Washington, D.C. (September 27, 1979).

5. Morgan, K.Z., "Mogliche Folgen einer Ubermassige Medizinischen Strahlen-belastung in den Vereinigten Staaten von Amerika," Rontgen-Blatter, Stuttgart (March 1974).

6. Morgan, K.Z., "Significance of Human Exposure to Low-Level Radiation," CONGRESSIONAL RECORD, Washington, D.C. (January 24, 1978).

7. Morgan, K.Z., "Radiation Risks from Nuclear Power: Final Round," NEW ENG. J. OF MEDICINE 303, 11, 645 (August 1, 1980).

8. Morgan, K.Z., "Appreciation of Risks of Low-Level Radiation Versus Nuclear Energy," COMMENTS ON MOLECULAR AND CELLULAR BIOPHYSICS, 1, 1, 419 (1980).

9. Morgan, K.Z., "Risk Assessment of Exposure to Ionizing Radiation — Another View," presented before American Nuclear Society, Miami, Florida (June 8, 1981).

10. Morgan, K.Z., "Medical Implications of Fallout," presented at conference in Albuquerque, New Mexico (September 25-26, 1981).

11. Morgan, K.Z., "Risks of Nuclear Power Plant Accidents and Consequences on Population and Biosphere," Colloquium on Energy and Society, Paris, France (September 16-18, 1981).

12. Morgan, K.Z., "The Linear Hypothesis of Radiation Damage Appears To Be Non-Conservative in Many Cases," proceedings of IV International Congress of IRPA 2, 11 (April 24-30, 1977).

13. Morgan, K.Z., "Radiation Dosimetry," SCIENCE 213, 604 (July 3, 1981).

14. Morgan, K.Z., "Comparison of Radiation Exposure of the Population from Medical Diagnosis and the Nuclear Energy Industry," presented at American Nuclear Society meeting, Las Vegas, Nevada (June 18-22, 1972).

15. Morgan, K.Z., "ESC, AIF, EPI Conference on Low-Level Radiation," Conference in Dirkson Senate Office Building, Washington, D.C. (February 10, 1978).

16. Morgan, K.Z., "The Purpose of Radiation Protection Monitoring," Proc. of IAEA Conference, Vienna, Austria (1979).

17. Morgan, K.Z., "Radiation Induced Cancer in Man," CONGRESSIONAL SEMINAR, John Glenn chairman, U.S. Senate, Washington, D.C. (March 6, 1979).

18. Morgan, K.Z., "Reducing Medical Exposure to Ionizing Radiation," AM. J. INDUSTRIAL HYGIENE 358 (May, 1975).

19. Morgan, K.Z., "Decommissioning of the Gorleben Facility," testimony before Gorleben, Germany Hearings (March, 1979).

20. Morgan, K.Z., "Hazards of Low-Level Radiation," ENCYCLOPEDIA BRITANNICA, 216 (1980).

21. Morgan, K.Z., "Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements," AM. IND. HYGIENE ASSN. J., 567 (August 1975).

22. Morgan, K.Z., "Risk of Cancer from Low Level Exposure to Ionizing Radiation," paper presented before AAAS, Washington, D.C. (February 17, 1978).

23. Morgan, K.Z., "How Dangerous is Low Level Radiation?" NEW SCIENTIST (April 5, 1979).

24. Morgan, K.Z., "The Dilemna of Present Nuclear Power Programs," presented at hearings before the Energy Resources Conservation and Development Commission, Sacramento, California (February 1, 1977).

25. Morgan, K.Z., "Significance of Human Exposure to Low-Level Radiation," CONGRESSIONAL RECORD (January 24, 1978).

26. Morgan, K.Z., "Radiation Induced Health Effects," SCIENCE 195, 344 (January 1977).

27. Morgan, K.Z., "The Particle Problem," Proc. of 3rd International Summer School on Radiation Protection, Boris Kindrick Institue (September 2, 1976).

28. Morgan, K.Z., "Release of Radioactive Materials form Reactors," NUCLEAR POWER SAFETY, Rust & Weaver, Georgia Tech Series IV, Perg. Press (1976).

29. Morgan, K.Z., "Ways of Reducing Radiation Exposure in a Future Nuclear Power Economy," NUCLEAR POWER SAFETY, Rust & Weaver, Georgia Tech series IV, Perg. Press (1976).

30. Morgan, K.Z., "Effects of Radiation on Man — Now and in the Future," ENERGY AND THE ENVIRONMENT - COST BENEFIT ANALYSIS, Karam and Morgan, Georgia Tech Series I, Perg. Press (1975).

31. Morgan, K.Z., "The Bases for Standards and Regulation," ENVIRONMENTAL IMPACT OF NUCLEAR POWER PLANTS, Karam and Morgan, Georgia Tech Series II, Perg. Press (1976).

32. Morgan, K.Z., "Types of Environmental Health Physics Data that Should Be Collected and Evaluated in a Nuclear Power Program," Karam and Morgan, Georgia Tech Series II, Perg. Press (1976).

The above is not a complete list, but perhaps a fair sample of Dr. Morgan's publications and other presentations showing there is and has been for some time a growing awareness that the risks of low-level exposure to ionizing radiation are far greater than was believed a few years ago, and the risks are infinitely greater than perceived when work on ionizing radiation was first begun over fifty years ago. Toward the beginning of World War II, most scientists subscribed to the threshold hypothesis, i.e., that there is a safe threshold level and as long as exposure is kept below this level there is no danger of radiation harm. In approximately 1950, a number of experts began to swing away from this belief and gravitated toward the linear hypothesis. However, it was still widely believed that the absolute cancer risk was not greater than approximately one lethal cancer per 100,000 persons, at low doses and low dose rates. By 1970, most scientists accepted the linear hypothesis and estimates of cancer risk had increased to approximately one lethal cancer per 10,000 persons.

This growing conviction that cancer risk from low-level exposure is greater than was previously believed resulted from many studies of human populations which had been exposed to low level radiation. Particularly convincing in this respect were studies of survivors of atomic bombing of Hiroshima and Nagasaki and ankalosing spondylitis patients treated with ionizing radiation. A problem with such studies, as pointed out in Dr. Morgan's above-referenced works, is that these did not represent normal populations. The ankalosing spondilitis patients were seriously ill and died early of common diseases which favored those who might have in situ malignancies, and there were thousands of early deaths among the Japanese survivers of fire, blast, radiation and diseases who again were selected for early death preferentially if they had an in situ radiation induced cancer such that they did not survive to die of cancer.

Some reports that indicate this progressive concern for the carcinogenesis of low-level exposure include:

1. The reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (1958, 1962, and 1972)

2. The reports of the Committee of the National Academy of Sciences and National Research Council on Effects on Populations of Exposure to Low Levels of Ionizing Radiation or the BEIR Reports I, II and III

3. The reports of the International Commission on Radiological Protection (about 30 altogether)

4. The reports of the National Council on Radiation Protection

5. The Reports of the Interagency Task Force on the Health Effects of Ionizing Radiation (June, 1979)

6. The Reports to the Congress on Problems in Assessing the Cancer Risks of Low-Level Ionizing Radiation Exposure, prepared by the U. S. General Accounting Office (January 2, 1981)

Unfortunately, all six of the above reports accepted the studies of survivors of atomic bombings of Hiroshima and Nagasaki as gospel truth. They did not appreciate the serious biases, a few of which are discussed in Dr. Morgan's above-referenced 32 papers. It is noteworthy that the BEIR Committee never did reach agreement on the magnitude of the radiation risks of low-level exposure and recently errors were found in the Hiroshima Nagasaki dosimetry data (see Morgan's SCIENCE 213 article [August 7, 1981]) which force one to conclude that the doses received at Hiroshima and Nagasaki were only half what was assumed by BEIR III, and the other five committees listed above. Thus the risk of low-level exposure would appear to be at least twice that espoused by the BEIR-III report and the other five committees. Yet all these committees were quick to throw out other human epidemiological studies that did not have these biases and for which dosimetry was the best health physics science could offer — this is particularly true of the Hanford radiation workers study.

(b) A few noteworthy studies that lend strong support to a cancer risk of approximately one lethal cancer per 1000 person rem are listed below. They not only lend support to the linear hypothesis, but go one step further and support the claim that in many cases the data fit a super linear-function better than a linear relationship. Thus in many — Dr. Morgan believes most — cases the risk per rem is greater at low doses than at high doses such that the linear hypothesis underestimates the risk of low level exposure. This means, of course, that the lower the dose, the greater the cancer risk coefficient such that it may be greater than one lethal cancer per 1000 person rem at very low doses. The best fit to the data on Handford radiation workers is six to eight lethal cancer per 1000 person rem.

A few of the reports listed below offer a broader and more accurate picture of the risk of low-level radiation exposure than the above-mentioned six committee repports:

1. Papers of A.M. Stewart, T.F. Mancuso and G.W. Kneale

(a) Stewart, "Delayed Effects of A-Bomb Radiation: A Review of Recent Mortality Rates and Risk Estimates for Five Year Survivors," JOURNAL OF EPIDEMIOLOGY AND COMMUNITY HEALTH 36, 80 (1982).

(b) Kneale, Stewart & Mancuso, "Re-Analysis of Data Relating to the Hanford Study of the Cancer Risk of Radiation Workers," LATE BIOLOGICAL EFFECTS OF IONIZING RADIATION, Vol. 1, IAEA, Vienna (1978).

(c) Kneale, Mancuso & Stewart, "A Cohort Study of the Cancer Risks from Radiation to Workers at Hanford (1944-77) Deaths By the Method of Regression Models in LIfe," TABLES' BRITISH JOURNAL OF INDUSTRIAL MED 38, 156 (1981).

(d) Stewart, "Atom Bomb and Bone Marrow Damage," given in briefing session with NRC (November 21, 1980).

(e) Mancuso, Stewart & Kneale, "Radiation Exposures of Hanford Workers Dying from Cancer and Other Causes," HEALTH PHYS. 33, 5, 369.

2. Original Paper by S. Milham, "Occupational Mortality in Washington State," 3 volumes, NIOSH 76-175.

3. Many publications by I.O.J. Bross and Rosalie Bertell, e.g., "Leukemia from Low-Level Radiation," NEW ENG. JOURNAL (1972). These studies show there is a strong synergistic effect when radiation damage interacts with other factors such as respiratory diseases.

4. J. Rotblat studies showing effects of low-exposure, e.g., BULLETIN #OF ATOMIC SC 41 (September, 1978).

5. E.E. Pockin, "Malignancies Folowing Low-Level Radiation Exposure in Man," BRITISH JOURNAL OF RADIOLOGY 49, 577 (July, 1976).

6. Studies showing a high risk of I-131 exposure:

(a) B. Modan, et al, "Radiation-Induced Head and Neck Tumors," LANCET 277 (February 23, 1974).

(b) C. Silverman and D.A. Hoffman, "Thyroid Tumor Risk from Radiation During Childhood," PREVENTIVE MEDICINE 4, 100 (1975). This paper indicates significant increases in radiation-induced thyroid carcinoma at dose of 6 rad.

(c) F. von Hipple, "The NRC and Thyroid Protection — One Excuse After Another."

(d) L. Schmitz-Feuerhaketh, et al., "Risk Estimation of Radiation — Induced Thyroid Cancer in Adults," LATE BIOLOGICAL EFFECTS OF IONIZING RADIATION, Vol. 1, IAEA (1978).

7. J.W. Baum, "Population Heterogeneity Hypothesis on Radiation-Induced Cancer," HEALTH PHYSICS 25, 97 (August, 1973).

8. A.G. Craig, "Alternatives to the Linear Risk Hypothesis," HEALTH PHYS. 31, 81 (July, 1976). This paper showed one can expect more radiation-induced cancer per rem at low doses than at high doses.

9. M.F. Lyon, et al., "Dose Rate and Mutation Frequency After Irradiation of Mouse Spermatogenia," NATURE NEW BIOL. 238 (July 26, 1972). This paper shows the genetic risk at low dose rates is as great as at high dose rates. This is contrary to conclusion of W.L. Russell's earlier studies.

10. T. Najarian and R. Colton - papers showing increased cancer risk among navy base submarine radiation workers. The most recent NIOSH studies confirm an increased radiation risk from this low exposure.

11. G.M. Matanoski, et al., "The Current Mortality Rates of Radiologists and Other Physician Specialists: Deaths from All Causes and from Cancer," AMER. JOURNAL OF EPIDEMIOLOGY 111, 3, 177 (1975) and 101, 3 (1975).

9(b) The documents referred to in the answer to Interrogatory 9(a) are either furnished herein or are in the public domain.

The discovery process and the League's own investigation continue. As new facts are ascertained, the answer to Interrogatory 9 may be expanded with supplemental answers.

RADIOLOGIC TECHNOLOGY
Copyright © 1973 by the American Society of Radiologic Technologists

Vol. 44, No. 6
Printed in U.S.A.

The Need for Radiation Protection*

Karl Z. Morgan, Ph.D.

Atlanta, Georgia

The amount of exposure to humans through medical uses of radiation continues to be a matter of great concern to the medical and lay public. Studies in the United States show that the average medical diagnostic radiation dose could be reduced by a factor of ten. An optimistic note in bringing about this reduction is seen in the leadership roles taken by radiologic technologists and their professional organization. One of the promising developments is the criticism by radiologists and technologists of their own standards. The radiologic technologist with his goals of improved and standarized educational programs and continued upgrading of his activities will play a major role in bringing about the needed improvements in diagnostic radiology.

NO ONE WILL QUESTION that diagnostic radiography is one of the most valuable tools of the medical profession. However, many persons do not realize that like most conveniences, luxuries and even necessities of modern society, x rays exact a severe price in suffering and human lives. Over 90 per cent of the population exposure to man-made sources of ionizing radiation in the United States derives from medical diagnosis, and, as shown in table 1, the genetically significant dose (GSD) from medical diagnosis in the United States is much higher than that in other countries.[23, 24] We are concerned about the genetically significant dose to our gonads because it causes some of our children, grandchildren and great-great-grandchildren to be born with birth defects, brain damage, and genetically related diseases and many to die an early genetic death. Likewise, we find that the somatic dose from diagnostic radiography in the United States is correspondingly higher than that in other countries, and many persons are particularly concerned about this because it increases the chance that they will die of some form of cancer, or will die an early death from nonspecific diseases and aging.

Although there is evidence of some repair of genetic and somatic radiation damage, a certain fraction of this damage appears to persist as irreparable and to accumulate linearly during the life of an individual as indicated in figure 1. These curves are plotted from data of the International Commission on Radiological Protection (ICRP),[4, 8] which sets the radiation protection standards at the international level on the prudent assumption that there is no safe threshold dose and that the probability of a person dying of one of these forms of damage increases linearly with the accumulated dose. Eye cataracts and acute forms of radiation damage such as skin erythema, acute radiation sickness and radiation death result only after large doses of radiation. The following outline summarizes both the types of radiation damage that relate more or less linearly to the accumulated dose and those which require a threshold dose before they are manifest:

1. Radiation damage relating more or less linearly to the accumulated dose
   a. Genetic mutations (first generation and recessive)
   b. Cancer (including leukemia)
   c. Life shortening
   d. Other biological changes

* Presented at the Southeastern Conference of Radiologic Technologists, Durham, North Carolina, January 22, 1972. Research sponsored by the U.S. Atomic Energy Commission under contract with Union Carbide Corporation. Dr. Morgan is Neely Professor, School of Nuclear Engineering, Georgia Institute of Technology. He was formerly director, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

agencies such as the USHS and EPA, which are charged with providing radiation protection of the public, tremble when they contemplate taking radiation protection measures that might offend the medical professions. Only if you the public act on your own behalf, will you be provided good medical radiography without unnecessary damaging radiation to yourself and your children. Do what you can to encourage your own state to adopt legislation such as that in the state of Illinois. Here the diagnostic exposure limits are set at: (a) 500mR and preferably <350 mR per abdomen A.P., (b) 1400 mR and preferably <1000 mR per lateral lumbar spine, (c) 150 mR and preferably <100 mR per cervical spine, and (d) 400 mR and preferably <200 mR per A.P. skull radiograph. The unnecessary exposure you prevent may be that to yourself.

References

1. Harting, F. H., and W. Hesse: *Vjschr. Gerichtl Med. Offentl Gesundheitswesen 30*, 296; 31, 102 and 313 (1879).
2. Morgan, K. Z., and J. E. Turner: *Principles of Radiation Protection*. Robert Krieger Publishing Co. (1973).
3. Grubbé, E. H.: *Radiology 21*:156 (1933).
4. Stone, R. S.: *Western J. Surg. Obstet. Gynecob. 54*:153, 201 (1946); *Protection in Diagnostic Radiology*. Rutgers Univ. Press, New Brunswick, N.J., (1957). p. 70; *Radiology 58*:639 (1952).
5. ....: *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*. NCRP Handbook 52, Nat. Bur. Std. (1953).
6. ....: *Transportation of Radioactive Material by Passenger Aircraft*. Report No. 1 to the JCAE of the Special Panel to Study Transportation of Nuclear Materials, J. T. Conway, Chairman (Sept. 1974).
7. ....: *Recommendations of the International Commission on Radiological Protection*. Pergamon Press, New York, ICRP Pub. No. 6 (1964).
8. McClenahan, J. L.: Wasted X-Rays. *Radiology 96*:453 (August 1970).
9. Morgan, K. Z.: The Need for Radiation Protection. *Radiologic Technology 44*:385 (1973).
10. Morgan, K. Z.: Possible Consequences of Excessive Medical Exposure in the United States—Mögliche Folgen einer ubermassigen medizinischen Strahlenbelastung in den Vereinigten Staaten von Amerika. *Röentgen-Blatter, Klinik und Praxis, Heft 3*:127, Stuttgart (Marz 1974).
11. ....: *What About Radiation? Mass Chest X-Ray Programs*. USPHS Pub. 1196 (February 1965).
12. ....: *Chest X-Ray Screening Recommendations for TB-RD Associations*. NTRDA Bulletin 57, No. 9 (October 1971).
13. Gitlin, J. N., and P. S. Lawrence: *Population Exposure to X-Rays*. US 1964 BRH-USPHS No. 1519 (1964).
14. ....: *Recommendations of the International Commission on Radiological Protection*, New York, Pergamon Press, Pub. No. 1 (Sept. 9, 1958).
15. Bross, I. D. J.: Leukemia from Low-Level Radiation. *New Eng. J. Med. 287*:107 (July 20, 1972).
16. Baum, J.: Population Heterogeneity Hypothesis on Radiation Induced Cancer. given orally at Houston, Tex. meeting of the Health Physics Society, July 10, 1974.
17. Muller, H. J.: Radiation and Heredity. *Amer. J. Pub. Health*, Sup. to Vol. 54, 1 (1964).
18. Russell, W. L.: Studies in Mammalian Radiation Genetics. *Nucleonics 23*:53 (Jan. 1965).
19. ....: *Report of the Advisory Committee on the Biological Effects of Ionizing Radiation*. BEIR Report, NAS, NRC (November 1972).
20. Morgan, K. Z.: Testimony before the Senate Commerce Committee on Bill 2067, "Reduction of Unnecessary Medical Exposure," August 28-30, 1967, Congressional Record Ser. No. 90-49 (1968); Congressional Record Hearings before the Committee on Radiation Control for Health and Safety Act, Washington, D. C., March 8, 1973.

Table 1

GENETICALLY SIGNIFICANT DOSE (MREMS/YEAR) FROM MEDICAL DIAGNOSIS IN VARIOUS ADVANCED COUNTRIES

Country	Millirems/Year
United States	95*
Japan	39
Sweden	38
Switzerland	22
United Kingdom	14
New Zealand	12
Norway	10

* Probable value is between 55 and 95 millirems/year.

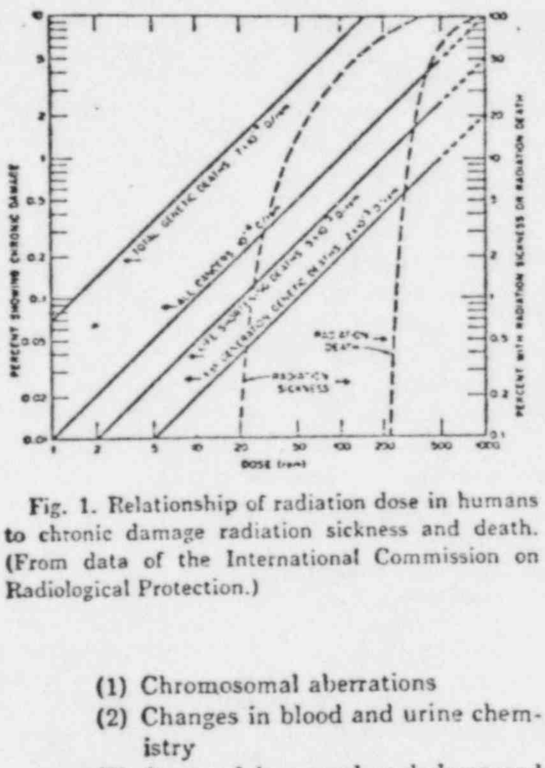


Fig. 1. Relationship of radiation dose in humans to chronic damage radiation sickness and death. (From data of the International Commission on Radiological Protection.)

(1) Chromosomal aberrations
(2) Changes in blood and urine chemistry
(3) Areas of increased and decreased bone density
(4) Polynucleated cells

2. Radiation damage requiring a threshold dose
   a. Eye cataracts
   b. Radiation sickness
   c. Skin erythema

A few persons, some of them radiologists, wish so strongly to believe there is a threshold or safe dose of radiation below which no radiation damage will result in man that they refuse to consider the evidence, and at times even resort to unscientific arguments. For example, we often hear such statements as that of the highly respected Dr. Moseley of the American College of Radiology: "There are no demonstrable deaths from x rays."[4] This is like saying there has never been a proven case where a person has died of lung cancer from smoking cigarettes. Of course, no deaths have been proven because the cancers are identical to those from natural causes, and they occur on a statistical basis. We can show decisively, however, that on a statistical basis diagnostic x rays as well as cigarettes do cause cancer. Statistical evidence is a basic requirement of all scientific proof. For example, the general gas law applies only to observations on a large number of gas molecules under changes of pressure, volume and temperature. It does not indicate the behavior of a single molecule. One can, of course, refer to the results of many experiments with animals exposed to low doses of x rays as evidence of radiation damage, but human data in the final analysis must provide the proof we require. The following list summarizes some of the more important types of human exposure experiences that are being studied and are lending support to the belief that there is no dose of radiation so low that the probability of its causing a malignancy and life shortening is zero:

Sources of Human Exposure Causing Radiation Damage

1. Radium ingestion—^{226}Ra, ^{228}Ra, ^{224}Ra—(sarcoma and carcinoma)
2. Thoratrast ingestion—ThO—(hepatic tumors)
3. Thyroid diagnoses and therapy—isotopes of iodine and x rays—(thyroid cancer)
4. Ankylosing spondylitis x-ray therapy—(leukemia and other malignancies)
5. Chest radiographs of tuberculosis patients—(lung and breast cancer)
6. X-ray exposure of *in utero* children—(leukemia and other malignancies)
7. Prenatal x-ray exposure—(leukemia and other malignancies)
8. X-ray and radium exposure of uterus to induce artificial menopause—(leukemia and other cancers)
9. Survivors of atomic bombing of Hiro-

shima and Nagasaki—(all forms of cancer, cataracts, brain damage, reduction in organ size, change in sex ratio)

10. Radiation accidents—criticality, radiographic sources, x rays, high voltage accelerators—(death, cancers, cataracts, radiation burns)
11. Early exposures of radiologists to x rays—(all forms of cancer and life shortening)
12. Exposure of uranium miners—radon daughters—(lung carcinoma)

Sometimes the data[2] on bone tumors that have resulted among persons who have ingested large amounts of radium are plotted on semi-log graphs, as shown in figure 2, which at first glance seem to suggest to the nonscientist proof of the existence of a threshold dose below which no bone tumors will appear. However, if these same data[3] are plotted on Cartesian coordinate paper, as shown in figure 3, they seem to support strongly the hypothesis of a linear relationship between radiation dose and effect. Table 2 is a summary of data showing the gradual increase of severity of biological changes as the radium dose is increased from 0.001 μc. ^{226}Ra (corresponding to an average skeletal dose of 0.3 rem/yr.) to 5.5 μc. ^{226}Ra (corresponding to 1,650 rem/yr.). In this case, 0.1 μc. ^{226}Ra (corresponding to 30 rem/yr.) is the maximum permissible body burden for the occupational worker.

Many studies[11, 17, 22] have been conducted that indicate the human fetus is very radiosensitive, and the malignancies produced per rad of x rays may be five to eight times the rate indicated in figure 1 for exposure of adults. The data of Stewart and Kneale[22] in figure 4, showing a linearly progressive increase in the number of cancers in children as a function of the number of pelvic x-ray examinations received by their mothers during pregnancy, are more than "suggestive" of a linear relationship between dose and effect. The estimated average dose per x-ray film was only 0.25 rem. Such studies led the ICRP[7] to recommend that, where practicable, for women in the childbearing age x rays to pelvic and abdominal regions be administered only during the ten-day interval following the beginning of menstruation. Members of the medical profession who have implemented this ICRP recommendation undoubtedly have prevented much misery and suffering and have saved many thousands of lives of young children.

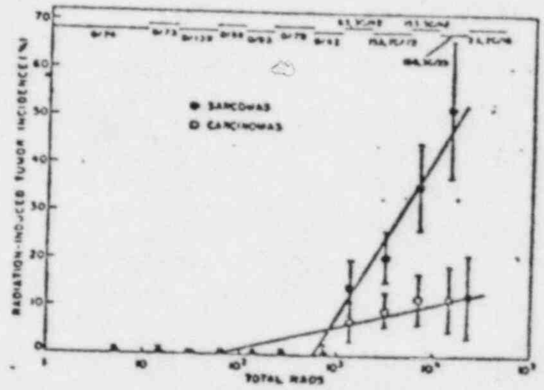


Fig. 2. The per cent incidence of sarcomas and carcinomas plotted separately on a linear scale against the median of the total skeletal dose in rads on a logarithmic scale. For the notation at the top of the figure, 0/42 means zero cancers among 42 persons in this dose range; 2S, 2C/16 means two sarcomas and two carcinomas among 16 persons in this dose range, etc. (ANL-7760, Part II, U.S. Department of Commerce, Springfield, VA, July, 1969-June, 1970.)

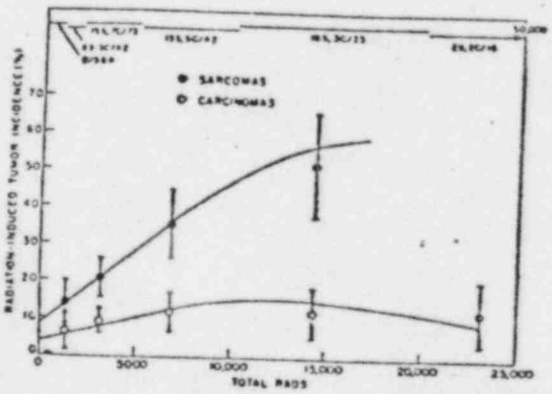


Fig. 3 The per cent incidence of sarcomas and carcinomas plotted separately against the median value of the total skeletal dose in rads in linear coordinates. For the notation at the top of the figure, 13S, 3C/25 means 13 sarcomas and three carcinomas in this dose range, etc. (ANL-7760, Part II, U.S. Department of Commerce, Springfield, VA, July, 1969-June, 1970.)

In this connection, it is of interest to note that the 1964 U.S. Public Health Service survey indicated the average abdominal x-ray skin dose in the United States is 0.79 rem, and that this dose is 0.636 rem if given under the care of

TABLE 2

LONG-TERM EFFECTS OF RADIUM IN MAN

Ra Body Burden (μc)	Average Bone Dose (rem/yr)	Biological Changes (%)					
		None	Minimal	Mild	Moderate	Advanced	Malignant*
0.001–0.03	0.3–9	92	8	0	0	0	0
0.03–0–0.1	9–30	83	13	0	4	0	0
0.1–0.3	30–90	69	16	3	6	6	3
0.3–1.0	90–300	12	25	25	16	22	16
1.0–3.2		6	6	14	12	62	32
3.2–5.5		0	0	0	9	91	35

* Those with malignancies were listed also under previous columns.
(Data from Finkel, Miller and Hasterlik, ICRP No. 11, 1968)

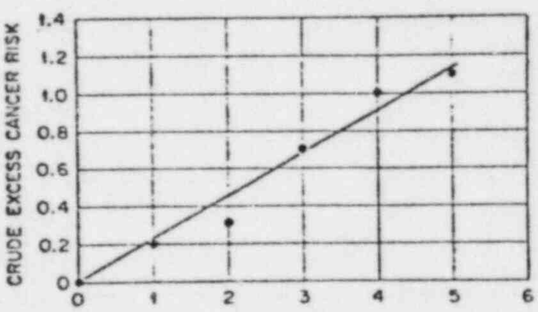


Fig. 4. Relationship of cancer in children to the number of pelvic x-ray examinations received by their mothers during pregnancy. (Data from Alice Stewart and G. W. Kneale, *Lancet*, June, 1970).

a radiologist, but is 1.253 rem, if given otherwise. I believe this does not mean the radiologist carried out these abdominal diagnoses himself at about half the dose delivered by other members of the medical profession for the same examination, but rather that on the average the x-ray technologists working in hospitals and private offices of radiologists were more likely to be educated and trained properly and to be certified. I think it is regrettable that proper training and certification of x-ray technologists is required in only three of our states—New York, New Jersey and California*—and it is deplorable that only one of our states—California—requires education and training in x-ray and radiation protection of all medical doctors, and that there be questions on these subjects on the state board examination.

I am pleased that The American Society of Radiologic Technologists has been working with the Bureau of Radiological Health of the USPHS and other medical organizations in the preparation of model legislation designed to correct these faults and to assure effective legislation that will guarantee eventually that all users of ionizing radiation in the healing arts have proper education, training and certification in its correct use. I am pleased, also, that in these negotiations the ASRT has been insistent that there be as much consistency as possible in the education and training requirements in the various states and that the standards maintained must be equal to and preferably superior to those presently enforced by The American Registry of Radiologic Technologists. It is a great encouragement, also, that regional and state organizations of radiologic technologists are beginning to take the lead in forming appropriate state and local legislation to maintain high standards in radiologic technology and to provide adequate protection of the patient who is to be radiographed and of his or her children who could suffer the consequences of unnecessary x-ray exposure for many generations to come. I only [illegible] equal progress was being made by other [illegible]mbers of the healing arts to assure appropriate training. I do not believe any doctor should have the right to request an x-ray examination in an x-ray department (much less administer the x-ray exposure himself) unless he has

* Kentucky now (1973) requires education, training, and certification of x-ray technologists.

appropriate education, training and certification in the proper use of x rays.

As outlined earlier, two important sources of human exposure causing radiation damage which have been under intensive study are (1) x-ray exposure of children *in utero*, and (2) survivors of atomic bombings of Hiroshima and Nagasaki, Japan. As often happens in research, the studies of children who received exposure *in utero* during the atomic bombings of Hiroshima and Nagasaki do not appear to confirm the findings of an unusually high incidence of malignancy as found by Stewart and others among children exposed *in utero* when their mothers received pelvic and abdominal x-ray exposure. Jablon and Kato[9] pointed out this discrepancy between their studies of Japanese children and Stewart's studies of children exposed *in utero*. I have examined both sets of data and compiled the following principal reasons why there seems to be a difference in the effects of the two types of radiation exposure.

- First, there was an unusually high abortion and infant mortality rate in Hiroshima and Nagasaki following the atomic bombings, and undoubtedly the children, who otherwise would have died of radiation-induced cancer, had the scales tipped against their surviving more than two years when such malignancies usually appear.
- Likewise, many studies[3] have shown that during times of community disasters it is the young children who suffer most and usually die of causes other than cancer. During such periods, incipient cancers can be mistaken very easily for acute infections.
- Also, we must not overlook the fact that species difference has been observed[21] in many animal experiments, and it should not be surprising to find different radiation responses in children in Japan, the United Kingdom and the United States.
- Most importantly, Jablon included in his study children who had received very high doses of radiation *in utero*, and very probably at these high doses one should expect a sharp decrease in the number of childhood malignancies. (Jablon's data included 33 children who had received more than 300 rads, while Stewart's data did not apply to doses at the far end of the parabola.) Marinelli[2] and many others have shown that at high doses of ionizing radiation the malignancy curves such as those plotted in figures 1-3 drop off to form a parabola-shaped curve, i.e., the number of malignancies reaches a maximum at some large dose and then declines at higher doses.
- Another reason for some of the differences may be due to the fact that the Japanese fetuses were exposed to both neutrons and gamma rays while the study groups in the United Kingdom and the United States were exposed only to x rays.
- Additionally, the Japanese control group of bomb survivors probably had a greater cancer risk than normal.
- Furthermore, the average fetal dose in the United Kingdom may have been greater than 500 millirads per examination.

When all of these factors are taken into account, all discrepancies in the data from the two types of *in utero* exposure disappear.

One of the earliest sources of human exposure that has been studied extensively is that of occupational exposure of the early radiologists. Table 3 summarizes some of the data collected by Seltser and Sartwell.[20] Here it is observed that these early radiologists in the age group

TABLE 3

RATIO OF DEATHS AMONG RADIOLOGISTS TO NUMBER EXPECTED FROM THE EXPERIENCE OF OPHTHALMOLOGISTS AND OTORHINOLARYNGOLOGISTS, BY CAUSE: 1935–1958*

Age Group (yr.)	Leukemia	Cause of Death		
		Other Malignant Disease	Cardio-vascular Renal Disease	Other Causes
35–49	1.0	1.2	1.0	1.7
50–64	7.3	1.7	1.1	1.4
65–79	1.9	1.5	1.4	2.0

*These data indicate the increased death rate among radiologists compared to the control groups or leukemia, other malignancies, cardiovascular and renal disease and other causes of death. The increased death rate of radiologists is thought to be the consequences of x-ray exposure. As a matter of explanation, in the age group 50-64 there were 7.3 times as many leukemic deaths and 1.7 times as many deaths from other malignancies among the radiologists between 1935 and 1958 as among the control group that did not receive occupational exposure to x rays.

50-64 had over seven times as many leukemias as the control group, and death from all causes in the age group 65-79 was considerably greater than for the control group. In table 4, it is noted that the early radiologist's life expectancy was shortened by 4.8 years in the period of 1935-44, four years in the period of 1945-54, and 2.9 years in the period of 1955-58. Studies of Warren[21] indicate that beginning about 1960 when radiologists conformed more nearly with the maximum permissible occupational exposure levels recommended by ICRP and, more importantly, when most of the diagnostic x-ray exposures were delivered to patients by the x-ray technologist (and not the radiologist), there apparently has been no detectable life shortening of radiologists.

This, of course, suggests immediately the question, "What about the x-ray technologist?" Unfortunately, we do not have an answer to this question. Certainly, unless technologists heed the warning of the experience of radiologists who operated the diagnostic x-ray machine in the early period, they can expect similar damage. Of even greater importance, however, is the fact that unless technologists avoid unnecessary radiation exposure of their patients, many thousands of these patients will suffer consequences as indicated in tables 3 and 4.

Another type of malignancy—thyroid carcinoma—likewise appears to increase more or less linearly with the dose of ionizing radiation. Hempelmann,[8] after examining the incidence of thyroid cancer among children at Ann Arbor and Rochester who had received x-ray treatment for thymic enlargement and children in the Marshall Islands whose thyroids were irradiated by ^{131}I fallout, concluded: "The incidence of thyroid and extra-thyroid tumors in the Rochester series is dose dependent, and the frequency of thyroid neoplasms is age dependent until age 18. Some evidence is presented suggesting that (1) the dose response to thyroid tumors is linear in the lower dose range, and (2) there is no threshold or at least the threshold is below 20 rad." Incidentally, Lewis[10] points out after examining data of Saenger, et al.[19] that in the case of medical exposure to ^{131}I delivering rather low doses of seven to 13 rads to bone marrow, there is a significant increase in leukemia among persons between ages 50 and 79. Other studies also have indicated an increased radiosensitivity in older age groups as well as among fetuses and children, so the rule for technologists should be to avoid all unnecessary radiation exposure regardless of the age of the patient.

As pointed out here, we are concerned not only about somatic damage from ionizing radiation, but genetic damage that can manifest itself in congenital defects and deaths among our children and children yet to be born for many generations. From the early genetic studies by Muller[15] of Drosophila (flies), it was thought that genetic damage increased linearly

TABLE 4

MORTALITY OF MEMBERS OF SPECIALIST MEDICAL SOCIETIES: DEATH RATE PER 1000 MEN PER YEAR, STANDARDIZED FOR AGE

Period	Age (yr.)	Death Rate: Radiologists		Death Rate: Specialist Physicians		Death Rate: Ophthalmologists and E.N.T. Surgeons	
1935-44	35-49	6.6	(71.4)*	4.6	(73.4)*	3.3	(76.2)*
	50-64	19.5		16.1		17.1	
	65-79	57.6		51.7		38.9	
1945-54	35-49	3.5	(72.0)	3.8	(74.8)	3.5	(76.0)
	50-64	17.8		14.9		12.9	
	65-79	57.9		45.6		39.0	
1955-58	35-49	2.1	(73.5)	2.1	(76.0)	2.7	(76.4)
	50-64	12.1		11.6		9.4	
	65-79	59.3		44.0		42.8	

*The values in parentheses are mean ages at death.

with dose, and there could be no dose rate dependence. More recent mouse studies of Russell[18] (the results of which are plotted in figure 5) indicate rate independence when the dose rate is above 5,000 roentgens per hour, but as the dose rate drops below 5,000 roentgens per hour, the mutation frequency for both oocytes (female) and spermatogonia (male) drops off rapidly. The rate for the oocytes drops down to background levels where, presumably, there is complete genetic repair. However, for the spermatogonia, there is a drop-off by a factor of about three where at 50 roentgens per hour there is a return to dose rate independence of mutation frequency at lower dose rates. Since there are the two sexes in every mating, and assuming a drop to zero mutation frequency for the oocyte and a drop by a factor of three for the spermatogonia, we conclude that at least in the case of the mouse, genetic damage below a dose rate of about 50 roentgens per hour is one-sixth that at higher dose rates. From this, however, we must not jump to the conclusion that genetic damage is zero at very low dose rates. At very low dose rates, it is one-sixth as great as previously considered and as at high dose rates, but at high dose rates such as are ordinarily used in medical diagnosis and therapy, there is no reduction below previous estimates and genetic damage is dose-rate independent.

If one takes the coefficient of radiation damage as given by ICRP[6, 8] and as plotted in figure 1, and applies it to the estimates of dose to the U.S. population from medical diagnosis as given by the USPHS,[24] the number of deaths per year from medical diagnosis in the United States can be obtained as summarized in table 5. The lower estimate of 1,100 genetic deaths per year includes only the first generation deaths while the higher figure of 44,000 genetic deaths per year includes those that will be introduced into future generations per year as a result of recessive mutations. For comparison, estimates of risk are given for the nuclear energy industry. Although much has been said recently in the public press concerning this risk, it is to be observed that it is very small by comparison.

In terms of the risks from diagnostic x-ray exposure as estimated from population exposure data reported by the USPHS in 1964, and as I have summarized in table 5, it is perhaps discouraging to note that, as shown in figure 6, the number of x-ray visits by members of the U.S. population was much greater in 1970 than in 1964. One encouraging observation of this latest (1970) USPHS survey,[18] however, is that, as indicated in figure 7, the mean ratio of beam area to film area has shown a great amount of improvement (reduction) in every area except there has been only slight improvement in private offices of radiologists and among public health agencies and other groups.

One of the most promising developments

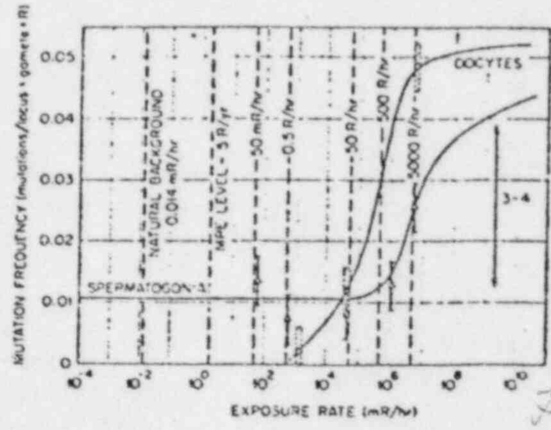


Fig. 5. Rate dependence of point mutations in mice. (Data from W. R. Russell, *Nucleonics*, 1965.)

TABLE 5

COMPARISON OF CONSEQUENCES OF X-RAY DIAGNOSTIC EXPOSURE PRESENTLY RECEIVED BY ALL U.S. POPULATION WITH THE CONSEQUENCES OF A CONTINUOUS EXPOSURE FROM ALL NUCLEAR INDUSTRIES OF 0.5 PER CENT OF THE ALLOWED 170 MREM PER YEAR (0.85 MREM/YEAR)

Types of Radiation Damage	Consequences of Medical X-Ray Diagnostic Exposure Presently Received by U.S. Population (Deaths per Year)	Consequences of Hypothetical Exposure of 0.85 mrem/year to U.S. Population from Nuclear Industries (Deaths per Year)
Genetic	1,100 to 44,000	3 to 120
Leukemia	500	3
Thyroid Cancer		0.2 to 2
Dental x rays	16 to 160	
Thorax x rays	2 to 20	
Other cancer	500	3
Life shortening	1,200	8.5
Total deaths (~)	3,300 to 46,000	18 to 140

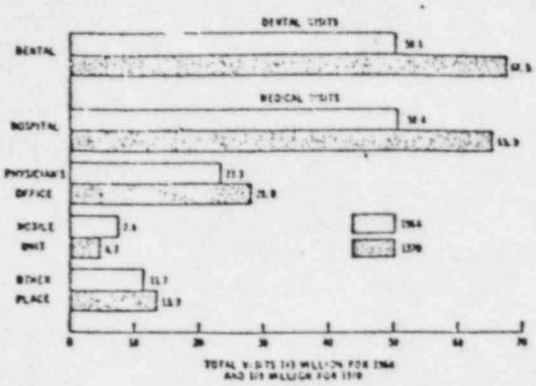


Fig. 6. Estimated annual number of x-ray visits in millions in the United States, 1964 and 1970. (Preliminary estimates from the USPHS 1970 x-ray exposure study.) Total visits 143 million for 1964; 175 million for 1970.

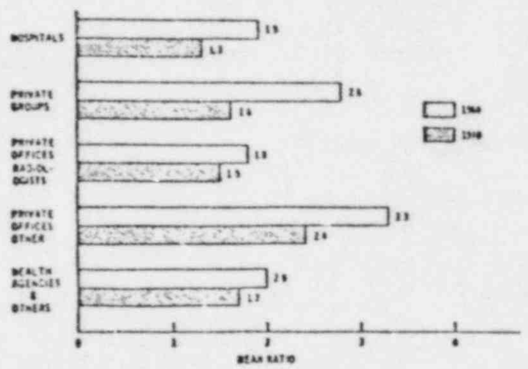


Fig. 7. Estimated mean ratio of beam area to film area for radiographic examination by type of facility in the United States, 1964 and 1970. (Preliminary estimates from the USPHS 1970 x-ray exposure study.)

recently is that a number of radiologists, technologists, dentists, and other members of the healing arts are beginning to speak out and criticize their own profession for its failure to give appropriate attention to reducing unnecessary diagnostic exposure of the patient. Perhaps the most frank and informative article of this type was by McClenahan.[22] Listed here is a summary of the main practices he emphasizes as causes of excessive patient exposure:

1. Easier to order an x-ray examination than to think.
2. Examinations are ordered "to rule out" when accurate diagnosis has been made with the naked eye.
3. Heavy legal penalties for failure to do radiographic examinations, but no penalties for unnecessary exposure of patient.
4. Insurance covers most costs for x-ray examinations.
5. More films per diagnosis now required than formerly.
6. Shortage of trained workers leading to hasty, hazardous techniques.
7. Folkways and traditional rites.

For good measure, I have added some of my own reasons for excessive patient exposure:

8. X-ray examinations add to income of doctors or the medical institution.
9. Patient ignorance. Patient judges medical competence in terms of the number of x-ray examinations.
10. Radiographs are required for certain jobs (nurses, teachers, restaurant workers, etc.).
11. X-ray surveys where there is little need (mass chest x-ray program).
12. Required pelvimetries sometimes a routine for first pregnancy.
13. Failure to use radiographs already in files of patient.
14. Failure to use tape and computer equipment for storing and retrieving x-ray data.
15. X-ray examinations used for pyschotherapy (neurotic patients).
16. Radiographs as a financial drain on Medicare and Medicaid.
17. Failure to observe special x-ray requirements for children and infants.
18. Use of fluoroscopy where dynamic information is not required.
19. Lack of education and certification requirements for all who own, operate, supervise or request diagnostic x-ray examinations.
20. Some medical x-ray examinations of questionable and bizarre benefit to patient, e.g., practice of some chiropractors.
21. Radiology not practiced as a profession —radiologist takes orders from others and fails to exercise professional judgment. Radiologist lacks proper motivation to maximize ratio of diagnostic information to radiation damage to patient.

22. Failure to establish professional rank of "senior technologist."
23. Medical radiography used by insurance companies and lawyers to verify claims of injury.
24. Failure to maintain patient dose records.
25. Failure to avoid exposure to critical tissue such as the central nervous system, active bone marrow, lens of eye, thyroid, etc.
26. Use of mass production and cookbook procedures in radiology.
27. Lack of appropriate state or federal legislation.
28. Medical diagnostic exposure of the population should be included as part of the population dose limit of an average of 170 mrem/year.
29. Poor equipment and techniques.
    a. Use of insensitive films (slow speed).
    b. Poor developing techniques.
    c. Edges of x-ray field not showing on film.
    d. Overexposure and underdevelopment of film.
    e. Target-skin distance too short.
    f. Improper voltage.
    g. Poor coning and diaphragming.
    h. Poor timing devices.
    i. Improper filters.
    j. Insufficient shielding.
    k. Poor calibration of equipment.
    l. Some imported equipment does not indicate voltage and current.
    m. Failure of radiologist to dark-adapt eyes.
    n. Use of substandard photofluorometric equipment.
    o. Lack of adequate beam centering devices.
30. USPHS report of 1964 indicated the genetically significant dose from diagnostic x rays was 55 mrem/year. The 1970 estimate may turn out to be considerably higher.

Elsewhere I have listed some 63 ways by which the average medical diagnostic dose to persons in the United States can be reduced at least to one-tenth the present values.[13, 14] Most of these can be summarized under three headings: (1) better and more extensive education, training and certification of all members of the medical profession; (2) better use of modern equipment, and (3) the application of better diagnostic techniques. Adrian[1] gave strong evidence that medical diagnostic exposure in the United Kingdom could be reduced when he said, "If all radiological departments in the United Kingdom employed the techniques already in use in 25 per cent of the departments in 1958, the population gonad dose from diagnostic radiology would probably be reduced by a factor of 7." This would mean, for example, a reduction of the genetically significant dose in the United Kingdom from 14 mrem/year to 2 mrem/year. Why, then, can't we in the United States reduce our genetically significant dose from the 1964 value of 55 mrem/year to 5 mrem/year? Present forecasts are that the 1970 survey, when the final compilations are complete, will indicate the genetically significant dose is now greater than 55 mrem/year. Much of the success we seek in reversing this trend depends upon the radiologic technologist. I am counting very much on him and the independent progressive thinking of leaders in his professional societies to take the necessary steps in reducing the genetic and somatic dose of the U.S. population.

Another strong incentive for reducing unnecessary diagnostic exposure of the patient is that almost every measure suggested for reducing this dose provides the opportunity for better radiographs and more meaningful diagnostic information. As indicated at the beginning of this lecture, there is no doubt that the x ray is one of the most valuable of medical tools. We do not know how many lives it saves each year in the United States, but we might assume arbitrarily that this number is 100,000. Some might contend that there is no cause for alarm if diagnostic x-ray exposure is causing 5,000 to 50,000 deaths a year while it is saving 100,000 lives. Our argument, however, is that by better use of x rays and the elimination of unnecessary x-ray exposure of the patient we might reduce the radiation deaths by a factor of 10 (i.e., to 500 to 5,000) while at the same time the benefits of x rays might be doubled (i.e., save 200,000 lives each year instead of 100,000).

I believe the radiologic technologist must play a major role in bringing about these improvements in diagnostic radiology. We hear a great cry these days about the hundreds of millions of dollars the U.S. taxpayers should spend to train more radiologists. Although a sufficient supply of well-trained radiologists is vital to an adequate medical program, I do not believe there is such an urgent need for additional radiologists. Rather, I believe we must recognize the situation that exists and has existed for a long time; namely, the senior radiologic technologist has become of stature and matured to a senior member of the medical profession. He does most of the diagnostic x-ray examinations and knows more about the use and maintenance of the x-ray machine than does the radiologist. Why not officially recognize this grade of senior radiologic technologist, then? Why not require that a technologist qualifying for this rank complete a carefully planned four-year program of education and training, pass a special certification examination and then be moved into the higher medical ranks? Here he would be given complete responsibility for the operation, maintenance and use of the diagnostic x-ray machine and would be paid at a rate becoming of his professional rank. He would make his own decisions commensurate with his responsibilities and plan and carry out his own program of providing the best possible diagnostic radiography with the minimum dose to the patient. Such an arrangement would relieve the need of expanding the number of radiologists and would set the radiologist free to work more closely with other members of the healing arts, to specialize on reading and interpreting the x-ray films and to concentrate most of his efforts and specialized skills on x-ray and radioisotope therapy. I believe such a working team could provide cheaper and better radiology of higher professional quality and with much less population exposure to ionizing radiation.

REFERENCES

1. Adrian, G. M.: Hazards and dose to the whole population from ionizing radiations. Ann. Occup. Hyg. *9*:83 (1966).
2. Argonne National Laboratory Radiological Physics Division Annual Report, ANL-7760, Part II, U. S. Dept. of Commerce, Springfield, VA. (July, 1969-June, 1970).
3. Bennet, Glin: Bristol floods 1968. Controlled survey of effects on health of local community dis[illegible]. Brit. Med. J., p. 454 (Aug. 22, 1970).
4. Gu[illegible]ert, David: Statement by Dr. Robert Moseley. The Wall Street Journal, VCLXXVIII, No. 122 (Dec. 23, 1971).
5. Hempelmann, L. H.: Risk of thyroid neoplasms after irradiation in childhood. Science *160*:159 (Apr. 12, 1968).
6. ICRP Publication 14: Radiosensitivity and Spatial Distribution of Dose. New York: Pergamon Press (1969).
7. ICRP Publication 6: Recommendations of the International Commission on Radiological Protection. New York: Pergamon Press (1964).
8. ICRP Publication 8: The Evaluation of Risks from Radiation. New York: Pergamon Press (1966).
9. Jablon, S. and Kato, H.: Childhood cancer in relation to prenatal exposure to atomic-bomb radiation. Lancet, p. 1000 (Nov. 14, 1970).
10. Lewis, E. B.: Leukemia, radiation and hyperthyroidism. Science *174*:454 (Oct. 29, 1971).
11. MacMahon, Brian: X-ray exposure and malignancy. JAMA *183*:721 (1963).
12. McClenahan, J. L.: Wasted x-rays. Radiology *96*:453 (Aug., 1970).
13. Morgan, K. Z.: Population exposure to diagnostic x rays and the resultant damage can be reduced to 10% of their present levels while at the same time increasing the quality and amount of diagnostic information. Testimony presented before the House of Representatives, Washington, DC, on HR 10790 (Oct. 11, 1967).
14. Morgan, K. Z.: Reduction of Unnecessary Medical Exposure. Hearings before the Committee on Commerce, U.S. Senate, 90th Congress, first session on S. 2067, Serial no. 90-49, p. 46 (Aug. 28, 1967).
15. Muller, J. H.: Man—his environment and health. Suppl. to Amer. J. Public Health, part II, *50*:45 (Jan., 1964).
16. Preliminary Estimates from the U.S. Public Health Service 1970 X-Ray Exposure Study. Charts for an oral presentation at the session sponsored by the American College of Radiology at the Roentgen Ray Society meeting, Boston, MA (Sept. 29, 1971).
17. Prenatal X-Ray and Childhood Neoplasia. Division of Biology and Medicine, USAEC Report TID-12383 (Apr. 1, 1961).
18. Russell, W. L.: Studies in mammalian radiation genetics. Nucleonics *23*:53 (Jan., 1965).
19. Saenger, E. L.: Radiation and leukemia rates. Science *171*:1096 (Mar. 19, 1971).
20. Seltser, R. and Sartwell, P. E.: The influence of occupational exposure to radiation on the mortality of American radiologists and other medical specialists. Amer. J. Epidemiol. *81*:no. 2 (1965); The effect of occupational exposure to radiation on the mortality of physicians. JAMA *190*:104[illegible] (Dec., 1964).
21. Warren, Shields: The basis for the limit [illegible] whole-body exposure—experience of radiolog[illegible] Health Phys. *12*:737 (1966).
22. Stewart, Alice and Kneale, G. W.: Rad[illegible] dose effects in relation to obstetric x-ra[illegible]

childhood cancers. Lancet, p. 1185 (June 6, 1970).
23. United Nations: Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, 17th Session, Suppl. No. 16 (A/5216). New York (1962).
24. U.S. Public Health Service Publication No. 2001: Population Dose From X-Rays, U.S. 1964 (Oct., 1969).
25. Warren, S. and Gates, O.: The inclusion of leukemia and life shortening in mice by continuous low-level external gamma radiation. Rad. Res. 47:480 (Aug., 1971).

School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

"YES" is the answer to question of R. H. Thomas and D. D. Busick, "Is it really necessary to reduce patient exposure?"

KARL Z. MORGAN
School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia

The above article by Thomas and Busick, "Reducing Patient Exposure to Ionizing Radiation - Is It Really Necessary?" calls for some comment. In this article the authors take issue and apparently conclude the answer to their question is "No, it is not really necessary to reduce patient exposure." I pointed out in my paper[1] that when a person has a chest x-ray the skin dose can be as low as 10-20 mR but it sometimes is as high as 2000mR or one may receive only 500-1000mR in a dental series but he may receive 100,000mR. We must conclude that Thomas and Busick see no need or urgency to correct this disparity and would not be concerned if a member of their families received for example 50,000mR in a dental series every six months. Perhaps also they would not quibble over the fact that invariably the larger and excessive doses provide less contrast on the x-ray film and much less medical information. I guess also we can assume they find no fault with the doctor who has a young woman x-rayed in the pelvic or abdominal region for some trifling reason when he has reason to believe the woman may be pregnant. The principle thesis of the Thomas-Busick article is "the risks at low levels have not been demonstrated." They repeat this thesis seven times in their article presumably because they labor under the misapprehension that if they repeat an untrue statement often enough, not only they believe it but it appears credible even in a scientific publication such as the AIHA JOURNAL. They doubt the public should be "alarmed" to take measures to reduce unnecessary medical exposure because medical radiology is so beneficial and they think the harmful effects are problematical.

No one questions for a moment the benefits of medical and dental radiology but this is no reason a person should receive unnecessary exposure. Contrary to the complaint of Thomas and Busick that "Morgan's thesis does not attempt in any way to balance the benefits that *do* occur from medical uses of radiation" I remind them that I stated in my article " . . . ionizing radiation can be one of our most valuable medical tools when it is used properly. Needed medical x-rays should not be avoided . . . Diagnostic x-rays in the U. S. without doubt result in the saving of hundreds of thousands of lives each year, but this is no excuse for using them carelessly and excessively so as to cause needless loss of tens of thousands of lives each year."

Of course, there is some uncertainty regarding the magnitude of any given type of radiation damage as the dose approaches zero because as I stated in my article " . . . as the doses (in population studies) approach zero, the probable errors approach infinity." Some persons would like to demand a one-for-one relationship in such individual cases but we are reminded by Heisenberg that when you determine one parameter (such as momentum) with very high precision a related parameter (such as position) cannot be known. We probably can never prove in an individual case that smoking cigarettes was the cause of his lung cancer but neither can we prove that an individual electron obeys Ohm's Law, $V=RI$, or that a molecule obeys the General Gas Law, $pv=RT$. We believe in these laws because we believe in statistics and this kind of conviction is a requirement for all scientific judgement and generalization of the laws of science.

Thomas and Busick quote extensively from R. D. Evans. I have the highest regard for Dr. Evans but it is well known that from time zero he has been a staunch supporter of the threshold hypothesis and I doubt he will ever change his views. Thomas and Busick quote from Dr. Evans, "As originally introduced, care was always taken in protection committee reports to point out that the true risk in the low-dose domain would be expected to be between zero and the upper limit given by the linear non-threshold approximation." Surely they are aware that the word "always" in the above quote takes in far too much territory to be applied during the present decade. There are a number of cases where these committee reports have taken a neutral position on this question. It is fortunate they have done so because more and more evidence today suggests that in many cases (and especially for high LET radiations such as α and fast neutron interactions) not only is the threshold hypothesis non-conservative but the linear hypothesis may be non-conservative also.

i. e. the risk per rad increases (instead of decreasing) at lower doses and dose rates. I will mention as example only two of a number of cases where such committees took a neutral position and fortunately they do not now have to recant their position. The ICRP committee chaired by Lamberton[2] stated, "It is recognized that factors involved in tissue response to high doses of radiation might lead to either a decrease or an increase of the response dose ratio obtaining at low doses and dose rates." As another example, the BEIR[1] report states, "Because a linear extrapolation model has been used in the calculation, the number of cancer deaths attributable to any dose other than 0.1 rem y can be estimated by simple multiplication; however, it must be borne in mind that the foregoing estimate of mortality from radiation exposure (at 0.1 rem y) may be too high, or too low, for a variety of reasons . . ."

The reader of the Thomas-Busick article may be as puzzled as I was at their comment that Dr. W. D. Rowe of the Environmental Protection Agency has had a "subtle metamorphosis" of his mind as indicated by his "unqualified use" of this model to calculate actual deaths and observe that on this model natural background radiation causes 13,000 health effects per year in the United Sates. Everyone agrees there must be some fine tuning in the application of a general model but I see nothing amiss in Dr. Rowe's use of this model. Apparently Thomas and Busick would object to our stating for example that if there were an average of x deaths from automobile accidents per car mile driven in the U. S. last year, we expect approximately y=nx deaths in 1976 if n is the number of car miles driven in the U. S. in 1976. Of course fine tuning should be applied to get the exact figure but this use of arithmetic does not imply there has been a subtle metamorphosis of mind or this use is unqualified.

Contrary to the seven times repeated thesis of Thomas and Busick "At the present time, no evidence is found that deleterious effects result from radiation exposures at the level of a few rads or less." I can point to a number of studies providing strong evidence and experimental data of statistical significance showing there are harmful effects in man from medical doses of a few rads. I will point to three examples of human population studies, each involving careful followup of many thousands of cases:

First, I mention the Oxford studies of Dr. Alice Stewart[4] *et al.* Her studies of thousands of children who received in utero exposure have extended over many years and have indicated that the mortality from leukemia and other forms of cancer is 50% higher on the average among children exposed to diagnostic x-ray in utero than among children not so exposed. The fetal dose was estimated to be between 0.3 and 0.8 rad. It is true that some "hardshell thresholdists" like Thomas and Busick have attempted to depreciate the findings of Stewart but Stewart's Oxford studies havestood the test and a number of writers[5-7] have shown that if she erred in estimating the risk, it most certainly was on the conservative side, i.e. she would have underestimated the risk.

Second, I mention the tristate studies of Dr. Bross. He pointed out at the Congressional Conference on Low-Level Radiation[7] that there are some groups in the population that have an unusually high susceptibility to radiation damage. He said that children in his study with such diseases as asthma, hives, eczema, allergy, pneumonia, dysentery or rheumatic fever have shown a 5000 percent increase in risk of leukemia as a result of exposure to x-rays.

Third, I mention the findings of Mondan et al[8,9] from their examination of the records of 11,000 migrants into Israel that were administered x-rays to the head in order to control tinea capitis. They found there is a very high risk of 6.1×10^{-6} thyroid carcinomas per year per child per rad. In this case the mean thyroid dose was only 6.5 rad. Thomas and Busick state, "There are no convincing data to show that exposures to x-rays at this intensity (referring to 10 rad) are harmful to humans." I contend these migrants into Israel are humans.

Thomas and Busick state that Rowland does not support my observation that his human ^{226}Ra exposure data are not in conformance with the threshold hypothesis. Of course, only Rowland can say what interpretation he makes of this data at the present time but being a careful researcher he has not ruled out the linear hypothesis in several of his publications. In fact he stated[10] "The radiation - induced carcinomas, however, seem to be better fitted by an expression of the form $I=KDe^{-D/D_o}$ in which I=carcomp,a omcodemce. K=constant, D=accumulated skeletal dose from ^{226}Ra and D_o = the dose value, 1.24×10^4 rad chosen to provide the best curve fit. I submit that this is a linear curve which is modified by the exponential e^{-D/D_o} which allows the incidence of carcinomas to begin to decrease at high doses D where there data demonstrate overkill from radiation. The persons with the higher Ra burdens did not survive long enough to die of cancer. This is borne out clearly in Figure 2 of the paper of Thomas and Busick. A much more important question is not what theory is supported by Rowland or Thomas or Busick or me but, "What cancer risks do the human Ra exposure data actually indicate?" It is clear that these data in Figure 2 (reproduced in paper of Thomas and Busick) fit best the curve $I=KD^n e^{-D/D_0}$ in which n=1/2. In other words the curves are concave downward near the origin such that not only does the effective threshold hypothesis (using n=2) break down but the linear hypothesis (using n=1) is non-conservative for this α-radiation as I have pointed out.[11] Rowland cautioned[10] that a large fraction of the Ra cases in his study (580 out of 777 cases in 1970) are still living. I would remind our readers too that in the early studies of the survivors of the atomic bombings at Hiroshima and Nagasaki many persons jumped to the conclusion that the only significant chronic cancer risk as a result of this radiation exposure was certain types of leukemia. Now, 31 years later essentially all types of malignancies are making their appearance with significant increases in number among the exposed populations. Our only conclusion is that the mean incubation period for the development of radiation induced malignancies in man is probably 20 to 60 years for many types of solid tumors. Thomas and Busick state "In public health matters prudence is necessary, but - contrary to Morgan's view - our experience with radium dial painters tends to suggest that we have indeed been prudent." I did not know that these authors have had experience with radium dial painters but I can only hope their conjecture about prudence is correct. My better judgement tells me to wait and see what happens to the remainder of Rowland's cases (the 580 surviving cases).

R. D. Evan's claim that his data on human exposure to radium support the linear hypothesis is refuted strongly by many scientists that have evaluated carefully his arguments. Gofman and Tamplin[12] for example after their evaluation of his data conclude, "This analysis of the occurrence of bone sarcomas and carcinomas in persons exposed to radium, occupationally or iatrogenically provides no support for any safe threshold of radiation with respect to carcinogensis." At the Congressional Hearings of the Joint Committee on Atomic Energy, W. S. Snyder, V. E. Archer, H. M. Parker and I[13] refuted again the claims of Evans that his data support the linear hypothesis and later I refuted again his claims at the hearings before the Labor Department. Dr. Goss[14] points out many errors in Evan's analysis and goes on to state, "Since a high proportion of the cases are still living, many of the histories are not yet complete and the higher than expected incidence of central nervous tumors in the A. N. L. series suggests that the range of radium induced malignancies may be wider than that normally assumed." He goes on to state, "On the basis of the M. I. T. and A. N. L. data and for the purposes of radiological protection, there would appear to be no justification for believing there is any factor of safety in the present value of MPL (0.1μCi) for ^{226}Ra."

In conclusion, I have been endeavoring for over 30 years to point up the need for reducing what I consider is an excessive amount of unnecessary medical exposure to ionizing radiation. The success that I and others have had in these efforts is to say the least, discouraging when we realize the long way we still have to go especially in assuring that those who use this most valuable medical tool (practioners, dentists, x-ray technologists, etc.) have proper education, training, certification and motivation that enables them to properly weigh and evaluate the need for diagonostic radiological information against the risks of chronic radiation damage. There have been a few marked successes of recent date such as "outlawing" the practice of marching our school children into vehicles carrying portable mass x-ray machines; the requirment for education, training and certification of radiation technologists in the states of New York, New Jersey, Kentucky, California and the Commonwealth of Puerto Rico; and the great success in the State of Illinois in setting limits of x-ray exposure for some fo the more common diagnostic procedures. I hope and pray the views expressed by Thomas and Busick will not delay progress in other states and in further developments to reduce unnecessary medical exposure in many other areas while at the same time improving medical radiology.

references

1. Morgan, Karl Z.: Reducing Medical Exposure to Ionizing Radiation. *Am. Ind. Hyg. Assoc. J. 36*:358 (1975).

2. Lamberton, L. F., Chairman: *Report of the Task Group on Spatial Distribution of Radiation Dose.* ICRP Pub. 14, Pergamon Press (1969).
3. BEIR Report: *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.* National Academy of Science, National Research Council, Washington, D. C., November, 1972.
4. Stewart, A. and G. W. Kneale: Radiation Dose Effects in Relation to Obstetric X-rays and Childhood Cancers. *Lancet.* 1186 (1970).
5. Holford, R. M.: The Relation Between Juvenile Cancer and Obstetric Radiology. *Health Phys.* 28:153 (1975).
6. Landau, E.: Health Effects of Low-Dose Radiation: Problems of Assessment. *Int. J. Environ. Stud.* 6:51 (1974).
7. Bross, I. D.: Testimony at the Congressional Conference on Low Level Radiation. Senate Office Building, Washington, D.C. Proceedings in preparation (May 4, 1976).
8. Modan, B., H. Mart, D. Baidatz, R. Steinitz and S. G. Levin: Radiation - Induced Head and Neck Tumors. *Lancet 1*, 277 (1974).
9. Silverman, C. and D. A. Hoffman: Thyroid Tumor Risk from Radiation During Childhood. *Prev. Med.* 4:100 (1975).
10. Rowland, R. E. and P. F. Gustafson: *Radiological Physics Division Annual Report.* Argonne National Laboratory, ANL - 7760 Part II (June 1970).
11. Morgan, K. Z.: Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements. *Am. Ind. Hyg. Assoc. J. 36*:567 (1975).
12. Gofman, J. W. and A. R. Tamplin: The Question of Safe Radiation Thresholds for Alpha Emitting Bone Seekers in Man. *Health Phys. 21*:47 (1971).
13. Congressional Hearings of Joint Committee on Atomic Energy on *Radiation Exposure of Uranium Miners.* Part 2, p. 1216 (May 9 - August 10, 1967).
14. Goss, S. G.: The Malignant Tumor Risk from Radium Body Burdens. *Health Phys. 19*:731 (1970).

187

CPS

THE NON-THRESHOLD DOSE/EFFECT RELATIONSHIP*

by

Karl Z. Morgan
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

For this brief discussion I am oversimplifying the dose/effect relationship of ionizing radiation and making use of the simple logrithmic expression,

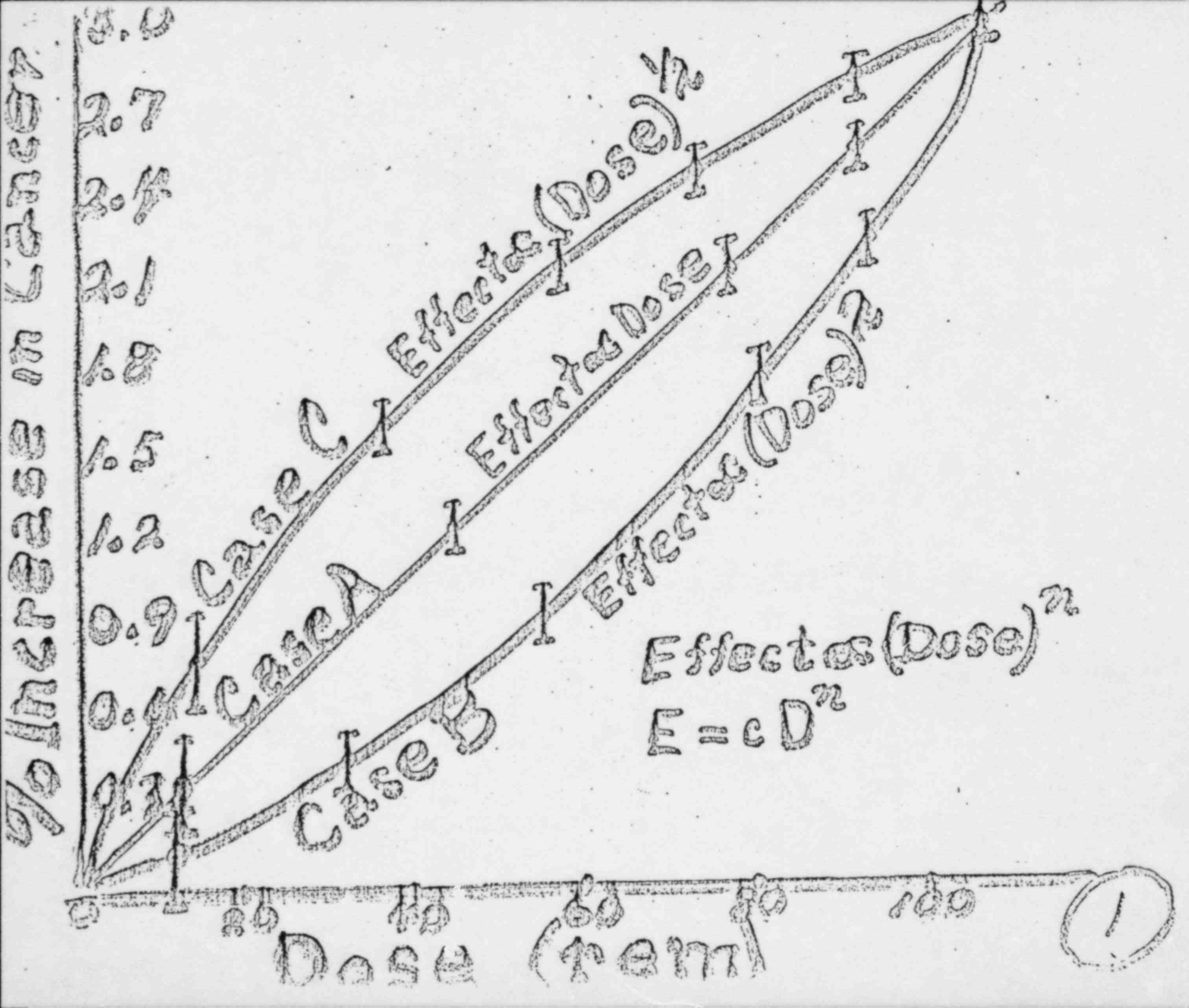
$$E(\text{effect}) = \text{Constant} \times [\text{Dose(rem)}]^n = CD^n$$

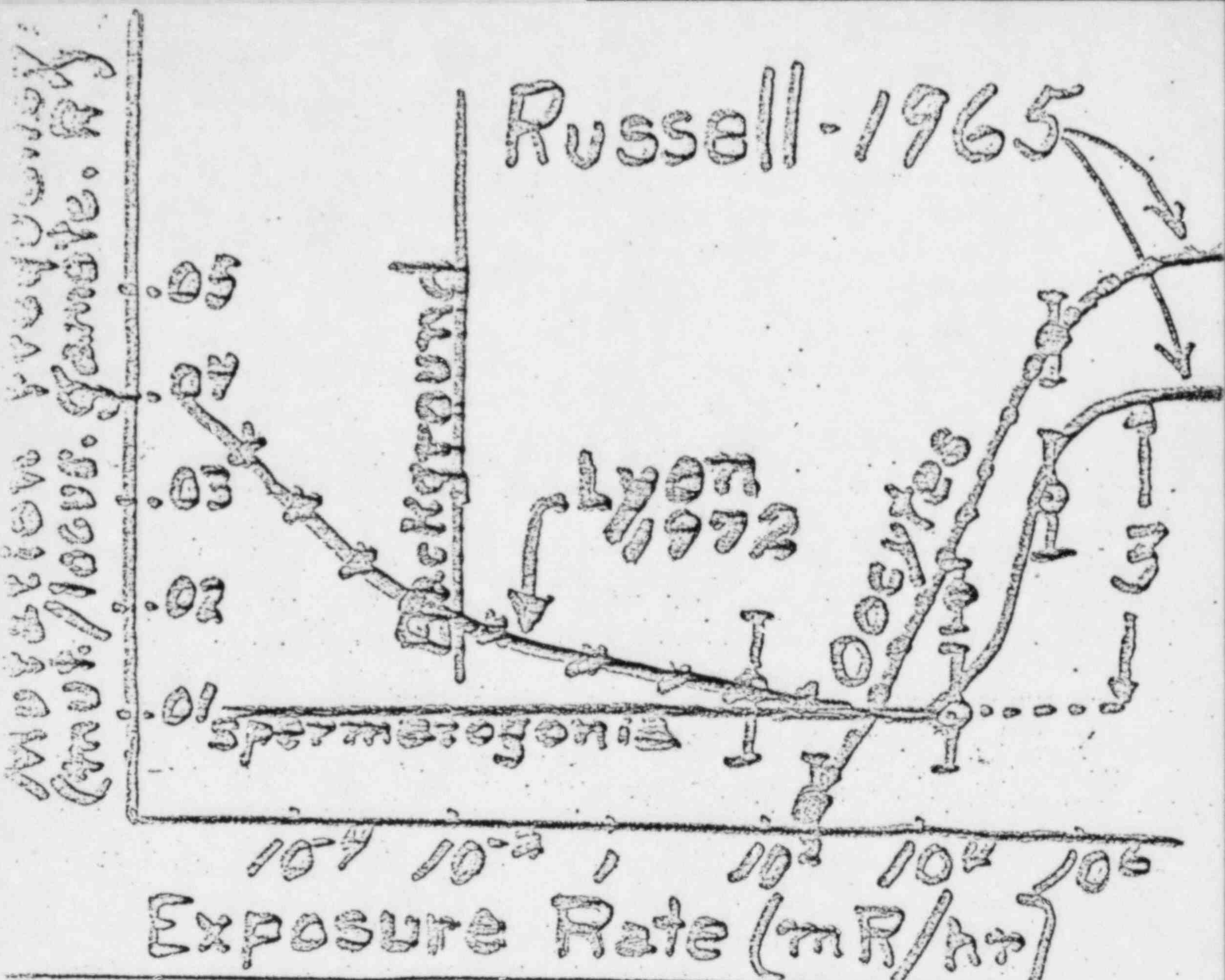
for human exposure below a few hundred rem as indicated in Fig. 1. It follows that when $n > 1$ and approaches 2 or 3 this approximates the threshold bypothesis; when $n = 1$ we have the linear hypothesis and when $n < 1$, e.g. when $n = 1/2$, we have the non-threshold hypothesis where as indicated in Fig. 1 the slope of the curve or the effect per rem is greater at low doses than at high doses.

In the few minutes I have I will discuss only somatic effects and in particular radiation induced malignancy, but as indicated by Fig. 2 some of the same arguments can be applied to genetic damage. Here it is noted that the early work of Russell suggested the genetic damage to mice (and presumably to man) per roentgen at low dose rates and low doses is only about 10% of that at high dose rates and high doses, but more recent publications[2] suggest that maybe the mutation frequency curve turns back up at very low dose rates near natural background and perhaps we are not warranted in making use of this 10% factor for genetic mutations.

Prior to about 1960 most health physicists and radiobiologists subscribed to the threshold hypothesis but since that time an overwhelming

*Given before the Academy Forum of the National Academy of Sciences, Washington, D.C., September 27, 1979.


% Increase in Cancer
0.9
1.2
1.5
1.8
2.1
2.4
2.7
Case C
Effect∝(Dose)½
Case A
Effect∝Dose
Case B
Effect∝(Dose)²
Effect∝(Dose)ⁿ
E = c Dⁿ
Dose (rem)
100
1



Corrections:

for dose rate: $\frac{1}{2} \times \frac{1}{3} = \frac{1}{6}$

for dose: $\frac{1}{2}$

Total: $\frac{1}{6} \times \frac{1}{2} \simeq \frac{1}{10}$

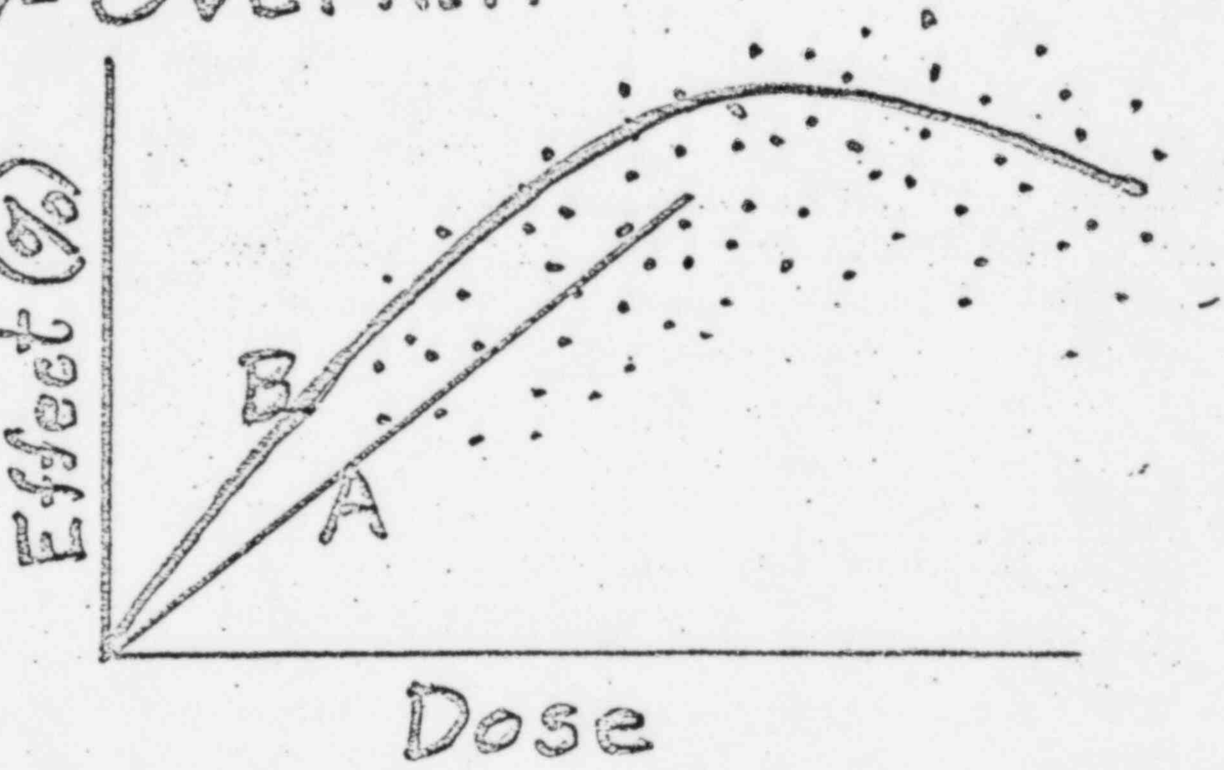
number of studies--many of them at low doses--have failed to give evidence of a safe threshold dose but rather have supported a non-threshold dose/effect relationship. Also, during this period a number of studies (and especially studies of human populations) have suggested the risk of cancer from low exposure is much greater than it had been considered to be some years earlier. As a result of these developments ICRP[3] in 1971 concluded "the ratio of somatic to genetic effects after a given exposure is 60 times greater than was thought 15 years ago." During this period national and international standards setting bodies (such as NCRP, AEC, FRC and ICRP) discarded the threshold hypothesis in favor of the linear hypothesis; however, many of those responsible for this change maintained this provided a generous factor of safety at low doses and dose rates and some even went so far as to make the false statement that there were no data on low level human exposure. These persons for unexplained reasons fail to recognize low exposure studies involving many thousands of subjects such as, for example: 1) Studies of Stewart and Kneale[4] of cancers in children who had received in utero exposure (doses from 0.2 to 0.8 rem to fetus), 2) Studies of Mancuso, Stewart and Kneale[5] of radiation workers at Hanford, Washington (average dose about 1 rem), 3) The Tri-State Studies of Bross[6] (doses < 1 rem) and 4) Studies of Modan et al.[7] of thyroid carcinoma in persons irradiated for tinea capitis (average thyroid dose 6.5 rad).

There are many reasons why some people still cling to the threshold hypothesis, why the risks of low level exposure are often underestimated and why many scientists fail to recognize that in many cases not only does the linear hypothesis fail to provide a generous safety factor but it actually is nonconservative, i.e. $n < 1$. A few of the reasons for this divergence of opinion and why the linear hypothesis often underestimates the cancer risk are:

1. Overkill. At high doses the cancer incidence curve drops over parabola shaped (as shown by Curve B in Fig. 3) because many of the animals do not live long enough to die of cancer. However, this overkill effect begins at intermediate doses such that if one extrapolates this curve from intermediate exposure levels as shown in Fig. 3 to zero without appropriate correction for overkill the cancer risk (as shown by Curve A) is underestimated.

Why the Linear Hypothesis Underestimates the Cancer Risk:

1- Overkill



2- Short Followup

3- Animal vs. Human Studies

4- Animals of Short Life Span

2. Short follow-up of both animal and human studies can only underestimate the cancer risk, r·,pecially for those cancers that have a very long period of in ·bation.

3. Animal vs human st dies. Man's oncogenic response in many respects is significan ɩy different from that of test animals. For example his ovarian tumor response has long been known to be less than that of some strains of mice and one wo'ld expect his response to bone marrow tumors and myelogenous leu emia to differ considerably from that of animals in which all the bone marrow remains active (red instead of partly yellow) during the entire life. Warren and Gates[8] found very large differences in carcinogenic response even among strains of the same animal, e.g. a large life shortening and leukemia incidence in one strain of mice and essentially no such obserable effects on another strain of mice for the same dose.

4. Short life-span animals with life spans ranging from 5 to 20 years are of necessity used to simulate the effects of radiation on man with a 70 year life span--this in spite of the fact that the latent period of some cancers in man is 30 to 50 years. It is generally accepted that oncogenesis and the cancer incubation (latent) period relates to the time since an exposure was received, yet sometimes the simplifying assumption is made that the malignancies developing in a fraction of the animal's life span following radiation exposure relates to the malignancies that would develop in man in the same fraction of his life span following the same dose.

5. Cell sterilization. Many studies (Fig. 4) are made on human and animal populations where the organ doses are so large that cell sterilization destroys preferentially those weak cells which are most likely to develop into cancer cells (they present a large cross section for cancer initiation) and extrapolation of these data to zero dose seriously underestimates the cancer risk at low doses. A classic example of this type of bias is the use by standards setting bodies (NCRP, ICRP, UNSCEAR) of very high thyroid doses of ^{131}I to human subjects in estimating the risk of low doses of ^{131}I. Perhaps someone should have reminded these organizations that a ·· c··rcinoma

5- Cell Sterilization

6- Heterogeneity of Population

7- Damage to Immune Surveillance System

6

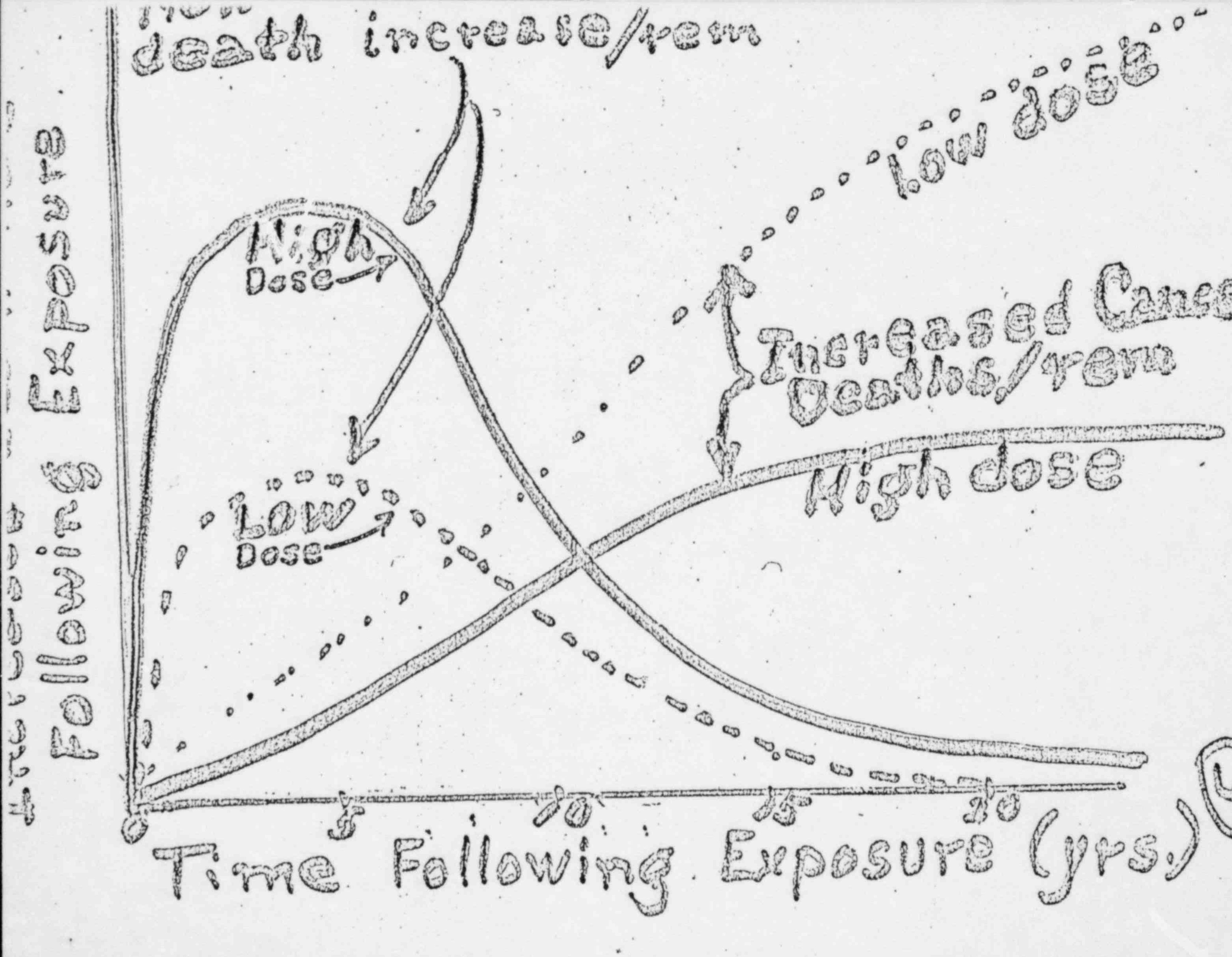
cannot orginate from a cell that was killed by ^{131}I!

6. Heterogeneity of population. The widely publicized paper[5] showing an increase of statistical significance in the incidence of cancers of bone marrow, pancreas and lung in relation to the recorded radiation exposures of Hanford radiation workers was published while I was editor-in-chief of the journal HEALTH PHYSICS and one of the criticisms I received most often for publishing this paper (in spite of the fact that it was reviewed by four very capable reviewers) was these data are useless because there are too many uncontrolled variables--sick, persons on drugs, fat, slim, black, white, young, old, chemical hazards, genetic differences, smokers, non-smokers, etc. I can hardly imagine a more ridiculous criticism. The authors of this work did correct for sex and internal dose and the other variables are being taken into account as fast as possible on a greatly reduced operating budget, but I interpret these critics were saying essentially one should ignore these human data and instead base our standards for low level exposure on animal studies where all these variables can be controlled. The cancer coefficient for this Hanford population was higher (7 to 8×10^{-3} radiation induced cancers per person rem) than that of other studies, so what should we do? Should we continue to base our standards on the data from the survivors of the atomic bombings of Hiroshima and Nagasaki or on the cancer incidence of ankylosing spondylitis patients treated with x-rays when as shown in the following they seriously underestimate the cancer risk? Man is not an inbred, caged animal; he is a dukes mixture of almost everything one can imagine. This is the kind of human study we so badly need and what the Hanford study was except for one exception--the "healthy worker snydrome." This is a healthy group (several cuts above the average) and one that is under the best of medical care. Maybe when we understand better the healthy worker syndrome we can explain why workers with 5 rem or more of recorded dose had an increase in longevity of 10 years. Maybe this is why the workers had a high incidence of myelomas and a low incidence of leukemias?

I believe it is the heterogeneity of a human population that causes a higher incidence of malignancies per rem at low doses than at high doses in so many studies (i.e. $E = cD^n$ in which $n < 1$ and often $n = 1/2$). Studies of Bross[6] seem to confirm the existence of subgroups in the population that are more susceptible to radiation induced malignances and the influence of cocarcinogenistic and synergistic factors. For example he found a very large increase in cancer risk (i.e. by 5000%) for children who received in utero-x-ray exposure and later developed certain respiratory diseases.

7. Damage to the immune surveillance system or man's reticuloendothelial system by ionizing radiation probably is an important reason why his dose response in so many cases follows the relation $E = cD^{1/2}$. Normally this immune system holds in check all sources of foreign protein including small colonies or clones of cancers in situ (cancers before they can be chemically recognized). However, radiation damages the ability of these scavanger cells to recognize virus and bacteria as well as as cancers in situ so as shown by Fig. 5 there is a large increase in non-cancer deaths per rem and a low increase in cancers per rem for those exposed to high radiation doses and a low increase in non-cancer deaths per rem and a high increase in cancers per rem for those exposed to low radiation doses. This, of course, is because of the short incubation period of many of the common diseases such as pneumonia which develop fast when a large fraction of the immune surveillence cells have been damaged or destroyed by high radiation doses. The weak persons who are most likely targets for death by cancer are taken early by a disease like pneumonia before they have time to die of cancer. This undoubtably is one reason why the data on the survivors of the bombings of Hiroshima and Nagasaki tend to support the relation $E = cD^{1/2}$ and why at the same time they underestimate the risk of cancer viz. most of the cases under study received intermediate to high doses.

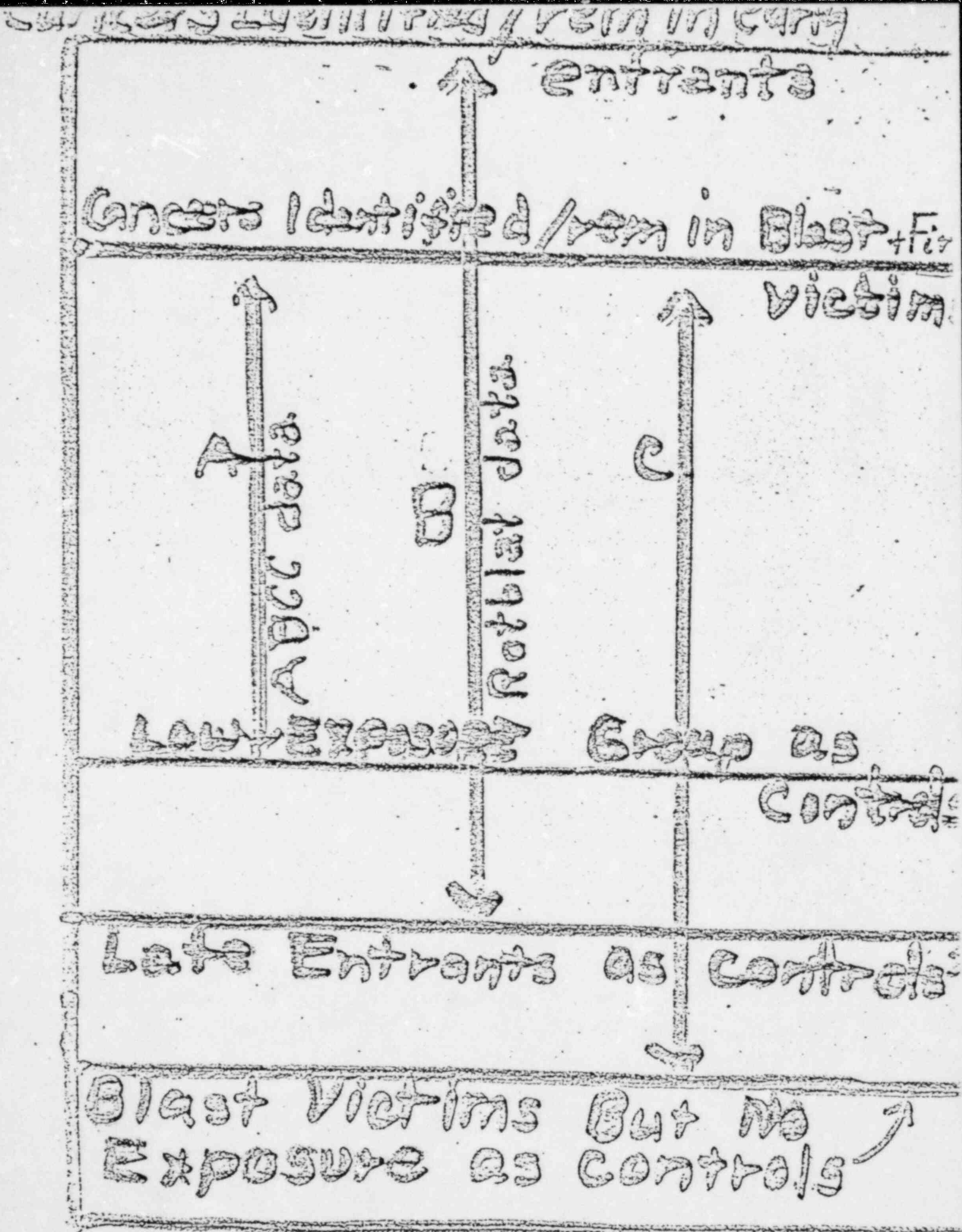
I have long been and continue to be a strong supporter of the studies of the survivors of the bonbings of Hiroshima and Nagasaki (i.e. while I was director of the Health Physics Division of ORNL we were in charge of the dosimetry for this study). I consider it


Following Exposure
death increase/rem
High Dose
Low Dose
low dose
Increased Cancer Deaths/rem
High dose
5
10
15
20
Time Following Exposure (yrs.)
5

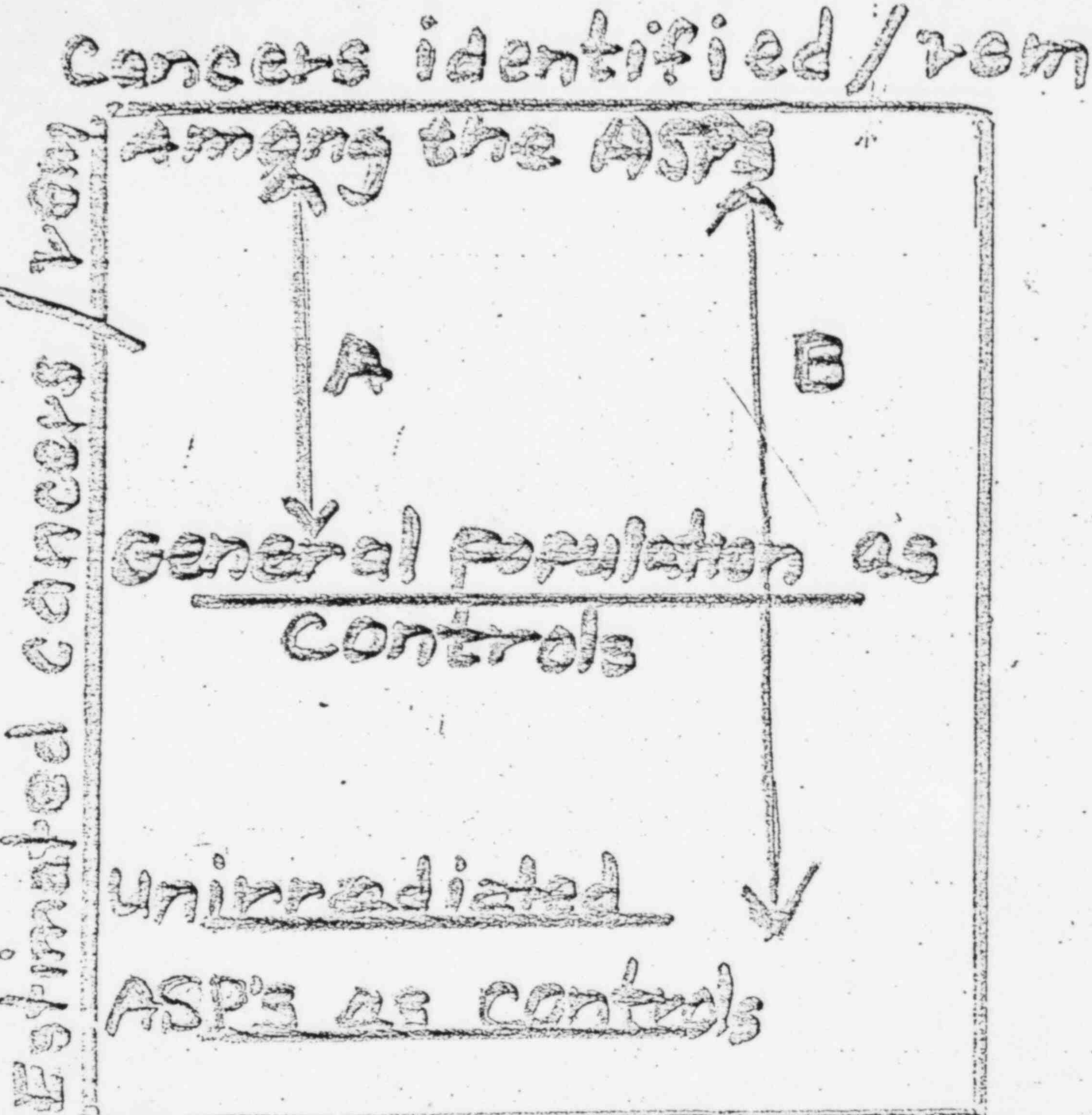
~~this~~ those ~~is~~ are

unfortunate, however, that ~~this~~ data ~~is~~ being misused by ICRP, NCRP, UNSCEAR, BEIR-I & II and other standard setting bodies. They ignore completely the factors 1-7 discussed above. The ABCC data identified the radiation induced cancers as A in Fig. 6 (i e. the difference in cancers per rem among the blast and fire victims and the low exposure group as controls). Ideally they should have identified C (i.e. the difference in cancers per rem among the blast and fire victims and blast and fire victims that received no exposure as controls). Practically, at best an effort should be made to correct for fire, blast and other traumatic influences of death, sickness, disease, hunger, etc. Kneale and Stewart[9] have shown that a year or more before cancers developed to the point of clinical recognition among the children in the ABCC study they were showing signs of being abnormally sensitive to infection and Kneale[10] has shown that the terminal phase of preleukemia is associated with a high risk of dying of pneumonia. However, long before this and in the early period after the events associated with the bomb explosion it would be the weaker and those more prone to develop cancer later on that succumbed to death from the radiation syndrome. Thus the stronger and less cancer prone survivors became the population upon whom cancer risk to a normal population is being judged by the standards setting agencies. Rotblat[11] based the cancer risk on B in Fig. 6 (i.e. the difference in cancer incidence per rem among early entrants into Hiroshima who were exposed to fallout and neutron induced activity and late entrants who received essentially no radiation exposure. Neither of these groups was subjected to fire, blast and trauma that existed shortly after the blast. He found a leukemia risk of 1.6×10^{-4} leukemias per person rem which is 8 times that commonly assigned to the Hiroshima survivors of the atomic bombing and is more in line with values found in other population exposure groups mentioned above.

The other human population that is extensively used or rather misused by these standards setting bodies in determining the cancer risk coefficient is the group of ankylosing spondylitis (AS) patients that is treated with large local doses of x-rays to the spine. As shown in Fig. 7 the incidence of cancer per rem (A) in this AS group was


entrants
Identified/rem in Blast
Victim
ABCC data
Rotblat data
A
B
C
Group as
Late Entrants as Controls
Blast Victims But No
Exposure as Controls

that which was above the incidence in the general population taken as controls. However, studies have shown that AS patients have a lower incidence of cancer than the general population because, as a result of the disease, they don't live as long as normal. An unirradiated AS group should be taken as controls (B in Fig. 7). Therefore, the studies of AS patients have led to a serious underestimate of the risk of radiation induced cancer.


Cancers identified/rem among the ASP's
Estimated cancers / rem
A
B
general population as controls
unirradiated ASP's as controls

7

REFERENCES

1. Russell, W.L., "Studies in Mammalian Radiation Genetics," Nucleonics, 23, 53, (Jan 1965)

2. Lyon, Mary F., D.G. Papworth and R.J.S. Phillips, "Dose-Rate and Mutation Frequencey after Irradiation of Mouse Spormatogonia," Nature New Biology 238, 101 (July 26, 1972)

3. International Commission on Radiological Protection, working paper ICRP/71/L:C-4 (1971)

4. Steward, Alice M. and G.W. Kneale, "Radiation Dose Effects in Relation to Obstetric X-rays and Childhood Cancer," Lancet 1185 (June 5, 1970)

5. Mancuso, T.F., Alice M. Steward and G.W. Kneale, "Radiation Exposure of Hanford Workers Dying from Cancer and Other Causes," Health Physics, 33, 5, 369 (Nov. 5, 1977)

6. Bross, I.D.J., "Leukemia from Low Level Radiation," New England Journal of Medicine 287 (July 20, 1972)

7. Mondan, B., D. Baidatz, H. Mart, R. Steinitz and G.L. Sheldon, "Radiation Induced Head and Neck Tumors;" Lancet 1, 7852 (1974)

8. Warren, Shields and C. Gates, "The Inclusion of Leukemia and Life Shortening of Mice in Continuous Low-Level External Gamma Radiation," Radiation Research 47, 480 (August 1971)

9. Kneale, G.W. and A.M. Stewart, "Pre-Cancer and Liability to Other Diseases," British J. of Cancer, in print.

10. Kneale, G.W., "The Excess Sensitivity of Pre-Leukemics to Pneumonia: A Model Situation for Studying the Interaction of an Infectious Disease with Cancer," British J. of Preventive and Social Medicine 25, 152 (1971)

11. Rotblat, J., "The Puzzel of Absent Effects," New Scientist 476 (August 1977)

Sonderdruck

Röntgen-Blätter

Klinik und Praxis

Schriftleitung: Prof. Dr. Werner Teschendorf, Köln

27. Jahrgang | Stuttgart, im März 1974 | Heft 3

Röntgen-Bl. 27 (1974) 127-146
© Georg Thieme Verlag Stuttgart

Mögliche Folgen einer übermäßigen medizinischen Strahlenbelastung in den Vereinigten Staaten von Amerika *

K.Z. Morgan

Röntgen-Bl. 27 (1974) 127-146
© Georg Thieme Verlag Stuttgart

Mögliche Folgen einer übermäßigen medizinischen Strahlenbelastung in den Vereinigten Staaten von Amerika *

K.Z. Morgan

Zusammenfassung

Die Anwendung ionisierender Strahlen in der Medizin stellt heute den größten Anteil der Exposition durch künstliche Strahlenquellen sowohl für den einzelnen als auch die gesamte Bevölkerung. Es ist zudem seit langem bekannt, daß auch die Strahlendosen biologische Wirkungen hervorrufen können, die in der Röntgendiagnostik erforderlich sind, um ein ausreichend zu beurteilendes Bild zu erzeugen. Forschungsergebnisse in neuerer Zeit haben außerdem gezeigt, daß auch nach Untersuchungen, bei denen der Fötus im Mutterleib einer zusätzlichen Strahlung ausgesetzt wird, durch Strahlen induzierte Leukämien und Tumoren auftreten.

In jedem Falle ist deshalb der Nutzen, den solche Untersuchungen bringen, dem damit verbundenen Risiko gegenüberzustellen.

In den Vereinigten Staaten von Amerika gibt es Bestrebungen, Patienten vor unnötigen Röntgenuntersuchungen zu bewahren. Die hierzu erforderlichen Maßnahmen werden im einzelnen besprochen und Anregungen gegeben, trotz der ständig zunehmenden Zahl der Untersuchungen die Strahlenexposition für den einzelnen so gering wie möglich zu halten.

Summary

The use of ionising rays in medicine provides the greatest portion of exposure today to sources of artificial rays both for the individual and for the total population. In addition, it has been known for a long time that even the radiation doses necessary to obtain a picture satisfactory for assessment purposes can also produce biological effects. The results of research in recent times have also shown that leucaemias and tumours induced by the radiation appear after investigations in which the fetus has been exposed to additional radiation within the womb.

For this reason the usefulness of such examinations must be set against the risks associated with them in each case.

In the United States of America attempts are being made to protect patients from unnecessary radiological examinations. The measures needed for this purpose are discussed in detail and suggestions given for keeping the exposure to radiation as small as possible for the individual, in spite of the constantly increasing number of examinations.

I. Medizinische Strahlenbelastung

Einleitend möchte ich betonen, daß es keinesfalls meine Absicht ist, den Wert der Röntgenstrahlen in Diagnostik und Therapie in Zweifel zu ziehen, wenn sie indiziert sind und fachgerecht angewendet werden. Ich glaube, daß Röntgenstrahlen und andere ionisierende Strahlen zu einigen der bedeutendsten Hilfsmittel der modernen Medizin geworden sind, daß sie jedoch, wie viele höchst nützliche oder wichtige Dinge in unserer modernen Gesellschaft (z.B. Sex, Autos, Drogen und Atomenergie) infolge Unwissenheit, Nachlässigkeit, Sorglosigkeit sowie Fehlen einer ausreichenden Ausbildung und der richtigen Motivierung häufig mißbräuchlich angewandt werden.

In den Vereinigten Staaten und einigen anderen hochentwickelten Ländern stammen etwa 90% der gesamten Einwirkungen künstlich erzeugter ionisierender Strahlung aus medizini-

---

* Vorgetragen auf der 7. Jahrestagung des Fachverbandes für Strahlenschutz e.V. am 21. März 1973 in Bern/Schweiz.

scher Diagnostik und Therapie. Tabelle 1 zeigt, daß der nächstgrößte Anteil dem Fallout von Kernwaffen (ca. 5%) zuzuschreiben ist, und daß in den Vereinigten Staaten der Anteil durch die Kernenergie, die so viel Auseinandersetzungen verursacht hat, nur etwa 0,004% beträgt. In Tabelle 2 sind einige der wichtigsten durch medizinische Anwendung von Röntgenstrahlen und Radiopharmaka verursachten mittleren Jahresdosen pro Person zusammengestellt, wie sie von dem Bureau of Radiological Health bei einer Erhebung im Jahre 1964 ermittelt wurden. Endgültige Angaben und Schlußfolgerungen aus der vom öffentlichen Gesundheitsdienst der Vereinigten Staaten im Jahre 1970 durchgeführten medizinischen Erhebung (3) wurden noch nicht veröffentlicht. Die Anzahl der jährlichen Röntgenuntersuchungen nahm jedoch im Sechsjahreszeitraum von 1964 bis 1970 folgendermaßen zu: Röntgenaufnahmen von 105 Millionen auf 129,5 Millionen, Zahnaufnahmen von 53,6 Millionen auf 67,5 Millionen, Durchleuchtungen von 10,5 Millionen auf 12,7 Millionen, das bedeutet eine Gesamtzunahme der Anwendung diagnostischer Verfahren von 24%. Diese gewaltige Zunahme der Zahl der Röntgenuntersuchungen in den Vereinigten Staaten, die mit einer Steigerung der Kosten verbunden ist, erscheint in einer Zeit, in der in vieler Hinsicht eine Verschlechterung der Qualität der medizinischen Leistungen eingetreten ist, schwer vertretbar zu sein (Tabelle 1).

Tabelle 3 zeigt, daß die genetisch-signifikante Dosis der Bevölkerung der USA beträchtlich über derjenigen in vielen anderen hochentwickelten Ländern liegt. Warum diese Dosis in den Vereinigten Staaten sehr viel höher ist als beispielsweise in England, ist nicht bekannt. Sicherlich sind an der stärkeren Exposition in den USA folgende Ursachen beteiligt:

1. Die Angewohnheit vieler Ärzte und Kliniker, automatisch Röntgenaufnahmen anzuordnen.
2. Die großzügige Kostenübernahme durch Krankenkassen und die Gesundheitsfürsorgeprogramme.
3. Die Tatsache, daß sich die amerikanischen Ärzte wenig darum kümmern, die Patientenexposition so gering wie möglich zu halten.
4. Unzureichende Ausbildung und Fehlen einer Prüfung von Ärzten und medizinischem Hilfspersonal, die der amerikanischen Bevölkerung Röntgenstrahlen verordnen und verabreichen.

Tabelle 4 gibt einen Aufschluß darüber, warum die Strahlenbelastung durch die medizinische Diagnostik in den USA übermäßig hoch ist. Es ist schwierig, eine stichhaltige Erklärung dafür zu finden, warum die Oberflächendosis bei einer Lungenaufnahme sowohl 10 mrem als auch 2000 mrem betragen kann. Wenn die Ärzteschaft behaupten könnte, mit 2000 mrem erhielte man mehr oder bessere Informationen, wäre das wenigstens eine schwache Rechtfertigung. Aber das Gegenteil ist der Fall. Fast ohne Ausnahme ergeben höhere Expositionen weniger brauchbare und detaillierte Informationen; mit anderen Worten, die Bildqualität wird schlechter. Dasselbe gilt für Zahnaufnahmen. Fragt einmal ein aufgeklärter Patient den Arzt, ob eine weitere Röntgenaufnahme tatsächlich notwendig ist oder warum eine kürzlich in einem nahegelegenen Krankenhaus aufgenommene Filmserie nicht genutzt wird, erhält er vom Arzt, der den Anschein erwecken möchte, stets recht zu haben, eine ablehnende Antwort. Oftmals fühlt sich der Arzt durch die Anmaßung eines Patienten, der es wagt, sein Urteilsvermögen und sein Wissen in Frage zu stellen, sogar beleidigt. Diese Haltung ist besonders bei den Ärzten oder Zahnärzten ausgeprägt, die über keinerlei Kenntnisse aus dem Gebiet des Strahlenschutzes und der Strahlenbiologie verfügen.

Tab. 1 Abschätzungen der jährlichen Ganzkörperdosis durch Strahleneinwirkung aus künstlichen Quellen in den Vereinigten Staaten (1970) (1)

Quelle	Durchschnittliche Dosisleistung (mrem/Jahr)		Prozent
Radioaktiver Fallout	4		5,01
Kernenergie	0,003		0,004
Medizinische Diagnostik	72	73	91,48
Radiopharmaka	1		
Berufliche Strahlenexposition	0,8		1,00
Verschiedene Ursachen	2		2,51
	79,803		100,000

Tab. 2 Geschätzte mittlere Jahresdosen pro Person der Gesamtbevölkerung der USA

Art der Exposition	Mittlere Jahresdosis pro Person der Gesamtbevölkerung der USA (mrem)	
Röntgendiagnostik 1964:		
Genetisch-signifikante Dosis	54,6	
Gonadendosis	83	
Knochenmarkdosis	59	
Schilddrüsendosis durch:		
Untersuchungen des Kopfes und Halses	6,9	44
Untersuchungen des Brustkorbs	19	
Untersuchungen der Zähne	18	
Diagnostische Anwendungen von Radiopharmaka 1966:		
Schilddrüsendosis durch:		
Schilddrüsenfunktionstest mit 131J	101	[illegible]5
Schilddrüsenszintigraphie mit 131J	101	
Andere Untersuchungen mit 131J	2,7	
Gehirnszintigramme mit 99mTc	1,2	
Schilddrüsenszintigramme mit 125J	0,7	
Andere Verfahren	3	
Gonadendosen durch alle Radionuklide bei Funktionstesten und Szintigraphien	~ 1,0	
Ganzkörperdosen durch alle Radionuklide bei Funktionstesten und Szintigraphien	~ 1,0	
Knochenmarkdosis durch alle Radionuklide bei Funktionstesten und Szintigraphien	~ 0,5	
Genetisch-signifikante Dosis durch:		
Röntgendiagnostik in der Medizin und Zahnheilkunde (1964)	55	61
Strahlentherapie mit Röntgenstrahlen (1966)	5	
Strahlentherapie mit Radiopharmaka (1966)	0,6	
Diagnostische Anwendung der Radiopharmaka (1966)	0,26	
Schilddrüsendosis durch:		
Röntgendiagnostik an Kopf und Hals (1964)	6,9	269
an Brustkorb und Thorax (1964)	19	
Röntgendiagnostik in der Zahnheilkunde (1964)	18	
Diagnostische Anwendungen von Radiopharmaka (1966)	225	

Anmerkung: Die obigen Werte sind aus den Berichten über die Erhebung des USPHS (2) von *K.Z. Morgan* zusammengefaßt.

Tab. 3 Jährliche genetisch-signifikante Dosis der Bevölkerung durch medizinische Strahlenexposition**

Bevölkerung von:	Genetisch-signifikante Dosis in mrem/a	Bevölkerung von:	Genetisch-signifikante Dosis in mrem/a
Buenos Aires, Argentinien	37+	Norwegen	10+
Finnland	16,8++	Schweden (1955)	38*+
Dänemark (1956)	22*	Schweiz	22+
Deutschland (Bayern)	13,70++	Alexandria, V.A.R.	7+
Frankreich	58+	Jugoslawien (Slowenien)	9,13++
Rom, Italien	43+	Kairo V.A.R.	7+
Japan (1960)	26,5++	Großbritannien (Sheffield)	8,6++
Niederlande	20,0++	Großbritannien (1957)	14*+
Neuseeland (1969)	11,69++	Vereinigte Staaten (1964)	54,6* (35,5) Δ

* Werte aus "Bevölkerungsdosis durch Röntgenstrahlen. USA. 1964" US Public Health Service Veröffentlichung No. 2001, Okt. 1969 (Brown u.a.) (4)
Δ Wert in Klammern ist eine Schätzung bei der Erhebung des USPHS (1970) (3)
\+ Werte aus dem UNSCEAR-Bericht, Suppl. No. 16-A/5216 (1962) (5)
++ Werte aus dem UNSCEAR-Bericht, Suppl. No. 25-A/8725 (1972) (6)
** Es wird geschätzt, daß die signifikante Organdosis für die meisten Organe das zwei- bis dreifache der genetisch-signifikanten Dosis beträgt (5, 7, 8)

Tab. 4 Übliche Eintrittsdosen (in mrem) bei Röntgenaufnahmen in den USA

	Bereich der Werte	Durchschnittswert
Lungenaufnahme in Oak Ridge Nat. Lab. (1972)	10 – 20	15
Lungenaufnahme in den USA	10 – 300	45*
Lungenschirmbildaufnahme	200 – 2000	504*
Zahnstatus in den USA	1000 – 100 000	20 000*
Abdomenaufnahme, ausgeführt von Radiologen		636*
Abdomenaufnahme, ausgeführt von Nichtradiologen		1 253*

* Diese Durchschnittswerte werden einem Bericht "Population Exposure to X-rays, U.S. 1964" von *J.N. Gitlin* und *P.S. Lawrence*, HEW-PHS 1964 (2) entnommen.

Kürzlich suchte ich einen neuen Zahnarzt auf und fragte ihn nach der Empfindlichkeit des von ihm verwendeten Filmes. Aus seiner Antwort entnahm ich, daß er nicht verstand, wovon ich sprach. Ich fragte ihn, warum er nicht, wie von der Amerikanischen Zahnärztevereinigung empfohlen, den langen, offenen Tubus sowie außerdem eine rechteckige Vorderblende im Tubus verwende. Ich erhielt die unglaublich dumme Antwort, dies sei nicht notwendig, weil die von seinem Gerät abgegebene Röntgenstrahlendosis geringer sei als die, die man bei einer kurzen Sonnenbestrahlung im Freien erhielte. (Wahrscheinlich wußte er nicht, daß UV-Strahlung nicht gleich Röntgenstrahlung ist.)

In diesem Zusammenhang scheint die Frage angebracht, warum sich so viele Zahnärzte in den USA nicht an die Empfehlungen der Amerikanischen Zahnärztevereinigung halten (9): "Radiologische Untersuchungen sollten nicht automatisch bei jeder routinemäßigen zahnärztlichen Kontrolle durchgeführt werden."

Eine ähnliche Frage müßte Ärzten, Amtsärzten des öffentlichen Gesundheitsdienstes und Trägern öffentlicher Gesundheitsprogramme gestellt werden. Warum warteten sie bis 1972, ehe sie die im Jahre 1965 ausgesprochene Erklärung des Public Health Service der USA beachteten (10): "Röntgenreihenuntersuchungen des Brustraumes sollten nicht an allen Bevölkerungsgruppen vorgenommen werden, sondern sich nur auf die Gruppen innerhalb von Gemeinden beschränken, bei denen eine hohe Tuberkulosehäufigkeit bekannt ist." Befolgt wurde diese Erklärung erst 1972, nachdem die "National Tuberculosis and Respiratory Disease Association" festgestellt hatte (11): "Röntgenreihenuntersuchungen bei allgemeinen Bevölkerungsgruppen mit mobilen Röntgeneinheiten sind zum Nachweis von Lungenerkrankungen nicht effektiv und sollten eingestellt werden. Gesellschaften für Tuberkulose und Krankheiten der Atmungsorgane sollten Röntgenreihenuntersuchungsverfahren des Brustkorbes nicht mehr routinemäßig durchführen."

2. Folgen medizinischer Strahlenexposition

Schädigungen durch Röntgenstrahlen sind nichts Neues. So beobachtete *Grubbe* (12), ein Hersteller Crooks'scher Röntgenröhren in Chicago, eine bis zur Ulzeration führende Schädigung des linken Handrückens als Folge einer im Januar 1896 erhaltenen Röntgenexposition. Wegen der starken Schmerzen suchte er bereits am 26. Januar 1896, also fast genau 3 Wochen nach Röntgens erster öffentlicher Bekanntgabe seiner Entdeckung der X-Strahlen, am 4. Januar einen Arzt auf. Seit dieser Zeit ist es durch die Anwendung dieser großartigen Entdeckung zu vielfältigen Strahlenschädigungen gekommen. Erst seit kurzem ist man jedoch in der Lage, eine Beziehung zwischen einigen der Spätfolgen, wie z.B. vielen Formen von Krebs, teratogenen (Mißgeburten, Mißbildungen), embryologischen, fötalen und genetischen Schädigungen und einer Strahlenexposition, die Jahrzehnte, ja sogar Generationen vor ihrem Manifestwerden erfolgte, aufzudecken. Obwohl man gewisse Zweifel an der Richtigkeit einiger Veröffentlichungen haben kann, die auf eine Zunahme der Mißbildungen bei Kindern hinzudeuten scheinen, wenn es zu einer Strahlenexposition vor der Empfängnis gekommen war, steht es außer Frage, daß eine Bestrahlung des befruchteten Eies und des menschlichen Fötus zu verschiedenen Arten von Mißbildungen und sonstigen teratogenen Wirkungen führen kann. Der menschliche Fötus ist während des ersten Schwangerschaftsdrittels gegen ionisierende Strahlung am empfindlichsten. Mit einer gewissen Sicherheit kann man jedoch davon ausgehen, daß die Leibesfrucht in allen Stadien der Schwangerschaft stärker strahlenempfindlich ist, als der Mensch in allen anderen Entwicklungsstadien. *Rugbh* (13) stellt fest: "Wenn das menschliche Becken zwischen dem 10. und 42. Tag (der Schwangerschaft) bestrahlt wird, könnte man erwarten, eine Mißbildung zu entdecken, wenn die Dosis mehr als 25 R betragen hat" und "es ist am besten, befruchtete menschliche Eizellen, Embryos oder Föten keiner unnötigen ionisierenden Strahlung auszusetzen, solange nicht beträchtlich mehr gesichertes Beweismaterial vorliegt."

Wachstumsverzögerungen (14) scheinen nach den Beobachtungen an Überlebenden der Atombombenabwürfe in Hiroshima und Nagasaki einer der vorherrschenden Folgen der Strahlenexposition von Föten und Kleinkindern zu sein. Mehrere Beobachter berichten auch über ein vermehrtes Auftreten von Mongolismus nach Röntgenbestrahlung. Nach *Ucbhida* und *Curtis* (15) führt wahrscheinlich "Verklebung oder Non-distunction von Chromosomen während der meiotischen Zellteilung zu überzähligen Chromosomen (z.B. triploiden Formen) in jeder somatischen Körperzelle des Mongoloiden." Diese Autoren zogen aus ihrer Untersuchung an 81 mongoloiden Kindern den Schluß, daß ihre Daten "sehr stark auf einen Zusammenhang zwischen dem Auftreten von Mongolismus und einer Strahlenbelastung des mütterlichen Abdomens hindeuten." Wohlgemerkt, bei diesen Fallen betrug die Dosis nur einige Rad.

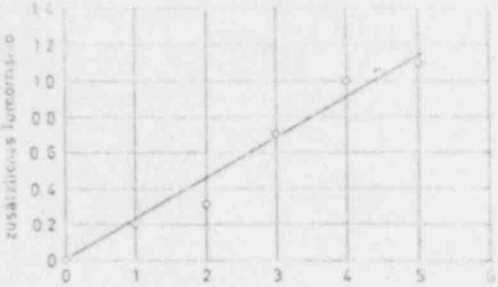


Abb. 1 Anzahl der Röntgenfilme für diagnostische Maßnahmen während der Schwangerschaft (nach Alice Stewart und G.W. Kneale, Lancet, Juni 1970)

Eine der beunruhigendsten Beobachtungen war in den letzten 10 Jahren das starke Auftreten von Leukämie (und anderer Krebsformen, besonders Tumoren des zentralen Nervensystems) bei Kindern, deren Mütter während der Schwangerschaft mit Röntgenstrahlen untersucht worden waren.

Es gibt viele Untersuchungen über die Auswirkungen der Pelvimetrie; die meisten weisen auf ein gehäuftes Auftreten maligner Erkrankungen bei Kindern hin, die in Utero bestrahlt worden waren. Eine sehr sorgfältige stammt von *Mac Mahon*. Er berichtet, daß nach den ersten Untersuchungen von *Alice Stewart* im Jahre 1953 etwa 12 weitere Arbeiten über die Beziehungen zwischen Pelvimetrie und anderen Strahlenexpositionen in Utero und Krebs bei Kindern veröffentlicht wurden. Er kam zu dem Schluß, daß, obwohl es positive und negative Ergebnisse gab, eine Berücksichtigung aller Ergebnisse, bewertet nach der Zahl der untersuchten Fälle, darauf hindeutet, daß die Sterblichkeit an Leukämie und an anderen Krebsarten bei Kindern, die in Utero durch Röntgendiagnostik exponiert wurden, um 40% höher liegt als bei nicht exponierten Kindern. Er gibt an, daß während der ersten zehn Lebensjahre das Risiko derartig exponierter Kinder, an Krebs zu sterben, bei 1 : 2000 liegt. Wenn also alle Frauen während ihrer Schwangerschaft im Jahre 1973 eine Pelvimetrie erhielten, würde das etwa 2000 Todesfälle pro Jahr in den Vereinigten Staaten bedeuten. Diese Zahl ist gering, jedoch nicht so gering, wenn zufällig das eigene Kind eine Zahl in dieser Statistik darstellt. Die Untersuchungen von *Stewart* und *Kneale* (1970) (17) über die Wirkungen einer diagnostischen Röntgenexposition bei Kindern ist besonders eindrucksvoll. In Abb. 1 sind einige ihrer Ergebnisse aufgetragen. Sie stützen sehr stark die Annahme einer linearen Beziehung zwischen Dosis und Wirkung bis hinunter zu wenigstens 1 rem, vielleicht sogar bis 0,25 rem. In neuerer Zeit haben einige Autoren *Taylor* (1972) (18) betont, daß diese Angaben aus Oxford nicht mit denen von *Jablon* u.a. (19) übereinzustimmen scheinen. Diese haben Untersuchungen über die Wirkungen der Bestrahlung bei Kindern, die als Föten die Atombombenabwürfe in Hiroshima und Nagasaki überlebten, gemacht. Eine genauere Analyse beider Untersuchungsergebnisse deutet jedoch darauf hin, daß es keine Widersprüche gibt. Offensichtlich stimmen die Daten aus Oxford und aus Japan vollkommen mit dem überein, was zu erwarten ist. Erstens sollte daran erinnert werden, daß nur Kinder, die älter als 2 Jahre sind, ein hohes Risiko einer Krebserkrankung im Jugendalter aufweisen, und daß es eine hohe Säuglingssterblichkeit unter den in Utero bestrahlten Kindern (43%) und eine sehr hohe Fehlgeburtenrate gab (*Miller* 1969) (20). So kam es bei vielen Kindern, die in Utero eine Strahlenschädigung erhielten, zu einem Abort oder sie überlebten die Zweijahresgrenze nicht, nach der sie an einer malignen Erkrankung hätten sterben können. Das heißt, viele Kinder, die nach dem zweiten Lebensjahr an einer malignen Erkrankung gestorben wären, aber in Utero große Strahlenschädigungen erlitten hatten, überlebten diese Zeitspanne nicht.

Zweitens geht aus vielen Untersuchungen (*Bennet* 1970) (21) hervor, daß während einer allgemeinen Katastrophe Kleinkinder und alte Leute am häufigsten erkranken und deshalb aus verschiedenen Gründen, einschließlich Krebs, sterben. Es ist bekannt, daß in solchen Zeiten beginnende Krebserkrankungen häufig als akute Infektionen fehldiagnostiziert werden.

Eine weitere Möglichkeit (vielleicht jedoch eine unwahrscheinliche) besteht darin, daß Neutronen einen Teil der Strahlenbelastung bei den japanischen Überlebenden der Atombombenabwürfe verursachten, und daß sie frühe Todesfälle durch andere Ursachen als maligne Erkrankungen begünstigt haben. Es könnte auch sehr wohl sein, daß es beträchtliche Artunterschiede zwischen diesen beiden Populationen gibt. Solche deutlichen Artunterschiede wurden z.B. bei Tieruntersuchungen festgestellt, die von *Warren* und *Gates* (22) und vielen anderen durchgeführt wurden.

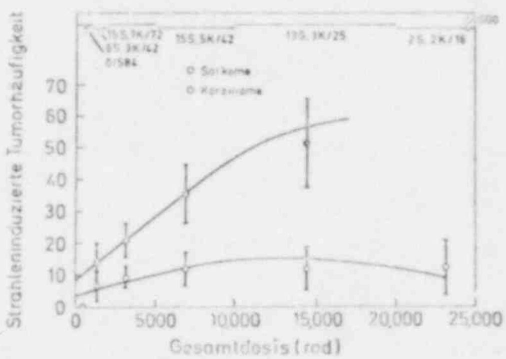


Abb. 2 Prozentuale Häufigkeit von Sarkomen und Karzinomen dargestellt über den Medianwert der Gesamtskelettdosis in rad in linearen Koordinaten (nach *R.E. Rowland* et al., ANL-7760, Teil II, Argonne National Laboratory, Argonne, III (Juli 1969 - Juni 1970)) (23)

Am wichtigsten ist möglicherweise die Tatsache, daß die Daten von *Jablon* sich auf 33 japanische Kinder beziehen, die eine Strahlenbelastung in utero von mehr als 300 rad erhalten hatten. Man muß sich fragen, ob die Daten von *Stewart* auf diese Bevölkerungsgruppe überhaupt angewendet werden sollten, weil diese Dosen so hoch waren, daß sie wahrscheinlich an das äußere Ende der Parabel über die Häufigkeit von Leukämien fallen, ähnlich wie es bei den in Abb. 2 dargestellten Kurven von *Rowland* (23) für Sarkome und Karzinome der Fall ist. *Marinelli* (24) und viele andere Forscher haben in ihren Veröffentlichungen darauf hingewiesen, daß sich die Linearität dieser Kurven nicht bis in hohe Dosisbereiche fortsetzt, obwohl es eine lineare Beziehung zwischen der Dosis und den Wirkungen auf Tiere bei niedrigen Dosen geben kann. Man kann nicht mehr als 100% der Tiere durch Bestrahlung töten. Bei den höheren Strahlenpegeln (z.B. denjenigen, die die Kinder erhielten, die Einzeitdosen von mehr als 300 rad in Hiroshima und Nagasaki überlebten) können viele der bestrahlten Personen, noch bevor sie an Krebs zugrunde gehen, an anderen Ursachen sterben.

Stewart hat auch die Vermutung geäußert, daß die Kontrollgruppe der Überlebenden der Bombenabwürfe in Hiroshima und Nagasaki wahrscheinlich ein höheres Krebsrisiko aufwies als eine normale Population, was wiederum dazu anregen würde, jede beobachtete Strahlenwirkung zu verkleinern. Schließlich wurde noch vorgebracht, daß *Stewart* vielleicht mit einem sehr niedrigen Wert für die durchschnittliche Fetaldosis durch Beckenmessungen in Großbritannien gerechnet hat. Wenn man diese Korrektur vornimmt und den niedrigsten bei der Untersuchungsreihe in Oxford von *Stewart* gefundenen Koeffizienten verwendet und eine Korrektur von 0,5 an den Werten von *Jablon* vornimmt, um die Dosis am Fetus aus der Hautdosis zu erhalten, würde man erwarten, daß man bei der japanischen Gruppe, die in utero mit 40 bis 299 rad bestrahlt wurde, zwei Krebsfälle findet. Tatsächlich wurde nur einer festgestellt. Keine Krebsfälle wären in der Gruppe zu erwarten, die zwischen 0 und 39 rad in utero erhalten hatte. Da die Strahlenbelastung für die Gruppe, die mehr als 300 rad erhielt, wahrscheinlich am äußeren Ende der Parabel liegt (vgl. Abb. 2), wären ebenfalls keine Krebsfälle mehr zu erwarten, und es wurden auch keine beobachtet. Angesichts der Unsicherheit bei den Daten und der kleinen Zahl der während der Bombenabwürfe in utero bestrahlten Kinder scheint es tatsächlich eine gute Übereinstimmung zwischen der Zahl der Krebsfälle, die bei den in Japan in utero bestrahlten Kindern beobachtet wurden und den Kindern in der Oxford-Studie, die diagnostisch exponiert wurden, zu geben.

Aus dieser Diskussion scheint hervorzugehen, daß es mehr als nur eine Annahme ist, daß eine lineare Beziehung zwischen der Knochenmarksdosis und der Leukämiehäufigkeit selbst bis zu einer so niedrigen Dosis wie 1 rem oder weniger bestehen kann. Ähnliche Beweise werden vielleicht zu gegebener Zeit für andere Krebsarten zur Verfügung stehen. *Hemplemann* (1968) (25) z.B. schloß aus seinen umfangreichen Untersuchungen, die sich auf einen weiten Dosisbereich in menschlichen Schilddrüsen (von 1 200 rad bis hinunter zu 20 rad) erstreckten:

"1. Die Beziehung zwischen Dosis und dem Auftreten von Schilddrüsentumoren ist in niedrigen Dosisbereichen linear.
2. es gibt keinen Schwellenwert oder er liegt zumindest unter 20 rad."

Die BEIR-Kommission (1972) (1) hebt hervor, daß das Risiko, durch Strahleneinwirkung Krebs zu erzeugen, für jüngere Personen in der Bevölkerung größer zu sein scheint. Sie weist darauf hin, daß die von *Saenger* u.a. (1968) (26) getroffene Feststellung, es gäbe kein erhöhtes Risiko eines Schilddrüsenkrebses durch Applikation von Jod 131, nicht dadurch gerechtfertigt ist, daß sie keine eindeutige Zunahme von Schilddrüsenkarzinomen bei Patienten mit Hyperthyreose fanden, die mit Jod 131 behandelt wurden. Dafür gibt es zumindest zwei Gründe:

1. war ihr Beobachtungszeitraum zu kurz und
2. würden sie bei diesen hohen Dosen am äußeren Ende der Parabel liegen, wie dies bereits für Leukämie geschildert und für Knochentumore in Abb. 2 dargestellt wurde.

Außerdem haben einige Autoren *Griffiths* und *Ballantine* (1973) (27) die Objektivität dieser Untersuchungen in Frage gestellt.

Angesichts dieser Auseinandersetzungen über die Wirkungen ionisierender Strahlung, das Ausmaß der Schädigung für den Menschen, die Frage, ob die Dosiswirkungsbeziehung bei niedrigen Dosen und Dosisleistungen linear ist, ob Strahlenschutznormen angemessen sind und inwieweit Maßnahmen zu einer starken Einschränkung unnötiger Strahlenbelastung wünschenswert sind, hat die National Academy of Science die BEIR-Kommission (1) eingesetzt. Sie hat ihr zur Aufgabe gemacht, die Gefahren der ionisierenden Strahlung durch Heranziehung neuerer biologischer Daten unter besonderer Berücksichtigung der verfügbaren Informationen über die menschliche Strahlenbelastung erneut abzuschätzen. Die Kommission machte darauf aufmerksam, daß es vier Möglichkeiten gibt, das genetische Risiko auszudrücken:

a) Das Risiko im Verhältnis zur natürlichen Grundstrahlung
Eine künstliche Strahlenexposition unterhalb des Pegels der natürlichen Grundstrahlung ist keine Rechtfertigung für ihre Anwendung an sich und läßt auch nicht die Annahme zu,

daß eine derartige Strahlenexposition vernachlässigbar oder harmlos ist. "Sie wird zusätzliche Wirkungen hervorrufen, die in ihrem Ausmaß geringer und in ihrer Art nicht anders sind als diejenigen, denen der Mensch während seiner gesamten Geschichte ausgesetzt war und die er hat ertragen können" (1).

b) Risikoabschätzungen für spezifische genetische Bedingungen

Aufgrund von Untersuchungen an der Maus und der Drosophila und bis zu einem gewissen Grad auch von Beobachtungen an menschlichen Populationen "wird geschätzt, daß die Dosis zur Verdoppelung der Mutationsrate beim Menschen bei Dauerbestrahlungen etwa im Bereich zwischen 20 und 200 rem liegt. Es wurde berechnet, daß die Wirkung von 170 mrem/a in der ersten Generation zwischen 100 und 1 800 Fälle schwerer dominanter oder X-chromosomengebundener Krankheiten und Schädigungen pro Jahr hervorrufen würde (unter Annahme von 3,6 Millionen Geburten jährlich in den USA).

Ist ein Gleichgewicht erreicht, das sich nach mehreren Generationen einstellt, würden diese Zahlen etwa das Fünffache betragen. Hinzu käme eine geringere Anzahl, die durch Chromosomenaberrationen und rezessive Krankheiten verursacht wäre" (1). Es sei hinzugefügt, daß die oben erwähnte Zahl von 1 800 Mutationen pro Jahr mit einer groben Berechnung übereinstimmt, wenn man Daten der ICRP (1966) (28) auf die gesamte Bevölkerung der USA anwendet, nämlich

$$2 \times 10^{-5} \frac{\text{1. Generation Mutation}}{\text{rem} \cdot \text{Person}} \times 2 \times 10{,}8 \text{ (Personen)} \times 0{,}170 \left(\frac{\text{rem}}{\text{Jahr}}\right) \approx 700 \text{ Mutationen}$$

in der 1. Generation pro Jahr.

c) Das Risiko im Verhältnis zur gegenwärtigen Quote schwerer körperlicher Schädigungen

Zu den unter (b) aufgeführten Schädigungen, die durch Defekte einzelner Gene und Chromosomenaberrationen verursacht werden, kommen noch angeborene Mißbildungen und konstitutionelle Krankheiten, die teilweise genetischen Ursprungs sind. Die Gesamtzahl aller genetischen Mutationen (einschließlich der unter (b) aufgeführten) in einer im Gleichgewicht befindlichen Bevölkerung der USA durch 170 mrem/Jahr wurde zwischen 1100 und 27000 pro Jahr geschätzt. Diese höhere Zahl könnte teilweise mit den Schätzungen der ICRP (28) verglichen werden, daß die Gesamtzahl von Mutationen im Gleichgewichtszustand das 40fache der in der ersten Generation auftretenden betragen würde, d.h. 40 x 700 = 28 000 pro Jahr in einer stabilen Bevölkerung der USA, die Hunderte von Jahren mit 170 mrem/Jahr belastet wurde.

d) Das Risiko, ausgedrückt als "allgemein schlechter Gesundheitszustand" (Overall illhealth)

Dies wird als das am günstigsten faßbare Maß für die genetische Schädigung betrachtet, da "schlechter Gesundheitszustand" die oben erwähnten Kategorien enthält, sich jedoch nicht auf sie beschränkt. Es wird geschätzt, daß zwischen 5 und 50% von Gesundheitsbeeinträchtigung der Mutationsrate proportional sind. Auf dieser Grundlage und bei Annahme von 20 rem als Verdoppelungsdosis für genetische Mutationen würden die 170 mrem/Jahr oder 5 rem/30 Jahre genetischen Lebens:

$$\frac{50}{20} \times 100\% \times \left(\frac{5}{100}\right) \text{ bis } \frac{50}{100} = 1{,}2 \text{ bis } 12\%$$

des schlechten Gesundheitszustandes einer Bevölkerung verursachen. Es wird angeregt, daß die Normenausschüsse mit Hilfe von Schätzungen über die finanziellen Kosten für eine 1,2- bis 12prozentige Zunahme des schlechten Gesundheitszustandes (einschließlich der Krankheiten, körperlicher Fehler und Sterbefälle) den Preis ausrechnen, den die Gesellschaft für

170 mrem/Jahr zahlen muß und ihn gegen den zu erwartenden Nutzen abwägen. 170 mrem/Jahr ist der von der ICRP (29) und des FRC (30) festgelegte Grenzwert für die Belastung der Bevölkerung.

Interessanterweise beträgt die gesamte genetisch signifikante Dosis des Durchschnittsmenschen in den Vereinigten Staaten aus allen Quellen ionisierender Strahlung (d.h. medizinische Strahlenexposition 61 mrem/Jahr + natürliche Grundstrahlung 100 mrem/Jahr + Fallout 3 mrem/Jahr + alle anderen, einschließlich beruflicher Exposition, Kernindustrie usw. 5 mrem/Jahr) etwa 170 mrem/Jahr. Obwohl die medizinische Strahlenexposition und die Grundstrahlung bei dem von der ICRP festgelegten oberen Grenzwert von 5 rem/30 Jahre oder 170 mrem/Jahr ausgenommen sind, könnte die Gesellschaft gewaltige finanzielle Kosten einsparen, wenn sie diese 1,2 bis 12 % an schlechtem Gesundheitszustand, Leiden, Krankheiten, geistigen und körperlichen Gebrechen (Mißbildungen) und Todesfälle, die eine Folge der gesamten genetisch signifikanten Dosis sind, in der 200 Millionen Bevölkerung der Vereinigten Staaten verringern würde. Es können Maßnahmen ergriffen werden, um die terrestrische Komponente der natürlichen Grundstrahlung herabzusetzen. Die größte Kostenersparnis könnte jedoch dadurch erreicht werden, daß man die unnötige diagnostische Strahlenexposition in der Medizin verringert.

Der Bericht der BEIR-Kommission erhärtet die oben erwähnte Sorge und die Erkenntnis, daß die somatischen Risiken einer Strahlenschädigung für eine Bevölkerung ebenso groß oder sogar größer sein können als die genetischen Risiken.

Tabelle 5 stellt eine Zusammenfassung der Risikoabschätzungen der *Beir*-Kommission dar.

Tab. 5 Risikoabschätzungen der BEIR-Kommission bei einer stabilen Bevölkerung der USA für eine genetisch-signifikante Dosis von 170 mrem/Jahr

	Gesamtzahl pro Jahr
Schwere körperliche Gebrechen, angeborene Mißbildungen, konstitutionelle Krankheiten, Sterbefälle usw.	1100 bis 27 000
Allgemein schlechter Gesundheitszustand	1,2% bis 12% derjenigen in den USA
Krebs (Todesfälle/Jahr)	3000 bis 15 000

In dem Bericht heißt es: "Noch bis vor kurzem wurde als selbstverständlich angenommen, daß genetische Risiken einer Exposition von Populationen durch ionisierende Strahlung in der Höhe der natürlichen Grundstrahlung von viel größerer Bedeutung sind als die somatischen Risiken. Diese Annahme kann jedoch nicht länger aufrechterhalten werden, wenn lineare Beziehungen ohne Schwellenwert als Grundlage für die Abschätzung des Krebsrisikos akzeptiert werden. Aufgrund von zugegebenermaßen unvollkommenen Kenntnissen der Wirkungsprinzipien muß festgestellt werden, daß die Tumorentstehung als Folge einer Strahlenschädigung einer oder mehrerer Körperzellen nicht ausgeschlossen werden kann. Es wurden Risikoabschätzungen angestellt, die auf dieser Voraussetzung beruhen und bei denen lineare Extrapolationen der Daten von Überlebenden der Atombombenabwürfe in Hiroshima und Nagasaki, bestimmter Patientengruppen, die therapeutisch behandelt wurden und von beruflich strahlenexponierten Gruppen vorgenommen wurden. Derartige Berechnungen aufgrund dieser Daten über exponierte Personen führen zu der Vorhersage, daß eine zusätzliche Strahlenexposition der Bevölkerung der USA in Höhe von 5 rem/30

Jahre (durchschnittlich 170 mrem/Jahr) annähernd 3000 bis 15000 Todesfälle durch Krebs jährlich verursachen könnte. ... Die Kommission hält eine Zahl von 6000 Krebstodesfällen jährlich für die wahrscheinlichste Schätzung, was eine Zunahme von ca. 2% der spontanen Sterbeziffer durch Krebs und eine Zunahme von etwa 0,3% der Gesamtsterbeziffer durch alle Ursachen bedeuten würde" (1). Weiterhin heißt es in dem BEIR-Bericht: "Die gegenwärtigen Richtwerte von 170 mrem/Jahr entstanden aus dem Bemühen, die sozialen Erfordernisse gegen genetische Risiken abzuwägen. Es scheint, daß diese Erfordernisse auch mit wesentlich geringeren durchschnittlichen Strahlenexpositionen und einem niedrigeren genetischen und somatischen Risiko, als es in den gegenwärtige Strahlenschutzrichtlinien (FRC 1960-1961) (30) gestattet ist, erfüllt werden können. Darum ist der gegenwärtige Richtwert unnötig hoch. Die Belastung durch die Strahlenanwendung in der Medizin und Zahnmedizin sollte nach demselben Prinzip behandelt werden. Um den Bereich, um den Belastungen ohne Beeinträchtigung des Nutzens herabgesetzt werden können, sind sie ebenfalls zu hoch" (1).

Die BEIR-Kommission faßte ihren 220 Seiten langen Bericht mit speziellen Beobachtungen und Empfehlungen zusammen, von denen einige lauten:

a) Strahlenexpositionen, von denen kein entsprechender Nutzen zu erwarten ist, sollten nicht gestattet werden.

b) Die Öffentlichkeit muß gegen Strahlung geschützt werden, jedoch nicht soweit, daß an ihre Stelle eine noch größere Gefahr tritt. Man sollte Geld zur Verringerung der Strahlenrisiken dort ausgeben, wo die größte Risikoverringerung pro Dollar erwartet werden kann.

c) Auch für die Einzelperson sollte ein oberer Grenzwert für künstliche nichtmedizinische* Strahlenexposition festgelegt werden, und zwar so, daß das Risiko einer schweren somatischen Schädigung sehr gering ist.

d) Der Grenzwert für eine künstliche nichtmedizinische Strahlenexposition der Allgemeinbevölkerung sollte wesentlich erniedrigt werden.

e) Die medizinische Strahlenexposition kann und sollte dadurch beträchtlich verringert werden, daß sie auch auf klinisch indizierte Verfahren in bester technischer Durchführung mit einwandfrei betriebener Apparatur beschränkt wird.
Folgende Punkte sollten berücksichtigt werden:
1. Einschränkung der Strahlenanwendungen bei der öffentlichen Gesundheitsüberwachung, falls nicht eine echte Wahrscheinlichkeit besteht, Krankheiten in signifikantem Ausmaß festzustellen.
2. Überprüfung und Genehmigung der Strahleneinrichtung und Zusatzausrüstung.
3. Angemessene Ausbildung des Personals und entsprechender Nachweis darüber. Ein Gonadenschutz (besonders eine Abdeckung der Hoden) wird ausdrücklich als einfache und sehr wirkungsvolle Methode zur Reduzierung der genetisch signifikanten Dosis empfohlen (1).

Eine weitere Diskussion der Folgen einer medizinischen Strahlenexposition ist hier nicht mehr erforderlich. Die Risikoabschätzungen der BEIR-Kommission, wie sie in Tabelle 5 (für eine Belastung der Bevölkerung der USA mit durchschnittlich 170 mrem/Jahr) zusammengefaßt wurden, sollen aber noch mit den in Tabelle 2 zusammengestellten Daten für die medizinische Strahlenexposition verglichen werden. Es ist nicht bekannt, wie hoch die

* Der Autor (KZM) ist der Meinung, daß obere Grenzwerte auch für die bei bestimmten routinemäßigen diagnostischen Strahlenanwendungen dem Patienten verabfolgten Dosen aufgestellt werden sollten.

durchschnittliche Ganzkörperdosis der Bevölkerung der USA aus medizinischen Strahlenquellen im Jahre 1964 war, ebensowenig ist sie infolge der unvollständigen Erhebung für das Jahr 1970 bekannt. Aus einem Vergleich mit Erhebungen in anderen Ländern ist jedoch mit Sicherheit zu erwarten, daß sie größer als die Gonadendosis ist. Die gesamte durchschnittliche Gonadendosis durch medizinische Strahlenquellen im Jahre 1964 wurde nicht veröffentlicht. Sie kann jedoch auch auf etwas über 90 mrem geschätzt werden, so daß die Ganzkörperdosis wahrscheinlich mindestens 100 mrem betrug. Die Ganzkörperdosis im Jahre 1970 unterscheidet sich wahrscheinlich nicht sehr stark von dem Wert von 1964, da die Anzahl der Röntgenaufnahmen beträchtlich zugenommen hat. Es kam zu einer Abnahme der genetisch signifikanten Dosis bei Männern (durch Anwendung lokaler Abschirmung), jedoch zu einer Zunahme der genetisch signifikanten Dosis bei Frauen. Damit betragen die Folgen einer medizinischen Strahlenexposition für die Bevölkerung der USA sicherlich mindestens 60% derjenigen, die für 170 mrem/Jahr angegeben wurden. Anders ausgedrückt heißt dies, aufgrund der linearen Beziehung zwischen Dosis und Wirkung, die sich aus der vorherigen Diskussion ergibt, und auf der die Daten in Tabelle 5 beruhen, können wir folgern, daß zum gegenwärtigen Zeitpunkt durch die Anwendung ionisierender Strahlung in der Medizin (meistens Röntgenstrahlung in der Diagnostik) eine mindestens so schwere Schädigung der Bevölkerung verursacht wird, wie sie Tabelle 6 zeigt.

Tab. 6 Mindestabschätzungen der Schädigung durch medizinische Strahlenexposition in den USA

	Gesamtzahl pro Jahr
Schwere körperliche Gebrechen, angeborene Mißbildungen, konstitutionelle Krankheiten, Todesfälle usw.	660 bis 14 000
Allgemein schlechter Gesundheitszustand	0,7% bis 7% des in den USA bestehenden Wertes
Krebs (Todesfälle/Jahr)	1800 bis 9000

3. Einige ermutigende Entwicklungen in den USA

In letzter Zeit gibt es einige ermutigende Entwicklungen, die zu einer Verringerung der medizinischen Strahlenexposition der Bevölkerung der USA führen.

Dazu gehören z.B.:

a) Es gab nachdrückliche und in gewisser Weise auch wirkungsvolle Erklärungen der nationalen Gesellschaft für Tuberkulose und Erkrankungen der Atemwege und des öffentlichen Gesundheitsdienstes der Vereinigten Staaten, daß Röntgenreihenuntersuchungen des Brustraumes, abgesehen von Gebieten, in denen eine große Tuberkulosehäufigkeit zu verzeichnen ist, nicht weiter durchgeführt werden sollen.

Die mittlere Hautbelastung pro Aufnahme bei Röntgenuntersuchungen des Thorax nahm ebenfalls ab (z.B. von 86 mR im Jahre 1964 auf 58 mR im Jahre 1970 bei den Gesundheitsbehörden und von 34 mR auf 24 mR in Privatpraxen).

b) Die jährliche genetisch signifikante Dosis durch diagnostische Verfahren sank von 54,6 mrad im Jahre 1964 auf 35,5 mrad im Jahre 1970. Diese Abnahme beschränkt sich ganz auf die Dosis an den Hoden, da in dieser Zeit die jährliche genetisch signifikante Dosis bei Männern (meist infolge lokaler Abschirmung), von 45,5 mrad auf 22,0 mrad zurückging, während sie bei Frauen von 8,3 mrad auf 12,5 mrad und beim Fötus von 0,9 mrad auf 1,0 mrad anstieg. Die Gonadendosis durch diagnostische Maßnahmen im Jahre 1964 betrug 143 mrad für den Mann und 26 mrad für die Frau oder durchschnittlich 84 mrad.

c) Das Verhältnis zwischen der Fläche des Nutzstrahlenbündels und der Filmfläche sank von 3,3 auf 2,3 in Privatpraxen, von 2,8 auf 1,6 bei privaten Gruppen, von 2,0 auf 1,8 bei Gesundheitsämtern, von 1,9 auf 1,3 in Krankenhäusern und von 1,8 auf 1,4 in Privatpraxen von Radiologen. Am stärksten wurde die genetisch signifikante Dosis durch diagnostische Verfahren im Sechsjahreszeitraum bei den Röntgenuntersuchungen der Lendenwirbelsäule verringert. Diese Untersuchungen machten 40% der genetisch signifikanten Dosis im Jahre 1964 aus, jedoch nur noch 16% im Jahre 1970.

Einen weiteren Fortschritt im gleichen Zeitraum bedeuteten die freimütigen und offenen Kritiken durch prominente Mediziner in medizinischen Zeitschriften hinsichtlich mißbräuchlicher Anwendungen von Röntgenstrahlen in der Diagnostik. Einige der zusammenfassenden Arbeiten über dieses Thema stammen von folgenden Autoren: *Sagan* (31), *McClenahan* (32), *Warren* (33), *Stewart* und *Kneale* (34), *Brook* und *Stevenson* (35), *Sutherland* (36), *Bell* und *Loop* (37) und *Kissick* (38).

Vielleicht die beste Möglichkeit, auf die wertvolle Selbstkritik, Ehrlichkeit und Offenheit einiger Mitglieder der Ärzteschaft hinzuweisen, mit der sie die Aufmerksamkeit auf unbefriedigende Bedingungen und die Notwendigkeit von Verbesserungen bei der Anwendung von Röntgenstrahlen in der Diagnostik lenkten, besteht darin, aus dem Artikel von *McClenahan* (1970) (32) zu zitieren:

"Jeder, der heutzutage in einer vielbeschäftigten Klinik neben einem Röntgengerät steht, wird innerhalb einer Stunde zu den folgenden Überlegungen kommen:

1. Eine Röntgenuntersuchung anzuordnen, ist leichter als nachzudenken. Das trifft besonders auf große Ausbildungsstätten mit Forschungsverpflichtungen zu.
2. Röntgenuntersuchungen werden regelmäßig durchgeführt, auch wenn eine genaue Diagnose mit dem bloßen Auge, dem Ohr oder dem Finger gestellt werden kann. Dieses Verfahren wird als "Ausschließverfahren" bezeichnet.
3. Es gibt schwere gesetzliche Strafen für jeden, der es versäumt, eine Röntgenuntersuchung anzuordnen, gleichgültig, wie geringfügig die Verletzung oder Krankheit war. Es gibt keinerlei Strafen für leichtfertige oder ständig wiederholte Röntgenuntersuchungen.
4. Fast jeder ist in irgendeiner Art von Versicherung, die für die Kosten von Röntgenaufnahmen aufkommt. Das bedeutet, daß die Kosten nicht länger abschreckend wirken.
5. Zwar haben technische Verbesserungen die Höhe der Patientenexposition pro Film verringert, jedoch werden jetzt zur Diagnosestellung mehr Filme als früher benötigt.
6. Qualifizierte Arbeitskräfte sind knapp. Anforderungen von Röntgenleistungen nehmen zu, gleichzeitig schwindet die Zahl der Radiologen und Röntgenassistenten, was zu hastigen und gefährlichen Techniken führen kann.
7. Im Volk verwurzelte Vorstellungen und andere traditionelle Riten, eine zweifelhafte Rationalität, führen zu höherer unnötiger Strahlenexposition der Patienten und zu sinnloserer Vergeudung als die meisten von uns ahnen." (32)

Der Sinn und die Wahrheit jeder der obigen Beobachtungen ist vermutlich eindeutig und braucht nicht weiter kommentiert zu werden. Jedoch sollten vielleicht einige unterstützende Beobachtungen erwähnt werden:

Beispielsweise geht *McClenahan* weiter auf Punkt 1 ein: "Einige Assistenten und einige Chefärzte ordnen automatisch eine Serie von Röntgenuntersuchungen erneut an, wenn ein Patient ihr Krankenhaus betritt, selbst wenn er eine Woche alte Filme mitbringt, die die Diagnose eindeutig erkennen lassen" (32).

Bell und *Loop* (1972) (37) unterstreichen diesen Punkt, indem sie eine Gruppe von Patienten erwähnen, bei denen die Ausbeute sehr gering war (eine Fraktur bei 435 Röntgenuntersuchungen) und kommentieren: "Röntgenuntersuchungen in dieser letzteren Gruppe hätte man aufschieben oder ganz wegfallen lassen können, ohne daß sich das auf die Versorgung des Patienten nachteilig ausgewirkt hätte." (37).

Hinsichtlich Punkt 2 hat eine Anzahl von Ärzten auf die geringe Ausbeute bei Röntgenaufnahmen des Schädels hingewiesen; *Sutherland* (1970) (36) sagt z.B.: "Bei den Schädelaufnahmen in der vorliegenden Studie zeigte sich die geringste Übereinstimmung zwischen klinischen und radiologischen Befunden. Lediglich eine krankhafte Veränderung, ein Hypophysenadenom, wurde unter 70 angeordneten Aufnahmen nachgewiesen" (36).

Hinsichtlich Punkt 3 wird allgemein anerkannt, daß irgend etwas geschehen muß, um die Androhung gesetzlicher Strafen für Ärzte zu mildern, die auf Röntgenaufnahmen verzichten, wenn sie sich davon nur wenige nutzbringende Informationen versprechen. Die Juristen könnten bei der Lösung dieses Problems vielleicht helfen, wie sie es auch in anderen ähnlichen Fällen schon getan haben. Beispielsweise verhinderte der "Verjährungsparagraph" in verschiedenen Staaten den Bezug einer Arbeitnehmerentschädigung, denn der Anspruch auf eine Entschädigung entfällt, wenn er nicht innerhalb von ein paar Jahren nach der durch die berufliche Tätigkeit verursachten Verletzung geltend gemacht wurde. Ganz offensichtlich berücksichtigen diese Gesetze die Möglichkeit strahleninduzierter maligner Erkrankungen, deren durchschnittliche Latenzzeit 10 bis 30 Jahre beträgt, kaum oder gar nicht. Der Sonderausschuß für Atomenergierecht der Amerikanischen Rechtsanwältevereinigung beriet über diese Angelegenheit und schlug 1968 vor, "die Laufzeit zur Geltendmachung eines Anspruches sollte nicht eher beginnen, als bis der Beschäftigte weiß oder aufgrund sorgfältiger Überlegungen wissen müßte, daß

a) er verletzt ist;
b) es eine mögliche Beziehung zwischen der Verletzung und der Tätigkeit, bei der die Strahlenbelastung erfolgte, besteht und
c) er eine Schädigung erlitten hat;

oder im Falle des Todes des Beschäftigten sollte die Laufzeit für die Geltendmachung eines Anspruches nicht vor dem Zeitpunkt des Todes beginnen."

Vielleicht kann man den öffentlichen Gesundheitsdienst der USA dazu bringen, um Unterstützung dieses Ausschusses zur Milderung der angedrohten gesetzlichen Strafen nachzusuchen, wenn der Arzt das vermeidet, was er mit Recht als unnötige Strahlenbelastung des Patienten ansieht.

Wie in Punkt [illegible] gelegt wurde, erübrigt sich durch die Möglichkeit, die Kosten für eine Röntgen[illegible]eintreiben (oder sogar einen Gewinn zu erzielen), die Frage, ob bei einem [illegible] eine Röntgenaufnahme gemacht werden soll oder nicht. *Kissick* (1970) (3[illegible]h, "die Bemühungen um die Gesundheit in den Vereinigten Staaten, ein 60-[illegible]-Unternehmen menschlicher Dienstleistungen, befinden sich in einem Krisenzustand, der ihre Fortsetzungen in ihrer bisherigen pluralistischen, unabhängigen freiwilligen Weise in Frage stellt".

Kosten für medizinische Maßnahmen können nicht im gegenwärtigen Tempo weiter steigen, während die Qualität der medizinischen Versorgung, wenn überhaupt, dann nur geringfügig verbessert wird.

Es ist schwer zu verstehen, warum jetzt mehr Filme pro Untersuchung erforderlich sind, es sei denn, man verbindet Punkt 5 mit Punkt 4. Vielleicht sind heute mehr Wiederholungsaufnahmen erforderlich, was durch Punkt 6 erklärlich wäre. *Brook* und *Stevenson* (1970) [35] stützen Punkt 6, indem sie aufgrund ihrer Untersuchungen betonen, "nur 37 von 98 Patienten, die röntgendiagnostisch untersucht wurden, wußten, ob der Befund normal oder pathologisch war, und nur 14 von diesen 38 Patienten mit einem pathologischen Röntgenbefund schienen angemessen therapeutisch behandelt worden zu sein" [35]. Vielleicht gibt es kein besseres Beispiel für Punkt 7 als die Tatsache, auf die *Nader* (1968) [39] öffentlich hingewiesen hat, daß nämlich viele Röntgenassistenten in den Vereinigten Staaten bei Patienten mit schwarzer Hautfarbe eine höhere Dosis verabreichen. Ein noch allgemeineres Beispiel ist die neurotische Patientin mit niedriger Schmerzschwelle, die ohne Röntgenaufnahme nicht zufrieden ist. Der vielleicht beste Ratschlag an den Arzt in diesem Fall lautet: Bei der Frau als Teil der erforderlichen Psychotherapie Röntgenaufnahmen vorzunehmen, aber ohne zu schalten.

Die Liste von *McClennahan*, in der er die Gründe anführt, warum heutzutage Patienten übermäßige medizinische Strahlenexpositionen erhalten, ließe sich noch um eine Reihe von Punkten erweitern. Einige davon sind in Tabelle 6a zusammengestellt.

Der vielleicht eifrigste und standhafteste Verfechter von Reformvorlagen zur Reduzierung unnötiger klinischer Strahlenbelastungen in den Vereinigten Staaten war der verstorbene Senator *E.L. Bartlett*. Er legte den Grundstein für das Public Law 90-602 (18.10.1968), das einen Zusatz zum Gesetz über den öffentlichen Gesundheitsdienst darstellt und für den Schutz der öffentlichen Gesundheit gegen Strahlenemission aus elektronischen Erzeugern sorgen soll. Das Gesetz soll alle elektronischen Erzeuger ionisierender oder nicht ionisierender, elektromagnetischer oder Teilchenstrahlung oder jeder Strahlung im Schall-, Infraschall- oder Ultraschallbereich überwachen, die zu einer übermäßigen Strahlenbelastung und möglichen Schädigung des Menschen führen könnten. Es überträgt dem Gesundheitsminister die Befugnis und Verantwortung, dafür zu sorgen, daß Röntgengeräte, Fernsehgeräte, Mikrowellenherde, Ultraschallgeräte und alle anderen derartigen Geräte und ihre Bestandteile so hergestellt, montiert und angewandt werden, daß jede übermäßige Strahlenexposition von Beschäftigten und Bevölkerung vermieden wird. Es verlangt vom Gesundheitsminister, geeignete Durchführungsbestimmungen für die Überwachung von Anlagen, die Strahlen erzeugen, aufzustellen und diese Normen durchzusetzen und wenn notwendig, neue Normen zu entwickeln. Er soll Forschung, Entwicklung, Ausbildung und betriebliche Tätigkeit so planen, leiten, koordinieren und unterstützen, daß die Strahlenbelastung der Bevölkerung durch unnötige Strahlung auf ein Mindestmaß beschränkt wird. Er soll bei der Ausarbeitung staatlicher Programme für die Ausbildung und Prüfung so mitwirken, daß die sachliche Zuständigkeit derjenigen sichergestellt ist, die Strahlenquellen anwenden oder für die Überprüfung und Bescheinigung ihres ordnungsgemäßen Betriebes und ihre Anwendung verantwortlich sind. Entsprechend dem Public Law 90-602 wurde ein spezieller Sicherheitsausschuß gegründet, der die Strahlensicherheitsnormen überprüft und für ihre Neufassung, falls eine solche wünschenswert erscheint, Empfehlungen gibt. PL 90-602 gilt für importierte Anlagen genauso wie für im Lande hergestellte und enthält entsprechende Ausführungsbestimmungen.

4. *Verbesserungsvorschläge für die USA*

Trotz der Fortschritte, die wir bei der Reduzierung unnötiger medizinischer Strahlenexpositionen in den USA gemacht haben, liegt noch ein weiter Weg vor uns. Ich habe schon

Tab. 6a Weitere Gründe für eine übermäßige Strahlenexposition der Patienten (Punkte 1-7 sind im Text aufgezählt).

8. Röntgenaufnahmen vergrößern das Einkommen von Ärzten oder medizinischen Institutionen.
9. Der unaufgeklärte Patient beurteilt ärztliches Können nach der Zahl der Röntgenaufnahmen.
10. Röntgenaufnahmen sind in bestimmten Berufen obligatorisch (Krankenschwestern, Lehrer, Angestellte in Restaurants usw.).
11. Es werden Röntgenüberwachungen durchgeführt, für die nur eine ganz geringe Notwendigkeit besteht (Röntgenreihenuntersuchungsprogramme).
12. Beckenmessungen werden manchmal routinemäßig bei Erstschwangerschaft angefordert.
13. Bereits in Patientenakten vorliegende Röntgenaufnahmen werden nicht benutzt.
14. Magnetbänder und Computer zur Speicherung und Wiederauffindung von Röntgendaten werden nicht benutzt.
15. Röntgenaufnahmen werden als psychotherapeutische Maßnahme durchgeführt (neurotische Patienten).
16. Gesundheitsvorsorge- und Überwachungsprogramme werden zur Erstattung der Kosten für Röntgenaufnahmen in Anspruch genommen.
17. Die speziellen Erfordernisse bei Röntgenaufnahmen von Kindern und Säuglingen werden nicht beachtet.
18. Es werden Durchleuchtungen durchgeführt, wo Informationen über Bewegungsabläufe nicht erforderlich sind.
19. Die Ausbildung ist mangelhaft, und es besteht auch kein Zwang zur Ausbildung für alle, die röntgendiagnostische Geräte besitzen, anwenden, überwachen oder entsprechende Untersuchungen anordnen.
20. Es werden manchmal Röntgenaufnahmen angefertigt, die für den Patienten von fraglichem und unverständlichem Nutzen sind bzw. sein sollen, z.B. Praktiken einiger Chiropraktiker.
21. Die Radiologie [illegible] nicht als Beruf ausgeübt – der Radiologe führt die Anordnungen anderer aus ohne sein fachliches Urteilsvermögen einzusetzen. Er fühlt sich nicht veranlaßt, den diagnostischen Nutzen gegenüber der Strahlenschädigung abzuwägen.
22. Es wurde versäumt, den Dienstgrad eines "leitenden Röntgenassistenten" einzuführen.
23. Medizinische Röntgenaufnahmen werden von Versicherungsgesellschaften und Juristen angefordert, um Schadensersatzansprüche zu klären.
24. Aufzeichnungen über die Patientendosis werden nicht aufbewahrt.
25. Es wird versäumt, die Bestrahlung kritischer Gewebe, wie z.B. des zentralen Nervensystems, des aktiven Knochenmarks, der Augenlinsen, der Schilddrüse usw. zu vermeiden.
26. Massenproduktion im Kochbuchverfahren in der Radiologie.
27. Es fehlt eine ausreichende staatliche oder bundesstaatliche Gesetzgebung.
28. Die Strahlenexposition der Bevölkerung durch medizinische Maßnahmen ist nicht Teil der Bevölkerungsgrenzwerte von durchschnittlich 170 mrem/Jahr.
29. Ausrüstung, Materialien und Techniken entsprechen nicht dem neuesten Stand,
    a) Verwendung unempfindlicher Filme,
    b) schlechte Entwicklungstechnik,
    c) Einblendung des Strahlenfeldes ist auf dem Film nicht sichtbar,
    d) Überbelichtung und Unterentwicklung des Films,
    e) Fokushautabstand zu kurz,
    f) ungeeignete Spannung,
    g) Anwendung ungeeigneter Tubusse und unzureichendes Einblenden,
    h) schlechte Schaltuhren,
    i) unzureichende Filter,
    j) unzureichende Abschirmung,
    k) nicht ausreichende Überprüfung der Geräte,
    l) bei einigen importierten Anlagen fehlt Anzeige von Spannung und Stromstärke,
    m) nicht ausreichende Dunkeladaptation des Radiologen,
    n) Verwendung von unzulänglichen Durchleuchtungseinrichtungen,
    o) Fehlen geeigneter Zentriervorrichtungen.

bei Anhörung vor dem Kongreß [40] darauf hingewiesen, daß wir in den USA eine durchschnittliche medizinische Strahlenbelastung erreichen können, die weniger als 10% der gegenwärtigen beträgt. Um dieses Ziel zu erreichen, sind folgende Schritte notwendig:

a) Verbesserte Ausrüstung

b) Ausbildung und Prüfung aller derer, die die medizinische Anwendung ionisierender Strahlung am Menschen anordnen oder durchführen

c) Bessere Techniken und eine sprechende Indikationsstellung von seiten aller Mediziner, damit die Strahlenbelastung des Patienten auf den minimal möglichen Wert reduziert wird.

Public Law 90-602 stellt einen gewaltigen Fortschritt in Richtung dieses Zieles dar. Doch gibt es in dieser Hinsicht noch viel mehr Verbesserungsmöglichkeiten, mit denen die Patientenexposition zu reduzieren ist. Ein Teil des Problems liegt darin, daß hinsichtlich der unter (b) und (c) erwähnten Ziele viele der möglichen Verbesserungen nicht oder nicht richtig angewendet werden. So gibt es z.B. automatische Einblendvorrichtungen, die jedoch in vielen Fällen nicht verwendet werden: Bildverstärker, die die Durchleuchtungsdosis auf weniger als 1% herabsetzen könnten, sind zwar im Gebrauch, jedoch werden oft die erforderlichen zusätzlichen Maßnahmen nicht durchgeführt, so daß eine so weitgehende mögliche Reduzierung selten realisiert wird. Zahnärzte könnten die gegenwärtige Patientendosis auf weniger als $\frac{1}{20}$ herabsetzen, wenn sie eine rechteckige Präzisionseinblendungsvorrichtung verwenden würden, aber weniger als 1% tun dies. Es gibt automatische Entwicklungsmaschinen für Zahnfilme, die, wenn sie einwandfrei betrieben werden, die schlechte Gewohnheit ausmerzen könnten, Filme überzubelichten und unterzuentwickeln (die mit Sicherheit zu einer unnötigen Belastung des Patienten und zu einer schlechten Filmqualität führt). Doch haben viele Zahnärzte nur geringfügige Verbesserungen ihrer Techniken vorgenommen. Vielleicht am rückständigsten sind wir im Augenblick hinsichtlich des Zieles Nr. b. Nur im Staate Kalifornien wird verlangt, daß in den medizinischen Fakultäten eine Unterweisung im Strahlenschutz (und vielleicht ein wenig in Strahlenbiologie) erfolgt, und daß Fragen über dieses Gebiet bei den staatlichen Prüfungen gestellt werden. In der Mehrzahl der Fälle in den Vereinigten Staaten weiß der Arzt, der bei seinen Patienten eine Röntgenaufnahme anfordert, tatsächlich nichts über die Wirkung dieser Strahlenexposition und scheint auch nicht in der Lage zu sein, dieses Problem von einem wissenschaftlichen Gesichtspunkt aus zu betrachten. Er weiß vielleicht, daß 200 bis 400 rad Röntgenstrahlung erforderlich sind, damit ein Mensch mit einer hohen Wahrscheinlichkeit an den Folgen einer Strahlenkrankheit stirbt. Jedoch scheint er in den meisten Fällen nicht darüber informiert zu sein, daß eine Ganzkörperdosis von 5 rad mit einer Wahrscheinlichkeit von 1:2000 dazu führt, daß ein Patient viele Jahre später an einer strahleninduzierten malignen Erkrankung stirbt. Vielleicht ist er auch der Meinung, daß es ein geringes Risiko ist, weil der Tod wahrscheinlich 20 Jahre später ohnehin eintreten würde, so daß diese Möglichkeit vernachlässigt werden kann. Wenn diese Strahlenexposition jedoch 2 Millionen Patienten verabreicht würde, so wäre zu erwarten, daß sie zu 1000 Todesfällen durch Krebs führt. Unser Land wartet immer noch auf eine führende Persönlichkeit wie den verstorbenen Senator *Bartlett*, der trotz vorauszusehender Opposition von seiten der American Medical Association, American Dental Association und des American College of Radiology die Billigung einer Gesetzgebung durchsetzt, die das Problem der übermäßigen Strahlenbelastung der Bevölkerung durch medizinische Strahlenquellen dadurch an der Wurzel packt, daß sie eine wirkungsvolle Ausbildung und Prüfung aller Ärzte, die ionisierende Strahlen bei ihren Patienten anordnen oder anwenden, erforderlich macht.

Abschließend sei auf etwas hingewiesen, was bisher vielleicht als die ermutigendste Entwicklung auf diesem Gebiet angesehen werden kann:
Im Senat und im Kongreß liegen Gesetzentwürfe vor, die einen Zusatz zum Gesetz über den öffentlichen Gesundheitsdienst darstellen und die Bevölkerung vor unnötigen Belastungen mit ionisierenden Strahlungen durch medizinische Maßnahmen schützen sollen. Der spezielle Zweck dieses Gesetzes ist es, eine angemessene Ausbildung der Röntgenassistenten dadurch sicherzustellen, daß Kriterien und Mindestanforderungen für die Zulassung als Ausbildungsstätte aufgestellt werden, Mindestanforderungen für die Anerkennung als Röntgenassistent festgelegt werden, und daß der Staat die Zulassung als Ausbildungsstätte und das Recht, Röntgenassistenten anzuerkennen, erteilt. Sollte ein US-Staat sich nicht vollkommen an dieses Programm halten, hätte der Gesundheitsminister die Befugnis, einzugreifen. Ich glaube, daß es mit dieser Gesetzesvorlage möglich ist, eine gegenwärtig bestehende unerträgliche Situation, nämlich, daß nur die Staaten New York, New Jersey, Kalifornien, Kentucky und das Commenwealth of Puerto Rico diese Ausbildung und Prüfung von Röntgenassistenten verlangen, abzuschaffen.

Fährt ein Kind mit dem Schulbus, so haben wir die Gewißheit, daß der Fahrer einen Führerschein besitzt. Wird eine Röntgenaufnahme angeordnet, kann sie in 46 unserer Staaten von einer Hilfskraft angefertigt werden, die keinen Befähigungsnachweis braucht, und die deshalb eine größere Gefahr darstellt als ein Busfahrer, der nicht weiß, wie man die Bremsen des Schulbusses richtig betätigt.

Es sind noch sehr viel mehr Fortschritte nötig, bevor unsere Ziele erreicht werden können. Die Einrichtungen müssen weiter verbessert werden. Sie müssen in noch höherem Maße automatisiert sein und dadurch bedienungs- und funktionssicherer. Beispielsweise sind automatische Einblendevorrichtungen ausgezeichnete technische Entwicklungen, aber sie müssen auch richtig angewendet werden, andernfalls sind sie keine Verbesserung. Typische Beispiele eindeutiger Verbesserungen, die schon vor Jahren bei der medizinischen Ausrüstung hätten vorgenommen werden müssen, sind unter anderem auch:

1. Eine Vorrichtung, die eine Inbetriebnahme der Röntgenröhre verhindert, wenn der Zentralstrahl nicht auf die Kassettenmitte ausgerichtet ist.
2. Ein Dosismonitor, mit dessen Hilfe der Röntgenapparat nach Erreichen einer vorher festgelegten Dosis am Film (und damit am Patienten) abgeschaltet und diese Dosis auf einer Patientenkarte vermerkt wird (sog. Belichtungsautomatik).

Ich bin der Meinung, daß unser Bureau of Radiological Health (das jetzt dem Landwirtschaftsministerium eingegliedert ist) für den Fortschritt zu loben ist, den es bei der Durchsetzung des PL 90-602 gemacht hat; es sollte jedoch mehr Mut entwickeln, um sich von den ärztlichen Vereinigungen, wie der American Medical Association, der American Dental Association und dem American College of Radiology unabhängiger zu machen. Es ist nicht richtig, daß diese Organisationen einen derartig starken Einfluß auf diese und andere Regierungsbehörden ausüben, die die Belastung der Bevölkerung mit ionisierender Strahlung überwachen und zu reduzieren versuchen, wenn die Ärzteschaft selbst hauptverantwortlich für die übermäßig große unnötige Belastung der Bevölkerung ist. Das Bureau of Radiological Health sollte sich von dem Einfluß aller Interessengruppen freimachen und eine Gesetzgebung unterstützen, durch die die Ausbildung und Prüfung nicht nur der Röntgenassistenten, sondern auch aller Ärzte erforderlich wird.

Ins Deutsche übertragen von Dipl.-Übersetzerin H. Günther, Bundesgesundheitsamt Berlin, Abteilung für Strahlenhygiene.

Literatur

1 Report of the Advisory Committee on the Biological Effects of Ionizing Radiations. BEIR Report-Nat. Acad. Sc., Nat. Res. Council (Nov. 1972)

2 *Gitlin, J.N.* and *P.S. Lawrence:* "Population Exposure to X-Rays", US 1964 BRH-USPHS No. 1519

3 Preliminary statements regarding expected results from the 1970 BRH-USPHS Medical Survey (charts, graphs and tables from BRH staff presentations at meetings in Boston, Mass. in 1971, San Francisco, Calif. in 1972 and Miami Beach, Florida in 1972)

4 *Brown, M.L.* (1969), project director, "Population Dose from X-Rays, United States, 1964". HEW-PHS (October 1969)

5 Reports of the United Nations Scientific Committee on the Effects of Atomic Radiations. Sup. No. 17 A/3838 (1958), and Sup. No. 16 A/5216 (1962)

6 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. "Ionizing Radiation: Levels and Effects". Vol. I, No. 25 A/8725 (1972)

7 *Pretre, S.* (1973): "We Are Being Fooled with These 'Genetically Significant Doses' from Diagnostic X-Ray", scheduled for publication in Health Physics about June 1973

8 Adrian Committee (1966), "Hazards and Dose to the Whole Population from Ionizing Radiations", Annals of Occupational Hygiene 9 (1966) 83

9 Bulletin and Highlights. J. Am. Dental Assn. 76, No. 2 (Feb. 1968)

10 "What about Radiation" Mass Chest X-Ray Programs. "USPHS Pub. 1196, Feb. 1965

11 "Chest X-Ray Screening Recommendations for TB-RD Associations", NTRDA Bulletin 57, No. 9 (Oct. 1971)

12 *Grubbe, E.H.:* Radiology 21 (1933) 156

13 *Rugbh, R.:* "Effects of Ionizing Radiation on the Developing Embryo and Fetus. "HEW-BRH Seminar Paper No. 007 (1969)

14 *Belsky, J.I.* and *W.J. Blot:* "Stature of Adults Exposed in Childhood to the Atomic Bombs of Hiroshima and Nagasaki". ABCC Tech. Rep. 35 (1971) 71

15 *Uchida, J.A.* und *E.J. Curtis:* "A Possible Association between Maternal Radiation and Mongolism". Lancet. pp. 848-850 (Oct. 14, 1961)

16 *MacMahon, Brian:* "X-Ray Exposure and Malignancy". J. Am. Med. Assn. 183 (1963) 721

17 *Stewart, Alice* and *G.W. Kneale:* "Radiation Dose Effects in Relation to Obstetric X-Rays and Childhood Cancers", Lancet 1 (1970) 1185

18 *Taylor, L.S.:* "What Do We Know About Low-Level Radiation", Environmental and Ecological Forum 1970-1971, A.B. Kline, Jr., editor USAEC-TID 25857 (1972)

19 *Jablon, S.M.* and *H. Kato:* Childhood Cancer in Relation to Prenatal Exposure to Atom-Bomb Radiation", Lancet, p. 1000 (Nov. 14, 1970)

20 *Miller, R.W.:* "Delayed Radiation Effects in Atomic-Bomb Survivors", Science 166 (1969) 569

21 *Bennet, G.:* Bristol Floods 1968. Controlled Survey of Effects on Health of Local Community Disaster, Brit. Med. J., p. 454 (Aug. 22, 1970)

22 *S. Warren* and *O. Gates:* The Induction of Leukemia and Life Shortening in Mice by Continuous and Low-Level External Gamma Radiation, Rad. Res. 47, 480 (Aug. 1971)

23 *Rowland, R.E.:* "Same Dose-Response Relationships for Tumor Incidence in Radium Patients". Radiol. Phys. Div. Annual Report ANL-7760, Part 2, p. 1 (1970)

24 *Marinelli, L.D.:* "Estimates of Radiation Induced Leukemia Risk in Man". ANL Radio. Phys. Div. Annual Report, ANL-7760, Part 2 (1970)

25 *Hempelmann, L.H.:* Risk of Thyroid Neoplasms after Irradiation in Childhood, Science 160, 159 (April 1968)

26 *Saenger, E.L.* and *E.A. Tompkins:* "Results of a Bu. Radiol. Health Survey of Effects of Medical Use of ^{131}I. Published in several pulications of HEW-PAS-BRH (1969-72)

27 *Griffiths, J.* and *R. Ballantine:* "Silent Slaughter", Regnery Pub., Chicago, Illinois (1973)

28 "The Evaluation of Risks from Radiation". Report of the International Commission on Radiological Protection, ICRP Pub. 8 (1966)

29 Recommendations of the International Commission on Radiological Protection. ICRP Pub. No. 1 (Sept. 9, 1958)

30 FRC Reports (1960-61). "Background Material for the Development of Radiation Protection Standards", Staff reports of the Federal Radiation Protection Council, Report Nr. 1, May 13, 1960 and Report No. 2 (September 1961)

31 *Sagan, L.A.* (1971): "Medical Use of Radiation", J. Am. Med. Assn. 215, (March 1971)

32 *McClenabhan, J.L.* (1970): "Wasted X-Ray". Penn. Medicine 72, 107-108 (Nov. 1969); also reprinted in Radiology 96, 453-456 (Aug. 1970)

33 *Warren, S.* (1966): "The Basis for the Limit on Whole-Body Exposure-Experience of Radiologists", Health Phys. 12, 737-741 (1966)

34 *Stewart, A.* and *G.W. Kneale* (1970): "Radiation Dose Effects in Relation to Obsteric X-Rays and Childhood Cancers", Lancet, pp. 1186-1188 (June 6, 1970)

35 *Brook, R.H.* and *R.T. Stevenson* (1970): "Effectiveness of Patient Care in an Emergency Room", The New Engl. J. of Med. 283, 17, 904-907 (Oct. 22, 1970)

36 *Sutherland, G.R.* (1970): "Agreement between Clinical and Radiological Diagnosis", British Med. J. 4, 212-214 (Oct. 1970)

37 *Bell, R.S.* and *J.W. Loop* (1971): "The Utility and Futility of Radiographic Skull Examination for Trauma", The New Engl. J. of Med. 284, 5, 236-239 (Feb. 4, 1971)

38 *Kissick, W.L.* (1970): Health-Policy Directions for the 1970's, The New Eng. J. of Med. 282, 1343-1354 (Jan.-June 1970)

39 *Morgan, K.Z.*: Testimony before the Senate Commerce Committee on the Bill 2067, "Reduction of Unneccessary Medical Exposure", (August 28-30, 1967), Congressional Record Serial No. 90-49 (1968); Congressional Record Hearings before the Committee on Radiation Control for Health and Safety Act. Washington, D.C. (March 8, 1973)

40 *Nadar, R.* (1968): "Wake Up America, Unsafe X-Rays", Ladies Home Journal 85, 126 (May 1968)

Prof. Dr. Karl Z. Morgan, School of Nuklear Engineering Georgia Institute of Technology Atlanta Georgia 30332/USA

Page 10

THE MEDICAL IMPLICATIONS OF FALLOUT*

by

Karl Z. Morgan
School of Nuclear Engineering and Health Physics
Georgia Institute of Technology

We do not have any direct information which can serve as a guide in describing the medical implications of fallout that can be expected over the United States in case of a nuclear war with the Soviet Union. The fire ball did not reach the ground when our weapons of the order of 1/100 MT were detonated at Hiroshima and Nagasaki. In an all out war we can expect weapons of 1 to 10 MT to be employed (100 to 1000 times more powerful). Modern weapons which are so much more powerful and which would be used in large numbers would make the nuclear holocaust of the two Japanese cities seem mild by comparison. Single weapons of 100 MT probably would not be used extensively because a cluster of ten independently targeted 10 MT weapons would be far more destructive.

We have some information on weapons fallout from our military blunders during our atmospheric testing of nuclear weapons in the South Pacific when the people of the Marshall Islands were showered with weapons fallout and when the Japanese fishermen on the Fukaryer Maru were injured from the fallout (one died with symptoms of the radiation syndrome). The natives on Rongelap, one hundred miles from the detonated weapons at Bikini Atoll, received an estimated total body dose of 175 roentgens of gamma radiation and 2000 rads of beta radiation to the feet. The children who went swimming fared much better than the others because they washed the fallout dust from their bodies. Epilation, erythema and

---

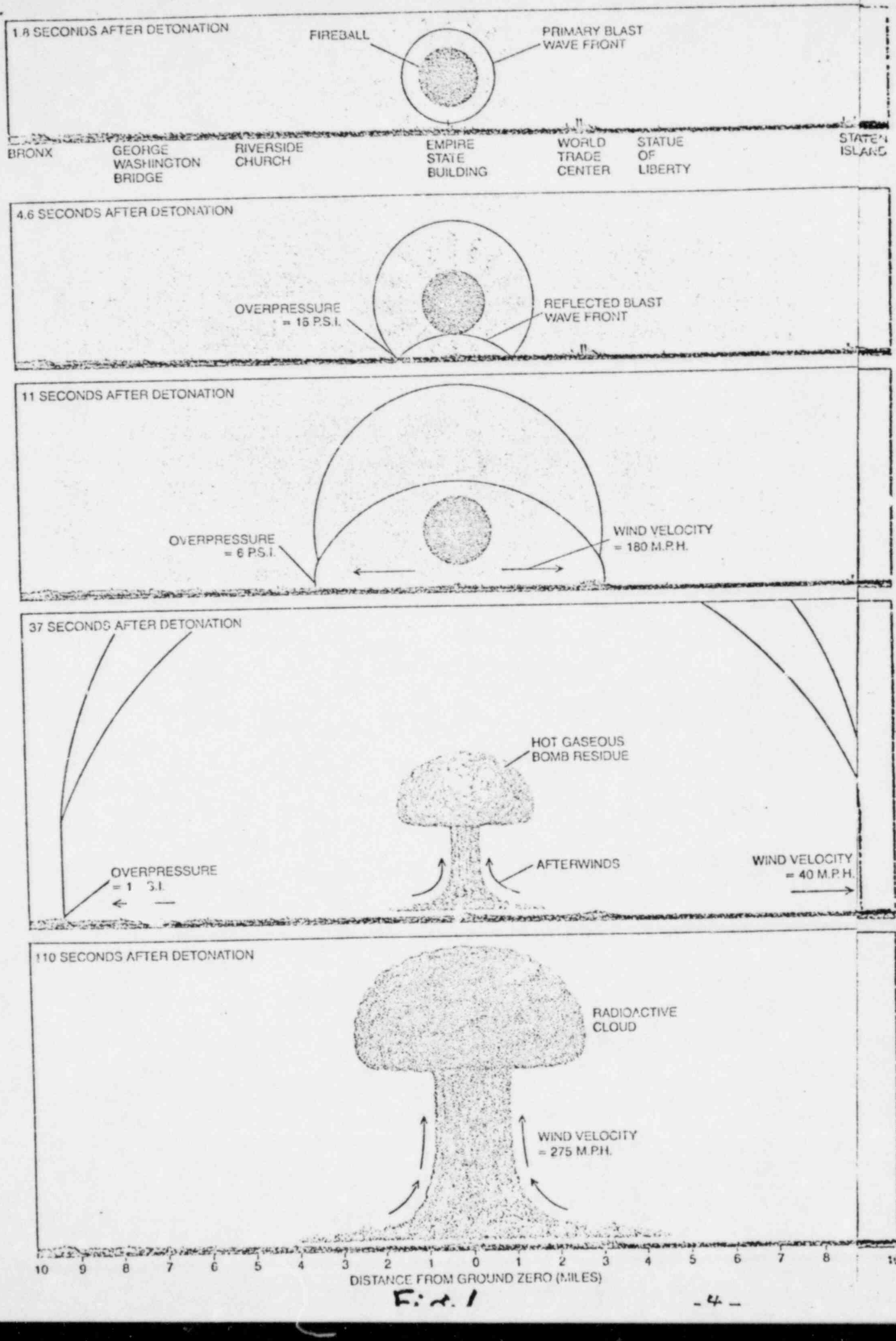
* Presented at conference on Medical Consequences of Nuclear Weapons and Nuclear War, Albuquerque, New Mexico, September 25-26, 1981

lesions were observed on those who did not remain indoors or wash themselves frequently. A number of the exposed persons developed thyroid nodules. In some cases these developed into thyroid carcinomas which were treated surgically. Some of the cancer deaths most certainly were casued by this fallout. Some other effects were slight growth retardation among the children, miscarriages, incomplete recovery of pripheral blood elements, and permanent scars. However, using this experience to estimate what we should expect from fallout in a nuclear war is like studying a mosquito bite to estimate the consequences of a rattle snake bite. The fallout on persons in Utah and other states downwind from the Nevada test site and the increase in malignancies, especially leukemia, which appear to be caused by this exposure provides us with a very mild suggestion of what we can expect as one of the long-range forms of damage to the survivors of a nuclear war.

The pattern of fallout depends very critically on the weather conditions, the mega-tonage of the weapon, its height of detonation, and in a few cases, the seriousness of the fallout may be greatly enhanced if a nuclear power plant and associated or similar facilities are encompassed by the fireball. It is very probable that some of the weapons will be detonated near ground or over water in order to greatly increase the amount of fallout. This fallout area would be deprived of use during the critical period and yet would be preserved for later occupation when the enemy invaded the country. For a ground (or near ground) burst a large crater would be formed, and the excavated and vaporized material would condense into dust particles of various sizes. The several hundred fision products, transuranium products and neutron-induced radionuclides would attach themselves to these dust particles and fallout due to the force of gravity; the large particles falling out over a distance of a few tens of miles and the small particles of a few microns in diameter would be carried hundreds of miles, the distance increasing with the megatons of the weapon and with the wind velocity. The gases and submicron size particles and radionuclides with relatively long-lived gaseous precursors would be carried into the troposphere (40,000-60,000 feet), and the smallest particles and gases would be ejected into the stratosphere (>60,000 feet) where they would remain from months to years and be carried around the earth many times before settling to the ground.

Fig. 1 from V. N. Lewis (Sc. Am., July, 1979) shows the sequence of events that would follow the detonation of a 1 MT weapon above the Empire State Building in New York; first the fireball at 1.8 seconds, then the reflected blast with outward winds at 180 MPH, followed by the characteristic mushroom cloud and upward vertical winds of 275 MPH at about two minutes.

Fig. 2 from S. A. Fetter and K. Tsipis (Sc. Am., April, 1981) shows this mushroom cloud moving with the prevailing wind. For comparison we have shown in the lower figure the moving cloud in a 15 MPH wind following a major accident at a 1000 MWe nuclear power plant; an explosion which breaches the containment vessel and releases one-third of the reactor's radioactive material. This would amount to 1.5×10^9 Ci one hour after release and would be only 1/1000 the activity of radionuclides released in the 1 MT weapon cloud in the upper part of the figure. Note that the height of the 1 MT weapon cloud is 60,000/200 = 300 times higher than the cloud from the 1000 MWe plant accident, and the distance of travel of the fallout cloud is far greater. It should be emphasized that although a major nuclear power plant accident would be an extremely grave disaster, it is hardly comparable to the calamity in terms of immediate deaths and destruction caused by a 1 MT weapon. This is because under no circumstances can a nuclear reactor explode with a force that is comparable to that of a nuclear weapon, even if there were brittle fracture of the reactor containment vessel, i.e., no deaths from blast, overpressure or burns. However, I must not fail to point out that in



1.8 SECONDS AFTER DETONATION
FIREBALL
PRIMARY BLAST WAVE FRONT
BRONX
GEORGE WASHINGTON BRIDGE
RIVERSIDE CHURCH
EMPIRE STATE BUILDING
WORLD TRADE CENTER
STATUE OF LIBERTY
STATEN ISLAND
4.6 SECONDS AFTER DETONATION
OVERPRESSURE = 15 P.S.I.
REFLECTED BLAST WAVE FRONT
11 SECONDS AFTER DETONATION
OVERPRESSURE = 6 P.S.I.
WIND VELOCITY = 180 M.P.H.
37 SECONDS AFTER DETONATION
HOT GASEOUS BOMB RESIDUE
AFTERWINDS
OVERPRESSURE
WIND VELOCITY = 40 M.P.H.
110 SECONDS AFTER DETONATION
RADIOACTIVE CLOUD
WIND VELOCITY = 275 M.P.H.
10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 10
DISTANCE FROM GROUND ZERO (MILES)

Fig. 1

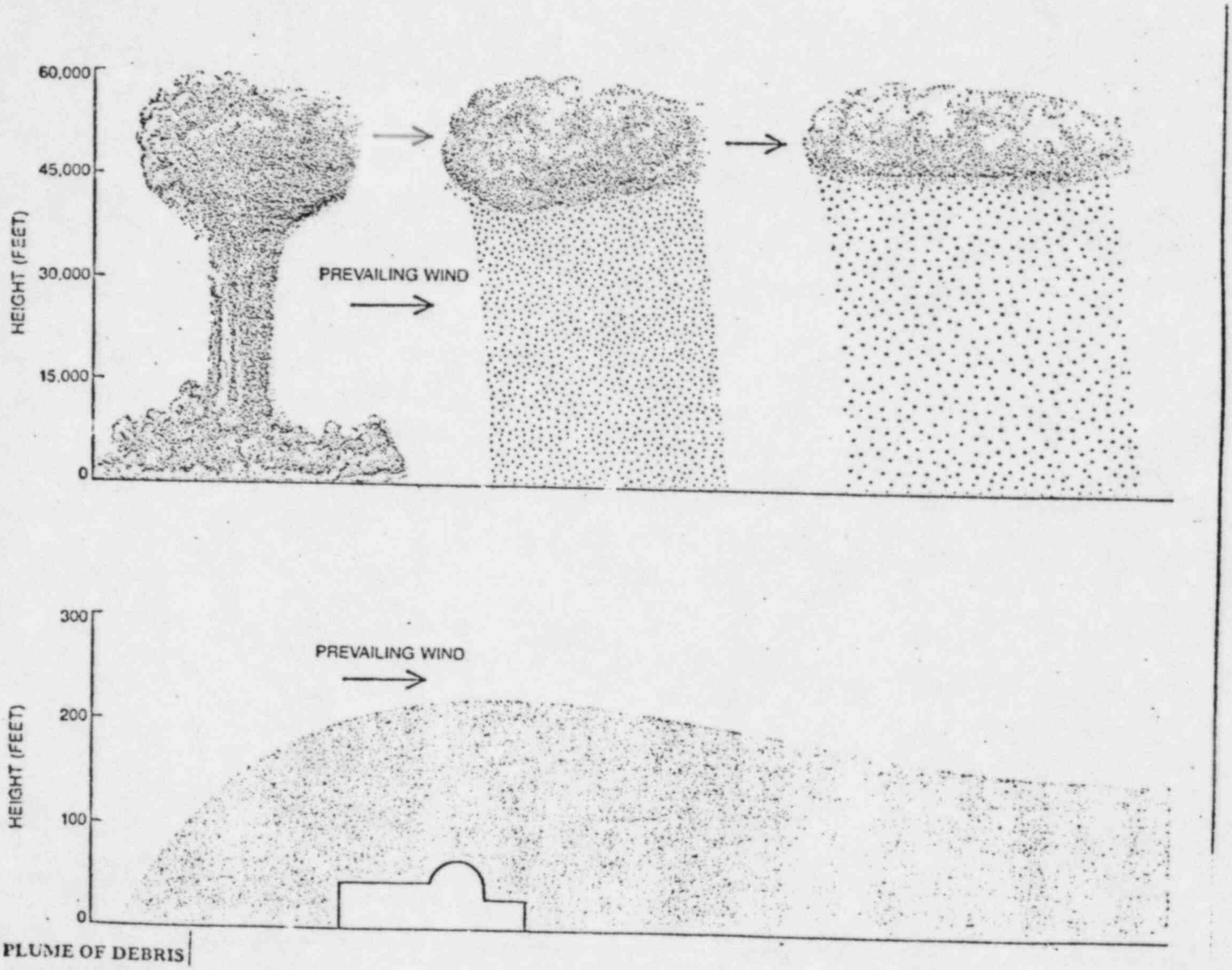

60,000
45,000
30,000
15,000
0
HEIGHT (FEET)
PREVAILING WIND
300
200
100
0
HEIGHT (FEET)
PREVAILING WIND
PLUME OF DEBRIS

Fig. 2.

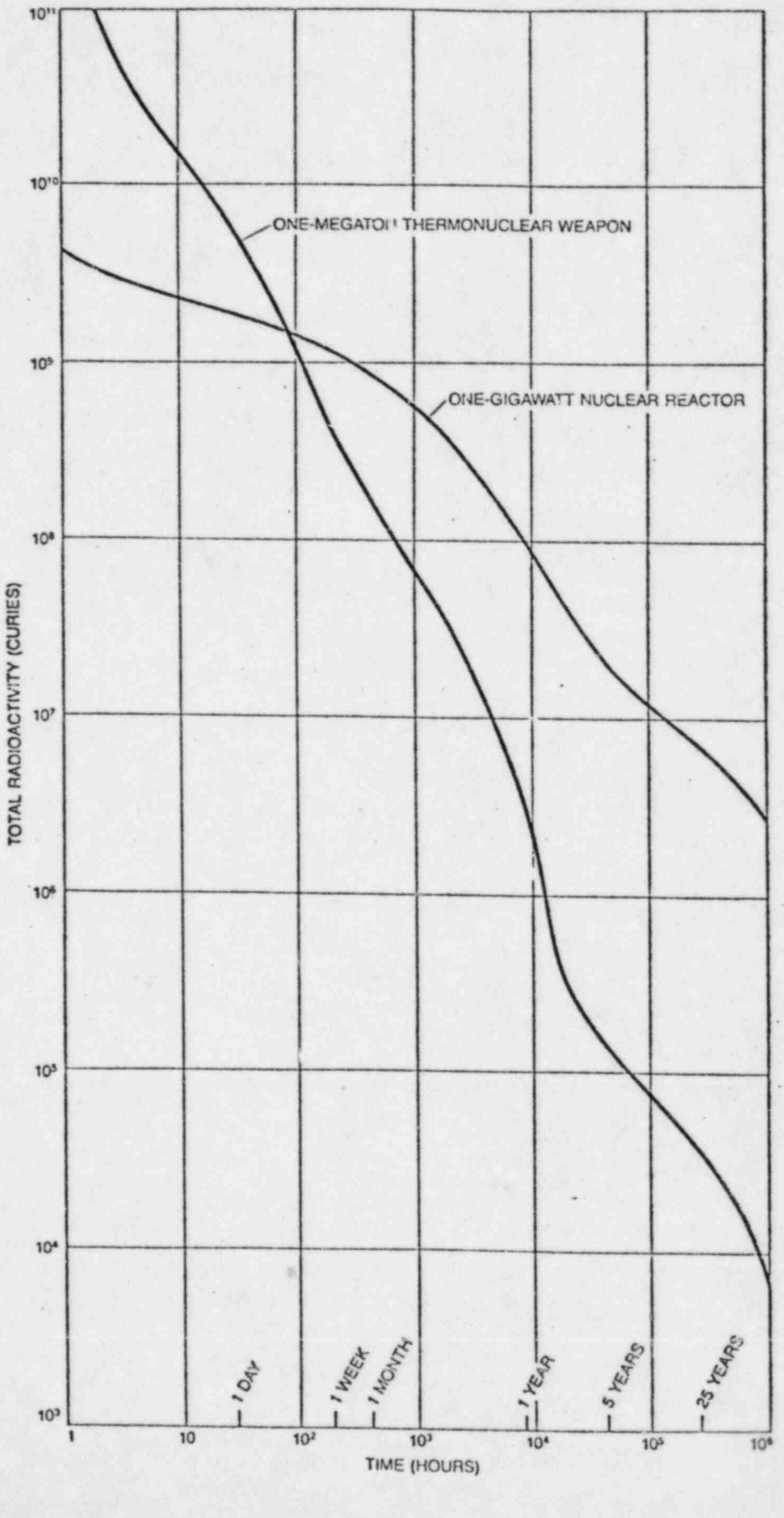

ONE-MEGATON THERMONUCLEAR WEAPON
ONE-GIGAWATT NUCLEAR REACTOR
TOTAL RADIOACTIVITY (CURIES)
TIME (HOURS)
1 DAY
1 WEEK
1 MONTH
1 YEAR
5 YEARS
25 YEARS

Fig. 3

many respects the fallout from a 1000 MWe reactor accident in which one-third of the reactor inventory of radionuclides is released would be potentially more dangerous over a long period of time than the fallout from a 1 MT weapon. Fig. 3 from Fetter and Tsipis compares the total radioactivity (Ci) of a 1000 MWe accident releasing one-third of the reactor radionuclide inventory with that of a 1 MT weapon. At time zero (not shown here) the weapon has over 3000 times the curies of activity released by this reactor, but at about four days the activities are about equal, and at five years the curies of activity on the countryside would be over one hundred times greater from this reactor accident than from the 1 MT weapon explosion. There are a few modifying factors that must be noted: (1) the fallout from the weapon probably would kill more people because of greater difficulties in providing dose rate information, limitations to evacuation and medical care, (2) in either case there could be release of transuranium radionuclides which could make the countryside uninhabitable for centuries, (3) as shown by Fig. 4-6, the worst accidents considered possible by the Rasmussen report (WASH-1400) of 1975 would not release one-third of the 1000 MWe reactor inventory. Here it is noted, for example, that the highest release of Ba and Sr radionuclides is ten percent (i.e., for a BWR category two accident). The Brookhaven report (WASH-740) of 1957 gave values of probability of a reactor accident and severity of accident that were considerably higher than values in the Rasmussen report. However, I believe both reports underestimated the risks as shown by Figs. 7 and 8, and I would not go on record as supporting these reports. Here we note that the probability of the TMI-2 accident turned out to be three chances per 1000 reactor years, while the estimates were one to ten chances per 10,000 reactor years by the Brookhaven report and five to fifty chances per million reactor years by the Rasmussen report. Also, in view of the fact that a $25,000,000 class action suit has been settled under the Price-

CATEGORY	FRACTION OF CORE INVENTORY RELEASED							
	Xe+Kr	ORG I	I	Cs+Rb	Te+Sb	Ba+Sr	Ru(a)	La(b)
PWR-1 9×10^{-7}(c) 1(e)	0.9	6×10^{-3}	0.7	0.4	0.4	0.05	0.4	3×10^{-3}
PWR-2 8×10^{-6}(c) 1(e)	0.9	7×10^{-3}	0.7	0.5	0.3	0.06	0.02	4×10^{-3}
PWR-3 4×10^{-6}(c) 2(e)	0.9	6×10^{-3}	0.2	0.2	0.3	0.02	0.03	3×10^{-3}
PWR-4 5×10^{-7}(c) 2(e)	0.6	2×10^{-3}	0.09	0.04	0.03	5×10^{-3}	3×10^{-3}	4×10^{-4}

(a) Includes Mo, Rh, Te and Co, (b) Includes Nd, Y, Ce, Pr, Nb, Am, Gm, Pu, Np and Zr, (c) Probability per reactor year, (e) Warning time for evacuation (hrs).

Fig. 4

CATEGORY	FRACTION OF CORE INVENTORY RELEASED							
	Xe+Kr	ORG I	I	Cs+Rb	Te+Sb	Ba+Sr	Ru(a)	La(b)
PWR-5 $7x10^{-7}$(c) 1(e)	0.3	$2x10^{-3}$	0.03	$9x10^{-3}$	$5x10^{-3}$	$1x10^{-3}$	$6x10^{-4}$	$7x10^{-5}$
PWR-6 $6x10^{-6}$(c) 1(e)	0.3	$2x10^{-3}$	$8x10^{-4}$	$8x10^{-4}$	$1x10^{-3}$	$9x10^{-5}$	$7x10^{-5}$	$1x10^{-5}$
PWR-7 $4x10^{-5}$(c) 1(e)	$6x10^{-3}$	$2x10^{-5}$	$2x10^{-5}$	$1x10^{-5}$	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$	$2x10^{-7}$
PWR-8 $4x10^{-5}$(c) N/A(e)	$2x10^{-3}$	$5x10^{-6}$	$1x10^{-4}$	$5x10^{-4}$	$1x10^{-6}$	$1x10^{-8}$	0	0
PWR-9 $4x10^{-4}$(c) N/A	$3x10^{-6}$	$7x10^{-9}$	$1x10^{-7}$	$6x10^{-7}$	$1x10^{-7}$	$1x10^{-11}$	0	0

(a) Includes Mo, Rh, Tc and Co, (b) Includes Nd, Y, Ce, Pr, Nb, Am, Cm, Pu, Np and Zr, (c) Probability per year per reactor, (e) Warning time for evacuation (hrs)

Fig. 5

CATEGORY	FRACTION OF CORE INVENTORY RELEASED							
	Xe+Kr	ORG I	I	Cs+Rb	Te+Sb	Ba+Sr	Ru(a)	La(b)
BWR-1 1×10^{-6}(c) 1.5(e)	1	7×10^{-3}	0.4	0.4	0.7	0.05	0.5	5×10^{-3}
BWR-2 6×10^{-6}(c) 2(e)	1	7×10^{-3}	0.9	0.5	0.3	0.1	0.03	4×10^{-3}
BWR-3 2×10^{-5}(c) 2(e)	1	7×10^{-3}	0.1	0.1	0.3	0.01	0.02	3×10^{-3}
BWR-4 2×10^{-6} 2(e)	0.6	7×10^{-4}	8×10^{-4}	5×10^{-3}	4×10^{-3}	6×10^{-4}	6×10^{-4}	
BWR-5 1×10^{-4}(c) N/A(e)	5×10^{-4}	2×10^{-9}	6×10^{-11}		4×10^{-9}	8×10^{-12}	8×10^{-14}	

(a) Includes Mo, Rh, Tc and Co, (b) Includes Nd, Y, Ce, Pr, Nb, Am, Cm, Pu, Np and Zr, (c) Probabitiy per reactor year, (e) Warning time for evacuation (hrs)

Fig. 6.

Type of Risk Due to TMI-2 Accident	Made By:	Amount of Risk
Probability of Accident	Brookhaven Report	10^{-3} to 10^{-4} per reactor year
Probability of Accidents	Rasmussen Report	5×10^{-6} to 5×10^{-5} per reactor year
Actual Risk of Accidents	Calculation: 1acc/300 ry	3×10^{-3} per reactor year
Noble Gas Released	NRC Staff & Consultants	1.2×10^{7} Ci
Noble Gas Released	Seo Takeshi	4.5×10^{7} Ci
Radioiodine Released	NRC Staff & Consultants	16.7 Ci
Radioiodine Released	Seo Takeshi	6.4×10^{4} Ci
Total Body Dose to Population	NRC Staff & Consultants	1600 to 5300 person rem
Total Body Dose to Population	Seo Takeshi	≥16200 person rem
Thyroid Dose to Population	NRC Staff & Consultants	1060 person rem

Fig. 7.

Type of Risk Due to TMI-2 Accident	Made By:	Amount of Risk
Induced Cancers (excluding thyroid)	NRC Staff & Consultants	0.15 to 2.4 cancer deaths
Induced Cancers (excluding thyroid)	Author of this Paper	15 cancer deaths
Induced Thyroid Cancers	NRC Staff & Consultants	?
Cost of TMI-2 Type Accident	Brookhaven Reports	<1,000,000,000 in 1981 dollars
Cost of TMI-2 Type Accident	Rasmussen Reports	<150,000,000 in 1981 dollars
Cost of TMI-2 Type Accident	Author of this Report	>> 10^9 dollars
Coefficient of Fatal Cancers	NRC Staff & Consultants	< 2×10^{-4} per person rem
Coefficient of Fatal Cancers	BEIR-III Report	2×10^{-4} to 3×10^{-4} per person rem
Coefficient of Fatal Cancers	Author of this Paper	9×10^{-4} per person rem
Coefficient of Fatal Cancers	Gofman (1981)	4×10^{-3} per person rem
Induced genetic effects	NRC Staff & Consultants	0.06 to 5.44 per person rem

Fig. 8

Anderson Act and the General Public Utilities Company (parent company of Metropolitan Edison) presented a damage claim against the Nuclear Regulatory Commission for $4,000,000,000, I believe the cost of the TMI-2 type accident in dollars was underestimated by at least an order of magnitude by the Brookhaven report and by a factor of seventy by the Rasmussen report.

Fig. 9 (from Fetter and Tsipis) shows the fifteen mph wind fallout patterns from a 1000 MWe reactor accident releasing one-third of its activity (i.e., 10^8 times the activity reported released by TMI-2). Here the two-rem isoplath line reaches from Racine almost to Detroit, while if a 1 MT weapon were detonated over Racine, the two-rem isoplath line reaches three tiems as far (i.e., to Scranton, Pennsylvania) as shown in Fig. 10. The figure at the right shows the two-rem isoplath line extending four times as far as for the 1000 MWe reactor accident. This is for the case in which the fireball reaches the reactor and vaporizes it. All these patterns are those that develop a week after the incident, and the isoplath lines are the doses a person would get if located there for one year.

It is clear from the above that the 1 MT weapon explosion is much worse than the maximum credible reactor accident. In the event a 1000 MWe reactor core were in the fireball, the fallout deaths from a 1 MT weapon explosion could be increased severalfold. Perhaps the fuel storage pools at the reactor and the waste storage tanks at the weapons reprocessing plants present a much greater risk in this respect than the reactors themselves because they are not protected with six feet of concrete, and their activity is mainly from radionuclides of much longer half-life than that fresh out of the reactor.

While I emphasize the detonation of a 1 MT weapon is far, far worse than a conceivable reactor accident, I do not wish to convey a feeling of complacency. Although the risk of a major reactor accident is relatively quite small, it is not zero, and each nuclear power plant must have an adequate and workable emer-

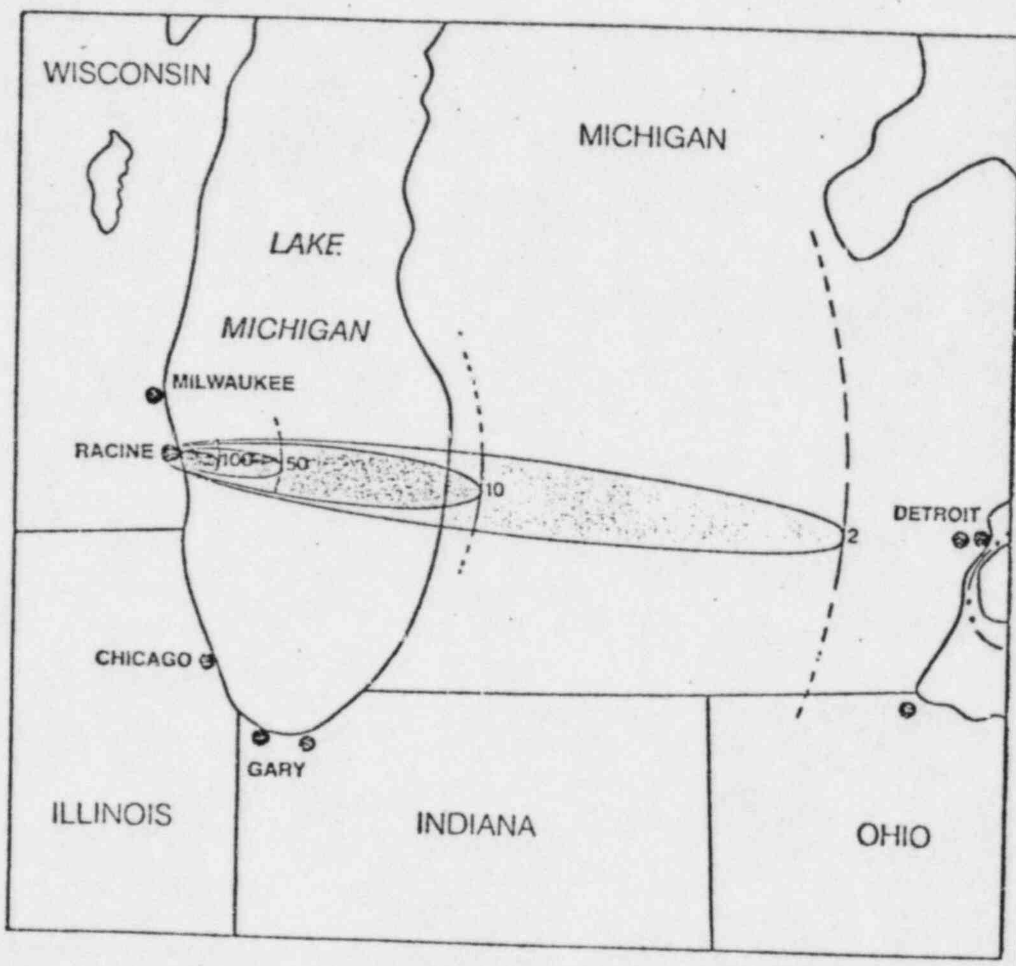

WISCONSIN
MICHIGAN
LAKE
MICHIGAN
MILWAUKEE
RACINE
100
50
10
2
DETROIT
CHICAGO
GARY
ILLINOIS
INDIANA
OHIO

Fig. 9.

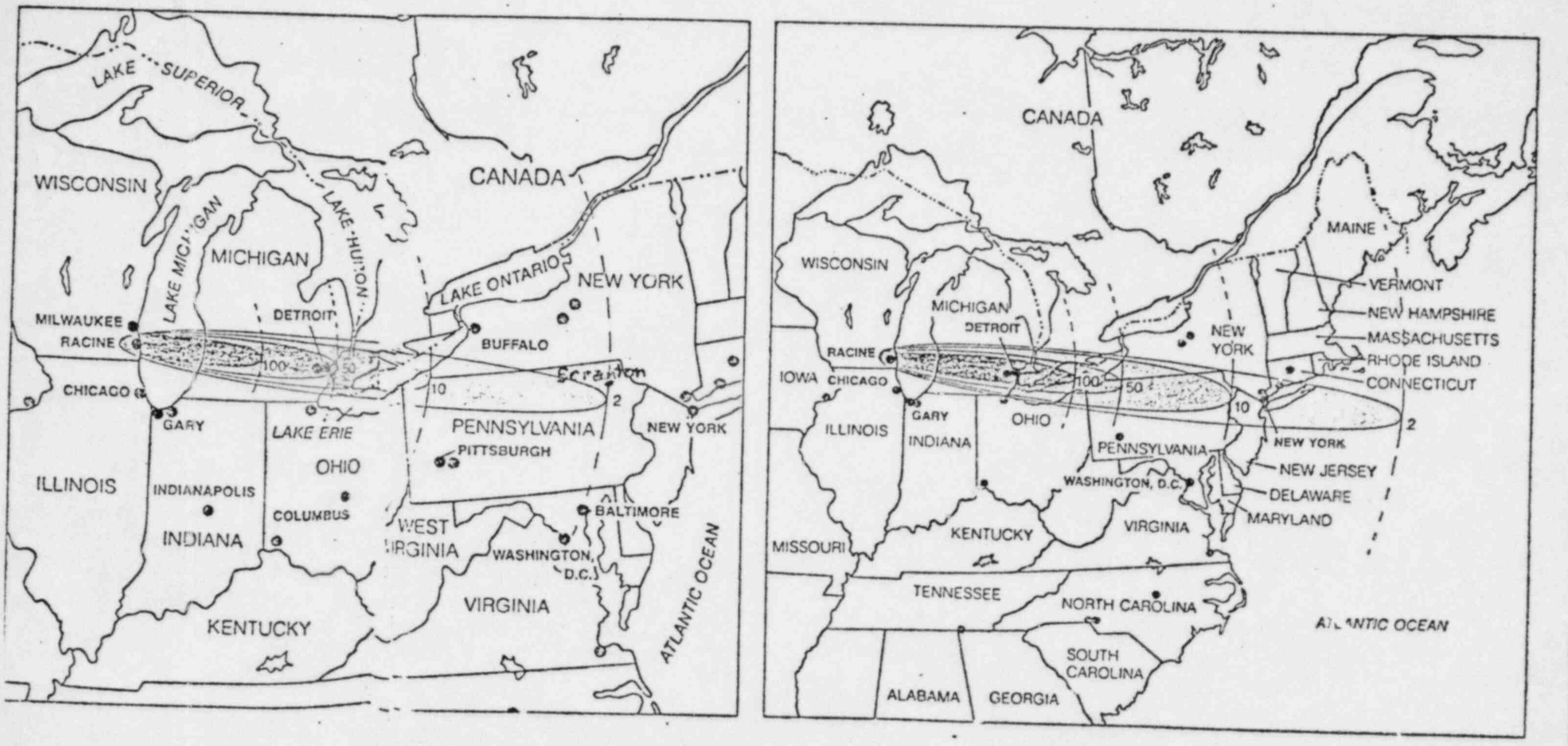

LAKE SUPERIOR
WISCONSIN
CANADA
LAKE MICHIGAN
MICHIGAN
LAKE HURON
LAKE ONTARIO
NEW YORK
MILWAUKEE
RACINE
DETROIT
BUFFALO
100
50
10
2
Scranton
CHICAGO
GARY
LAKE ERIE
PENNSYLVANIA
NEW YORK
PITTSBURGH
ILLINOIS
INDIANAPOLIS
OHIO
COLUMBUS
BALTIMORE
INDIANA
WEST VIRGINIA
WASHINGTON, D.C.
VIRGINIA
KENTUCKY
ATLANTIC OCEAN
CANADA
MAINE
WISCONSIN
VERMONT
MICHIGAN
NEW HAMPSHIRE
DETROIT
NEW YORK
MASSACHUSETTS
RACINE
RHODE ISLAND
IOWA
CHICAGO
CONNECTICUT
GARY
OHIO
ILLINOIS
INDIANA
NEW YORK
PENNSYLVANIA
NEW JERSEY
WASHINGTON, D.C.
DELAWARE
MARYLAND
KENTUCKY
VIRGINIA
MISSOURI
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ALABAMA
GEORGIA

Fig. 10.

gency plan. I have indicated that the risks seem to be much greater than the estimates of the Rasmussen report and somewhat greater than assumed by the Brookhaven report. Figs. 11 and 12 summarize some of the risk estimates of a 1000 MWe plant from the Rasmussen report. Just to focus on the early fatalities, as did the Rasmussen report, can seriously distort the seriousness of the medical problems associated with a nuclear power plant accident. Jan Beyea (Nucl. Policy Alternatives, Princeton U., September 7, 1979), for example, gives us a much better perspective of the TMI-2 accident. TMI-0 in Fig. 13 indicates that there were zero to four deaths caused by the accident as reported (i.e., ten percent of noble gases released). Designation TMI-1 through TMI-5A indicate a much more serious situation had more of the noble gases, iodine and Cs escaped. Fig. 14 shows the consequences had TMI-2 been operating much longer than three months at the time of the accidnet. It is to be noted that in this case the delayed deaths might have been up to 60,000 and that there might be 450,000 persons with thyroid nodules.

Fig. 15 shows the areas contaminated to three levels: 10, 50 and 100 rem per year for the three types of accidents (left to right: (1) major accident with one-third of radionuclides of a 1000 MWe reactor released, (2) a 1 MT weapon detonation, and (3) the reactor in the fireball. If the annual dose limit were set at 100 rem in time of war, we would expect no cases of the radiation syndrome for those who received this dose at a relatively uniform dose rate over a year, but the denial area would be 18 and 680 mi^2 in cases (2) and (3), respectively. If at that time we had 100 reactors operating at 1000 MWe which were within the fireball of a 1 MT blast, this would restrict the use of 680,000 square miles except for overlap due to clustered reactors. Thus, ten percent of the area of the U. S. might be restricted from use by only 100 nuclear bombs detonated close to our reactors.

MAGNITUDE OF EFFECT FOR EACH 1000 MW_E REACTOR	PROBABILITY PER REACTOR YEAR
CORE MELT ACCIDENT	$5x10^{-5}$
ACCIDENT CAUSING 1 EARLY FATALITY	$4.5x10^{-7}$
ACCIDENT CAUSING 10 EARLY FATALITIES	$3x10^{-7}$
ACCIDENT CAUSING 100 EARLY FATALITIES	10^{-7}
ACCIDENT CAUSING 1000 EARLY FATALITIES	10^{-8}
PROBABLE WORST ACCIDENT (3500 EARLY FATALITIES	10^{-9}
ACCIDENT CAUSING 1 EARLY ILLNESS	$7x10^{-6}$
ACCIDENT CAUSING 10 EARLY ILLNESSES	$5.3x10^{-6}$
ACCIDENT CAUSING 100 EARLY ILLNESSES	$2x10^{-6}$
ACCIDENT CAUSING 1000 EARLY ILLNESSES	$3x10^{-7}$
ACCIDENT CAUSING 10^4 EARLY ILLNESSES	$2x10^{-8}$
ACCIDENT CAUSING 1 GENETIC EFFECT PER YEAR	$1.5x10^{-5}$
ACCIDENT CAUSING 10 GENETIC EFFECTS PER YEAR	$3.5x10^{-6}$
ACCIDENT CAUSING 100 GENETIC EFFECTS PER YEAR	$1.5x10^{-8}$

Fig. 11.

MAGNITUDE OF EFFECT FOR EACH 1000 MWE REACTOR	PROBABILITY PER REACTOR YEAR
ACCIDENT CAUSING DAMAGE OF 10^6 DOLLARS	4.5×10^{-5}
ACCIDENT CAUSING DAMAGE OF 10^9 DOLLARS	7.5×10^{-7}
ACCIDENT CAUSING DAMAGE OF 10^{10} DOLLARS	4×10^{-9}
ACCIDENT CAUSING 1 LATENT CANCER DEATH PER YR	2.5×10^{-5}
ACCIDENT CAUSING 10 LATENT CANCER DEATHS PER YR	1.2×10^{-5}
ACCIDENT CAUSING 100 LATENT CANCER DEATHS PER YR	2×10^{-6}
ACCIDENT CAUSING 1000 LATENT CANCER DEATHS PER YR	5×10^{-9}
ACCIDENT CAUSING 1 THYROID NODULE PER YR	3.3×10^{-5}
ACCIDENT CAUSING 100 THYROID NODULES PER YR	1.5×10^{-5}
ACCIDENT CAUSING 1000 THYROID NODULES PER YR	1.7×10^{-6}
ACCIDENT CAUSING DECONTAMINATION AREA OF 0.1 SQ MI	5×10^{-5}
ACCIDENT CAUSING DECONTAMINATION AREA OF 100 SQ MI	1.6×10^{-6}
ACCIDENT CAUSING DECONTAMINATION AREA OF 1000 SQ MI	3×10^{-7}

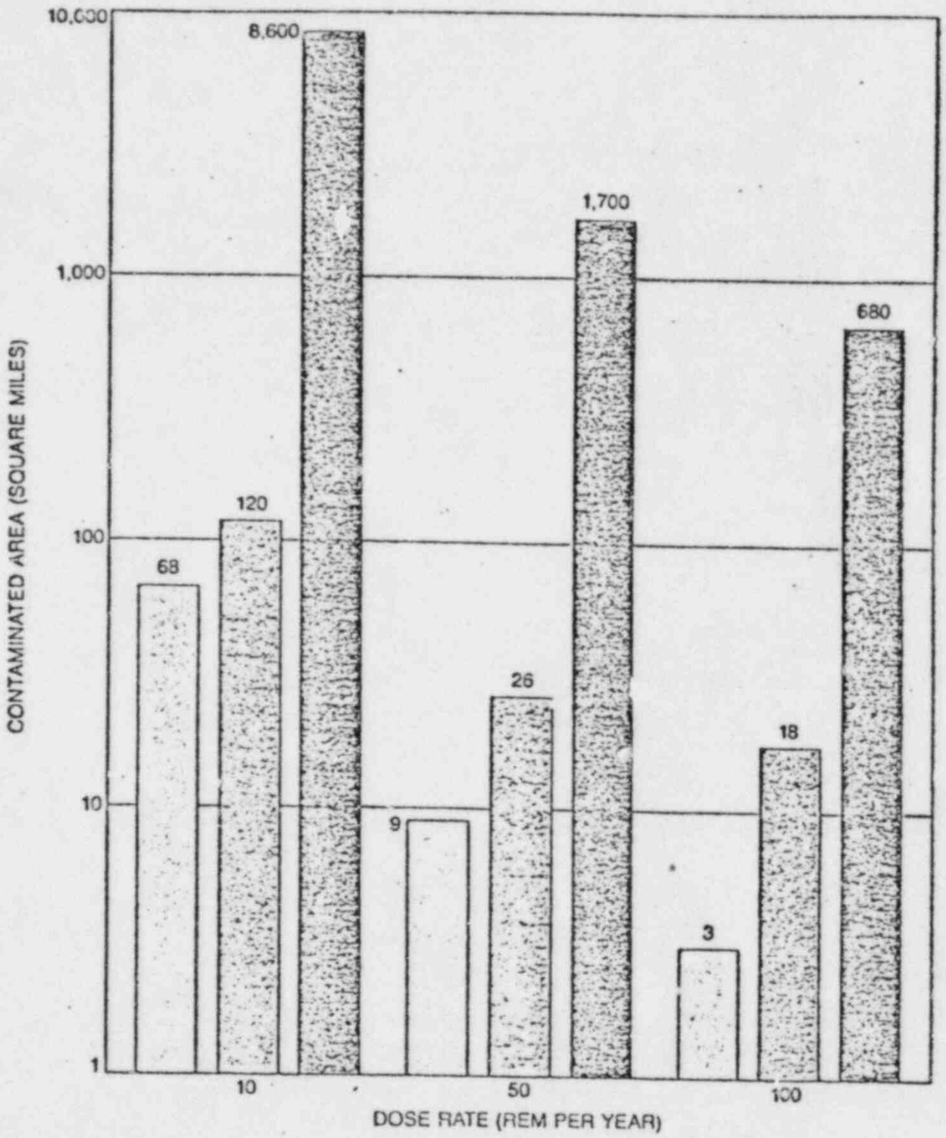
Fig. 12.

Accident Designation	Releases to Atmosphere	Delayed Cancer Deaths low/high	Thyroid Nodule Cases low/high	Temporary Agricultural Restrictions	Areas Requiring Decontamination or Long-term Restrictions
TMI-0	10% of noble gases (similar to actual accident)	0/4	-	0	0
RELEASES GREATER THAN ACTUALLY OCCURRED					
TMI-1	60% of noble gases	1/25		0	0
TMI-2	5% Iodines plus 60% noble gases	3/350	200/27,000	25,000 mi^2	0
TMI-3A	TMI-2 plus 10% of Cs	15/2000	200/27,000	25,000 mi^2	75 mi^2
TMI-4A	50% of Cs	100/12,000		3,700 mi^2	650 mi^2
TMI-5A	"PWR2" Release with 70% I Release	200/23,000	3,500/450,000	175,000 mi^2	1400 mi^2

Fig. 13.

ACCIDENT DESIGNATION	RELEASES TO ATMOSPHERE	DELAYED CANCER DEATHS LOW / HIGH	THYROID NODULE CASES LOW / HIGH	TEMPORARY AGRICULTURAL RESTRICTIONS	AREAS REQUIRING DECONTAMINATIO OR LONG-TERM RESTRICTIONS
CONSEQUENCES ASSUMING THE REACTOR CORE HAD BEEN IN OPERATION FOR MUCH LONGER THAN 3 MONTHS (MATURE CODE)					
TMI-3B	TMI-2 PLUS 10% OF Cs	65 / 8500	200 / 27,000	25,000 MI^2	550 MI^2
TMI-4B	50% OF Cs	440 / 48,000		18,000 MI^2	4300 MI^2
TMI-5B	"PWR2" RELEASE 70% I RELEASE	550 / 60,000	3,500 / 450,000	175,000 MI^2	5300 MI^2

Fig. 14.



DENIAL OF LAND

Fig. 15.

Radioactivity R following a nuclear detonation drops off as:

$$R = ct^{-1.2}$$

in which t = time since the detonation and C = constant provided the induced activity is negligible and there is no partition of the radionuclides. Thus, since $t^{-1.2} \approx 1/t$, we have a simple means of estimating the dose at any time if we know the dose at some earlier or later period of time. For example, if the dose rate R_i in the fallout area is 300 rem per hour at t_i = 6 hours after the detonation, the dose rate R_2 would be:

$$R_2 = R_1\left(\frac{t_1}{t_2}\right)^{1.2} = 300\left(\frac{6}{18}\right)^{1.2} = 80.3 \text{ rem/hr}$$

for t_2 = 18 hours after the detonation and this is approximately

$$R_2 \approx R_1\left(\frac{t_1}{t_2}\right) = 300\left(\frac{6}{18}\right) = 100 \text{ rem/hr}$$

Fig. 16 shows the effects of whole body irradiation of the average adult by a single dose or one administered over a few days. These affects most likely would be expected were the dose delivered to the trunk of the body. Chromosome aberrations can be detected at doses as low as one rem. Vomiting and nausea are the common consequences of all large doses. Erythemia may appear some time after the exposure (several weeks) for doses above 300 rem. Exposure to beta radiation, in this case, delivers its dose to a skin depth of about one centimeter and is particularly effective in producing erythemia and epilation, and at high doses (greater than 300 rad) it may cause cataracts.

Fig. 17 and 18 give the general picture of what the medical doctor can expect following a high exposure, i.e., at low doses damage is pronounced in its suppression of the formed element of the blood, at intermediate doses (200 to 1000 rads) the damage is to the GI tract, while at high doses (greater than 1000 rads) damage to the CNS begins to appear. The midlethal dose ranges between 300

$$R = C t^{-1.2}$$

R = dose rate

t = time

C = constant

Let $R_1 = 300$ rem/hr. @ $t_1 = 6$ hrs

$$R_2 = R_1 \left(\frac{t_1}{t_2}\right)^{1.2} = 300 \left(\frac{6}{18}\right)^{1.2} = 80.3 \text{ rem/hr.}$$

at $t_2 = 18$ hrs after detonation.

But $R_2 \simeq R_1 \left(\frac{t_1}{t_2}\right) = 300 \left(\frac{6}{18}\right) = 100$ rem/hr

Fig. 16.

TABLE 3. *Probable Short-Term Effects of Acute Whole-Body Irradiation.*

ACUTE DOSE r	PROBABLE EFFECTS
0 to 50	No obvious effect, except possibly minor blood changes
80 to 120	Vomiting & nausea for about 1 day in 5-10% of exposed persons; fatigue but no serious disability.
130 to 170	Vomiting & nausea for about 1 day, followed by other symptoms of radiation sickness in about 25% of persons; no deaths anticipated.
180 to 220	Vomiting & nausea for about 1 day, followed by other symptoms of radiation sickness in about 50% of persons; no deaths anticipated.
270 to 330	Vomiting & nausea in nearly all persons on 1st day, followed by other symptoms of radiation sickness; about 20% deaths within 2-6 wk. after exposure; survivors convalescent for about 3 mo.
400 to 500	Vomiting & nausea in all persons on 1st day, followed by other symptoms of radiation sickness; about 50% of deaths within 1 mo.; survivors convalescent for about 6 mo.
550 to 750	Vomiting & nausea in all persons within 4 hr. after exposure, followed by other symptoms of radiation sickness; up to 100% deaths; few survivors convalescent for about 6 mo.
1000	Vomiting & nausea in all persons within 1-2 hr.; probably no survivors.
5000	Incapacitation almost immediately; all persons dead within 1 wk.

Fig. 17.

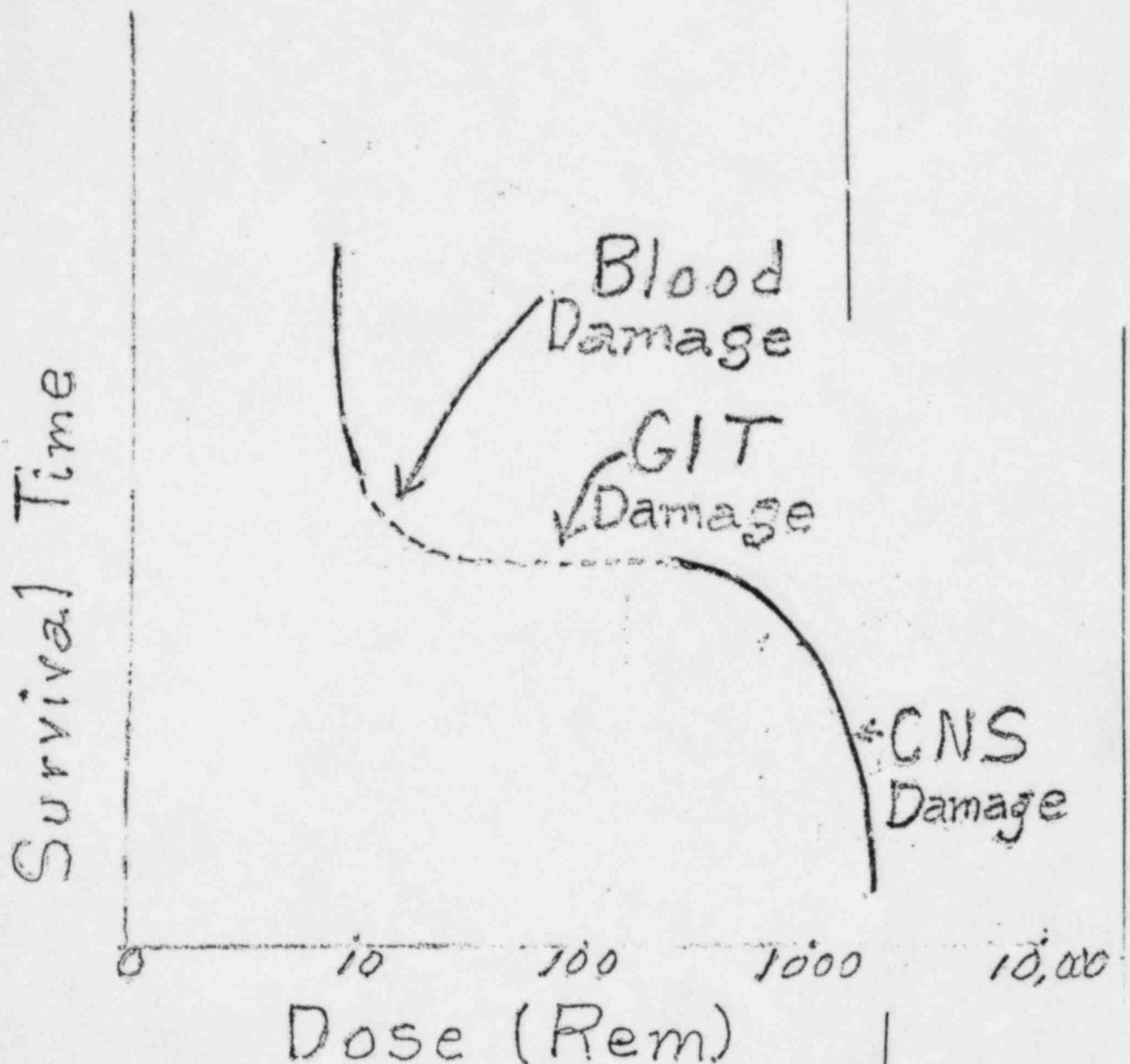

Survival Time
Blood Damage
GIT Damage
CNS Damage
0
10
100
1000
10,000
Dose (Rem)

Fig. 18.

and 500 rem depending on the age and health of the person and whether or not medical care is available. Probably in time of war the MLD would be about 300 rem. Fig. 19 shows the differential blood count following a single exposure to a large dose of radiation. The initial rise in the leukocyte count is observable only over the first few hours. The lymphocyte count is the most responsive to dose.

I will not discuss treatment of persons exposed to radiation because I do not wish to be accused of practicing medicine.

The above discussion has been in reference to dose equivalent (rems). It should be kept in mind that when absorbed dose (rad) units are given we have (Fig. 20) dose equivalent (rem) = absorbed dose (rad) QN, and QN is set equal to 1 for external exposure to x, gamma and beta radiation. For neutron dose, QN is a function of the type of effect, energy of the neutrons and the time over which the dose is delivered. As a rule of thumb QN is approximately equal to two for acute exposure to fast neutrons and twenty for chronic exposure. It commonly is taken as 2.5 for thermal neutrons. This may be important if neutron bombs are used in a nuclear war. For internal dose Q = 1 for β^+, β^-, e^-, x and γ radiations, 10 for alpha and 20 for recoil atoms. N = 1 if parent element is Ra and for X and gamma radiation and for all organs exept bone. It is 5 for bone in all other cases (α, β^+, β^-, recoils).

The body burden of a radionuclide is given by

$$q = \frac{5.4 \times 10^{-5}\ mR}{f_2 EQN} \quad \mu Ci$$

in which R = average dose rate (rem/y), m = mass of organ (g), E = MeV of radionuclide and f_2 is fraction in organ of that in total body. For illustration the above equation is applied to Pu-239 in Fig 20.

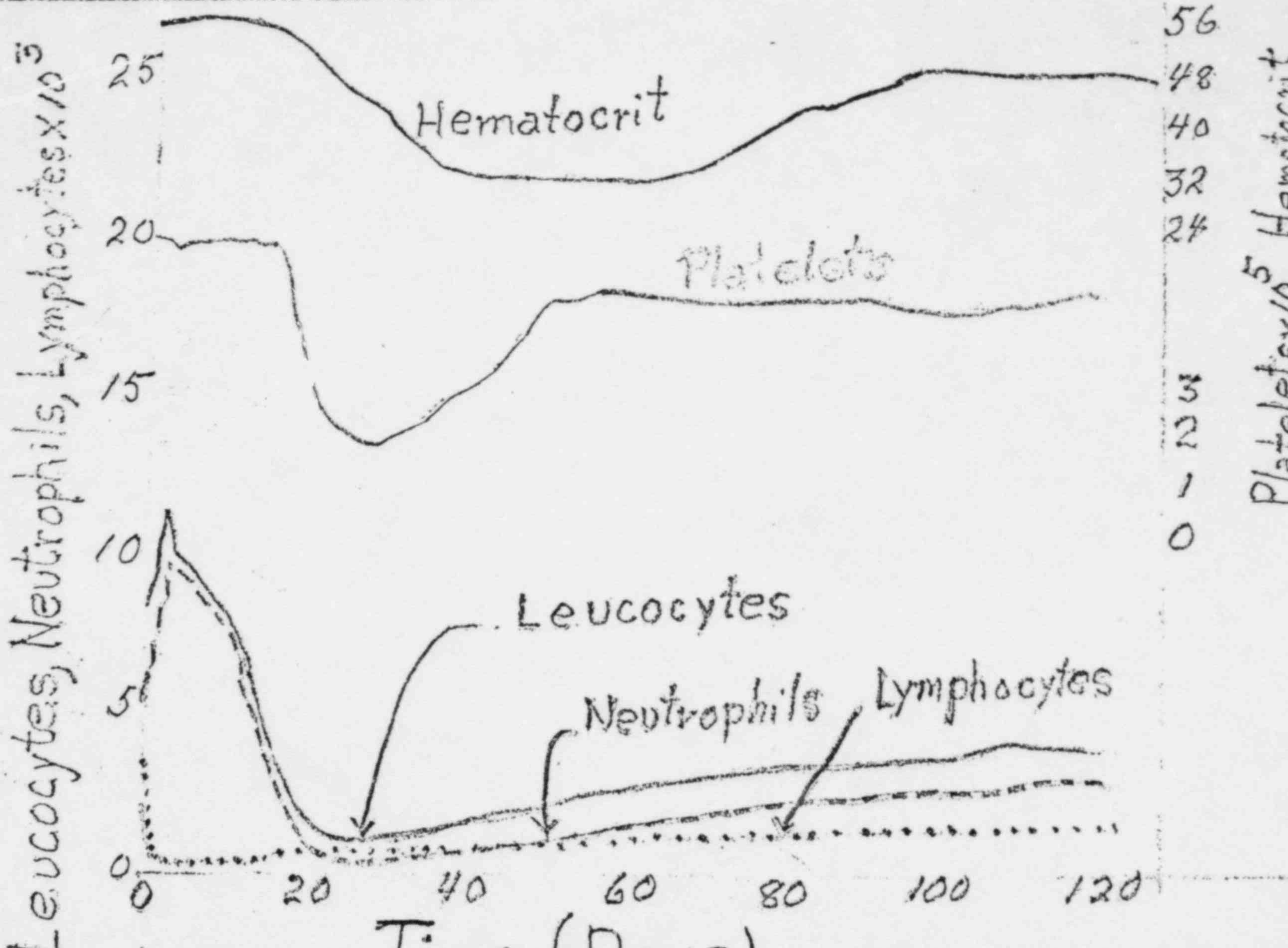

Hematocrit
Platelets
Leucocytes
Neutrophils
Lymphocytes
Leucocytes, Neutrophils, Lymphocytes X 10³
Platelets x 10⁵
Hematocrit Vol %
25
20
15
10
5
0
56
48
40
32
24
3
2
1
0
0
20
40
60
80
100
120
Time (Days)

Fig. 19

Dose Equivalent (rem) = Absorbed Dose (rad) × Q × N

Q = 1 for external exposure
Q = 1 for X, γ, β^-, β^+, e
Q = 20 for α
Q = 2.5 for thermal neutrons
Q = 2 for acute exposure to fast neutrons and acute effects
Q = 20 for chronic exposure to fast neutrons.
Q = 20 for recoil atoms during α emission

N = 1 for internal dose for X and γ
N = 1 when Ra is parent element
N = 5 for α, β^-, β^+, e in bone if Ra is not parent element

Fig. 20.

CALCULATION OF MAXIMUM PERMISSIBLE BODY BURDEN

OF PU-239 FOR THE OCCUPATIONAL WORKER

From ICRP Publication No. 2:

Critical body organ is bone

$$m = 7 \times 10^4 g, \; R = 30 \text{ rem/y}, \; f_2 = 0.9$$

$$E_\alpha = 5.16 \text{ MeV}, \; Q_\alpha = 10, \; N_\alpha = 5$$

$$E_r = \frac{4E_\alpha}{A-4} = \frac{4 \times 5.16}{239 - 4} = 0.088, \; Q_r = 20, \; N_r = 5$$

$$q = \frac{5.4 \times 10^{-5} \text{ mR}}{f_2 EQN}$$

$$q = \frac{5.4 \times 10^{-5} \times 7 \times 10^3 \times 30}{0.9[(5.16 \times 10 \times 5) + (0.088 \times 20 \times 5)]} = 0.047 \approx 0.04 \; \mu\text{Ci}$$

But Q_α is now taken as 20 instead of 10 so

$$q = \frac{5.4 \times 10^{-5} \times 7 \times 10^3 \times 30}{0.9[(5.16 \times 20 \times 5) + (0.088 \times 20 \times 5)]} = 0.024 \approx 0.02 \; \mu\text{Ci}$$

Fig. 21

My principal interest during the past decade has been the induction of various types of malignancies by ionizing radiation. As shown in Fig. 8, there is a very wide variation in estimates of the total fatal cancer-risk coefficient as follows:

By NRC staff and consultants: less than 2×10^{-4} per person rem

By BEIR III: 2×10^{-4} - 3×10^{-4} per person rem

By myself: 9×10^{-4} per person rem

By J. Gofman: 4×10^{-3} per person rem

From Hanford Study: 6×10^{-3} to 8×10^{-3}

It is to be noted that the BEIR III value will have to be raised by a factor of two because of a dosimetry error in the Hiroshima and Nagasaki atom bomb survivor data (see K. Z. Morgan, Science, August 7, 1981).

Finally, Fig. 22 indicates there is no solution to a nuclear war except prevent it by disarmament.

I would like to close by saying I hope and pray this time we do not give up in our efforts to prevent a nuclear war. After Hiroshima and Nagasaki, I and many of my scientist associates spent many months traveling about the country giving lectures and trying to gain support for outlawing nuclear weapons, for strengthening the United Nations and eventually forming a world federal government. I worked with some of the leading scientists and sat around the fire with Einstein in his home discussing how we might bring this about. Senator Koeffer was our political leader, but we were before our time. When Koeffover died an early death, we gave up the fight in deep discouragement and frustration. National sovereignty, or the right to wage war, kill our neighbor and have the glory of being killed ourselves was more important than sanity. Now we must organize and enlarge our efforts at home and draw in our supporters from abroad in a worldwide effort to save the human species. With God's help we can, and this time we must succeed.

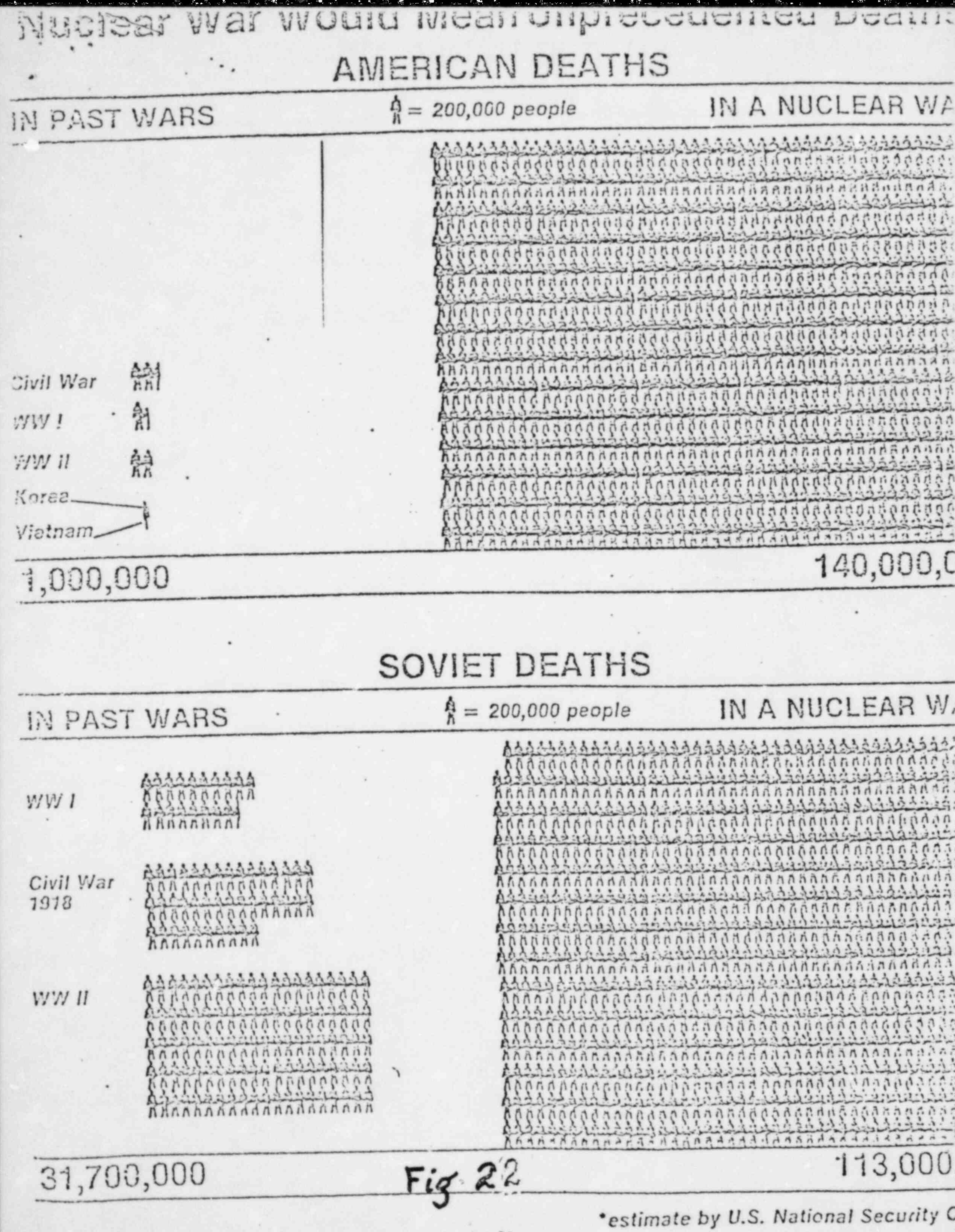

Nuclear War Would Mean Unprecedented Death
AMERICAN DEATHS
IN PAST WARS
= 200,000 people
IN A NUCLEAR WA
Civil War
WW I
WW II
Korea
Vietnam
1,000,000
140,000,0
SOVIET DEATHS
IN PAST WARS
= 200,000 people
IN A NUCLEAR W
WW I
Civil War 1918
WW II
31,700,000
113,000,
*estimate by U.S. National Security C

Fig 22

RADIATION RISKS FROM NUCLEAR POWER: FINAL ROUND

To the Editor: In the May 22 issue of the *Journal*, Dr. Arthur C. Upton of the National Cancer Institute expressed the opinion that Chivian et al., writing in the October 4, 1979, issue, exaggerated the risk of cancer after the Three Mile Island incident when they stated, "Karl Z. Morgan, a founder of the science of health physics, estimates there will be 50 excess cancer cases in the area surrounding Three Mile Island."

This figure of 50 cases was an off-the-cuff estimate. On the basis of early reports, I had estimated that the total effective man-rem dose would be about 10^4; accordingly, I expected at least six deaths from radiation-induced cancer. I indicated that some federal agencies had initially made lower dose estimates, which had been forced to increase from time to time, and that further increases could be expected. Also, they had applied one of the lowest risk estimates that they could find — 10^{-4} cases per man-rem. I stated that if one used the study of Mancuso et al.[1] on risk estimates of cancer in radiation workers at the Hanford dump in Washington, one might expect not six but about 50 cases of radiation-induced fatal cancer from 10^4 man-rems.

The low risk estimate of 10^{-4} was based mostly on data in survivors of the atomic bombings of Hiroshima and Nagasaki and on patients with ankylosing spondylitis treated by irradiation. I do not believe that these data are as applicable to inhabitants near Three Mile Island as are the data of the Hanford study on a normal population, because the Japanese, in addition to radiation, suffered from a terrible holocaust that weakened their immune systems. As a result, large numbers died of common diseases, such as pneumonia, that have a much shorter latency period that cancer's. Rotblat[2] compared leukemia in a Japanese group who had entered Hiroshima early after the explosion and had received a large dose from neutron-induced radioactivity with leukemia in a group who had entered later, after radiation had mostly disappeared. He found a risk of leukemia that was nine times that reported for Japanese who survived concurrent ionizing radiation and fire, blast, and deprivation. The situation is essentially the same for patients with spondylitis: they are sick people suffering from a disease, and, like the Japanese groups, many do not survive to die of a malignant process.

It may be true that the total-body dose to the population living within 50 miles (83 km) of Three Mile Island could be only 3300 man-rems; if so, I would estimate the number of cases of fatal cancer to be between two and 20. However, the number of nonfatal cases of cancer may be about three times the number of fatal cases, owing to a disproportionate number of cases of skin cancer from the large beta dose. Unfortunately, the beta dose could not be measured by the meters available when the radioactive clouds passed over the neighboring population. Some of the beta radiations from the noble gases have ranges in excess of 1 cm of tissue; therefore clothing could not provide adequate protection. To these estimates of risk, of course, must be added the risks of thyroid carcinoma from radioiodine.

I agree with the implication of the title of Upton's letter — that radiation risks from nuclear power should not be exaggerated. I too am working for survival of nuclear power, but I do not believe that this can be accomplished if risks are underestimated or if some risks are not even taken into consideration.

Karl Z. Morgan
Atlanta, GA 30332 Georgia Institute of Technology

1. Mancuso T, Stewart A, Kneale G. Radiation exposures of Hanford workers dying from cancer and other causes. Health Phys. 1977; 33:369.
2. Rotblat J. The risks for radiation workers. Bulletin of Atomic Science. September 1978.

To the Editor: The two letters on radiation risks from nuclear power by Upton and Ahrens et al. in the May 22 issue were fascinating. They expressed a 200 per cent difference in the estimated radiation dose. Ahrens et al. noted a radiation dose of "1000 person-rems," and Upton noted one of "3300 person-rems" from Three Mile Island.

Ahrens et al. stated: "If not ingested or inhaled and if kept at a distance, nuclear wastes will not cause cancer." How can one challenge such a simplistic statement? Translated, it might well have read: "If man is not exposed to radiation, man will not have cancer caused by radiation." Exposure to radioactive isotopes can only occur by ingestion, by inhalation, by intravenous injection, or by proximity to the source so that the isotopes act as an external source of radiation. "If kept at a distance": What distance? A thousand miles away? If so, their statement is indisputable. If the distance is 1 inch, and if some children in Hanford, Washington, are playing near an eroded receptacle that has nuclear waste leaking from it, the probability that they will have leukemia or cancer will depend on the dose that they receive and their leukemogenic or carcinogenic threshold.

Conservatives who believe that caution is warranted perhaps more for our offspring than for ourselves look on the Three Mile Island accident as a near disaster, rather than an encouraging demonstration of the "safety" of nuclear plants. Not all of us would make the sharp separation of nuclear energy from nuclear weapons that Ahrens et al. insist on. Their experts agree that "nuclear power is a small addition to the problems of proliferation of nuclear weapons." But it is not small enough to prevent India, hardly the most technologically advanced nation, from building and testing a thermonuclear weapon. A recent article in *Science** notes that with large-scale reprocessing of nuclear fuel under consideration, "safeguards technology is not evolving quickly enough to detect major diversion of weapons-grade plutonium." Although "150 tons of plutonium would be processed...annually,...it requires only 8 kilograms or less to create a bomb." Such prospects must concern anyone who thinks about the relation between nuclear power and thermonuclear weapons.

It may well be true that the Three Mile Island incident cannot be implicated in the production of a considerable number of neoplasms within the next few decades. Its central importance to society was as a major signal, a warning, a message that the nuclear establishment, with all its assurances and its apologists, must be viewed critically and cautiously by those who believe that exposure to radiant energy should be avoided unless there is potential medical benefit to be derived.

Herbert L. Abrams, M.D.
Boston, MA 02115 Harvard Medical School

*Smith RJ. Reprocessing plans may pose weapons threat. Science. 1980; 209:250-2.

Note: We do not like to prolong controversies in these columns and ordinarily would not have published this fourth and final round of letters. However, the subject is important, and these two letters seem to us worth bringing to our reader's attention. Those interested in further information on the subject of low-level radiation should consult the so-called BEIR III report on "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," recently released by the National Academy of Sciences. — Ed.

WOMEN IN MEDICINE

To the Editor: In response to your editorial "Here Come the Women" (May 29 issue): It's about time!

Kathleen Mayzel, M.D.
Brighton, MA 02135 St. Elizabeth's Hospital

To the Editor: I was interested to read the comments on women physicians. First of all, you mentioned that women doctors "work fewer hours on the average than do their male colleagues." Historically, society has expected women physicians to fulfill its expectations of the woman as wife, mother, and hostess as well as career person. Indeed, I have yet to meet a middle-aged attending physician who can claim that he did at least half the shopping, laundry, carpooling, and cooking for his growing family.

LEAVE THIS SPACE BLANK

RISKS OF NUCLEAR POWER PLANT ACCIDENTS AND CONSEQUENCES ON POPULATION AND BIOSPHERE

Karl Z. Morgan

School of Nuclear Engineering and Health Physics
Georgia Institute of Technology
Atlanta, Georgia, USA

ABSTRACT

Any estimates of probabilities of major nuclear power plant accidents are perforce only conjectures because we have had only 25 years of experience with commercial LWRs and less than 10 years experience with breeders. There have been two major efforts in the US to determine these probabilities - the Brookhaven report (1957) and the Rasmussen report (1975). The Brookhaven report provided a basis for the Price Anderson Act which is a source of irritation in the US. Many considered the Brookhaven report exaggerated the risks and so the Rasmussen report 18 years later was warmly received. However, shortly before the TMI-2 accident following several near misses of serious reactor accidents, the US Nuclear Regulatory Commission disengaged itself from support of the Rasmussen report. The LMFBR was a bad choice of a breeder reactor primarily because of weapons proliferation and health effects. The US has 73 power reactors operating at this time so the probability of a TMI-2 accident would be once in 270 to 2700 years using the Rasmussen report value of one in 20,000 to 200,000 per reactor year. The Rasmussen report estimate of a core melt accident of 5×10^{-6} to 5×10^{-5} per reactor per year does not compare well with the 300 power reactor years experience at the time of the TMI-2 accident or 3×10^{-3} accidents per reactor year. The Brookhaven report estimates of accident and risk probabilities come closer to this crude estimate from TMI-2. The USNRC claims there was very little early release of noble gas and iodine radionuclides and so begins its risk estimates at 7:00 a.m. rather than at 4:00 a.m. when the accident actually began. The early activity of the short lived radionuclides of noble gases and iodine were orders of magnitude greater than that of Xe-133 and I-131 on which most of the dose estimates are primarily based. Several sources of data suggest the population dose was greater than the USNRC estimates and early leakage of these short lived radionuclides may be the answer. The USNRC estimates of risk of cancer and genetic mutations from given doses of radiation are low - probably by an order of magnitude - because of uncorrected biases in data based on survivors of Hiroshima and Nagasaki bombings and on the x-ray dose given to patients suffering with ankylosing spondylitis. If nuclear power is to be successful, we must be more honest and candid with the public and find a way to prevent minor incidents from escalating into major accidents -mostly because of failure of the human element.

KEYWORDS

Accidents, PWR, TMI-2, Noble Gases

INTRODUCTION

Perhaps at the outset of this discussion I should explain that I am not an anti-nuke (a person fanatically opposed to nuclear power) nor am I a nuclear zealot like most of those in the nuclear and nuclear related industries. Many of the anti-nukes are poorly informed and have a case of radiation phobia such that they fear 1 mrem per year from a nuclear power plant far more than they fear 200 mrem from a completely unnecessary medical diagnostic procedure and they often ignore the risks of hydrocarbons, NO_x, SO_x, CO, CO_2 and particulates from a fossel fueled plant. The typical nuclear zealot, on the other hand, underestimates the radiation risks by more than an order of magnitude, gives half-truths and often resorts to cover-up and even censorship of information in order not to "frighten" the public. Members of this clan are often very arrogant and seem to take the attitude that "father knows what is best for the stupid public." They are skillful in obtaining industrial and government support and in manipulating figures that minimize the total cost of nuclear power because they "overlook" some of the costs such as research, enforcement, radioactive waste, decommissioning, accidents, etc.

I am for nuclear energy but not at all costs or at the expense of other sources of energy. I think we have made and continue to make many serious mistakes and improper choices in nuclear energy. I think some of the nuclear power plants are of poor design and poorly located and are unsafe. I believe some of them should be shut down for safety reasons, and because of high occupational exposures and potential high exposure to large populations. I will do all I can to make nuclear power operations (including the entire nuclear cycle) as safe as possible and will try to understand and make clear to others the total risks associated with ionizing radiation so they can make some meaningful energy choices. A few of the nuclear operations go all out to support safety while others do the opposite.

Much of this discussion is perforce hypothetical and consists of conjectures, suppositions and assumptions regarding what might happen in case of a major accident at a nuclear power plant. This is because nuclear power is relatively new and only one accident at a nuclear power plant (TMI-2) has resulted in very serious consequences. There have been more serious accidents in research reactors and in plutonium producing reactors but they are not under discussion at this conference. Table 1 summarizes the early nuclear power operations emphasizing that we have had only two decades of nuclear power plant experience and less than one decade experience with modern 1000 MWe reactors and experimental LMFBR's. Here it is noted the first commercial nuclear power plants began operating at 50

TABLE 1

Date of First Operation	Power Mwe	Country	Reactor Identification and Type
Sept 1956	Each 50	UK	Calder Hall (1-4)-GCR
Nov. 1958	Each 50	UK	Chapel Cross (1-4)-GCR
Dec. 1958	Each 100	USSR	Siberian (1-6)-LGR
Apr. 1959	40	France	Marcoule G2 (Gard)-GCR
June 1973	1100	US	Zion 1 - PWR
Dec. 1973	233	France	Pheonix (Card) - LMFBR
- 1973	350	USSR	Shevchenko (BN-350)-LMFBR

MWe in the UK in September 1956 and were followed shortly by operations in the USSR and France. All the early plants were operated at relatively low power levels and it was not until June 1973 that in the US the first plant was operated at more than 1000 MWe. It was a PWR of the type with which we are mostly concerned in this conference. Some of us also have serious reservations concerning the commercial operation of LMFBR's and the first of these is the French Phoenix which began operating commercially in December 1973. The US has in operation or various stages of construction a total of 177 nuclear power plants with (over half of the world's MWe nuclear power capacity) but to date our operating experience is far too limited to make estimates of risk of major reactor accidents that have statistical significance. This limited experience does not provide us with an adequate basis of judging the frequency or severity of major nuclear power accidents which have been reckoned to take place only once in more than a million years per reactor. Rasmussen (1975) gives a probability of a PWR core melt category-1 accident as only 9×10^{-7} per reactor year.

There have been two major studies in the US of the probability and consequences of nuclear power plant accidents; the first WASH-740 by a group at Brookhaven National Laboratory (1957) was prepared primarily to serve as a basis for the controversial Price-Anderson Act which provides for indemnification in case of major nuclear power plant accidents. This Brookhaven report received widespread criticism from representatives of the nuclear industry which claimed it had seriously exaggerated the risks by assuming greater releases of radioactivity to the environment than were likely or possible, made inadequate provision for evacuation of the exposed population and included other assumptions that led to estimates of numbers of deaths and illnesses that were too high by about two orders of magnitude. As a result a much more costly and elaborate study was conducted involving over 70 man-years of effort and an expenditure of four million dollars. This is referred to as the Rasmussen report (1975). This report which arrived at much less severe consequences of a major nuclear power plant accident than WASH-740 is summarized in Table 2 along with comparative values from WASH-740. It was

TABLE 2. Comparison of Consequences from Accidents in a 500 MWe (160 MWe) Reactor as Calculated in the Brookhaven Report and as Predicted in the Rasmussen Report (1975)

Parameter	Wash-740 Peak	WASH-1400 Peak	WASH-1400 Average
Acute Deaths*	3,400	92	0.05
Acute Illnesses*	43,000	200	0.01
Total Dollar Damage	1×10^{10}**	1.7×10^{9}	5.1×10^{8}
Approximate Chance per Reactor	-	10^{-9}	10^{-4}

*These values should be multiplied by 6 to obtain acute deaths and illnesses for a 1000 MWe power reactor

**The Brookhaven value of $\$7 \times 10^{9}$ for 1957 dollars was converted to $\$1 \times 10^{10}$ 1973 dolars for comparison with 1973 values in the Rasmussen report (1975). Both the Brookhaven and Rasmussen values listed here should be multiplied by 1.6 for conversion to 1981 dollars. All values in this table should be escalated upward to apply to modern nuclear power plants of 1000 MWe or more.

warmly welcomed at first by the US Atomic Energy Commission and members of the nuclear power community. For a period of 2 to 3 years it was used as the Bible which provided "reliable" estimates of the probabilities of reactor accidents of various magnitudes and furnished the "best estimates" of risks and consequences. However, there were many close calls with power reactors operating in the 900 to 1100 MWe range; accidents such as the multi-million dollar Brown's Ferry (1067 MWe BWR) accident on March 22, 1975 and the accident at the Davis-Besse 906 MWe PWR in September 1977. The Brown's Ferry accident was caused when an inspector used a candle to check air leaks and started a fire in the insulation in a control cable channel. Perhaps it is a bit ominous that the Davis-Besse plant was one of the 8 PWR's manufactured by Babcock & Wilcox Co. operating in the US at the time of the TMI-2 accident and TMI-2 also was one of these 8 B and W reactors. Also the Davis-Besse accident, like the TMI-2 accident, was due to a feedwater transient. I believe this series of accidents was responsible for the fact that the US Nuclear Regulatory Commission a few weeks before the TMI-2 accident indicated it was disenchanted with the Rasmussen report and no longer based its risk estimates on the report. It should be recalled that the General Public Utilities Corp., the parent company of Metropolitan Edison (the operator of TMI-1 and TMI-2) presented a damage claim of $4 billion against the US Nuclear Regulatory Commission because this government agency allegedly failed to make utilities aware of implications of how this chain of events at the Davis-Besse plant could lead to an accident of the TMI-2 type which occurred March 28, 1979. As expected, the NRC has rejected responsibility for the TMI-2 accident and as a result GPU has announced it will sue the NRC (Note: Buck-passing is not limited to children each of whom, for example, accuses the other of stealing the cookie; it takes place also between large utilities and powerful government agencies). Persons interested in a quick review of the major nuclear power plant accidents that have occurred in the world are referred to a publication of Bertini (1980). Twenty-nine such accidents are described which meet one or more of seven severity criteria: (1) caused death or significant injury, (2) released significant offsite radioactivty, (3) core damage, (4) severe equipment damage, (5) caused inadvertent criticality, (6) a precursor to a potentially serious accident or (7) resulted in significant recovery cost.

Estimates of Probability of a Nuclear Power Plant Reactor Accident as Given in Rasmussen Report

The Rasmussen report (1975) used the method of event tree analysis to define certain system failures whose probabilities were needed to determine the risk. Then the fault tree method was used to estimate the majority of these failure probabilities. Care was taken to include the various common modes of failure, i.e. events are not necessarily independent and a single failure may increase the probability of one or more additional failures or what causes one control or safety device to fail can cause others to fail also. After the fault trees were quantified, the event tree quantification stage combined the individual fault tree probabilities to obtain the accident sequence probabilities. All the calculations were based on the typical present day 1000 MWe power reactor of the PWR and BWR light water reactor, LWR types. The differences in effects/probability curves of the PWR and BWR were less than the inherent uncertainties so the average results could be applied to either type of reactor system in common use in the US (in the US 65% of power reactors in operation or under various stages of construction are PWR's and 34% are BWR's). Table 3 is a summary of the risks of various types of power reactor accidents as obtained from Fig. 5-3 and Fig. 5-8 of the main Rasmussen report, (1975).

TABLE 3. Probability of Risks of Various Magnitudes Associated with Nuclear Power Reactors as Given in the Rasmussen Report (1975)

Magnitude of Effect for Each 1000 MWe Reactor	Probability per Reactor year
Core melt accident	5×10^{-5}
Accident causing 1 early fatality	4.5×10^{-7}
Accident causing 10 early fatalities	3×10^{-7}
Accident causing 100 early fatalities	10^{-7}
Accident causing 1000 early fatalities	10^{-8}
Probable worst accident (3500 early fatalities)	10^{-9}
Accident causing 1 early illness	7×10^{-6}
Accident causing 10 early illnesses	5.3×10^{-6}
Accident causing 100 early illnesses	2×10^{-6}
Accident causing 1000 early illnesses	3×10^{-7}
Accident causing 10^4 early illnesses	2×10^{-8}
Accident causing 1 genetic effect per year	1.5×10^{-5}
Accident causing 10 genetic effects per year	3.5×10^{-6}
Accident causing 100 genetic effects per year	1.5×10^{-8}
Accident causing damage of 10^6 dollars	4.5×10^{-5}
Accident causing damage of 10^7 dollars	3.3×10^{-5}
Accident causing damage of 10^8 dollars	1.2×10^{-5}
Accident causing damage of 10^9 dollars	7.5×10^{-7}
Accident causing damage of 10^{10} dollars	4×10^{-9}
Accident causing 1 latent cancer death per year	2.5×10^{-5}
Accident causing 10 latent cancer deaths per year	1.2×10^{-5}
Accident causing 100 latent cancer deaths per year	2×10^{-6}
Accident causing 1000 latent cancer deaths per year	5×10^{-9}
Accident causing 1 thyroid nodule per year	3.3×10^{-5}
Accident causing 10 thyroid nodules per year	2.5×10^{-5}
Accident causing 100 thyroid nodules per year	1.5×10^{-5}
Accident causing 1000 thyroid nodules per year	1.7×10^{-6}
Accident causing 8000 thyroid nodules per year	10^{-9}
Accident causing decontamination area of 0.1 square mi	5×10^{-5}
Accident causing decontamination area of 1 square mi	4×10^{-5}
Accident causing decontamination area of 10 square mi	1.8×10^{-5}
Accident causing decontamination area of 100 square mi	1.6×10^{-6}
Accident causing decontamination area of 1000 square mi	3×10^{-6}

A principal objective of this conference is to evaluate various estimates of the probability of occurrence of nuclear power reactor accidents and the harmful consequences. Thus we would like to know actually how unreliable were the estimates of the Brookhaven report (1957) and how accurate and reliable are the estimates of the Rasmussen report (1975) that replaced it. I will not presume to answer these questions because I am not a sage or prophet -- perhaps a Gypsy fortune-teller would give a better answer to these questions which I am sure even Solomon would hesitate to try to answer. The difficulty comes not so much in evaluating the failure probabilities of man made equipment but rather the almost impossible task of out-guessing what man might do when faced suddenly with a variety of choices some of which he must make post haste and other choices that might spell disaster if taken in improper sequence. I am one of those people who believes we could have safer operation of nuclear power reactors if they were operated by computers rather than have us depend on "highly skilled" reactor operators. TMI-2 would never have resulted in serious consequences if its operation had been left to the computer. The difficulty with human operators is that they often take corrective measures which make matters worse and they take remedial measures to keep the generators on line when there is a very weak indication the reactor should be scrammed. I believe in the short run the computer may not chalk-up as many MWHs on line as the human reactor operator but perhaps over the reactor lifetime fewer serious outages and mistakes would result. The computer would not likely be as cost conscious as the reactor operator. This inferiority of the human compared with the computer is because there is a limit to how fast the human brain can recall and process information no matter how intelligent, how calm and well trained the person may be. For example, the skilled reactor operator may without warning suddenly face 50 different possible courses of action. He cannot be certain of choosing the best of the 50 choices because it would take at least seconds to follow through in his mind's eye the ultimate consequences of each course. Thus literally he must make a snap judgement since he has only seconds to decide. The computer on the other hand has all this figured out for it in advance in a calm and unhurried environment where hopefully every conceivable combination of events was carefully evaluated to the end point and if there is doubt, it scrams the reactor. The computer has the advantage of having compressed into milliseconds what its master thought through over a period of days or weeks and it very seldom "forgets" its instructions. It, of course, is not infallible but I believe with proper computer backup it would make safer choices more often than the hurried, excited and perhaps confused reactor control operator during a serious emergency. I believe for nuclear power to be acceptable there is no question but that we must find a way to stop minor events or small incidents from escalating into major Class IX accidents (i.e. core melt accidents of categorys PWR-1 through PWR-7 in Rasmussen report (1975)). None of the PWR categories in the Rasmussen report (1975) corresponds very closely with the TMI-2 accident but the mean of the probabilitys per reactor year of a core melt accident of categories PWR-3 through PWR-7 is about 5×10^{-6} and in the general case of a core melt the conservative estimate of 5×10^{-5} per reactor year is given. Thus on the average we might have expected an accident of the TMI-2 type only once in 20,000 to 200,000 years per reactor or we would expect such an accident among the 73 power reactors we now have operating in the US only once in 27 to 2700 years. Thus it seems we were very unlucky at TMI-2 or perhaps the Rasmussen estimate is not sufficiently conservative and unless effective remedial measures are taken, we can expect serious accidents with power reactors at a relatively high frequency among the more than 500 power reactors operating or under construction in the world at the present time. Perhaps one would like to place the blame specifically on the B and W type PWR's but I believe in some respects they are actually safer than those manufactured by other companies. Perhaps in some ways the BWR's are safer than the PWR's as suggested by the Rasmussen report (1975) (which gives the probability per reactor year of accidents causing one early fatality as 1.2×10^{-7} for the BWR and 6.2×10^{-7} for the PWR) but as indicated above this report states this difference is not of statistical significance. The Rasmussen prediction of a TMI-2 accident is a bit better if we consider the 300 reactor years of power reactor operations in the US, i.e. one such accident every 70 to 700 years but this is little consolation.

In the case of breeder power plants we have much less experience than with LWR's because at the present time only 4 such reactors are operating commercially. Our (US) first breeder reactor experience was disappointing. Fermi, an experimental breeder, was completed in 1966 and failed spectacularly in its initial steps of operations; it suffered a partial core melt. I believe there is no way in which breeders can be made safer than the safety capability of LWR's. In fact from the very advent of these porgrams I have opposed the LMFBR principally for two reasons: (1) I believe their widespread deployment would increase greatly the risks of nuclear weapons proliferation. In this age of hijacking and clandestine operations the fresh fuel for these plants would be an extremely tempting prize of unlimited blackmail value. The plutonium in this fuel could not be used to make as efficient weapons as are made from weapons grade plutonium because of the high percent of Pu-238 and Pu-240 although this percentage is less in the LMFBR recycled fuel than in the LWR fuel. However, even weapons of 50,000 T destructiveness serreptitiously planted in Washington or New York a few months after the hijacking of a reactor fuel shipment could present the president of the US with the most serious case of blackmail our country has every imagined. Such weapons could be fabricated in only a few weeks following a hijacking of LMFBR fresh fuel if rather simple preparation had been made prior to the hijacking, (2) The second reason I oppose LMFBR is because it operates on the Pu-cycle and its inventory of Pu and transplutonic radionuclides imposes an unacceptable radiation risk. There are many other reasons why I have opposed LMFBR such as the positive void coefficient in the Na-coolant of some designs, its high cost, long doubling time and low breeding ratio and its relative inefficiency compared with some other breeding systems. I believe all LMFBR's should be located only in areas remote from large populations and should be supervised by and under the control of the United Nations or a greatly strengthened IAEA. Breeders operating on the Th-U-233 cycle circumvent many of the undesirable features of the LMFBR. This is because the U-233 fuel contains enough U-232 and U-234 that the intense gamma radiation would seriously impede hijacking and clandestine operations leading to weapons fabrication and U-233 dilution with U-238 would greatly extend the time for effective and successful serreptitious operations. And I believe in this unstable world-society more time for man to learn how to live together in peace is important. Table 4 is data from Pigford (1974) which emphasizes why the LMFBR is more dangerous from the standpoint of proliferation and the accumulation of dangerous transuranic elements. For clandestine weapons fabrication the LMFBR reprocessed fuel presents less problems of heat generation, spontaneous fission and dilution because of the lower percentages of Pu-238 and Pu-240 than in the LWR which is uranium fueled. It is important to note that fresh fuel for the LMFBR or LWR do not emit intense radiation from fission products. The first LMFBR loading is likely to be that from the LWR's with the composition of Pu isotopes as shown in Table 4 and the first reloadings would be like that shown for the LMFBR.

TABLE 4. Comparison of Spent Fuel from a 1000 MWe LWR and a LMFBR with Values of Relative Hazard of the Given Radionuclides

Isotope Half-lives(a)(b) Relative Hazard	Activity of Fuel Reprocessed yearly (Ci/y) for LWR[1]	Activity of Fuel Reprocessed yearly (Ci/y) for LMFBR[1]	% by Weight of Pu in Reprocessed fuel for LWR[1]	% by Weight of Pu in Reprocessed fuel for LMFBR[1]
Pu-236 2.85(a) 3.5×10^{9} -	0.85×10^{4}	0.9	0.007	10^{-6}
Pu-238 86.4(a) 4.3×10^{10}(b) 152	7.57×10^{4}	2.68×10^{5}	1.8	0.77
Pu-239 24,360(a) 5.5×10^{15} 1	8.89×10^{3}	0.81×10^{5}	59.3	66.9

TABLE 4 (cont)

Pu-240 6,580(a) 1.2×10^{11}(b) 3.8	1.29×10^{4}	1.00×10^{5}	24.0	22.4
Pu-241 13.2(a) -(b) 3.2	3.10×10^{6}	1.34×10^{7}	11.1	6.1
Pu-242 3.79×10^{5}(a) 7.1×10^{10}(b) 6.2×10^{-2}	37	292	3.8	3.8
Am-241 460(a) 2×10^{14}(b) 16	6.25×10^{3}	3.71×10^{4}	-	-
Am-242m 152(a) -(b) 50	1.10×10^{2}	1.87×10^{3}	-	-
Am-242 1.8×10^{-3}(a) -(b) 7.5×10^{-3}	1.10×10^{2}	1.87×10^{3}	-	-
Am-243 7.95×10^{3}(a) -(b) 0.97	4.74×10^{2}	1.07×10^{3}	-	-
Cm-242 0.447(a) 7.2×10^{6}(b) 2.4	3.13×10^{5}	1.10×10^{6}	-	-
Cm-243 32(a) -(b) 45	1.09×10^{2}	8.31×10^{2}	-	-
Cm-244 18.1(a) 1.4×10^{7}(b) 32	6.78×10^{4}	2.65×10^{4}	-	-

(1) From T. H. Pigford (1974)
(2) From K. Z. Morgan (1964)

Estimates of Consequences of a Power Reactor Accident as Given in Brookhaven and Rasmussen Reports

The Brookhaven report (1957) considered various types of serious nuclear power plant accidents and consequences in 3 cases: (1) the contained case, (2) the volatile release case and (3) the 50% release of all fission products case. In case 1 the report concluded there would be no lethal exposure and no injurys if there were evacuation in 2 hours but 6 injuries for evacuation in 24 hours. In case 2 where all the volatile fission products and 1% of strontium were released the Brookhaven report concluded there would be 2 lethal exposures for the temperature lapse weather conditions and 900 if there were a temperature inversion at the time of the release. The assumed injuries for these two weather conditions were 10 and 13,000 respectively. For case 3 it concluded there would be no lethal exposures for a hot release (as shown in Table 2) and 3400 for a cold release; the assumed injuries for these two meteorological conditions were 0 and 43,000 respectively. All these values were for a small nuclear power plant of only 500 MW_t or 165 MWe so they should be multiplied by 1000/165 = 6 for comparison with the values applying to a modern reactor or those given in the Rasmussen report (1975). The estimates in the Brookhaven report of probability of release were simply opinions of knowledgeable experts. These estimates of the risk of accidents per year per reactor were 10^{-2} to 10^{-4} for case 1, 10^{-3} to 10^{-4} for case 2 and 10^{-5} to 10^{-9} for case 3. It is to be noted that these risk estimates are much larger than those of the Rasmussen report (1975) summarized in Table 3.

The Rasmusen report (1975) considered 9 categories of accidents for the PWR and 5 categories for the BWR. Both categories PWR-1 and BWR-1 refer to the largest releases of radionuclides of any of the categories and result in stem explosions and rupture of the reactor with eventual leakage from the reactor building. There is core melt in categories PWR-1, 2, 3, 4, 5, 6, and 7 and BWR-1, 2, 3, and 4. Table 5 gives the Rasmussen probabilities of release, the warning time for evacuation and fractions released of core inventories of some of the radionuclides which are considered to present the greatest threat of radiation injury and death to the neighboring community.

TABLE 5. Summary of Accidents Involving the 1000 MWe Reactor Core(c)

Category(d) Probability per year per reactor Warning Time(e)	Fraction of Core Inventory Released							
	Xe+Kr	Org I	I	Cs+Rb	Te+Sb	Ba+Sr	Ru(a)	La(b)
PWR-1(d) 9×10^{-7} 1(e)	0.9	6×10^{-3}	0.7	0.4	0.4	0.05	0.4	3×10^{-3}
PWR-2(d) 8×10^{-6} 1(e)	0.9	7×10^{-3}	0.7	0.5	0.3	0.06	0.02	4×10^{-3}
PWR-3(d) 4×10^{-6} 2(e)	0.9	6×10^{-3}	0.2	0.2	0.3	0.02	0.03	3×10^{-3}
PWR-4(d) 5×10^{-7} 2(e)	0.6	$2. \times 10^{-3}$	0.09	0.04	0.03	5×10^{-3}	3×10^{-3}	4×10^{-4}
PWR-5(d) 7×10^{-7} 1(e)	0.3	2×10^{-3}	0.03	9×10^{-3}	5×10^{-3}	1×10^{-3}	6×10^{-4}	7×10^{-5}
PWR-6(d) 6×10^{-6} 1(e)	0.3	2×10^{-3}	8×10^{-4}	8×10^{-4}	1×10^{-3}	9×10^{-5}	7×10^{-5}	1×10^{-5}

TABLE 5 (cont)

PWR-7(d) $4x10^{-5}$ 1(e)	$6x10^{-3}$	$2x10^{-5}$	$2x10^{-5}$	$1x10^{-5}$	$2x10^{-5}$	$1x10^{-6}$	$1x10^{-6}$	$2x10^{-7}$
PWR-8(d) $4x10^{-5}$ N/A(e)	$2x10^{-3}$	$5x10^{-6}$	$1x10^{-4}$	$5x10^{-4}$	$1x10^{-6}$	$1x10^{-8}$	0	0
PWR-9(d) $4x10^{-4}$ N/A	$3x10^{-6}$	$7x10^{-9}$	$1x10^{-7}$	$6x10^{-7}$	$1x10^{-7}$	$1x10^{-11}$	0	0
BWR-1(d) $1x10^{-6}$ 1.5(e)	1	$7x10^{-3}$	0.4	0.4	0.7	0.05	0.5	$5x10^{-3}$
BWR-2(d) $6x10^{-6}$ 2(e)	1	$7x10^{-3}$	0.9	0.5	0.3	0.1	0.03	$4x10^{-3}$
BWR-3(d) $2x10^{-5}$ 2(e)	1	$7x10^{-3}$	0.1	0.1	0.3	0.01	0.02	$3x10^{-3}$
BWR-4(d) $2x10^{-6}$ 2(e)	0.6	$7x10^{-4}$	$8x10^{-4}$	$5x10^{-3}$	$4x10^{-3}$	$6x10^{-4}$	$6x10^{-4}$	
BWR-5(d) $1x10^{-4}$ N/A(e)	$5x10^{-4}$	$2x10^{-9}$	$6x10^{-11}$		$4x10^{-9}$	$8x10^{-12}$	$8x10^{-14}$	

(a) Includes Mo, Rh, Tc and Co
(b) Includes Nd, Y, Ce, Pr, Nb, Am, Cm, Pu, Np and Zr
(c) From reference Rasmussen (1975)
(d) Release category
(e) Warning time for evacuation

Underestimate of Power Reactor Accident Probabilities and Risks by the US Nuclear Regulatory Commission and its Contractors in the Brookhaven and Rasmussen Reports

As pointed out above, a principal motive that led the US Atomic Energy Commission to have the Brookhaven report prepared in 1957 was to provide a better basis for indeminification in case of nuclear power plant accidents than was available from the actual reactor experience. Experimental reactors such as the Idaho Falls SL-1 reactor which exploded on January 3, 1961, and killed three operators and the plutonium production reactor at Windscale, England, which caught fire on October 10, 1957, releasing tens of thousands of curies of radioactive contamination into the environment did not provide the kind of basis the USAEC or the utilities wanted for encouraging insurance companies to insure power reactors at a reasonable rate. They were disappointed, however, with the Brookhaven report because the estimates of risk were considered to be far too large. Insurance companies had had no actuarial experience with power reactors and were not willing to insure these plants and the US government was providing strong support for advancement of nuclear power so did not want to see them lapse and become museum pieces. The Brookhaven report (1957) as indicated in Table 2 provided a peak liability of ten billion dollars. With this information in hand the US Congress passed our Price-Anderson Act which releaves the nuclear power industry of any liability claims beyond $560 million dollars. This means that for the peak accident a person in he US can collect only 3.5 cents on a 1981 dollar or ½ cents on a dollar if the cost of a 1000 MWe reactor accident is 6.25 times that of a 160 MWe reactor accident. It is noteworthy that the insurance companies whose main business and specialty is evaluation of the probability and consequence of an accident were so apprehensive about the nuclear risks that the Act had to be written to provide that they would be held liable for only 100 million dollars of the cost and the American taxpayer is left holding the bag to cover the remaining 460 million dollars. Needless to say the Price-Anderson Act is a source of considerable resentment by many of us in the US. If nuclear power is as safe as heralded by the nuclear zealots, why can't it stand on its own feet the same as other industries? It is bad enough for us taxpayers to have to underwrite the costs of nuclear research, enforcement of regulation, misleading publicity (propaganda) and insurance of this kind but why shouldn't we at least receive full compensation for any damage we sustain from a major nuclear accident? Surely there can be no justification for putting major reactor accidents in the same category as "acts of God" that have limited liability coverage in some cases. The Brookhaven report (1975) has little to say about probabilities of an accident like the TMI-2 accident but does give the probability of 10^{-3} to 10^{-4} of an accident that following a core melt, would release significant amounts of fission products outside the reactor vessel but not outside the containment building. If this applies to the TMI-2 accident, they hit it within an order of magnitude because at the time of the accident (March 28, 1979) the US had chalked up about 300 reactor years and based on this 1 accident (awful statistics) the probability turns out to be 1/300 or 3×10^{-3} TMI-2 type accidents per reactor year. The highest Rasmussen value of 5×10^{-5} core melt accidents per reactor year on the other hand, is off by a factor of 60. So the sagacious Brookhaven wise men made a much better prediction (or guess) in 1957 than the Rasmussen team in 1975 with all their computers and sophisticated forests of fault trees they employed.

Regarding consequences of the TMI accident it is too early to make a good estimate. I believe the principal difficulty is that estimates of the US Nuclear Regulatory Commission and its consultants of the radionuclide releases and population dose (person/rem) appear to be too low and probably the estimates made by Takeshi (1980) of Kyoto University, Nuclear Reactor Laboratory, are closer to fact. The values listed for comparison in Table 6 indicates the wide disparity of risk estimates.

TABLE 6. Estimates Relating to Risk to a Population as a Result of a Nuclear Accident

Type of Risk Due to TMI-2 Accident Estimates	Made by:	Amount of Risk
Probability of Accident	Brookhaven report	10^{-3} to 10^{-4} per reactor year
Probability of Accidents	Rasmussen report	$5\text{x}10^{-6}$ to $5\text{x}10^{-5}$ per reactor year
Actual Risk of Accidents	Calculation: 1acc/300 ry	$3\text{x}10^{-3}$ per reactor year
Noble Gas Released	NRC Staff & Consultants	$1.2\text{x}10^{7}$ Ci
Noble Gas Released	Seo Takeshi	$4.5\text{x}10^{7}$ Ci
Radioiodine Released	NRC Staff & Consultants	16.7 Ci
Radioiodine Released	Seo Takeshi	$6.4\text{x}10^{4}$ Ci
Total Body Dose to Population	NRC Staff & Consultants	1600 to 5300 person rem

TABLE 6 (cont)

Total Body Dose to Population	Seo Takeshi	≥16200 person rem
Thyroid Dose to Population	NRC Staff & Consultants	1060 person rem
Induced Cancers (excluding thyroid)	NRC Staff & Consultants	0.15 to 2.4 cancer deaths
Induced cancers (excluding thyroid)	Author of this paper	15 cancer deaths
Induced thyroid cancers	NRC Staff & Consultants	?
Cost of TMI-2 type accident	Brookhaven reports	< 1,000,000,000 in 1981 dollars
Cost of TMI-2 type accident	Rasmussen reports	< 150,000,000 in 1981 dollars
Cost of TMI-2 type accident	Author of this paper	$>> 10^9$ dollars
Coefficient of fatal cancers	NRC Staff & Consultants	$< 2x10^{-4}$ per person rem
Coefficient of fatal cancers	BEIR-III report	$2x10^{-4}$ to $3x10^{-4}$ per person rem
Coefficient of fatal cancers	Author of this paper	$9x10^{-4}$ per person rem
Coefficient of fatal cancers	Gofman (1981)	$4x10^{-3}$ per person rem
Induced genetic effects	NRC Staff & Consultants	0.06 to 5.44 per person rem

There are numerous reasons in addition to those given by Takeshi why one might doubt the accuracy of release and risk values given by the US-NRC and its consultants. For example, there were 3 monitors off scale in the vent stack in the early period of the accident and others did not operate properly. Their estimates of population dose began at 7:00 a.m. on March 28, 1979, but the accident actually began at 4:00 a.m. and the dose rate from radionuclides of iodine and noble gases of short half life was hundreds of times higher than that of those of long radiactive half life (e.g. initially the activity of Xe-138 was over 400 times that of Xe-133). It is easy to understand why they considered only the 5 noble gases (above the solid line in Table 7) because the environmental program did not get underway before 7:00 to 8:00 a.m. and after 4 hours

TABLE 7. Relative Percents of Kr and Xe at Various Times after Reactor Shutdown

Radionuclides Half-life Yield	Percent Kr and Xe Activity Present at Various Times							
	0h	1h	4h	8h	32h	40h	30d	1y
Xe-133 5.65d 6.62%	0.186	0.957	3.35	6.69	39.97	53.5	98.5	-
Xe-133m 2.2d 0.166%	-	-	-	0.40	1.93	2.48	0.02	-
Xe-135 9.1h 6.3%	2.65	12.65	35.72	53.88	57.9	43.9	-	-

TABLE 7 (cont)

Xe-135m 15m 0.1%	1.53	0.48	-	-	-	-	-	-
Kr-88 2.8h 3.57%	4.87	19.60	33.1	25.19	-	-	-	-
Xe-131m 11.9d 0.025%	-	-	-	-	-	0.11	1.22	-
Kr-85(1) 10.7y 0.293%	-	-	-	-	-	-	0.25	100
Kr-85m 4.5h 1.0%	0.73	3.75	8.38	9.29	0.50	-	-	-
Kr-87 1.3h 3%	8.83	26.7	19.2	4.54	-	-	-	-
Xe-138 17m 6%	81.1	36.1	-	-	-	-	-	-

(1) Percents assuming equilibrium; the actual percents would be somewhat less for Kr-85.

the other radionuclides listed in Table 7 made only a small contribution to the population dose. However, during the first hour they contributed almost all the dose from the radioactive cloud passing over the country side unless there were some unspecified hold up in release at the disabled reactor. Even at the close of this first hour Xe-138, Kr-87 and Kr-85m were contributing 67% of this noble gas dose and after 4 hours Kr-85m and Kr-87 were contributing 28% of this dose. The wind during this period was blowing at about 2 miles per hour in the west and north-west direction or in general toward Harrisburg, the center of which was about 12 miles away. Thus people in the direction of the nearest large city must have received considerable dose from the intense gamma emitting radionuclides Kr-87 and Xe-138 during this early period -- a dose that apparently was not taken into account. Some of the reports suggested the population dose was due mostly to Xe-133 but this was true only if most of the dose was delivered 40 hours or more after 4:00 a.m. on March 28, 1979. Of course, after a few months essentially all the dose from the escaping noble gases was due to Kr-85. Fortunately TMI-2 had operated only a few GWe months at the time of the accident so the Kr-85 inventory was far below saturation. The short lived radioisotopes of iodine present a similar problem to that of the noble gases. Here again the big question is the hold up time provided by the wet and otherwise damaged charcoal filter system. The reports of the NRC consultants state that most of the radioiodine released from the TMI-2 accident was I-131. If there were no appreciable hold up by the damaged filters, the activity of the I-133 (20.8h, yield 6.9) would exceed that of I-131 (8d, yield 3.07) and during the first few hours the activity of I-132, I-133 plus I-135 would be far in excess of that of I-131. Noble gas and radioiodine could have leaked from the TMI-2 facility from a number of places yet the official reports claim no significant release except via the plant vent. The USNRC (1980) concluded "that no relationship can be established between the operation of TMI or the accidental releases of radioactivity and reported health effects" in spite of the fact that of 96 farms containing between 9000 and 10,000 herd of livestock there were 11 farms reporting problems characteristic of radiation sickness. Recent studies (Field, Field, Zegers and Steucek, 1981) however, lead me to question this conclusion of the USNRC and its estimate of only 16.7 Ci of I-131 release. This group measured the I-131 concentration in thyroids of voles trapped at three sites in the vicinity of TMI-2 between April 6 and 16, 1979, (9 to 19 days after the accident) and found I-131 in thyroids of all those animals. These animals are particularly well suited as monitoring "instruments" because they have a very limited home range (< 0.66 ha) and they consume a variety of vegetation equivalent to 1/3 their body weight per day. They found the mean I-131 concentration in the thyroids of voles at the site III (1.9 km from TMI-2) was 1860 pCi/g. Assuming a person had this I-131 concentration I estimate his dose rate would be 4.3×10^{-3} Q = 8 rem/y. Of course, I-129 (1.7×10^{7} y) was at a low concentration in the melted fuel elements because of the short time the reactor had operated. I believe with so many radiation detection instruments paralized from high doses and others operating erratically I cannot accept the claim that there were no significant airborn releases during the first 3 hours of the accident. Federal and state officials acknowledged they could not gauge exactly how much radioactive material escaped to the environment and that there are some unanswered questions about the releases so it is doubtful we will ever know all that went on during these first very critical and hectic 3 hours. Perhaps if more cancers than expected show up in the exposed population 20 to 30 years from now we will have a better answer to some questions being asked. It is unfortunate the first measurements from the air were not made a least within the first hour of the accident. The aerial monitoring of the cloud did not get underway until 4:00 p.m. March 28, 1979, (12 hours after the accident began). Such measurements made early would have told not only where the cloud went but its radionuclide composition and provided a more reliable method of estimating the population dose. We should have learned a lesson from the British during their Windscale accident (October 10, 1957). They found early information provided by flights of small aircraft was very valuable. The TLD meters at 20 TMI stations provided a very unsatisfactory basis for estimating the population dose from a passing cloud of radioactivity. This was especially true since during the first day only 2 of the stations were at any time anywhere near the passing cloud and it was this early radioactive cloud that delivered most of the total body dose to the population. When two TLD meters were placed at the same station, the readings often differed by a factor of two or more and on a given day the TLD readings at various stations differed by factors of several hundred. Thus it is very likely some persons received doses several hundred times that recorded at the 20 stations.

None of the utility TLD's measured the beta dose during the early period. The NRC contractors made a weak effort to estimate the beta dose but mostly that from Xe-133 (β0.346), Xe-133m ($\bar{e}$ 0.198, 0.227), Xe-135 (β0.92, $\bar{e}$ 0.214) and I-131 (β0.806, 0.606) and they estimated the dose at 70 μm below the skin surface. They should have considered the higher energy betas from the noble gas and iodine radionuclides with high beta energies, e.g. Kr-85m (β 0.82), Kr-87 (β 2.8), Xe-138 (β 2.4), I-132 (β 2.12) and I-133 (β1.27). Also, they should have considered the dose at lesser depths where much of the melanin of the skin is located because malignant melanoma, unlike basal cell and squamous cell carcinoma, is the kind of radiation induced skin cancer that has a poor response to medical treatment and is very often fatal. Beta rays of Xe-138 which had the highest of the noble gas activities in the early period, for example, have a range in soft body tissue of about 1 cm or a range in air of about 10 m. Thus they delivered dose not only to the melanon of the skin but to the lense of the eye, some of the lymph nodes and male gonads. Thus cataractagenesis and tumors of the lymph nodes as well as genetic mutations could be the consequence.

If the General Public Utilities is successful in collecting its damage claim of 4 billion dollars from the USNRC, the Rasmussen estimates of cost of a nuclear accident such as that of TMI-2 are off by more than a factor of 25 for this one account alone. Already a consolidated class action complaint filed under the Price-Anderson Act is being settled for $25 million and with the passage of time we can expect individual damage claims to escalate the costs into the billions of dollars. Although this TMI-2 accident was far less severe by orders of magnitude in terms of injuries and deaths than the peak accident hypothecated by the Brookhaven report (1957) (i.e. no acute deaths vs 3400 hypothecated) the final cost may be close to the $10 billion shown in Table 2. It is likely that much of the costs of a nuclear accident will be hidden. For example, electric bills in the TMI-2 area have increased 30 percent and it is reported that Metropolitan Edison Co. has requested a rate hike of $76.5 million and proposed that every consumer of nuclear power throughout the US be billed 10¢ per month to help defray the cost of the accident.

Long Range Risks of a Nuclear Accident

As indicated above there are both the short range and long range causes of damage, inury and death from a nuclear power plant accident. The original Rasmussen report (1975) did not give adequate consideration to the long range dose/effects and especially the contribution by Cs-137 and as a result underestimated the population dose by a factor of 25 as pointed out by the American Physical Society (1975) LWR Safety Study. Fortunately this correction was made in the final report. Because of the relative remoteness of most nuclear power plants I believe the number of injuries and deaths from a major accident will be far greater from the long range effects than from those of short range. Table 8 from the Rasmussen

TABLE 8. Relative Importance of Various Radionuclides for Health Effects Following A Nuclear Power Plant Accident

Radio-nuclide	Early Effects Inhalation							Late Effects Inhalation						
	CD	GD	BM	L	GI	Th	T	GD	BM	L	MB	O	T	Σ
Te-122	1	2	2	2	2	1	2	–	2	2	2	2	2	22
Cs-134	–	–	2	1	–	–	2	2	2	1	2	2	2	16
I-131	1	2	1	1	–	2	1	–	1	1	1	1	1	13
I-133	2	2	1	1	1	1	1	–	1	1	–	1	1	13
I-135	2	2	1	1	1	1	1	–	1	1	–	1	1	13
I-132	2	2	1	1	–	–	1	–	1	1	–	1	1	11
Ba-140	–	1	2	–	2	–	1	–	2	–	1	1	1	11
Cs-137	–	–	1	–	–	–	1	2	1	–	1	2	2	10
Sr-89	–	–	2	–	1	–	1	–	2	–	2	1	1	10

2-Substantial contribution to dose
1-Small but important contribution to dose

CD-Cloud Dose — L-Lung Dose — MB-Mneod Bone Dose
GD-Ground Dose — Gd-GIT Dose — O-Other Dose
BM-Bone Marrow Dose — Th-Thyroid Dose — T-Testes Dose

report (1975) lists the radionuclides that are considered to be of greatest concern both for short and long range consequences. I believe weighting factors much larger than 2 should be given to I-131 and Cs-137 so that they would come first in this listing. Also there are accident scenarios in which relatively large amounts of actinide radionuclides escape into the environment and these could cause very serious environmental contamination lasting over many centuries. Many studies have shown that when these elements contaminate the environment, natural as well as commercial chelating agents in the soil increase their uptake from the soil by roots of plants by orders of magnitude. Even the use of chlorine in water from city reservoirs can increase the human uptake of these radionuclides by two to three orders of magnitude. Standard agricultural practices will not greatly modify the distribution of these elements in the soil, hence they would have only a minor effect upon uptake by crops planted for human consumption. Then too there is the worldwide genetic and somatic problem due to the release of C-14 and H-3 into the environment. The studies of the Heidelberg (1978) group have shown that the USNRC and its consultants, the authors of the Brookhaven and Rasmussen reports and those preparing risk estimates for environmental impact statements of the utilities have in many cases used questionably low and unrealistic values for factors that go into the calculation of dose to man, i.e. transfer from soil into plants, from fodder into animal products, from the GI tract into the blood, from blood into the various body organs and for the biological half lives in these organs. In some cases there may be serious special problems such as Co-58 and Co-60 bound in vitamin B-12 or radioiodine damaging the thyroid of the fetus during its early development. In any case when there are large releases of radioiodine there will be many cases of the thyroid nodules (as shown in Talbe 3), a large number of cases of thyroid diseases leading to some serious consequences and numerous thyroid carcinomas. Among those highly exposed survivors of a nearby major nuclear power plant accident there will be lenticular opecities (some of which may develop into cataracts), chromosomal aberrations in the peripheral blood lymphocytes, impairment of growth, microcephaly, mental retardation and an increase in all forms of cancer with the possible exception of chronic lymphatic leukemia. Many of the cancers will be benign and about half of the cancers will respond successfully to medical treatment but all can be costly in terms of medical bills and suffering and expensive law suits. The peak period for maximum anomalies from exposure to the fetus is about age 20 to 25 days. Unfortunately, some women may not realize they are pregnant during the period of maximum radiosensitivity of the human. Some have criticized the governor of Pennsylvania for calling for evacuation of pregnant women living nearby during the TMI-2 accident but I feel this was a very wise move and after many costly cases have been settled in court I suspect these same critics will abrade the governor for not calling the evacuation earlier after 4:00 p.m. on March 28, 1979.

One type of damage that is seldom considered is psychological in nature (e.g. anxiety, stress, mental breakdown, suicide). A $375,000 stress survey of pregnant mothers during the TMI-2 accident has shown this to be a matter of considerable important and the insurance companies may hear more from these mothers in the days ahead.

There have been many reports addressing the generic question of risks associated with accidents at nuclear power plants. One of these reports which I found of particular interest and value was prepared by Beyea (1979) of the Program on Nuclear Policy Alternatives at Princeton University. This report considers the TMI-2 accident where releases were of various hypothetical magnitudes as indicated in Table 9. This report is of great interest because it indicates what we might expect in terms of long term consequences if a TMI-2 type accident were to progress to various stages of severity. The higher risks are related almost entirely to higher releases of radioactive cesium.

TABLE 9. Some Long-Term Consequences of Hypothetical Accidents at Three Mile Island[a]

(Not including any early illness or deaths which might be associated with high doses to unevacuated population a few tens of miles from the reactor.)

Accident Designation	Releases to Atmosphere	Delayed Cancer Deaths[b,c] low / high	Thyroid Nodule Cases[c,e] low / high	Temporary Agricultural Temporary Agricultural Restrictions	Areas Requiring Decontamination or Long-term Restrictions
TMI-0	10% of noble gases (similar to actual accident)	0 / 4	-	0	0
RELEASES GREATER THAN ACTUALLY OCCURRED					
TMI-1	60% of noble gases	1 / 25		0	0
TMI-2	5% Iodines plus 60% noble gases	3 / 350	200 / 27,000	25,000 mi^2 g)	0
TMI-3a	TMI-2 plus 10% of CE	15 / 2000	200 / 27,000	25,000 mi^2 g)	75 mi^2
TMI-4a	50% of Ce k)	100 / 12,000		3,700 mi^2 h)	650 mi^2
TMI-5a	"PWR2" Release with	200 / 23,000	3,500 / 450,000	175,000 mi^2 g)	1400 mi^2
CONSEQUENCES ASSUMING THE REACTOR CORE HAD BEEN IN OPERATION FOR MUCH LONGER THAN 3 MONTHS (MATURE CORE)					
TMI-3b	TMI-2 plus 10% of Ce	65 / 8500	200 / 27,000	25,000 mi^2 g)	550 mi^2
TMI-4b	50% of Ce k)	440 / 48,000		18,000 mi^2 h)	4300 mi^2
TMI-5b	"PWR2" Release i) 70% I Release	550 / 60,000	3,500 / 450,000	175,000 mi^2 g)	5300 mi^2

Footnotes for Table 9

a) All accidents are assumed to take place under "typical" meteorological conditions. Wind shifts and changes in weather neglected. Health effects are totalled for people living beyond 50 miles.

b) Cumulative total over a 75 year period after the accident. The range of genetic defects would be equal, very roughly, to the range of delayed cancer deaths.

c) The low number is for the most favorable wind direction (Eastern Maryland), assuming the most optimistic coefficient relating dose to health effects, and

and evacuation out to 50 miles. (Without evacuation, the low number would be a factor of 2-5 higher depending on the accident.)

The high number is for the least favorable wind direction (N.Y.C./Boston) and assuming the most pessimistic coefficient relating dose to health effects. (Evacuation is also assumed out to 50 miles, but has a small impact on the high results.)

d) Reduce high value by a factor of about 4 to obtain the prediction which would result using the Rasmussen Study Model. Multiply by 4 to obtain the prediction which would result using health effects coefficients based on data of Mancuso, Stewart and Kneale.
e) Cumulative total over a 25 year period after the accident. A blank entry implies a small number.
f) Details given in reference report, Beyea (1979).
g) Milk restrictions (Beyea 1979). Much of this area would be water for a wind from the west.
h) First year crop restrictions. (Harvested food not suitable for children.) Much of this area could be water for a wind from the West.
i) A PWR2 accident as defined in the Rasmussen (1975) Study. A core melt with breach of containment due to overpressure.
j) This number possibly could be reduced in half if massive decontamination or relocation efforts were undertaken in urban areas to avoid low-level radiation doses.
k) Assumes only Cs released to emphasize that Cs dominates long term consequences.

Genetic Consequences of a Nuclear Power Plant Accident

The evaluation of genetic damage resulting from a nuclear power accident has been almost neglected in the various accident reports and I will have very little to say about it here because I like the others realize how little we know in a quantitative sense about the genetic risks from radiation exposure of a human population. Beyea in Table 9 note (b) simply states the genetic defects would about equal the number of delayed cancer deaths. I react strongly against statements of some nuclear advocates who imply the genetic risk is negligible by reminding us that no genetic effects have been observed among the offspring of survivors of atomic bombings of Hiroshima and Nagasaki. First of all the population is too small and the time too short and second, there have been some observed genetic effects. The sex ratio change was in the direction one would expect (i.e. more daughters than sons of exposed fathers) but the results so far (1974), are not of statistical significance. The Neel-Kato-Schull (1974) study examined dominant genetic diseases among these Japanese survivors; diseases which may be expected to cause death early in life in children before the age of 17. They found a very significant elevation in these diseases among children whose parents received radiation exposure. Several animal studies have indicated an increase in chromasomal aberrations where both rearranged chromosomes do not have the normal gene content. This can result in genetic mutations of equal or greater genetic damage than those resulting from single gene mutations. Down's syndrome resulting from an extra representative of chromosome 21, has been reported in some studies of human populations to relate to exposure to ionizing radiation. If we are concerned about the quality of the human race, we should be most concerned about the non-visible mutations; mutation which cannot be easily detected in animal studies but which relate to man's superior abilities, his originality, his resilience, his mental vigor, etc. It was this kind of radiation damage that mostly concerned Dr.

Muller (1964), the great geneticist. Perhaps at the present time there is no better source of information for estimating the genetic risk from exposure to ionizing radiatin than the BEIR-III (1980) report. The reader is referred also to BEIR-I (1972) and the UNSCEAR report (1972) for detailed information. Many of our common diseases relate to our genetic inheritance and so any contribution radiation exposure makes either to dominant or recessive mutations places a serious added burden on our children and on future generations. Some of the values of genetic risk given in the above reference reports have been reduced by as much as a factor of 10 to take advantage of the lower risk estimates at low doses and low dose rates. However, one should be cautious in using these reduced values because some publications (Lyon 1972) suggest these reductions are not warranted and they certaintly would not be applicable in cases of high exposure and high dose rates. The BEIR-III report adopts rather arbitrarily the overall genetic risk coefficient of 0.004 to 0.02 genetic mutations per rem or a doubling dose of 50 to 250 rem. Thus if this is applicable to the estimated total body population dose due to the TMI-2 accident this would correspond to (1600 to 16,200) x (0.004 to 0.02) or 6.4 to 324 genetic mutations introduced into the population by this accident. Table 3 from the Rasmussen report indicates the probability of a nuclear power plant accident which causes 100 genetic effects is only 1.5 x 10^{-8} per reactor year and one causing 10 genetic defects has a probability of 3.5 x 10^{-6} so again the Rasmussen report does not seem to find confirmation within many orders of magnitude.

Consideration of the genetic risks becomes especially important in terms of genetic damage to the world population in the case of H-3, C-14 and P-32 which are incorporated in DNA in the germ cells. Here transmutation to other elements in the cell neucleus (i.e. H-3 to He-3, C-14 to N-14 and P-32 to S-32) as well as local ionization contribute to the genetic damage.

The Risk of Radiation Induced Cancer

Perforce, during the early period most of the studies on the effects of low-level exposure were conducted on inbread animals rather than on man. These animal studies in many cases grossly underestimated the cancer risk to man because of the greater radiosensitivity of man, because man is a heterogenous animal and because many types of cancer have long incubation periods that are longer than the life span of most experimental animals; cancer incidence, of course, relates to time since a given exposure and not fraction of life span. Most human studies cover periods less than ten to twenty years, so additional cancers appearing after completion of a study can only increase the risk estimate. In recent times it has been possible to conduct a limited number of extensive epidemiological studies of humans exposed to low levels of radiation (Oxford in utero x-ray exposure studies of Stewart and Kneale (1970); studies of Modan Baidatz, Mart, Steinitz, and Levin (1974) of persons whose scalps were x-rayed for ringworm; studies of Hanford radiation workers by Mancuso, Stewart and Kneale (1977); etc.). These studies reveal a cancer risk that is ten to fifty times the risk suggested from many of the animal studies or as indicated by studies of survivors of atomic bombings of Hiroshima and Nagasaki and of ankylosing spondylitis patients treated with x-rays.

The folly of placing reliance on animal experiments was emphasized by a study of Shields Warren and Gates (1971). They exposed two strains of mice to identical regimes of x-ray doses. In one strain there was a high incidence of leukemia and significant life shortening while in the other strain of mice there was hardly any observable effect.

Unfortunately, the standards-setting bodies have accepted two human studies (i.e., Japanese bomb survivors and spondylitis patients) as though they were the inspired word and have not attempted to evaluate the dose esimtates or to examine their serious biases I (Morgan 1981) believe the dose to the Japanese survivors was ~~at least twice~~ one half that assumed in the BEIR-III report (1980). Thus the cancer risk estimate must be increased. The most significant of the biases introduced by the standards-setting bodies and especially by the BEIR-III report and our recent General Accounting Office (GAO), (1981) report result from failure to account for after-effects of fire, blast and a traumatic situation faced by the Japanese survivors. The physical injuries along with concomitant pain and mental anguish resulted in a weakening of the immune (reticuloendythelial) system such that they could no longer fight off the ravages of common diseases; as a result many died early before cancer manifest itself. The weaker members who already had a large probability of developing cancer or had cancer in stiu were the first to die of common diseases. Many of those who survived these early diseases succumbed later to cancer; leukemias reaching a peak incidence during a period of six to eleven years. Later, and even now, all other types of malignancy (with the exception of chronic lymphatic leukemia) have been on the increase. A somewhat similar bias exists in the case of patients with ankylosing spondylitis. These are sick persons suffering with a painful and serious disease such that studies of Radford, Doll and Smith (1977) indicate they too die early of common diseases--during the usual latency period of most cancers. Kneale and Stewart (1978a, 1978b) have shown that persons with in situ cancer have a propensity, a large cross section for, or are in grave danger of dying from secondary infections and accidents before malignancies are diagnosed clinically. This is shown to result from the fact that the precancer state is associated with lowered immunological competence.

There are, of course, ways of correcting the biases from fire, blast, etc., but this was not done in the case of Hiroshima and Nagasaki. Mortality patterns have been studied in a number of cities following ordinary bombing, fires, floods, earthquakes, etc. In many cases the increased death rate from common causes in the year following the disaster was much greater than during the year before it, and in every case the death rates were higher among the weaker segments of the population. It is difficult to appreciate the fact that the national and international standards setting bodies have leaned over backwards to try to depreciate and discredit the Mancuso-Hanford study (Mancuso, 1977) where the dosimetry was the best in existence anywhere and did not faret out large errors in dosimetry in the Japanese data (their hallmark reference). In addition, even the critics agreed there was a singificant increase of two malignancies--cancer of the pancreas and multiple myeloma relating to Hanford radiation exposures.

In the simple case, risk of cancer from low-level exposure to ionizing radiation may be given by the relation $P(d) = a + bd^k$ in which $P(d)$ is the probability of succumbing to a malignancy from a dose d(rem), and a, b and k are constants. When $k = 1$ we have the linear hypothesis, when $k > 1$ we have the threshold hypothesis (because at low doses the error bars overlap the abscissa), and when $k < 1$ we have the superlinear hypothesis. Baum (1978) was one of the first of a number of researchers to show that $k < 1$, or the superlinear relation gives the best fit for a number of malignancies among the survivors of Hiroshima and Nagasaki bombings (i.e., $k = 0.5$ for all malignancies at Hiroshoma; $k = 0.8$ for acute leukemia at Nagasaki, $k = 0.86$ for leukemia at Hiroshima, and for the combined cities $k = 0.19$ for lung cancer, $k = 0.35$ for stomach cancer and $k = 0.5$ for female breast cancer. It should be noted that since recent investigations (Morgan, 1981) show the dose to the Japanese bomb survivors was less than assumed by Baum and by BEIR-III (1980) and GAO(1981) Committees, the values of K are less than the values shown above or superlinearity in now more pronounced. A series of papers (Baum, 1973;

Parker, Belsky, Yamamoto, Kawamoto and Keehn, 1973; Silverman and Schmitz-Feuerhake, Muschol, Batjer and Schafer, 1978) strongly suggests that the induction of thyroid carcinoma at low doses of ionizing radiation is more serious than was thought a decade ago and that $k < 1$, or it too may be best represented by a superlinear relation to dose.

In their analysis of the ankylosing spondylitis data on x-ray induced leukemia the GAO (1981) concluded, "All mixed models tested did much better than the linear model, and the unusual square root-cubic model did the best of all." Since at doses less than 100 rem their cubic term contributed $< 1\%$ to the cancer risk, $P(d)$, this means that at low doses the best fit related to $k = 0.5$ or $P(d) \propto$ d. The GAO (1981) report concluded that for the Japanese survivors, "Dose-response curves that were square root, linear, quadratic or cubic at low levels all gave acceptable fits for at least one set of data" and that "highly sensitive groups at low doses could lead to dose-response curves for the entire population that show larger effects per rad at low than at high doses", i.e., a superlinear relationship. The BEIR-III (1980) Committee stated, "the existence of exquisitely sensitive subgroups of suitable size conceivably would produce a dose-response curve that showed a greater effect per rad at very low doses than at high." I believe there is strong evidence from studies of Bross (1972) and others for the existence of such radiosensitive subgroups in a heterogeneous population of humans that may not be apparent in a group of the usual homogeneous inbred animals that are studied to find dose-effect relationships and that the results of such animal studies can and have led to false assumptions about human populations.

Many scientists in examining the information on the effects of low level exposure to ionizing radiation have concluded the coefficient of risk of cancer as used by the standards setting bodies and as applied in the foregoing discussion are too low. I agree with these scientists but in view of poor statistics in most cases and biases and errors in dosimetry that have not been corrected I am unable to fix firmly on a specific number at this time. For the present, however, I am using the general value applied to a mixed population of 9×10^{-4} lethal cancers per person rem and twice this number for the total cancer risk. Gofman (1981) makes an excellent review of the cancer risk in man and arrives at 3.8×10^{-3} lethal cancers per person rem. The value from the Hanford Stduies is slightly larger ($\sim 7.5 \times 10^{-3}$ lethal cancers per person rem) Government officials in the US used the lowest risk estimate they could find (1×10^{-4} lethal cancers per person rem) immediately after the TMI-2 accident presumably to "play down" the risks. If the super linear relationship holds to every low doses, the risk of small increments to population dose may be even greater than the Hanford value. Unless man is to have the burden of proof for his own safety, we cannot afford to use a smaller value than 9×10^{-4} lethal cancers per person rem.

REFERENCES

American Physical Soc. (1975). Study group on light water reactor safety. Rev. Modern Phys. 47, Suppl. 1

Baum, J. W. (1973). Population heterogeneity hypothesis on radiation-induced cancer, Health Physics 25, 97

BEIR Report (1972). The effects on populations of exposure to low levels of ionizing radiation. National Research Council. Washington, D.C.

BEIR Report (1980). The effects on populations of exposure to low levels of ionizing radiation. National Research Council. Washington, D.C.

Bertini, H. W. (1980). Descriptions of selected accidents that have occurred at nuclear reactor facilities. Oak Ridge Nat. Lab. ORNL/NSIC-176

Beyea, J. (1979). Some long-term consequences of hypothetical major release of radioactivity to the atmosphere from Three Mile Island. Program on Nuclear Policy Alternatives, Princeton Univ., Princeton, NJ

Brookhaven (1957). Theoretical possibilities and consequences of major accidents in large nuclear power plants. A report prepared by staff members of Brookhaven National Laboratory and its consultants. USAEC-WASH-740

Bross, I. D. J. (1972). Leukemia from low-level radiation, New England J. Med., 287:107

Field, R. W. , E. H. Field, D. A. Zegers and G. L. Steucek (1981). Iodine-131 in thyroids of the meadow vole (microtus Pennsylvanicus) in the vicinity of TMI nuclear generating plant. Health Phys. 41, 2, 297

GAO Report to the Congress of the U.S. (1981) Problems in assessing the cancer risks of low-level ionizing radiation exposure. 2

Gofman, J. W. (1981). Use of Gofman's doubling dose estimating low-level radiation risk and response. Health Phys. 41, 1, 204

Heidelberg Study (1978). Radiological assessment of the WYHL nuclear power plant. Dept. of Environmental Protection of Univ. of Heidelberg, Germany

Kneale, G. W. and A. M. Stewart (1978). Precancers and liability to other diseases. Br. J. Cancer

Kneale, G. W.; A. M. Stewart; and T. F. Mancuso (1978). Reanalysis of data relating to the Hanford Study of the cancer risk of radiation workers, International Atomic Energy Agency Conference, Vienna, Austria

Lyon, M. F.; D. G. Papworth and R. J. S. Phillips. Dose rate and mutation frequency after irradiation of mouse spermatognia. Nature New Biol. 238, 101

Mancuso, T. F.; A. M. Stewart; and G. W. Kneale; (1977) Radiation exposure of Hanford workers dying of cancer and other causes. Health Physics 33, 5, 369

Modan, B; D. Baidatz; H. Mart; R. Steinitz; and S. G. Levin; (1974) Radiation-induced head and neck tumors. Lancet, 23, 277

Morgan, K. Z.; W. S. Snyder and M. R. Ford (1964). Relative hazard of the various radioactive materials. Health Phys. 10, 151

Morgan, K. Z. (1981). Radiation dosimetry. Science 263, 4508, 604

Muller, H. J. (1964) Radiation and heredity. Amer. J. Public Health, Sup. Vol. 51, 1

Neel, J. V.; H. Kato and W. L. Sehull (1974). Mortality in the children of atomic bomb survivors and controls. Genetics 76, 311

Parker, L. N.; J. L. Belsky; T. Yamamoto; S. Kawamoto; and R. J. Keehn (1973). Thyroid carcinoma diagnosed between 13 and 26 years after exposure to atomic radiation, ABCC-Tech. Report 5-73

Pigford, T. H. (1974). Radioactivity in plutonium, americeum and curium in nuclear reactor fuel. Univ. California, Berkeley, CA

Radford, E. P.; R. Doll; and P. G. Smith (1977) Mortality among patients with ankylosing spondylitis not given X-Ray therapy, New Eng. J. of Med. 296, 11, 572

Rasmussen, N. C. (1975). Reactor safety study. An assessment of accidental risks in US commercial nuclear power plants. USAEC-WASH-1400

Schmitz-Feuerhake; E. Muschol; K. Batjer and R. Schafer (1978). Risk estimation of radiation-induced thyroid cancer in adults. IAEA-SM-224/712

Silverman, C. and D. A. Hoffman (1975). Thyroid tumor risk from radiation during childhood, Preventive Medicine 4, 100

Stewart, A. M. and G. W. Kneale (1970). Radiation dose effects in relation to obstetric X-Rays and childhood cancers. Lancet, 1186

Takeshi, S. (1980). NRC's gross underestimation of the radioactive releases and population doses during the TMI-2 accident. Kyoto Univ. Nuclear Reactor Laboratory.

U. S. Nuclear Regulatory Commission (1980). Investigations of reported plant and animal health effects in the Three Mile Island area. USNRC-NUREG-0738 and USEPA-EPA600/4-80-049

USNSCEAR Report (1972). Ionizing radiation: levels and effects. UN, New York

Warren, S. and O. Gates (1971) The Inclusion of leukemia and life shortening of mice in continuous low-level externals gamma radiation. Rad. Res. 47, 480

12

ASSOCIATION INTERNATIONALE DE RADIOPROTECTION
INTERNATIONAL RADIATION PROTECTION ASSOCIATION

IV[e] CONGRÈS INTERNATIONAL
IVth INTERNATIONAL CONGRESS

RECUEIL DES COMMUNICATIONS

VOLUME 2 - Mardi 26 avril
et mercredi 27 avril

PROCEEDINGS

VOLUME 2 - Tuesday April 26th
and Wednesday April 27th

PARIS 24-30 AVRIL 1977

N° 451

THE LINEAR HYPOTHESIS OF RADIATION DAMAGE APPEARS TO BE NON-CONSERVATIVE IN MANY CASES

Karl Z. Morgan
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332, USA

The purpose of this paper is to express a word of caution to those members of the International Radiation Protection Association (IRPA) and to members of the International Commission on Radiological Protection who seem to believe our present levels of maximum permissible dose (MPD) for occupational workers and dose limits (DL) for members of the public are unnecessarily low and should be increased. At the same time, I would caution persons in the United States who are advocating that present levels should be reduced by an order of magnitude. Likewise, I wish to discourage some members of IRPA from repeating their claim that the linear hypothesis, upon which we base our present radiation protection standards, is overly conservative.

I believe present values of MPD are satisfactory, but only because in industry and in the vast majority of nuclear energy programs these values are considered as upper limits so that on the average exposure to radiation of workers does not exceed 10% of MPD. This practice has developed as a result of the principle of ALARA (exposures As Low As Reasonably Achievable). Were the day to come when occupational exposures are averaging 50 to 80% of the MPD, I would be first to urge a reduction in present MPD. In this connection, I deplore the fact that some nuclear power plants and fuel reprocessing plants in the United States have ignored the principle of ALERA, have adopted the practice of "burning out" employees by using "expendable" temporary employees, and have exceeded 1000 man-rem/y at some of the power plants. It is unfortunate, also, that for the most part the medical profession ignores the principles of ALARA for patient exposures. I do not believe, however, that the solution to these problems is to lower MPD and DL by an order of magnitude, for then many health physicists would feel obligated to reduce exposures to 1% or less of our present values; this could deprive us some great benefits that can be expected from proper use of ionizing radiation. For example, I believe present average occupational exposure of 5 to 10% MPD = 250 to 500 mrem/y to total body does not present an unreasonable or unusual occupational risk. We might expect this risk to be of the order of $500 \times 10^{-3} \times 3 \cdot 10^{-4}$ c/rem $\times$ 40 y = 6 chances of cancer from occupational exposure per 1000 radiation workers. The long range genetic risk would be about the same magnitude as somatic risks, and I consider this acceptable in comparison with risks in safe occupations. However, I would consider a 6% cancer plus a 6% genetic risk too high. I feel the same about not changing population DL so long as present practice limits this on the average to less than 10%.

With the demise of the treshold hypothesis, the linear hypothesis has gained acceptance as the basis for setting radiation protection standards and this has led some health physicists to decry its use and make incorrect claims: 1) The linear hypothesis holds only in the high dose range, 2) There are no human exposure data indicating radiation damage due to low doses (ionizing or non-ionizing), and 3) The linear hypothesis is always overly conservative in the low dose range.

Regarding claim number 1, just the opposite is true. In the high dose range the linear hypothesis always breaks down because one cannot cause deaths in over 100% of exposed population and a maximum effect is reached at some intermediate dose because at higher doses the animals do not survive long enough to die of effects under study. It is true that for low LET radiation the linear hypothesis is often conservative for low doses administered to animals because time is allowed for cell repair and cell replacement. However, studies of production of leukemia as a result of in uteral x-ray exposure[1,2], and exposure to young people[3,4,5], as well as some studies on old animals, suggest that very young and very old members of a population are radiosensitive and the linear hypothesis, as applied to them, is non-conservative even for low LET radiation. Many evaluations of[6,7,8,9,10,11] cancer production from high LET radiation of humans as a consequence of body burdens of radium indicate that if there is departure from the linear hypothesis in the low dose range it is in the direction of more cancers produced per rad at low doses than at high doses and that protraction[12] of time over which dose from ^{224}Ra is delivered to patients increases rather than decreases the risk of cancer.

Regarding claim number 2, there are many publications reporting harmful effects of low exposures to both ionizing[1,2,3,4] and non-ionizing[13,14] radiations, so I can only conclude those who repeatedly claim such data do not exist must completely discount the validity of such studies. I do not agree that findings of these studies can be ignored and believe the validity of some of the findings is sufficiently substantiated that we must take seriously enforcement of the principle of ALARA.

It is easy to understand why there are adherents to claim 3, and why many disciples of the old threshold hypothesis are reluctant to abandon belief that if one does not exceed a threshold dose there is no risk of radiation damage, or if the dose is kept below a threshold value, the rate of repair can keep pace with the rate of damage produced. It is true in many cases, and especially for low LET radiation, the rate of repair may keep up with the rate of damage. In some cases also the average incubation period for certain malignancies may be longer than expected remaining life. However, we should not take too much comfort in such observations because each person differs in response to radiation such that the only safe assumption is that no dose can be so low that the probability of radiation damage is zero.

Generally accepted theories of damage lead to the conclusion that a given type of radiation damage from a given type of exposure is simply a matter of chance. By this we mean that of the millions of photons and alpha particles that loose energy in an organ of our body each day; there is always the remote chance that one of these will damage a cell in such a way that it survives, but only to reproduce itself in its perturbated form and that in time there developes a clone of perturbated cells which is identified as a malignancy. The fact that there is no "safe" level of radiation exposure is not a unique type of risk--we all know, for example, there is never a trip in a Paris taxi that is "safe."

Now that we have discarded the threshold hypothesis, let us summarize reasons why in some cases use of the linear hypothesis to estimate risk at low doses is not a conservative assumption as follows:

1. Overkill at high doses. Most estimates of risk from radiation exposure are based on linear extrapolation of effects at high doses down to zero dose. Often with such extrapolation insufficient account is taken of overkill and that in no case can more than 100% of the animals be killed by radiation. Sometimes one simply determines the best least-squares line which will pass through the (0,0) point. Some points used in determining the slope of this line may be on the bend of the curve where the animals are injured by large doses of radiation such that they do not survive long enough to die of the effect under study.
2. Short follow-up period of human studies. Most studies[15] of effects

of ionizing radiation on man extend over only a small fraction o. his life span. If one determines the slope of curve of thyroid carcinoma risk vs x-ray dose and the followup period is only 7 years; studies of population until all have died would increase the slope of curve and risk estimate.

3. Fractional life span animal studies. Sometimes comparisons are made between fetal damage during first trimester of a mouse and damage we might expect during first trimester of a woman, or a comparison is made over life of animals having a life span of 20 years with expected effects over life span of man. Since in many cases damage from radiation exposure may relate more closely to what happens in a given number of years following exposure rather than what happens over a certain fraction of the animals' life span, such extrapolations to man can only lead to underestimates of risk.

4. Radiosensitivity differs among animal species. Many studies have emphasized the risk of extrapolating data on effects of radiation exposure from one animal to another or to man. Differences in metabolism, turnover rate, GI tract uptake, skin perspiration, blood circulation, mitotic index, etc., can have a marked effect on animal response to a given dose of ionizing or non-ionizing radiation. An examination of data leads me to conclude that more often than not this kind of extrapolation to man results in an underestimation of risks.

5. Heterogeneity of human population. The vast majority of studies of effects of radiation exposure are carried out with imbred animals. Radiation ecology programs must be extended to animals in the wild if we are to simulate effects we expect from low doses to human populations. Studies of Bross[16] have indicated that risk of leukemia as a consequence of in utero x-ray exposure increases by 5000% if the child had diseases such as asthma, hives, eczema, allergy, pneumonia, dysentary or rheumatic fever compared with the child without this exposure and history of such disease. In accessing population risk of low levels of exposure we need to know dose response for young and old, male and female, sick and well, fat and slim, the person of average eating habits and the one with peculiar eating habits, etc. When we have such data, our estimates of risk from low level exposure will increase.

6. Cell sterilization. It is well established that as old age is approached, the percent of abnormal cells in the body increases; for example, the percent of chromosomal aberrated cells increases with age of an animal. It is commonly believed that some types of malignancies develop as a result of a series of changes that take place in the 46 chromosomes that comprise the nucleus of a normal somatic cell in man. Sometimes certain of these changes may be the result of genetic mutation conveyed from one's parents. Thus, we have a scattering of cells and clones of cells which have one or more abnormalities, and may present a much larger cross-section for the production of a malignancy than a normal cell. It may be that the etiology of cancer is similar to throwing of a series of switches such that cancer cannot develop unless all switches are thrown. Children born in a family with one of "switches" thrown genetically have a higher cancer risk than average children and persons who have been exposed to higher levels of carcinogens have more high cross-section cells that are likely targets for the origin of a malignancy. When studies are conducted on animals exposed to high doses of radiation, cell sterilization may take place such that many cells that are likely targets for development of a malignancy are destroyed. Thus, such data points at high exposure levels would tend to reduce the slope of the curve that is extrapolated to zero dose

and may result in an underestimate of risk at low levels of exposure.

REFERENCES

(1) STEWART, Alice, KNEALE, G.W., "Radiation Dose Effects in Relation to Obstetric X-Rays and Childhood Cancers," Lanaet, 1185 (June 6, 1970)

(2) BROSS, I.D.J., NACHIMUTHU, N., "Leukemia from Low Level Radiation," New England Journal of Medicine 287, 107 (July 20, 1972)

(3) MODAN, B., BAIDATZ, D., STEINITZ, R. LEVIN, S.G.,"Radiation-Induced Head and Neck Tumors," Lancet, 277 (February 23, 1974)

(4) SILVERMAN, Charlotte, HOFFMAN, D.A., "Thyroid Tumor Risk from Radiation During Childhood," Preventive Medicine 4, 100 (1975)

(5) BOICE, J.D.,Jr., MONSON, R.R., "Breast Cancer Following Repeated Fluoroscopic Examinations of the Chest," Bureau of Radiological Health, PHS, HEW, Rockwille, MD 20857, (December 1976)

(6) GOFMAN, J.W., TAMPLIN, A.R., "The Question of Safe Radiation Tresholds for Alpha Emitting Bone Seekers in Man," Health Physics 21, 47, (1971)

(7) BAUM, J.W., "Population Heterogeneity Hypothesis on Radiation Induced Cancer," Health Physics 25, 97 (August 1973)

(8) BROWN, J.M., "Linearity vs. Non-Linearity of Dose Response for Radiation Carcinogenesis," Health Physics 31, 231 (September 1976)

(9) LANDAU, E., "Health Effects of Low-Dose Radiation: Problems of Assessment," Intern. Journal Environmental Studies 6, 51 (1974)

(10) HOLFORD, R.M., "The Relation Between Juvenile Cancer and Obstetric Radiology," Health Physics 28, 153 (February 1975)

(11) CRAIG, A.G., "Alternatives to the Linear Risk Hypothesis," Health Physics 31, 81 (July 1976)

(12) MAYS, C.W., SPIESS, H., GERSPACH, "Skdetal Effects Following ^{224}Ra Injections into Humans," Symposium on Biological Effects of Injected ^{224}Ra and Thorotrast, Alta, Utah, (July 21-23, 1974)

(13) WORLD HEALTH ORGANIZATION. et.al., "Biologic Effects and Health Hazards of Microwave Radiation," Proceedings of an International Symposium-Warsaw 15-18 October 1973, Warsaw Poland: Polish Medical Publishers, (1974)

(14) CARPENTER, R.L., "An Experimental Study of the Biological Effects of Microwave in Relation to the Eye," (RADC-TDR-62-131) Griffiss Air Force Base, New York; Rome Air Development Center; (February 1962)

(15) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, a report of the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR-Report), National Academy of Science, NRC page 89, (November 1972)

(16) BROSS, I.D.J., "Proceedings of the Congressional Conference on Low Level Radiation," Senate Office Building, Washington, D.C., (May 4, 1976)

COMPARISON OF RADIATION EXPOSURE OF THE POPULATION FROM MEDICAL DIAGNOSIS AND THE NUCLEAR ENERGY INDUSTRY*‡

by

Karl Z. Morgan**
Neely Professor
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332
U.S.A.

Linear Vs. Threshold Hypothesis

All chronic forms of radiation damage with the possible exception of radiation-induced cataracts appear to increase more or less linearly with the accumulated dose of ionizing radiation. Even in the case of cataracts, the International Commission on Radiological Protection (ICRP)[1] points out, "Possibly no one has sought to see if senile cataract in man is augmented or accelerated by exposure to radiation, and a synergistic interaction of radiation and age must remain a possibility until the investigation is made." Although there is known to be some repair of both genetic and somatic forms of radiation damage (at least in the case of x, γ and β radiation), there appears to be some component of damage which is irreparable and accumulates throughout the life of the individual in proportion to the integrated dose. When radiation passes through a cell of the body, three things are possible: (1) it passes through without any energy loss; (2) sufficient energy is lost to cause the death of a cell or at least to prevent it from further cell division, and (3) the cell is damaged in such a way that it survives and may become the precursor of a malignancy or some other form of chronic damage or may be repaired. We have no concern about the death of a few thousand cells because they are readily replaced. Each somatic cell of our body contains a nucleus which normally has 46 chromosomes, and each of these might be thought to represent an immense library of information, giving instructions to the cell regarding not only all the actions it must take in the future but actions of many successive generations of daughter cells. When ionizing radiation has passed through this nucleus or library of information of a surviving cell, more commonly the damage is so slight that it is repaired or the body is able to tolerate the aberration. It is only

*Presented at the American Nuclear Society meeting, Las Vegas, Nevada, June 18-22, 1972.
‡Work sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.
**Formerly Director, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

in the exceptional case that serious damage or disorder is introduced into this library of information in the nucleus of the cell such that it is still able to survive and reproduce but without adequate instructions for future cell division. Thus, we believe radiation tends to increase the entropy of the system, and on this type of reasoning it is difficult to imagine how all radiation damage could be completely reparable. Having examined the vast amount of experimental evidence of the effects of radiation on many forms of living organisms, including man, the International Commission on Radiological Protection and the National Council on Radiation Protection have concluded that the only prudent assumption is that there is a linear relationship between dose and effect, and all exposure to ionizing radiation even at the level of maximum permissible exposure involves some risk. In other words, no dose of ionizing radiation can be so low that the probability of damage--even serious damage such as leukemia--is zero. However, the ICRP[2] states that in its best judgment the probability of severe somatic or genetic injuries at recommended permissible exposure levels is negligible, and any effects which ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities, and any severe somatic injuries resulting from exposure to individuals at the permissible exposure levels would be limited to an exceedingly small fraction of the exposed group, and effects such as shortening of life-span which might be expected to occur more frequently would be very slight and would be hidden by normal biological variations. Fig. 1 gives the coefficients suggested by ICRP[1-3] for chronic forms of damage to man which are assumed to relate linearly to the dose, and, in addition, I have plotted curves for radiation sickness and acute radiation death. These latter two curves become asymptotic to the ordinate at about 20 and 200 rem, respectively. The mid-lethal dose (50% lethality) is thought to occur in man at about 400 rem, and at high doses all the curves reach saturation. The curves for radiation sickness and radiation death apply only to the case where large doses are delivered over a short period of time, whereas the other curves apply to relatively low doses and dose rates. Because of very limited information relative to the effects of ionizing radiation on man, the values of coefficients given in Fig. 1 must be considered only as first approximations. Table 1 summarizes some of the types

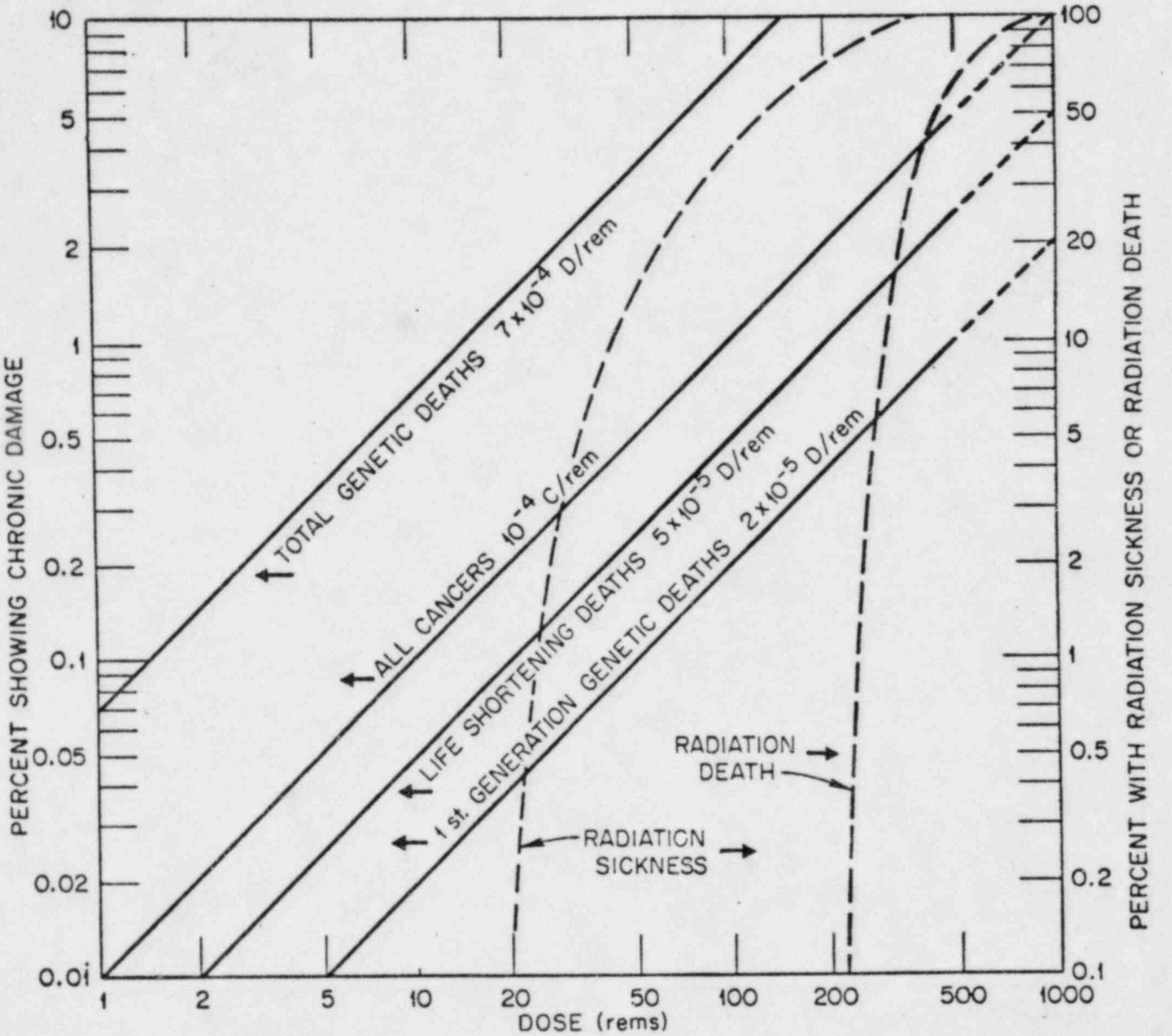


FIG. 1

Linear Relations Between Dose and Effect for Chronic Forms of Radiation Damage to Man and the Commonly Assumed Threshold Relationships to Dose in the Cases of Radiation Sickness and Radiation Death.

TABLE 1

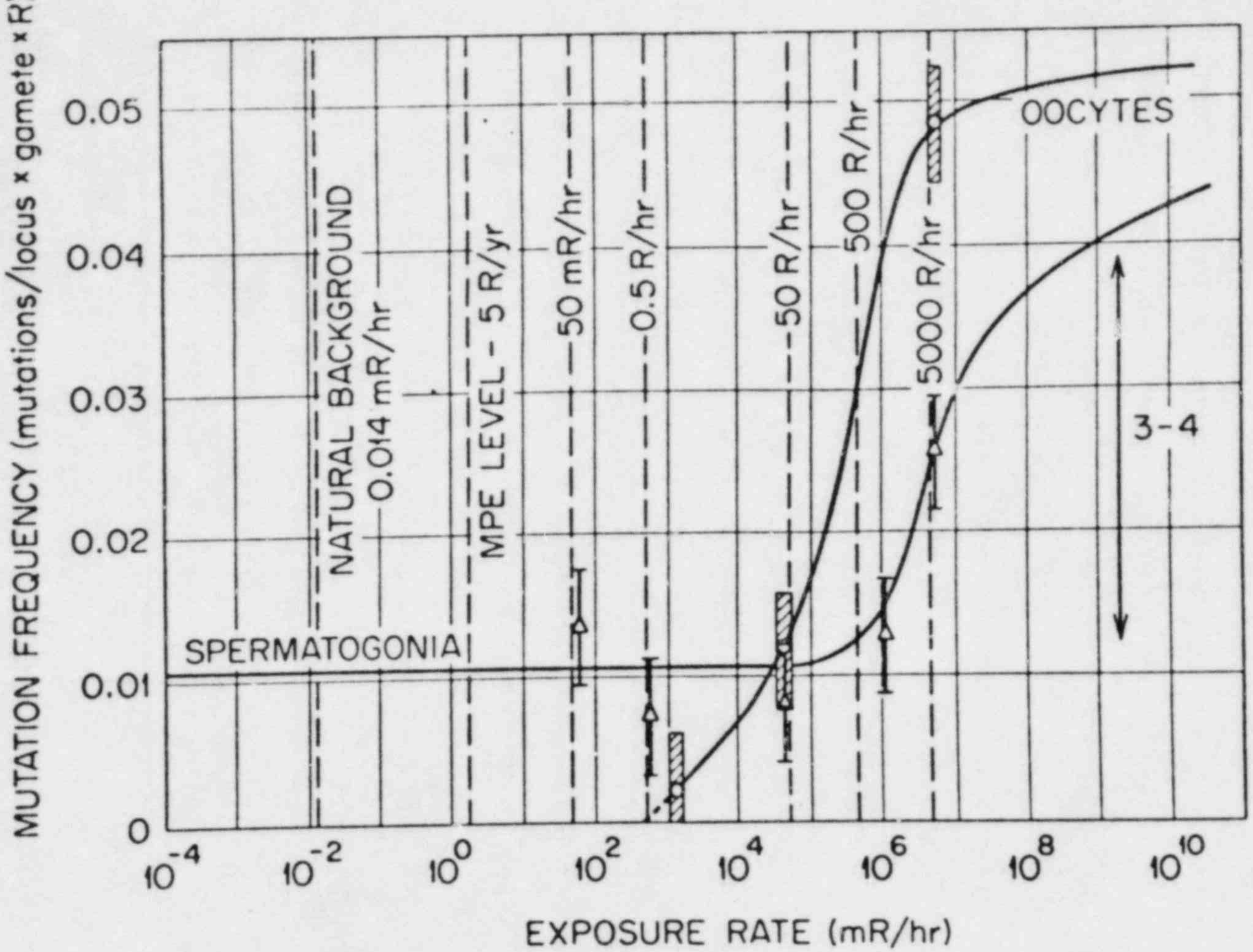
TYPES OF DAMAGE RELATING MORE OR LESS LINEARLY TO THE ACCUMULATED DOSE

1. Genetic Mutations (1st generation and recessive)
2. Cancer (including leukemia)
3. Life shortening
4. Other Biological Changes
   (a) Chromosomal abberations
   (b) Changes in blood and urine chemistry
   (c) Areas of increased and decreased bone density
   (d) Polynucleated cells

TYPES OF DAMAGE REQUIRING A THRESHOLD DOSE

1. Eye Cataracts
2. Radiation Sickness
3. Skin Erythema

of damage which vary more or less linearly with the dose and types of damage which are thought to require a threshold before they make their appearance in man. Early studies of Muller[4] of Drosophila (flies) seem to suggest complete linearity between dose and genetic damage and no dose-rate dependence. The more recent, very fine studies of Russell[5] (a speaker at this symposium) have shown, however, there is at least a slight kink in the curve (by a factor of 1/6) at very low dose rates. In Fig. 2, I have made a rough plot of some of Russell's data showing that at high dose rates there is no dose-rate dependence, but when the dose rates drop to about 5,000 R/hr, there is a precipitous decrease in the mutation frequency, both for exposure to the oocytes and spermatogonia of the mouse. In case of the oocytes, the curve drops rapidly into the background region where in effect there may be complete repair. In the case of the spermatogonia, however, he found a decrease by a factor of three or four, and the curve leveled out again on another plateau with no evidence of further decrease with reduced dose rate. Thus, since there are the two sexes and a reduction by a factor of three for the male, we use in our estimates of risk a reduction by a factor of 1/6 in the risk estimate from radiation exposure at very low dose rates. However, I do not believe we are justified in assuming any further deviation from linearity other than a slight reduction perhaps by a factor of two because of a low dose-effect. In other words, we might be justified in an over-all reduction in an estimate of the risk by a factor of 1/10 for very low doses and dose rates for the mouse and possibly in the case of man. However, I do not see any possibility of a complete reversal of the law of entropy and the complete repair of all radiation damage to a surviving somatic cell or germ cell at very low levels of exposure. Oddly enough, some persons seem to feel that lack of a "safe" exposure level is an exception to the general rule or a unique situation, and there must certainly be a threshold or safe level of exposure to radiation below which there is no risk. For example, we are accustomed to thinking it is completely safe to take one aspirin per day and that such a dose is below a threshold at which there is any risk whatsoever. I submit, however, that almost all, if not all, insults to which man is subjected probably present some risk even at very low levels of exposure. For example, as we go about our daily tasks, there is some risk of being struck by lightning. For the past number of years, there have been official reports[6]



Rate Dependence of Point Mutations in Mice. (Data from W. R. Russell, *Nucleonics*, 1965)

Figure 2

indicating an average of about 100 deaths/yr in the United States from lightning, so the risk would be about 5×10^{-7} that a person would be struck by lightning in a given year. This figure then can be compared, for example, to the risk of cancer shown in Fig. 1 of 10^{-4} cancers per year if a person were exposed to 1 rem/yr or 0.01% of persons exposed to 1 rem would be expected to develop cancer as a consequence of this exposure.

I am inclined to believe that sometimes the public is misled by the manner in which we present our data. For example, in Figs. 3 and 4, we have given plots indicating the risk of bone sarcomas and carcinomas from various levels of accumulated dose from body burdens of radium. In this case, Rowland et al[(7)] have presented their data properly so as not to be misleading. In Fig. 3, they plotted their data on a semi-log graph. Seeing only this, the non-scientific observer might conclude that there is a threshold at about 80 rad for carcinomas and 800 rad for sarcomas for these forms of radium-induced cancer. However, another observer when looking in the same report at the same data which Rowland plotted also in Fig. 4 might conclude at low doses there is a linear relationship and no dose so low that the risk of cancer is zero. I believe a typical example of a case in which the non-scientists were misled occurred following testimony of a number of scientists at the 1967 Congressional hearings regarding deaths which have occurred from lung carcinoma among uranium miners who worked in the Colorado Plateau. At these hearings[(8)] in 1967, Dr. Gehring, Acting Surgeon General of the Public Health Service, made an estimate of the risk of lung carcinoma that might be expected among 10,000 exposed underground uranium miners based on the linear hypothesis. Representative Holifield replied, "I think your assumptions relating to the straight-line theory and the threshold theory are subject to the most vigorous opposition . . . I consider (them) to be non-scientific on the basis not that I am a scientist but on the basis of the weight of evidence that has been before this committee for a long time." To the contrary, I believe Gehring would have the support of most of the scientific community in applying the linear hypothesis to his data. Since that time, a more recent report[(9)] on cancer among these miners lends stronger support to the linear hypothesis even down to the 120 WLM level of exposure of these miners. I

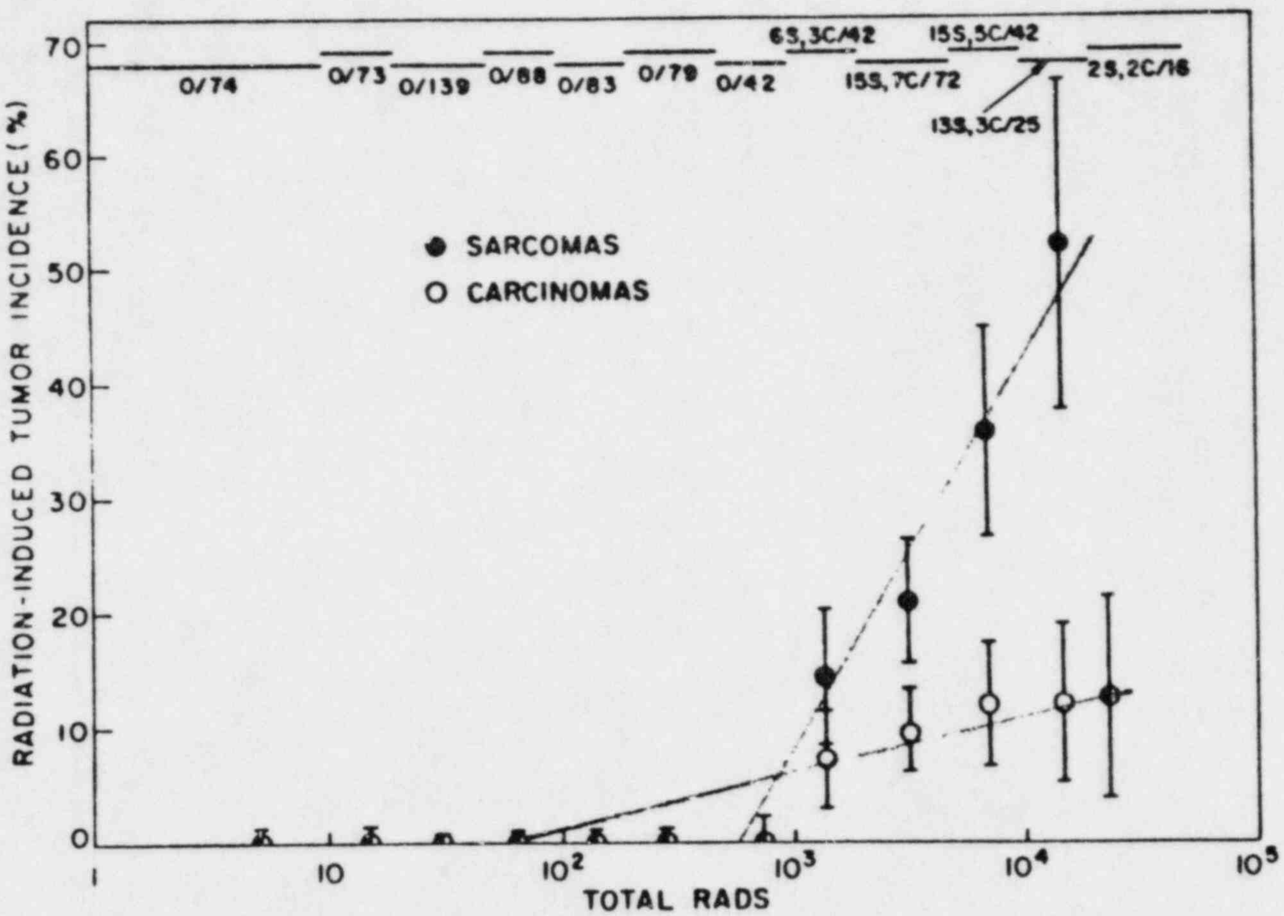


FIG. 3
The Percent Incidence of Sarcomas and Carcinomas Plotted Separately on a Linear Scale Against the Median of the Total Skeletal Dose in Rads on a Logarithmic Scale.
(Data from R. E. Rowland et al, ANL-7760, Part II, Argonne National Laboratory, Argonne, Ill. (July 1969–June 1970))

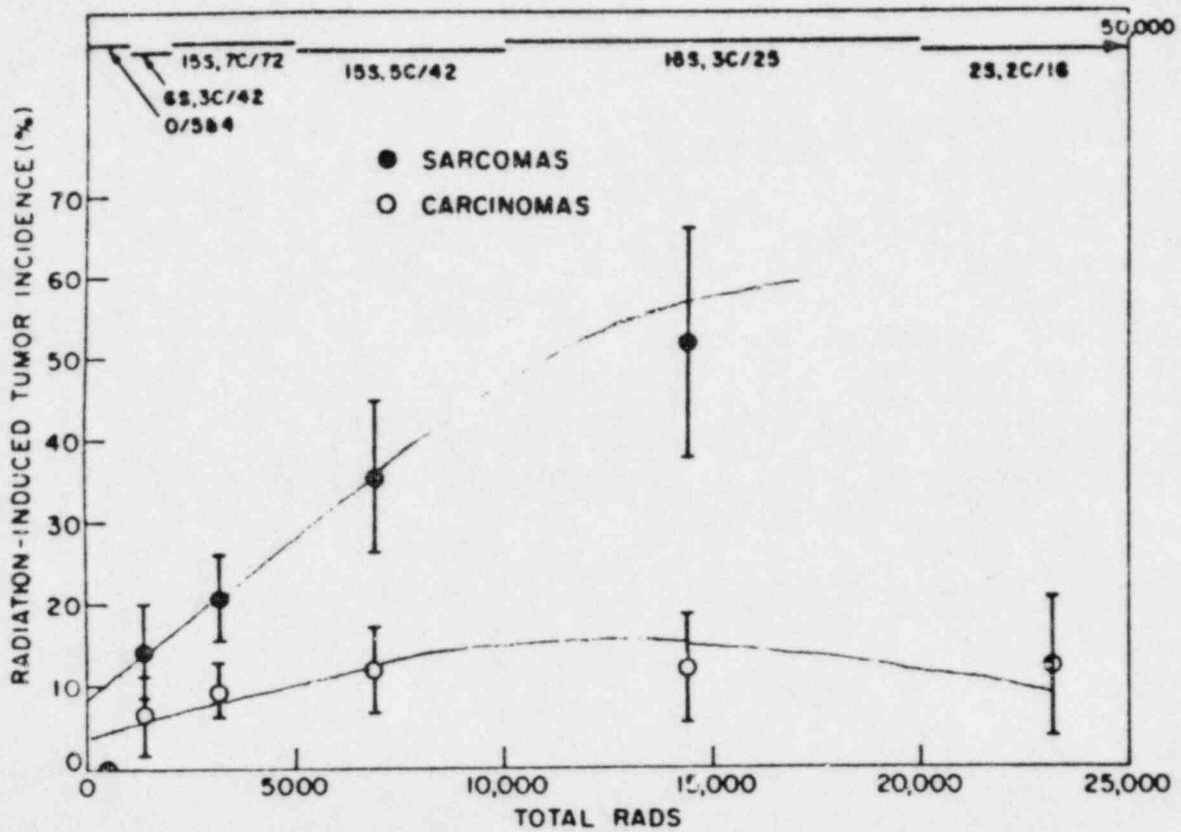


FIG. 4

The Percent Incidence of Sarcomas and Carcinomas Plotted Separately Against the Median Value of the Total Skeletal Dose in Rads in Linear Coordinates. (Data from R. E. Rowland et al, ANL-7760, Part II, Argonne National Laboratory, Argonne, Ill. (July 1969-June 1970)) believe we must be very careful in presenting our data in order not to mislead the public. I do not believe at the present time we have--or in the foreseeable future we will have--sufficient information to prove whether the linear hypothesis or the threshold hypothesis applies at very low doses and dose rates because as the dose approaches zero the number of animals required to obtain a point on the curve showing a given effect approaches infinity for reasonably low probable errors. I do not believe the question can ever be answered by animal studies, much less from observations on man. In the long run, I believe our answer must be derived from the development of a coherent theory which explains all mechanisms of radiation damage. Since this takes us beyond the foreseeable future, I would like the present to be in conformance with the law of entropy and assume that when a very large disruptive force has been applied to the nucleus of a surviving cell, the end result is most likely a disorganization of the intricate structure and some residual damage.

There are many experiments which seem to lend strong support to the linear hypothesis and to the conclusion that as the dose is increased not only does the probability of serious damage increase, but there is a gradual progression of events pointing to the imminence of impending crises as indicated under item 4 of Table 1. In Table 2, I have simply drawn a wide band diagonally across the table of data prepared by Finkel et al.[10] You will note this includes the summation of most of the numbers in the table suggesting a gradual progression as one increases the body burden of radium from no effects, to minimal, to mild, to moderate, to advanced, and finally to malignancies. You will note, also, the progression toward serious symptoms seems already to have begun even in the range of a permissible body burden of 0.1 μCi of radium-226. In terms of dose rate, the body burden of 0.1 μCi of radium-226 as applied to the occupational worker corresponds approximately to 30 rem/yr when averaged over the entire skeleton and about 15 mrem/yr to the endosteal tissue of the bone. Endosteal tissue is currently considered by ICRP[11] to be most critical in terms of radiation-induced bone tumors. The 0.1 μCi of radium-226 is one of the two principal hallmarks or reference standards to which all levels of maximum permissible exposure are referred or from which they are derived. This level of 0.1 μCi of radium-226 was set by the U. S. Advisory Committee on the

Table 2

LONG-TERM EFFECTS OF RADIUM IN MAN

Ra Body Burden (μc)	Average Bone Dose (rem/yr)	Biological Changes (%)					
		None	Minimal	Mild	Moderate	Advanced	Malignant*
0.001-0.03	0.3-9	92	8	0	0	0	0
0.03-0-0.1	9-30	83	13	0	4	0	0
0.1-0.3	30-90	69	16	3	6	6	3
0.3-1.0	90-300	12	25	25	16	22	16
1.0-3.2		6	6	14	12	62	32
3.2-5.5		0	0	0	9	91	55

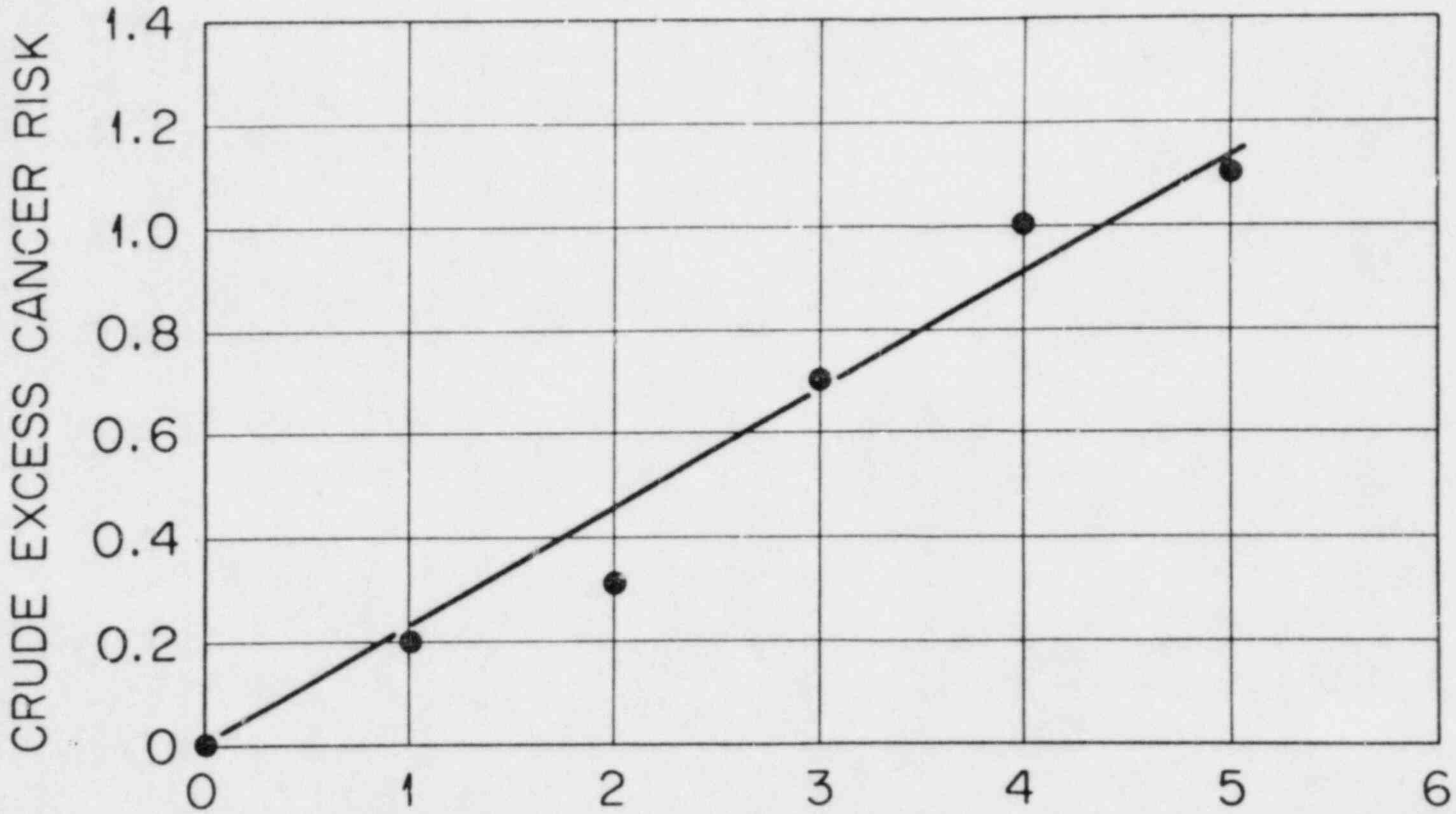
*Those with malignancies were listed also under previous columns.
(Data from Finkel, Miller and Hasterlik, ICRP No. 11, 1968)

Safe Handling of Radioactive Luminous Compounds in 1941.[12] The other reference standard was the early exposure of radiologists who were thought to have averaged in the neighborhood of 15 rem/yr of exposure. Seltser and Sartwell[13] indicated that radiologists in the period 1935 to 1958 in the age group of 50-64 had seven times the leukemic incidence of members of the medical profession who were not exposed to x-rays and that their average life was shortened approximately five years. If one applies the coefficients of ICRP as plotted in Fig. 1 to these data, it can be shown[14] that this average exposure in terms of leukemic risk or of life shortening was on the order of 15 to 30 rem/yr. Perhaps it is a coincidence that we arrive at these same numbers both in relation to leukemia risk and life shortening of radiologists, but I believe it does provide some evidence that the effective dose to the active bone marrow and other, more important body tissues of early radiologists was not as large as some persons have thought and probably averaged no more than 30 rem/yr, our present dose limit to the bone of the occupational worker.

Although some representatives[15] of the American College of Radiology, the American Medical Association and the American Dental Association seem to go to great pains to indicate that medical exposure to patients is harmless and of no consequence, I believe the record speaks for itself and to the contrary. For example, we recall the follow-up study of Albert[16] of patients treated by x-rays for tinea capitis (or ringworm). In this case, among the 4,000 member study group there were nine times as many malignancies and four times as many mental disorders among the children whose tinea capitis was treated with x-rays as among those for whom other treatments were used. Although the dose to the brain in this case was fairly large, probably about 100 rad, the average dose to other tissue such as the active bone marrow where many of the malignancies originated was very small. Sigler and other investigators[17] at Johns Hopkins University carried out a study involving 216 families, each with a Mongoloid child, living in the city of Baltimore. Their investigations revealed that mothers of Mongoloid children had received seven times as much x-ray exposure as the group of control mothers. Studies of Court-Brown and Doll[18] of a large number of persons suffering with ankylosing spondylitis whose spines were treated with x-rays have indicated a coefficient of about 2×10^{-5}

leukemias per rad delivered to the active bone marrow (approximately the figure given in Fig. 1). A study of Doll and Smith[19] of 2,000 women whose ovaries were irradiated for artificial menopause indicated that mortality from leukemia as a result of irradiating these small volumes of tissue was six times higher than would otherwise be expected five or more years after treatment. They concluded, "The results are therefore consistent with the hypothesis that the risk of leukemia induction is proportional to the total energy absorbed in the marrow." The work of Hempelmann[20] (a speaker at this symposium) is particularly impressive in that it lends strong support to a linear relationship between dose and effect down to relatively low doses. He states, "The incidence of thyroid and extra-thyroid tumors in the Rochester series is dose dependent, and the frequency of thyroid neoplasms is age dependent until age 18. Some evidence is presented suggesting that (1) the dose response to thyroid tumors is linear in the lower dose range, and (2) there is no threshold or at least the threshold is below 20 rad." Present evidence seems to show that the most sensitive members of the population are probably the fertilized ovum and the fetus. The curve of radiosensitivity as a function of age is probably an inverse parabola because there is some evidence of an increasing radiosensitivity also with advancing age. For example, Lewis[21] after examining data published by Saenger et al[22] points out that in the case of medical exposure to iodine-131 delivering rather low doses of 7 to 15 rad to bone marrow, there is a significant increase in leukemia among the persons in this study between ages 50 and 79. Regarding exposure to younger members of the population and, in particular, in utero children, some of us believe this to be a very serious matter. For example, Hammer-Jacobsen[23] points out that relatively firm measures are taken in Denmark which suggest the need for therapeutic abortion in cases where the fetal doses are estimated to have exceeded 10 rem. Because of concern for what we believed to be excessive fetal exposure, Muller and I, beginning about 1959, worked very hard toward obtaining an ICRP recommendation which would discourage unnecessary medical diagnostic exposure to unborn children. As two of the 13 members of ICRP, we were rather proud when in 1964 ICRP[24] came out with the recommendation that diagnostic exposure of women in the childbearing age to ionizing radiation be limited to the 10-day interval following the onset of menstruation except in those cases where the immediate x-ray was needed because of illness of the woman. Muller and I were disappointed, however, when some months later we read in the Bulletin of the American College of Radiology,[25] "ACR differs with international body . . . The College agrees with the minority opinion taken in the ICRP that the problem is neither so simple nor so serious as the Commission statement might indicate. College members Robert S. Stone of San Francisco and L. S. Taylor of the National Bureau of Standards, Washington, D. C., sit on the ICRP and among those taking the minority position . . . ." In spite of such opposition to this recommendation, I believe it has been one of the more important developments toward reducing unnecessary risks throughout the world from diagnostic x-ray exposure. We were pleased that the American College of Obstetricians and Gynecologists[26] recognized the risk of in utero exposure when it stated, "The risk of radiation injury is real . . . and physicians should avoid the use of routine pelvimetry and routine radiologic examination of the abdomen throughout the prenatal era."

There have been many studies on the effects of pelvimetries, the vast majority of which have indicated an increased incidence of malignancy among children who received in utero exposure. One of the more careful survey studies was carried out by MacMahon[27] in which he reported that after Alice Stewart's original observations in 1953, some 12 studies of the question of the relationship between pelvimetry and other x-ray exposure in utero and cancer in children have been published. He pointed out that although there were positive and negative findings, a combination of the data from all of them weighed according to the number of cases studied, indicated that the mortality from leukemia and other forms of cancer is about 40% higher among children exposed to diagnostic x-ray study in utero than among children not so exposed. He indicated that over the first 10 years of life of the child the risk amounts to about one cancer death per 2,000 children so x-rayed. This may seem a small number, but if all women received pelvimetries during pregnancy in 1970, this would amount to about 2,000 deaths per year in the United States. Again, this is a small number but not so small if one's child happened to be one member of this statistic. The studies of Alice Stewart[28] (a speaker at this symposium) of the effects of diagnostic x-ray exposure on children are particularly impressive. Fig. 5 is a plot of some of her data



NUMBER OF DIAGNOSTIC X-RAY FILMS DURING PREGNANCY
(Data from Alice Stewart and G.W. Kneale, *Lancet*, June 1970)

Figure 5

which lend strong support to the suggestion of a linear relationship between dose and effect at least down to 1 rem and perhaps as low as 0.25 rem. Of recent date, some members of the medical profession have delighted in pointing out that Alice Stewart's data are not consistent[29] with that reported by Jablon[30] on the effects of in utero exposure of children who survived the atomic bombings at Hiroshima and Nagasaki. I have been interested for many years in both studies and consider them among our best sources of data indicating the effects of radiation on man. In fact, our Health Physics Division at Oak Ridge has been responsible for determining the dosimetry of the survivors at Hiroshima and Nagasaki. Having examined both sets of data, I can only conclude there are no inconsistencies in the results, and the two sets of data are completely in line with what one might expect. In Table 3, I have listed some of the reasons why there is an apparent difference in the two sets of data, i.e., there have not been as many cancers observed in the children who survived in utero exposure at Hiroshima and Nagasaki as one might expect from casual application of the Stewart data. First, we should recall that only children of age greater than two have a high risk of juvenile cancer, and there was a very high infant mortality among in utero exposed children and a very high abortion rate.[31] Thus, many children who received in utero damage from radiation exposure were aborted or did not survive the two-year period to die of a malignancy, i.e., many children who received sufficient in utero radiation damage to otherwise be programmed to die of a malignancy after age two did not survive this period. In the second place, many studies[32] have indicated that during the time of community disasters it is the young children and older people who suffer most and die of a variety of causes including cancer. It is well recognized that during such periods incipient cancers are often very easily mistaken for acute infections. Another possibility (but I believe an unlikely one) is the fact that neutrons were present as a component of exposure to the Japanese survivors of the atomic bombings, and this may have favored early deaths from causes other than malignancies. It could well be that there were species differences of considerable importance in these two populations. For example, marked species differences have been observed in animal studies carried out by Warren and Gates[33] and by many others. I believe, most important of all, the Jablon data included 33 Japanese children who had received

Table 3

SOME POSSIBLE REASONS WHY ALICE STEWART'S X-RAY DATA DIFFER FROM JABLON'S JAPAN DATA

1. Only children of age greater than two years have a high risk of juvenile cancer. Infant mortality was 43% among in utero children who received high exposure, and there was a very high abortion rate among them. In utero initiated cancers concurrently with other body insults tipped scales for early nonmalignant death.

2. In most catastrophic situations (floods, war, disease, starvation), children and older people suffer most.

3. Neutron irradiation at Hiroshima and Nagasaki.

4. Japanese children may differ from European children, and/or European children may be uniquely exposed to a co-carcinogen.

5. Jablon data included 33 children who received greater than 300 rad. Stewart's data do not apply to doses at the far end of the parabola relating leukemia to dose.

6. Incipient cancers during the bomb aftermath were likely mistaken for acute infection.

7. Japanese control group of bomb survivors probably had a greater cancer risk than normal controls.

8. It has been suggested the average fetal dose in the United Kingdom may have been greater than 500 mrad per examination and perhaps about 800 mrad.

9. The Japanese exposures above 300 rad probably were on the far side of the parabola relating leukemia to dose. Thus, perhaps no cancers would be expected, and none were observed in this range. Among Japanese exposures from 0 to 39 rad, no cancers were observed and none were to be expected. Among Japanese exposures from 40 to 299 rad, Stewart's minimum coefficient (correcting Jablon's data for fetal dose) would predict two cancers and one was observed. Thus, the two sets of data are in good agreement.

in utero exposure of more than 300 rad. I do not believe Stewart's data can be applied to this population group because it would seem likely their doses were so high that they would fall at the far end of the parabola for leukemia similar to the curves shown in Fig. 4 for sarcoma and carcinoma. Marinelli[34] and many othe investigators have indicated in their publications that although you may have a linear relationship between dose and the effects on animals at low doses, the curves cannot continue this linearity indefinitely. In the first place, one cannot kill more than 100% of the animals from radiation exposure, and at the higher exposure levels many of the animals may begin dying of other causes before they have time to die of a malignancy. Stewart has pointed out that the control group of bomb survivors in Hiroshima and Nagasaki probably had a higher cancer risk than a normal population which, in turn, would tend to reduce any observed effect of radiation. Finally, it has been suggested that perhaps Stewart may have used a low figure for the average fetal dose from pelvimetries in the United Kingdom. Making this correction and using the minimum coefficient found by Stewart for her Oxford study group and applying a correction of 1/2 to the Jablon data to obtain the fetal dose from the skin dose, one would expect to find two cancers among the Japanese in utero exposures in the range of 40 to 299 rad, and one was found. No cancers would be expected in the group exposed in utero to 0 to 39 rad, and because exposures probably were on the far side of the parabola for the group receiving exposures greater than 300 rad, no cancers would be expected. In view of the uncertainties in the data, I consider this perfect agreement between the number of cancers observed among the in utero exposed children in Japan and the diagnostically exposed children in the Oxford study.

Comparative Radiation Risks

From the above discussion, I believe it seems reasonable to assume the validity of the linear hypothesis for the purpose of making comparisons of risks from medical diagnosis and the nuclear energy industry. If one knows the average or effective dose to the critical body tissue, it then becomes a simple matter of multiplication to determine the deaths caused each year from these two sources of exposure. In previous publications, I have attempted to use the data published in the UNSCEAR reports[35,36] and in the U. S. Public Health Service reports[37,38] to estimate the x-ray doses to various body organs from medical diagnoses and multiply these values by the appropriate coefficients, as indicated in Fig. 1, to determine the number of deaths per year. However, the 1970 survey of the Public Health Service has now been completed, and the data are in the process of final analysis, so I will simply use their most recent estimate that the genetically significant dose to the U. S. population from medical diagnoses may have dropped from 55 mrem/yr to 36 mrem/yr. I will further make the approximate assumption that the effective somatic dose is three times this 36 mrem/yr. This probably is not far wrong, but it is the best that can be done until additional information from the survey becomes available. In the case of the nuclear energy industry, Struxness and I[39] made some estimates two years ago of the upper limit of the dose from all nuclear sources (occupational exposure of the nuclear power plant employees, occupational exposure of national laboratories and other AEC contractors and employees, exposures at chemical processing plants, and environmental exposure from all of these sources but excluding the lung carcinoma deaths resulting from exposure to uranium miners in the United States) and concluded the average dose could not be in excess of 1/2% of the exposure limit of 170 mrem/yr. Subsequent studies of the problem suggest that it is definitely less than 0.5 mrem/yr. Therefore, the comparative estimates of risk from the nuclear power industry and from medical diagnostic exposure are given in Table 4 where it is assumed the upper limit of exposure is 0.5 mrem/yr in the nuclear energy industry and is 36 mrem/yr and 3 x 36 mrem/yr for the genetically significant dose (GSD) and somatic dose, respectively, from medical diagnoses. [illegible] making these estimates, the coefficients for genetic damage in the case of medical diagnostic exposure were taken to be six times those indicated in Fig. 1 because of the high exposure rate. From these results, the contrast as shown in Table 4 is very striking. The number of deaths in the nuclear energy industry would be 11 compared to 3,000 from medical diagnosis each year. The corresponding figures are 40 and 33,000 when one considers the highest estimate of deaths introduced into the population each year as a result of recessive mutations. From such a comparison, I do not wish to leave the impression that we have no concern for possible chronic damage to the population from the nuclear power industry, for we must do all possible to further reduce the dose and the possible effects on man. I would emphasize, however, that if one is truly concerned

Table 4

Consequences of Present United States X-Ray Diagnostic Exposures Compared With Those of A Possible Population Exposure of 0.5 Mrem/Year From The Nuclear Power Industry‡

Types of Radiation Damage	Medical Exposure* (deaths/yr)	Nuclear Power Industry at 0.5 Mrem/Yr (deaths/yr)
Genetic (First Generation)	700	1
Genetic (Future Generation)Δ	30,000	30
Cancer**	2,000	10
Total Deaths/Yr	~ 3,000	11
Deaths Introduced Into Population Each Year	~ 33,000	40

‡Assume population of 2×10^8 in the United States.

*Assume medical GSD of 36 mrem/yr at a high dose rate.

**Assume effective somatic dose is three times the GSD.

ΔUpper limit of estimate of risk from recessive mutations.

about radiation effects on man of man-made radiation, most of his efforts could better be spent in reducing unnecessary diagnostic exposure.

Excessive Medical Diagnostic Exposure

There is no question that medical diagnostic exposure is one of the most valuable of all medical tools and should be made use of when there is an indicated need and the expected benefits are greater than the radiation risks. However, there is overwhelming evidence that this exposure in the United States is excessive. Many of the x-ray diagnoses are unnecessary, of no benefit to the patient and of questionable value to the doctor. Those x-rays which are given could be carried out in such a way that the average patient absorbed dose (rem) would be less than 10% of the present value; the average energy dose (gram . rem) would be less than 1% of the present value, and the genetically significant dose (GSD) would be less than 0.1% of the present values received in the United States. Table 5 summarizes some data indicating that the GSD in the United States is higher than that in other advanced countries. As stated above, preliminary estimates from the 1970 U. S. Public Health Service survey indicate the GSD may have dropped since 1964 from 55 to 36 mrem/yr. There are indications,[40] also, that there have been similar reductions in the other indicated countries. Adrian[41] of the United Kingdom stated that if all the radiological departments in the United Kingdom employed the techniques in use already in 25% of the departments in 1958, the population gonad dose from diagnostic radiology would probably be reduced by a factor of 7. In other words, he has indicated that by this simple procedure the dose could be reduced in the United Kingdom to 2 mrem/yr. Following the 1964 survey, the U. S. Public Health Service[38] stated, "Restriction of the x-ray beam to an area no larger than that of the film size would result in a reduction of the GSD from 55 to 19 mrem/person/yr." In Congressional testimony[42] and in a number of publications,[43-45] I have listed over 100 ways by which the diagnostic exposure in the United States could be reduced to less than 5 mrem/yr. You may ask why is the genetically significant dose in the United Kingdom and other advanced countries less than that in the United States. We cannot give an accurate answer to this question. Some radiologists have suggested we may have better

Table 5

Genetically Significant Dose (mrem/yr) from Medical Diagnosis in Various Advanced Countries

United States	55*
Japan	39
Sweden	38
Switzerland	22
United Kingdom	14
New Zealand	12
Norway	10

*The 1964 survey of the USPHS reported the GSD as 55 mrem/yr. Preliminary estimates from the 1970 survey indicate it may have dropped to 36 mrem/yr.

medical practice in our country. This may or may not be true, but it goes without question that they have had medical physics and radiation protection programs in some of these countries much longer than in the United States. In fact during the period beginning with World War II a number of leading medical physicists (health physicists) were imported to this country. Some of these countries have had effective programs for inspection and upgrading of equipment and diagnostic techniques for many years--something that is still lacking in most of the United States. I believe, also, members of the medical profession in some of these countries have a greater knowledge and appreciation of the genetic and somatic risks of medical exposure and a stronger motivation to avoid its excessive use. Probably the best evidence that unnecessary and excessive diagnostic exposure is being delivered to our population derives from an examination of the wide range in values of exposure for a given diagnosis as shown in Table 6. Here it will be noted that the average skin dose from a chest x-ray when delivered to employees of our Laboratory (Oak Ridge National Laboratory) by a certified x-ray technologist using modern techniques and equipment is only 15 mrem, whereas a U. S. Public Health Service[37] survey indicated the average in the United States for a chest radiograph was 45 mrem, and when using the photofluorographic technique the average was 504 mrem. Our studies have shown a range in skin dose from photofluorograms of between 200 and 2,000 mrem. The spread in dose values is even greater in terms of energy dose (gram . rem) and GSD. For example, Penfil and Brown[46] and others have shown the x-ray beam cross-sectional area to film area for chest x-rays in the United States ranges between 1 and 4.1. Even worse, there are many chest x-rays made which should be avoided. For example, in 1965 the Public Health Service[47] stated, "Mass chest x-ray programs should not be given to all population groups but instead should be focused on groups within communities where the incidence of tuberculosis is known to be high." As seen in Table 6, there is a similar variation in the skin dose from a dental series. Unfortunately, the energy dose variation is much greater because only about 1% of the dentists are using the long, open-ended cones with rectangular collimation. The American Dental Association[48] has pointed out that the long, open-ended cones are preferable to the stubby, pointed, plastic cones. The long, open-ended cones can

Table 6

Common Diagnostic X-Ray Exposures (Mrem to Skin) in the United States

	Range	Average
Chest X-Ray at ORNL	10-20	(15)
Chest X-Ray (Photofluorographic)	200-2000	(504)
Chest X-Ray (Radiographic)	10-300	(45)
Dental X-Ray Series	400-100,000	(20,000)

be provided with a precision rectangular collimator[49-51] such that the cross-sectional area of the beam is essentially the same as that of the film. This device, also, provides a metal backing behind the film to limit the amount of the beam passing on into the critical tissue of the body and is constructed in such a way that retakes will not be necessary because of film cutting (improper alignment). Another promising device for limiting the cross-sectional area of the x-ray beam to more or less the area of the film is the automatic collimator.[52] Surveys of the Public Health Service[37] indicate that for dental x-rays in the United States the ratio of beam cross-sectional area to film area is greater than 6.8 for 2.1% of exposures, 3.8 to 6.8 for 18.4%, 3.2 to 3.8 for 35.7%, and less than 3.2 for 43.8%. It is hard to understand why about 99% of the dentists are using a beam with a circular, cross-sectional area when the film is rectangular. The portion of the beam beyond the area of the film not only unnecessarily exposes the patient but produces additional x-ray scattering onto the film so that the image of the teeth suffers from loss of resolution and detail. Public Health surveys[53] have indicated that most of the dentists do not even have a thermometer in their darkroom although specifications for best results in developing dental films indicate the temperature control of developing solutions should be maintained within a few degrees. Until recently, most of the dentists were using slow-speed dental films. For example, in 1967 65% of the dentists in New York City were still using slow-speed films, and 72% were still using mechanical timers which were inadequate for fast-speed films. I do not have the statistics on the present situation in New York City, but I understand in this respect dental exposure has improved considerably. I believe with this observation we should keep in mind that the medical surveillance program in New York City is very likely the best in the United States. As with chest x-ray programs, many unnecessary dental x-rays are given. The American Dental Association[54] has said, "Radiologic examinations should not be used as an automatic part of every periodic or routine dental examination." In other words, dental and chest x-rays should be given only where there is an indicated need and not as a routine procedure unless there are unusual circumstances. Even then they should be given only when using the best of techniques with modern equipment. I believe, for example, if a person has reached the age of 50, it is a good investment to have an annual chest x-ray but not if the skin dose is greater than 50 mrem. Similarly, if a person has something wrong with his jaw that cannot be diagnosed adequately from visual inspection, he should have a dental x-ray, but, hopefully, the single exposure dose would be less than 1,000 mrem (the mean exposure per film for dental x-rays in the United States in 1964 was 1,140 mrem), and the ratio of beam area to film area would be close to one. Unfortunately, many of our well meaning city fathers and public school officials often sponsor mass chest x-ray and dental survey programs that are not warranted. In 1964 over 1/4 of the non-institutional civilian population in the United States was exposed to dental x-rays.

In the case of dental exposure, as with other sources of population exposure, more attention should be given by our state and federal public health agencies to new sources or types of exposure which become commonplace before any of us give consideration to possible excessive exposure. For example, in 1971 the International Commission on Radiological Protection called attention to the new radiation protection problem posed by the use of intra-oral x-ray tubes in dental radiography. With the present trend to use tubes of decreasing diameter, the radiation dose at the surface of the tube may amount to 50 to 100 rad or even more per exposure. It indicated that such uses clearly should be depreciated and that if appropriate filtration were used with extra-sensitive films, the doses could be reduced by an order of magnitude.

The most important steps toward reducing unnecessary medical diagnostic exposure are summarized in Table 7. Of these, education, training and certification are by far the most important. Only the States of New York, New Jersey and California require education, training and certification of x-ray technologists who operate most of the x-ray equipment in the United States, and only one State, California, requires that there be courses on x-ray and radiation protection offered in the medical schools and that there be questions on the state board examinations on these subjects. I am sure it is almost inconceivable to you that in all 50 of our states a person is required to have a driver's license before he can operate a school bus, but, in the case of x-rays, the only requirement is how to press the red button on the machine and hope the timers and other equipment operate properly. Even some of the better x-ray departments do not have meters with which they can calibrate

Table 7

IMPORTANT STEPS TO REDUCE UNNECESSARY MEDICAL EXPOSURE TO X-RAYS

1. Education, Training and Certification Requirements
   (a) Presently required of doctors only in California
   (b) Presently required of x-ray technologists only in New York, New Jersey and California
   (c) Establish a grade of senior x-ray technologist

2. Improve Techniques
   (a) Require better techniques in developing x-ray films
   (b) Require edges of x-ray field to show on film
   (c) Require dark adaptation of eyes even with improved fluoroscopy

3. Reduce Number of Diagnostic X-Rays
   (a) Transfer x-ray films from one doctor to another
   (b) Limit requirements of insurance companies for medical x-rays
   (c) Discontinue and/or curtail certain types of medical x-rays

4. Use Better Equipment
   (a) Require use of long cones with rectangular collimation for dental x-rays
   (b) Forbid use of medical x-ray machines unless equipped with proper meters
   (c) Require use of patient shields and lead aprons

5. Require Records of Patient Exposure
   (a) Require a permanent record of dose for each patient exposure
   (b) Furnish patient with record of x-ray exposures
   (c) Obtain information to aid in avoiding exposure of fetus

6. Increase Inspections
   (a) Inspect all medical x-ray machines and associated equipment annually
   (b) Inspect techniques used in medical diagnoses annually
   (c) Post conspicuously a dated inspection record for each x-ray machine and its use

the x-ray beam. Even worse, most of the diagnostic x-ray equipment in the United States is owned and operated by non-radiologists who have little or no training in its use. Fortunately, the x-ray workload of this equipment by practitioners, chiropractors, osteopaths, etc., is relatively low. It seems to me unthinkable that a practitioner or his secretary without training and certification in the proper use of x-rays would be allowed to operate these machines and almost as unacceptable that a doctor would be permitted to prescribe an x-ray for his patient when he has no education, training and certification in its use and is not able to weigh the benefits against the risks from such an examination. There is a bill in Congress, S.426, sponsored by Senator Randolph which is designed to require appropriate education, training and certification of all x-ray technologists. I hope this bill has successful passage through Congress and that it will be followed by other legislation which will require similar education, training and certification of all members of the medical profession. I think it is important we establish a grade of senior x-ray technologist and give him complete responsibility for the calibration and operation of the diagnostic x-ray machine. He should complete a minimum of four years of specified education and training and be given a special certification examination. Such a professional grade of technologist could assure much better and safer x-ray diagnoses and would save the public many millions of dollars by obviating the need for thousands of additional radiologists.

Regarding the improvement in techniques, little more need be said except perhaps to give another example where poor techniques are used which result in the average exposures being many times what they should. Surveys of the Public Health Service[53] have indicated that most dentists in the United States overexpose x-ray films and underdevelop them. This assures an image of the teeth on the film but guarantees the patient will be overexposed and that the film will be of poor quality. I have over 200 letters in my file from persons from all over the United States who apparently have received an excessive number of diagnostic x-rays. For example, I have a letter from a medical physicist dated January 13, 1971, which states, "A pediatrician brought up the fact that he was furious because Radiology had taken 22 chest x-rays of one of his patients (an infant) between October 2, 1970, and November 30, 1970.

When the matter was brought to the attention of the Radiology Department, the radiologist replied it was not the responsibility of the X-Ray Department to keep track of the times a patient is x-rayed and that if an order comes down for an x-ray, they will give it." Hopefully, there are very few departments where the head radiologist takes this attitude. However, where this is the case, he is not practicing radiology but rather doing the job of an unqualified technician, taking orders for the mass production of x-rays. Regarding the need for better x-ray equipment, we may add, for example, to what has been stated above the results of a survey by the Public Health Service of x-ray facilities within the Bureau of Prisons during 1968.[55] In this survey, they found, for example, the improper cone was used and that the proper cone was not available in 20.6% of the medical x-ray machines surveyed, and the timers were inaccurate and/or gave non-reproducible results in 68% of the dental x-ray machines.

Regarding item 5 in Table 7, the matter of keeping records of patient exposure, I readily concede there will be some problems, but the principal problem is that of the reluctance of members of the medical profession to change established practices. They point out the difficulties and time-consuming efforts in making these measurements and recordings, but there have been several publications pointing out how this could be done mechanically while taking very little additional time of the medical man or the x-ray technologist. For example, Hurst et al[56] have described a recording ionization chamber which can be adapted to any diagnostic x-ray machine. The recording of the dose would be made automatically on a card containing the name of the individual, type of exposure, target-skin distance, kvp, filtration, and exposure area. It is difficult to understand why such equipment is not already in use in this day of computers and information retrieval devices. One can walk into an airport and in a matter of seconds receive information on the availability of airline connections in any part of our country. Such information should be equally retrievable regarding an individual's entire exposure history. This information should be stored in such a way that the doctor by pressing a few buttons would have it displayed before him.

It is well known that natural background radiation exposure and medical exposure are not included as components of the ICRP upper limit of 500 mrem/yr to the individual or 170 mrem/yr average to the population. I firmly believe medical diagnostic exposure should be included as part of this 170 mrem/yr limit for the average population exposure. If this were done, greater attention would be given to weighing the benefits against the risks by members of the healing arts as well as by those concerned with the future of the nuclear energy industry. I think it goes without saying that more frequent and more thorough inspections of medical facilities and practices by properly qualified state public health organizations would go a long way toward improving the equipment used for medical diagnosis, upgrading the techniques employed and assuring proper education, training and certification of all those involved. In order to accomplish these objectives, we will require cooperation at all levels of society and government beginning with widespread education of the public not to fear radiation but to give it proper respect; not to avoid a needed diagnosis or x-ray treatment, but when it is required to seek the best medical advice and make use of those medical facilities most likely to deliver the minimum dose consistent with the radiographic information needed. In order to reduce unnecessary medical diagnostic exposure, it will require the concern and active assistance of many professional groups and especially of those knowledgeable in matters of radiation exposure (such as health physicists, nuclear engineers, radiologists, x-ray technologists, etc.). Even the legal profession will have an important part to play in these efforts because many x-rays are given not for the benefit of the patient but to protect the doctor from possible legal implications and to establish legal claims in case of an accident. I believe in legal matters the Special Committee on Atomic Energy Law of the American Bar Association can be of considerable benefit. For example, in 1968 it was instrumental in correcting a serious disparity in many state laws which applied the statute of limitations to claims for radiation injury. Prior to this committee's decision, in order to lay claim for radiation injury a claimant would have to establish that he received radiation injury within a period of about five years after his radiation exposure in order that his case be given legal consideration. The recommendations of this committee were adopted by the House of Delegates and have been instrumental in modifying state laws and their interpretation such that a person receiving chronic damage from radiation (i.e., more than five years after radiation exposure) may expect to receive just compensation through court procedures. I have information concerning persons who have been required by insurance companies to receive 10 to 30 x-ray exposures in order to establish the existence or cause of rather minor injuries from automobile accidents. It seems to me that such use of x-rays is not acceptable, and the Public Health Service should seek the assistance of the Special Committee on Atomic Energy of the American Bar Association in avoiding such misuse of x-rays.

Perhaps the picture I have painted so far regarding the misuse and excess of medical diagnostic x-rays appears a bit discouraging, but there are some signs of slow progress as indicated in Table 8. Some of us were instrumental in the passage of Public Law 90-602 which has given important authority to the Surgeon General to bring about some of these corrections. However, in order to implement some of the things discussed in this paper, it will be necessary for the various states to pass a number of laws, and here is where all of us as concerned citizens should come into the picture. Perhaps one of the most encouraging recent developments is that radiologists themselves are chiding and rebuking their profession in their own publications because of unnecessary and harmful patient exposure. For example, Table 9 is a summary of some of the comments made in a paper by Dr. McClenahan[57] entitled "Wasted X-Rays." Here, he is saying that the ordering of a radiogram has become more or less a mechanical and foregone conclusion even when there is no question about the diagnosis or need for an x-ray. Such practice is justified in the eyes of the doctor because it rules out some finite or remote chance that something else was overlooked (and I might add that it adds a significant cost item to the bill). A number of papers in the medical journals, however, have pointed out that these low yield x-ray diagnoses should not be conducted, not only because of possible damage to the patient, but, also, because they add substantially to the soaring cost of medical care. Drs. Bell and Loop[58] point out there are certain types of examinations, for example, where only one fracture in 435 radiographic examinations yielded positive results and even in this case the information was not needed in the treatment of the patient. They point out further that if x-ray examinations of this type would be deferred or omitted, such a strategy on a national scale potentially could result in a yearly saving of 15 million dollars in health care. Brook and Stevenson[59] reported on the outcome

Table 8

FAINT SIGNS OF PROGRESS IN REDUCING UNNECESSARY MEDICAL EXPOSURES

1. Passage of Public Law 90-602 in 1968.

2. Several states have pending legislation designed to reduce medical exposure.

3. Genetically significant dose from medical diagnosis may have been reduced from 55 mrem/yr (1964) to 36 mrem/yr (1970.

4. For the first time, radiologists are chiding their profession because of unnecessary patient exposure.

Table 9

SOME PRACTICES CAUSING EXCESSIVE PATIENT EXPOSURE

1. Easier to order an x-ray than think.

2. Exercise "ruling out," i.e., order x-rays when accurate diagnosis has been made with the naked eye.

3. Heavy legal penalties for failure to x-ray but no penalties for unnecessary exposure of patient.

4. Insurance covers most x-ray costs.

5. More films per diagnosis now required than formerly.

6. Shortage of trained workers leading to hasty, hazardous techniques.

7. Folkways and traditional rites.

of 141 emergency room patients who were given various diagnostic x-ray procedures and found that these examinations resulted in effective medical care for 27%, ineffective care for 60%, and neither effective nor ineffective for 13%. Dr. Sutherland[60] reported skull x-ray examinations showed the lowest incidence of clinical radiological agreement in his study. Only one lesion, a pituitary adenoma, was detected in 70 requests from the medical department. Dr. Sagan[61] was particularly forthright and effective in some of his comments regarding the need for improvement in medical diagnosis. Regarding Dr. McClenahan's reference to folkways and to regional rites, probably he had in mind the prevalent practice until a few years ago, when brought into the limelight by Nader,[62] of x-ray technologists in our country giving more exposure to black patients than to white patients. In fact, one of the textbooks commonly used for the training of x-ray technologists recommended this as a general procedure. McClenahan in his article goes on to point out that many x-rays are given for psychological reasons because the doctor wishes to satisfy the patient. I agree this is an important use of x-ray diagnosis and should be continued, but in such case there is no need to turn on the high voltage on the x-ray machine--perhaps add a buzzer that could be activated.

Fig. 6 summarizes some of the foregoing discussion, emphasizing again the relative insignificance of exposure in the nuclear energy industry in comparison with that from medical x-ray diagnosis. I, for one, believe the potential for population exposure as a result of accidents with nuclear power plants is much more important than the risk of exposure from their routine operations. However, even when we take this into account, the risk again becomes relatively insignificant. In this case in which I consider what I believe are the worst credible consequences of a nuclear accident, I estimate the average number of deaths per year would be about 25, and I believe a more reasonable figure would be three. These figures were obtained by what I consider to be an appropriate scaling and adjusting of some of the factors given in the earlier major accident report, WASH-740.[63] In this case, I applied risk estimates to 1,000 MW(e) power reactors having a probability of 10^{-4} accidents per reactor per year. I assumed in this case 25% release of iodine and 100% release of noble gases (or a few 100 million curies), and concluded the exposure, at least with proper

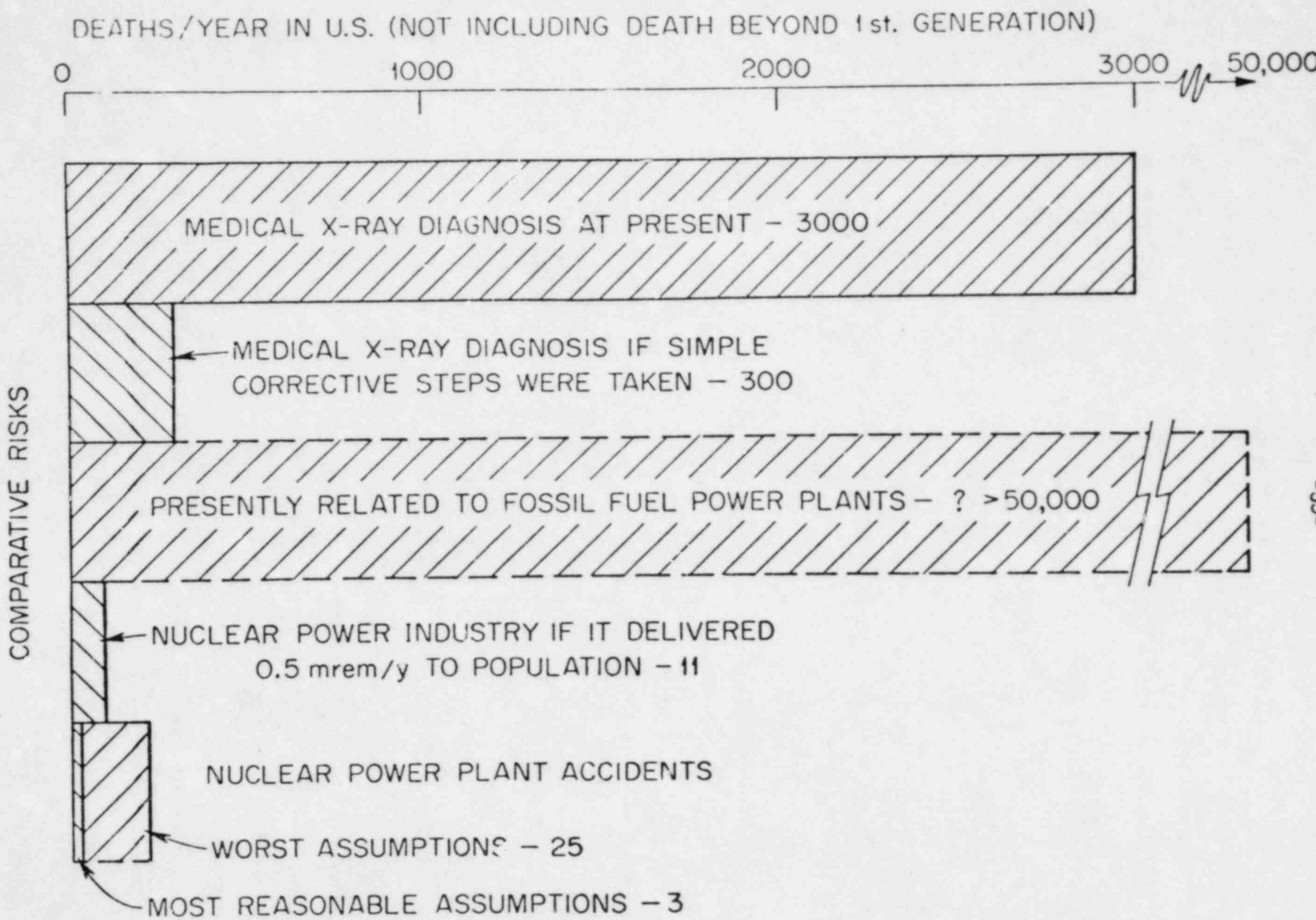

DEATHS/YEAR IN U.S. (NOT INCLUDING DEATH BEYOND 1st. GENERATION)
0
1000
2000
3000
50,000
COMPARATIVE RISKS
MEDICAL X-RAY DIAGNOSIS AT PRESENT – 3000
MEDICAL X-RAY DIAGNOSIS IF SIMPLE CORRECTIVE STEPS WERE TAKEN – 300
PRESENTLY RELATED TO FOSSIL FUEL POWER PLANTS – ? >50,000
NUCLEAR POWER INDUSTRY IF IT DELIVERED 0.5 mrem/y TO POPULATION – 11
NUCLEAR POWER PLANT ACCIDENTS
WORST ASSUMPTIONS – 25
MOST REASONABLE ASSUMPTIONS – 3

Fig. 6

preparations, could be maintained at less than 2.5×10^6 man-rem to the total body and 30×10^6 man-rem to the thyroid. This would correspond, for example, to an average of 10% of the USAEC accident design doses (i.e., 10% of 25 rem to the total body and 10% of 300 rem to the thyroid to 10^6 people). Using the coefficients given in Fig. 1, this would correspond to 500 deaths. If we have an average of 500 operating nuclear power plants of 1,000 MW(e) over the next 20 years, this corresponds to one accident or an average of 25 deaths/yr plus a possible 100 to 150 genetic deaths introduced into future generations. Certainly, from past experiences one would expect more likely the release of something between a few thousand curies, and this amount representing a worst possible accident, and on this basis I rather arbitrarily arrived at what I believe is a more reasonable upper figure of three deaths/yr. Table 10 compares the risks from medical diagnosis and the nuclear energy industry with the risks of dying from other causes. Here it will be noted that even on the worst assumptions regarding risk from the routine operations and accidents in the nuclear power industry, we should be more concerned about reducing the risk from getting struck by lightning. However, these low reactor risk estimates assume continued isolation of nuclear power plants and an adequate health physics program in each of them--something which is not necessarily assured by present plans. Finally, referring again to Fig. 6, we should keep in mind that in choosing nuclear power we do so after comparing the risks in the use of fossil fuels. We know far less about the risks from chemical environmental pollutants such as hydrocarbons, oxides of nitrogen, oxides of sulphur and particulates than about radiation risks, but the evidence is rather clear that they lead to an increased incidence of chronic bronchitis and emphysema and seem to relate to many other diseases. Furthermore, we must not overlook the fact which was pointed out by Martin et al[64] that the radioisotopes discharged from a modern coal plant exceed in quantity and toxicity those discharged from some of the more modern pressurized water reactors. I agree with them that it is fair to say the risk in terms of the fraction of ICRP population dose limit is at least 400 times greater in the case of the fossil fuel plant than the pressurized water reactor plant. Considering, also, the 1,600 year half life of radium-226 (the principal radionuclide of concern with fossil fuel plants) in comparison with the short-lived

Table 10

Radiation Risks on the Linear Hypothesis (Deaths/Yr)*

Medical Diagnosis	3,000 (30,000)
Nuclear Energy Industry	
Routine at 0.5 mrem/yr	11 (40)
Accidents**	
Worst Assumptions	25 (150)
More Reasonable	3 (15)

Deaths Per Year From Other Causes in 1967

Heart Disease	721,000
Cancer	311,000
Stroke	202,000
All Accidents	113,000
Struck by Lightning	~ 100

*Values in parentheses are upper limits of genetic deaths introduced into the population each year on the average.
**Figures do not include acute deaths from blast and radiation sickness.

tritium and the fact that the residence time of tritium, the noble gases, and iodines in the local environment is far less than that of radium, the relative radiation risks are probably at least an order of magnitude greater than this figure of 400.

References

1. Radiosensitivity and Spatial Distribution of Dose, ICRP Publication 14, Pergamon Press, New York (1969).

2. Recommendations of the International Commission on Radiological Protection, ICRP Publication 1, Pergamon Press, New York (1959).

3. The Evaluation of Risks from Radiation, ICRP Publication 8, Pergamon Press, New York (1966).

4. J. H. Muller, "Man--His Environment and Health," Suppl. to Amer. J. Public Health, Part II, Vol. 50, No. 1, p. 45 (January, 1964).

5. W. L. Russell, "Studies of Mammalian Radiation Genetics," Nucleonics, Vol. 23, No. 1, p. 53 (January, 1965).

6. Accident Facts, National Safety Council, Chicago, Illinois, 1970 and 1971 Editions.

7. R. E. Rowland et al, "Some Dose-Response Relationships for Tumor Incidence in Radium Patients," Radiological Physics Division Annual Report, ANL-7760, Part II, p. 1, U. S. Department of Commerce, Springfield, Va. (July, 1969-June, 1970).

8. Hearings Before the Congress of the United States on Radiation Exposure of Uranium Miners, Ninetieth Congress, Parts 1 and 2, U. S. Government Printing Office, Washington, D. C. (May, June, July and August, 1967).

9. F. E. Lundin, Jr., J. K. Wagoner, V. E. Archer, Radon Daughter Exposure and Respiratory Cancer Quantitative and Temporal Aspects, Monograph No. 1, U. S. Dept. of Commerce, Springfield, Va. (June, 1971).

10. A. J. Finkel, C. E. Miller, and R. J. Hasterlik, "Long Term Effects of Radium Deposition in Man: Progress Report," Health Division Gamma-Ray Spectroscopy Group Semiannual Report, ANL-6839, p. 7 (1964).

11. A Review of the Radiosensitivity of the Tissues in Bone, ICRP Publication 11, Pergamon Press, New York (1968).

12. Safe Handling of Radioactive Luminous Compound, National Bureau of Standards Handbook 27, U. S. Government Printing Office, Washington, D. C. (1941).

13. R. Seltser and P. E. Sartwell, "The Influence of Occupational Exposure of Radiation on the Mortality of American Radiologists and Other Medical Specialists," Am. J. Epidemiol., Vol. 81, p. 2 (1965); "The Effect of Occupational Exposure to Radiation on the Mortality of Physicians," J. Amer. Med. Assoc., Vol. 190, p. 1046 (December, 1964)

14. K. Z. Morgan, "Maximum Permissible Levels of Exposure to Ionizing Radiation," Radiation Dosimetry, Proceedings of the International Summer School on Radiation Protection, held in Cavtat, September 21-30, 1970, Boris Kidric Institute of Nuclear Sciences, Belgrade, Yugoslavia (1971).

15. Statement of Dr. Robert Moseley reported in article by David Gumpert, The Wall Street Journal, VCLXXVIII, No. 122 (December 23, 1971).

16. R. E. Albert, "Follow-up Study of Patients Treated by X-Rays for Tinea Capitis," Amer. J. Public Health, Vol. 56, p. 2114 (December, 1966).

17. A. T. Sigler et al, "Radiation Exposure in Parents of Children with Mongolism Down's Syndrome)," Bulletin Johns Hopkins Hosp., Vol. 117, p. 374 (1965).

18. W. M. Court-Brown and R. Doll, "Mortality from Cancer and Other Causes After Radiotherapy for Ankylosing Spondylitis," Brit. Med. J., Vol. 2, p. 1327 (1965).

19. R. Doll and P. G. Smith, "The Long-Term Effects of X-Irradiation in Patients Treated for Metropathia Haemorrhagica," Brit. J. Radiol., Vol. 41, p. 362 (May, 1968).

20. L. H. Hempelmann, "Risk of Thyroid Neoplasms After Irradiation in Childhood," Science, Vol. 160, p. 159 (April 12, 1968).

21. E. B. Lewis, "Leukemia, Radiation and Hyperthyroidism," Science, Vol. 174, p. 454 (October 29, 1971).

22. E. L. Saenger, "Radiation and Leukemia Rates," Science, Vol. 171, No. 3976, p. 1096 (March 19, 1971).

23. E. Hammer-Jacobsen, "Therapeutic Abortion on Account of X-Ray Examination During Pregnancy," Danish Med. Bulletin, Vol. 6, p. 113 (1959).

24. Recommendations of the International Commission on Radiological Protection, ICRP Publication 6, Pergamon Press, New York (1964).

25. American College of Radiology Bulletin, Vol. 20, No. 5 (May 15, 1964).

26. "American College of Obstetricians and Gynecologists Adopts New X-Ray Policy," American College of Radiology Bulletin, Vol. 20, No. 9 (September, 1964).

27. Brian MacMahon, "X-Ray Exposure and Malignancy," J. Amer. Med. Assoc., Vol. 183, p. 721 (1963).

28. Alice Stewart and G. W. Kneale, "Radiation Dose Effects in Relation to Obstetric X-Rays and Childhood Cancers," Lancet, p. 1185 (June 6, 1970).

29. American College of Radiology, X-Ray Examinations . . . A Guide to Good Practice, U. S. Government Printing Office, Washington, D. C. (1971).

30. S. Jablon and H. Kato, "Childhood Cancer in Relation to Prenatal Exposure to Atomic-Bomb Radiation," Lancet, p. 1000 (November 14, 1970).

31. R. W. Miller, "Delayed Radiation Effects in Atomic-Bomb Survivors," Science, Vol. 166, p. 569 (October 31, 1969).

32. Glin Bennet, "Bristol Floods 1968. Controlled Survey of Effects on Health of Local Community Disaster," Brit. Med. J., p. 454 (August 22, 1970).

33. S. Warren and O. Gates, "The Induction of Leukemia and Life Shortening in Mice by Continuous and Low-Level External Gamma Radiation," Rad. Res., Vol. 47, p. 480 (August, 1971).

34. L. D. Marinelli, "Estimates of the Radiation-Induced Leukemia Risk in Man," Argonne National Laboratory Radiological Physics Division Annual Report, ANL-7760, Part II, U. S. Dept. of Commerce, Springfield, Va. (July, 1969 - June, 1970).

35. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, 13th Session, Suppl. No. 17(A/3838), United Nations, New York (1958).

36. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, 17th Session, Suppl. No. 16(A/5216), United Nations, New York (1962).

37. J. N. Gitlin and P. S. Lawrence, Population Exposure to X-Rays, U. S., 1964, USPHS Publ. No. 1519, U. S. Gov. Printing Office, Washington, D. C. (1966).

38. Population Dose from X-Rays, U. S., 1964, USPHS Publ. No. 2001, U. S. Gov. Printing Office, Washington, D. C. (October, 1969).

39. K. Z. Morgan and E. G. Struxness, "Criteria for the Control of Radioactive Effluents," Proceedings of the Symposium on Environmental Aspects of Nuclear Power Stations, held in New York, August 10-14, 1970, IAEA-SM-146/10, IAEA, Vienna (1971).

40. J. C. Matthew and H. Miller, "Radiation Hazards from Diagnostic Radiology," Brit. J. Radiol., Vol. 42, p. 814 (1969).

41. G. M. Adrian, "Hazards and Dose to the Whole Population from Ionizing Radiations," Annals of Occup. Hyg., Vol. 9, p. 83 (1966).

42. K. Z. Morgan, "Reduction of Unnecessary Medical Exposure," Hearings before the Committee on Commerce, U. S. Senate, on S.2067, Serial No. 90-49, p. 46, 90th Congress, 1st Session (August 18, 1967); K. Z. Morgan, "Population Exposure to Diagnostic X-Rays and Resultant Damage Can Be Reduced to 10% of Their Present Levels While at the Same Time Increasing the Quality and Amount of Diagnostic Information," testimony presented before the U. S. House of Representatives, Washington, D. C., on H. R. 10790 (October 11, 1967).

43. K. Z. Morgan, "Why the 1968 Act for Radiation Control for Health and Safety Is Required," Radiology (June, 1971).

44. K. Z. Morgan, The Need for Standardization Procedures in the Application of Ionizing Radiation to Medical and Dental Patients, Seminar Paper No. 003, Clearinghouse for Federal Scientific and Technical Information, Springfield, Va. (June, 1969).

45. K. Z. Morgan, "Adequacy of Present Radiation Standards," presented before the Environmental and Ecological Forum, Silver Spring, Md., Jan. 20, 1971, and to be published by the USAEC Office of Information Services (1972).

46. R. L. Penfil and M. L. Brown, "Genetically Significant Dose to the United States Population from Diagnostic Medical Roentgenology, 1964," Radiol., Vol. 90, p. 209 (February, 1968).

47. What About Radiation? Mass Chest X-Ray Programs, USPHS Publ. 1196, U. S. Gov. Printing Office, Washington, D. C. (February, 1965).

48. American Dental Assoc. Council on Dental Materials and Devices and Council on Dental Research, "Radiation Hygiene and Practice in Dentistry. IV," J. Amer. Dental Assoc., Vol. 76, p. 363 (February, 1968).

49. R. G. Winkler, "Influence of Rectangular Collimation and Intraoral Shielding on Radiation Dose in Dental Radiography," J. Amer. Dental Assoc., Vol. 77, No. 1 (July, 1968).

50. D. D. Weissman and G. E. Longhurst, "Clinical Evaluation of a Rectangular Field Collimating Device for Periapical Radiography," J. Amer. Dental Assoc., Vol. 82, p. 580 (March, 1971).

51. F. M. Medwedeff and W. H. Knox, "Radiation Reduction for Children," The Journal of the Tenn. State Dental Assoc., Vol. 42, No. 4 (October, 1962).

52. R. L. Walchle, H. F. Stewart and J. M. Morel, Development and Evaluation of an Automatic Collimator for Medical Diagnostic X-Ray Machines, MORP 68-9, U. S. Gov. Printing Office, Washington, D. C. (1968).

53. D. R. Chadwick, "USPHS Division of Radiological Health Program in X-Ray Protection," presented at the Public Health Conference on the Use of X-Rays in Medicine and Industry, University of Miami, Coral Gables, Fla. (April 13-15, 1966).

54. "Bulletins and Highlights," J. Amer. Dental Assoc., Vol. 76, No. 2 (February, 1968).

55. L. C. Seabron, Radiation Safety Surveys of X-Ray Facilities Within the Bureau of Prisons During 1968, BRH/DEP 70-19, p. 7, USDHEW, Public Health Service, Rockville, Md. (July, 1970).

56. G. S. Hurst, Norbert Thonnard and Karl Schneider, "A Recording Exposure Control for X-Ray Machines," Health Physics, Vol. 21, No. 1, p. 91 (July, 1971).

57. J. L. McClenahan, "Wasted X-Rays," Radiology, Vol. 96, p. 453 (August, 1970).

58. R. S. Bell and J. W. Loop, "The Utility and Futility of Radiographic Skull Examination for Trauma," The New England J. of Med., Vol. 286, p. 236 (February 4, 1972).

59. R. H. Brook and R. L. Stevenson, "Effectiveness of Patient Care in an Emergency Room," The New England J. of Med., Vol. 283, p. 904 (October 22, 1970).

60. G. R. Sutherland, "Agreement Between Clinical and Radiological Diagnosis," Brit. Med. J., Vol. 4, p. 212 (October 24, 1970).

61. L. A. Sagan, "Medical Uses of Radiation," J. Amer. Med. Assoc., Vol. 215, No. 12, p. 1977 (March 22, 1971).

62. Ralph Nader, "Wake Up America, Unsafe X-Rays," Ladies Home Journal, Vol. 85, p. 126 (May, 1968).

63. Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants, WASH-740, Division of Civilian Application, USAEC, Washington, D. C. (March, 1957).

64. J. E. Martin, E. D. Harward and D. T. Oakley, "Comparison of Radioactivity from Fossil Fuel and Nuclear Power Plants," unpublished Public Health Service report (November, 1969).

ESC, AIF, EPI Conference on Low-Level Radiation

Are the Current Standards and Guidelines for Low-Level Radiation Adequate to Protect Public Health?

What Are the Current Standards?

by

Karl Z. Morgan*
Neely Professor
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

If I attempted to summarize all the standards, guides and recommendations on radiation protection that have (or intend to have) some influence in providing protection of radiation workers and members of the public, it would take most of this morning session. Even if I were able to do a thorough job in such an effort, I do not believe it would contribute importantly to the question of adequacy of radiation protection standards which we are eager to begin disucssing at this Congressional Conference. I will, however, indicate briefly what are our basic radiation standards and how they have been developed. At this Conference we will limit our discussions to standards as they relate to ionizing radiations; however, some of us are acutely aware of the need for a similar Conference to deal with non-ionizing radiation (sonic, ultrasonic, infrasonic, light, ultra violet, infrared, microwave, radio frequency and very long wave radiations).

---

*These introductory comments were made by the Panel Moderator, Dr. Karl Z. Morgan. This Conference was held in the Dirksen Senate Office Building, Washington, D. C. 20515, February 10, 1978.

At the outset it must be recognized that the most important, most influential, and universally applied standards are not laws or regulations or even codes of practice. They are simply recommendations of the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection (NCRP) and publications of the National Academy of Sciences - National Research Council such as recommendations in the so called BEIR report.

There are many Government agencies which get into the act of setting, interpreting and enforcing radiation protection standards and this is part of the problem. For example there are many Case-Agency situations, a few of which are:

TABLE I

Case of Exposure	Responsible Government Agency
1. Exposure in uranium mines	Bureau of Mines, Labor Dept., NRC, PHS, DOE, EPA, State Agencies
2. Population exposure in city 51 miles from a nuclear reactor	EPA, BRH, HEW, DOE, NRC, State Agencies
3. Transportation of radioactive materials	DOT, EPA, NRC, DOE, State Agencies
4. Permanent disposal of radioactive waste	EPA, DA, DOE, DOT, NRC, ICC, State Agencies
5. Dangerous or ineffective use of radioisotopes, e.g. Am-241 in smoke detectors	DOE, HEW, HUD, NRC, OSHA, NIOSH, State Agencies
6. Excessive medical exposure of members of public	EPA, BRH, State Agencies (up until recently essentially no control)

As indicated in testimony I gave before Congressional hearings last week,(1) since 1950 there have been quantum drops in the maximum permissible exposure (MPE) levels by a factor of 10 for occupational exposure (from 52 R/y to 5 rem/y) and by a factor of 300 for members of the public (from 1.5 rem/y to 5 mrem/y). As a matter of fact, these jumps are much larger in some cases because it is generally recognized from both theory and experiments that there can be no safe level of exposure to ionizing radiation in the sense that the risk (e.g. the risk of causing cancer) is zero and no MPE can be set so low that the risk is zero. As a consequence the philosophy of keeping exposures As Low As Reasonably Achievable (ALARA) has been adopted by ICRP, NRC, EPA, the BEIR Committee, etc. Thus, if the dose from color TV or from a luminized watch or a smoke detector can be kept reasonably at or near zero, this is what should be done and for such products the drop in MPE becomes essentially infinite (i.e. down to zero). Unfortunately, our government Agencies often are faced with an after-the-fact situation and must set appropriate levels for plutonium and americium in the environment due to messy and unsatisfactory operations at a plant in Rocky Flats, Colorado. Or the State of New York, DOE, NRC, etc., must set specific standards (or make choice of the evils) that are applicable to the West Valley Reprocessing Plant (about 30 miles from Buffalo, NY).

The principal radiation standard we are here to discuss (or debate) today is the occupational MPE level of 5 rem/y to the total body and by implication we may refer to the numerous environmental levels of 0.5 rem/y (max), 0.17 rem/y (av), and operational levels of NRC such as 0.003 rem/y for liquid effluents, 0.01 rad/y for γ-gaseous effluents, 0.015 rem/y for radioiodine and particulates, etc. We would be seriously remiss in our discussions were we to fail to consider internal dose from radioactive materials deposited inside the body or values of maximum permissible body burden, q(μC) and corresponding maximum permissible concentration, MPC (μCi/cc), for the various radionuclides in air, water and foods. At the present time values of q are based on the amount of the radionuclide in the total body that would under equilibrium conditions or in 50 years result in the limiting occupational dose rate R (rem/y) to the critical body organ. The values of MPC are the concentrations of the radionuclide (μCi/cc) in air or water (including that in food) that would after 50 years of occupational exposure (40 hrs/wk with 2 wks/y vacation) result in a body burden q or a dose rate R to the critical organ (see Table II for present values of R of MPE). For most radionuclides equilibrium is reached in days or weeks; for example, exposure to the MPC of I-131 for 50 days results in a dose rate of 29.69 rem/y to the thyroid (99% of the MPE of 30 rem/y for thyroid) because the effective half life of I-131 is only 7.6 days while exposure of Pu-239 for 50 years results in a dose rate of 30 rem/y to the bone but only 16% of equilibrium is reached because the effective half life of Pu-239 in human bone is 197 years. It is for this very reason that it would be unfortunate for an employee to deposit a total body burden of Pu-239 in his body because then with no additional intake of Pu-239 he would receive a dose to the skeleton of 30 rem/y essentially for the rest of his life.

One of the most unfortunate recent developments in the setting of standards for exposure to ionizing radiations is that ICRP has issued its report ICRP No. 26[2] in which it is recommending weighting factors, W_i, which I interpret will result in large increases in the present ICRP values of MPE (or R) and in all values of q and MPC except where the radionuclides are rather uniformly distributed throughout the body (i.e. they are total body seekers). The table below summarizes these values.

TABLE II*

Organ	Present value of MPE or R (rem/y)	Values of W_i in ICRP No. 26	New Values of MPE or R (rem/y)
total body	5	1	5
gonads	5	0.25	20
breast	15	0.15	32
red marrow	5	0.12	42
lung	15	0.12	42
thyroid	30	0.03	167
bone	30	0.03	167
skin	30	—	—
remainder	15	0.3	17

*I should say that it was only yesterday after many months effort that I finally received a xerox copy of ICRP No. 26 so my interpretation above may be in error.

I consider this report a retrograde step of the ICRP because it comes at a time when their own reports emphasize that the cancer risk is 10 to 20 times what we considered it to be 15 years ago. This change was made in an effort to remove the inconsistency that the MPE for total body has been the same as that for gonads and red marrow. What ICRP should have done is normalize on an MPE of 5 rem/y for gonads and red marrow and set the MPE for total body at some value less than 5 rem/y. I sincerely hope NCRP, BEIR, NRC, EPA, etc., in this country will raise strong objection to this move of ICRR and reject these new values which would tend to increase q and MPC.

Finally, we must keep in mind that according to the linear hypothesis it is not the values of annual MPE which we set that limit the annual risks of cancer and genetic mutations but the annual population dose (man.rem/year). This is why I have been skeptical about the effectiveness of lowering the MPE. For example, most of the National Laboratories of DOE, EPA, BRH, etc., maintain individual exposure levels at less than 5 to 10% of the MPE. However, operations like West Valley and many of the nuclear power plants have not been able to stay below the individual values of MPE without hiring more people on temporary basis and spreading out the dose. This practice is called "burning out employees." This always increases the population dose (man.rem/y) because on hot operations, much of the dose is on entering and leaving the hot area and because temporary employees are not as familiar with the risks or skilled in the job. I consider this practice immoral. I hope in our discussions today we will provide the Congress of the United States a better basis for setting radiation protection standards.

REFERENCES

1. K. Z. Morgan, "Significance of Human Exposure to Low-Level Radiation," presented at the hearings on Low-Level Exposure before the Subcommittee on Health and the Environment of the Committee on Interstate and Foreign Commerce of the Congress of the United States, Washington, D. C., January 24, 1978.

2. Recommendations of the International Commission on Radiological Protection, ICRP No. 26, Pergamon Press (1977).

Reprint from

"ADVANCES IN RADIATION PROTECTION MONITORING"

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1979

Invited Paper

THE PURPOSE OF RADIATION PROTECTION MONITORING

K.Z. MORGAN
School of Nuclear Engineering,
Georgia Institute of Technology,
Atlanta, Georgia,
United States of America

Abstract

THE PURPOSE OF RADIATION PROTECTION MONITORING.

In the early period (1942–1960) of nuclear energy programmes with which I was associated, most radiation protection standards seem to have been formulated on the assumption that there is a threshold dose of ionizing radiation below which no radiation damage is expected to result in the lifetime of the exposed individual. It was in this climate of opinion that health physics began as a profession, and levels of maximum permissible exposure (MPE) to external sources of radiation, maximum permissible concentrations in air, water and food, and maximum permissible body burdens of radionuclides inside the human body were set and enforced. Some of the levels of MPE were quite high in comparison with present standards but, fortunately, the health physicists at the national laboratories in which most radiation workers were employed were very conservative; in most cases the average annual exposures were less than 10% of the MPE levels. However, there was not much concern with the man-rem concept, as exemplified by rather high levels of radioactive waste discharged from the plants or placed in temporary holding facilities – where there was a likely possibility of seepage into the environment. This situation was understandable and justifiable at a time when the purpose of radiation protection monitoring was simply to prevent individuals from exceeding a threshold dose. The period of the recent past up to the present time (1978) has been one in which there has been a gradual change from the concept of a threshold dose hypothesis to the linear hypothesis. In this period the International Commission on Radiological Protection (ICRP) and the national standards setting bodies have pointed out that the levels they have selected are based on the linear hypothesis, but in most respects they leave us with the impression that this is most probably a conservative assumption, subject to revision when better data become available. Also, during this period, the concept of exposure As Low As Reasonably Achievable (ALARA) was developed. However, some parts of the nuclear industry began to experience difficulties in living within the MPE levels and ignored the principles of ALARA. In spite of strong evidence that the risk of radiation injury at low levels of exposure is related more to the man-rem dose than to the MPE of individuals, they resorted to the pseudo solution of spreading out the dose from "hot jobs" by hiring temporary employees or to a practice commonly referred to as "burning out of employees". This practice is frowned on by the United States Nuclear Regulatory Commission and, hopefully, it will soon be discontinued by better conformance with ALARA. The period of the present and into the future seems to portend an increasing awareness that no level of exposure to ionizing radiation can be so low that the risk of radiation injury is zero. Thus, the purpose and mission of health physics must be that of ALARA, and of balancing the benefits against the risks, and of choosing the energy sources for which this balance is most favourable to all mankind.

useful to have a quick answer to the isotopic abundance of radionuclides of strontium, caesium, iodine, cobalt, plutonium, americium, etc. Some nuclear reactor power plants are using simpl[illegible]ng BF_3 counter to assess the neutron dose when it is well known this [illegible]n only provide some estimate of the total neutron flux $\sum_E N(E)$, whi[illegible]mber of terms in the well known neutron dose, D_n (rem), equa[illegible]

$$D_n = 1.602 \times 10^8 \sum_i \sum_j \sum_E N_i \, \sigma_{ij}(E) \, E_E \, \bar{\epsilon}_{ij} \, N(E) \, Q_{Ej} \, N_j \, t$$

Also many plants either provide no neutron personnel monitoring or are using the NTA photographic emulsion which may be as useful as no monitoring at all. Although it has been shown by Sohrabi and Morgan [1] that personnel monitoring with polycarbonate foils that are processed by the electrochemical etch technique provides a sensitivity of more than 10 000 times that of the NTA film and does not lose information due to track fading, only one company in the USA is providing this type of neutron monitoring service and it has only a few customers for this service.

Underground uranium mines

Underground uranium mines are still operated without adequate personnel monitoring of ^{222}Rn in spite of the fact that several promising metering systems have been developed. Maybe most of the fault is with mine operators and the miners themselves; but perhaps if more reliable, convenient and cheap radon personnel monitors were provided, they would be in common use.

Decommissioning

Decommissioning of nuclear facilities is becoming a specialized, very common and important health physics operation. Especially adapted instruments would improve these operations. Here, for example, instruments are needed that can be used to survey rapidly and with precision very large areas. The US Bureau of Radiological Health developed an instrument of this type consisting of an array of thin window Geiger-Müller counters operated in such a manner that the output response was only that from the GM counter detecting the highest dose rate. This instrument was used for rapid survey of TV sets to measure beams of low

energy (< 30 kV) X-rays. Similar instruments could be developed for X, γ, α, β and neutron area surveys and for air sampling. If such instruments had been available to the Radiological Health Service Department of the State of Georgia in 1972 when the nuclear reactor site near Dawsonville, Georgia [2], was decommissioned, much adverse publicity could have been avoided.

Microdosimetry, too, would require better instrumentation. There is an increasing need to know the local dose in body organs, such as the absorbed dose at the third bifurcation of the bronchus, the dose in lymph nodes, the dose to the endosteal tissue of bone, etc.

Much of this Symposium is devoted to a discussion of desirable characteristics of radiation detection or measuring instruments, so here I will only list what I consider to be some of the more important or essential characteristics of an instrument that is to meet the purpose and requirements of a well developed health physics programme. Typically one requires:

1. Survey meters that are easy to read and not likely to be misread.
2. Meters that are energy independent over the range for which they are used.
3. Survey and personnel monitoring instruments that are rugged.
4. Instruments that can be zero set in the operating area.
5. Instruments that can be decontaminated easily.
6. Instruments that operate properly under weather conditions to which they are exposed.
7. Pulsed instruments with a short time constant.
8. Instruments whose readings are not affected by external electric or magnetic fields or by light and temperature changes.
9. Instruments whose sensitivity can be adjusted easily during calibration.
10. Instruments whose cost is low.
11. Instruments that are convenient to use: low weight, small size, easy to carry, etc.
12. Instruments with a low zero drift.
13. Instruments giving the desired accuracy in measurement of absorbed dose.
14. Instruments that are not excessively geotropic with a small parallax error.
15. An instrument that, when it fails, should *fail safe* so that the operator can be confident that it is operating properly at all times.
16. Batteries should last a long time and be of rechargeable type.
17. Instruments should have proper range settings.
18. Instruments should respond essentially to one type of radiation at a time.
19. Instruments should not loose information due to leakage or track fading.

From the above list it is recognized that no health physics instrument is perfect but, as seen from papers presented at this Symposium, many instruments are in use that can and should be improved to provide a more reliable radiation monitoring service.

3. PURPOSE OF RADIATION PROTECTION MONITORING DURING THE EARLY PERIOD

During the first half of the atomic age (1942–1960) most persons who were knowledgeable in health physics and radiobiology accepted the threshold hypothesis or subscribed to the theory that there is a safe level of exposure to ionizing radiation and that no harm will result to a person or that radiation damage will be repaired as fast as it is produced as long as a person does not exceed this threshold dose. This appeared to be true especially for somatic damage such as erythema (reddening of the skin) and it was supposed to be true also for chronic somatic damage such as radiation induced malignancies. Opinion was somewhat divided regarding genetic damage, and early studies on drosophila by H.J. Müller provided disquieting evidence that probably in the case of man there would be little, if any, repair of genetic damage. Thus, in 1958 the International Commission on Radiological Protection (ICRP) [3] suggested that the genetic dose to the whole population from all sources additional to natural background should not exceed 5 rem (= 5000/30 = 170 mrem/a) plus the lowest practicable contribution from medical exposure. Prior to 1960 there were numerous cases where researchers, dentists, radiologists and others were seriously injured or lost their lives as a result of exposure to ionizing radiation even though in most cases the exposures were kept below the so-called threshold dose. For example, Seltser and Sartwell [4] showed that the incidence of leukaemia among radiologists in the age group 50–68 years was 7.3 times that of the control group during the period 1935 to 1958 and there was a life shortening of about 5 years of radiologists during the period 1935–44.

During this early period when the threshold hypothesis was in vogue, exposures or potential exposures of large numbers of people were permitted at levels much higher than would be considered acceptable today. For example, when in 1943 I was faced with setting the maximum permissible concentration of radioactive contamination in White Oak Lake, which impounded the low-level liquid radioactive waste discharged from Oak Ridge National Laboratory (ORNL), the only standard I had to provide guidance was the occupational exposure level of 0.1 R/d set by the forerunner of the National Council on Radiation Protection in 1934 that had remained in use in the USA until 1950. Some of the engineers at ORNL insisted I should set the level for water in White Oak Lake at 100 R/d because the lake was in a restricted area and it was very unlikely a person would drink or swim in the water. Had I yielded to those early pressures, the 100 R/d level would have been over 7×10^6 times the 5 mrem/a level that is commonly used in the USA today. I deserve no credit, however, for sticking to the 0.1 R/d level, because it was over 7000 times the 5 mrem/a level I would use today.

Radiation exposure permitted to persons during the atmospheric testing of nuclear weapons by the USA in the South Pacific and at the Nevada test site is another case where too much reliance was placed on the threshold hypothesis. This situation was brought into the limelight last year when it was publicized that there is a large increase of statistical significance in the malignancy rate among men who were exposed during test Smoky at the Nevada test site in 1957. Young men who had been drafted into military service were required to take part in military manoeuvres during test Smoky and a number of other weapons tests at the weapons test sites in the South Pacific and Nevada. The radiation doses to which they were exposed were not accurately assessed and in any case were higher than would be permitted now that we no longer subscribe to the threshold hypothesis.

Another example of too much reliance on a safe threshold dose is the case of the nuclear workers at the Portsmouth Naval Shipyard in New Hampshire, USA. Radiation work began at this shipyard in 1959. The shipyard workers were limited to not more than 5 rem/a, and Navy records indicate [5] no one ever accumulated more than 40 rem. The leukaemia rate among these workers is reported to be 450% higher than that of the general population and, in the age group 60–69, nearly 60% of the nuclear employees died of cancer.

Another example of high-level radiation exposure to a large population group during this early period is that of the underground uranium miners in the Colorado Plateau of the USA. Although the pitchblende miner's death was a well recognized cause of early death among pitchblende miners in Saxony and Bohemia as early as the year 1500 and ICRP had set a maximum permissible air concentration (MPC) of 3×10^{-8} μCi/cm^3 of ^{222}Rn (approximately 0.3 working levels) in 1959, many underground miners in the Colorado Plateau areas were being exposed at ten or more working levels as late as 1968. At the Congressional Seminar on Low-Level Ionizing Radiation in 1977, Archer [6] indicated that 170 uranium miners among his 4000 study group have already died of lung cancer and over half of these are of the small oat cell undifferentiated type that is characteristic of miners exposed to ^{222}Rn and its daughter products. Probably belief in the threshold hypothesis influenced this long delay in our adopting the 0.3 WL (or 4 WL months per year) in the USA until 1969.

Many other examples could be given of where things would be done differently today – now that we have abandoned the threshold hypothesis. For example, I suspect that the present day philosophy of radiation protection (ALARA) and support for the linear hypothesis would dictate against some of the early waste disposal methods (such as used at Hanford, Washington) where leaks resulted in thousands of curies of high-level waste escaping into the soil. Or, I daresay, today greater precautions would be taken at Rocky Flats, Colorado, to see that plutonium from storage drums did not leak and contaminate thousands of acres of land with plutonium in residential areas near Denver, Colorado. Hindsight can be a great thing if it provides us with foresight in improving radiation protection monitoring in the years ahead. Experiences such as those related above plus the results of a number of epidemiological studies on the effects of exposure to low levels of ionizing radiation have resulted in "quantum" drops in the levels of MPE. For example, the occupational MPE was reduced by a factor of 10 by ICRP from 1950 to 1956 (from ~ 1 R/week in 1950 to 5 rem/a in 1956) and the exposure limit for members of the public was reduced by a factor of 300 from 1952 to 1974 (NCRP suggested 1.5 rem/a in 1952 and the USERDA suggested 5 mrem/a near a nuclear plant in 1974).

The situation in this early period (1942–60) has resulted in surprisingly few overexposures (e.g. few occupational exposures in excess of the total body MPE of 5 rem/a). The main problem was that a philosophy based on the threshold hypothesis strove to keep individual exposures below the MPE but did not address adequately the question of population exposure (i.e. man·rem). Because of this, it is extremely fortunate that most health physicists have been conservative in setting radiation exposure limits for operations under their supervision and in most large operations the average annual doses have been kept below 10% of the MPE.

4. PURPOSE OF RADIATION PROTECTION MONITORING DURING THE PRESENT PERIOD

Since 1960 a vast amount of human exposure data have been accumulated which lend strong support to the non-threshold hypothesis. I say non-threshold rather than linear hypothesis since much of these data [7] suggest the linear hypothesis is non-conservative at low doses and dose rates especially for high-LET radiation. This is somewhat in contradiction to the ICRP, which implied in early publications (in which it based its standards on the linear hypothesis) that it was most probably making conservative assumptions. Thus, the threshold hypothesis is no longer tenable and there is no so-called safe level of exposure. No dose of ionizing radiation can be so low that the risk of radiation damage (even damage such as fatal cancer) is zero. The risk is simply one of chance that one of the billions of ionizing particles (photon, α, β, neutron, etc.) that strikes the body during a small exposure will produce a change in a single cell of the body such that it survives in its perturbated form to grow into a clone of cells that 5 to 50 years later is diagnosed as a malignancy. Even with a small dose of X-rays of one rad, about 2.2×10^9 photons/cm^2 strike the body, so it is simply a matter of chance that one of the many damaged cells survives to become the precursor of a cancer. Thus, radiation risk is similar to other common risks in everyday life. For example, like the risk we take when we ride in a taxi – the more and the longer the trips we take, the greater the risk; but only one taxi ride in an unlucky person's life could be the one that takes his life.

Without question there is a wide variation in the susceptibility of persons for the development of cancer. Burch [8] suggests that the development of cancer may require a series of random events in a single cell of the body, like throwing electrical switches that are connected in series. For example, one switch may be thrown genetically in certain families and other switches may be thrown by bacteria, viruses, chemicals, radiation, etc. As a person gets older his body contains more and more surviving cells with one or more switches thrown and an increasing number of sites in the body where a malignancy may first manifest itself. Studies by Bross [9] lend strong support to such a series of events and indicate that certain diseases may throw one of these switches in many cells of the body such that there is a synergistic relation between these diseases and exposure to low levels of radiation. He [10] found that the risk a child will die of leukaemia increases 5000% if the child received medical in-utero X-ray exposure and had a disease such as asthma, hives, eczema, allergy, pneumonia, dysentery or rheumatic fev

Many studies indicate that middle aged persons are less susceptible to radiation induced cancer or that it is the young persons [9–19] and the older persons [5, 19, 20] that are most radiosensitive. Such studies suggest to some of us that when we have a "hot" job that must be performed, perhaps we should select healthy middle aged persons for the task; and certainly we should not give these assignments to women who could be pregnant.

As indicated above, many studies [7, 21–26] have indicated that in the case of man the linear hypothesis is non-conservative.

Many times we hear the rather careless statement that there are no data showing a significant increase in radiation related malignancies in man at low doses. If we are willing to define low doses as the annual occupational MPE values, this statement is untrue. Stewart and Kneale [11, 27] have shown that the risk of leukaemia is about 3×10^{-4} leukaemias per man·rem and the total cancer risk is about 6×10^{-4} cancers per man·rem down to doses in the range of 0.2 to 0.8 rad for in-utero exposure. Modan et al. [17], and Silverman and Hoffman [18] have shown that the risk of thyroid carcinoma is about 1.2×10^{-4} thyroid cancers per man·rem down to 6.5 rad. Mancuso et al. [19] report a risk of several types of cancer among Hanford workers that is about 70×10^{-4} cancers per man·rem for doses in the range of 1 to 2 rad. These doses (0.2–0.8, 6.5 and 1–2 rad) are the lowest for which studies of statistical significance of large human populations have been conducted and for which a non-threshold hypothesis applies – they should not be construed as the doses at which the linear hypothesis breaks down for those malignancies in man. Present evidence suggests that the non-linear hypothesis probably holds down to zero dose and that the relationship between cancer induction, C, and dose, D, is given by the simple equation:

$$C = aD^n$$

in which $n < 1$ in most cases of human exposure. Studies of Baum [21] indicate that, in the case of cancer production in man by ^{226}Ra, the best fit for this equation is for n = 1/2. Thus, the cancers produced per rem are greater at low doses than at large doses. Some persons have been misled to believe that cancer production by ^{226}Ra in man conforms to the threshold hypothesis, but when these data are plotted on cartesian co-ordinates rather than semi-log co-ordinates [26, 28] (as is usually done), it is clear that these data conform to a non-threshold hypothesis. Also, some persons have emphasized that the data on cancer induction among the survivors of the atomic bombings of Hiroshima and Nagasaki, although conforming to a linear hypothesis, give a cancer risk much lower than those indicated above, i.e. $(0.5 \text{ to } 1.7) \times 10^{-4}$ cancers per man·rem. Many studies [29] have been published, however, which explain why the data on survivors of atomic bombings underestimate the cancer risk.

From the above, I believe it is clear that the risk of radiation induced cancer by exposure to low levels of ionizing radiation is much greater than it was considered to be 10 to 20 years ago. It may well be that the estimate of 70×10^{-4} cancers per man·rem received by Hanford atomic workers is too large because of the uncertainty of dose measurements in the range of 5 to 30 mrem per meter reading as determined by film badge meters in the early period, but this is no fault of the authors of the study [19] or of the health physics programme at Hanford (which probably was the best in existence at the time). It is, however, a challenge to us at this Symposium to develop personnel monitoring instruments of higher sensitivity and precision at low doses. The TLD meters are a step in this direction, but I fear even in this case the probable errors at 10 mrem are too large for X and γ-radiation and certainly are too large for β-radiation. The uncertainties are definitely too large for α and neutron dose measurements.

In the USA, the Natural Resources Defense Council has petitioned the Nuclear Regulatory Commission and the Environmental Protection Agency to reduce the occupational MPE from 5 rem/a to 0.5 rem/a. Also, the question of effects of low-level exposure has been the subject of heated Congressional hearings in the House and Senate. In my testimony before these two Congressional bodies, I indicated I do not agree that we should reduce the MPE from 5 to 0.5 rem/a for the reasons outlined below:

A. This reduction is directed primarily against the nuclear energy industry and it is the medical profession at whom the finger of guilt should be pointed. The present values of MPE do not apply to patient exposure, yet more than 90% of the dose in the USA from man-made sources derives from medical exposure of the patient. I have shown [30, 31] in many publications that this could be reduced to 10% of the present level and yet have improved medical radiology. Just 1% reduction of medical exposure would reduce the population dose in the USA more than the complete elimination of the nuclear energy industry.

B. I fear this would eliminate much of our nuclear power industry. A shortage of electrical power or a very large increase in power from fossil-fuelled plants would, in my opinion, cause more deaths than the 5 rem/a MPE.

C. Many power plants undoubtedly would solve the problem by hiring more temporary employees and greatly increasing the practice of "burning out of employees". This would lead to an increase in the man·rem dose [32] because temporary employees always receive larger exposures than experienced employees and because a large part of the dose is received in going to and from the hot job, adjusting face masks, learning how to use special tools, etc. This increase in man·rem would mean an increase in radiation induced cancers; the very thing we are trying to reduce.

I recommended that at this time we: (i) reduce the occupational MPE from 5 to 2.5 rem/a; (ii) make certain that this 2.5 rem/a applies where possible to medical exposure of the patient also, and that special efforts be made to apply the principle of ALARA to medical exposure; (iii) set a limit of 200 man·rem/1000 MW(e)·a. While some plants might not be able to reach these two limits I have suggested, I believe most of them would try and, in such a case, there would be a decrease in radiation induced cancers – not an increase.

Finally I close in expressing disappointment with recent action of ICRP [33]. I interpret that the weighting factors, w_T, which it has introduced will result in a large increase in the present values of MPE for individual body organs (although the 5 rem/a for total-body exposure would remain unchanged). This comes at a time when ICRP itself recognizes the increased risk of radiation induced cancer. I am confident that this backward step of ICRP will be rejected for application by the standards setting bodies in the USA.

REFERENCES

[1] SOHRABI, M., MORGAN, K.Z., Some new characteristics of a polycarbonate fast neutron personnel dosimeter, Am. Ind. Hyg. Assoc. J. (1978).

[2] GOOBRICK, C., Abandoned nuclear site still has hot spots, Atlanta Journal and Constitution (14 May 1978).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the ICRP, ICRP Publication 1, Pergamon Press, Oxford (1959).

[4] SELTSER, R., SARTWELL, P.E., The influence of occupational exposure to radiation on the mortality of American radiologists and other medical specialists, Am. J. Epidemiol. **81** 2 (1965).
The effect of occupational exposure to radiation on the mortality of physicians, J. Am. Med. Assoc. **190** (1964) 1046.

[5] TORREY, L., Radiation haunts shipyard workers, New Sci. (16 Mar. 1978) 726.

[6] ARCHER, V., Proceedings of a Congressional Seminar on Low-Level Ionizing Radiation, Environmental Policy Institute, 317 Pennsylvania Ave. S.E., Washington, DC 20003 (Jul. 1977).

[7] MORGAN, K.Z., "The linear hypothesis of radiation damage appears to be non-conservative in many cases", Proc. 4th Int. Congr. IRPA (Paris, 1977), IRPA (1977) *out of print.*
[8] BURCH, P.R.J., "Age and sex distribution of some idiopathic non-malignant conditions in man", Radiation and Conditions in Man, Radiation and Ageing (Proc. Colloq. Austria: LINDOPAND, P.J., SACHER, G.A., Eds), Taylor & Francis (1966) 117. (Also see Chapter 11 and references in text of Principles of Radiation Protection (MORGAN, K.Z., TURNER, J.E., Eds), R.E. Krieger, Publisher (1973).)
[9] BROSS, I.D.J., Leukemia from low-level radiation, New Engl. J. Med. **287** (22 Jul. 1972) 107.
[10] BROSS, I.D.J., Proceedings of a Congressional Seminar on Low-Level Ionizing Radiation, House of Representatives 94th Congress, reprinted by and available from the Environmental Policy Institute, 317 Pennsylvania Ave. S.E., Washington, DC 20003.
[11] STEWART, A., KNEALE, G.W., Radiation dose effects in relation to obstetric X-rays and childhood cancer, Lancet (5 Jun. 1970) 1185.
[12] MACMAHON, B., X-ray exposure and malignancy, J. Am. Med. Assoc. **183** (1963) 721.
[13] BEIR Committee, The effects on populations of exposure to low levels of ionizing radiation, Natl. Acad. Sci. and Natl. Res. Council (Nov. 1972).
[14] HEMPLEMAN, L.H., Neoplasms in youthful populations following X-ray treatment in infancy, Environ. Res. **1** (1967) 338.
[15] HEMPLEMAN, L.H., Risk of thyroid neoplasmas after irradiation in childhood, Science **160** (1968) 159.
[16] ALBERT, R.E., SHORE, R.E., Follow-up study of irradiated tinea capitis cases, Presented at 100th annual meeting of the Am. Public Health Assoc. (1972).
[17] MODAN, B., MART, H., BAIDATZ, D., STEINITZ, R., LEVIN, S.G., Radiation induced head and neck tumors, Lancet **i** (23 Feb. 1974) 277.
[18] SILVERMAN, C., HOFFMAN, D.A., Thyroid tumor risk from radiation during childhood, Prev. Med. **4** (1975) 100.
[19] MANCUSO, T.F., STEWART, A., KNEALE, G., Radiation exposures of Hanford workers dying from cancer and other causes, Health Phys. **33** 5 (5 Nov. 1977) 369.
[20] LEWIS, E.B., Leukemia, radiation and hyperthyroidism, Science **174** (29 Oct. 1971) 454.
[21] BAUM, J.W., Population heterogeneity hypothesis on radiation induced cancer, Health Phys. **25** (Aug. 1973) 97.
[22] CRAIG, A.G., Alternatives to the linear risk hypothesis, Health Phys. **31** (Jul. 1976) 81.
[23] BROWN, J.M., Linearity vs. non-linearity of dose response for radiation carcinogenesis, Health Phys. **31** (Sep. 1976) 231.
[24] HOLFORD, R.M., The relation between juvenile cancer and obstetric radiology, Health Phys. **28** (Feb. 1975) 153.
[25] LANDAU, E., Health effects of low-dose radiation: Problems of assessment, Int. J. Environ. Stud. **6** (1974) 51.
[26] GOFMAN, J.W., TAMPLIN, A.R., The question of safe radiation thresholds for alpha emitting bone seekers in man, Health Phys. **21** (1971) 47.
[27] STEWART, A., Low dose radiation cancers in man, Adv. Cancer Res. **14** (1971) 359.
[28] ROWLAND, R.E., FAILLA, P.M., KEANE, A.T., STEHNEY, A.F., Dose Response Relationships for Tumor Incidence in Radium Patients, Argonne National Laboratory, Radiol. Phys. Div. Ann. Rep. ANL-7760 (July 1969-June 1970), Part II, US Dept. of Commerce, Springfield, VA (1970).
[29] ROTBLAT, J., The puzzle of absent effects, New Sci. (25 Aug. 1977) 476.
[30] MORGAN, K.Z., Risk of cancer from low level exposure to ionizing radiation, accepted for publication Bull. At. Sci., Sep. 1978.

[31] MORGAN, K.Z., Reducing medical exposure to ionizing radiation, Am. Ind. Hyg. Assoc. J. **36** (May 1975) 358.
[32] GOLDEN, J.C., Effect of a change in regulatory limits for occupational radiation exposures of manpower requirements and radiation dose (man·rem) experiences at a nuclear power station, Commonwealth Edison Co. (16 Dec. 1975).
[33] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the ICRP, ICRP Publication 26, Ann. ICRP **1** 3,Pergamon Press, Oxford (1977).

DISCUSSION

D. BENINSON *(Chairman)*: The ICRP dose limits are not (as in previous recommendations) values for design and planning. At present they are the lower limits of a forbidden region: while doses above the limits are automatically forbidden, doses below the limits are not automatically permissible. In this sense the limits are only boundary conditions for the optimization requirement (ALARA, i.e. as low as reasonably achievable).

K.Z. MORGAN: The ICRP is to be commended for its development of the concept of ALARA and for the emphasis it now places on it. I am pleased that our Nuclear Regulatory Commission (NRC) and some of our agencies such as the Environmental Protection Agency emphasize the importance of the ALARA concept. For example our NRC has attached a dollar value of $1000 to the man·rem and stipulated that modifications in equipment or its use should be made if a man·rem can be saved by the expenditure of $1000, even though individual exposures are far below the MPE values. It is to be noted that, if the overall cancer risk is 6×10^{-4} cancers per man·rem this corresponds to $1 700 000 per cancer prevented.

For purposes of design, operation and control, however, we must provide values of maximum permissible exposure (MPE). I hope ICRP will not make use of its values of w_T given in ICRP Publication 26 in such a way that values of MPE for the occupational worker or members of the public will be increased. This is of special importance with reference to permissible body burden or MPC in cases where a radionuclide has a large local concentration in a single body organ.

B. LINDELL: Mr. Morgan's problem with the new ICRP recommendations and the retention of the 5 rem annual dose limit is probably due to the lack of guidance on the *application* of the recommendations in the new ICRP Publication 26. ICRP has clearly stated that continued work over many years near the dose limit would mean work which cannot be classified as "safe" in the same sense as in occupations which are usually considered safe. Such high doses would only be acceptable (just as less safe non-radiation work such as construction work, mining, high-sea fishing, etc. are accepted even though they are not "safe") if (i) the practice is *justified* and (ii) the protection is *optimized* so that, below the dose limits, it is not reasonable to improve protection further.

In most cases of radiation work, however, it will be found that it is *not* reasonable to accept doses near the limits. As a result of optimization assessments, therefore, authorities would be expected, for various purposes, to set authorized operational limits below the ICRP dose limits. Without this extra limitation, Mr. Morgan's concern is understandable. The confusion arises from the fact that ICRP has not yet issued the application recommendations.

K.Z. MORGAN: We will look forward to the publication by ICRP of recommendations on the application of dose limits and of the concept of ALARA. Regardless of what we call the values (e.g. maximum permissible exposure, dose limits or radiation protection guides), we must have limits for proper control of radiation exposure.

In the early period, when most exposures were at large laboratories such as Oak Ridge National Laboratory or Harwell, it was easy for the average exposures in health physics programmes to be limited to less than 10% of the MPE. Now, however, with certain difficulties encountered at many of our reactors (such as the build-up of ^{58}Co and ^{60}Co in th[illegible] generator of the PWR), many workers are averaging close to the MPE of 5 rem/a. In fact the exposures are so high that manufacturing company employees and temporary employees are called in to share the exposure and reduce that received by the local power plant operators (the practice referred to in my paper as "burning out of employees"). Now that we all recognize the risk of radiation-induced cancer to be much greater than was once considered the case, I believe it is very important that ICRP should not take any action that might increase individual or population dose.

G. COWPER: You have suggested that more effort has been made at national nuclear energy research establishments than at other institutions to limit average dose levels to a small fraction of the maximum permissible values. However, this apparent success may be due only to the fact that at such institutions nearly all the workers, no matter how slightly they are exposed to radiation, are required to wear dose-meter badges and records of their trivial exposures are available.

K.Z. MORGAN: I am sure that to a certain extent what you suggest is true; at some of the national laboratories everyone is monitored with a film badge and a considerable fraction of these personnel receive little or no radiation exposure. However, I believe we should expect the radiation risks to be much greater at these laboratories than at a nuclear power plant because of the great variety of radiation sources and the unpredictable nature of research. In 1976 the average man·rem dose at a nuclear power plant operating in the USA was 1200. The average number of employees in each plant was about 600, so the average dose was 2 rem. On the other hand, large national laboratories with over 6000 employees (e.g. Oak Ridge National Laboratory and Argonne National Laboratory) were averaging less than a total of 1000 man·rem. In some of the power plants half of the exposure was to temporary employees who were hired on a short-term basis for "hot" operations. Thus the average dose per man-day was far less at national laboratories than at nuclear power plants. At these power plants 39.5% of the dose was from special maintenance and 31.7% from routine maintenance in 1976. A large fraction of the man·rem dose at the PWRs was from ^{60}Co and ^{58}Co exposure from steam generator repair and inspection, while much of the dose at the BWRs was from work around the recirculation pumps and clean-up systems, fuel-handling equipment, etc. I think the principal fault with power reactors is that they were not designed with the principle of ALARA in mind. Inadequate provision was made for maintenance, repair and inspection to keep the man·rem dose ALARA. In contrast to the situation at nuclear power plants, at ORNL each piece of equipment, each reactor, each project was carefully planned – from its initial design stage to its grave – with ALARA in mind.

M. HÖFERT: In view of what has been said and referring specifically to the example of the increased leukaemia rate among American shipbuilders, none of whom received a dose of more than 40 rem during their working life, would you advocate a limit for a "working-life dose"? It is indeed a fact that it is always the same relatively small number of radiation workers who receive the high doses in a nuclear establishment.

K.Z. MORGAN: Perhaps the Chairman would care to respond to that?

D. BENINSON (*Chairman*): The purpose of the ICRP dose limitation system regarding occupational exposure is to limit the risks *resulting from the occupation*, irrespective of other types of risk or of risks that might be experienced in the future when working in the same or other radiation occupation. The selection of annual limits instead of working-life limits ensures that the safety of the occupation is maintained at the prescribed level.

Y. NISHIWAKI: We are very grateful to you for giving us such a comprehensive introductory lecture. However, because the paper covers a wide field of radiation protection, I noticed a few points which may need some clarification. Firstly, you state that neutron personnel monitoring with polycarbonate foils processed by the electrochemical etch technique provides a sensitivity more than 10 000 times greater than that of NTA film. However, according to our limited experience, cellulose nitrate would be more sensitive than the polycarbonate for detecting fast neutrons directly by counting the etched recoil tracks on the plastic foils. If we use fissile materials with high neutron fission cross-sections placed in contact with the plastic foils and count the etched tracks of fission fragments on the plastic foils after neutron irradiation, a much higher sensitivity would be obtained. For what range of neutron energy did you obtain such a high sensitivity and what particular methods did you use?

K.Z. MORGAN: The increased sensitivity by a factor of 10^4 refers to the ratio of the sensitivity obtained when measuring absorbed dose (rad) with our polycarbonate foil electrochemical etch technique to that obtained when measuring absorbed dose with NTA films. When NTA films are used to measure neutron dose, they only give some indication of the fluence of fast neutrons which, on the basis of a series of assumptions, enables one to estimate (guess at) the neutron absorbed dose. I was perhaps the first person to use these thick photographic emulsions for personnel monitoring at Oak Ridge National Laboratory in 1945, because as a former cosmic ray physicist I recognized that they might at least provide us with information on the neutron flux to which our workers were exposed. As time went on, these NTA films were placed in the film badges of all persons working in areas where neutron exposures were possible, and they were processed routinely on a quarterly basis. Mr. J. Cheka of our health physics division showed that there was a serious loss of information on neutron dose because of track fading. By special packaging to seal out moisture, we were able to extend the half-life of the proton tracks in the emulsion to more than one month, but it was never certain just how many tracks were lost when the films were read on a 13-week basis. Thus we gave the uncertainty in the absorbed dose as estimated from the track density in the NTA films as ± 5–10 rad. With our polycarbonate electrochemical foil technique there is no appreciable track fading over 13 weeks and the absorbed dose is surprisingly close to being proportional to the track density. With proper choice of type of foil, its thickness, the concentration of the KOH used as etchant, etching time, temperature of etchant, voltage and frequency we were able to measure 1 mrad of fast neutrons. Rather than go into a detailed discussion here, I would refer you to an article by M. Sohrabi and myself which is scheduled for publication this summer in the Journal of the American Industrial Hygiene Association. At this point I should like to call on my co-author to respond to your question in more detail. He has worked for many years on various systems of personnel neutron monitoring.

M. SOHRABI: Mr. Morgan has given a detailed and comprehensive answer to the questions asked, and so all I can do is elaborate a little on certain points. There is no doubt that cellulose nitrate is also sensitive to fast neutrons. As you know, we have been working with cellulose nitrate too, using both LR-115 and clear foils. Although regular etching can register tracks very clearly in LR-115, electrochemical etching has not given satisfactory results in this polymer. Also the fading rate is high in cellulose nitrate, as is the case with NTA film, and this can be very serious in tropical climates. On the other hand, polycarbonate has been proven to be unique in many aspects for numerous dosimetry applications, as demonstrated in some of our publications, especially the one cited by Mr. Morgan. Its unlimited range, energy response, insensitivity to gamma rays, zero fading rate and moisture absorption, low cost, availability and simplicity make it superior to other substances. Regarding the question of using fissionable materials, our studies have shown that, for polycarbonate foils, the sensitivity obtained by electrochemical etching can be equal to the sensitivity obtained with the spark counting technique using a combination of 2.8 mg/cm^2 ^{237}Np – 10 μm polycarbonate and there is no range limitation. Of course one should avoid the use of fissionable materials in dose meters placed on the bodies of personnel unless no equally good alternative dosimetry method is available.

Y. NISHIWAKI: Some of the dose-response or dose-effect relationships associated with the cases of exposure at various nuclear facilities cited in your paper are extremely valuable. You emphasize the significance of medical exposure. To what extent are medical exposure and the possibility of exposures to other chemical mutagens or carcinogens taken into consideration in the USA in estimating radiation dose-effect relationships, particularly in cases of low-dose or low-dose-rate exposures and late biological effects?

K.Z. MORGAN: Oddly enough there is great concern in the USA regarding exposure to ionizing radiation from nuclear power facilities but almost no worry about ionizing radiation exposure from medical sources. Also there is very little concern about exposure to sources of non-ionizing radiations (ultraviolet, visible, infrared, microwave, r.f., long wave sonic, ultrasonic and infrasonic). Until very recently, scarcely any attention has been given to other environmental pollutants such as SO_x, NO_x, hydrocarbons, CO_x and particulate matter from fossil-fuelled power plants or to the numerous harmful effluents from our chemical industries. Fortunately, these other industries are now being required to reduce environmental pollution. Likewise various drugs and food additives are being removed from the market because some tests suggest that they may be carcinogens or mutagens.

The medical profession in the USA was until two or three years ago almost free from restrictions in its use of radiation (X-rays, radioisotopes, ultrasonic), yet it delivers more than 90% of the radiation from man-made sources to our population. I have shown that this medical dose could be reduced to 10% of its present value and yet provide improved medical diagnoses and therapy. In our efforts to reduce medical exposure, we have had a few successes but they were long in coming; these include the discontinuance of mass chest X-ray programmes, restrictions on breast survey programmes and the establishment of upper limits for common diagnostic X-ray procedures. Our greatest weakness is in education and certification. Only the States of New York, New Jersey, Kentucky and California require education, training and certification of X-ray technologists in health physics and the harmful effects of radiation. Only California requires such training plus the inclusion of questions on these subjects in the State Board examinations.

Y. NISHIWAKI: In your paper you referred to Burch's work, published in 1966, in which it is suggested that the development of cancer may require a series of random events in a single cell of the body, like throwing electrical switches that are connected in series. In this respect I should like to mention that in the paper I presented at the session on induced mutation at the International Symposium on Genetics held in Japan in 1956, a living cell system is compared to a combination of series and parallel switching circuits, with each switch corresponding to a gene-enzyme system. The action of radiation is then compared to random disturbances of these complex switching circuit systems. Using this assumption, it was shown by means of symbolic logic and target theory that various dose-response curves for cell mutations could be explained quite consistently. The paper was published sometime later in the Japanese Journal of Radiation Research[1,2], but it appeared unfortunately with some misprints in the symbolic logic notation. The full text was published in a limited edition as a Monograph[3] by the Musashi Institute of Technology Press in Tokyo in 1960. I think I gave a copy to Turner of Oak Ridge when he visited me in Tokyo about 15 years ago, but I shall be very glad to give you a full reference to my papers on this subject if you are interested.

K.Z. MORGAN: This is indeed most interesting. I'm sorry I missed seeing these articles in Japanese journals, and would appreciate it very much if you would send me reprints of the papers. As you know, many theories have been proposed to explain carcinogenesis. I think it is almost certain that a malignancy has its origin in a series of random events such that we have no way of knowing which photon or ionizing particle will throw one of the switches in a cell of our body that survives in a perturbed form to be the origin of a cancer. In some cases or for some types of malignancy all the switches in this chain of events may be within a single cell or within the nucleus of this cell and these switches may be connected in series, while in other cases, as you pointed out, the switches may be connected in a parallel-series arrangement. Some of the switches that may be connected in parallel are for example: damage to blood supply of the cell, changes in immune response, damage to cell wall, etc. The point that should be emphasized here is that, if cancer develops in this manner, there is no safe level of exposure to ionizing radiation and the situation is simply one of risk which increases with the amount of radiation exposure. The problem becomes one of balancing the risks against the benefits and of avoiding all unnecessary exposure. It is for this reason that ICRP and many radiation control agencies now emphasize ALARA. The question then is not: "What is a safe level of exposure?" Nor is it: "Is there a risk from low-level exposure?" The question is simply: "How much risk is acceptable from a given exposure?" This question is thus similar to a question such as: "How much risk is there in a given trip in a taxi?"

---

[1] NISHIWAKI, Y., Biophysical interpretation on the biological actions of radiation (I): Correspondence between the relay-contact system and the gene-enzyme and some discussions on the target theory, J. Radiat. Res. (Chiba, Japan) 2 1 (June 1961) 42–60.

[2] NISHIWAKI, Y., Biophysical interpretation on the biological actions of radiations (II): On the examples of the type-analysis of the dose-survival and the dose-effect curves, J. Radiat. Res. (Chiba, Japan) 2 2 (Sep. 1961) 98–123.

[3] NISHIWAKI, Y., Biophysical Interpretation on the Biological Actions of Radiations, Bull. At. Energ. Lab. Musashi Inst. Technol. 1 1, Monogr. (Dec. 1960) pp. 231.

Radiation Induced Cancer in Man*

by

Karl Z. Morgan
Neely Professor
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

A - Introduction

Following the invitation of Senator John Glenn, Chairman of the Subcommittee on Energy, Nuclear Proliferation and Federal Services, I have hurriedly prepared this review of some of the less understood aspects of radiation induced cancer in man. This also is a brief review of the report of the Interagency Task Force on Ionizing Radiation (ITFIR) dated February 20, 1979. Also, at the suggestion of J. Weiss, Staff Director of this Subcommittee, I am submitting a few of my papers on this subject to be entered into the Record and used as references in this discussion. These papers are as follows:

1. "What is the Misunderstanding All About?" by B. L. Cohen and response of K. Z. Morgan and J. Rotblat, Bulletin of Atomic Scientists, 53-59, February, 1979.

2. "Cancer and Low-Level Ionizing Radiation," by K. Z. Morgan, Bulletin of Atomic Scientists, 30-41, September, 1978.

3. "The Linear Hypothesis of Radiation Damage Appears to be Non-Conservative in Many Cases," by K. Z. Morgan, Proceeding IV International Congress of the International Radiation Protection Association, Paris, France, Vol 2, April 26-27, 1977.

4. "Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranic Elements," by K. Z. Morgan, Amer. Industrial Hygiene Assn. Journal, 567, August, 1975.

---

*Presented to the Subcommittee on Energy, Nuclear Proliferation and Federal Services at the invitation of Senator John Glenn, Ohio, Chairman, U. S. Senate, March 6, 1979.

B - Comments on the Report of the ITFIR, February 20, 1979

In general, I believe these are useful reports which help the reader to focus more clearly on some of the major issues, to better understand these problems, and to appreciate the difficulties in obtaining early, definitive answers to questions about the effects of low-level exposure of man to ionizing radiation. I have, however, a few criticisms of this report.

Throughout the text there is failure of the ITFIR to appreciate the fact that there is an abundance of evidence to show that in many and perhaps most cases of low level human exposure to ionizing radiation the cancer risk per rad is greater than at high levels of exposure. Some of the evidence is summarized in reference 3 above.

The reports mention that 78% of research in the U.S. on human studies in this area is supported by DOE. It would have been useful and most appropriate for ITFIR to express an opinion of whether this is good or bad, unfortunately it failed to do so. I believe the way DOE (and its predecessors, ERDA and AEC) handled the Hanford study (moving it inhouse when it appeared it could provide the wrong answers) emphasizes that other government agencies would be more appropriate for this responsibility. It usually is not the best choice to ask the fox to find out who is killing the chickens! In the early period when other government agencies did not appreciate these problems, it was appropriate and was to the credit of AEC that is took the initiative in fostering these research programs, but now times and the climate have changed. It is to the credit also of DOE that so much of its research budget in these areas has been on basic studies and on pathways. It may well be as ITFIR suggests, we will never know the effect of low level exposure of man to ionizing radiation because as the dose approaches zero, the required number of subjects for the study approaches infinity if the answers are to be of statistical significance. Thus, in the long run the answers we seek in a coherent theory of radiation damage may come only from an understanding of the basic mechanisms of radiation damage. It may be of interest to note in passing that the AEC was not always interested in radiation ecology (or pathways research). Over a quarter of a century ago E. G. Struxness of ORNL, Orlando Park of Northwestern University, and I fought long and hard with the AEC to obtain support for these programs which have now proven so rewarding.

It is unfortunate that the ITFIR fails to point out in more detail why some of the data that were used by the BEIR committee, the UNSCEAR, the ICRP, the NCRP, the FRC, and more recently by EPA, DOE, NRC, BRH, etc. in estimating risks of low-level exposure to ionizing radiation, seriously underestimate the radiation risk. I discuss this below.

Throughout the text, ITFIR uses a risk coefficient of only 10^{-4} fatal cancers per person rem. This is the UNSCEAR value for fatal cancers but its value for total cancers is 2×10^{-4} cancers per person rem. Unless there is an urgent requirement to give more business to the doctors and to make medical care more expensive, it seems we should try to reduce the total cancer risk. I doubt seriously many women wish to have their breasts removed or that people delight in living without their thyroids! There are many data which suggest the risk coefficient for man should be at least as large as 6×10^{-4} cancers per person rem. The data of Bross suggest it is about 3×10^{-3} cancers per person rem for children with respiratory diseases (see reference 2, above) while the Hanford data of Mancuso, Stewart, and Kneale suggest a value of about 7×10^{-3} cancers per person rem. Thus, it seems a bit presumptuous for ITFIR to use the value of 10^{-4} without some qualification. One is forced to recognize the bias of the ITFIR when he reads on page 37, "If studies of inadequate size are performed, not only are their results likely to be inconclusive, but they may also mislead by producing exaggerated risk estimates." The reader is disappointed to realize that the ITFIR does not appreciate that it is equally likely the results might underestimate the radiation risk.

The ITFIR seems to cast doubt that the risk, R, could be given by an equation

$$R = CD^n \text{ (where C and n are constants)}$$

in which the power of dose, D, or $n < 1$ because in such a case one might have to assume more than 1% of the natural cancers are caused by background radiation. It is surprising that ITFIR places any confidence in this 1% guesstimate when so much evidence would set the value > 30%.

It is disappointing that ITFIR points out that "Studies of possible interactions between ultraviolet and ionizing radiation have suggested no obvious synergism" and yet, does not mention the recently discovered synergism between UV-B (280-315 nm) and UV-A (315-400 nm).

The ITFIR is to be commended for recommending a more universal record keeping system to record radiation exposures. I did all I could to encourage and boost the efforts of Charles Eason of the AEC in his efforts to establish such a system some two decades ago. Unfortunately, it was strongly opposed by the American College of Radiology and the Health Physics Society and got only lukewarm support of the AEC. We tried to have it include records of all exposure - medical, occupational, internal, external, etc.

The ITFIR is to be commended for encouraging the federal support of epidemiologic studies of human populations exposed to ionizing radiation. I have two comments on this:

1. Unnecessary duplication must be avoided. A case in point is the fact that NIOSH has been charged with the responsibility to investigate the observation that there seems to be an increase of statistical significance in the incidence of leukemia of radiation workers at the Portsmouth Navy Shipyards. In the meantime DOE, not wanting to be outdone, has given a contract for a duplicate study to John Hopkins University.
2. There are many population groups that look promising but after a more careful investigation they would be hopeless. As an example, many years ago Libby of the AEC wanted to study the effects of cosmic radiation on populations at various altitudes. I discouraged such studies not only because of the obvious biases due to changes in oxygen tension, UV radiation, lung volume, etc. but for the fact that the very nature of the radiation under study not only changes in intensity with elevation but its composition changed. For example, at sea level cosmic radiation consists approximately of 84% muons, 14% electrons, and 1% each of neutrons and protons while at 10,000 feet it consists approximately of 45% muons, 32% electrons, 13% protons, and 9% neutrons.

Since the dE/dx or LET of these radiations differ considerably and in an unknown way for various forms of cancer and because terrestrial background differs from place to place, I felt such a study would not be fruitful or worthy of taxpayer support.

Now I wish to comment on some specific topics as follows:

C - Why Some of the Data Used in Setting Radiation Protection Standards Grossly Underestimate the Radiation Risk of Low Exposure

Some of the reasons for this underestimation of radiation risk are given in references 1-4 above, but I wish to expand on this briefly. Two of the most important studies on which our present radiation risks are based are 1) the studies of patients treated with large localized doses of ionizing radiation for ankylosing spondylitis, and 2) Japanese survivors of the bombings of Hiroshima and Nagasaki. Both of these studies grossly underestimate the radiation risk, especially for low exposure.

The ankylosing spondylitis patients (ASP) are a select group in which the increased cancer risk A in Fig. 1 was estimated as the difference between the cancers per rem identified in the ASP's and the general population as determined from national statistics.

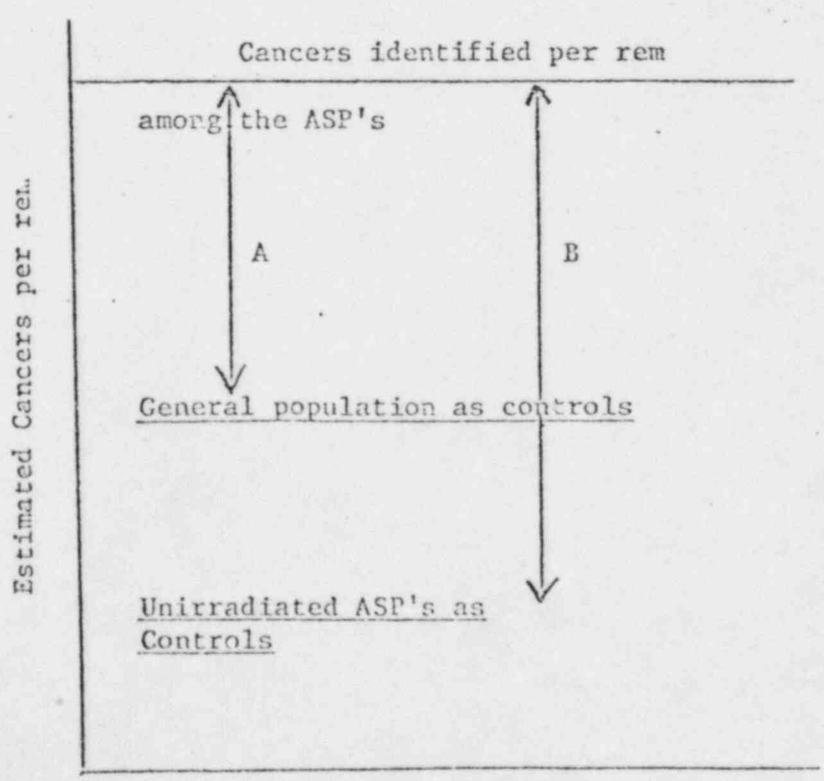


Fig. 1 Cancer risk should be given by B instead of A for the ASP's

Unfortunatley, this was a bad choice because ASP's have been shown to have a lower risk of dying of cancer than the national average because the disease itself reduces the chance they will survive the long incubation period of cancer. The control group should have been the unirradiated ASP's so that B rather than A represents the true cancer risk.

A similar situation exists with the risk estimates of the radiation exposed survivors of the atomic bombings of Hiroshima and Nagasaki. In this case the lower exposed (internal) group was taken as controls to give risk A as shown in Fig. 2. However, this group was exposed. Rotblat, comparing early entrants with late entrants into the blast area found B much greater than A. Although a group of blast victims not exposed to radiation should be used to obtain C, such a group unfortunately is not available.

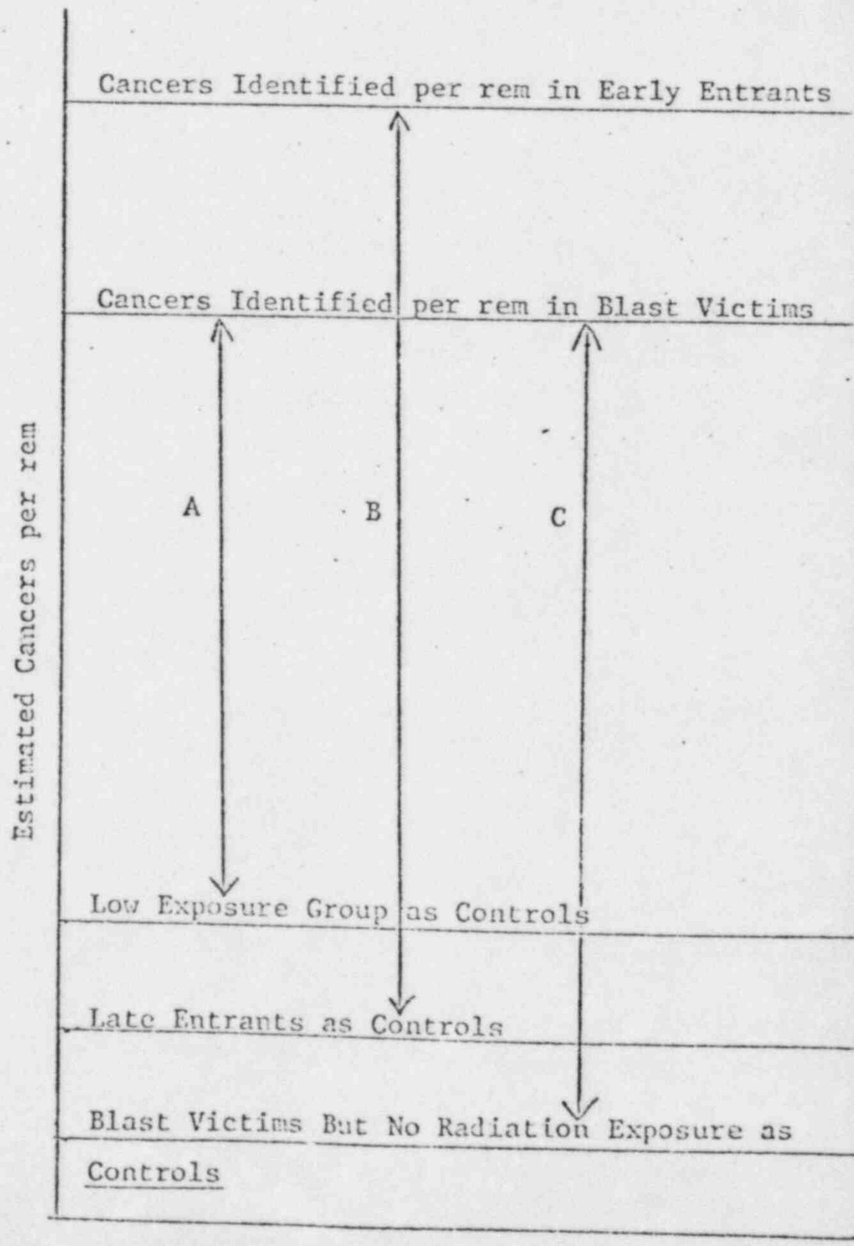
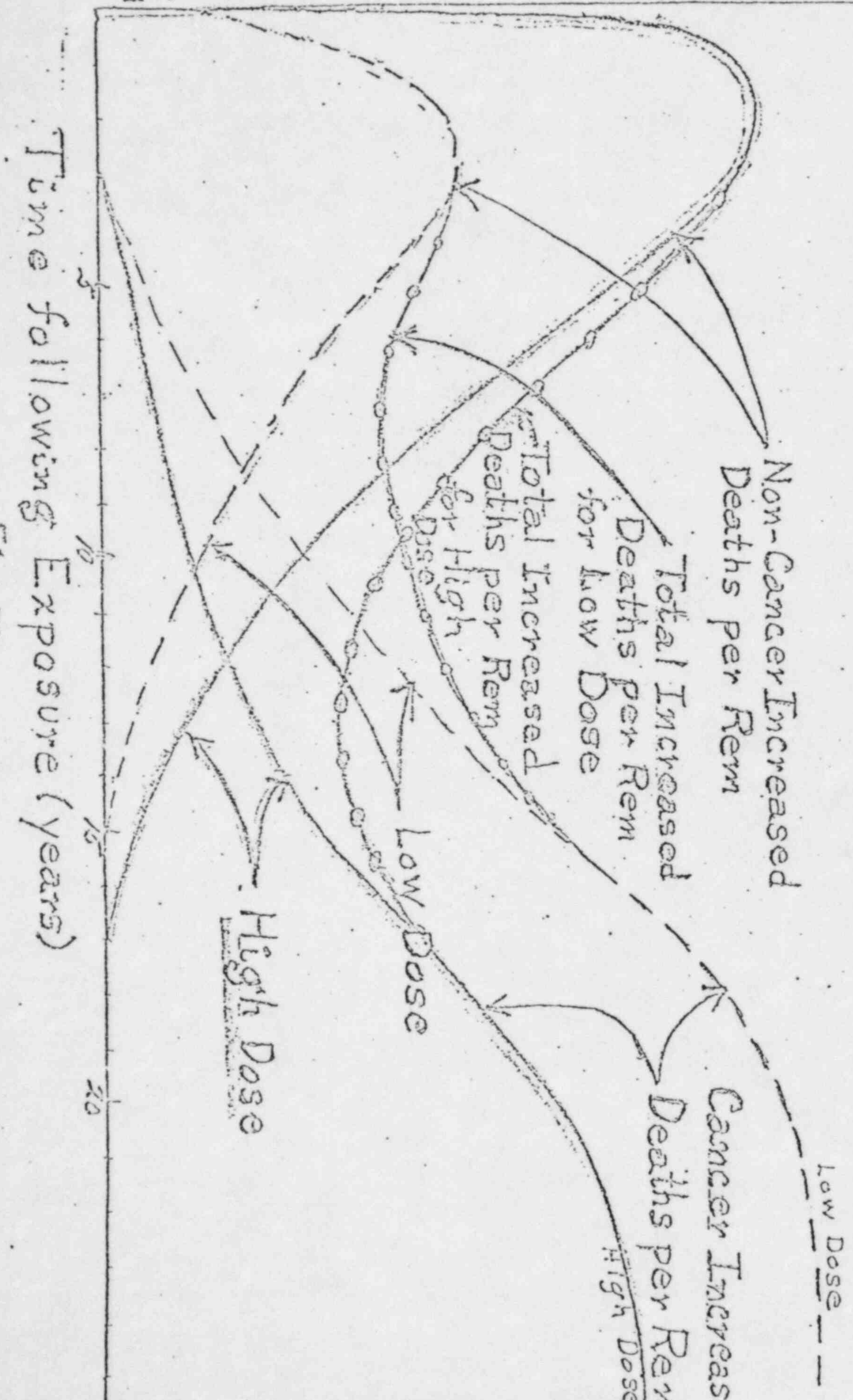


Fig. 2 Cancer risk should be given by C rather than by A. The B may be a close approximation to C.

Increased Death Rate following Exposure



D - Damage to Surveillance Immune System in Relation to Long Latency Period for Cancer Results in a Higher Cancer Risk per rem at Low Doses than at High Doses of Ionizing Radiation

This is shown clearly in Fig. 3. Man's surveillance immune system or reticuloendothetial systems normally holds in check sources of foreign protein including mutant somatic cells or those that are potentially malignant. However, when the body is irradiated there is some loss in immunological competence. This has exactly the same effect on pre-cancer cells and on bacteria and viroses associated with diseases such as pneumonia. However, the latency period for these diseases is much shorter than for cancer and the latency period for the development of a malignancy increases with decreasing dose as shown in Fig. 3 so that the cancers per rem are greater at low doses than at high doses. As indicated by the references above, this seems to be true for all exposure to high LET radiation (α and neutron) and for low LET radiation (x, γ or β) in the case of fetal radiation and for exposure of old persons. In other words, curve C in Fig. 4 seems to provide the best fit in these cases.

Cancer Induction as a Function of Dose of Ionizing Radiation from 0 to 100 rem

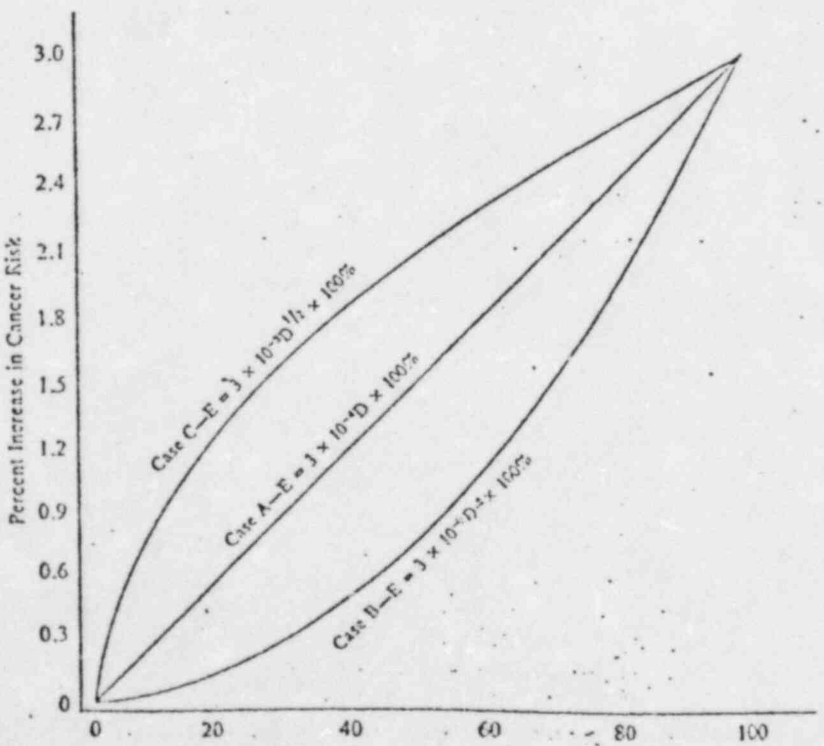


Fig. 4 Dose of Ionizing Radiation (rem)

This figure is a plot of equation

$$E = kD^n\% \qquad (1)$$

in which E = cancer risk (percent of persons with cancer) as a result of exposure to a dose D (rem) of ionizing radiation.

Case A, in which n = 1, illustrates the *linear hypothesis* in which one would expect 3×10^{-4} cancers per person.rem.

Case B, in which n = 2, illustrates the old *threshold hypothesis* where the cancer risk becomes negligible or statistically insignificant at low average dose per person. Perhaps it typifies the low leukemia risk of middle-aged persons that are exposed to low LET (linear energy transfer) radiation.

Recent human studies suggest that Case C, or some other curve for which n < 1, applies to leukemia among the young and the old and perhaps to most other forms of cancer irregardless of the age of the person. In such cases the risk per person.rem is greater at low doses than at high doses.

Curves A, B and C are given primarily for illustration, but each curve appears to be applicable in certain cases. Perhaps it is of interest to note that for a dose of 1 rem the cancer risk is 0.03 percent by the linear hypothesis (curve A) and 3×10^{-4} percent (negligible) by the threshold hypothesis (curve B).

This figure is taken from reference 2 above. There is, of course, always some repair of cell damage caused by exposure to ionizing radiation. This may explain why the low leukemia risk among middle-aged persons where perhaps curve B provides the best fit. In deciding why human data fit curve A, B, or C it is very important to take into proper account the "healthy worker syndrome" such as was the case with the Hanford workers. In the case of children, passive leukemia may be mostly a teratogenic defect following fetal radiation exposure. It may be true that leukemia is a somatic disease in adults which requires more than one insult (as suggested by Burch) before it can develop. Thus, in the case of adult workers with the healthy worker syndrome at Hanford, leukemia follows curve B and has not as yet been a problem. In the case of children, Bross found a synergistic relationship between respiratory disease and radiation exposure which resulted in an increased leukemia incidence of about 5,000%. Here curve C would seem to give the best fit.

E - Uncertainties Regarding Values of Internal Dose

I believe some of the values of maximum permissible body burden, q, and maximum permissible concentration of radionuclides in air $(MPC)_a$ and in water $(MPC)_w$ as published by ICRP and NCRP are very much too high or non-conservative. In stating this I do not intend to be critical of ICRP and NCRP because I was chairman of the Internal Dose Committee of both of those organizations where the present standards (ICRP No. 2, 1959 and NCRP No. 69, 1959) were published. The FRC guidelines and the NRC permissible levels in 10CFR20 are based on these standards. I believe they were based on the best data available in 1959 but much new data have been made available over the past two decades. I will limit this discussion to ^{239}Pu but similar comments might be in order regarding other elements and their radioisotopes.

When we selected the present value for ^{239}Pu or $(MCP)w = 5 \times 10^{-5}$ µCi/cc water for occupational exposure 168 hours per week or 5×10^{4} pCi/ℓ and suggested a value of $(MPC)_w = 1/30\ (MPC)_w^{occ} = 1.7 \times 10^{3}$ pCi/ℓ as an upper limit for drinking water of members of the public, we thought that ^{239}Pu would be in the Pu(IV) state where the fractional uptake from the GI tract was found to be 3×10^{-5}. Recently, however, an article by Larson and Oldham (Science 201, Sept. 15, 1978) indicates that for chlorinated water the state is Pu(VI) so the fractional uptake probably should be about 0.3. Therefore, the ^{239}Pu value for chlorinated water used by members of the public should be

$$1.7 \times 10^{3} \times 3 \times 10^{-5}/0.3 = 0.17 \text{ pCi}/\ell.$$

These values corresponded to a calculated average bone dose of 1 rem per year.

In Carl Johnson's letter to Gip Wilson of Bloomfield, Colorado, he reported that "a composite sample of finished water at Bloomfield for April of last year (1977) indicated levels of 3.03 pCi of ^{239}Pu, ^{240}Pu per liter." This is about 20 times the permissible limit. I would estimate the cancer risk to be

$$70/2 \times 3.03 \left(\frac{\text{pCi}}{\ell}\right) \frac{1}{0.17} \left(\frac{\ell\text{rem}}{\text{pCi}}\right) 10^{-4} \left(\frac{\text{C}}{\text{pers.rem}}\right) 10^{2}\% = 6.2\%$$

risk of cancer of bone or liver over a lifetime use of such water. Since the average cancer risk of everyone in the U.S. is about 20%, this represents a 30% increase in cancer risk of such persons. This added risk might be acceptable because of certain advantages in living in such a community, but one should not overlook the fact that in reference 4 above I point out the present $(MPC)_w$ values may already be too high by a factor of 240 for other reasons.

In closing, I would like to point out that although I am an emeritus member of ICRP, I cannot refrain from saying I believe the ICRP made the greatest mistake of its history when last year it adopted values of w_i (weight factor) which will have the effect of increasing most of the MPC values. This comes at a time when it acknowledges the fact that the cancer risk is much greater than we believed it to be two decades ago. I understand some of our government agencies are considering rejection of this ICRP No. 26 report and I believe this is a very wise move on our part.

Bir 14

Reducing Medical Exposure to Ionizing Radiation

KARL Z. MORGAN

School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332

The author discusses the dangers of indiscriminate and uninformed use of medical x-ray facilities. He points out a lack of effective standards, controls and practices to minimize exposures to x-ray and to prevent the excessive use of diagnostic x-ray examinations. A list of practices whereby an individual can minimize his possible exposures to x-rays is presented. Several approaches to the question of acceptable exposure levels are considered.

Introduction

DAMAGE FROM IONIZING RADIATION was first observed among the pitchblend miners of Saxony and Bohemia about 500 years ago. It is recorded that these miners died of a so called "mountain illness" after 5 to 10 years of underground mining.[1] It was not until after Becquerel's discovery of ionizing radiations from natural uranium that it was realized these early cancer deaths among pitchblend miners were due to exposure to and inhalation of the daughter products of ^{222}Rn from the uranium contained in the ores associated with the pitchblend.

After Roentgen publicly announced his discovery of x-rays on January 4, 1896, man was not long in finding out about the harmful effects of these rays. In fact, only 23 days later Grubbe,[2,3] a manufacturer of Crookes tubes sought medical aid for serious radiation burns on his hands. During the next few decades hundreds of cases of radiation damage—mostly as a result of medical application of x-rays—were reported in the literature. This early reported damage from the medical use of x-rays consisted mostly of skin erthyema which in many cases progressed to ulceration and in some cases resulted in cancer. In a few cases there were reported cases of lens cataracts and radiation deaths.

Reductions in Levels of Permissible Exposure

Through the years there have been many reductions in levels of maximum permissible exposure to ionizing radiation. Rather, one should say there were reductions in tolerance levels for during the early period it was generally believed there was a safe threshold dose below which there would be no radiation damage. So long as this tolerance dose (or threshold) was not exceeded and there were no sign of skin erythema, it was assumed no radiation damage would ever manifest itself. Some of the early tolerance levels were very high in comparison with present values. For example, Rollins[2,4] in 1902 suggested an occupational exposure level which corresponded to about 10 R/day. It is recognized that this value is over 700 times the present day maximum permissible occupational exposure, MPE, of 5 rem/year. It is fortunate there were very few persons that were occupationally exposed in this early period and the x-ray tube voltages in use were relatively low. Even as late as 1925 Mutscheller and Sieveret[2,4] suggested an erythema dose which corresponded to about 25 R/year or a value five times the present occupational MPE.

Landauer Memorial Lecture given at Stanford University, September 27, 1974.

There have been corresponding reductions in exposure limits for members of the public. For example in 1952, the International Commission on Radiological Protection, ICRP,[2,5] suggested a value of 1.5 rem/y and this is over 300 times the present guide of 5 mrem/year as suggested by the U.S. Atomic Energy Commission as an exposure limit for persons living near a 1000 MWe light water cooled nuclear power plant.

Perhaps no one at the present time can give an accurate answer to the question, "Will there be further reductions in permissible exposure levels in the years ahead?" I suspect the ICRP and the National Council on Radiation Protection, NCRP, will make some minor adjustments in the present dose limits to the various body organs in an attempt to make them a bit more internally consistent, but otherwise I do not expect changes. There will be many changes next year in the ICRP values of maximum permissible annual intake of the various radionuclides, but these changes reflect new data applied to more sophisticated metabolic models rather than basic changes in organ dose limits. Also, there will be many changes in radiation regulations, codes of practices and laws, but these changes will reflect for the most part an effort to update them so that they conform to the current philosophy of keeping radiation exposures of members of the public "as low as practicable." For example, present regulations permit passengers and crew of airplanes to be exposed at the rate of 10 mrem/hr which is not at all consistent with the AEC "as low as practicable" guide of 5 mrem/y for persons living near a nuclear power reactor. The panel of the Joint Committee on Atomic Energy[6] (of which I am a member) has just recommended this limiting dose rate in passenger aircraft be reduced to 1 mrem/hr at any point in the aircraft, *i.e.* at floor level.

Are Medical Exposures in the U.S. Excessive?

This question can be answered only with a resounding *yes*. Medical diagnostic exposure in the U.S. is 2 to 10 times that in most advanced countries of the world and in many respects our medical benefits per dollar spent on medical care are not better or worse than in these other countries. This average medical exposure in the U.S. could easily be reduced to 10% of its present level by the application of better techniques, in the use of improved x-ray equipment which is operated only by medical and paramedical personnel with proper education, training, certification, and motivation. Our medical institutions are in financial difficulties and in many cases x-rays are given to patients to provide needed revenue. Often x-rays are required of the patient before he can be admitted to a hospital, before he can take a new job, or before he can settle claims resulting from an automobile accident. It is a sad commentary on our society and a serious infringement on the civil rights of an individual that in many cases he is forced to have these x-rays (many of which he knows are completely unnecessary) or suffer serious financial loss, lose his job, or be deprived of needed medical and dental care. The same situation seems to be developing in the excessive use of radiopharmaceuticals. This situation is aggravated by the extreme ignorance of the average medical man or doctor who knows absolutely nothing about the harmful effects of ionizing radiation on man and yet is presumed to weigh the benefits against the risks when he prescribes an x-ray for his patient. I think there is a serious flaw in the recommendations of NCRP and ICRP in that all their radiation exposure limits exempt medical exposure—even those from routine diagnoses—from any regulatory control on the thesis the doctor knows best and can weigh the benefits of the diagnosis against the radiation risks. Unfortunately, the medical "crown" does not compensate for ignorance and stupidity of the average medical doctor or dentist. Some of the finest and most competent people in the world are members of the medical profession. However, collectively, as represented by their professional organizations, they seem to be far more interested in maintaining a high income, an unquestioned authority, and having a blank check which permits them to expose the patient to any amount of ionizing radiation. Often there is displayed an arrogance which leaves the impression that the American Medical Association, American College of Radiology, American Dental Association, etc. are far more interested in convincing the public they have an unblemished record and have made no mistakes than in preventing radiation damage to the patient. For example, when the ICRP[7] first recommended that a radiological examination of the pelvis and abdominal regions of a woman in the child-bearing age be limited to the 10 day interval following the onset of menstruation unless the examination is of importance in connection with her immediate illness, the ACR and some of its members were the first to object to this recommendation and use ridiculous arguments against it.

The sad state of medical diagnostic radiology in the U.S. was emphasized by Dr. McClenahan[8] when he enumerated some of the reasons for excessvie patient exposure as follows:

"1. It is easier for the doctor (and I might add, in many cases the nurse) to order an x-ray examination than to think.

2. Examinations are ordered "to rule out" when accurate diagnosis has been made with the naked eye.

3. Heavy legal penalties for failure to do radiographic examinations, but no penalties for unnecessary exposure of patient.

4. Insurance covers most costs for x-ray examinations.

5. More films per diagnosis now required than formerly.

6. Shortage of trained workers leading to hasty, hazardous techniques.

7. Folkways and traditional rites."

In another publication[9] I have added to the list 28 other important reasons why the use of ionizing radiation in medical diagnoses in the U.S. is excessive.

The data[10] given in Table I emphasize the fact that there is unnecessary and excessive dose to the patient from diagnostic x-rays.

For years it has been possible to obtain a good chest x-ray with a skin dose to the patient of 5 to 10 mrem, yet even today many patients are subjected to doses of several thousand mrem. For many years it was known that mass chest x-ray programs in the U.S. were almost worthless. For example, in 1965 the United States Public Health Service[11] urged that they be discontinued yet it was only in 1972 that a halt was brought[12] to the practice of driving a truck up to our schools and marching our children through to be x-rayed much the same as we brand sheep except the x-ray is more harmful to the child than the brand is to a sheep. It would be interesting to know how many of these children, as a consequence of this radiation exposure, later developed cancer of the lung, breast, or thyroid, or how many cases of leukemia resulted.

Table I also indicates the wide range in skin dose from the usual series of dental x-rays. Perhaps one could justify slightly larger doses in some cases if better radiographic information were obtained, but just the contrary is true. Almost always the higher doses result in less detailed radiographic information.

Which Is More Tenable, the Linear or the Threshold Hypothesis?

As the population doses of ionizing radiation are reduced in any animal or human study, it requires a larger and larger population (and correspondingly greater expense) to obtain information on the effects of this radiation and as the doses approach zero the probable errors approach infinity. Therefore, it will never be possible to show experimentally whether the linear or the threshold hypothesis applies at very low doses. It may, however, be possible some day to develop a coherent theory of radiation damage which will answer this question.

As mentioned above, during the early period the threshold hypothesis of radiation damage was commonly accepted and as a

TABLE I
Common Diagnostic X-Ray Exposures
(mrem to skin) in the United States

	Range of Values	Average
Chest x-ray at ORNL (radiographic)	10-20	15[a]
Chest x-ray in U.S. (radiographic)	10-300	45[b]
Chest x-ray in U.S. (photofluorographic)	200-2000	504[b]
Dental x-ray series in U.S.	1000-100,000	20,000[b]
Abdomen (radiograph):		
Given by a radiologist		636[b]
Given by others		1,253[b]

[a]Average chest x-ray dose delivered at Oak Ridge National Laboratory (1972).

[b]These average values were given in the report "Population Exposure to X-Rays, U.S. 1964," J. N. Gitlin and P. S. Lawrence, HEW-PHS 1964 (13).

consequence in the early period reference was made to "tolerance dose" and "threshold erythema." The exposure was considered safe and no ill effects were expected so long as the tolerance dose rate and dose were not exceeded. During the past 25 years, however, there has accumulated a preponderance of evidence which indicates there is no safe threshold dose and in fact both experimental and theoretical evidence seem to indicate there is no dose or dose rate of ionizing radiation so low that the risk of radiation damage is zero. Perhaps the best way to emphasize how the present philosophy of "as low as practicable" evolved is to refer back to the 1958 ICRP[14] description of the "permissible dose" which was as follows:

> "The permissible dose for an individual is that dose, accumulated over a long period of time or resulting from a single exposure which in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities. Any severe somatic injuries, such as leukemia, that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can, therefore, be expected to produce effects that could be detectable only by statistical methods applied to large groups."

When a photon of high energy radiation enters the human body, one of four things is likely to happen: (a) it will pass through the body without hitting anything, (b) it hits some part of a cell in the body and causes damage but the damage is completely repaired, (c) it hits a cell of the body causing its destruction or damages it such that it cannot reproduce itself, and (d) it is damaged and survives to produce a clone of perturbated cells which eventually is diagnosed as a cancer.

Every normal living cell of the human body has a nucleus in which are 46 chromosomes (with exception of germ cells which contain only 23). Each of the chromosomes carries the genes which in combinations correspond to millions of books instructing the cell what to do under a great variety of situations (*e.g.* when to reproduce, when to produce certain essential chemicals, how large an organ should be, etc.). When radiation enters this cell it is like a madman entering the library and destroying pages from thousands of books in this "cell library." In the physics world this corresponds to an increase of entropy of the system, an introduction of static or a loss of organization. One chance in a million this random change in the nucleus of a cell may be of benefit to the race—thus evolution—but from a practical point of view for the individual the risk of cell damage is overwhelming so that all radiation exposure must be considered potentially harmful to the cell and to the individual.

Many people seem not to understand why there isn't a "safe" level of radiation exposure and we must explain to them that damage—even serious damage—from radiation exposure is merely a matter of chance like most other things in life. Often medical doctors and representatives of their professional organizations make the foolish and most ridiculous defensive statement that there has never been a case where a person has suffered from a diagnostic exposure—they say there is no evidence. In making such a statement they belie themselves and prove they are not scientific in their thinking. The scientist that accepts the General Gas Law ($PV = RT$) or Ohm's Law ($V = RI$) must believe in statistics.

Exposure to high energy radiation is like running blindfolded across a highway on which cars are moving at a high rate of speed. If we are hit, we can be just as dead whether we try this foolish crossing during rush hour or after midnight. In like manner, radiation exposure even at the permissible level can cause our death but the risk at this level is so small in comparison to other risks that we willingly accept it but we keep in mind that the higher the radiation dose and the greater the number of exposures, the greater the risk. Thus, in all areas except where the medical patient is involved, we have developed the philosophy of keeping radiation exposures as low as practicable and permitting no radiation exposure unless the benefits exceed the risks. It is true there is repair of many of the body cells that are damaged by radiation but there is always some residual body change which may in time manifest itself in one or more forms of radiation damage such as cancer.

There are many insults in man's environment which can cause body damage. Some may act independently, others collectively and some synergistically with one another. Cancer probably is brought on by a series of events and may be triggered finally by such things as virus, bacteria, chemicals, radiation, etc. Perhaps the developments leading to the onset of cancer are like throwing several switches in series—nothing happens until all switches are closed. One of these switches may be an inherited factor, another

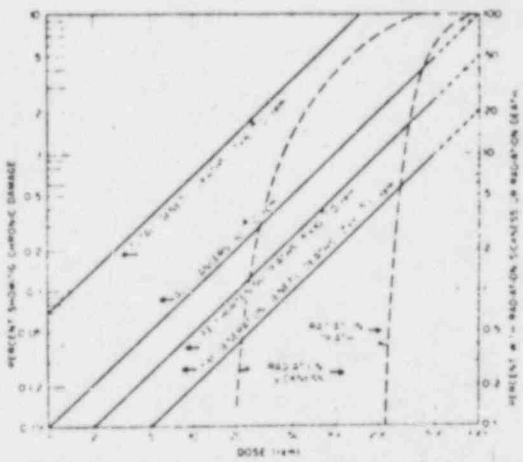


Figure 1. Relationship of radiation dose in humans to chronic damage radiation sickness and death. (From data of the International Commission on Radiological Protection.)

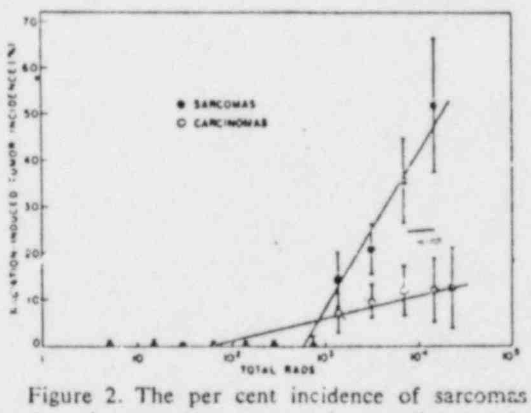


Figure 2. The per cent incidence of sarcomas and carcinomas plotted separately on a linear scale against the median of the total skeletal dose in rads on a logarithmic scale. (ANL-7760, Part II, U.S. Department of Commerce, Springfield, VA, July, 1969-June, 1970.)

a virus infection, and the final triggering event might be a radiation exposure.

Figure 1 indicates that the threshold hypothesis applies to such things as radiation sickness and acute radiation death from large doses of radiation delivered over a short period of time of not more than a few days while the incidence of such things as genetic damage, life shortening and cancer production seem to relate, more or less, linearly to the accumulated dose.[9]

Sometimes data are presented in such a way as to suggest to the non-scientist that the threshold hypothesis applies. For example, Figure 2 is a plot of the incidence of cancer (sarcomas and carcinomas) as a function of the accumulated dose from radium deposited in the human body (mostly among radium dial painters).[9] The non-scientist may not appreciate the fact that the curves do *not* suggest threshold doses at about 80 rads for carcinomas and about 900 rads for sarcomas because the abscissa is a logrithmic scale. When the same data are replotted by Rowland on a linear scale as in Figure 3, it is clear that at low doses there is no suggestion of a deviation from the linear hypothesis.[9] The curves in Figure 3 bend over at the higher doses because the radiation exposure causes death in many of the persons before they have time to develop cancer.

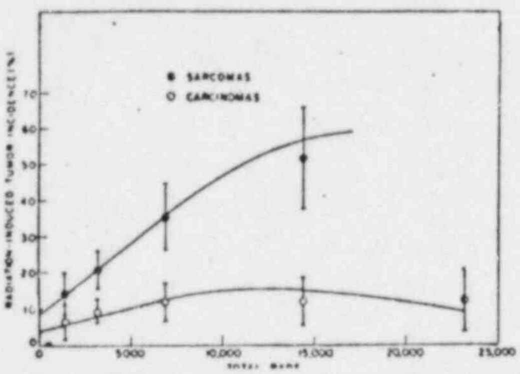


Figure 3. The per cent incidence of sarcomas and carcinomas plotted separately against the median value of the total skeletal dose in rads in linear coordinates. (ANL-7760, Part II, U.S. Department of Commerce, Springfield, VA, July, 1969-June, 1970.)

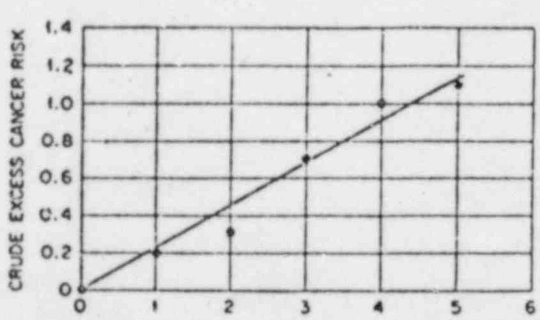


Figure 4. Relationship of cancer in children to the number of pelvic x-ray examinations received by their mothers during pregnancy. (Data from Alice Stewart and G. W. Kneale, *Lancet*, June, 1970).

Figure 4 is a plot of a typical set of data[9] that seem to support the linear hypothesis The fetus is probably the most radiosensitive member of the population but there are many data which suggest that older people also have a high radiosensitivity. Jablon pointed out that his data on the survivors of the atomic bombings at Hiroshima and Nagasaki, Japan do not seem to support Alice Stewart's findings in her Oxford study of the effects of in utero exposure. However, I have shown that there does not appear to be any inconsistency in these two sets of human exposure data.[10]

There is good evidence also that the radiation insult does not act independently of other human insults such as chemical contaminants and diseases (especially respiratory diseases such as asthma). Table II indicates that there are special groups in the population who are far more radiosensitive than the average member of the public.[15] For example, children of age 1-4 had 3.7 times the risk of developing leukemia if they had allergic disease and 24.6 times the risk if they had both allergic disease and had received intrauterine x-ray exposure.

Is the Linear Hypothesis Conservative?

Often it is stated in the literature that the linear hypothesis, as presently applied, is a

TABLE II
Relative Risks of Leukemia and Probabilities According to Age, Exposure to Intrauterine Radiation and Indicators of Susceptibility

Age	Intra-uterine	Relative Risk				P Value			
yr	Exposure	Group O	Group C	Group B	Group A	Group O	Group C	Group B	Group A
1-4	No	1.0	1.7	2.6	3.7	—	0.06	0.01	0.0009
	Yes	1.5	2.8	8.2	24.6	0.14	0.01	0.0002	0.003
5-9	No	1.0	1.2	2.2	4.4	—	0.64	0.09	0.005
	Yes	1.3	1.3	1.8	5.4	0.73	0.62	0.47	0.01
10-14	No	1.0	1.0	1.6	2.4	—	0.91	0.37	0.17
	Yes	1.1	0.83	4.3	9.5	0.83	0.68	0.06	0.005
1-14	No	1.0	1.4	2.2	3.5	—	0.11	0.003	0.0001
	Yes	1.4	1.7	4.1	8.4	0.16	0.06	0.0001	0.0001

Group A: Children with allergic diseases (*e.g.* asthma and hives)
Group B: Children with bacterial diseases (*e.g.*, pneumonia, whooping cough and dysentery
Group C: Children with childhood virus diseases (*e.g.* chicken pox and red measles)
Group O: Children not in groups A, B, or C.

very conservative assumption. During the past few years, however, many studies have indicated that this probably is not true in general and that at very low doses and dose rates somatic damage per rad probably is usually greater than would be assumed on the linear hypothesis. There are many reasons for this, some of which are:

1. The linear hypothesis is based on extrapolations to zero dose of effects of radiation on humans at intermediate to high doses. The points used on the curves at high doses may be on the down part of the curve as explained above and shown in Figure 3, *i.e.* from the portions of the curve where a large fraction of the highly exposed died of other types of radiation damage and did not survive to die of the radiation effect under study.

2. The extrapolations are made on human data which in general relate human damage such as bone cancer for observation periods of no more than about 20 years. Many of the conclusions are based on studies of animals of life spans less than 10 years. Since man lives for more than 70 years, the slopes of these curves can only increase as more human data are accumulated over his entire life span.

3. The linear hypothesis assumes that man is a uniform and more or less homogeneous population. It applies to the average man and may not be sufficiently conservative for the fetus and for old people. It never takes into consideration special groups such as shown in Table II.

4. There may be cell sterilization at intermediate and high doses. By this we mean there may be many cells in the body which are likely targets to become precursors of a clone of cells which are malignant but they are killed by the higher doses. In other words, these cells may already have two of the "series cancer switches" closed and a low dose of radiation would likely close the last switch in the final step toward cancer production. A high dose, however, might kill most such cells as it does in radiation therapy which is used to destroy a cancer.

5. For many types of radiation damage the best fit curve is a plot of equation $E = CD^n$ in which E = effect, C = constant, D = radiation dose, and n = constant. For the linear hypothesis $n = 1$. In some cases $n > 1$ indicating lesser damage at low doses but in many cases the best fit to experimental data is obtained when $n < 1$. Baum[16] recently showed a best fit for cancer induc-

tion when $n = 1/2$. In such case the linear hypothesis would be non-conservative.

Is Genetic Risk Still the Limiting Form of Radiation Damage?

In the early period and following the genetic studies on flies by Muller[17] it was generally considered that genetic damage to one's children and to future generations from exposure to ionizing radiation was far more serious than damage to oneself (or somatic damage). Two things have happened which have changed this belief: (a) Genetic risk now appears to be less of a problem and (b) Cancer risk in man now appears to be 10 or more times greater than was considered to be the case 10 to 15 years ago.

Russell[18] showed that the genetic risk of ionizing radiation was less than had been suggested by earlier studies on flies. His mouse studies indicated that for radiation exposure at low dose rates the number of point mutations from exposure to the spermatogonia were about 1/3 as frequent per rad as at high dose rates and in the case of females there appeared to be complete recovery of any radiation damage to the oocytes. Also, he found that low doses of radiation produced less genetic damage per rad than high doses. The overall result is that exposure at low doses and at low dose rates (as might be expected at permissible levels of population exposure) is now considered to produce about 1/10 the genetic damage that would be produced per rad at high doses and high dose rates.

The studies[19] which indicated human cancer risk from exposure to ionizing radiation is much greater than formally considered were primarily: (a) studies of ankylosing spondylitis patients treated with x-rays, (b) studies of children exposed in uterally to x-ray diagnosis, and (c) studies of survivors of the atomic bombings at Hiroshima and Nagasaki, Japan. As a consequence of these findings, the International Commission on Radiological Protection (ICRP) in 1971 pointed out that "the ratio of somatic to genetic effects after a given exposure is 60 times greater than was thought 15 years ago." In view of these developments the National Academy of Sciences formed the committee on the Biological Effects of Ionizing Radiation (BEIR) and asked it to evaluate the radiation risk to man. It too came out with the conclusion that perhaps somatic risk from exposure to ionizing radiation is greater than the genetic risk. It should be pointed out, however, that this committee gave very little consideration to the risk from recessive mutations, to damage beyond the first generation, and the burden to society from the non-visible mutations. When this is done, it may well be that the genetic risk as claimed by Muller is far greater than the somatic risk from exposure to ionizing radiation.

Are Low Level Exposures Such as Those in Medical Diagnosis Harmful?

The consequences of low level exposure to ionizing radiation on the linear hypothesis

TABLE III
Summary of BEIR Committee Estimates of Risk to a Stable U.S. Population from 170 mrem/y

Serious disabilities, congenital abnormalities, constitutional diseases, death, etc.	1100 to 27,000 (660 to 14,000)[a]
Overall ill health	1.2 to 12% of that in U.S. (0.7 to 7%)[a]
Cancer (deaths/year)	3000 to 15,000 (1800 to 9000)[a]

[a]The values in parentheses are crude extrapolations (by K. Z. Morgan) of the BEIR data giving estimates of the risk to the U.S. population from present medical exposure.

can best be summarized from data given in the BEIR report[19] and as shown in Table III. Here I have applied the BEIR linear hypothesis to obtain crude estimates of the present risk to the U.S. population from medical exposure (mostly diagnostic).

Some persons would like very much to believe that the linear hypothesis is very conservative but as pointed out in the BEIR report and as indicated above, just the reverse may be true. Thus it becomes very important to maintain radiation exposures as low as practicable and not to permit any exposure (such as excessive diagnostic exposure to x-rays when they are not needed for one's health) unless the benefits are considered to exceed the overall risks. We have much to learn about the risks from chronic exposure to ionizing radiations but maybe it is somewhat reassuring that we know far more about the effects of ionizing radiation on man than about the effects of non-ionizing radiations, chemical pollutants, food additives, insecticides, common drugs, etc. It was with this in mind that the BEIR Committee warned that levels of exposure to ionizing radiation should indeed be kept as low as practicable but not at the cost of making some other risk greater such that the overall risks are increased.

It should be kept in mind also that ionizing radiation can be one of our most valuable medical tools when it is used properly. Needed medical x-rays should not be avoided but efforts should be made to confirm their need in terms of the risk and if x-rays are called for, they should be given with the minimum absorbed dose (rem) and energy dose (gm-rem). Diagnostic x-rays in the U.S. without doubt result in the saving of hundreds of thousands of lives each year, but this is no excuse for using them carelessly and excessively so as to cause the needless loss of tens of thousands of lives each year.

The BEIR Committee also gave specific recommendations regarding medical exposure as follows:

"Medical radiation exposure can and should be reduced considerably by limiting its use to clinically indicated procedures utilizing efficient exposure techniques and optimal operation of radiation equipment. Consideration should be given to the following:

1) Restriction of the use of radiation for public survey purposes, unless these is reasonable probability of significant detection of disease.
2) Inspection and licensing of radiation and ancillary equipment.
3) Appropriate training and certification of involved personnel. Gonad shielding (especially shielding the testes) is strongly recommended as a simple and highly efficient way to reduce the Genetically Significant Dose."

How Can We Reduce Unnecessary Medical Exposure?

Obviously this question must be answered differently for each person and each professional group. The doctor, x-ray technologist, dentist, chiropractor, etc. can improve his education and training and make use of better equipment while employing the best of techniques. To begin with he can follow the hundreds of dose reducing measures that many have suggested (for example, the 73 ways to reduce medical exposure which I gave in Congressional testimony).[20] Those in research and industry can look into ways that x-ray equipment can be further developed and improved. This would include not only the development of sophisticated x-ray equipment (for example the pulsed fluoroscopic equipment that provides instant image display), but the improvement of many simple dose reducing devices such as for example: (a) an arrangement such that the x-ray tube cannot be operated unless the center ray is centered to the cassette and (b) a dose device that would operate the x-ray machine to deliver a predetermined does to the film (and to the patient) and record this dose on a patient I.D. card.

Each individual in his own case can seek out the best medical advice when x-rays are needed. Specifically, some of the dose reducing actions each of us can take are for example:

1. Don't have dental x-rays unless there is a specific individual need.
2. Seek out a dentist that uses the long open-ended cone with rectangular collimation on his x-ray machine.
3. Find out the speed of films used by the dentist and avoid dentists that use slow speed film.
4. Find out if the x-ray technologist is certified. Refuse the medical x-ray unless taken by a certified technologist or a radiologist.
5. Never permit a chiropractor to x-ray you and in general avoid the practitioner who takes x-rays.
6. Ask to wear a lead apron or other shielding.
7. Avoid x-rays using the photofluorographic technique.
8. Refuse fluoroscopic examinations except by the specialist (radiologist) using image amplification techniques. Find out if he dark adapts his eyes.
9. Wear gonad shields for pelvic and abdominal examinations.
10. Insist that x-rays be transferred and not repeated except where absolutely necessary.
11. Insist on substituting the tuberculin test for the chest x-ray unless the tuberculin test is positive.
12. Take legal action if necessary to avoid x-rays "required" to satisfy insurance claims.
13. Refuse x-rays in the pelvic and abdominal regions if there is the possibility of pregnancy unless the x-rays are urgent for your health.
14. Ask the x-ray technologist or dentist that delivers the x-rays (or the radiologist) how much skin dose is delivered by each x-ray you receive. Keep a permanent record of each x-ray you (or your young children) receive, recording also the type of x-ray, area of body x-rayed, and the energy (keV). If the x-ray technologist or dentist cannot answer your questions, phone the office of radiological safety of your state for the information.
15. Support your state office of radiological health so that it interfaces with *you* as well as with members of the medical professions. See that this organization has adequate manpower supported by the operating funds it needs.
16. Bring about appropriate legislation at all levels—city, state, federal—to provide adequate radiation protection of the medical patient. Only the states of New York, New Jersey, California, and Kentucky require education, training, and certification of x-ray technologists. Do everything possible to make this certification mandatory in all the states. The Randolph bill that would bring this about has "lingered in waiting" for a long time in Washington and now is attached to Kennedy's Health Professions Educational Assistance Act of 1974 as S-3585. Give this your strong support. Similarly, only the state of California requires training in health physics and radiobiology in its medical schools and questions on the state board examinations on these subjects. Unfortunately, the future of this California law may be in doubt because of opposition by members of the medical profession. Give this law your strong support and bring about similar (or better) legislation in all the states. Without doubt if the doctor or dentist is to decide whether or not you should be x-rayed, he should know how to evaluate the risks and weigh them against the benefits.

The medical professions have not only been dragging their feet in the matter of patient protection from unnecessary medical radiation but have in many cases opposed measures for improvement. They are a powerful political force against which government agencies such as the USHS and EPA, which are charged with providing radiation protection of the public, tremble when they contemplate taking radiation protection measures that might offend the medical professions. Only if you the public act on your own behalf, will you be provided good medical radiography without unnecessary damaging radiation to yourself and your children. Do what you can to encourage your own state to adopt legislation such as that in the state of Illinois. Here the diagnostic exposure limits are set at: (a) 500mR and preferably <350 mR per abdomen A.P., (b) 1400 mR and preferably <1000 mR per lateral lumbar spine, (c) 150 mR and preferably <100 mR per cervical spine, and (d) 400 mR and preferably <200 mR per A.P. skull radiograph. The unnecessary exposure you prevent may be that to yourself.

References

1. Harting, F. H., and W. Hesse: *Vjschr. Gerichtl Med. Offentl Gesundheitswesen 30*, 296; 31, 102 and 313 (1879).
2. Morgan, K. Z., and J. E. Turner: *Principles of Radiation Protection*. Robert Kriege Publishing Co. (1973).
3. Grubbé, E. H.: *Radiology 21*:156 (1933).
4. Stone, R. S.: *Western J. Surg. Obstet. Gynecob. 54*:153, 201 (1946); *Protection in Diagnostic Radiology*. Rutgers Univ. Press, New Brunswick, N.J., (1957). p. 70; *Radiology 58*:639 (1952).
5. ....: *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*. NCRP Handbook 52, Nat. Bur. Std. (1953).
6. ....: *Transportation of Radioactive Material by Passenger Aircraft*. Report No. 1 to the JCAE of the Special Panel to Study Transportation of Nuclear Materials, J. T. Conway, Chairman (Sept. 1974).
7. ....: *Recommendations of the International Commission on Radiological Protection*. Pergamon Press, New York, ICRP Pub. No. 6 (1964).
8. McClenahan, J. L.: Wasted X-Rays. *Radiology 96*:453 (August 1970).
9. Morgan, K. Z.: The Need for Radiation Protection. *Radiologic Technology 44*:385 (1973).
10. Morgan, K. Z.: Possible Consequences of Excessive Medical Exposure in the United States—Mögliche Folgen einer ubermassigen medizinischen Strahlenbelastung in den Vereinigten Staaten von Amerika. *Röentgen-Blatter, Klinik und Praxis, Heft 3*:127, Stuttgart (Marz 1974).
11. ....: *What About Radiation? Mass Chest X-Ray Programs*. USPHS Pub. 1196 (February 1965).
12. ....: *Chest X-Ray Screening Recommendations for TB-RD Associations*. NTRDA Bulletin 57, No. 9 (October 1971).
13. Gitlin, J. N., and P. S. Lawrence: *Population Exposure to X-Rays*. US 1964 BRH-USPHS No. 1519 (1964).
14. ....: *Recommendations of the International Commission on Radiological Protection*, New York, Pergamon Press, Pub. No. 1 (Sept. 9, 1958).
15. Bross, I. D. J.: Leukemia from Low-Level Radiation. *New Eng. J. Med. 287*:107 (July 20, 1972).
16. Baum, J.: Population Heterogeneity Hypothesis on Radiation induced Cancer, given orally at Houston, Tex. meeting of the Health Physics Society, July 10, 1974.
17. Muller, H. J.: Radiation and Heredity. *Amer. J. Pub. Health*, Sup. to Vol. 54, 1 (1964).
18. Russell, W. L.: Studies in Mammalian Radiation Genetics. *Nucleonics 23*:53 (Jan. 1965).
19. ....: *Report of the Advisory Committee on the Biological Effects of Ionizing Radiation*. BEIR Report, NAS, NRC (November 1972).
20. Morgan, K. Z.: Testimony before the Senate Commerce Committee on Bill 2067, "Reduction of Unnecessary Medical Exposure," August 28-30, 1967, Congressional Record Ser. No. 90-49 (1968); Congressional Record Hearings before the Committee on Radiation Control for Health and Safety Act, Washington, D. C., March 8, 1973.

Rev 19

DECOMMISSIONING OF THE GORLEBEN FACILITY*

A. Introduction

1. Attention given to decommissioning by Gorleben planners

It is difficult to believe or understand why so little consideration has been given to the subject of decommissioning by the Gorleben planners. One must conclude that the subject has been seriously neglected or considered to be of very minor importance, or perhaps a subject that can be addressed when the time comes to decommission the plant 30 to 40 years from now. Sections 1.6, 2.6, 3.6, 4.6 and 5.6 of the Safety Report devote nine pages (lines double spaced) to the subject of decommissioning but each of the five parts of the report is simply a repetition of only a broad outline of the subject so that it corresponds essentially to less than one page (lines single spaced) of text on this subject when one might expect to find at least a 300 to 400 page discussion. Then, too, there is reference in the material provided for committee review to the so called Decommissioning Center but there is no discussion in this report of the subject of decommissioning. To persons who are familiar with the importance of careful planning for decommissioning of such plants in the design stage and long before construction begins the subject of Decommissioning is very conspicuous in all the Gorleben reports, projects, reviews and evaluations because of its omission from material provided to the International Review Committee.

2. Proper time to consider decommissioning

One of the cardinal rules of health physicists throughout the world (and members of the Fachverband für Strahlenschutz in this part of Europe) is that all well conceived and properly planned programs involving potential high level exposure to ionizing radiation must be carefully planned in considerable detail well in advance of every stage of development of a program. This includes stages of conception, design, construction, operation, maintenance, and decommissioning with special attention given during early stages of conception and design. It is only because of this

*Preliminary report of Committee 8 on Decommissioning (members: Lindström, Resnickoff and chairman Morgan) January 5, 1979.

"cradle to the grave" type of health physics responsibility that nuclear power has been considered to be acceptably safe and 1979 is no time and Gorleben is no place in which to change this basic philosophy. Everything that goes into a hot cell, a nuclear reactor or any operation involving high level radioactive material, must be so planned and designed that it can be removed and disposed of in terms of minimum cost in man·rem and in dollars (marks) at the conclusion of the operation. This is true especially in respect to the hot waste tanks, floor drains, pumps, air ducts, piping, etc. at Gorleben.

3. Major goal of a well planned and acceptable radiation protection program

Since many studies during the past few decades have shown that all ionizing radiation exposure is potentially harmful and that the probability of chronic radiation damage (e.g. cancer or genetic mutations) increases approximately linearly with the accumulated dose,* there is no dose so small that the risk becomes zero. Thus the question is not, "What is a safe dose of radiation?," but, "How much dose or consequent risk of harm is acceptable in terms of the overall expected benefits of the operation?" As a result we have developed the philosophy of balancing the benefits against the risks and keeping all exposure as low as reasonably achievable (ALARA).

Sometimes we permit the immediate objective to confuse or obscure what should be the major long range goal or objective of a large operation. For example the objective of a high level radioactive waste facility such as Gorleben is sometimes stated to be the isolation of radioactive waste from man and his environment as long as possible. This may fall far short of what should be the objective or major goal, namely to isolate and dispose of the waste in such a manner that the total dose, integrated over infinite time and space and for all people is a minimum. Generally the two objectives can be quite different because often most of the man·rem dose is not from integrating low population doses over thousands of years but from some of

---

*Recent studies indicate that at low doses the cancer risk per rem is greater than at high doses. Therefore, in many cases the linear hypotheses is non-conservative. (See K. Z. Morgan, "The Linear Hypothesis of Radiation Damage Appears to be Non-Conservative in Many Cases," Proceedings of IRPA, Vol. 2, Paris, France (April 1977).

the methods of decommissioning and long range disposal that do not take into sufficient account the large occupational and environmental short term exposures associated with such operations in terms of man·rem and often the internal dose is seriously underestimated or improperly accessed. In carrying out this calculation special care must be taken to consider <u>dose commitment</u> and not just annual dose. For example, ^{239}Pu with a radioactive half life of 24390 years and a biological half life in the human skeleton of 200 years continues to irradiate the skeleton of a man at the rate of about 30 rem/y all the rest of his life if he happens to deposit in his body a so called maximum permissible body burden of 0.04 μCi of which 90% is localized in the skeleton. Thus the major goal of the Gorleben decommissioning operation should be to minimize $\int_o^t \int_o^p \int_o^s D(t) \cdot D(p) \cdot D(s) dt dp ds$ where D(t), D(p), D(s) are dose functions related to time, persons exposed and all space respectively and this integration must give careful consideration to internal dose and especially that received by those engaged occupationally in the decommissioning operation. Also, decommissioning must be considered as it relates to each part of the cycle of operations at Gorleben because it is not an independent variable that can be treated in isolation.

4. <u>Cost of decommissioning</u>

As suggested by the above discussion the success of a decommissioning operation in terms of minimizing cost when expressed in man·rem and dollars depends critically on whether or not sufficient attention has been given to the problem from the beginning of the operation. Actually all the costs can be expressed in dollars if one considers each man·rem to correspond to \$1000 (1974 dollars) as is done for example by the Nuclear Regulatory Commission of the U.S. Also the cancer risk can be estimated by using the overall cancer risk coefficient as 6×10^{-4} cancers/man·rem which corresponds to $1000\ \$/\text{man}\cdot\text{rem} \times \frac{1}{6 \times 10^{-4}} \left(\frac{\text{man}\cdot\text{rem}}{\text{cancers}}\right) = \$1.7 \times 10^6/\text{cancer}$. One is reluctant to place a dollar value on a human life (especially if its his own life) but maybe the value of a human life has become more stable than the dollar or an ounce of gold.

Only a few serious efforts have been made to estimate the costs of decommissioning a reprocessing plant. The U.S. Nuclear Regulatory Commission report (NUREG-0278) estimates the costs to range from $58 to 81 million dollars (1978 dollars) for a reprocessing plant such as the Barnwell, South Carolina plant in the U.S. if it were constructed and operated with detailed consideration given to decommissioning. The estimated costs in man·rem range between 80 and 523. The lower values in man·rem are for the layaway plan and the higher values are for immediate dismantlement while the higher values in dollars are for layaway with deferred dismantlement after 30 years and the lower values are for immediate dismantlement. No data are available on the costs for entombment although this might be the cheapest method both in terms of man·rem and dollars. These estimates are for a plant that has given considerable consideration to decommissioning beginning with the conception and design stages of the plant and where eventual decommissioning was given consideration in all parts of the daily operations. A good example of the decommissioning costs for a plant that was designed and operated with very little consideration to eventual decommissioning is the West Valley plant, New York, U.S.A. This was a far smaller operation than Barnwell or the proposed Gorleben reprocessing facility but still the estimated cost is $800,000,000 (in 1977 dollars) so the cost for Gorleben decommissioning would be well in excess of $\$10^9$ unless appropriate attention is given to decommissioning in all stages of this operation. The situation at West Valley is particularly serious because the state of New York, which is on the verge of bankruptcy was left "holding the bag" when the former operator pulled out. The total decommissioning cost probably would be less than $20,000,000 if appropriate attention had been given at West Valley to this problem. It is to be hoped that the State of Lower Saxony will profit from this sad experience of the State of New York lest it too wakes up and finds it has an expensive white elephant on its hands or a bear by the tail it would like to let loose but dares not do so.

B. <u>Types of decommissioning that should be considered</u>

There are several types of decommissioning of a reprocessing and waste disposal system that should be given serious consideration before choosing which is most appropriate for Gorleben. The choice could well be a combination of these types and plans for decommissioning should not be so rigid that they cannot be changed as conditions in the plant change (e.g. due to accidents or new types of reactor fuel to be reprocessed) and as regulations and safety standards are modified. It is especially important that detailed plans for decommissioning be taken into careful account in the conceptual and design stages of the program. These types may be classified as:

1. In-place entombment (for example, pour reinforced concrete over the process and operating buildings thus encasing them and their contents as a perpetual monument.

2. Complete dismantlement and removal of all radioactive components and unconditional release of the facility to public or private use without any restrictions on its future use.

3. Mothballing or protective storage. This includes removing all equipment that is highly contaminated (tanks, pipes, mixers, columns, etc.) to hot cells or other storage areas within the facility and sealing them off from access by welded steel plates and securely locked doors. Most of these operations would be conducted by the use of remote control equipment to reduce occupational exposure. The process buildings and all operating areas would be made inaccessable to the public. Alarms would be installed for protection from fire and intrusion and to give warning should radiation levels increase. Guards would be stationed around the clock in process buildings and operating areas to guarantee security and to sound the alarm in case of fire, explosion, utility malfunction, etc. The storage tanks would be emptied completely and removed. All the site area outside the buildings would be released for public use provided this did not compromise security. Uncontaminated offices, lunch rooms, medical facilities, counting rooms, and administrative buildings could be released to public use. There would be no intention of ever using the facility again for fuel reprocessing and waste disposal. Plans would be laid for complete decommissioning of the facility (i.e. complete dismantlement of

processing buildings and removal of all contaminated materials from the site or perhaps for entombment at a later date). This would be done after 10, 30 or maybe after 100 years or more.

The rationale for choosing the mothball procedure is that a delay in complete decommissioning results in a reduced dose (man·rem) to the population and to the occupational workers although it does increase the dollar cost.

4. Layaway is similar to mothballing except that much of the equipment is just deactivated or placed in a standby condition. There are fewer welded access ways, there are more alarm systems and a tighter guard surveillance force is required. The total site remains inaccessible to the public. It might be possible to put the facility to some future use as a nuclear operation but such conversion would be very expensive and rather unlikely. The most likely ultimate choice would be entombment or decommissioning as with the case above (i.e. deferred dismantlement).

C. Advantages of each type of decommissioning

1. In-place entombment.

In general this method has been frowned upon and it was not even considered in the NUREG-0278 report. Some of the reasons for this are: (1) This choice is not easily reversible at some later date, (2) If radioactive contamination leaked from this monument at a later date, corrective measures might be very difficult, (3) To many people such a monument would be a constant reminder of an unsolved problem, (4) This land might be needed at a later date for a more useful purpose, (5) This could place an unfair burden or a dangerous temptation on future generations; it is not fair that people living thousands of years hence should be required to pay our debts. In spite of these objections entombment might be the method of choice because it probably could be carried out with the least occupational exposure of the four methods under consideration in this review and as a consequence might meet the basic requirement of a decommissioning operation, namely to minimize the dose relation, $\int_0^t \int_0^p \int_0^s D(t)\cdot D(p)\cdot D(s)\,dt\,dp\,ds$.

In the employment of the entombment method of decommissioning of a reprocessing facility such as Gorleben, one of the early steps would be to drain all radioactive waste tanks and flush them thoroughly. All filters, chemicals, resins, liquids, etc. should be treated in the usual manner and placed in perpetual storage in the salt repository along with the other high level radioactive waste. The high level waste tanks would be disintered, reduced to the smallest possible volume by means of remote operations and dropped into the process building. This building in turn, along with all its contents would be demolished to a heap of rubble. The twisted steel could be cut by the use of remotely operated torches. The radiation workers would be encased in pressure suits. After the volume of this material had been reduced to a minimum, it would be mixed with concrete and made into a pyramid or similar monument. Steel for reinforcement would be added as needed to make a monument of high resistance to weather, tampering by man, earthquakes, etc. If entombment is selected, it will call for careful planning before the Gorleben plant is built and will require the development of special equipment and carefully thought out and innovative demolition techniques that can be conducted with a minimum of direct human contact, with very little dust and water runoff during demolition and will call for the development of new ideas and new types of remote control equipment and operations. The effectiveness of the use of the demolition ball, placed charges of explosives and nets and the mixing of the final rubble with concrete can be increased if plans are made for the use of entombment in the conception and design stages and long before construction of Gorleben begins. The actual number of curie years contained in the monuments resulting from entombment could and should be kept very small and consist mostly of radionuclides in the crud of pipes, sumps and demolished tanks, contamination in cement floors, walls and shielding materials from normal operations, spills and accidents and contamination accumulated in ventilation ducts, fans, motors, crains and general reprocessing and waste handling equipment that was used in the hot cells. With proper design of the plant in its present stage and with carefully planned operations after construction there need be very little residual contamination from long lived radionuclides such as $^{238,239,240,241,242}Pu$, $^{241,242m,243}Am$, $^{235,238}U$, ^{237}Np, ^{129}I, ^{90}Sr, ^{137}Cs, ^{99}Tc, etc. There would be a small amount of induced activity due to (α,n) reactions and from ^{244}Cm neutron activity (especially from reprocessing of MOX fuel). Most of the high level wastes would be removed in the tank solutions and liquids used for flushing operations, in the resins, fuel element jackets and small hot cell components that would be removed before demolition operations began and disposed of in the salt formation in the usual manner.

2. Complete dismantlement.

This type of decommissioning is the only method that removes the problem over a short period of time so that it is "out of sight, out of mind." Also, as indicated above, it is the cheapest of the methods in dollars except perhaps for entombment for which no cost estimates are available. This method has a serious disadvantage in that it leads to the highest costs in man·rem (estimated in NUREG-0278 at 523 man·rem). This might be acceptable, however, because at $1000 per man·rem this would be only $523,000 (1978 dollars) and would correspond only to a 30% risk of one radiation induced cancer and about the same amount of genetic risk. All these risk estimates in NUREG-0278 must be taken with considerable skepticism, however, because they apply only to a well planned operation in an almost perfectly designed plant from the standpoint of decommissioning in which everything goes according to plans and in which there are no accidents. This method of decommissioning is without doubt the most hazardous of the four methods in relation to occupational and environmental exposure and since such operations can never be conducted with perfection, it would be prudent to assume this method as applied to Gorleben probably would be more hazardous by at least an order of magnitude than these estimates or would result in at least three radiation fatalities and three genetic mutations. If no prior detailed plans were made for decommissioning as seems to have been the case with West Valley, this method could easily lead to far greater risks, e.g. 30 radiation induced fatilities and 30 genetic mutations.

Unlike the Barnwell operation for which the NUREG-0278 estimates were made, the Gorleben plant does offer an especially attractive feature for this method of decommissioning, namely Gorleben is a combination reprocessing and radioactive waste disposal facility, all on the same site. Thus it is suggested that Gorleben might be modified from its present design in such a way that th waste disposal facility could continue in operation until all the reproces.. ng plant and waste tanks were completely decommissioned, taken apart and buried in the underground salt formation. Then, section by section the waste facility could be disassembled and taken into the salt formation. In a sense the salt dome would act like black holes in outer space--everything top-side would disappear (hopefully forever) into the hole in the salt. The final step could be to fill all remaining cavities and shafts of the salt mine with reinforced steel and concrete (i.e. an underground monument).

3. Mothballing or protective storage.

As indicated above, both mothballing and layaway offer the advantages of extra time and this in turn allows an opportunity for additional research and the development of improved methods of final dismantlement or entombment and at the same time it permits appreciable decay of the relatively short-lived radionuclides such as $^{89,90}Sr$, ^{91}Y, ^{95}Zr, ^{140}Ba. $^{134,135,137}Cs$, $^{103,106}Ru$, $^{93m,95}Nb$, ^{93}Mo, ^{126}Sb, $^{127m,129m}Te$, ^{140}Ba, $^{141,144}Ce$, ^{143}Pr, etc. However, time is no panacea for the unobtrusive disappearance of the more dangerous radionuclides because many of the radionuclides have daughters of longer half life. For example among the fission products we have $^{129}Te(33.6d)\xrightarrow{\beta}{}^{129}I(1.57\times10^{7}y)$ and $^{147}Nd(11.06d)\xrightarrow{\beta}{}^{147}Pm(2.62y)$ and among the actinide elements $^{241}Pu(13.2y)\xrightarrow{\beta}{}^{241}Am(458y)$, $^{238}Pu(86.y)\xrightarrow{\alpha}{}^{234}U(2.47\times 10^{5}y)$, $^{243}Cm(32y)\xrightarrow{\alpha}{}^{239}Pu(24,390y)$, $^{244}Cm(17.6y)\xrightarrow{\alpha}{}^{240}Pu(6580y)$, $^{242}Cm(162.5d)\xrightarrow{\alpha}{}^{238}Pu(86y)$ etc. T e radioactive decay of $^{232}U(70y)$ is bad because it is the daughter of $^{236}Pu(2.85y)$ and leads to the ingrowth of granddaughter radionucledes that emit very energetic γ-radiation. Over a much longer period of time (thousands of years) $^{243}Am(7380y)$, $^{239}Pu(24390y)$, $^{226}Ra(1600y)$ and its daughter products and ^{129}I in succession become the major contributors to the radiation hazards in PWR and BWR fuel. For the first 200 years there is a rapid reduction by three orders of magnitude in the levels of radioactivity in spent fuel from a light water reactor, but over the next 10,000 years only a slow drop in radioactivity by about two orders of magnitude. Thus, if the eventual plan is to remove all above ground radioactive contamination, complete dismantlement should be undertaken during the first 200 years and preferably during the first 100 years because little would be gained by a considerably longer delay.

The breakdown in dollar costs (in millions of 1978 dollars) and in man·rem as given in NUREG-0278 for this method of decontamination is

Initial costs.	19	Occupational.	81
Care costs for 30 years. .	4	Public.	11
Final dismantlement. . . .	44		92 man·rem
Total	$67M		

Because of the complete disfunction of equipment and the low radiation risks after mothballing, surveillance and guard expenses are minimal (only $140,000/year). Thus if final dismantlement were delayed for 100 years instead of 30 years, the additional cost would be only ten million dollars (see Fig. 1).

This mothball method has an advantage over the layaway arrangement in that most of the area and buildings (except the contaminated process and waste disposal facilities) could be released to public use. The income from the use of these areas could more than offset the care costs and if dismantlement is delayed for 100 years, its costs might be considerably cheaper than immediate complete dismantlement or entombment. Certainly if the contamination levels have dropped by a factor of three or four hundred during a 100 year delay period, all radiation exposures (occupational and environmental) and the dollar costs of final dismantlement can be reduced drastically. Also with appropriate design of Gorleben and properly developed operating and decontamination procedures it should be possible to remove most of the more bothersome radionuclides during the early stages of decontamination so that the costs of decommissioning (in dollars and in man·rem) will be materially reduced.

4. Layaway

Perhaps the principal advantage of layaway over mothballing or protective storage is that it does not exclude the possibility of using the facility for a nuclear operation in the future or even setting most of the old plant back into operation at some future date. Layaway could be carried out in such a way that it consists of the first steps of mothballing (see Fig. 1). It includes draining all tanks, other containers, pipes, etc. of their radioactive contents and thoroughly flushing them with various cleaning solutions without damaging their integrity. All reactor fuel and casings, resins, air filters, cleaning and flushing solutions would be removed and along with other radioactive material in the waste facility would be processed, encased in glass and deposited in the geological salt formation. Highly contaminated sumps in the floors, plenums and fans in the air vent system, etc. could be replaced. The equipment in the hot cells of the reprocessing facility would be left intact. It might even be practical to layaway the reprocessing facility and leave the waste disposal facility in full operation. It is certain that the time will come when the fuel reprocessing plant will have to curtail its operations. This will come about as a result of one or more of the following circumstances:

1. Accidents (major or minor) which indicate the operation does not provide adequate occupational or environmental safety
2. Routine operations which do not provide adequate occupational or environmental safety, e.g. releases of high levels of radioactivity into working areas or into general envrionment
3. Development and enforcement of more stringent safety standards by the State or Federal Government
4. Deterioration of equipment and facilities as a result of accidents or from normal ware and tear. This would include fires, earthquakes, fall of aircraft, etc.
5. Encroachment of neighboring populations
6. Objections of the people to such nuclear operations
7. Changes in types of nuclear power reactors and in their fuel requirements
8. Development of other equipment and techniques that are more efficient and that provide greater safety
9. Other types of power (fusion, solar, fossil fuel, geotherm, biomass, etc.) become preferable due to less costs (in dollars or in safety)
10. International developments (treaties, agreements, wars, etc.).

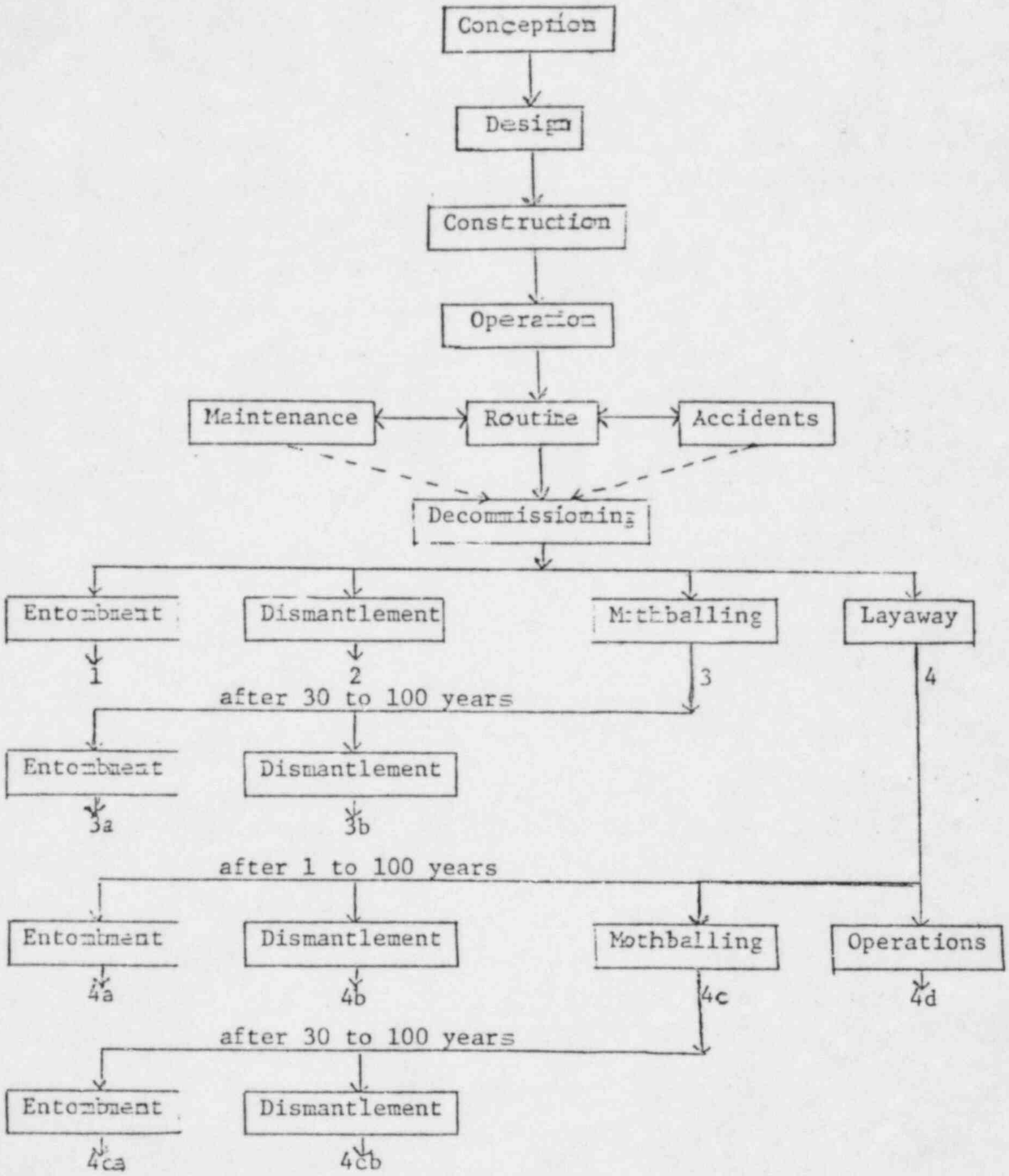


Fig. 1. Time Sequence of Events at Gorleben. From this chart is is seen there are nine possible sequences of events (1,2,3a,3b,4a,4b,4ca,4cb,4d) if all the plant is decommissioned in the same way. It is likely, however, that the reprocessing plant will be decommissioned by one method and the waste facility by another. In such case there would be 9×9 or 81 possible sequences of events.

Therefore, decommissioning of Gorleben is not something that may have to be considered at some time in the future but rather it is something that must be and will be carried out in the future.

The breakdown in dollar costs (in millions of 1978 dollars) and in man rem as given in NUREG-0278 for the layaway method of decommissioning is

Initial costs.	18	Occupational.	69
Care costs for 30 years. .	20	Public.	11
Final dismantlement. . . .	43	Total	80 man.rem
Total	$81M		

Unless there were believed to be some possibility that the Gorleben reprocessing plant and/or the waste disposal facility would be returned to use as a nuclear facility at some future date, it is almost certain that layaway would not be chosen as the method of decommissioning because as seen above it saves only 12 man·rem over the mothball procedure (i.e. 92-80 man·rem) and its cost for 30 year deferment of complete dismantlement is $14M greater (i.e. $81-67M) than mothballing. Also the care costs would be far greater than for mothballing, (i.e. $680,000/y compared with $140,000/y) so that if final dismantlement were delayed for 100 years instead of 30 years, the additional cost would be $48M. It seems possible also that the cost in man·rem might actually be greater than for mothballing because the radiation areas would not be as secure (i.e. passage ways would be locked instead of welded and there would be a risk that one of the guards might unlock a door and enter an area where he would receive a large exposure. If there were some uncertainty regarding whether the plant or some part of it might be used for nuclear operations in the future, it would seem reasonable to follow a layaway plan and then as shown in Fig. 1, one of four choices could be made at a later date. For example, if there were a serious shortage of oil and natural gas after a 20 year layaway at Gorleben, the plant could be put back into operation again much faster and at less cost than building a new plant although the efficiency of this renovated plant would not be as great as that of a new plant.

D. Conclusions

Decommissioning of Gorleben is not something that might be needed in the future but something which definitely will be required and must be provided.

The cost of decommissioning in dollars or in man·rem will be greater by several orders of magnitude if proper plans for its eventuality are not made in all stages of development of Gorleben--the conceptual and design stages being the most important.

The major goal of a well planned decommissioning operation is not to remove and isolate a nuclear plant from man and his environment as long as possible or to remove it completely but it is to discontinue the operation in such a way that $\int_0^t \int_0^p \int_0^s D(t)\cdot D(p)\cdot D(s)dtdpds$ is a minimum when the limit of t is the time when D(t) becomes insignificant. Special care must be taken to consider dose commitment when applying this formulation to internal dose.

All radionuclides do not present the same hazard or radiation risk per curie year when they are in the human environment. Therefore, special attention should be given to the relative hazard, H, of the various radionuclides in providing radiation protection to occupational workers and members of the public during decommissioning operations. Several attempts have been made to list the radionuclides in accordance with their relative hazard. One such attempt (K. Z. Morgan, W. S. Snyder and M. R. Ford, "Relative Hazard of the Various Radioactive Materials," Health Physics 10, 151, 1964) lists values of H for some of the radionuclides of interest as given in Table I. It is to be noted that some radionuclides such as ^{238}Pu, ^{241}Am or ^{244}Cm are far more hazardous curie-for-curie than others such as ^{87}Rb, ^{232}Th or ^{238}U.

The types of deommissioning may be classified as entombment, complete dismantlement, mothballing and layaway. Depending on circumstances and objectives the order of preference in Fig. 1 is probably

1st choice:	3 + 3b	(Mothballing + dismantlement)
2nd choice:	2	(Immediate dismantlement)
3rd choice:	1	(Entombment)
4th choice:	4 + 4c + 4cb	(Layaway + mothballing + dismantlement)

It is very probable that the reprocessing plant and the radioactive waste disposal facility will not be decommissioned at the same time or in the same way. In such case there would be 81 choices for decommissioning as shown in Fig. 1.

TABLE I. Relative Hazard of Airborn Radionuclides on a Curie Basis

Radio-Nuclide	T	H	Radio-Nuclide	T	H	Radio-Nuclide	T	H
^{85}Kr	10.76y	2.5×10^{-5}	^{103}Pd	17d	3.9×10^{-4}	^{144}Nd	2.4×10^{15}y	4.4×10^{-13}
^{86}Rb	18.7d	4.3×10^{-3}	^{105}Ag	40d	3.6×10^{-3}	^{147}Pm	2.62y	4.5×10^{-3}
^{87}Rb	4.8×10^{10}y	3.7×10^{-11}	^{125}Sb	2.71y	1.1×10^{-2}	^{147}Sm	1.05×10^{11}y	7.7×10^{-9}
^{85}Sr	64d	2.8×10^{-3}	^{125m}Te	58d	2.3×10^{-3}	^{151}Sm	87y	4.5×10^{-3}
^{89}Sr	52.7d	1.1×10^{-2}	^{127m}Te	109d	7.1×10^{-3}	^{210}Pb	139d	2.33
^{90}Sr	27.7y	1.01	^{129}I	1.7×10^{7}y	2.9×10^{-6}	^{226}Ra	1602y	1.00
^{90}Y	64h	2.9×10^{-3}	^{131}I	8d	3.4×10^{-2}	^{232}Th	1.41×10^{10}y	1.68×10^{-6}
^{91}Y	58.8d	9.1×10^{-3}	^{131m}Xe	11.8d	1.7×10^{-5}	^{232}U	72y	10.5
^{93}Zr	1.5×10^{6}y	9.2×10^{-7}	^{133}Xe	5.3d	2.0×10^{-5}	^{235}U	7.1×10^{8}y	4.85×10^{-7}
^{95}Zr	65.5d	9.1×10^{-3}	^{135}Cs	3×10^{6}y	2.8×10^{-7}	^{238}U	4.51×10^{9}y	1.37×10^{-7}
^{93m}Nb	13.6y	2.4×10^{-3}	^{136}Cs	13.7d	1.7×10^{-3}	^{237}Np	2.14×10^{6}y	4.91×10^{-3}
^{95}Nb	35d	2.9×10^{-3}	^{137}Cs	30y	2×10^{-2}	^{238}Pu	86.4y	152
^{96}Tc	4.35d	1.2×10^{-3}	^{134}Cs	2.0y	2.5×10^{-2}	^{239}Pu	24,390y	1.04
^{97m}Tc	91d	1.9×10^{-3}	^{131}Ba	12d	8.3×10^{-4}	^{240}Pu	6580y	3.84
^{97}Tc	2.6×10^{6}y	3.6×10^{-5}	^{140}Ba	12.8d	6.7×10^{-3}	^{241}Pu	13.2y	3.23
^{99}Tc	2.12×10^{5}y	8.6×10^{-6}	^{141}Ce	32.5d	1.8×10^{-3}	^{241}Am	458y	15.9
^{103}Ru	39.5d	3.5×10^{-3}	^{144}Ce	284d	4.5×10^{-2}	^{243}Am	7.95×10^{3}y	9.74×10^{-1}
^{106}Ru	368d	5.3×10^{-2}	^{143}Pr	13.59d	1.6×10^{-3}	^{244}Cm	17.6y	32.3

Appendix

I. Sources of Information on Decommissioning of Nuclear Facilities

A. General Discussion

The early project reports and scientific publications before 1960 are almost silent on the subject of radioactive waste disposal and a similar vacuum in research and general or specific information on decommissioning of nuclear facilities continues even to the present date. Serious consideration to the problems of radioactive waste disposal was given by the small research group at Lyons, Kansas, U.S.A. (a program of Permanent Disposal of High Activity Waste, HAW, in Bedded Salt conducted by the Health Physics Division of Oak Ridge National Laboratory, ORNL, Oak Ridge, Tennessee, U.S.A., Karl Z. Morgan, Division director) and by the small group working in the Asse salt mine in the Federal Republic of Germany (Placement of Medium Activity Waste, MAW, in a Salt Dome Formation) prior to 1970. At present some studies are underway on permanent disposal of HAW in the Konrad Mine, F.R.G. and exploratory studies are underway in the U.S.A. However, only during the past year (1978) has research gotten underway by a few groups that have published a handfull of reports on deommissioning of nuclear facilities. It is difficult for this writer (KZM) who has striven for the success of the nuclear power industry since early 1943 to appreciate this lack of interest and absence of support of research in these two vital parts of the nuclear industry. In considerable measure it is the lack of research, development and visible progress in areas such as reactor safety, proliferation resistance, radioactive waste disposal and decommissioning of nuclear facilities that has brought about strong and effective national and international opposition to nuclear energy. This has been the cause of considerable frustration and discouragement to the writer (KZM) who for 35 five years has striven to make nuclear energy one of the safest of all industries. Our early HAW studies in the Kansas salt mines were supported with less than enthusiasm by the early U.S. Atomic Energy Commission--in fact they were begun only because I and my associate, E. G. Struxness, realizing their vital importance, bootlegged or diverted other program funds into these studies and many years later when our Salt research showed great promise this waste dispcsal program became a political issue and all support in the ORNL Health Physics Division was discontinued. Only during the past two years have serious programs of study, research and on the spot investigation in the area of decommissioning gotten underway at Battelle Pacific Northwest Laboratory, BPNL, and at ORNL (e.g. one of the writer's students' is doing his Ph.D. research on decommissioning of Nuclear Facilities at the present time in cooperation with the ORNL group). Hopefully, in a few years there will be some better numbers from actual field data on decommissioning and fewer guesses regarding the effectiveness and appropriateness of various methods of decommissioning of various types of nuclear facilities. Unfortunately, to the present time almost all the studies on decommissioning have been limited in application to nuclear power plants--and in particular to LWRs (PWR and BWR)--so that there is a serious paucity of information on the decommissioning of nuclear fuel reprocessing plants and radioactive waste disposal facilities.

B. Source of Information on Decommissioning of Nuclear Power Plants

Recently several reports have been published on Decommissioning of Nuclear Power Plants. Although these reports do not address the question of Decommissioning of Nuclear Reprocessing Plants or Decommissioning of Radioactive Waste Disposal Facilities (the subjects of interest here), they do provide some useful general guides and certain specific data that have application to these last two stages (back end) of the nuclear cycle. In preparing this report some of the more useful documents of reference are those relating to LWRs and are as follows:

1. Recommendations for Nuclear Facility Design with Special Regard to Decommissioning Potential, by H.V. Eyss, H. Kofahl and D. Leven GRS-A-110 (February 1978).

2. Technology, Safety and Costs of Decommissioning a Reference Pressurized Reactor Power Station, NUREG/CR-0130 (June 1978).

3. Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, by R. I. Smith, G. J. Konzek and W. E. Kennedy, Jr., Battelle Pacific Northwest Laboratory, Volumes I and II, NUREG/CR-0130 (June 1978).

C. Sources of Information Relating to the General Problems of Decommissioning and to Those Which are Specific to Nuclear Reprocessing Plants

Some of the more useful documents of reference in this area are:

1. Technology, Safety and Costs of Decommissioning a Reference Nuclear Fuel Reprocessing Plant, NUREG-0278 (October 1977).

2. Decommissioning and Decontamination of Nuclear Facilities, a report prepared for the Subcommittee on the Environment and the Atmosphere of the Committee on Science and Technology, U.S. House of Representatives, 95th Congress (February 1978).

3. Plan for Reevaluation of NRC Policy on Decommissioning of Nuclear Facilities NUREG-0436, March 1978.

4. Studies of Decommissioning a Pressurized Water Reactor and a Fuel Reprocessing Plant, Discussion Material for the Advisory Committee on Reactor Safeguards, Battelle Pacific Northwest Laboratories, K. J. Schneider and R. I. Smith, July 26, 1978.

5. Standards and Guidelines Pertinent to the Development of Decommissioning Criteria for Sites Contaminated with Radioactive Material, ORNL, by H. W. Dickson, ORNL/OEPA-4 (August 1978).

6. Sections from the Gorleben Safety Report (1.6, 2.6, 3.6, 4.6, 5.6) a total of about one page (1978).

7. Situation der Entsorgung der Kernkraftwerke in der Bundesrepublik Deutschland, Section 6 (11 pages), (November 30, 1977).

8. Decommissioning Criteria for Nuclear Facilities, U.S. Federal Register, Vol. 43, No. 49 (March 13, 1978).

9. Termination of Operating Licenses for Nuclear Reactors, USAEC Regulatory Guide 1.86 (June 1974).

II. Some Comments on the Proposed Gorleben Plant Based in Part on the Above Sources of Information

A. Reasons why Much of the Published Data May not Apply to Gorleben and Shortcomings and Difficulties Likely to Develop During the Decommissioning of Gorleben

1. The studies by the BPNL group apply only to a limited extent to Gorleben because they are based on the Barnwell Nuclear Fuel Plant (BNFP) and the assumption that decommissioning has been given appropriate attention in all stages of the reprocessing plant development--conception, design, construction, operation (routine and accident), maintenance and decommissioning. This is not the case with Gorleben.

2. Gorleben is the only plant of its type which incorporates both reprocessing and waste disposal at a single site. This provides some very substantial advantages to Gorleben but it could be a handicap if a major accident in the reprocessing plant, put the waste disposal facility out of operation for a long time.

3. None of the published data take into account the unique problems introduced at Gorleben when it begins reprocessing mixed oxide (MOX) fuel. Some of these problems relate to security (proliferation), neutron dose, activation products, large increase in the more dangerous trans Pu-239 radionuclides, etc.

4. Entombment need not be followed necessarily by dismantlement. In fact I believe entombment should never be considered if there is any reason to believe it must be followed at a later date by dismantlement. As can be seen from Fig. 1 one may choose either entombment or dismantlement but neither is to be followed by the other. As shown, entombment may follow by any one of four routs: 1, 3 + 3a, 4 + 4a or 4 + 4c + 4ca and in all cases it is the terminal or final step.

5. Dose estimates are grossly underestimated in some of the reports for the various methods of decommissioning. Insufficient account is taken of internal dose and of dose commitment. The annual permissible dose commitment corresponds to the intake of a long lived radionuclide (where $T = T_r T_b/(T_r + T_b)$) such that the integrated dose to the

critical body organ over the unsuing 50 years is equal numerically to the limiting dose rate for that body organ.

6. Insufficient account is taken of the serious mistakes made by previous operations such as the West Valley, New York, commercial reprocessing plant and the Cimarron Kerr-McGee fuel fabrication plant near Oklahoma City, Oklahoma. For example, West Valley made a routine immoral practice of burning out of employees (giving a temporary employee the limited dose in a few days) and the Kerr-McGee plant at Cimarron had almost daily incidents of personnel contamination. These two operations went out of operation in considerable part because they did not learn from their own mistakes and certainly Gorleben will want to profit by avoiding these same mistakes and showing now how such serious mistakes can and will be avoided. Both West Valley and Cimarron are faced with very difficult and expensive decommissioning operations that Gorleben should strive to avoid with great passion.

7. The salt dome waste repository may be filled (reach its maximum capacity) prior to the shutdown of the reprocessing facility for decommissioning. Space should be set aside and reserved in the salt repository to accommodate all the HAW, MAW and LAW of the facility including all buildings, structures, equipment, tanks, broken concrete, pipes, etc. that contain residual radioactive contaimination.

8. Insufficient attention has been given to the problems of airborn dust and water runoff during the decommissioning operations. This can be serious especially during entombment or dismantlement.

Following a large chemical explosion in one of the reprocessing tanks at ORNL while I was director of the Health Physics Division there I found it necessary to take immediate and rather unusual measures to hold down the transuranic contamination in the vicinity. For example, we covered the roads and grounds that were contaminated with a heavy layer of tar and the contaminated buildings were sprayed with especially selected paint. Some months later the roads, and other tarred areas, were taken up with the aid of jackhammers, demolation balls and backhoe diggers, dropped into plastic bags and hauled off to the radioactive waste disposal facility. Then the buildings were taken down, piece by piece, (using additional quick drying sprayed paint as needed), placed in plastic bags and hauled off to the radioactive waste disposal facility. All water runoff was collected, treated and disposed of.

The airborn pollution during the use of the demolition ball, jack hammers, shaped charges of explosives, grinding, sandblasting, surface polishing, etc. can be expected to be especially dusty operations and are certain to increase the risks of large internal dose to occupational workers and possibly to members of the general public. The more common ameliorating measures that have been used will not be summarized here because none have been adequate or completely satisfactory. There is a pressing need for new and innovative methods such as the use of enclosures made by large air pressure supported tents to contain the dust and the digging of deep trenches about the facility to catch all the water runoff from the surface and that which percolates more slowly a few meters below the surface.

9. Housekeeping.

Far more needs to be said in the Gorleben reports about daily routine housekeeping operations. These relate very critically to the buildup of contamination, radiation exposures of radiation workers and members of the public and to the success of final decommissioning operations.

10. Health Physics Organization. Very little is said about the Gorleben Health Physics organization--its size, education, training and experience requirements, instruments (portable, monitors for buildings, hot cells, cooling pond, tanks, etc., area monitors, total body counter, etc,), types of surveys, kinds of records, and action levels. It is important that detailed emergency plans be developed and that education programs be provided for personnel at all levels of the organization. In order for the Gorleben program to be successful, health physicists must have their imput and make their

imprint at all stages of plant development--conception, design, construction, operation, maintenance and decommissioning. The Federal Republic of Germany has many very capable health physicists in the Fachverband für Strahlenschutz so one might expect to see more imput from them in the various Gorleben reports. The experienced Gorleben health physicists must be retained during the last three years of plant operation and be given a major role in all decommissioning operations.

II. Maximum Permissible Exposure Levels.

There seem to be some naivety in setting the radiation standards and too much willingness to accept the antiquated levels set by the International Commission on Radiological Protection, ICRP. For example, the internal dose values of MPC in ICRP Pub 2 were published in 1959 while I was Chairman of the ICRP International Dose Committee and more recent data are available which have not been used in the Gorleben reports. Also, some of the more recent ICRP recommendations should be looked at critically. For example, it is doubtful some of the countries (e.g. the U.S.) will accept the values of Wi given in ICRP Pub 26 because in many cases they would result in higher values of MPC at a time when ICRP and many other agencies are pointing out and emphasizing that the risk of radiation induced cancer is much greater than it was considered to be a decade ago and the quality factors for α-radiation and neutrons is considerably greater than it was believed to be when ICRP Pub 2 was published. There is strong evidence that the maximum permissible body burdens of Pu and the transplutonic radionuclides are too high by several orders of magnitude. Such refinements of the permissible exposure levels will result in higher dose estimates during decommissioning operations than given in present BPNL reports and Gorleben reports and this should necissitate the implementation of more stringent radiation protection measures.

12. Reducing surface contamination. Surface contamination is one of the major problems to be faced during the decommissioning of Gorleben.

The best way to ease this problem is to prevent it. More should be said in the reports about the kinds of surfaces (steel, aluminum, nickel, cement, tile, glass, plastic, iron, etc.) that will be exposed to potential surface contamination and how this contamination can be prevented and removed with minimum occupational exposure. Some paints are to be preferred over others because they resist surface contamination, others are chosen because they wear long and are cleaned easily while peelable paints and plastics are used frequently because techniques have been developed to remove them quickly by remote equipment. Because of poor surface properties some materials such as tars, concrete and iron should be avoided for surfaces that are liable to be contaminated. New ideas are needed of ways to reduce the surface and near surface contamination that must be reckoned with at the time of decommissioning. Inner surfaces of pipes and tanks should be so treated and inclined that they will accumulate a minimum of crud, rust and scale.

13. Simplifying job of dismantlement of massive components. Some components of a reprocessing plant are difficult to reduce to small pieces during decommissioning operations so they can be disposed of in the salt disposal facility. Thick reinforced concrete walls and floors and large waste disposal tanks can present some rather tough jobs; especially when their surfaces are badly contaminated. When concrete has to be used, holes should be provided for explosives when the day of decommissioning arrives. Systems should be developed to improve the spallation of concrete by the use of heating systems. Ways should be explored to avoid the use of thick reinforced concrete. For example the use of double walled steel plates for hot cells with innerspace filled with iron balls and fine sand might be examined. During decommissioning a vacuum system could be used to remove this iron ball-sand mixture. Lugs and lifting rings left on all heavy equipment will aid in their removal with remotely operated rigs.

14. Drawings, Plans and Records. All the original drawings and plans must be retained and detailed records must be kept of all changes in design, new construction, underground hot lines, etc. Several

very serious and near serious accidents have occurred at some of the reprocessing operations in the U.S. because poor records were kept of where new lines were added and what each was used for.

15. <u>The ^{129}I problem</u>. It is estimated in NUREG-0278 that ^{129}I would be the principal contributor to annual dose, as a result of decommissioning the reference reprocessing plant (Barnwell in this case). Gorleben plans to process and retain the ^{129}I but historically past reprocessing operations in the U.S. have experienced difficulties in removing all the radioiodine. Detailed consideration should be given to the three chemical forms of iodine-organic, inorganic and metal-organic--with special attention to the organic forms. There is another solution to this problem--isotopic dilution. Isotopic dilution can be used as a substitute or partial solution for methods of ^{129}I removal (filters, caustics, Ag, Cu, cryogenics, etc.). Mixing ^{129}I with stable, iodine (^{127}I) is the only known absolute way of reducing thyroid exposure from ^{129}I that is taken into the body and it offers many practical as well as theoretical advantages which should be considered carefully in Gorleben planning.

16. <u>Disposal of ^3H</u>. Presumably it is planned to use deep well disposal for the HTO. First of all measures should be taken to assure that all the ^3H is in the oxide form (water). It would be ideal to dispose of the HTO in deep wells at the Gorleben site but this may not be a possibility. In such case the HTO would be accumulated and shipped to a suitable site for disposal elsewhere. Shipment of radioactive water (T = 12.26y) is always a very risky business and should be avoided because this turns out to be the major source of population exposure in the BPNL study of decommissioning a fuel reprocessing plant. One method of disposing of the HTO might be to use it in making cement blocks which could be stored in the salt formation. The formation of ^3He, OH, H_2, O_2, etc. in the concrete blocks would not be expected to damage them appreciably over a few half lives of the ^3H. If there are large accumulations of HTO in storage tanks at Gorleben at the time of decommissioning, the above methods of disposal might be considered rather than shipping the HTO.

17. When should decommissioning begin and what are the first steps? Plans for decommissioning should begin in the conception and design stage of Gorleben and be continued through all other stages (construction, operation, maintenance decommissioning). NUREG-0278 says the active planning and preparation stage of decommissioning should take place during the last two years of operation of a reprocessing plant. Because of the size of Gorleben and its dual operations (reprocessing and waste disposal) this active and vital part of decommissioning should get under way at least three years before planned shutdown. The program that should be conducted during this first stage of decommissioning depends very much upon which of the decommissioning paths shown in Fig. 1 are to be followed. The path in Fig. 1 to be followed must be determined by a cost benefit analysis (in reference to man rem and dollars). In any case some of the activities of this three year phase, just preceding plant shutdown are:

a. Assemble and train the decommissioning staff. Members of the regular operations staff are preferable to new employees although some new blood is desirable.

b. Plans and procedures are prepared.

c. Safety and safeguards analysis reports and an environmental impact evaluation are prepared.

d. Application is made for a modified license and it is approved.

e. Quality assurance program is established.

f. Health and safety requirements are developed.

g. Bulk quantities of unneeded process chemicals, radioactive materials and nonessential equipment are removed.

h. Modification of effluent control systems to meet new and changing requirements during decommissioning.

i. If the reprocessing plant and the waste disposal facility are to be shut down at the same time, detailed plans must be finalized to coordinate these operations so that in as far as possible each operation can complement the other to the very end.

j. A training area for personnel to be engaged in this decommissioning operation should be provided. Here they would test the use of back hoes, small explosive charges, drilling, rocksplitting, jackhammering, impact balls, plasma torch, protective coverings (paint, plastic, tar), tent enclosures, face masks, pressure suits, dust samplets, special rigs, etc.

k. Modification of area and environmental monitoring program to conform with changing plant operations.

l. Plans for other uses of part or all of the plant site by the public.

m. Upgrading of criteria for various stages of release of the property both for qualified and for unrestricted use by the public. In setting these criteria or radiation protection standards prime consideration must be given to the fact that, unlike present generations future generations may derive only risks and no benefits from the Gorleben operation. Typical criteria that must be agreed upon during this first stage of decontamination of the Gorleben plant are: 1) levels of surface contamination (α, β, γ) that must be reached on a structure or piece of equipment before it can be released for unrestricted use, 2) action to be taken for levels higher than in 1 above, 3) requirements for identification of individual radionuclides comprising the contamination, 4) assume all objects in plant that cannot be surveyed on all surfaces (e.g. pipes) are contaminated and cannot be released for public use, etc.

n. Scrapping and decontamination facility (SDF). It may be possible to divert some section of the reprocessing plant or the waste disposal facility to become the SDF or perhaps a new facility will have to be constructed on the Gorleben site during this three year period. Certain equipment such as tanks, pipes, pumps, motors, fans manipulatiors, toots, etc. can be brought to the SDF for a more professional job of decontamination, disassembly and scrapping. Here there will be dipping tanks (caustics, acids, detergents), ultrasonic cleaning, electrolytic cleaning, sandblasting equipment, crushing and compacting equipment, cutting tools, drills, scrapers, jets (for steam, water or paint), cement mixers and forms for making the final loaded cement blocks for storage in the salt mine, etc. When cleaning tanks, pipes and equipment that may contain considerable Pu, special precautions must be taken to avoid a critical assembly in any of the solutions.

o. Personnel requirements for decommissioning. These requirements differ markedly, depending on which of the decommissioning schemes in Fig. 1 is selected. For example, if scheme 1 is selected, all personnel requirements are minimized; if scheme 2 is chosen, health physics requirements are a maximum, and if scheme 4 + 4c + 4 cb is chosen, security requirements are a maximum. In any case prepara-tions to meet these requirements on a timely basis must be completed in this first stage of decommissioning.

p. Storage area. Since operations in the SDF facility may not procede as fast as the head end operations of decommissioning--especially if scheme 2 is selected--, a storage area should be provided during stage 1 for hot equipment. Such equipment must not be stored in the open because then environmental contamination may become a very serious problem as it is in the Rocky Flats area near Denver, Colorado, U.S.A. It may develop that enough room can be provided in the pool fuel storage facility to meet this need, but this must be determined during this three year 1st stage of decommissioning.

q. Testing of remotely operated equipment and of mock up facilities. This can be one of the most productive activities during this first stage of decommissioning. New types of remotely operated equipment can be developed and tested on mockups. When a workman begins on a hot job, it is too late to develop proficiency, so extensive training and experience with mockups may be the best solution to this problem. Just learning how to work in pressure suits during such operations requires a long period of training and a high measure of patience and appreciation of the risks involved. The publication, "Situation der Entsorgung der Kernkraftwerke in der Bundesrepublik Deutschland," mentions a number of examples in Europe and in the U.S. where large contaminated equipment was dissassembled as though these are rather routine tasks. This publication failed, however, to mention many problems of long delays and personnel contamination associated with these and other similar demolition operations. Also, it should be noted that decommissioning of the only commercial reprocessing plant that has operated in the U.S. (i.e. West Valley, New York) has been stall. d for two years and has not commenced because it is not known how the job can be done safely and at a reasonably cost of man.rem and [illegible] dollars (i.e. less than $8 × 10^8$). The U.S. Congressional Report, Washington, February 1978 (see paragraph C-2 above) listed 320 facilities of the Department of Energy in the U.S. as of June 1976 that are past due the time for decommissioning. The entire decommissioning program in the U.S. is running behind schedule and cases are turning up in the news media every few months where past decommissioning operations have failed. This results in piecemeal emergency measures being taken awaiting a satisfactory solution. Three commercial fuel reprocessing plants have been built in the U.S. but none is currently reprocessing spent fuel. As pointed out in NUREG-0436 (March 1978), Battelle PNL has three studies underway in an effort to offer guidance on decommissioning and to obtain information on the impact on public and occupational safety, on the costs of decommissioning, and on methods for improving decommissioning. These studies are on decommissioning of reactors, fuel cycle facilities and the design facilitation of decommissioning. Altogether there are six of these Battelle PNL reports in various stages of preparation; the last one is scheduled in March 1980. Hoepfully these studies will provide some urgently needed information in the U.S. and maybe this would be useful to Gorleben.

B. Dollar Costs of Decommissioning Gorleben

The costs and financing of Gorleben decommissioning have not been given adequate consideration. As indicated in the above reference reports there are three ways that have been given serious consideration for financing the decommissioning of nuclear facilities.

1. Pay for the costs while they are incurred (i.e. when decommissioning begins).
2. Make annual payments into a sinking fund.
3. A prepaid sinking fund.

Each of the above methods has its advantages and disadvantages and combinations of the three methods would be possible. The first method would not be fair because 40 to 50 years after the plant was built, those persons paying for decommissioning would not be those who benefited most from Gorleben's past operation. Number 3 might not be appropriate because of the changing value of the dollar. Number 2 might be satisfactory provided each annual payment were adjusted to the estimated cost of decommissioning when it would have to be paid for.

Cost estiamtes of decommissioning of nuclear reprocessing plants are notorious for their underestimates. For example, the West Valley decommissioning fund originally approved by the USAEC was only $\$4 \times 10^6$ when now the estimated costs are $\$8 \times 10^8$ (an underestimate by a factor of 200). Cost for partial decommissioning of the Hanford operation near Richland, Washington is $\$4 \times 10^9$ (in 1972 dollars). The Report to the U.S. Congress of the Subcommittee on ~~the Report to the U.S. Congress of the Subcommittee on~~ the Environment and the Atmosphere, February 1978 (see above paragraph C-2) stated, "Hanford reservation will probably be a permanent monument to the nuclear enterprise (since the site can never be returned to unrestricted use)." It went on to say, "In the past ERDA (now DOE) has been concerned about the ultimate disposition of its nuclear facilities only after they have become excess. This has resulted in the accumulation of a large number of radioactively contaminated facilities (over 300 as of June 1977) where decontamination and decommissioning must be planned and paid for." This writer might comment here that putting land out of commission (out of use) for long periods of time or indefinately would be more serious in Germany than in the U.S. where vast areas of land remain undeveloped.

III. Conclusion

Inadequate consideration has not been given to decommissioning of the Gorleben plant and plans for construction and operation of this plant should not procede or be approved until appropriate consideration has been given to decommissioning.

Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements

KARL Z. MORGAN

Georgia Institute of Technology, School of Nuclear Engineering, Atlanta, Georgia 30332

The historical development of the value of maximum permissible body burden of ^{239}Pu is presented and present considerations for the revision of this standard are given. Some evidence is presented that the linear hypothesis may not be sufficiently conservative at low dose rates and especially for the actinide elements. Until certain questions are answered about the particle problem, it will not be possible to set a satisfactory maximum permissible body burden for ^{239}Pu based on lung as the critical organ, but in the meantime some studies suggest that the present maximum permissible body burden based on bone should be reduced at least by a factor of 200.

Introduction

PERHAPS THERE HAS NEVER BEfore been an enterprise that was planned so carefully for its safety and never before a risk that has been so thoroughly studied and guarded against as has been the case with the nuclear energy industry and its concern to avoid unnecessary exposure to ionizing radiation. It is ironical that in part because of this concern and in spite of the fact that we now probably know far more about the effects of this radiation on man than about any of the other common hazards, exposure to the radiations associated with nuclear energy seem to frighten and engender fear that is all out of proportion in comparison with the everyday risks from such things as medical x-ray, food additives, and environmental pollutants from the burning of fossil fuels. However, on second thought this public concern for radiation exposure probably should not be surprising because, except for unusual precautionary measures and constant vigilance, there likely some day will be a major accident with very serious consequences. Even though most of the public may be convinced of a very low probability of such a serious accident, we are reminded frequently in our newspapers of what could happen from accidental release into the public domain of large quantities of radioactive material from nuclear power plants, from spent fuel operations, or from shipping accidents.

A considerable portion of the credit for the remarkable safety record of the nuclear energy industry as one of the safest of all modern industries must be given to the untiring efforts of members of the health physics profession with whom I have been associated for over 30 years, and which profession I have seen grow from a group of 5 health physicists at the University of Chicago in 1943 to a worldwide organization today of over 10,000 professionals. Our lot as a growing profession of health physicists has been a most interesting and challenging one but it has not always been easy, because there were times when some of my associates were demoted or lost their jobs because they refused to yield to pressures to lower our standards or compromise for unsafe conditions.

We were constantly resisting pressures of engineers and production supervisors to relax what they called our ridiculous conservatism. Sometimes we were forced to set exposure limits that were lower than our management wanted and perforce they were often little better than guesses because in some areas we had almost no experience or supporting experimental data. For example, one of the earliest papers[1] showing how to calculate dose from internally deposited radionuclides and giving values of permissible body burden and permissible concentration of some 20 radionuclides was delayed for almost a year when I presented it for publication in 1945 because some of the permissible occupational exposure values I calculated were much lower than those in use in weapons production operations. I had at that time almost no metabolic data for some of these radionuclides. For the most part I had to rely on a series of publication by J. G. Hamilton et al.[2] on the metabolism of fission products, plutonium, and other actinide elements in mice and rats and in a few cases data on only 3 or 4 rats were available. The maximum permissible internal dose rates for occupational exposure that I used in making these early calculations were 36 R/y for β and γ radiation and 3.6 rep/y ($\sim$3 rad/y) for α radiation. On this basis and using available metabolic data the value I obtained for ^{239}Pu for maximum permissible lung burden of the occupational worker was 0.035 μCi and for bone burden was 0.42 μCi. The standard man data I used were based on typical human values collected and summarized for me by M. J .Cook.[3]

The first semiofficial values for body burden of the radionuclides were developed at the Chalk River Canada Conference[4] in 1949. These values were later reviewed at the Harwell, England Conference in 1950. From about 1950 to 1973, I was chairman of the Internal Dose Committees of both the International Commission on Radiological Protection (ICRP) and of the National Council on Radiation Protection (NCRP) and so must assume some of the blame for shortcomings of our Handbooks on Internal Dose. During this period there were four principal publications of our Internal Dose Handbooks giving values of organ burden (qf_2) and body burden (q) and maximum permissible concentrations in air (MPC)$_a$

TABLE I
Maximum Permissible Body Burdens for ^{239}PU

	Occupational		For Population at Large	
Source of Value	qf_2 (μc)	q (μc)	qf_2 (μc)	q (μc)
Early Oak Ridge Nat. Lab.	0.42 ^{B}	0.70 ^{B}	——	——
(KZM-1947)$^{(1)}$	0.035^{L}	0.12 ^{L}	——	——
Chalk River Conference	——	0.006^{B}	——	0.00006 ^{B}
1949$^{(4)}$	——	——	——	——
Early Los Alamos Nat. Lab.	——	0.063^{**B}	——	——
(WHL-1938)$^{(4)}$	——	——	——	——
NCRP—Handbook 52	0.03 ^{B}	0.04 ^{B}	(0.003) ^{B}	(0.004) ^{*B}
(1953)$^{(5)}$	0.008^{L}	0.008^{L}	(0.0008)^{*L}	(0.0008)^{*L}
ICRP—Br. J. Radiol.	0.03 ^{B}	0.04 ^{B}	——	——
Supp. 6 (1954)$^{(6)}$	0.02 ^{L}	0.02 ^{L}	——	——
NCRP—Handbook 69	——	0.04 ^{B}	——	(0.004) ^{*B}
(1959)$^{(7)}$	——	——	——	——
ICRP—Handbook 2	0.036^{B}	0.04 ^{B}	——	——
(1959)$^{(8)}$	——	——	——	——

^{B}—value based on dose to bone; ^{L}—value based on dose to lung; *—values in parentheses are based on suggested safety factor of 10; q—μc in total body based on indicated organ; qf_2—μc in indicated organ (bone or lung); **—W. H. Langham gave 0.032 μCi as a proposed LNL value in 1950.

and water $(MPC)_w$ for a large number of radionuclides including values for ^{239}Pu and some of the other actinide elements. Table I summarizes these values of q and qf_2 for ^{239}Pu. Similar values to those in Table I have been given in these same publications for the other actinide radionuclides and for the most part there have been few changes since 1953. In most cases the ICRP and NCRP recommended dose limits are identical. In 1964, ICRP[9] made a few revisions for the actinide elements but the values for ^{239}Pu remained unchanged.

Changes Being Considered for Revised ICRP Internal Dose Handbook

There are many changes being considered for the ICRP Internal Dose Handbook which has been under revision for over 12 years. Only a few of these changes which relate to the permissible exposure levels for the transuranium radionuclides will be mentioned here. Two rather obvious improvements are: (1) Where possible doses to the bone will be calculated for specific critical tissue of this organ rather than average the dose over the entire bone and (2) The dose to a critical organ (or tissue) will be the sum of the doses to that organ originating from deposits of the radionuclide in all body organs including that from deposits in the critical organ.

The present ICRP and NCRP values[7-9] of q, qf_2, $(MPC)_a$, and $(MPC)_w$ were calculated on the basis of uniform distribution of the radionuclides in the critical body organ (e.g. uniform deposition in the skeleton) and irradiation only from the deposits of the radionuclide within this organ. These assumptions were made because of a lack of biological information. The assumption of uniform distribution of a radionuclide may have given rather reliable results in some cases for gamma and high energy β-emitting radionuclides that are fairly uniformly deposited in an organ but the risk (of bone cancer) from ^{239}Pu could have been seriously underestimated because most of the α-emitting ^{239}Pu is deposited on bone surfaces of the trabecular matrices adjacent to the thin layer of endosteal tissue which happens to be the most critical tissue in this case. Obviously, the inclusion in the calculation of dose only from the radionuclide deposited within the critical tissue itself could lead to underestimates of the risk except for α and low energy β-emitting radionuclides that are highly localized in the critical organ so that cross irradiation from other organs is insignificant. The decision of the ICRP has been to consider the critical tissues of the skeleton the endosteal tissue (as it relates to bone cancer) with an average thickness of 10 μm and the active (red) bone marrow (as it relates to leukemia), and to limit the maximum permissible annual occupational dose (MPAD) to these tissues to no more than 15 rem/y (a limit of 1.5 rem/y for members of the general public). Unfortunately our knowledge of the microdeposition of ^{239}Pu in the bone probably is too limited at the present time to apply these refinements and so it is likely the present practice will be continued; namely, calculate the dose from ^{239}Pu to the entire skeleton, as is done with some justification for ^{226}Ra, and apply an N-factor (= 5) to the absorbed dose (rad) as well as the usual Q factor (= 10) for α-radiation in obtaining estimates of the dose equivalent (rem).

The new ICRP Internal Dose Handbook probably will not give values of q, qf_2, or $(MPC)_w$ but these quantities can be calculated from values of A (μCi days of residence time in the critical tissue of reference or standard man), B (dose commitment in rem to this critical tissue for the next 50 years per μCi intake), and MPAD (maximum permissible annual dose, e.g. occupational limits of 5 rem/y to total body and gonads; 30 rem/y to total bone, thyroid, and skin; 75 rem/y to hands, feet, arms, and ankles; and 15 rem/y to all other body organs or tissues). Two equations[10] as follows can be used in making these calculations:

$$q = \frac{5.4 \times 10^{-5}\ m\ (MPAD)}{f_2 \epsilon} \qquad (1)$$

$$q = \frac{(MPAD)A}{365\ f_2 B} \qquad (2)$$

in which A,B and (MPAD) are defined above, f_2 is the fraction of the radionuclide in the critical tissue of that in the total body. ϵ(MeV × Q × N) is the total effective energy deposited in the critical tissue of mass m(g) per disintegration of the radionuclide in the entire body.

The Linear Hypothesis May Not Be Sufficiently Conservative

Frequently in the literature it is stated that the linear hypothesis is a very conservative assumption. During the past few years, however, many studies have indicated that this probably is not true in general and that at low doses and dose rates somatic damage per rad (and especially that from α-irradiation) probably is usually greater than would be assumed on the linear hypothesis. There are many reasons for this, some of which are:

1. The linear hypothesis is based on extrapolations to zero dose of effects of radiation on animals or humans at intermediate to high doses. The points used on the curves at high doses may be on the descending part of the curve, i.e. from portions of the curve where there was overkill or where a large fraction of the highly exposed died of other types of radiation damage and did not survive to die of the radiation effect under study.
2. Extrapolations are made on human data which in general relate human damage such as bone cancer from ^{239}Pu for observation periods of no more than about 20 years. Many of the conclusions are based on studies of animals of life spans less than 10 years. Since man lives for more than 70 years, the slopes of these curves can only increase as more human data are accumulated over his entire life span.
3. The linear hypothesis assumes that man is a uniform and more or less homogeneous population. It applies to the average man and may not be sufficiently conservative for the fetus and for old people. It never takes into consideration special groups such as those studied by Bross[11] where he found that children of age 1-4 had 3.7 times the risk of developing leukemia if they have allergic disease such as asthma and 24.6 times the risk of the children of this age group if they had both allergic disease and had received intrauterine x-ray exposure.
4. There may be cell sterilization at intermediate and high doses. By this we mean there may be many cells in the body which are likely targets to become precursors of a clone of cells which are malignant but they are killed by the higher doses. In other words, these cells may already have two of the "series cancer switches" closed and a low dose of radiation would likely close the final switch in the step toward cancer production. A high dose such as that from which extrapolations usually are made, however, might kill most such cells as it does in radiation therapy which is used to destroy a cancer.
5. For many types of radiation damage the best fit curve is a plot of equation $E = CD^n$ in which E = effect, C = constant, D = radiation dose, and n = constant. For the linear hypothesis $n = 1$. In some cases $n > 1$ indicating lesser damage per rad at low doses but in many cases the best fit to experimental data is obtained when $n < 1$. Baum[12] recently showed a best

fit for cancer induction when $n = 1/2$. In such case the linear hypothesis would be non-conservative.

6. As pointed out above ^{239}Pu is an α-emitting, bone seeking, radionuclide like ^{224}Ra, but unlike ^{226}Ra, it is deposited on the bone surfaces adjacent to the radiosensitive endosteal and perisoteal tissues. The use of the N-factor equal to 5 for all α-emitting radionuclides in bone except ^{226}Ra somewhat compensated for this increased risk from surface deposition but has always left some questions to be answered when we determined all q and qf_2 values for bone as given in Table I by comparison with ^{226}Ra burdens in man. Our 50 year human experience with ^{226}Ra has been of extreme importance in setting these values for bone but one was not completely satisfied in using the University of Utah[13] data on ^{239}Pu and ^{226}Ra in dogs to provide guidance in making these extrapolations in humans where there are very little ^{239}Pu data. Fortunately, a recent finding may be of great assistance in relating ^{239}Pu exposure to ^{226}Ra which has been studied intensively for many years in some humans who have varying quantitatively determined body burdens of ^{226}Ra in their skeletons. Here I refer to the important studies of Mays et al.[14] of over 1000 patients in Germany who were injected with known amounts of the short lived (3.64 day), α-emitting radionuclide, ^{224}Ra as a treatment for extra-pulmonary tuberculosis. Because of its short radioactive half life ^{224}Ra, unlike ^{226}Ra, does not have time to be deeply imbedded in bone and thus may simulate to a considerable degree the deposition of ^{239}Pu in man. Mays[14] et al. have made an interesting observation regarding human exposure to ^{224}Ra which may have important bearing on chronic exposure of large populations to α-emitting, bone surface seeking radionuclides; namely, there is a greater incidence of bone sarcoma from a given total dose of radiation when the span of ^{224}Ra injections was increased. This increased risk with increased protraction of α-radiation exposure is opposite from what has been observed generally with exposure to x-rays where protracted dose allows time for more repair of radiation damage. Mays has suggested that maybe this may be attributable to (a) increased number of cells irradiated, (b) less kill of pre-malignant cells (i.e. cell sterilization), (c) prolonged stimulus of cell division, and (d) greater difficulty for cell repair of local α-damage.

Since ^{239}Pu when dispersed into the environment in very low concentration (except in the unlikely accident) delivers a protracted rather than an acute exposure to man, the risks may be greater than those suggested by animal studies at high acute levels of exposure to ^{239}Pu.

Changes in the Permissible Exposure Level for ^{239}Pu as Suggested by the Author

As noted in Table I, no values of q and qf_2 for occupational exposure are given at the present time in NCRP and ICRP Handbooks on Internal Dose for lung. However, using the data provided in ICRP Handbook 2, the value of 0.015 μCi ^{239}Pu for uniform distribution can be obtained. This of course raises the question of the so-called hot particle problem and adequacy of a value of q or qf_2 based on the assumption that the risk of lung damage (i.e. lung carcinoma) is proportional to the average dose delivered to the entire lung ($m = 10^3$ g).

No one knows the answer to this question at the present time. Certainly we would like to have more information. Tamplin and Cochran[15] suggest that because of the very large dose (thousands of rem/y) in the vicinity of a micron size particle of ^{239}Pu lodged in lung tissue, the present q for lung (~ 0.015 μCi) and the corresponding values of $(MPC)_a$ for occupational exposure as well as those for members of the public should be lowered by a factor of 10^5. Perhaps they are right, but I believe they have not made a strong case for this factor simply because adequate biological data are not available and much of that which we have seems to give contradictory information. Early experiments of Lisco, Finkel, and Brues[16] have indicated there is a high probability (about 50%) of a malignancy at the site of injections of as little as one μg (~ 0.06 μCi) of ^{239}Pu in the skin of animals and data of Cember[17] perhaps suggest a higher risk due to localized doses in the lungs. On the other hand, later experiments of Brues[18] have shown when plaques of radioactive materials are placed on the skin of an animal, the risk of skin carcinoma is greater for a uniform distribution of a μCi than for a μCi localized in hot spots. The outstanding research of Bair and Thompson[19] shed much light on the hot particle problem but unfortunately they do not provide us with unequivocal proof that there is or isn't a hot particle problem. They[19] leave the question as one still to be resolved when they state "The mean dose to a tissue may be less important, however, than the dose to localized regions within the tissue." There is no question that epithelial cells of the skin are very radiosensitive and local doses such as are produced by μg quantities of ^{239}Pu in wounds are very carcinogenic. The tissues at risk in the lungs also are epithelial and the most important question remaining is whether or not this large localized dose to the epithelial cells of the lung can likewise result in a high incidence of lung tumors when small dust particles of the highly insoluble $^{239}PuO_2$ are inhaled and find their way to the terminal bronchioles, alveolar epithelial cells, or are translocated to thoracic and abdominal lymph nodes. It certainly is encouraging that there is no clear evidence at the present time that human occupational exposure to plutonium and other transuranium elements has resulted in any form of cancer. We should realize, however, that no extensive epidemiological and autopsy study of the exposed human populations has been completed and with man the average incubation period for tumors of the lung, bone, liver, or lymph nodes may be 40 to 50 years.

In theory at least the occupational exposure values of q and qf_2 for α-emitting radionuclides that are bone seekers have not been set by the use of equations 1 and 2 in the past but by direct comparison with the value of q = 0.1 μCi of ^{226}Ra in the human body. It develops, however, that the same values of q and qf_2 as are given by NCRP[2] and ICRP[3] can be obtained by setting (MPAD) in equation 1 equal to 30 rem/y for bone seeking radionuclides. This standard of 0.1 μCi of ^{226}Ra was set by the U. S. Advisory Committee on Safe Handling of Radioactive Luminous Compounds[20] in 1941. The ICRP[3] stated, "At the present time, it would be difficult to say which is more harmful to man (a) the dose rate to the total body of 0.1 rem/wk or (b) the dose rate to the bone resulting from a body burden of 0.1 μCi of ^{226}Ra . . . Although tumors have not been observed in persons with body burdens of radium as low as 0.1 μCi, the factor of safety may not be as large as 10 because tumors have been observed in persons having a body burden less than 1 μCi of radium at the time the tumor was first detected . . . Several workers have described changes in skeletal density and/or histopathological changes in the bone of patients who had 0.1 μCi or less of radium, and more pathological changes may be expected as these individuals become older." In spite of uncertainties regarding the 0.1 μCi standard for ^{226}Ra, it is based on over 50 years of human (not other animal) experience. With proper adjustments to determine the equivalent dose (rem) to the critical body tissue from α-emitting actinide radionuclides, I believe comparison with ^{226}Ra and ^{224}Ra provides the best method now available for setting suitable radiation protection standards for these radioactive materials.

I believe the most reliable values of q based on bone as the critical tissue can be obtained for ^{239}Pu and some other transuranium radionuclides by making use of the comparative data on bone carcinoma and sarcome incidence in dogs that have been injected with known amounts of ^{226}Ra and ^{239}Pu as well as a number of other α-emitting radionuclides. This outstanding work has been carried out over a period of many years by a team at the University of Utah[13] and as pointed out by Bair and Thompson[17] these data can be used in making comparison of the values of q for ^{239}Pu and the other transuranium α-emitting radionuclides with ^{226}Ra. If one makes these comparisons, the corrections listed below should be made to the value of q = 0.04 μCi of ^{239}Pu which as indicated above is based on the 0.1 μCi ^{226}Ra standard when setting N = 5 or on the average dose rate of 30 rem/y to the adult skeleton:

(a) The value of q = 0.04 makes use of an N-factor of 5 for the α-radiation of ^{239}Pu and other α-emitting radionuclides in the skeleton. As pointed out above, this N is intended to be the relative risk from bone seeking, α-emitting radionuclides (e.g. ^{239}Pu) in comparison with ^{226}Ra on the basis of absorbed dose (i.e. on a per rad basis). Data of Daugherty and Mays[21] have shown that this value of N for dogs is somewhere between 5 and 15. If we accept the value of 15, the appropriate correction factor for ^{239}Pu is 5/15 or 1/3.

(b) The surface to volume ratio for the trabecular bone of the dog (the tissue in which it is believed most of the bone cancers originate) is about twice that for man. Thus the same amount of ^{239}Pu in man would have twice the concentration of ^{239}Pu near the trabecular surfaces as that in the dog. This would be a correction factor for ^{239}Pu of 1/2.

(c) The rate of turnover (burial) by apposition of new bone of the deposits of α-emitting radionuclides on the trabecular surfaces is probably about ten times that in the dog of that in man. This corresponds to a correction factor for ^{239}Pu of 1/10.

(d) Studies of Metivier et al.[22] on the survival time of baboons relative to the dog for various concentrations of $^{239}PuO_2$ in the lungs suggest that the baboon is about 4 times as radiosensitive as the dog. Assuming this same ratio would apply for bone burden of ^{239}Pu (perhaps a poor assumption) and that the radiosensitivities of the baboon and man are the same we have a correction factor for ^{239}Pu of 1/4.

The above would correspond to an overall reduction in q for ^{239}Pu of 1/240 (or q = 0.00017 instead of 0.04 μCi) when endosteal tissue of the bone is the critical tissue. Insufficient data are available to attempt any such correction to the value of q for the lungs other than apply correction (d) above. Thus we would have q = 0.015/4 $\cong$ 0.004 μCi when total lung is the critical tissue. This of course does not address the hot particle problem but rather shelves it until we have more data. This unfortunately is what society has done for generations in the case of environmental pollutants from burning of fossil fuels.

A somewhat similar problem, namely the possible use of pulmonary lymph nodes as the critical body organ for $^{239}PuO_2$ has been under discussion for many years by Committee 2 of ICRP. There is no question but that when dogs inhale $^{239}PuO_2$ in finely divided particles a major fraction ends up in the thoracic lymph nodes. Park et al.[23] for example give the percents of alveolar-deposited $^{239}PuO_2$ 11 years after exposure of about 40% for thoracic lymph nodes, 13% for liver, and 5% for bone. After many years of consideration of this question the ICRP finally decided not to use the lymph nodes as critical body tissue because no animal studies had indicated this to be the critical tissue in terms of carcinogenesis. Perhaps in this case of large doses to the lymph nodes we have a good example of cell sterilization or complete kill of all the radiosensitive cells in the nodes that are within the range of the α-radiation. The picture might be quite different for lesser $^{239}PuO_2$ concentrations in these nodes which might be experienced by members of the public from chronic exposure to low dust levels of $^{239}PuO_2$. Perhaps only time can tell whether or not the present practice of ICRP of averaging the ^{239}Pu dose in the pulmonary lymph nodes and in alveoli and terminal bronchioles with the dose to the total lung mass (1000 g) is non-conservative. Likewise, as many researchers have pointed out, plutonium and the other transuranium elements tend to localize in the liver during chronic environmental exposure or from chronic leakage of Pu from the lymph nodes to the body fluids. Thus in the years ahead we could have some surprises and find that not the bone but the liver or even the lymph nodes after all are the critical tissues for human damage from chronic exposure to low levels of the transuranium elements. Hopefully, in the meantime we will learn more also about other environmental insults because when we do, I believe we will recognize an even greater urgency to keep their exposure to man as low as practicable.

References

1. Morgan, K. Z.: Tolerance Concentrations of Radioactive Substances. *J. of Physical and Colloid Chem. 51*:984 (1947).
2. Hamilton, J. G., et al.: A series of 80 papers published by Hamilton and his group at the University of California from 1937 to 1947. Summarized in the Bibliography for Biological Data by M. J. Cook, *Health Physics 3*:235 (1960).
3. Cook M. J.: These data on the standard man collected by Ms. Cook of Oak Ridge National Laboratory in 1946 were never published but these data together with data collected by H. Lisco of the Argonne National Laboratory were the basis of the standard man data in the 1949 Chalk River Reports.
4. Chalk River Canada Conference of members of radiation protection committees from the United States, United Kingdom and Canada. September 29 and 30, 1949. Minutes of this meeting were never published but separate sets of minutes by K. Z. Morgan, W. H. Langham, G. J. Neary, and G. E. McMurtrie were widely circulated in 1950.
5. Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. NCRP Handbook 52, NBS, March 20, 1953.
6. Recommendations of the International Commission on Radiological Protection. *British J. of Radiology, Sup. No. 6*:1 (1955).
7. Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure. NCRP Handbook 69, NBS, June 5, 1959.
8. Permissible Dose for Internal Radiation. ICRP, Pub. 2, Pergamon Press (1959).
9. Recommendations of the International Commission on Radiological Protection. ICRP Pub. 6, Pergamon Press (1964).
10. Morgan, K. Z.: *Proper Use of Information on Organ and Body Burdens of Radioactive Materials.* IAEA/WHO Symposium on the Assessment of Radioactive Organ and Body Burdens. Stockholm, Sweden, Nov. 22-24, 1971, IAEA/SM/150-50.
11. Bross, I. D. J.: Leukemia from Low-Level Radiation. *New Eng. J. of Med. 287*:107 (1972).
12. Baum, J.: *Population Heterogeneity Hypothesis on Radiation Induced Cancer.* Given orally at Houston, Tex. meeting of the Health Physics Society, July 10, 1974.
13. Mays, C. W. and T. F. Daugherty: Progress in the Beagle Studies at the University of Utah. *Health Physics 22*:793 (1972).
14. Mays, C. W.; H. Spiess, and A. Gerspach: Skeletal Effects Following ^{224}Ra injections into Humans. Reported at the Symposium on Biological Effects of Injected ^{224}Ra and Thorotrast, Alta, Utah, July 21-23, 1974. To be published in *Health Physics* in 1975.
15. Tamplin, A. R. and T. B. Cochran: *Radiation Standards for Hot Particles.* Publication of Natural Resources Defense Council, 1710 N. Street, N.W., Washington, D. C. 20036, February 14, 1974.

16. Lisco, H., M. P. Finkel, and A. M. Brues: Carcinogenic Properties of Radioactive Fission Products and of Plutonium, *Radiology 49*:361 (1947).
17. Cember, H.: Radiogenic Lung Cancer, Progress in Experimental Tumor Research. Vol. 4, p. 251 (1964); Cember, H., J. A. Watson, and T. B. Brucci: Pulmonary Effects from External Radiation. Presented at AIHA meeting, Philadelphia, April 26, 1956.
18. Brues, A. M.: Unpublished experiments. Argonne National Laboratory (1953).
19. Bair, W. J. and R. C. Thompson: Plutonium: Biomedical Research. *Science 183*:715 (1974).
20. National Bureau of Standards Handbook 27. *Safe Handling of Radioactive Luminous Compounds* (1941).
21. Daugherty, T. F., and C. W. Mays: Bone Cancer Induced by Internally-deposited Emitters in Beagles. In *Radiation Induced Cancer*, International Atomic Energy Agency, Vienna. 361 (1969).
22. Metivier, H.: D. Nolibe, R. Masse and J. Lafuma; Excretion and Acute Toxicity of $^{239}PuO_2$ in Baboons. *Health Physics* 27:512 (1974).
23. Park, J. F., W. J. Bair, and R. H. Busch: Progress in Beagle Dog Studies with Transuranium Elements at Battelle-Northwest. *Health Physics* 22:803 (1972).

Vienna, Austria to Host International Atomic Energy Agency Symposium

Development of nuclear-based techniques for the measurement, detection and control of environmental pollutants will be the theme of the symposium, to be held March 15-19, 1976.

Inquiries on participation should be directed promptly to John H. Kane, Special Assistant for Conferences, Office of Public Affairs, MS: A1-5216, United States Energy Research and Development Administration, Washington, DC 20545.

Errata, Changes, Addition . . .

June, 1975 The Market Basket: Food for Thought
by William B. Deichmann, Ph.D., M.D. (hon.)

page 411—In the author's line, *Deichman* should have read *Deichmann*.

page 415—The phrase "*(nine calories per gram)*" is changed to read "*(nine Calories per gram)*".

page 421—The statement "The *diminishing* incidence of metastatic . . ." is changed to read "The *increasing* incidence of metastatic . . ."

June, 1975 Occupational Exposure Limits for Novel Work Schedules
by R. S. Brief and R. A. Scala

page 469—The author requests that preparation of the "*Comments*" portion of this article be credited to Dr. Herbert Stockinger, Chairman of the ACGIH Committee.

First European Plant Engineering Exhibition Opens September 15th

A major five-day conference will accompany this show, to be held at Earls Court, London. Among the subjects to be covered are health and safety law compliance and physical working environments. U.S. and Canadian visitors information from Clapp & Poliak, Inc., 245 Park Ave., New York, New York 10017.

Risk of Cancer from Low Level Exposure to Ionizing Radiation*

by

Karl Z. Morgan
Neely Professor
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

During the first half of the atomic age (1942-1960) a large number of scientists, perhaps most who were knowledgeable in health physics and radiobiology, accepted the threshold hypothesis or the theory that there is a safe level of exposure to ionizing radiation, and so long as a person does not exceed this threshold or safe level no harm will result or the radiation damage on the average will be repaired as fast as it is produced. During the last half of this period (1960-present) an overwhelming amount of data have been accumulated that show there is <u>no safe</u> level of exposure and no dose of radiation can be so low that the risk of it causing a malignancy is zero. The question before us today, therefore, is not: Is there a risk from low level exposure? or: What is a safe level of exposure? rather it is: How great is this risk? or: How large may a particular radiation risk be before it exceeds the expected benefits?

It is obvious to all scientists in this field as well as to the diehards for the threshold hypothesis that at least for some types of radiation damage and for some kinds of radiation exposure (especially from low LET radiation, i.e., x, γ and β radiations) there is some repair of the radiation damage going on in the body, but the diehards do not seem willing or able to accept the preponderance of evidence that there is never complete repair of radiation damage in the practical case for man since even at very low exposure levels there are many thousands of interactions of the radiation with cells of the human body. For example, one rad of x-rays of 1 MeV energy corresponds to 2.2 billion photons per

---

*Presented before the American Association for the Advancement of Science Washington, D.C., February 17, 1978. Some of this information was presented by the author in Congressional testimony, January 24, 1978 and February 10, 1978.

cm^2 acting on the body. It is inconceivable that all the billions of irradiated and damaged cells would be repaired completely. There are undoubtedly many mechanisms of radiation damage such as damage to cell membranes, damage to the body repair mechanisms, indirect damage (e.g. damage to cell blood supply and formation of harmful chemicals such as H_2O_2 in cell cytoplasm, etc.), impairment of efficiency of reticuloendothelial system function, etc. Each of the mechanisms may contribute to the development of a malignancy; perhaps, however, the most significant damage from low level exposure is that which results from direct interaction of the stream of ions with the nucleus of one of the billions of cells that is irradiated. There are 46 chromosomes in the nucleus of each normal somatic cell of the human body and along each chromosome are coded millions of bits of information like an immense library which enables or instructs the cell to function properly and to divide or stop dividing at the appropriate time. When radiation passes through the human body, four principal things can happen: 1) the radiation passes through or near the cell without producing any damage, 2) the radiation kills the cell or renders it incapable of cell division, 3) the radiation damages the cell such that the damage is repaired adequately and 4) the cell nucleus (or library of information) is damaged such that the cell survives and multiplies in its perturbated form over a period of years (5 to 70 years) in forming a clone of cells that eventually is diagnosed as a malignancy. It is only this last event that concerns somatic damage from low level exposure. It seems obvious that if this etiology or a similar series of events leads to the development of a malignancy, there can be no dose so low that the risk is zero. Thus the risk of induction of cancer from radiation exposure increases more or less with the increase or accumulation of radiation exposure and the risk is simply one of chance, just the same as the risk or chance of an accident each time we take an automobile trip.

It is evident also that all persons do not run the same risk of developing a malignancy from a given radiation exposure and that the risk of some types of cancer are greater for certain people than they are for the average or so called standard man. Burch[1,2] has shown, for example, that the final onset of a malignancy or other disease may require a series of events and a given type of leukemia may require as many as three successive events (like throwing three electrical switches which are connected in series). Thus, for example, one switch may be thrown genetically so that if one identical twin dies of a particular type of leukemia (1 switch thrown genetically), the other twin has a high probability of eventually suffering a similar fate. Some of these switches may be thrown by viruses, bacteria, chemicals, mechanical insults or by radiation. Studies of Bross[3,4] lend support for such a series of events and suggest synergistic relationships between them. He has shown that children (age 1-4) with allergic diseases such as asthma or hives have a 300-400% increased risk of dying of leukemia compared with other children (i.e. allergic diseases throw one switch). Children who received in utero diagnostic x-ray exposure have a 40 to 50% increase in risk of dying of leukemia (in confirmation of the extensive studies in the United Kingdom conducted by Alice Stewart and George Kneale,[5] while children with two switches thrown (i.e. in utero exposure and later developing a virus disease) have 5000% increase in risk of dying of leukemia. Studies of Stewart and Kneale,[5] B. MacMahon,[6] BEIR Committee,[7] and Bross[3,4] as well as those of many other researchers suggest that children have a higher risk of dying of radiation induced leukemia than do middle aged persons. Also, it has been shown by others, for example Hempelmann[8] Albert,[9] Modan,[10] Silverman et al.,[10,11] etc., that radiation induced thyroid carcinoma presents a higher risk in children than in an adult population. There are studies also which indicate sex plays a part in the type of a malignancy which is likely to develop. Mancuso et al.[12] have shown that older and younger men have a higher risk of radiation induced malignancies than do men of middle age. E. B. Lewis[13] pointed out that after examining data of Saenger and Tompkins[14] that they failed to note there was a significant increase in leukemia among persons between ages 50 and 79 who received ^{131}I treatments. Thus certain members of the general population, because of genetic inheritance, various diseases, age, sex, and perhaps many other individual characteristics, have a higher risk of radiation induced malignancies than does the average man.

The cancer risk from exposure to ionizing radiation is much greater than was thought to be the case some years ago. In the early period, following deaths from radiation sickness that occurred among Japanese survivors in Hiroshima and Nagasaki, it appeared to many scientists that the principal chronic risk from radiation exposure was only an excess of cases of leukemia which reached a peak about six years after the bombing and since then have slowly declined. Many persons jumped to the conclusion that the only chronic risk among these survivors was that of developing leukemia. Unfortunately, however, as the study of these survivors has continued and extended further into the incubation periods of the various malignancies, other forms of cancer (bone, breast, lung) have shown a significant increase above the controls. Probably with the passage of time we will find that this exposure has resulted in an increase of statistical significance in many or most kinds of malignancies that are common among human populations.

It should be emphasized here that although this paper treats only the oncogenicity of ionizing radiation, the genetic risks and especially those associated with recessive mutations may be as harmful and debilitating to the human race as the increase in risk of cancer. Therefore, I wish to pause and sound a warning that I'm sure my long-time friend, the genetist H. J. Muller, would urge me to make were he alive today, namely the BIER report only treated the long term recessive mutation question in a superficial way and it may well be that many and perhaps most of our human diseases including cancer are related to a genetic factor and especially to the 10,000 non-visible or "small" mutations that result per visible mutation that we can observe. It may be that in the long run Muller's small mutations that result in such things as lack of vigor, susceptibility to disease, a slight reduction in mentality and physique, etc., will be a far greater burden to society than the easily identifiable dominant mutations because small mutations are eliminated so slowly from the gene pool.

There has been a number of reductions in the permissible exposure levels for occupational workers and for members of the public during the past 35 years. Table 1 indicates some of the quantum drops in permissible exposure levels during this period. The occupational maximum

TABLE 1. CHANGES IN LEVELS OF PERMISSIBLE EXPOSURE TO IONIZING RADIATION

FOR RADIATION WORKERS:

Recommended Values		Comments
0.1 erythema dose/y (~1R/wk for 200 kV x-ray)	52 R/y	Recommended by A. Mutscheller and R. M. Sievent in 1925. This was recommended by ICRP in 1934 and used world-wide until 1950.
0.1 R/day (or 0.5 R/wk)	36 R/y	Recommended by NCRP on March 17, 1934.
0.3 rem/wk	15 rem/y	Recommended by NCRP on March 7, 1949 and ICRP in July, 1950 for total body exposure.
5 rem/y	5 rem/y	Recommended by ICRP in April, 1956 and NCRP on January 8, 1957 for total body exposure.

FOR MEMBERS OF THE PUBLIC:

0.03 rem/wk	1.5 rem/y	Suggested by NCRP in September, 1952 for any body organ.
0.5 rem/y	0.5 rem/y	Suggested by NCRP on April 15, 1958 and by ICRP in July, 1959 for gonads or total body.
5 rem/30 y	0.17 rem/y	Suggested by ICRP on September 9, 1958 for gonads or total body.
25 mrem/y	0.025 rem/y	Suggested by USEPA on January 13, 1977 for any body organ except thyroid
5 mrem/y	0.005 rem/y	Suggested by USERDA in 1974 for persons living near a nuclear power plant.

NOTE: (1) 1 R = 0.88 rem.
(2) See Reference 15 for additional information.

permissible exposure level has dropped by a factor of 10 and the level for members of the public by a factor of 300.

Much of what has been said about the risks of exposure to low levels of ionizing radiation would have considerably less weight if it could be shown that although the linear hypothesis holds at intermediate to high levels of exposure it provides a very large element of conservatism at low doses and dose rates. Unfortunately, in most cases there is no evidence of a safety factor at low doses when assuming the same linear relationship exists between radiation dose and cancer induction at high doses and at low doses. We have a large amount of data, much of it is human, showing a statistically significant increase in a number of types of malignancies as a consequence of exposure to low doses of ionizing radiation and the number of malignancies increases progressively as the dose accumulates. These doses in some cases are considerably lower than the present levels of maximum permissible annual exposure of the radiation worker. In fact, many researchers[16,17,18,19] have shown that in some cases the linear hypothesis is non-conservative and it actually underestimates the risk.

Table 2 indicates the magnitude of the cancer risk and that this risk increases linearly with the accumulated dose down to very low values. i.e. down to 1 rad or less for leukemia or other forms of cancer resulting from pelvimetries, and to 6.5 rad for thyroid carcinoma resulting from x-ray therapy of the scalp for ringworm (tinea capatis). It must be pointed out that these doses (0.8 and 6.5 rad) are not the doses below which the linear hypothesis breaks down but the lowest points on the human exposure curves for these two malignancies and we have every reason to believe the linearity of these curves continues on down to zero dose and that there is a similar linearity for other types of cancer that simply have a longer incubation period or have not been studied over a wide range of doses to a human population. It should be emphasized also that this 0.8 rad is only 5% of the 15 rad permitted each year to the active bone marrow of the radiation worker and that the 6.5 rad is only 22% of the 30 rad permitted each year to his thyroids. (The MPC values given by ICRP and NCRP for members of the public are calculated on the basis of 10% of

TABLE 2. CANCER RISK AND KNOWN RANGE OF LINEARITY

Linearity of Dose Down To:	Risk Per Person Per Rad	Comments	References
<10 Rad	$0.3 - 1.0\times10^{-4}\ell$ $0.5 - 1.7\times10^{-4}C$	Hiroshima & Nagasaki atom bomb survivors	7, 23, 24 25
Av. 370 Rad	$0.2 - 0.3\times10^{-4}\ell$	Ankylosing spondylites patients	7, 20
0.2 - 0.8 Rad	$3\times10^{-4}\ell$ $6\times10^{-4}C$	Pelvimetry Exposures - Stewart & Kneale	5, 20
~ 1.0 Rad	$3 - 30\times10^{-4}\ell$	Pelvimetry Exposures - Bross et al	3, 4
20 Rad	$0.5 - 1.1\times10^{-4}T$	X-Ray Therapy - Hempelmann	8
6.5 Rad	$1.2\times10^{-4}T$	X-Ray for Tinea Capitis - Modan et al	10

ℓ = Leukemia risk/person. rad
C = Total cancer risk/person. rad
T = Thyroid cancer risk/person. rad

these dose rates, i.e. 1.5 rem/y for bone marrow and 3 rem/y for thyroid). From this table it follows that if a million children each received 1 rad from in utero exposure, we would expect from 300 to 3000 leukemias, depending upon whether or not the child had certain respiratory diseases, some of which, as indicated by Bross,[3,4] act syergistically with radiation exposure. There is not as much data available on the effects of low-level exposure of adults as for children but as seen from recent data of Mancuso et al.,[12] their risk of radiation induced malignancies other than leukemia may be as great or greater than that for children (perhaps as high as 20×10^{-4} cancers/person.rem). Furthermore, studies of Stewart,[5,20] MacMahon,[6,21] and many others indicate that following in utero exposure the incidence of focal cancers (such as central nervous system tumors) is about that of leukemia so the number of fatal malignancies might be twice the numbers given in Table II, (i.e. 600 to 6000 cancers for a million children exposed to only 1 rad).

In 1970, Jablon and Kato[22] pointed out that their data on the survivors of the atomic bombings who were exposed in utero do not support the findings of Stewart,[5,20] MacMahon[6,21] and others. They indicated that on the basis of findings of Stewart and Kneale and upon the corresponding linear hypothesis they should expect 36.9 excess cancers in this group during 10 years following exposure, but there had been only one (a case of liver cancer). As a consequence many persons were quick to proclaim that there was something wrong with the retrospective studies of cancer induction by diagnostic in utero x-ray as reported by Stewart, MacMahon and others and that now we could relax. Unfortunately (for in utero exposed children), this was not the case. Stewart and a number of other researchers[16,24,26,27,28] have published reports which give strong support of the studies of Stewart, MacMahon, etc., of cancer induction by diagnostic in utero x-ray such that there is now little doubt the Japanese studies greatly underestimate this cancer risk. In fact, Jablon and Kato[22,7] in their original publication gave an explanation that now seems to be one of the principle reasons they observed such an unusually low cancer rate among children who had received in utero exposure at the time of the bombing; they said, "Conceivably such a result might follow if there were an excessive spontaneous abortion-rate for fetuses by large doses." Thus the fetuses which were most likely to have developed into cases of radiation induced leukemia received such high doses and were subjected to so much trauma that they did not survive to become statistics. In fact, there is reason to believe there was an unusually high incidence of abortions and rate of infant mortality following the atomic bombings. Many studies[29] have shown that during periods of stress and community disasters it is the infants and young children that suffer the most. It is known also that during such periods of suffering and unrest incipient cancers can easily be mistaken for acute infections. Also, it seems likely that the Japanese control group may have had a greater cancer risk than normal. Thus it would seem the Japanese data probably greatly underestimate the risk of radiaton induced cancer.

Some of the reasons[16] why in certain cases use of the linear hypothesis to estimate risk at low doses is not conservative are as follows:

1. Overkill at high doses. Most estimates of risk from radiation exposure are based on linear extrapolation of effects at high doses down to zero dose. Often with such extrapolation insufficient account is taken of overkill and that in no case can more than 100% of the animals be killed by radiation. Sometimes one simply determines the best least-squares line which will pass through the (0,0) point. Some points used in determining the slope of this line may be on the upper bend of the curve where the animals are injured by large doses of radiation such that they do not survive long enough to die of the malignancy.
2. Short follow-up period of human studies. Most studies[7] of effects of ionizing radiation on man extend over only a small fraction of his life span. If, for example, one determines the slope of the curve of thyroid carcinoma risk vs x-ray dose and the followup period is only 7 years, studies of the population until all have died would most likely increase the slope of curve and the risk estimate.

3. Fractional life span animal studies. Sometimes comparisons are made between fetal damage during the first trimester of a mouse and damage we might expect during the first trimester of a woman, or a comparison is made over the life of animals having a life span of 20 years with expected effects over the life span of man. Since in many cases damage from radiation exposure may relate more closely to what happens in a given number of years following exposure rather than what happens over a certain fraction of the animals' life span, such extrapolations to man can only lead to underestimates of risk.

4. Radiosensitivity differs among animal species. Many studies have emphasized the risk of extrapolating data on effects of radiation exposure from one animal to another or to man. Differences in metabolism, turnover rate, GI tract uptake, skin perspiration, blood circulation, mitotic index, etc., can have a marked effect on animal response to a given dose of ionizing or non-ionizing radiation. An examination of data leads me to conclude that more often than not this kind of extension of data from animals to man results in an underestimation of risks.

5. Heterogeneity of human population. The vast majority of studies of effects of radiation exposure are carried out with inbred animals. Radiation ecology programs must be extended to animals in the wild if we are to simulate effects we expect from low doses to human populations. Studies of Bross[3,4] have indicated that the risk of leukemia as a consequence of in utero x-ray exposure increases by 5000% if the child had diseases such as as asthma, hives, eczema, allergy, pneumonia, dysentary or rheumatic fever compared with the child without this exposure and history of such disease. In accessing population risk of low levels of exposure we need to know dose response for young and old, male and female, sick and well, fat and slim, the person of average eating habits and the one with peculiar eating habits, etc. When we have such data, our estimates of risk to certain groups of the population from low level exposure will be much greater than the risk to the average man.

6. Cell sterilization. It is well established that as old age is approached, the percent of abnormal cells in the body increases; for example, the percent of chromosomal aberrated cells increases with age of an animal. It is commonly believed that some types of malignancies develop as a result of a series of changes that take place in the 46 chromosomes that comprise the nucleus of a normal somatic cell in man. Sometimes certain of these changes may be the result of a genetic mutation conveyed from one's parents. Thus, we have a scattering of cells and clones of cells which have one or more abnormalities, and may present a much larger cross-section for the production of a malignancy than a normal cell. It may be that the etiology of cancer is similar to throwing of a series of switches such that cancer cannot develop unless all switches are thrown. Children born in a family with one of the "switches" thrown genetically have a higher cancer risk than average children and persons who have been exposed to higher levels of carcinogens have more high cross-section cells that are likely targets for the origin of a malignancy. When studies are conducted on animals exposed to high doses of radiation, cell sterilization may take place such that many cells that are likely targets for development of a malignancy are destroyed. Thus, such data points at high exposure levels would tend to reduce the slope of the curve that is extrapolated to zero dose and may result in an underestimate of risk at low levels of exposure.

There is no question but that with some animal studies of exposures to x or γ radiation the cancer risk per rem is less at low doses than at high doses or that the radiation damage from a given dose is less when the dose is protracted or fractionated. This seems, however, not to be true for high LET radiation (e.g., α or neutron exposure) where there is little or no repair of damaged cells and where only a single particle (α or heavy recoil ion) passing through the cell is required to initate the development of a malignancy if the cell survives. However, for some types of low LET (x,γ,β) radiation damage (e.g. leukemia induction in middle age persons), it may require two or more close encounters with the nucleus of a cell before it became a precurser of a malignancy. In such a limited case the risk per rad would be less at low doses than at high doses and the linear hypothesis would be conservative. Figure 1 is a plot of equation

$$E = kD^n\% \qquad (1)$$

in which E = cancer risk (% of persons with cancer) as a result of exposure to a dose D (rem) of ionizing radiation. Case A in which $n = 1$ illustrates the linear hypothesis in which one would expect 3×10^{-4} cancers per person.rem. Case B, in which $n = 2$, illustrates the old threshold hypothesis where the cancer risk becomes negligible or statistically insignificant at low average dose per person. Perhaps it typifies the leukemia risk of middle aged persons that are exposed to low LET radiation. Recent human studies suggest that Case C applies to leukemia among the young and the old and to all other forms of cancer irregardless of the age of the person. In this case the risk per person per rem is much greater at very low doses than at high doses. For comparison all three curves are normalized at 100 rem (i.e. 100 rem is assumed to give a person a 3% risk of a radiation induced cancer by case A, B or C). It is obvious also that all three curves, A, B and C, must begin to decrease their positive slope and eventually assume a negative slope or drop with further increase in dose at some dose beyond 100 rem. This is because high doses would cause death from other causes before the person would have time to die of cancer and because not more than 100% of the persons could develop radiation induced cancer. For example, like shortening from causes other than radiation induced cancer may be given by equation $E = k(D)10^{-4}$ life spans per person rem in which $k(D) = 1$ when $D = 10^3$ rem. Such drop off in cancer rate has been observed in the bone cancer vs dose curves for persons with very large amounts of radium in their skeletons[30] because in such case they did not survive long enough to die of bone cancer. Curves A, B and C are given primarily for illustration but each appears to be applicable in certain cases. Perhaps it is of interest to note that for a dose of 1 rem the cancer risk is 0.03% by the linear hypothesis, $3\times10^{-4}\%$ (negligible) by the threshold hypothesis (i.e., Curve B). The average radiation dose of the Hanford workers who died of cancer as reported by Mancuso, Stewart and Kneale[12] was only about 1 rem so their cancer risk was about 25 times the 0.03% risk given by Curve A. This suggests perhaps that actually the power of D in Curve C should be less than 1/2 or a more likely explanation is that the majority of the Hanford exposures were less than the average of 1 rem. Baum[17] found that $D^{\frac{1}{2}}$ gave the best fit in a number of studies of cancer induction by ionizing radiation.

In converting from absorbed dose (given in rad in which 1 rad corresponds to an energy deposition of 100 ergo per gram) to the quantity, dose equivalent (given in rem) we use the relationship,

$$\text{Dose Equivalent (rem)} = \text{Absorbed Dose (rad)} \times Q \times N \qquad (2)$$

in which Q is a physical correction factor related to stopping power (-dE/dx) or linear energy transfer (LET) and N is a biological correction factor. As a general simplification (especially for internal dose calculations) we set $Q = 1$ for x, γ, e and β radiations and $Q = 10$ for α-radiations when they are emitted by internally deposited radionuclides. It is easy to see why Q for α should be much greater than the Q for x-rays or for the electrons produced by x-rays because the specific ionization is much greater along an α-track than an e-track. For example, $S_\alpha = 8000$ ion pairs/μm tissue for α-particles while $S_e = 8$ ion pairs/μm of tissue for an electron when both particles have energies of about 1 MeV. Thus, the difference in damage to a living cell in the two cases is like the difference in damage from a bulldoser or a rabbit running through a cornfield. Many rabbits may have to step on the same corn sprout over a short period of time to damage it (or many secondary electrons may be required near the cell nucleus in a short time to cause damage). Thus it is easy to see why for some types of x or γ radiation damage (e.g. leukemia among middle aged persons) Curve B in Fig. 1 provides the best fit to experimental data or $n = 2$ in equation 1. It is easy also to see why $n <$ for Curve C applies in the case of all forms of chronic damage from internal α-emitters. This is because at high doses or dose rates there is "overkill" or much of the α-energy is wasted as would be the case were we to try to kill a squirrel with a cannon rather than with a rifle.

The other modifying factor, N, in Eq. 1 is not as well understood as Q. When I first began using N in 1947, I thought we needed a biological correction factor to account for additional biological damage from certain internally deposited radionuclides and that this factor was related mostly to non-uniform deposition or "hot areas or spots" of radiation of select parts of critical organ tissue (e.g. the endosteal or perosteal tissue of the bone). However, it was soon recognized that N related to other things as well, among which were 1) the essentialness of the tissue at risk in terms of proper body function and 2) the relative radiosensitivity of the radiated tissue. Thus N may be an important factor also in determining whether the radiation damage function behaves like Curve A, B, or C and why there are marked differences in the dose response curves for various animals (including man) and as a function of age, sex, genetic factors, certain diseases, etc. This N factor may in time explain why it is the very young and the very old persons that are most susceptible to radiation damage and why even for x or γ radiation Curve C probably gives the best fit for cancer induction among the young and among the old. The difference in the applicable cure in Fig. 1 for some animals and for man as a function of age may be due in part to the fact that skeletal and bone marrow development continue rather uniformly throughout the life of some animals but not in man. In man bone turnover is rather uniform and all the bone marrow is active in early life, but later in life much of man's bone is less active and much of the marrow becomes inactive (yellow marrow).

The radiation biologists have conducted thousands of experiments with various types of animals in order to determine the dose effect relationships and in many cases have extrapolated these data to man (perhaps brazenly or at best with some misgivings). Some ecologists and health physicists have warned that much of the animal data may not be applicable to man for many reasons, a few of which are:

1. Studies have shown the dose response of various kinds of animals can differ markedly in going from one phyle to another (e.g. fly to fish to mouse to monkey to man).

2. Studies have shown that even slight species or strain differences can cause a marked change in dose response. For example, Warren et al.[31] found very large differences in leukemia induction and in life shortening between studies with different kinds of mice. Man is a wild or heterogenous animal living in many types of environments, with many diseases and eccentricities, of various ages, two sexes, etc., and yet we have set our standards on the basis of carefully controlled animal studies and as they apply to the average or "standard" man. It is little consolation to a mother to know that the average risk to persons living in her community is 3×10^{-4} cancers/man rem or 0.003% from an environmental dose of 100 mrem accumulated over a 10 year period from a nuclear power plant when in fact her child with asthma has a risk 50 times this or 0.15% chance of developing cancer from this exposure. It helps very little to tell the mother that natural background radiation is 100 mrem each year or it gives her child a 1.5% risk of radiation induced cancer over the same 10 year period. Neither does it help to tell her that if a coal burning power plant (even an unusually clean one) were to replace the nuclear power plant, the risk from the power plant probably would go up from 0.15 to 5% and then the primary risk would become one of chronic bronchitis and emphysema rather than cancer.

Many see the solution is to reduce the levels of maximum permissible exposure (MPE) of occupational workers and of members of the public by a factor of ten. However, I am not convinced this would be an adequate solution. To me this seems like putting a finger in the hole of the leaking dyke. I see it this way primarily for three reasons: 1) our goal should be an exposure that approaches zero and especially one that reduces the population dose (man.rem dose) as low as reasonably achievable (ALARA), 2) the real culprit is not so much the nuclear industry but rather the medical professions, and 3) a smaller reduction of the occupational MPE from 5 rem/y to 2.5 rem/y rather than the proposed reduction to 0.5 rem/y probably could be accomplished without completely depriving ourselves the benefits of having nuclear power.

Item 1) above is partly a matter of education and acceptance of a moral obligation. For decades the average occupational exposures at the National Laboratories such as ORNL, BNWL, ANL, BNL and at Savannah River have been kept in accordance with ALARA and an average of less than 10% of the MPE (i.e., < 0.5 rem/y) and accidents involving large individual exposures have been very rare events. This of course does not rule out the possibility of mistakes in exposure estimates and especially the risk of greater internal dose than was measured with techniques available at the time but at least a sincere effort was made to keep all exposures ALARA. This applied to the individual occupational doses (rem) and the man.rem doses and to doses delivered to members of the general public as well as to radiation workers. Unfortunately, however, this is not completely the case with some parts of the nuclear industry. I was particularly unhappy with what went on at the West Valley reprocessing plant and the Kerr McGee fabrication plant in what I construed to be wanton disregard of good health physics practices. I am now very much concerned about the growing practice of "burning out" of temporary employees or the fact that many of the nuclear power plants are finding it necessary to solve the problem of repair work in persistantly high radiation exposure areas of the plant by hiring temporary employees to spread out the dose on "hot" operations. This has increased the man.rem dose or the overall cancer and genetic risks to the population and I believe this is what we should strive to avoid. I cannot be sure what would be the effect of lowering the occupational MPE to 10% of its present level (i.e. down to 0.5 rem/y). Certainly, it would reduce individual exposure levels, but I fear in many cases it would just mean the hiring of more people, each to receive small doses of less than 0.5 rem/y with a marked increase in the total man.rem dose. The man.rem dose would increase for the same radiation job for two reasons: 1) inexperienced persons always get more exposure, and 2) much of the exposure on a "hot" job is received going unto and away from the hot operation.

Regarding the second reason for hesitating to rely on solving our problem by simply lowering the occupational MPE to 0.5 rem/y is that at present the medical professions are exempt even though they are delivering over 90% of the man made dose from ionizing radiation. I[32] have shown that this dose (mostly from medical diagnoses) could be reduced to 10% of its present value while at the same time improving medical radiography. Only the states of New York, New Jersey, Kentucky and California require x-ray technologists to have training and certification in the proper use of x-ray equipment and only California requires questions on the subject of effects of x-rays and health physics on the State Board Examinations. Is it a wonder that those who are responsible for over 90% of the man made dose from ionizing radiation ignore almost completely the ALERA? Is it surprising that studies show that the skin dose from a chest x-ray from one medical facility may be 10 mr while at another it may be 3000 mr and yet far more useful medical information is provided by the 10 mr? Is it surprising that less than 1% of the dentists are using long open ended cones with rectangular calcination to fit the rectangular dental film while the rest use a circular x-ray field for a rectangular film and most of the dentists are using a short cone? Why haven't our responsible Government Agencies corrected these medical problems 20 or 30 years ago instead of carry on endless discussions with members of the AMA, ACR, ADA, etc., to see how improvements can be made without any cost or inconvenience to the medical professions? When these questions are answered and we have licked this 90% of the problem of unnecessary exposure of the American public to ionizing radiations, perhaps I can see more clearly that a next step will be to reduce the MPE to 0.5 rem/y for the occupational worker and reduce the corresponding value for members of the population at large to 0.05 rem/y.

Finally, were we to reduce the present MPE by a factor of 10, I seriously doubt that many of our present nuclear power plants would find it feasible to continue in operation. The pressurized water reactors (PWR) especially would be in difficulty because of the high background radiation in the vicinity of the steam generator d[illegible] to the accumulation of ^{58}Co and ^{60}Co. The solution to such a problem seems to be to go to the source of the trouble and redesign the PWP in such a way that the precursor elements do not enter the high neutron flux region of the reactor or they are prevented from circulation in the cooling water. Also more room must be provided for shielding and the use of remote control equipment, TV cameras, etc.

I believe one of the most unfortunate recent developments in the setting of standards for exposure to ionizing radiations is that ICRP has issued its report ICRP No. 26[32] in which it is recommending weighting factors, W_i, which I interpret will result in large increases in the present ICRP values of MPE and in all values of total body burden and maximum permissible concentrations (MPC) in air, water and food for radionuclides except where they are rather unformly distributed throughout the body (i.e. they are total body seekers). The table below summarizes these values.

TABLE 3

Organ	Present value of MPE or R (rem/y)	Values of W_i in ICRP No. 26	New Values of MPE or R (rem/y)
total body	5	1	5
gonads	5	0.25	20
breast	15	0.15	32
red marrow	5	0.12	42
lung	15	0.12	42
thyroid	30	0.03	167
bone	30	0.03	167
skin	30	--	--
remainder	15	0.3	17

I consider this report a retrograde step of the ICRP because it comes at a time when their own reports emphasize that the cancer risk is 10 to 20 times what we considered it to be 15 years ago. This change was made in an effort to remove the inconsistency that the MPE for total body has been the same as that for gonads and red marrow. What ICRP should have done is normalize on an MPE of 5 rem/y for gonads and red marrow and set the MPE for total body at some value less than 5 rem/y. I sincerely hope NCRP, BEIR, NRC, EPA, etc., in this country will raise strong objection to this move of ICRR and reject these new values which would tend to increase internal dose from radionuclides deposited within the body.

In conclusion I suggest action as follows:

1. Reject proposals at this time to reduce the MPE by a factor of 10 but consider the possibility of reducirg it by a factor of 2.

2. Consider the feasibility of reducing the MPE by a factor of 10 at some later date.

3. Take immediate measures to reduce the man.rem dose. This could be accomplished in several ways. For example in the nuclear energy industry a limit of 200 man.rem/1000 MWeY might be set for presently operating plants and those under construction and 50 man.rem/1000 MWeY for plants now on the design board.

4. Take bold steps to reduce unnecessary exposure from medical sources of ionizing radiation. Recently (February 1978) the EPA and the BRH have made some encouraging progress in this area, but we still have a long way to go.

5. Apply the principle of ALARA in all areas of exposure to ionizing radiations.

6. In making the choice of fuel for a central power station consider all the risks and all the advantages of each type of fuel. In this evaluation keep in mind that exposure to ionizing radiation is only one of the risks and in many cases the risks of chemical exposure may be far greater than those from radiation; don't forget there is a serious expsoure from radiation (^{226}Ra, ^{228}Ra, ^{222}Rn, etc.) in the burning of coal.

7. Give adequate support to research programs designed to define more accurately the risks from human exp sure to ionizing radiation.

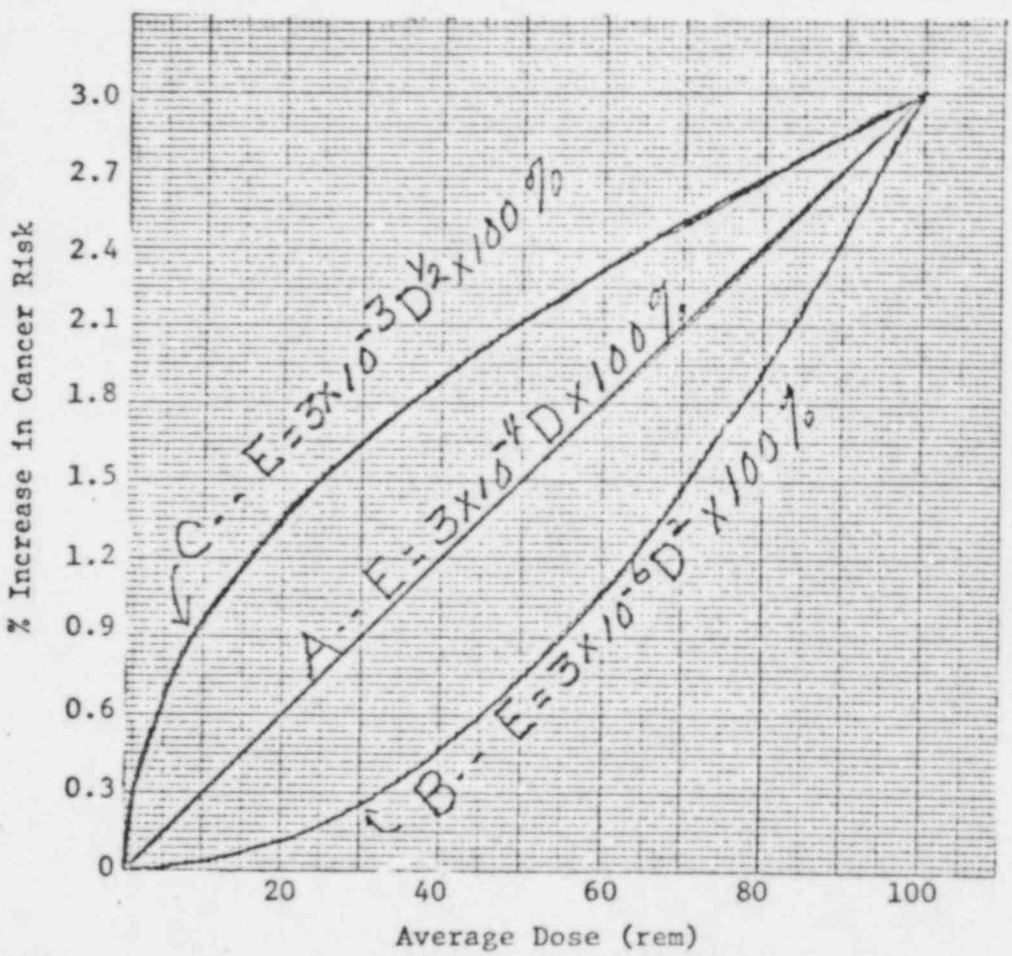


Fig. 1. Cancer Induction as a Function of Dose of Ionizing Radiation from 0 to 100 rem.

REFERENCES

1. P. R. J. Burch, "Age and Sex Distributions for Some Idiopathic Non-Malignant Conditions in Man," Radiation and Ageing, Proceedings of a Collogqium held in Austria, Ed. P. J. Lindopand, G. A. Sacher, Taylor & Francis Pub. page 117 (June 23-24, 1966).

2. P. R. J. Burch. See Chapter 11 and references on page 396 of text, Principles of Radiation Protection, ed. K. Z. Morgan and J. E. Turner, R. E. Krieger Pub. 1973.

3. I. D. J. Bross, "Leukemia from Low-Level Radiation," New England Journal of Medicine 287:107 (July 20, 1972).

4. I. D. J. Bross, Conference on Low-Level Radiation, Washington, D. C. (May 4, 1976).

5. Alice Stewart and G. W. Kneale, "Radiation Dose Effects in Relation to Obstetric X-Rays and Childhood Cancer," Lancet, 1185 (June 5, 1970).

6. Brian MacMahon, "X-Ray Exposure and Malignancy," Journal Am. Med. Assn. 183, 721 (1963).

7. BEIR Committee, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Nat. Acad. Sc. & Nat. Res. Council (November 1972).

8. L. H. Hempelmann, "Neoplasms in Youthful Populations Following X-Ray Treatment in Infancy," Environmental Research 1, 338 (1967).
   L. H. Hempelmann, "Risk of Thyroid Neoplasms After Irradiation in Childhood," Science 160, 159 (1963).

9. R. E. Albert and R. E. Shore, "Follow-up Study of Irradiated Tinea Capitis Cases," Presented at 100th Annual Meeting of the American Public Health Assn. (1972).

10. B. Modan, H. Mart, D. Baidatz, R. Steinitz and S. G. Levin, "Radiation-Induced Head and Neck Tumors," Lancet 1, 277 (February 23, 1974).

11. C. Silverman and D. A. Hoffman, "Thyroid Tumor Risk from Radiation During Childhood," Preventive Medicine 4, 100 (1975).

12. T. F. Mancuso, A. Stewart and G. Kneale, "Radiation Exposures of Hanford Workers Dying from Cancer and Other Causes," Health Physics 33, No. 5, 369 (November 5, 1977).

13. E. B. Lewis, "Leukemia, Radiation and Hyperthyroidism," Science 174, 454 (October 29, 1971).

14. E. L. Saenger, "Radiation and Leukemia Rates," Science 171, 1096 (March 19, 1971).

15. K. Z. Morgan, "Maximum Permissible Levels of Exposure to Ionizing Radiation," Proceedings of the International Summer School on Radiation Protection, Boris Kidric Institute of Nuclear Sciences, Cavtot, Yugoslavia, 1, 7 (September 21-30, 1970).

16. K. Z. Morgan, "The Linear Hypothesis of Radiation Damage Appears to be Non-Conservative in Many Cases," Proceedings of the Fourth International Congress of the International Radiation Protection Assn., Paris, France, Paper No. 451, 11 (August 1976).

17. J. W. Baum, "Population Heterogeneity Hypothesis on Radiation Induced Cancer," Health Physics 25, 97 (August 1973).

18. A. G. Craig, "Alternatives to the Linear Risk Hypothesis," Health Physics 31, 81 (July 1976).

19. J. M. Brown, "Linearity vs Non-Linearity of Dose Response for Radiation Carcinogenesis," Health Physics 31, 231 (September 1976).

20. A. Stewart, "Low Dose Radiation Cancers in Man," Advances in Cancer Research 14, 359 (1971).

21. B. MacMahon, "Prenatal X-Ray Exposure and Childhood Cancer," Journal of the Natl. Cancer Institute, 28, 1173 (1962).

22. S. Jablon and H. Kato, "Childhood Cancer in Relation to Prenatal Exposure to Atomic-Bomb Radiation," Lancet, No. 14, 1000 (November 14, 1970).

23. I. M. Moriyama and H. Kato, "Mortality Experience of A-Bomb Survivors 1970-72," JNIH-ABCC Life Span Study Report 7, Tech. Report 15-73 (1973).

24. E. E. Pochin, "Malignancies Following Low Radiation Exposures in Man," British J. of Radiology 49, 577 (July 1976).

25. ICRP Pub. 8, "The Evaluation of Risks from Radiation," International Commission on Radiological Protection, Committee I Report, Perg. Press (1966).
-1 eRP/71/L:C2-4-working paper of the International Commission on Radiological Protection (1971).

26. R. M. Holford, "The Relation Between Juvenile Cancer and Obstetric Radiography," Health Physics 28, 153 (February 1975).

27. E. Landau, "Health Effects of Low-Dose Radiation: Problems of Assessment," International Journal of Environmental Studies, 6, 51 (1974).

28. R. H. Nole, "Ante-natal Irradiation and Childhood Cancer: Causation or Coincidence?" British Journal of Cancer, 30, 199 (1974).

29. G. Bennet, "Bristal Floods 1968. Controlled Survey of Effects on Health of Local Community Disaster," British Medical Journal 454 (August 22, 1970).

30. R. E. Rowland, P. M. Failla, A. T. Keane and A. F. Stehney, "Dose Response Relationships for Tumor Incidence in Radium Patients," Argonne National Laboratory, Radiological Physics Division Annual Report, ANL-7760, Part II, U. S. Dept. of Commerce, Springfield, Va. (July 1969-June 1970).

31. Shields Warren and O. Gates, "The Inclusion of Leukemia and Life Shortening in Mice by Continuous Low-Level External Gamma Radiation," Radiation Research 47, 480 (August 1971).

32. K. Z. Morgan, "The Need for Radiation Protection," Radiologic Technology, 44, No. 6, 385 (1973).
K. Z. Morgan, "Population Exposure to Diagnostic X-Rays and the Resultant Damage Can Be Reduced to 10% of Their Present Levels While at the Same Time Increasing the Quality and Amount of Diagnostic Information," Testimony presented before the House of Representatives, Washington, D. C., on HR10790 (October 11, 1976).
K. Z. Morgan, "Reducing Medical Exposure to Ionizing Radiation," Landauer Memorial Lecture at Stanford Univ., Sept. 27, 1974, Am. Industrial Hygiene Assn. Journal 36, 358 (May 1975).

33. Recommendations of the International Commission on Radiological Protection, ICRP No. 26, Pergamon Press (1977).

How dangerous is low-level radiation?

The risks of developing cancer because of exposure to low doses of ionising radiation are much greater than once thought. But this need not restrict the future of the nuclear industry—the medical profession is responsible for 90 per cent of man-made radiation to which people are exposed.

Professor Karl Z. Morgan is Neely professor in the School of Nuclear Engineering at the Georgia Institute of Technology, Atlanta

In the first years of the "atomic age" many scientists accepted the theory that there is a safe level of exposure to ionising radiation, and that so long as a person does not exceed this threshold level no harm will result as any radiation damage will, on the average, be repaired as fast as it is produced. From 1960 to the present, an overwhelming amount of data has accumulated to show that there is no safe level of exposure and there is no dose of radiation so low that the risk of a malignancy is zero. Therefore, the question is not: "Is there a risk from low-level exposure?" or, "What is a safe level of exposure?" The question is: "How great is this risk?" or, "How great may a particular radiation risk be before it exceeds the expected benefits, such as those from medical radiography or nuclear power?"

At least for some types of radiation damage and for some kinds of radiation exposure (especially from X, gamma and beta radiations) there is some repair of the radiation damage going on in the body. The diehards for the threshold hypothesis, however, do not seem willing or able to accept the evidence that for man there is never a complete repair of the radiation damage. Even at very low exposure levels there are many thousands of interactions of the radiation with the cells of the human body. For example, the relatively small dose of one rad of X-rays of 1 million electron volts corresponds to 2·2 billion photons per square centimetre acting on the body. It is inconceivable that all the billions of irradiated and damaged cells would be repaired completely or replaced.

The most significant damage from low-level exposure to radiation results from the direct interaction of the stream of ions produced by radiation with the nucleus of one of the billions of irradiated cells. The cell may be killed, the radiation may produce no damage, or such damage as is caused may be repaired. But it is a fourth possibility that concerns us: that the cell nucleus may be damaged but the cell survives and multiplies producing, over a period of years, a clone of cells that is diagnosed as a malignancy.

It seems obvious that if the cell nucleus is damaged and some information is lost or if a similar series of events leads to the development of a malignancy, there can be no dose so low that the risk is zero. Thus the risk of induction of cancer from radiation increases more or less with the increase or accumulation of exposure. The risk is simply one of chance, just the same as the risk of an accident every time a trip is made in a taxi.

It is also evident that all persons do not run the same risk of developing a malignancy from a given radiation exposure and that the risk of some types of cancer is greater for certain people than it is for others. The final onset of a malignancy or other disease may require a series of events. For example, a given type of leukaemia may require as many as three successive events (like throwing three electrical switches connected in series). Some of these switches may be thrown by viruses, bacteria, chemicals, mechanical damage or radiation.

Studies by Irwin Bross, of the Roswell Park Memorial Institute in New York, support this hypothesis of a series of switches in disease processes and suggest that there may be interactions (synergisms) between the events in the series. Bross has shown, for example, that children under four with allergic diseases such as asthma or hives have a 300 to 400 per cent increased risk of dying of leukaemia compared with other children. Allergic diseases throw one switch. Children who were exposed to diagnostic X-rays in the womb have a 40 to 50 per cent increase in risk of dying from leukaemia. But children with two switches thrown (that is, *in-utero* exposure and later aller- gic disease) have a 5000 per cent increase in risk of dying from leukaemia.

Thus, because of genetic inheritance, various disease, age, sex, eating and smoking habits and, perhaps, man other individual characteristics, certain members of th general population have a higher risk of radiation-induce malignancies than others.

The cancer risk from exposure to ionising radiation much greater than was thought to be the case some yea ago. Following the deaths of the Japanese survivors Hiroshima and Nagasaki from radiation sickness, ma scientists believed that the only principal chronic ri from radiation exposure was an excess of cases of le kaemia, which reached a peak about six years after t bombing and then slowly declined. Unfortunately as th study of these survivors continued, other forms of canc (bone, breast, lung, salivary gland, prostate, thyroid a so on) showed a significant increase. With the passage time we will probably find that this exposure has result in an increase in many or most kinds of malignancies th are common among human populations.

Until 1960 almost everyone assumed that the gene risk from low-level radiation exposure far exceeded t risks of chronic somatic damage such as cancer. But it h become increasingly clear that this assumption may be u warranted. In 1971 the International Commission on Rad logical Protection (ICRP) concluded that: "the ratio somatic to genetic effects after a given exposure is times greater than was thought 15 years ago". Most of now recognise that the risk of inducing cancer at doses of radiation is far greater than we once thought a may be as great or greater than genetic risk.

No safety factor

Much of what has been said about the risks of expos to low levels of ionising radiation would have considera less weight if it could be shown that the linear hypoth (which predicts that dose and effect are directly rela provides a very large safety margin at low doses and d rates. Unfortunately, in most cases of human expo there is no evidence of a safety factor at low doses, if assume that the linear relationship between radiation cancer at high doses also applies at low doses.

We have a large amount of data—much of them huma showing a statistically significant increase in maligna as a consequence of exposure to low doses of ionising ra tion and indicating that the number of malignancies creases progressively as the dose accumulates. These d in some cases are considerably lower than the pre levels of maximum annual exposure permitted for radiation worker. Indeed in some cases the data show the linear hypothesis actually underestimates the risk.

Table 1 indicates the magnitude of the cancer risk shows that this risk falls linearly with decreasing down to a very low value. These low doses (0·8 to 6·5 are not doses below which the linear hypothesis breaks down, but the lowest points on the human exposure curves for the two malignancies considered here—leukaemia and thyroid cancer. We have every reason to believe that the linearity of these curves continues down to zero dose and that there is a similar linearity for other types of cancer that simply have a longer incubation period or have not been studied over such a wide range of doses to a human population. A dose of 0·8 rad is only 2 per cent of the 42 rad permitted by the International Commission on Radiological Protection (ICRP) to be accumulated each year in the active bone marrow of a radiation worker. And 6·5 rad is only 13 per cent of the 50 rad permitted each year to his thyroid.

Chris Mason

If a million children each received 1 rad from exposure in the womb to X-rays we might expect 300 to 3000 leukaemias. Less data are available on the effects of low-level exposure of adults than of children. But recent observations by Thomas Mancuso and others on workers at the Hanford reprocessing plant in the US (*Health Physics*, vol 33, p 369) indicate that the risk of radiation-induced malignancies other than leukaemia may be as great or greater for adults than for children (perhaps as high as 7 cancers for every 1000 people exposed to 1 rem). Furthermore, other studies (Alice Stewart and George Kneale, *Lancet*, 1970, vol 2, p 1185) indicate that the incidence of focal cancers (such as central nervous system tumours) following *in-utero* exposure is about the same as the incidence of leukaemia. So the total number of fatal malignancies might be twice the number of leukaemias given in Table 1—600 to 6000 cancers for a million children exposed to only 1 rad.

Data on the survivors of the atomic bombings who were exposed *in utero* seem not to support these conclusions. On the basis of Stewart and Kneale's findings and the linear hypothesis, we should expect 36·9 excess cancers among atomic bomb survivors during the 10 years following exposure, but only one case of liver cancer was reported. As a consequence many people were quick to proclaim that there was something wrong with the retrospective studies of cancer induction by *in-utero* X-rays as reported by Stewart, M. MacMahon and others and that we could relax about radiation-induced cancer. Unfortunately, this is not the case. There is little doubt that the Japanese studies greatly underestimate this cancer risk. The fetuses which were most likely to have developed into cases of radiation-induced leukaemias received such high doses and were subject to so much trauma that they failed to survive. In fact, an unusually high incidence of abortions and high rate of infant mortality followed the atomic bombings.

Professor Joseph Rotblat recently confirmed the above explanation of why the cancer risk as determined from survivors of Hiroshima and Nagasaki atomic bombings is too low (*New Scientist*, vol 75, p 475). He compared the cancer risk in two groups: one that entered Hiroshima during the first three days after the explosion and were exposed to the residual neutron-induced activity and radioactive contamination from the fallout; and the other group that entered Hiroshima at a later date and received negligible radiation exposure. Neither of these groups was subjected to the trauma of blast, fire, burial under debris and so on. The leukaemia risk to the first group exposed to residual radiation was $1·6 \times 10^{-4}$ leukaemias per person rad. This value for adults is in agreement with the leukaemia risk estimate in Table 1 of 3×10^{-4} which applies to children that received *in-utero* exposure from medical diagnostic X-rays. Rotblat points out that this risk estimate is eight times the estimate of ICRP.

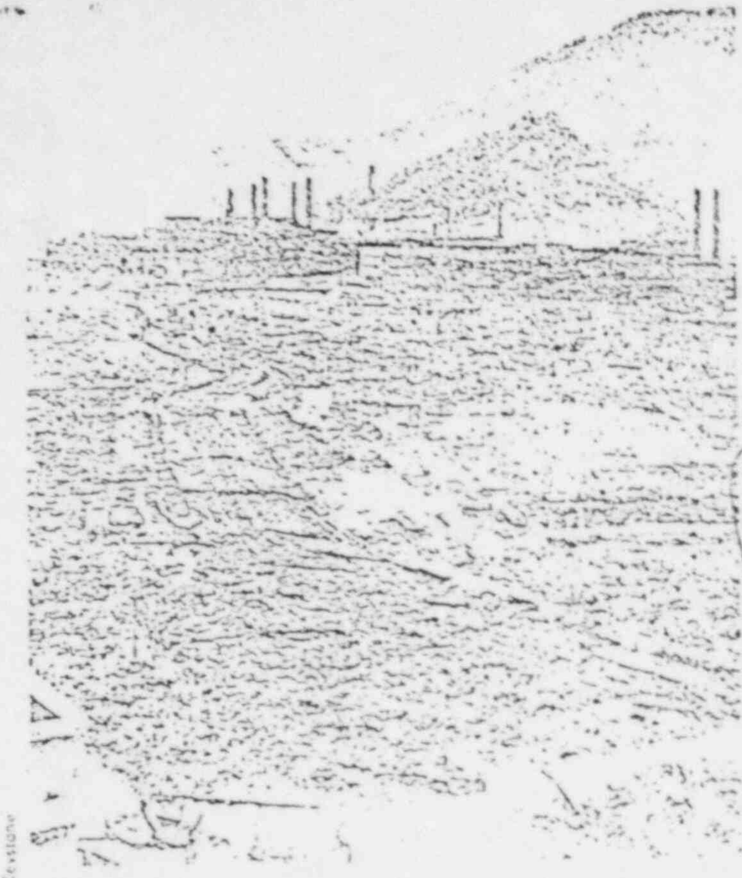
Estimates of the risk of cancer associated with exposure to radiation at the Hanford plant have created considerable controversy. The average radiation dose of the 442 Hanford workers who died of cancer between 1944 and 1972 was only about 1 rem. Mancuso, Stewart and Kneale estimate that only 6 to 7 per cent of the cancer deaths (26 to 31 cancers) were induced by this radiation. The total number of deaths in the study group was 3520 so their cancer risk was 7 to 8×10^{-3} or about 10 to 25 times the commonly accepted total risk of radiation-induced malignances. I believe that the controversy about these findings developed because many people in the nuclear industry and in US Federal Agencies have been inadvisably proclaiming

Table 1: cancer risks and known range of linearity

Linearity of dose down to	Risk per person per rad	Source of dose
≤10 rad	$0·3—1·0 \times 10^{-4}$* $0·5—1·7 \times 10^{-4}$***	Hiroshima and Nagasaki atom bomb survivors
370 rad	$0·2—0·3 \times 10^{-4}$**	arthritis of spine (ankylosing spondylitis) patients
0·2—0·8 rad	3×10^{-4}* 6×10^{-4}**	pelvimetry exposures
about 1·0 rad	$3—30 \times 10^{-4}$*	pelvimetry exposures
20 rad	$0·5—1·1 \times 10^{-4}$***	X-ray therapy
6·5 rad	$1·2 \times 10^{-4}$***	X-ray therapy for ringworm (*Tinea capitis*)

* risk of leukaemia
** total risk of cancer
*** risk of thyroid cancer

This is an edited version of an article that first appeared in *Bulletin of the Atomic Scientists*, September 1978.



Keystone

Nagasaki: cancer rates among survivors are unreliable

that there is no radiation risk at low doses. If the proponents of nuclear energy had been more reasonable in their claims about radiation safety, they would not now be trying desperately to save face.

Radiation biologists have conducted thousands of experiments with various types of animals in order to determine the dose-effect relationships of radiation and in many cases have extrapolated these data to man (perhaps brazenly or at best with some misgivings). Some ecologists and health physicists have warned that much of this animal data may not be applicable to man for many reasons.

- The dose response of various kinds of animals can differ by orders of magnitude in going from one species to another (for example, fly to fish to mouse to monkey to man).
- Even slight differences in species or strains can cause a marked change in dose response. For example, there are very large differences in leukaemia induction and in life shortening between studies with different kinds of mice. Yet, the standards are based on observations of carefully controlled inbred, healthy animals. But man is a wild or heterogeneous animal living in many types of environment with various eating and drug habits, with many diseases and eccentricities, of various ages, and so on.

It is little consolation to a mother to know that the average risk to the persons living in her community is 3×10^{-4} cancers per man rem (or 0·003 per cent) from an environmental dose of 100 millirem accumulated over a 10-year period from a nuclear power plant when she learns that in fact her child with asthma has a risk of 50 times this (0·15 per cent chance) of developing cancer. It helps very little to tell the mother that natural background radiation is 100 millirem each year and this gives her child a 1·5 per cent risk of radiation-induced cancer over the same 10-year period. Neither does it help to tell her that if a coal-burning power plant (even an unusually clean one) were to replace the nuclear power plant, the risk from the power plant probably would go up from 0·15 to 5 per cent and the primary risk would then become one of chronic bronchitis and emphysema rather than cancer. It is difficult for this mother to understand why she should risk the life of her child so that the power plant can be located at a particular river site or, as she may rationalise, so the stockholders can expect a better return to their investments.

Many see the solution to this problem in reducing levels of maximum permissible exposure (MPE) for occupational workers and for the public by a factor of 10. A number of citizens' organisations in the US have petitioned safety agencies asking for such reductions. However, although sympathetic, I am not convinced this would be an acceptable solution: it seems like putting a finger in the hole of a leaking dyke. I see it this way primarily for three reasons:

First, our goal should be a radiation exposure that approaches zero and especially one that reduces the population dose (man×rem dose) as low as reasonably achievable (ALARA). This is partly a matter of education and acceptance of moral obligation by those responsible for human exposure.

Secondly, the real culprit for unnecessary population dose is not the nuclear industry but rather the medical profession.

Thirdly, a smaller reduction of occupational maximum permissible exposure—for example, from 5 rem per year to 2·5 rem per year rather than a reduction to 0·5 rem per year—probably could be accomplished without threatening the option of nuclear power.

There have been examples (in the US at least) of wanton disregard of the ALARA principle. I am very much concerned, for example, about the growing practice of "burning out" temporary employees: the fact that many nuclear power plants are finding it necessary to solve the individual exposure problem of repair work in persistently high radiation exposure areas of the plant by hiring temporary employees to spread out the dose on "hot" operations. This has increased the man rem dose and thus the overall cancer and genetic risks to the population and I believe this is exactly what we should strive to avoid.

I cannot be certain of the effect of the proposal in the US by a number of citizen's groups and scientists to lower the occupational maximum permissible exposure (MPE) to 10 per cent of its present level (that is, down to 0·5 rem per year). Certainly, it would reduce individual exposure levels; but I fear in many instances it would just mean the hiring of more people, each to receive small doses of less than 0·5 rem per year with a marked increase in the total man rem dose. The man rem dose would increase for the same radiation job because inexperienced persons always get more exposure and much of the exposure on a "hot" job is received going into and away from the hot operation.

Medical X-rays

The second reason for my hesitation on solving the problem by simply lowering the occupational MPE to 0·5 rem per year is because at present the medical profession are exempt from the recommendations suggested by the ICRP for the maximum permissible exposure from ionising radiation—even though they are delivering over 90 per cent of the man-made dose. The dose delivered by medical diagnostic X-rays could be reduced to 10 per cent of its present value, at the same time increasing the quality and amount of diagnostic information from medical radiography. Those who are responsible for over 90 per cent of the man-made dose from ionising radiation ignore almost completely the principle of ALARA.

When we have stopped unnecessary medical exposure to ionising radiations, which is 90 per cent of the pro lem, then, perhaps, I can see that the next step might be to reduce the maximum permissible exposure to 0·5 rem per year for workers and to reduce the corresponding value for members of the population at large. A reduction of only 1 per cent in unnecessary diagnostic exposures in the United States would reduce the population dose of man-made sources of radiation more than the elimination of the nuclear power industry to the year 2000.

There should be some tightening of the measures to reduce occupational exposures in the nuclear power plants that are now in operation; but the major effort should be with those power plants that are now in the design stage. The US Nuclear Regulatory Commission took the bold and commendable step of setting the dollar cost of the man rem at $1000 at a time when ICRP was suggesting a value as low as $10 per man rem. Although most of us probably recoil from the thought of setting a monetary value on a human life, in the practical world we must recognise that there may be no other alternative. Using an overall risk coefficient of 6×10^{-4} cancers per man rem, $1000 per man rem corresponds to $1·7 million per cancer. To put it bluntly, a nuclear plant should spend as much as $1·7 million to prevent an employee from developing cancer.

One of the most unfortunate recent developments in the setting of standards for exposures to ionising radiation is a recommendation of the ICRP published in 1977. ICRP's report recommended weighting factors for calculating maximum permissible doses to various organs, which I interpret may result in large increases in the present ICRP values of maximum permissible exposure (MPE) and in all values of total body burden and maximum permissible concentrations (MPC) of radionuclides in air, water and food, except where they are rather uniformly distributed throughout the body.

I consider this report from the commission a retrograde step because it comes at a time when ICRP's internal re-ports emphasise that the cancer risk is many times what we considered it to be 15 years ago.

In conclusion I suggest the following actions:

- Reject proposals to reduce the maximum permissible exposure by a factor of 10, but consider the possibility of reducing it by a factor of two.
- Consider the feasibility of reducing the maximum permissible exposure by a factor of 10 at some later date if it can be shown that all unnecessary exposure (especially medical) can be reduced and that there will be a net benefit to mankind by such action.
- Take immediate measures to reduce the man rem dose. This could be accomplished in several ways. For example, in the nuclear energy industry a limit of 500 man rem per 1000 megawatt (electrical) years might be set for presently operating plants and those under construction, and 200 man rem per 1000 megawatt (electrical) years for plants now on the design board.
- Take bold steps to reduce unnecessary exposure from medical sources of ionising radiation.
- Apply the principle of ALARA—as low as reasonably achievable—in all areas of exposure to ionising radiation and apply it to all hazardous agents, including, for example, non-ionising as well as ionising radiation, and chemical agents.
- In making the choice of fuel for a central power station consider all the risks and all the advantages of each type of fuel. In this evaluation keep in mind that exposure to ionising radiation is only one of the risks and in many instances the risks of chemical exposure may be far greater than those of radiation.
- Give adequate support to research programmes designed to define more accurately the risks from human exposure to ionising radiation. □

Jupiter's enigmatic variations

The latest spacecraft to visit the jovian system has discovered features as diverse as volcanoes on one moon and ripples of ice on another

A sequence of views of the moon Io: Left Io (about the size of Earth's Moon) passing the Great Red Spot on 13 February, when Voyager 1 was 20 million km distant. The other moon visible here is Europa. Centre A closer view on 4 March from a range of 860 000 km. Right One of Io's active volcanos throwing material more than 100 km above the moon's surface

Dr Christine Sutton The success of the Voyager 1 mission to Jupiter is clear from the superb pictures sent back to NASA's Jet Propulsion Laboratory over a distance of 800 million kilometres. These pictures produced a state of euphoric delight among the sober scientists at JPL when, after a journey lasting 18 months, Voyager 1 passed within 280 000 km of the swirling cloud tops of the largest planet in our Solar System at around noon GMT on 5 March (*New Scientist*, vol 75, p 400). And, thanks to colour TV, many non-scientists around the world were also able to view the awesome coloured whirlpools of Jupiter's atmosphere, in pictures likened by some viewers to J. M. W. Turner's paintings.

But the beauty of the pictures is only the icing on the cake as far as the JPL team is concerned. The scientific results from the mission are equally spectacular, revealing many unexpected aspects of the Jovian system, including the moons. Dr Gary Hunt, from University College, London, was the only UK scientist at JPL during the close fly-by, and he has sent back news of some of the discoveries which have left him elated by the success of the mission.

Clearly, the atmosphere and magnetosphere of Jupiter are highly energetic. As Voyager approached Jupiter, on 27 February when still more than 6 million km away, its

THE DILEMMA of PRESENT NUCLEAR POWER PROGRAMS*

by

Karl Z. Morgan
School of Nuclear Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

A. Where We Are Today in Nuclear Power Programs

There is only one naturally occuring element, uranium, that can be used to sustain nuclear reactions in what we call a nuclear power reactor and only about one part of natural uranium in 140 is ^{235}U (i.e., 0.7196%), which is capable of being fissioned by thermal neutrons in a chain reaction. In the early period this offered only a few choices for nuclear power. All of them employed the U-cycle, and in my opinion all those methods selected were unfortunate choices and at best poor second best alternatives as long-range solutions in an impending world energy crises.

Although, nuclear reactors can be and have been built using unenriched natural uranium as fuel, these reactors because of size and other limitations are not considered to be practical as a source of power unless the neutrons produced in fission can be slowed down by an expensive material, such as heavy water (^2H_2O). This is the option, the CANDU reactor, selected by Canada and the United Kingdom as their near future nuclear power source. The other principle option, and the one followed in the US, USSR, France, West Germany, and Japan, is the light-water reactor, LWR, which is cooled by ordinary water but uses uranium that is enriched in ^{235}U to a few percent. The commercial enrichment process used until recently is the very expensive gaseous diffusion method, but it now appears that other methods of isotope enrichment, such as the centrifugal or laser method, may lessen the cost and

*Presented at Hearings before the Energy Resources Conservation and Development Commission, Sacramento, California, February 1, 1977.

do away with the monopoly inherent in the use of gaseous diffusion techniques.

From the very beginning of the nuclear power program it has been obvious that fusion (and not fission) offers the only very long range source of nuclear power because here the $^{2}H_2O$ of the oceans would become our source of fuel. However, at the present time it seems unlikely that the first power plants operating on ^{2}H-fusion can be in operation before the year 2050, and only then if we are successful in solving some very difficult problems, such as attaining very high pressures and temperatures in plasma which must be retained relatively long times by intense magnetic fields produced with super conductors maintained at extremely low temperatures. The retention of the fusile material ^{3}H for economic and health reasons becomes an extremely important and difficult problem at these high plasma temperatures.

Considering that fusion power plants must await the solution of some very basic, as well as practical, engineering problems, it is not surprising the major nations of the world have taken advantage of the advanced technology gained from operation of nuclear reactors in the production of plutonium for the manufacture of nuclear weapons. As explained above, this meant perforce that nuclear power development has been almost entirely in the U-cycle rather than what I will show would have been a much better direction, the Th-cycle. Also, because of limited uranium resources it was obvious from the beginning of the nuclear age that power from U-fission would, at best, be able to make a major contribution to the world's energy needs for only a few decades unless the ^{238}U (which comprises 99.276% of natural U) could be converted to a fissile nuclide, such as ^{239}Pu and ^{241}Pu, and used to supplement the scarce ^{235}U as a source of fuel.

In the operation of LWR nuclear power plants in many parts of the world large quantities of Pu have accumulated in the fuel elements. Except for a few experimental separations at government controlled facilities (e.g., Idaho Falls, Hanford, Savannah River, Oak Ridge, etc.) and at the small operations of Nuclear Fuels Services, West Valley, New York, or specialized operations, such as the Kerr-McGee facility near Oklahoma City, Oklahoma., these fuel elements have been stored intact in large pools of water, located mostly at the nuclear power plants. These fuel elements represent a valuable inventory of Pu and of partly enriched U.

The only way to stretch the contribution of the U-cycle in meeting the world's energy needs from decades to millennia is to develop breeder power plants that would produce, in U-Pu breeders, more of the fissile Pu from ^{238}U than the ^{235}U + Pu consumed, or to produce in Th- ^{233}U breeders more ^{233}U from ^{232}Th than the ^{233}U, or ^{239}Pu consumed. Unfortunately, the US, UK, USSR, France, and Japan, have taken the first option, namely, the U-Pu breeder and have compounded the problem by choosing the liquid metal fast breeder reactor, LMFBR. In the interim, and faced with problems related to a large inventory of Pu and fission products in the fuel elements (i.e., shortage of space and hazards of fuel storage at the nuclear power plants) there is now a concerted effort by the NRC and ERDA to reprocess these fuel elements, to dispose of the radioactive waste in some manner and recycle a mixture of $Pu\ O_2$ and $U\ O_2$ in the LWR's.

B. Serious Problems Faced in Present Nuclear Power Programs

a. Coverup by Government Agencies and other proponents of nuclear power is I believe our most serious national problem with nuclear power. It is for this reason that the AEC and now the NRC and ERDA are nuclear power's worst enemy. It is hoped that the new Carter administration will make changes in these agencies and in their methods of operation so that the, become more worthy of public trust. I consider all the coverups and half truths espoused by the AEC and its contractors about the reliability of the emergency core cooling system, ECCS, a travesty of public trust that is exceeded in seriousness only by the failure of the NRC to make public announcements and take immediate steps to shut down PWR's when there are indicents of overpressurization.[1] In consideration of the fact that the temperature at which the stress curve (pressure vs temperature) reaches the brittle fracture curve increases with age of the reactor and with accumulation of radiation dose to the pressure vessel , this presents a frightening prospect of what we might expect in the future. The public cannot and should not be expected to accept nuclear power so long as its public servants charged with reactor safety cannot be trusted with confidence and be relied upon to present the true facts clearly to them.

b. Proliferation of countries with nuclear weapons is one of the more serious world problems. Some persons were shocked when they learned that India has nuclear weapons, but it should come as no surprise that other nations also probably have surreptitiously manufactured nuclear weapons from the plutonium produced in their LWR's. To a considerable degree U. S. industry that furnished these LWR's must accept responsibility as an accomplice. We all agree, we cannot afford, and civilization probably could not survive a world nuclear war, and it might be that nuclear weapons used by a minor nation against its neighbor could light the fuse to a world disaster.

c. Hijacking of plutonium, or to a lesser extent hijacking of nuclear fuel, or a radioactive waste shipment, could lead to one of the most serious cases of national blackmail in the history of our country. A similar problem is suggested in the fact that enough plutonium has been reported "unaccounted for" in some of the fuel reprocessing plants to construct many nuclear weapons. It is not an extremely difficult problem to construct a rather powerful nuclear weapon if a knowledgeable person has a small amount of plutonium (the critical mass for Pu is only about 13 pounds). Such a clandestine operation followed by blackmail could present the president of the United States with one of the most serious problems ever faced by a president. Necessary measures to prevent these things from happening in our loosely scattered nuclear programs could result in what amounts to local police states.

d. The reprocessing of fuel and disposal of high level radioactive waste are problems that should have been solved and put into operation in a satisfactory manner 30 years ago for the separation and permanent disposal of radioactive waste from nuclear weapons operations. Thus, commercial plants to handle radioactive wastes of nuclear power plants could have been ready for operation soon after the startup of the first nuclear power plants. I consider it inexcusable and intolerable that we have progressed thus far in the nuclear power industry without having demonstrated a safe and satisfactorally operated fuel reprocessing plant, or an acceptable permanent repository for high level radioactive waste. From the standpoint of health physics the Nuclear Fuels Services plant at West Valley, New York, made about every mistake conceivable. The record of plant incidents, occupational and environmental exposures, contamination, environmental pollution, burning out of temporary employees, waste handling and disposal, is extremely discouraging to those of us who believe reprocessing can be done properly, and that nuclear power can be made reasonably safe and acceptable. It must be a shocking experience to the officials in the state of New York to realize that the company which has operated Nuclear Fuels Service intends to abandon the operation and pullout leaving the state in its time of financial crisis with a multimillion dollar decommissioning and cleanup operation. No state should permit any nuclear operations within its boundaries unless there is sufficient insurance guarantee that the sites can be returned to the original condition (contamination free) at the completion of the operations.

e. Plutonium and the transplutonium elements lead to an untoward operation that should be avoided. Radionuclides of these elements are among the most hazardous materials known to man. When they are allowed to escape into the environment, as has been the case for example at Rocky Flats near Denver, Colorado, we have an area of many square miles that is unsafe for habitation and perhaps should be treated as a forbidden area for hundreds, or thousands of years. These radionuclides are for the most part alpha emitters of very long radioactive and biological half-lives, and when they become deposited in the body (via inhalation, ingestion, or through open wounds), they present a high probability of causing a malignancy some time later in life (10-50 years). The matter of internal dose from these radionuclides is particularly serious because the risk per rad of exposure appears to be greater at low doses than at high doses[2,3], and they are capable of producing malignancies in bone, liver, and lung; in some cases they may lead to appreciable doses to the gonads leading to genetic damage.

f. Scarcity of uranium is a strong point in its disfavor as a source of power unless it can someday be extracted economically from the sea. Rose, et al[4], point out the United States national energy consumption in 1974 was 73Q ($1Q=10^{15}$Btu), and the proven uranium is equivalent to only 610 Q. If it is used in LWR's, this would amount to only about 8 years' total energy supply with essentially no growth. He indicates this could be increased by two orders of magnitude (i.e., 800 years) if we could use it in breeder reactors. At such time the sea could become the source of uranium because we could afford to pay over $1,000 per poound. For the next few decades, and because the LMFBR probably was a very bad choice it is evident the shortage of uranium will be a serious problem in terms of availability and cost. As a consequence, there is some pressure from industry and the NRC to get on with GESMO, or the use of mixed oxide fuel (PuO_2 + UO_2) in light-water reactors. Part of this pressure derives from the failures of the LMFBR program.

g. LMFBR - the great mistake. I have opposed the LMFBR from the day of its inception because of its large inventory of plutonium and transplutonium elements. I expressed this opposition in portions of a paper I was to give at Nuremberg, Germany, July 5-9, 1971, but these portions of my paper were censured and deleted by Oak Ridge National Laboratory management by whom I was employed at the time. I believe the LMFBR programs including especially the Clinch River Breeder program should be terminated as soon as possible for reasons as follows:

(1) The LMFBR produces and operates on plutonium, one of the more dangerous substances known to man. This means great risks not only at the breeder and its local environment, but in shipments to and from the plant and at the fuel reprocessing and fabricating plants.

(2) The LMFBR produces large quantities of transplutonium elements such as Am and Cm, and radionuclides of these in general are 'ar more hazardous than ^{239}Pu. The buildup of ^{241}Am (from ^{241}Pu-13.2y $\beta\rightarrow$ ^{241}Am-485y) and ^{243}Am (from ^{243}Pu (4.89hr) $\beta\rightarrow$ ^{243}Am-7.95 x 10^{3}y) present special problems of their own for t e LMFBR and LWR-GESMO cycles. These heavier isotopes of Pu tend to buildup in recycled fuel. Since $^{240,242,}Pu$ do not fission from thermal neutrons, they build up in fuel and high level radioactive waste where over hundreds of years Am will constitute the principle hazard in radioactive waste. In addition, the lighter radionuclide of Pu(viz., ^{238}Pu) tends to build up also in the recycled fuel and radioactive waste of the LMFBR or LWR-GESMO and this ^{238}Pu (curie for curie) is at least 150 times move hazardous in general than ^{239}Pu.[5] In addition, I have shown that ^{239}Pu probably is 240 times more hazardous than was assumed when the present maximum permissible body burden values were published.[3] It is nfortunate that most all the U. S. eggs have been put in the LMFBR basket and there is relatively little work being done on other breeder systems. This is particularly a sad situation since the Th-^{233}U breeder systems look so promising and do not have most of the faults listed above.

(3) The LMFBR uses liquid sodium as a coolant. This is very explosive when it comes into contact with water. This resulted in a sodium fire in one of the Russian LMFBR's; this was detected via our satellite system

(4) The LMFBR has a positive void coefficient in the sodium. I consider this a very serious and most undesirable characteristic. It means that if a hot spot develops in the coolant, the reactor power goes

up and the hot spot gets hotter until the control rod compensates. Thus, it is more difficult and more dangerous to operate than some other systems which have negative void coefficients.

(5) In general it is more dangerous and more difficult to operate in the fast neutron flux region because the thermal reactor systems provide a relatively sluggish but safer operation.

(6) There is a shortage of uranium. This was discussed above.

(7) The LMFBR is extremely expensive. Already it has cost almost 3 billion dollars and this will provide us only with the Clinch River demonstration plant of 380MW in 1983 if now it is on schedule. Anything less than 1000 MWe makes hardly a dent in our nations's energy needs.

(8) Finally, even if the LMFBR reaches its present projected mission, it cannot possibly be considered a success. All of us are shocked to realize the breeding ratio of the LMFBR is too small (~ 1.12) to be significant and the doubling time of 30 to 50 years is so long that is must be considered a complete failure. If it takes 40 years for a LMFBR to produce enough Pu to duplicate itself, we might as well forget it. At best it will be an interesting museum piece for our great, great grandchildren.

Some have been impressed by the unique success the French have had with their Phenix LMFBR and with the fact that they are now building Super Phenix. However, we hear that the breeding ratio and doubling time of these reactors are as bad as they are with the Clinch River Breeder. How long will it take man to switch over to a better breeder system?

C. A Better Long Range Solution for Nuclear Power

a. General Solution for Nuclear Power. From the above it goes without saying that I believe the LMFBR and the LWR-GESMO choices are a bad mistake and our long range direction of nuclear power should be changed drastically. However, in spite of the fact there will always be some serious risks with any nuclear power system, I believe the risks of nuclear power could be made and maintained low enough to be acceptable and in such case would impose risks that are no more and probably less than those commonly accepted with power generated from fossil fueled plants. I consider the Rasmussen Reactor Safety Study[6] an interesting excerise but a big waste of public funds and that anyone who takes seriously the risk estimates given in this report has not studied the causes and effects of many of the past reactor accidents (e.g., Windscale England accident on October 10, 1957, SL-1, Idaho Falls explosion on January 3, 1961, or even the recent Brown's Ferry common mode failure). The statements of R. M. Fluegge[1] (a defector from NRC) on October 21, 1976 that 16 of the 36 operating PWR's have experienced 29 incidents of overpressurization since 1969 puts the fear of a catastrophic failure in many like myself who would like to be a strong supporter of our nuclear energy programs. He reported that on one occasion the Trojan plant went up to 3326 psi at 100 to 105°F. Such high pressure at this low temperature is a frightening reminder that pressure values and blow out plugs, as presently designed, can fail to operate at low temperature where the danger of brittle facture of the pressure vessel is greatest, and even more serious it is evidence again that one cannot and should never rely very much on administrative control when the stakes in lives and property are so high. The Rasmussen report gives risk values that are too low by several orders of magnitude for this reason alone, namely it discounts a brittle fracture accident because it assumes the temperature and pressure will always be under administrative control. From my 34 years experience with safety related to nuclear energy programs I can list scores of cases of human errors, most of which would have been difficult to predict and almost impossible to prevent. The only safe and certain assumption is that if man (scientist, engineer, operator) can make a mistake, give him time and he will. I agree with A. M. Weinberg's comments on our "Faustian bargain," but I do not agree with his conclusions that we must create, maintain, and rely upon a cadre of scientists, engineers and operators of unusual dedication, of the highest expertise and integrity, to operate this nuclear power industry and that it is safe to leave these operations in their hands. For my part I would put more trust in equipment designed to operate safely and to fail safe and in computers which we instruct for routine, remedial and emergency operations.

The type of long range nuclear power program which I favor is one that would change over to the $Th^{233}U$ cycle as soon as possible and in principle would convert the dangerous ^{239}Pu to ^{233}U while producing nuclear power. I think this conversion should be carried out at isolated internationally supervised reactor parks which are located in immediate proximity to a permanent high level radioactive waste disposal facility.

b. Solution to Radioactive Waste Disposal Problems. During the almost 30 year period that I was director of the Health Physics Division of Oak Ridge National Laboratory my research group investigated many methods of radioactive waste disposal, and the most satisfactory method we found for high level waste was to solidify it in metal containers and place these containers in holes drilled in the floor of rooms carved out in deep underground deposits of bedded salt (NaCl). We carried out extensive studies in mines near Lyons, Kansas. We explored such things as container deterioration, clorine formation, thermal conductivity of salt, changes in salt structure and creep rate, the Wigner effect, self plugging of cracks in the salt formations that might permit water entry, etc. In fact the salt program looked so good it was taken away from our Health Physics Division in 1971, and about this same time it was decided prematurely to convert our research facility in an abandoned salt mine at Lyons into a waste production facility for the nuclear power industry. The whole program backfired, however, when hordes of Washington bureaucrats went out to Lyons and announced plans to make our research facility the hot waste garbage dump of the U.S. Also several abandoned exploratory oil wells were found that had been drilled into this formation and it was feared water might at some future time have access to this salt mine. The principle reason this program backfired, however, was political and the fact that the new invading Washington force into Lyons did not have the protocal we has so carefully developed over a period of many years.

I believe additional studies should be conducted on salt disposal before a big industrial operation gets underway, but I have reasons to believe if salt formations are properly located, salt provides an almost ideal formation for permanent disposal of high level radioactive wastes. Salt would not be there in the first place unless it had been well isolated from circulating water for hundreds of millions of years. If cracks should be formed by earthquakes or during the next ice age, the plasticity of salt would result in self sealing to close the cracks very quickly. If water enters a crack to the salt formation, it usually brings along mud and silt that self plugs very shortly. The slow rise in temperature due to the self heat of the radioactive waste safety releases the Wigner energy of the salt. Clorine formation is very low and no problem. When the floor of a room in the salt formation is filled with containers of waste, the room would be backfilled with loose salt and in a few decades self sealing and creep of the salt formation will completely fill the room locking the radioactive waste in the solid bedded salt formation for many more millions of years. Other geological formations such as horrizontal shale beds may in time prove to be as good as salt, but since we already have conducted extensive studies on salt, I believe an appropriate site should be selected and a pilot hot waste disposal program should be gotten underway as soon as possible. This should have the highest priority.

C. A Solution to Breeder Reactor and Fuel Reprocessing Problems

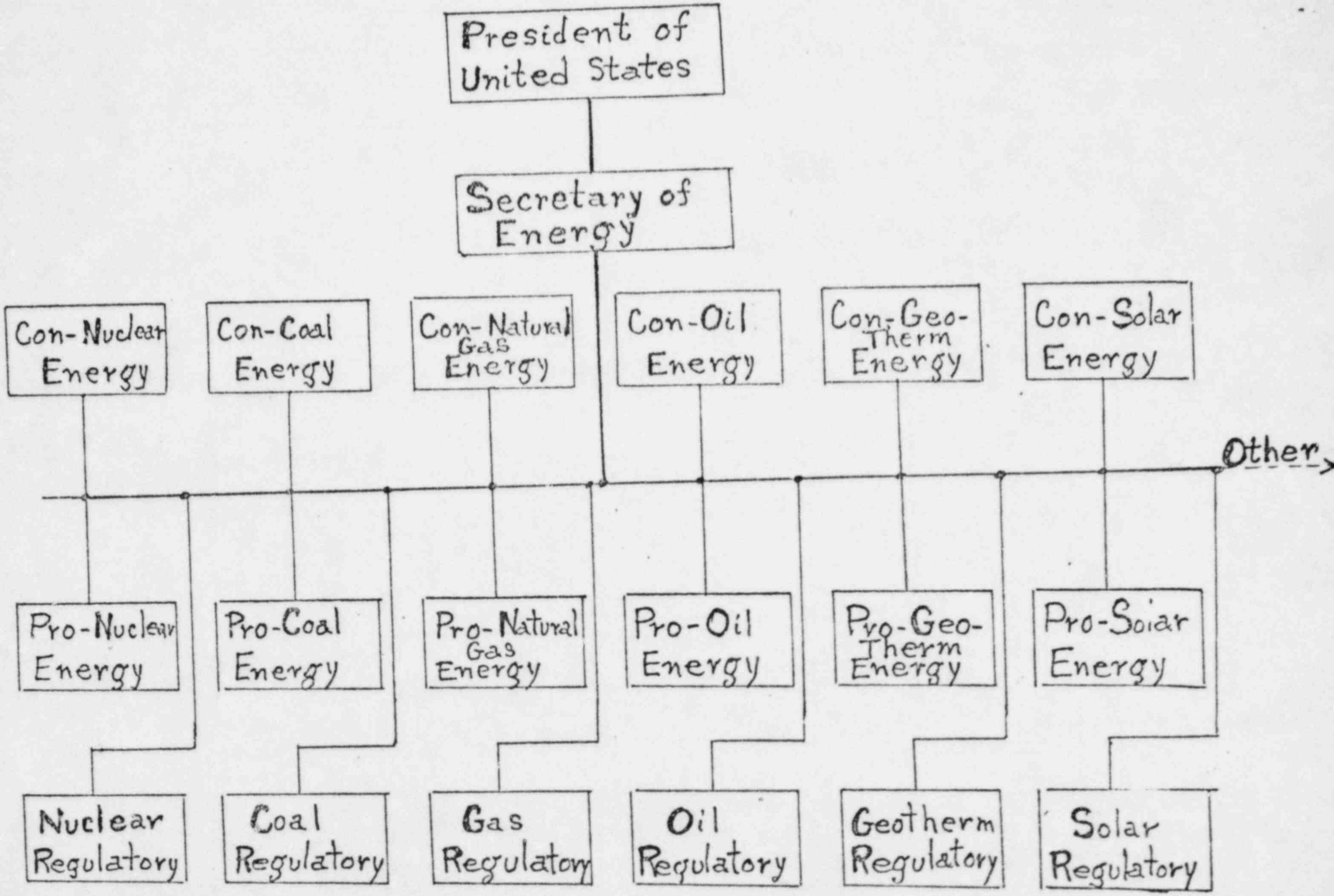
If at all possible this first commercial pilot-plant-hot-waste disposal facility should be located on a site that is suitable for a reactor park. By this I mean it not only should be a suitable bedded salt formation, but the site should have other features such as isolation, low rainfall, away from earthquake zones, near railroad facilities, not too far from electrical load demand, etc.

A number of specially designed Th^{-233} U reactors, as well as a fuel reprocessing plant and a fuel fabrication plant, would be located on the same site. Initially, these reactors would be loaded with Pu and ^{232}Th and following Pu fission and the reaction: $^{232}Th + n \rightarrow {}^{233}Th\ (22.1m) \beta \rightarrow {}^{233}Pa\ (27.0d)\ \beta \rightarrow {}^{233}U\ (1.62x10^{5}y)$, the ^{239}Pu and ^{241}Pu would be destroyed and replaced by the far less hazardous fissile ^{233}U. Much of the ^{238}Pu and ^{240}Pu would be converted to the fissile ^{239}Pu and ^{241}Pu respectively and fissioned to form more ^{233}U. Later when the surplus of Pu is consumed in this manner the Pu-^{232}Th reactors would be replaced by ^{233}U-^{232}Th reactors and gradually all commercial reactors except perhaps those in these isolated internationally supervised reactor parks could be converted to ^{233}U-^{232}Th system. This system would contain no Pu or transplutonium elements except for traces -- mostly resulting from tramp uranium in the system and from the low yield chain $^{233}U + 6n \rightarrow {}^{239}U(23.5m)\beta \rightarrow {}^{239}Np(2.35d)\beta \rightarrow {}^{239}Pu(24{,}400y)$. The radionuclides produced in this ^{233}U-^{232}Th reactor system would be orders of magnitude less hazardous than those produced by the present reactor systems. Some of the short lived daughter products in the ^{232}U chain might necessitate some extra requirements for gamma shielding in the fuel fabrication operations, but they would be of less consequence than the gamma problems caused by the ^{241}Am and ^{243}Am that grow into the recycled fuel from the ^{241}Pu and ^{243}Pu respectively. Also, one would not have the problem of spontaneous neutron emission from ^{244}Cm that can be a problem with the GESMO program.

A number of studies have been conducted, for example, those by R.A. Karam at Georgia Tech., indicating several possibilities of breeding with the ^{233}U-Th cycle and that with some of the proposed systems the doubling time most certainly would be less than 10 years (compared with 40 to 50y with the LMFBR) and some of the systems could use a coolant in such a way that they would have a negative void coefficient (rather than the positive void coefficient of the LMFBR). Also, it is estimated the Th available in the earth's crest is tem times the amount of U available.

As pointed out above, portions of my paper in 1971 pointing out the advantages of the ^{233}U-Th cycle over the LMFBR were censored by ORNL management. Perhaps one of the most important advantages I showed in the ^{233}U-Th system was that the ^{233}U produced in reactor parks as described above could be denatured with ^{238}U so that it would not be weapons grade material. Feiveson and Taylor[7] recently have made the same observation and suggest the ratio of ^{238}U to ^{233}U might be 6/1 with most of the reactor loading consisting of Th. Such 6/1 fuel supplied to LWR's or modifications of them from the few well isolated and internationally supervised reactor parks would mean that fresh reactor fuel could not be used for production of nuclear weapons, that the amount of Pu in spent fuel would be much less than that in fuel of the LMFBR or the LWR and that it would be contained in fuel elements in association with large concentrations of very radioactive and dangerous fission products. This would greatly simplify the safeguards program and lessen the risks of hijacking, and claudestine weapons production. If the reactor parks were limited in number and to a few countries (e.g., U.S., USSR, UK, France, and Japan), the problem of preventing the spread of nuclear weapons to other countries could be greatly simplified and this hopefully could reduce the risks of a Third World War.

d. Type of Federal Nuclear Program Needed in the U.S. The split of the AEC into the NRC and ERDA removed a serious problem of conflict of interest but to a considerable extent was mostly a switching of people and organizations in a game of musical chairs with very little change in personnel or direction of nuclear power programs. Our present system of environmental impact statements, public hearings and licensing of nuclear power programs represents considerable progress over the past, but still has much to be desired. Three of the greatest shortcomings in the present system are: 1) The NRC and ERDA do not have a proper line of responsibility to Congress or to the President; 2)The opponents of the nuclear program do not have adequate opportunity to present their case; 3) Too many rulings of the lower courts are reversed by the higher courts. The first shortcoming could be corrected by President Carter's proposal to combine ERDA, the Federal Energy Administration, the Energy Resources Council, and parts of the Dept. of Interior into a new Dept. of Energy. The second problem could be solved in part by having each energy division in the Dept. of Energy composed of two parts -- a pro and a con as indicated by the enclosed figure. The con side would be quite small for each type of energy, but it would work actively with, and lend limited financial support to the interveners, environmentalists, and others who wished to raise objects of a given energy proposal. It is not clear how best the third shortcoming can be corrected except through improved educational programs and better lines of communication with the Dept. of Energy. Hopefully, the new Attorney General, Griffin Bell, will assist in correcting this defect in our system.


President of United States
Secretary of Energy
Con-Nuclear Energy
Con-Coal Energy
Con-Natural Gas Energy
Con-Oil Energy
Con-Geo-Therm Energy
Con-Solar Energy
Other
Pro-Nuclear Energy
Pro-Coal Energy
Pro-Natural Gas Energy
Pro-Oil Energy
Pro-Geo-Therm Energy
Pro-Soiar Energy
Nuclear Regulatory
Coal Regulatory
Gas Regulatory
Oil Regulatory
Geotherm Regulatory
Solar Regulatory

References

1. Fluegge, R. M., "Charges of a U.S. Nuclear Regulatory Coverup," Nuclear News, 19, No. 14, p 29 (November 1976)

2. Morgan, K. Z., "Reducing Medical Exposure to Ionizing Radiation," American Journal of Industrial Hygiene, 36, p 358 (May 1975)

3. Morgan, K. Z., "Suggested Reduction of Permissible Exposure to Plutonium and Other Transuranium Elements," American Journal of Industrial Hygiene, 36, p 567 (August 1975)

4. Rose, D. J., Walsh, P. W., and Leskovjan, L. L., "Nuclear Power — Compared to What?", American Scientist, 64, p 291 (May-June 1976)

5. Morgan, K. Z., Snyder, W. S., and Ford, M. R., "Relation Hazard of the Various Radioactive Materials," Health Physics, 10, p 151 (1964)

6. Rasmussen, N. C., "Calculations of Reactor Accident Consequences," USAEC-WASH-14-- (August 1974)

7. Feiveson, H. A., and Taylor, T. B., "Security Duplications of Alternative Fission Futures, " Bulletin of the Atomic Scientists, 32, p 14 (December 1976)

Interrogatory No. 10:

With reference to Contention 47, (a) specify what is meant by the phrase "seismic design sequence" as used in the first sentence of the Contention; (b) identify all inadequacies in the conservatism of the "seismic design sequence" for the Byron site; (c) identify all measures which would have to be taken to provide an adequately conservative "seismic design sequence" for the Byron site; (d) identify all factual issues that this Contention purports to raise which are not raised by Contentions 61, 71, or 77; and (d) identify and produce all documents which support your answers to parts (b) and (c) of this Interrogatory.

Response to No. 10:

10(a) "Seismic design sequence" is a term coined by the NRC Staff, not the League, and means precisely what the NRC Staff has used it to mean in discussing (for example) Task A-40 in Appendix A (at page A-16) of NUREG-0510 and in the Task Action Plan for Task A-40 — i.e., the entire process of developing site specific seismic design criteria and applying them to both the design (structural and equipment) and equipment qualification of a nuclear power plant (in this case, Byron).

10(b)(c) The Concern with Byron's seismic design sequence and, indeed, the Byron seismic problem generally, has been previously dealt with at length in the League's Answers to Commonwealth Edison's First Round of Interrogatories, particularly in the responses relating to Contentions 28, 32, 61, 63, 71, 77, and 106. Those responses are incorporated herein by reference. The seismic problems are also discussed in the League's other answers to Commonwealth Edison's Amended Second Round of Interrogatories, specifically the responses to Interrogatories 5, 13, 15, 16, 17, and 18. Those responses are also incorporated herein by reference.

The League has only very recently acquired through discovery CECO documents relating to seismic design and seismic qualification. Pending expert analysis of those documents, no further particulars on the seismic problems can be provided. However, as details become available, further information will be supplied to CECO in the form of supplemental answers to Interrogatory 10.

10(d) Contention 47 deals with the adequacy and possible limits of applicability of the seismic design standards to all plant sizes. Contention 61 is broader and is concerned with the sufficiency of all environmental qualification standards. Contention 71 pertains to the ability of the seismic qualification standards to accurately assess a plant's ability to withstand a seismic event. Contention 77 is concerned with the effects of aging and radiation exposure on seismic qualification.

10(e) The documents referenced in the answers to Interrogatory 10 are noted at the appropriate points in the text. These documents have already been furnished to or by CECO or are in the public domain and available to CECO.

Discovery and the League's own investigation continue. As new facts are ascertained, they will be provided in supplemental answers to Interrogatory 10.

Interrogatory No. 11:

With reference to Contention 53, (a) identiy the "associated controls" which along with the pressurizer heaters the League believes necessary to maintain natural circulation at hot standby conditions; (b) identify the "Staff's resolution" regarding pressurizer heaters and associated controls at Byron; (c) identify the modifications to the Byron design and/or operating procedures which you believe are necessary to provide an "acceptable level of protection" at Byron; and (d) identify and produce all documents which support your answers to subparts (a), (b), and (c) of this Interrogatory.

[illegible] nse to No. 11:

11(a) In addition to the pressurizer heaters, all portions of the heater power supply and control circuits including supports, interconnecting wiring, indicators, controllers, switches, etc. should be required to meet the applicable safety grade design criteria.

11(b) The "Staff's resolution" is the apparent finding by the Staff that only the ESF bus vital breakers, bus to breaker cabling, and breaker control switches are required to meet safety related criteria.

11(c) As indicated in our response to Part (a) above, all pressurizer heater power supply and control electrical equipment should meet safety related criteria.

11(d) All documents currently available have already been presented in LWV's Response to CECO's First Round of Interrogatories under the discussion for Contention 53. Documents subsequently obtained through discovery will be identified to CECO. As the discovery process and the League's own investigation continue, newly ascertained facts related to Interrogatory 11 will be provided in supplemental answers.

Interrogatory No. 12:

With reference to Contention 54, (a) identify the basis for your assertion that proper operation of power-related relief valves, associated block valves and the instruments and controls for these valves is essential to mitigate the consequences of accidents; (b) describe the manner in which a failure of the power operated relief valves, associated block valves and the instruments and controls for these valves can aggravate a LOCA; and (c) identify and produce all documents which support your answers to subparts (a) and (b) of this Interrogatory.

Response to No. 12:

12(a) As was previously stated by LWV in response to CECO's First Round of Interrogatories, the PORV's and block valves perform several functions which have safety significance to the plant. Among their functions are maintaining integrity of the primary coolant pressure boundary, providing pressure relief for low temperature overpressurization conditions, reducing the number of challenges to the safety valves, reducing the number of challenges to the ECCS and providing a bleed capacity during the feed and bleed mode of operation to remove decay heat from the reactor core. Failure of these components to perform these functions satisfactorily can either initiate or exacerbate an accident condition.

12(b) As indicated in our response to Part (a) above, failure of the PORV's and/or block valves to perform their function properly can prevent accomplishment of the feed and bleed mode of operation to remove decay heat from the reactor core. This is a procedure that may be used following a LOCA and failure to perform this function could aggravate the accident sequence.

12(c) Documents currently identified include all documents referenced in LWV's previous response to CECO's First Round of Interrogatories on this Contention. Also included is an October 16, 1979 Memorandum for Norman C. Moseley, NRC, from James M. Allan, NRC, on the subject of

Operations Team Recommendation -- IE/TMI Unit 2 Investigation. These documents should already be in the possession of CECO, but copies will be made available if they are not. In adition, LWV intends to rely upon other documents which have yet to be obtained through discovery. Also, the League will supply facts ascertained during the discovery process or through the League's own investigation in the form of supplemental answers.

Interrogatory No. 13:

With regard to Contention 61, (a) identify the "equipment previously deemed to be environmentally qualified" which failed during the TMI accident; (b) identify each piece of equipment for use at the Byron station which is identical to equipment identified in response to part (a) of this Interrogatory: (c) identify the "safety-related equipment at Byron", the environmental qualification of which is deficient and the nature of the deficiency; (d) identify and produce all documents which support your answers to subparts (a), (b), and (c) of this Interrogatory; and (e) identify each factual issue which this Contention purports to raise which is not raised in Contentions 32, 47, 71, or 72.

Response to No. 13:

13(a) The accident at TMI-2 was plagued by failure of equipment during the accident and during the recovery period. There was also the discovery that the environmental range for some equipment was not adequate for accident conditions. Examples of this are the connectors and leads to the pressurizer heaters, cable insulation, incore thermocouples, area radiation monitors, and pressurizer level measurements. These components had been declared by the utility to be adequately sized, designed and qualified and had been considered adequate to meet the requirements for an NRC license. However, they were shown to be deficient by actual experience. The key point is that the qualification (and in some cases, classification) was inadequate to insure operation during accident and post accident environments.

13(b) A listing of equipment found at Byron which is similar or identical to the equipment which failed at TMI-2 may be found in the FSAR in the section dealing with NUREG-0737.

13(c) Byron claims to have adequately classified and qualified their structures, systems, and components, but has not provided enough detail in their FSAR to ensure that this will cover the necessary range of environmental concerns. For instance, Table 3.2-1 (FSAR Vol. 1, Section 3.2) makes no distinction between safety-related equipment and important-to-safety equipment. There is no detail of which parts (if any) of 10 CFR 50 Appendix B apply to their Safety Category II equipment. Also, in this table there is no indication which equipment is qualified to operate over the extended ranges of environment given in RG 1.97. See Reg. Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Access Plant and Environs Conditions During and Following An Accident," Rev. 2, December, 1980. There is no indication whether cables for systems important-to-safety are considered Safety Category I or II. To the contrary, Item 4 of Table 3.2.1 lists "all equipment necessary for Category I items to perform their safety functions." All other equipment is listed as Category II. However, this is under the heading of Instrumentation and Control Power and does not include any reference to control room indications, cables or support functions. Only Category I equipment is required to meet 10 CFR 50 Appendix B, with other Category II equipment only required to meet normal industry standards. This does not provide sufficient information to know if the necessary equipment is properly classified and fully qualified.

13(d) The references included are only those supplied on the Docket for Byron.

13(e) This contention also brings in the issues of classification, accident environment definition, and documentation of qualification status. The discovery process and the League's own investigation continue. Newly ascertained facts will be provided to CECO in the form of supplemental answers to Interrogatory 13.

Interrogatory No. 14:

With reference to Contention 62, (a) identify the accident scenarios within the category of "Class 9" accidents which the League believes are credible; and (b) are the accident scenarios referred to in subpart (a) the ones that the League believes must be accommodated within the design basis for Byron.

Response No. 14:

14(a) The generic PWR accident scenarios within the category of "Class 9" accidents which the League believes are potentially credible for Byron are described in the documents set forth in response to Interrogatory No. 2 concerning Contention 8. In addition, as previously set forth in response to Interrogatory No. 2, the League believes that Byron specific accident scenarios should be developed by CECO utilizing a systematic methodology which encompasses such techniques as Probabilistic Risk Assessment, Systems Interaction analysis and plant walkdowns, and Failure Modes and Effects Analysis. The systematic methodology should include the development of credible multiple-failure accidents (i.e., accidents in excess of those prescribed by the "single failure criterion").

14(b) The accident scenarios set forth in subpart (a) are those that the League believes must be accommodated within the design basis for Byron. Implementation of such a systematic methodology would identify the important safety features of the Byron plant as required by the General Design Criteria (GDC) of Apendix A to 10 CFR 50. The GDC for nuclear power plants establish criteria which are used to ensure the quality and qualification important to safety. Thus, the GDC establish requirements for quality standards and records commensurate with the importance of the safety function to be performed (GDC-1) and specify that components important-to-safety be designed for accident environments (GDC-4). Absent a systematic and thorough method of component classification, there is no assurance that the full and necessary set of SS&C's has been subjected to the requirements of these GDC or, conversely, that compliance with the GDC has been assured.

The GDC also establish criteria to guide the design, redundancy, separation and analysis of SS&C's importance to safety in order to ensure their safety function will be accomplished. These include design for protection against the effects of natural disasters, fires and missiles (GDC-2, 3, and 4). These conditions must be applied to the design and analysis of components to be considered and the possible interactions resulting from the accident initiators of concern.

Three of the GDC concern themselves with the necessity of redundancy and/or design features to protect against vulnerability to single failures in protection systems (GDC-21), the diversity of protection system design (GDC-22), and the assurance of failsafe modes for protection systems (GDC-23). Other GDC address the need for careful design of reactor protection and control systems to ensure their separation and thus prevent unfavorable interactions (GDC-24) and the assurance that the reactivity control and protection systems will be capable of performing their functions under all anticipated operational occurrences (GDC-29). For each of these GDC, it is necessary to assure that the classification of systems is accurately and systematically performed to identify all systems which should be included and their independence from interactions with other systems.

There are criteria for fuel temperature limits which must be met to ensure integrity of the fuel cladding under worst case conditions. These cover the design of the reactor and the ECCS and the necessity that cooling water sources be available under the most adverse conditions (GDC-10 and 35), plus the need for testing of ECCS under a range of conditions and power sources (GDC-37). Part of the protection system, cooling system and testing system requirements is that there be a thorough set of insrumentation and control for the range of accident conditions (GDC-18). There is a clear need to have a full description of the safety components which must be tested and the system conditions which could interact with the emergency systems to create adverse operation conditions.

It is not possible to find that Byron has met the above criteria until there has been a systematic analysis to identify the SS&C's necessary for important-to-safety and safety-related functions. This analysis must also include a systems interaction analysis of Byron to find all systems and components whose actions may have importance to safey.

The Applicant's FSAR, together with the Staff's SER, are supposed to constitute the definitive documents in support of licensing a nuclear plant. At Byron these documents are deficient and do not in fact provide a basis for issuance of an operating license. Thus, as documented briefly in the preceding:

-- The Byron classification system is not consistent with the GDC;

-- The problems of systems interactions have not been systematically analyzed; and

-- CECO has failed to supplement its analyses in Chapter 15 of the FSAR with alternative available methodologies that would assist in the classification of equipment and identify adverse systems interactions including multiple failure accident sequences.

Interrogatory No. 15:

With reference to Contention 63, identify specifically those "systems and components presently classified as non-safety related" which you contend should be identified and classified as "components important to safety"; and (b) identify and produce all documents which support your answer to subpart (a) of this Interrogatory.

Response to No. 15:

15(a) The Denton memorandum of November 20, 1981 provides the general definition for components "important to safety" (in addition, see responses to Interrogatories Number 1, 5, 13, and 14). The background concerning the requirements to identify items "important to safety" is set forth on page 90 of NUREG-0936, Vol. 1, No. 2 (July, 1982) as follows:

> "In the aftermath of the Three Mile Island Unit #2 accident, a number of studies have concluded that the scope of the items to which the quality assurance criteria of Appendix B to 10 CFR Part 50 apply needs to be broadened to include the full range of safety matters as was originally intended. Typical examples of structures, systems, and components for which the Appendix B quality assurance program criteria may not have been fully implemented are in-core instrumentation, reactor coolant pump motors, reactor coolant pump power cables, and radioactive waste system pumps, valves, and storage tanks. The proposed rule is intended to clarify the Commission's original intent by revising Criterion 1 of Appendix A to state specifically that the criteria to be used for the quality assurance program required in Appendix A are those criteria contained in Appendix B. Additionally, in order to eliminate confusion over definition of the terms 'important-to-safety' as used in Appendix A and 'safety-related' as used in Appendix B, the proposed rule would, in Appendix B, delete the term 'safety-related'."

The League also believes that the Byron Emergency Operating Procedures (EOPs) direct operators to utilize or rely on equipment which has not been classified or qualified commensurate with the safety functions performed. As the EOPs become available during discovery, this response will be supplemented to identify examples of the preceding equipment.

15(b) In addition to the publicly available documents referenced herein, and in documents noted in responses to Interrogatories 1, 5, 13, and 14, the following additional documents which are publicly available support the preceding answer in subpart (a):

(i) Three Mile Island: A Report to the Commissioners and to the Public (the "Rogovin Report")

(ii) NUREG-0585, TMI-2 Lessons Learned Task Force - Final Report

(iii) NUREG-0578, TMI-2 Lessons Learned Task Force Status Report and Short-Term Recommendations

(iv) Report of the President's Commission on the Accident at Three Mile Island (the "Kemeny Report")

Interrogatory No. 16:

With reference to Contention 71, (a) identify each requirement of the general design criteria in Appendix A to 10 CFR Part 50 with which Byron is not in compliance; (b) identify each of the effects of aging and cumulative radiation on the ability of electrical equipment to withstand seismic stresses which have not been considered for the Byron Station as alleged in the first sentence of the third paragraph of this Contention; (c) identify each factual issue which this Contention purports to encompass which is not encompassed within Contentions 47, 61, or 77; (d) identify and produce all documents which support your answers to parts (a) and (b) of this Interrogatory.

Response to No. 16:

16(a) Contention 71 deals specifically with the lack of an adequate method of seismically qualifying the Byron structures, systems, and components which are important to safety. It is not concerned with each requirement of the general design sequence with which Byron is not in compliance. Many of those items of non-compliance are dealt with in other Contentions.

The lack of adequate seismic qualification methodology is discussed at length in Contention 71 itself. The problem is also admitted by the Staff in Byron SER, Appendix C, on pages C-14 to C-15 and C-21 in the sections concerned with Tasks A-40 and A-46.

On page C-14, the Staff states that it "does not expect" the results of Task A-40 to affect its earlier conclusions of the acceptability of Byron's seismic design basis and the seismic design of the facility. However, the Staff's expectations have not always been correct as evidenced by the events of TMI-2 and, therefore, cannot provide any sort of guarantee of the kind necessary to meet the criteria of 10 CFR Section 50.57. This is especially true given the fact that the staff admits on page C-21 in regard to Task A-46 that it is still attempting to establish the "explicit set of guidelines" necessary to judge the seismic qualification of mechanical and electrical equipment at operating plants and that the matter is an unresolved safety question.

In essence, the Staff is saying that Byron is "qualified" for operation, but that there is not an acceptable method of determining how "qualified" it is. This position amounts to no qualification at all and certainly does not put Byron in compliance with either the spirit or the explicit requirements of 10 CFR Section 50.57.

The particular failures of the Byron seismic design are discussed in the answer to Interrogatory 10. The deficiencies in the actual qualification of Byron equipment and structures are handled in the answers to Interrogatories 5, 13, 16, and 17. The need for a further analysis of Byron's seismic qualification is commented upon in a letter from Phillip Gustafson, Director, Illinois Department of Nuclear Safety, to the Director of Licensing, USNRC, which appears at page A-26 of the Byron FES, Appendix A.

16(b) The problem of qualification of equipment important-to-safety such that it includes the effects of aging has been addressed in the response to Interrogatory 5. Also, in the response to Interrogatory 5, reference is made to reports dealing with the uncertainty of various methods of life testing for radiation effects on electrical equipment. Problems of the nature described for insulation are likely to effect other materials subjected to a radiation environment. Thus, the qualification testing for the applicable important-to-safety equipment may not be adequate to predict the effects of a lower dose rate. The reports indicate that more mechanical damage (lesser tensile strength, swelling, etc.) was observed at lower dose rates. However, the qualification testing is more often done at high dose rates for a shorter period of time.

16(c) These Contentions are differentiated in the answers to Interrogatories 5 and 10.

16(d) The reports referenced in response 16(b) are those which were referenced in response to Interrogatory 5. The documents referenced in answer 16(a) are in the public domain or were previously supplied by CECO or the NRC. The discovery process and the League's own investigation continue. As additional facts are ascertained, they will be provided in supplemental answers to Interrogatory 16.

Interrogatory No. 17:

With reference to Contention 77, (a) for each component which you believe will be progressively weakened by aging, explain (i) the relationship between aging of that component and the extent to which that component may be weakened as a result of aging and (ii) the extent to which aging will impair the ability of that component to withstand natural forces such as earthquakes and the accident environment and still perform its safety functions; (b) identify and produce all documents which support your answer to subpart (a) of this Interrogatory; and (c) identify all factual issues raised in this contention which purport to address new issues not raised in Contentions 32, 47, 61, or 71.

Response to No. 17:

17(a) The relationship between aging and weakening of equipment is the result of deterioration of the materials' strength or physical properties due to the constant or periodic impact of radiation, temperature, vibration, etc. A structure, system, or component which is weakened by aging would be less capable of withstanding the effects of an earthquake than a new piece of equipment subjected to only accelerated aging. Additional discussion of this point is included in the response to Interrogatory 5.

IEEE 323-1974 defines a testing sequence wherein the equipiment to be qualified should be subjected to aging effects of radiation, temperature, and vibration, then subjected to the seismic test requirements of IEEE-344-1971. See IEEE-344, "Recommended Practice for Seismic Qualification of Class IE Equipment," 1971.

However, the aging environment must be set to represent the worst case conditions to insure that the device will perform properly over its entire installed lifetime and will still be capable of performing its safety function. Because of the uncertain compliance with NUREG-0588 and CLI-80-21, there is no assurance that full qualification has been conducted on all Byron equipment which is important-to-safety. Similarly, there is no assurance based on Table 3.2-1 of the FSAR that the equipment has all been properly classified so that important-to-safety equipment will be subjected to the proper QA and qualification.

17(b) Only Docket references and documents readily available in the public domain or already in the possession of Byron have been used in response to this Interrogatory.

17(c) The specific concern that is raised here is the combination of qualification for aging and seismic to insure that the safety function will be capable of being performed, even at the end of the installed life of equipment. Interrogatories 32, 47, 61, and 71 deal with other areas of qualification or with the qualification standards themselves.

Interrogatory No. 18:

With reference to Contention 106, (a) identify each "serious seismic related site [problem] discovered subsequent to the construction permits herein" referred to in the first sentence of this Contention; (b) identify all of the "recent information" which indicates that the Plum River Fault should be considered a capable fault as alleged in the third sentence of this Contention; (c) identify each "new fact" referred to in the second to the last sentence of this Contention which calls into serious question the decision at the construction permit phase; and (d) identify and produce all documents which support your answers to parts (a), (b), and (c) of this Interrogatory.

Response to No. 18:

18(a) The principal seismic-related site problem which has been discovered subsequent to the issuance of the Byron construction permits is the discovery of the Plum River Fault Zone. To date, no significant attempt has been made to determine any possible future movements of this fault zone as, for example, by conducting testing with a strain gauge. According to Dr. Henry Woodard, geologist at Beloit College, Beloit, Wisconsin, "Not enough work has been done to find decisive evidence as to whether or not this is a capable fault." "Plum River Fault Zone of Northwestern Illinois," Illinois Geological Survey Circular 491 (1976).

18(b) The "recent information" which indicates that the Plum River fault is capable include Dr. Woodard's comments referred to in answer 18(a) and testimony elicited at the hearing held in Bethesda, Maryland on August 26, 1975. At that hearing, the witnesses indicated that faults found at the Byron site were probably very old, but would only say that they may be older than 250,000 years or as much as 500,000 years old. This recent information indicates that the Plum River fault is capable; however, the real problem is that not <u>enough</u> study has been done to determine whether or not the fault truly is capable. If proved to be a capable fault or that new movement could be expected in the near future, the fact it ends 5.3 miles from the site boundary would require that careful analysis be made of its probable connection with the minor faults found on that site. If it were shown that the Plum River fault was indeed capable, then a stronger seismic design for the plant would be required under the NRC regulations.

18(c) The FSAR conclusion that there is no evidence that seismic activity in the area is related to major structures is questionable according to Dr. Woodard. The 1972 earthquake had an epicenter about 30 miles from the Byron site located on the flank of the LaSalle anticline and was probably a surface reflection of an underlying fault to which the earthquake was related. According to Dr. Woodard, "not enough study has been done to define what part 'old structures' might play in controlling modern day movement in the northern central structure region. Geologists don't know the stress strain relationships in rocks of northern Illinois and southern Wisconsin." No analysis has been done using data from earthquake epicenters in this area which can show the type of movement which would be associated with these epicenters. Additionally, the re-analysis done by Livermore Laboratory changes the recurrence period of MM VI earthquakes at the Byron site to 200-1,000 years instead of the 2,150 year interval previously predicted. This fact, in conjunction with all the other uncertainties and lack of factual data concerning this entire problem, invalidate the reason for using a lower maximum vibratory ground acceleration than is required by the regulation, e.g., .09g instead of the specified .10g.

This entire matter needs substantial further analysis especially in light of the other unresolved problems at Byron including, of course, the seismic qualification of the structures and the equipment. This is particularly true in light of comments made in EGN #59, "Illinois State Geological Survey Notes on the Earthquake of September 15, 1972 in Northern Illinois," (December, 1972), p. 13, where it is stated: "In areas where surficial materials such as those under portions of flood plains tend to enhance ground movement, the maximum expected intensity values may be increased as much as one unit of damage." This possible effect on the structures along the Rock River has not been analyzed nor has any analysis included mention of the December 16, 1811 Mississippi Valley earthquake which was of MM X intensity. All of the above factors call into serious question any decisions made at the construction permit phase.

18(d) In addition to the documents mentioned above, reliance has been placed on the following documents in answering Interrogatory 18: Circular 519, "Structural Features in Illinois — a Compendium" (1981); Herrmann, Robert, "Surface Wave Focal Mechanisms for Eastern North American Earthquakes with Tectonic Implication," Journal of Geophysical Research (July, 1979). These documents have either been furnished by CECO or are in the public domain.

The discovery process and the League's own investigation continue. As additional facts are ascertained, they will be provided to CECO in supplemental answers to Interrogatory 18.

Interrogatory No. 19:

With reference to Contention 109, (a) provide page citations to NUREG-0440 where the subject matter of this Contention is addressed; (b) identify the "recent events" which "indicate that [Applicant] has not complied with" the commitments referenced therein; (c) (i) identify the "commitments" which Applicant has not complied with and (ii) state specifically how Applicant has failed to comply with such "commitments"; and (d) identify and produce all documents which support your answers to subparts (b) and (c) of this Interrogatory.

Response to No. 19:

19(a) With the exception of the portions of NUREG-0440 concerned with dry sites, estuary sites, Great Lake sites, and Atlantic coastal or oceanic sites, all portions of NUREG-0440 are relevant to contention 109 and of particular importance are sections 4 and 7.

19(b) The "recent events" which indicate that CECO has not complied with its commitments regarding hydrological analysis which were made at the construction permit stage should more probably be characterized as non-events. Specifically, these include CECO's non-response, as regards hydrology, to the events at TMI-2 and the resulting Kemeny report, Rogovin report, and the TMI Tasks. In addition, nothing has been done by CECO regarding the repudiation by the NRC in January of 1979 of portions of the Rasmussen Reactor Safety Study. Furthermore, no action has been taken to allow for the deficiencies in NUREG-0440 upon which CECO placed great reliance in its hydrological analysis of the Byron site. These deficienies, of course, resulted from the fact that NUREG-0440 was written prior to the events at TMI-2 and the repudiation of the Rasmussen report to which it refers. See answer to Interrogatory 7, Affidavit of Richard B. Hubbard and Gregory C. Minor, November 12, 1980, pp. 46-52, previously supplied to CECO and incorporated herein by reference. This lack of compliance with CECO's previous commitments has been most recently exemplified by the inadequate water pathway study contained in the Byron FES, NUREG-0848 (April, 1982), pp. 5.56-5.59.

19(c) The commitments with which CECO has failed to comply were, in large part, listed in Contention 109 itself. For example, based upon USEPA comments found in SER Appendix A, p. A-21, "Accident Risk and Impact Assessment" and SER p. 5.57, et seq., CECO has still not performed a site specific study or assessment of the effects of radioactive contaminants in the sediment of the Rock River bottom nor the contaminants' contribution to long term radioactivity in the hydrology of the Byron area. This is particularly significant in light of the errors which have been found in the Rasmussen report which were incorporated into CECO's original analysis of the area hydrology through NUREG-0440 and which still guide the Byron hydrological policy. See answer to Interrogatory 7. Special problems arise in this regard with the long lived radionuclides such as Cs-137, I-129, and tritium.

Additionally, consequences of Class 9 accidents on liquid pathways have not been sufficiently examined. Only ground water models for core melt accidents have been constructed. FES, pages 4-16.

No specific interdiction has been planned to mitigate accident consequences to ground water and the Rock River despite the fact that NUREG-0440 at p. 5.29 states that the impact of such an accident could be stopped by concrete curtains previously constructed underground. See the models for liquid pathway interdiction suggested by the Sandia Study (Draft) for USNRC, "Effect of Liquid Pathways on Consequences of Core Melt Accidents," (January, 1980), at p. 5.

In addition, ground water models have still not been constructed and the monitoring of exposure pathways to drinking water has not been planned. Furthermore, a hydrological survey is needed in order to assess the amount of contaminants present in underground water. See USEPA comment, FES,

Appendix A, p. A-21. CECO should not be allowed to omit the use of ground water models simply because CECO's position is that no radionuclides will be released into any ground water supply.

Also, the Byron Environmental Report stated at page 24.6 regarding supply dependability that the permeable sand and gravel deposits in the Rock River Valley will induce infiltration of surface water through the stream bed into wells. The FES estimates that this process will supply 25% of the recharge water to these wells. Since the report admits that radionuclides will b n the stream sediment, it is highly important that an adequate analysis of stream bed radioactivity on ground water be made. Ground water models could also assess the possibility of contamination from runoff from the surrounding terrain to the site and then to the river and ground water. See NRC First Round of Questions to CECO, p.37-5.

No assessment of the long term effects of withdrawal of the Rock River water has been done. Byron's anticipated use of Rock River water will amount to 30,000,000 gallons per day. This will be coming at a time when the overall use of the Rock River is increasing. According to the statement of the Rock Valley Metropolitan Council contained in the Byron Environmental Report, the predicted increase in water demand on the Rock River will be from 88,000,000 gallons per day in 1980 to 173,000,000 gallons per day in 2020. In addition to the "use" factor, the level of water in the river may also be affected by local drought cycles. Consequently, extreme doubt is cast upon the conclusion that the Byron site will have little effect upon ground water supply in the future.

Furthermore, the effects of long term radioactivity in water pathways have not been adequately assessed. This is true despite comments in NUREG-0440 in relation to waste and decommissioning that a serious accident would have severe effects on the eggs and larval development of river organisms.

Finally, the synergistic effects of chemicals and radionuclides have not been adequately assessed. See answer to Interrogatory 7.

19(d) All documents referenced in answers 19(a), (b), and (c) are noted at the appropriate point in the text. These documents have either been provided by CECO or are in the public domain.

The discovery process and the League's own investigation continue. As new facts are ascertained, they will be provided in supplemental answers to Interrogatory 19.

Interrogatory No. 20:

With reference to Contention 111, (a) identify the specific "deficiencies in the Byron plant which fail to keep radiation levels as low as achievable,"; (b) identify what steps would constitute an adequate resolution of the problem; (c) identify and produce supporting all documents which support your answers to parts (a) and (b) of this Interrogatory.

Response to No. 20:

20(a) There is much evidence that Byron has neither taken ALARA as seriously as warranted, nor provided protection as adequately as members of the public can reasonably expect. Some of these deficiencies are as follows: (1) Emphasis in the Byron reports is placed on the maximum dose per year and, at best, on the average dose per year. However, many studies indicate that a human population is heterogeneous and some members of the population are 30 or more times more radiosensitive to cancer induction by ionizing radiation than the average person (see references 3 and 7 cited on page 9-1, infra). Therefore, CECO must change its method of dosage measurement.

(2) No adequate plans have been developed for use the of KI during an emergency release of radionuclides of iodine (see reference 6[a-d] cited on page 9-1, infra). Such plans should be developed as was explained in the answer to Interrogatory 3.

(3) During the Windscale accident it was found that some of the most valuable information in a reactor accident can be provided by the use of simple instruments that are airborne by light aircraft. There was little or no use made of such aircraft during early statges of the TMI-2 accident and we find no evidence that Byron has such aircraft and instruments to conduct the early warning (within first hour) surveys which we believe are esssential to provide adequate warning by following the micro-meteorlogical patterns of cloud passage and of radioactive fallout. CECO must provide some way of performing these surveys.

(4) It is very important that the public have a proper understanding and appreciation of what to do in case of a radiation emergency. Toward this end, selected members of the public should be instructed in what to expect and what action to take in the case of accidents where radiation is confined to the plant (i.e., risk only to radiation workers) and in the case where there is radiation exposure beyond the plant. Some special groups who require such information include medical personnel, firemen, policemen, and schoolteachers. Byron should find out what some other nuclear plants have done in this regard, and then provide a means of adequately instructing the appropriate people as set forth above.

(5) Internal dose limits and dose commitments are calculated to periods of less than 70 years (typically to 50 years), whereas some persons in the neighborhood of Byron would like to live to 70 or 80 years of age. Again, CECO should alter its methods of dosimetry.

(6) The Byron reports use the words dilution and dispersion of radioactive gas and water from the plant as though this were a panacea which could solve problems of radiation exposure and meet ALARA's requirements. On the contrary, as indicated by the 32 references by Dr. Karl Morgan (cited on pages 9-1 through 9-3, infra), spreading out the dose only distributes the person rem to more people each of whom receives less dose but, as indicated in the above-mentioned documents, there is strong evidence that a given person rems will cause more malignancies if distributed among more persons. Byron has not solved this problem by increasing the number of radiation-induced cancers; rather, cancers are more difficult to identify with the Byron operations. This is especially true for radiationuclides such as C-14, H-3, I-129, Cs-137, Sr-90, Kr-85, and the actinide radionuclides. CECO must provide some acceptable method of dealing with radioactive gas and water and not rely upon "dilation" and "dispersion".

(7) Byron has not demonstrated that it is prepared to measure beta dose in the environment of the plant, yet there is increasing evidence that beta radiation may be a major contributor to radiation-induced skin cancer (basal cell, squamous cell and malignant melanoma). Malignant melanoma is the most feared form of skin cancer because by the time it is first diagnosed it usually has already metastasized and it is too late. Dr. Caldwell (see Morgan document 8, on page 9-1, infra) reported a significant increase of malignant melanoma among the men who took part in Test Smoky and there is a large increase among radiation workers at Lawrence Livermore National Laboratory. Byron must therefore provide better beta dosimetry.

(8) Byron has not indicated that it has adequate monitoring for its workers who are exposed to fast and epithermal neutrons. The best one can determine from Byron reports is that they still depend on the use of NTA film techniques which were introduced into health physics in 1945 by Dr. Karl Morgan. Since then, Morgan and his doctorate students at Georgia Tech have developed the electrochemical etch-pit of polycarbonate foils and CR-39 which has a sensitivity 1000 times that of the NTA film method and has essentially no trace fading. Unless the NTA neutron films are read within a few days, the tracks have disappeared and the neutron dose information is lost completely. It is Dr. Morgan's feeling that beta and neutron doses must be measured properly to achieve conformance with ALARA.

(9) There is no indication that Byron has made use of the information in numerous reports showing that biological indicators are useful in monitoring the radionuclide releases to the environment. These techniques not

only serve as a valuable addition to the GM counter ion chambers, etc., but they serve to identify food chain, that lead to man. For example, Co-60 and Co-58 are two of the most troublesome radionuclides with these power plants and D. Tenfel (IAEA-SM-237/17 March 26-30, 1979) showed a significant concentration of Co-60 as complexed into vitamin B-12 via the food chain of animals and man. CECO must begin using such monitoring practices.

2(c) All documents are referenced in the appropriate point in the text and have either been made available to CECO or are in the public domain. The discovery process and the League's own investigation continue. As soon as additional facts are ascertained, they will be provided by supplemental answers to Interrogatory 20.

Interrogatory No. 21:

With reference to Contention 112, (a) identify the "plant designs" and "new evidence" referred to in part (a) of this Contention; (b) identify "improved record keeping" referred to in part (b) thereof; (c) identify each improvement to applicant's training called for in part (c) thereof; and (d) identify and produce all documents which support your answers to this Interrogatory.

Response to No. 21:

2(a) There are a number of areas where improvements are called for in the design of this 1120 PWR Westinghouse type Byron reactor. For example, J. Beyea and F. von Hippel ("Containment of a Reactor Meltdown," TECH. OF NUCLEAR REACTOR SAFETY 2, Chapter 21, MIT Press [1973]) points out the problems of overpressure in a reactor under emergency conditions and the urgent need for a safe means of relieving that pressure. The authors discuss the benefits as well as the unanswered questions about the use of a PWR Filtered Vent System, but the nuclear industry has been convinced a Type 8 or 9 kind of accident has so low a probability that it may forget about such an eventuality. Other protective measures, such as a protective catch basin for the reactor core, have been considered but again were dropped from serious consideration or adequate valuation of their utility. The absence of these secondary devices for protection in case of a major accident may be an invitation for a disaster. (See also the related discussion in the answers to Interrogatories 9 and 20.)

2(b) Byron earns low marks in regard to dosimetry and record keeping. For example, one might ask how often calibrated blind TLD metes are run through the system; or how many times have exposure runs with TLD's been exchanged with other facilities. If the answers to such questions are not zero, then the data should be examined. Or one might ask how many thyroid samples from nearby slaughterhouses have been analyzed. Unless these dry runs have been under way for many months and the persons are well-trained and experienced in these health physics activities before the first megawatt is produced in a reactor, an early accident of minor potential could become a major catastrophe.

2(c) The deficiency in training of the health physics personnel is best answered by asking Byron management how many of those persons assigned permanently to this plant are certified health physicists. Since a low mark must be given for this answer, the next question is how many permanent employees have passed part one of this certification examination.

These considerations exist in addition to the need to better educate <u>all</u> plant employees, not only as to <u>how</u> to perform their job functions, but also <u>why</u> those functions must be performed as required as well as the implications of performance or non-performance to themselves, their co-workers, and the surrounding areas.

2(d) The document relied upon in this Answer to Interrogatory 21 is in the public domain.

The discovery process and the League's own investigation continue. As additional facts are ascertained, they will be provided by supplemental answers to Interrogatory 21.

Interrogatory No. 22:

With reference to each of the above Interrogatories, identify all persons who participated in the preparation of the answers, or any part thereof, or who directly provided information to the League, its counsel, or agents for use in the preparation of the answers or any portion thereof, to these Interrogatories.

Response to No. 22:

The persons who have participated in the preparation of the answers to Commonwealth Edison Company's Amended Second Round of Interrogatories include: Dr. Karl Morgan; Messrs. Dale Bridenbaugh, Richard Hubbard, Gregory Minor; Dr. Henry Woodard; and Mrs. Betty Johnson.

By: Bruce Ros[signature]
One of the Attorneys
for Rockford League of
Women Voters

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
COMMONWEALTH EDISON COMPANY	)	Docket Nos. 50-454-OL 50-455-OL
(Byron Nuclear Power Station Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I certify that copies of (1) Answers of Rockford League of Women Voters to Amended Second Round of Interrogatories of Commonwealth Edison Company, and (2) Motion for Leave to File Instanter Answers of Rockford League of Women Voters to Amended Second Round of Interrogatories of Commonwealth Edison Company in the above-captioned proceeding were served by messenger upon counsel for the Commonwealth Edison Company the 5th day of October, 1982. Additionally, the foregoing documents were served by mailing a copy of same, by Express Mail to the Office of the Secretary of the Commission and to counsel for the Staff, and by first-class mail to the members of the Panel, postage prepaid and properly addressed, on this 5th day of October, 1982:

Morton B. Margulies, Chairman
Administrative Judge
Atomic Safety and Licensing Board
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dr. Dixon Callahan
Administrative Judge
Union Carbide Corp.
Post Office Box Y
Oak Ridge, Tennessee 37830

Dr. Richard F. Cole
Administrative Judge
Atomic Safety and Licensing Board
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Steven C. Goldberg, Esq.
Office of the General Counsel
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Office of the Secretary of the Commission
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Bruce Rose pp

One of the Attorneys
for the Rockford League
of Women Voters