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ANNOTATED BIBLIOGRAPHY: HAZARD ASSESSMENTS FOR THE GEOLOGIC ISOLATION OF NUCLEAR WASTES

Final Report

November 1977

MASTER

By: Benjamin E. Suta
Susan J. Mara
Shirley B. Radding
and
Leo W. Weisbecker

Prepared for:

Union Carbide Corporation
Nuclear Division
Office of Waste Isolation
Oak Ridge, Tennessee 37830

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ANNOTATED BIBLIOGRAPHY: HAZARD ASSESSMENTS FOR THE GEOLOGIC ISOLATION OF NUCLEAR WASTES

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November 1977

Center for Resource and Environmental Systems Studies
Report No. 41

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FOREWORD

SRI International prepared this report under a subcontract with Union Carbide Corporation, Nuclear Division, a USERDA contractor. This subcontract was administered by the Office of Waste Isolation (OWI), program manager for the National Waste Terminal Storage (NWTs) Program. The principal objective of the NWTs Program is to provide facilities in various deep geologic formations that will safely dispose of those radioactive wastes generated by commercial operations and that must be delivered to a federal repository for terminal storage.

This report presents an annotated bibliography of risk assessments that are pertinent to constructing, operating, and decommissioning a federal repository for the underground storage of radioactive waste. This might be considered as a first phase in an assessment of the risks associated with radioactive waste storage. Only those documents judged to be the more pertinent are abstracted. The abstracts are grouped under 13 classifications. A subject and author index is provided.

I INTRODUCTION

A. Objective

This report presents an annotated bibliography of risk assessments that are pertinent to constructing, operating, and decommissioning a federal repository for the geologic isolation of radioactive waste. For the purposes of this bibliography, a risk is considered to encompass both the likelihood and the actual adverse consequences of an event. Continuous events such as wind erosion or leaching and episodic events such as earthquakes or sabotage are included. The material presented is intended to aid the preparation of risk analyses, safety analyses, and environmental impact reports.

The federal repository is to be constructed and operated under the Energy Research and Development Administration's (USERDA) National Waste Terminal Storage Program (NWTSP). Radioactive waste to be accepted for disposal in federal repositories may include all commercially generated high-level waste (HLW), cladding hull waste (CW), intermediate-level waste (ILW), transuranic and low-level waste (LLW). Options include disposal of unprocessed spent fuel elements and disposal of PuO_2 . In the latter case, the PuO_2 may be either mixed with the HLW or packaged separately in canisters for disposal. These wastes will be received at surface facilities designed to handle and prepare the various categories of wastes for storage. Radioactive wastes will be disposed of by emplacement of waste containers in an underground storage area excavated in a suitable geologic formation. The storage tunnels will be backfilled with excavated material, and at decommissioning the entire facility will be backfilled and sealed.

B. Risk from Radioactive Waste Isolation

The radioactive wastes produced as a consequence of nuclear electric power generation can, under certain conditions, be a hazard to the well-being of human and other life forms. The objective of nuclear waste isolation, therefore, is to prevent such hazardous conditions from occurring. Since nuclear wastes exist a decision must be made as to their ultimate deposition. In the United States the decision to proceed with a particular scheme for waste isolation requires the express consent of the people's governing representatives. Before this consent is forthcoming, the public and various constituencies must be assured and convinced that the procedure for waste isolation is safe, or that any risk involved is minimal and necessary.

Thus, determining the potential consequences of a proposed set of actions leading to waste isolation requires the following series of steps:

- Assessment of the costs, benefits, and risks of the proposed set of actions.
- Assessment of how these characteristics are perceived by the groups concerned.
- Assessment of the attitudes that are formed, based on the perceptions.
- Assessment of political consequences as these attitudes affect decisions concerning the proposed set of actions.

Each of these steps involves a wide range of relevant considerations. A bibliography of risk related to nuclear waste isolation must include, therefore, the literature that contains sufficient knowledge to define these considerations. Accordingly, each of these steps is discussed below to demonstrate how entries were chosen for inclusion in the bibliography. However, by contractual directive, this bibliography primarily addresses the first step.

Assessment of the Costs, Benefits, and Risks of the Proposed Set of Actions

This assessment requires knowledge of:

- The actions themselves; the underlying safety considerations, both operational and long-term; the possible sequence of events and occurrences by which the safety considerations could be voided; the consequences of voiding the safety considerations; the possibility of mitigating these consequences; and the regulation and control measures required to preclude unsafe situations or reduce their severity.
- The methodologies for determining the probabilities of occurrences leading to different consequences; the data and judgments used in these methodologies; and the simplifying assumptions incorporated in the methodologies.
- The possible human health, environmental, and ecological consequences; the uncertainties and controversies concerning human health.
- The methodologies for determining the benefits of the actions and of what they facilitate and induce along with the costs and the risks; and aggregate effects, as well as those distributed among different elements of society at various times in the future.
- The basis for determining benefits, costs, and risks compared to alternatives both in terms of energy and other social goods.

Assessment of Perceptions of Costs, Risks, and Benefits

This assessment requires a knowledge of:

- How people perceive costs, risks, and benefits that are expressed in probabilistic terms; that are based on complex analytical methodologies; that are based on data that are highly judgmental and subjective; and that may challenge their existing beliefs.
- How people are influenced by competing and possibly conflicting analyses.
- How people respond to analyses performed by institutions funded by the federal government.
- How people perceive the need for nuclear power as opposed to its possible alternatives.
- Whether people perceive and respond to a social crisis.

Assessment of Attitudes Formed Based on Perceptions

This requires a knowledge of how people tend to evaluate and trade benefits, costs, and risks:

- How people view risks of differing probabilities and consequences.
- How people view the burdening of future generations with risks that may be offset by benefits to the present, other future generations, or the future generations affected.
- How people view health effects that may be chronic; that may be delayed; that may afflict individuals at any time of life; or that may affect offspring of some future generation.
- How people view the benefits and risks of conserving fossil fuels for use as chemical feedstock for future generation by increasing the present use of nuclear power.
- How people view the potential environmental effects of increased use of fossil fuels compared with the potential risks of nuclear waste isolation.
- How people view the need for nuclear power development in conjunction with the need for economic growth, in contrast with energy conservation and other forms of energy that are perceived as being relatively environmentally benign.
- How people view risks that are freely accepted as opposed to those that are imposed.

- Whether people view new risks in contrast with those they normally face.
- Whether, when valuing human life, people's decisions concerning risks are based on moral or economic issues.

Assessment of Political Consequences

In understanding how people holding certain attitudes are likely to respond politically, the following questions are addressed:

- Who are the stakeholders; what are their interests; and how might their interests be affected?
- What avenues of intervention are open to various groups and which ones are certain groups likely to use?
- Who are the decision makers and whose decisions are critical?
- What constituencies support which issues?
- Which publics decide different issues?

C. Approach

Appropriate literature was obtained by searching Atomindex (1976-1977); Nuclear Science Abstracts (1969-1976); Chemical Abstracts (1970-1977); Business Periodicals Index (1970-1977); Engineering Index (1970-1977); Public Affairs Information (1975-1977); U.S. Government Research Abstracts (1970-1977). In addition, the Nuclear Safety Information Center operated by the Oak Ridge National Laboratory performed a computer search.

Abstracts were retrieved and sorted to eliminate duplications and references of little interest. Full-text copies were ordered of all references deemed to be of sufficient interest to warrant review. About 700 documents were retrieved, all of which were reviewed in regard to their applicability to the risk assessment of the underground storage of radioactive wastes.

To assist in this review and in the groupings of documents in the bibliography, a classification scheme of 13 headings was developed. This scheme was devised to be consistent with the requirements for a risk assessment of radioactive waste storage and with the topics that typified the literature available.

In the selection of documents for inclusion in the bibliography, we emphasized hazard studies that come within the context of the nuclear fuel cycle and studies that provide methods, data, or an approach that could apply to a risk assessment of nuclear waste management. In accordance with contractual directives, studies were included that deal with the socioeconomic and environmental effects of new large technological facilities in rural areas, and low priority was assigned to documents

describing transportation risks or presenting general sources of data that might be useful in the risk assessment (e.g., data on the effects of localized heat on salt deposits). Those documents reviewed that were judged to have little or no value for this bibliography were excluded. Textbooks were also excluded although we acknowledge that those in the fields of reliability, decision analysis, operations research, nuclear engineering, medicine, geology, hydrology, meteorology, and economics could be useful for a risk assessment of radioactive waste management.

The abstracts were written to focus on the documents' usefulness for the purposes of this bibliography. In many cases it was found possible to rewrite or modify abstracts given in the documents.

The documents abstracted were assigned a relevance value of 1, 2, or 3. These values indicate those documents that provide methodology or information that, respectively, would be highly, moderately, or marginally useful for a risk assessment of the underground storage of radioactive material. These relevance values pertain only to the value of the document adjudged for the purposes of this bibliography and do not relate to the quality of the work presented. As far as could be determined, all documents abstracted have merit in one or more contexts; documents that were clearly lacking in this respect have not been included.

To increase the usefulness of the bibliography, indexes based on key words and authors' names are included. Each document abstracted was given a unique identification number. These identification numbers have an alphabetical and a numerical component. The alphabetical component refers to the various sections in the bibliography and the numeric component refers to the order in which the abstracts are listed within sections.

Sections A and I of the bibliography provide applicable data and methodology for writing socioeconomic and environmental impact statements. Table I correlates sections of the bibliography with steps required in the preparation of safety analysis reports for long-term waste isolation and Table II provides a similar correlation for the steps required in the preparation of risk analyses.

Table I

APPLICABILITY OF BIBLIOGRAPHIC SECTIONS TO STEPS
REQUIRED IN THE PREPARATION OF A
SAFETY ANALYSIS REPORT FOR LONG-TERM WASTE ISOLATION

Steps	Bibliographic Sections
1. Selection of a Stable Formation	A, D, L
2. Isolation from Subsurface Fluids	A, D, L
3. Leachability of Waste	A, D, L
4. Waste-Surrounding Medium Interaction	A, D, L
5. Waste and Waste Container Processes	A, L
6. Surrounding Medium Modifications	A, L
7. Waste-Surrounding Medium Interaction	A, L
8. Tectonic Events	D
9. External Events	D
10. Human Intervention	E
11. Combinations and Interactions	A, B, D, E
12. Effects of Tectonic and External Processes on Waste Containment	A, B, D, E
13. Possible Biota Pathways	J, L
14. Hypothetical Biota Pathways	J, L
15. Potential Human and Non-Human Exposures	A, B, C, D, E, G, H, J

Source of safety analysis report steps: Weisbecker, L.W., et al, "Proposed Outline of Safety Analysis Report for Facilities for Geologic Isolation of Radioactive Wastes," Stanford Research Institute, Menlo Park, California, Y/OWI/SUB-77/22320, June 1977.

Table II

APPLICABILITY OF BIBLIOGRAPHIC SECTIONS TO STEPS
REQUIRED IN THE PREPARATION OF A RISK ANALYSIS

Steps	Bibliographic Sections
1. Definitions of Confined Sources	A, B, C
2. Definitions of Management System Containment/ Confinement Barriers	A
3. Identification of Potential Release Sequences	A, B, C, D, E
4. Definition of Dispersed Sources	A, D, E
5. Probability of Release	A, B, C, G, H
6. Liquid Transport	A, B, C, L
7. Airborne Transport	A, B, C, L
8. Contained Environment	A
9. Plant, Animal, Seafood Uptake	A, B, C, L
10. Population Distribution	Site specific
11. Definition of Man's Diet and Habits	A, B, C, L
12. Dose to Man	A, B, C, J, L
13. Risks	A, B, C, G, H, J, K

Source of risk analysis steps: Smith, T.H., et al, "A Methodology for Risk Analysis of Nuclear Waste Management Systems," presented to the American Nuclear Society 20th Annual Meeting, Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-SA-4899, June 1974.

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II ABSTRACTS

Section A

NUCLEAR WASTE HAZARD STUDIES

A-1 Relevance: 1

Smith, T. H., W. K. Winegardner, G. Jansen, Jr., L. D. Williams, and
T. I. McSweeney

A METHODOLOGY FOR RISK ANALYSIS OF NUCLEAR WASTE MANAGEMENT SYSTEMS

Battelle Northwest, Richland, Washington, BNWL-SA-4899, 1975.

This report describes a methodology for risk assessment of nuclear waste management systems. The required information and calculations are discussed, along with computer codes used for inventory calculations, fault tree evaluations, liquid and airborne transport, and doses to man. The report analyzes a high-level waste management scheme proposed for the year 2000. The results are intended to guide R&D efforts, formulations of waste product criteria, and comparisons of alternative waste management schemes.

A-2 Relevance: 1

Smith, C. F.

RISK ASSESSMENTS FOR THE DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTES

Ph.D. Dissertation, University of California, Los Angeles, California, 1975.

This Ph.D. dissertation assesses the risks for release of radioactive material into the environment associated with the disposal of high level wastes. A probabilistic risk assessment approach was used. The radioactive source term was characterized by using the ORIGEN computer code. An index of relative nuclear hazards appropriate to problems involving the management of high level radioactive wastes was developed. This new index was designed to apply to the specific problems of high level radioactive waste management, as well as to other situations involving material undergoing radioactive decay. As an illustration of the methodology, risk analyses were made for two proposed methods of waste management: extraterrestrial disposal and interim surface storage. Accident events possible for the surface storage assessment include: effluents during normal operations, major rupture of a waste canister dropped during handling or inspections, ruptured canister plus ventilation system failure, meteor impact on the

storage area, and meteor impact on the receiving facility. The results of the analyses given in this dissertation indicate that, within the assumptions used, the risks of these management schemes are small compared with natural background radiation sources.

A-3 Relevance: 1

Smith, C. F. and W. E. Kastenberg

ON RISK ASSESSMENT OF HIGH LEVEL RADIOACTIVE WASTE DISPOSAL

Nuclear Engineering and Design, 39:293-333, 1976.

This article is essentially a publication of Smith's Ph.D. thesis abstracted under A-2 in this bibliography.

A-4 Relevance: 1

Claiborne, H. C. and Ferruccio Gera

POTENTIAL CONTAINMENT FAILURE MECHANISMS AND THEIR CONSEQUENCES AT A RADIOACTIVE WASTE REPOSITORY IN BEDDED SALT IN NEW MEXICO

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-TM-4639, October 1974.

This report examines potential containment failure mechanisms and estimates their probabilities and consequences, when possible, for a hypothetical waste repository in bedded salt in southeastern New Mexico. Failure mechanisms examined include sabotage, nuclear warfare, drilling, meteorite, faulting, volcanism, erosion, and groundwater contamination. The study concludes that a serious breach of containment for such a repository, either by human or natural events, is only a very remote probability and falls into the category of the least likely occurrences that affect society.

A-5 Relevance: 1

McClain, W. C. and R. L. Bradshaw, editors

PROJECT SALT VAULT: A DEMONSTRATION OF THE DISPOSAL OF HIGH-ACTIVITY SOLIDIFIED WASTES IN UNDERGROUND SALT MINES

Union Carbide Corporation, Oak Ridge, Tennessee, ORNL-4555, 1971.

This report documents the background, design, installation, operation, and conclusions derived from Project Salt Vault. Project Salt Vault was a demonstration of the disposal of high-level solidified radioactive wastes in a salt mine in Lyons, Kansas. Chapter 9 evaluates the safety of the

demonstration for cask design, shipping hazards, transfer operations, fission product containment, and accident causation.

A-6 Relevance: 1

U.S. Atomic Energy Commission

ENVIRONMENTAL STATEMENT: RADIOACTIVE WASTE REPOSITORY, LYONS, KANSAS

Washington, D.C., June 1971.

This environmental impact statement describes potential environmental affects that would have resulted from a proposed repository for solid radioactive wastes in the underground bedded salt formations near Lyons, Kansas. The proposed repository would have utilized an existing, 200-acre nonproducing salt mine for emplacement of alpha wastes; an adjacent 800-acre of the salt bed would have been mined for the emplacement of high-level wastes; and surface facilities would have been constructed for the receipt and handling of waste packages. The statement describes the environmental impact, thermal impact, geophysical effects, ecological effects, sociological effects, transportation safety, and monitoring programs.

A-7 Relevance: 1

Gera, Ferruccio and D. G. Jacobs

CONSIDERATIONS IN THE LONG-TERM MANAGEMENT OF HIGH-LEVEL RADIOACTIVE WASTES

Oak Ridge National Laboratories, Oak Ridge, Tennessee, ORNL-4762, February 1972.

The high-level radioactive wastes from reprocessing spent fuel elements in the nuclear power industry require a waste management scheme. Long-lived transuranics require the assurance of waste containment for hundreds of thousands of years that only deep, stable geologic formations offer. The amounts of radioactive wastes accumulated to 2020 are projected, and important radionuclides in the waste are compared, based on their potential hazards to mankind over their lifetimes. Based on these considerations, the most prudent scheme of management of these wastes involves solidification with final disposal into a deep geologic formation, with further handling minimized. The characteristics of products from suggested solidification processes are compared. The conditions of interim storage of high-level solid waste are reviewed, and possible mechanisms of activity release from the storage facility are considered. To ensure prolonged safe containment, the rate of several geologic processes that can affect the disposal formation must be estimated. Possible mechanisms of activity release from the geologic formation are described.

A-8 Relevance: 1

Office of Radiation Programs

PROCEEDINGS: A WORKSHOP ON ISSUES PERTINENT TO THE DEVELOPMENT OF ENVIRONMENTAL PROTECTION CRITERIA FOR RADIOACTIVE WASTES

U.S. Environmental Protection Agency, Washington, D.C., ORP/CSD-77-1, February 3-5, 1977.

Working Group 2 of this workshop addressed risk considerations of radioactive waste management. Four papers were presented on the subject, in addition to a statement of issues and objectives and a summary and conclusions of the working group. The four papers are:

- Control of Radioactive Waste: Issues, Problems, and Questions--Terry Lash
- Long Term Waste Management: Criteria or Standards?--Gene Kochlin
- The Legacy Questions--J. W. Healy
- The Legacy of Radioactive Wastes: Infinity and Zero--G. Hoyt Whipple.

The stated issues and objectives identified three major areas fundamental to the question of risk from the management of radioactive wastes:

1. Methodology for identification and assessment of risk.
2. Risk associated with the management of radioactive wastes.
3. Incorporation of risk and risk acceptance in decision making.

A-9 Relevance: 1

Office of Radiation Programs

PROCEEDINGS: A WORKSHOP ON POLICY AND TECHNICAL ISSUES PERTINENT TO THE DEVELOPMENT OF ENVIRONMENTAL PROTECTION CRITERIA FOR RADIOACTIVE WASTES

U.S. Environmental Protection Agency, held in Albuquerque, New Mexico, April 12-14, 1977.

EPA is developing environmental protection criteria for radioactive waste. This is the second workshop held by EPA to address public policy issues relevant to radioactive waste storage. Topic 3 of this workshop was entitled Public Acceptability of the Risk Associated with Radioactive Waste; it contains six papers, plus the working group summary and conclusions. The six papers are:

- Public Acceptability of the Risk Associated with Radioactive Waste: A Statement of Issues and Objectives
- Radioactive Waste and Public Acceptance--Bill Perkins
- Enhancing Public Acceptability--Emilio E. Varanini, III
- Public Acceptance of Radioactive Waste Disposal: An Archaeologist's Perspective--William L. Rathje
- Public Acceptability of Risk from Radioactive Waste--Burns W. Roper
- Public Acceptability of Risk of Radioactive Waste Disposal--William H. Millerd.

A-10 Relevance: 1

Weisbecker, L. W., L. L. Gerchman, B. R. Holt, S. J. Mara, S. L. McHugh, H. M. Taylor, J. E. Van Zandt, and D. R. Zoellner

PROPOSED OUTLINE OF SAFETY ANALYSIS REPORT FOR FACILITIES FOR GEOLOGIC ISOLATION OF RADIOACTIVE WASTES

Stanford Research Institute, Menlo Park, California, Y/OWI/SUB-77/22320, June 1977.

The NRC generally requires that an SAR be prepared by the applicant for a license for a major facility that is part of the nuclear fuel cycle. ERDA also requires SARs to be prepared for all new nuclear facilities constructed under its programs. Neither ERDA nor NRC has developed guidelines for the contents of SARs for federal waste repositories. This outline therefore provides guidance in planning SAR contents for federal repositories. Site characteristics, principal design criteria, facility design, operational systems and components, long-term waste isolation, conduct of operations, technical specifications, and quality assurance are discussed.

A-11 Relevance: 1

Logan, S. E.

A TECHNOLOGY ASSESSMENT METHODOLOGY APPLIED TO HIGH-LEVEL RADIOACTIVE WASTE MANAGEMENT

Ph.D. thesis, University of New Mexico, Albuquerque, New Mexico, 1974.

A radioactive waste management system model (AMRAW) is developed to evaluate damage charges for potential environmental and population exposure damages. Parallel branches of the model represent the management phases of residual treatment, repository operations, and long-term storage at the repository. Each branch includes fault tree analysis for determining release probabilities and magnitudes, an environmental model for calculating transport of radionuclides through environmental pathways to man-dose and other environmental effects, and an economic model for evaluating associated damage charges. Studying the application of the model to three disposal concepts, the thesis concludes that the complete sequence of high-level radioactive waste management operations can be described by a simple systems model.

A-12 Relevance: 1

Oak Ridge National Laboratory

PRELIMINARY SAFETY ANALYSIS REPORT, FEDERAL REPOSITORY, KANSAS

Union Carbide Corporation, Oak Ridge, Tennessee, ORNL/TM-5764.
1972.

This PSAR is based on the conceptual design of a proposed federal repository, that was to be located in Lyons, Kansas, to provide facilities for receiving, handling, and depositing radioactive solid wastes in bedded salt. The report includes impacts of the proposed action, a safety analysis, a management plan, and a decommissioning plan.

A-13 Relevance: 1

U.S. Atomic Energy Commission

ENVIRONMENTAL STATEMENT: MANAGEMENT OF COMMERCIAL HIGH-LEVEL AND
TRANSURANIUM-CONTAMINATED RADIOACTIVE WASTES

Washington, D.C., WASH-1539, September 1974.

This environmental statement dealt with the AEC's program to develop repositories for storing or disposing of commercial high-level radioactive waste and handling commercial transuranium-contaminated waste. The environmental consequences of developing an engineered surface storage facility for retrievable storage of commercial high-level waste is assessed; geological formations and sites are evaluated for a repository for permanent disposal; and retrievable storage for commercial transuranium-contaminated waste, pending availability of permanent disposal, is considered.

A-14 Relevance: 1

Denham, D. H., D. A. Baker, J. K. Soldat, and J. P. Corley

RADIOLOGICAL EVALUATIONS FOR ADVANCED WASTE MANAGEMENT STUDIES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1764,
September 1973.

This report describes the methods, assumptions, and parameters that apply to evaluating radiation doses for waste management studies. A comprehensive dose computational model, developed and used for other AEC studies, has been adopted to improve flexibility and to assist in evaluating alternative means for disposal of high-level waste. Typical input terms for normal use include source terms and dilution factors.

Outputs include individual pathway doses and total doses to the maximum numbers of urban and rural populations. Whole body doses, plus doses to other critical organs, are obtained, as well as the fractional dose contributions of individual nuclides. Doses for 1 year or total doses for 50 years of exposure are available.

A-15 Relevance: 2

Oak Ridge National Laboratory

PROCEEDINGS OF THE INTERNATIONAL SYMPOSIUM OF THE MANAGEMENT OF WASTES FOR THE LWR FUEL CYCLE

Symposium sponsored by ERDA at Denver, Colorado, CONF-760701, July 11-16, 1976.

The symposium covered topics that ranged from policy issues to technology. Presentations were made by national and international speakers involved in all aspects of waste management. They included government and agency officials; laboratory managers, directors, and researchers; and industrial representatives. Many speakers advocated pragmatic action on programs for the management of commercial nuclear wastes to complete the LWR fuel cycle. Papers were presented under the following general topics: National Program and Objectives, Governmental Responsibilities and the Public's Interest, The Nature of Wastes and the Options for their Management, High-Level Wastes, Non-High-Level Solid and Liquid Wastes, Gaseous Wastes and Wastes from Decommissioning Nuclear Facilities, Packaging and Transport, Pathways and Exposure Potentials, Isolation in Geologic Formations, Other Waste Management Considerations. An open discussion was also held.

A-16 Relevance: 2

U.S. Energy Research and Development Administration

ALTERNATIVES FOR MANAGING WASTES FROM REACTORS AND POST-FISSION OPERATIONS IN THE LWR FUEL CYCLE

Report Coordinated by Battelle Pacific Northwest Laboratories, Richland, Washington, ERDA-76-43, UC-70, May 1976.

This report, published in five volumes, describes technical alternatives for managing wastes from the back end of the commercial LWR fuel cycle. It describes waste types, alternative technologies that can be used to manage the wastes, and the availability of those technologies. The report provides a comprehensive digest of the technical information required for future decisions, assessments, and environmental impact statements.

A-17 Relevance: 2

Schneider, K. J. and A. M. Platt (Editors)

HIGH-LEVEL RADIOACTIVE WASTE MANAGEMENT ALTERNATIVES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1900, May 1974.

This report is an overview of potential alternative methods for long-term management of high-level radioactive waste. The study's four volumes include a compilation of information relevant to technical feasibility, safety, cost, environmental consideration, policy conflicts, public responses, and research and development needs for (1) disposal in terrestrial locations, (2) disposal in space, and (3) elimination by transmutation. Disposal of waste in bedded salt deposits was studied in other AEC programs, and the concept is included in the discussion of geological disposal techniques.

A-18 Relevance: 2

Murphy, E. S. and W. K. Winegardner

SAFETY ANALYSIS OF THE TRANSPORTATION OF HIGH-LEVEL RADIOACTIVE WASTE

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-SA-5314, 1975.

This paper describes a current program to assess the risk of transporting solidified high-level waste from a fuel reprocessing plant to a retrievable storage facility at a federal repository. The methodology to accomplish transportation risk analysis goals uses fault trees to identify failure events and to specify combinations of events that could breach the shipping containers and release radioactive material to the environment. Progress in quantifying transportation risk is reported. Events that can produce container failure during shipment include (1) railroad accidents, (2) natural disasters, (3) physical or chemical reactions induced by the radioactive waste, and (4) monitoring and package closure errors. Preliminary data indicate that railroad accidents present the highest risk. Study contributions include procedures for screening failure sequences to determine those that dominate the risk, methods for quantifying the effects of probabilistic failure events, and computer code development.

A-19 Relevance: 2

Chezem, C. G., M. S. Krick, and W. Meyer

RECOMMENDED APPLICATIONS OF NUCLEAR SAFEGUARDS TO THE STORAGE OF MATERIALS IN THE PROPOSED NATIONAL NUCLEAR WASTE REPOSITORY, LYONS, KANSAS

Kansas State University, Manhattan, Kansas, June 1971.

This paper discusses an authentication and evaluation procedure for a nuclear waste safeguards program. The accounting of materials contained in low-level waste at the disposal site was proposed to proceed on a largely automated, assembly-line basis as follows: Incoming containers would undergo serial number, tag, and tamper-indication verification. Additional checks, such as a measurement of total container weight, could be imposed at this point. The waste containers would then proceed through several physically separate assay stages for the determination or estimation of, for example, (1) the possibility that they might contain massive fissile material, (2) total fissile material content, and (3) total plutonium content. Containers passing all inspections would be forwarded directly to a burial location. Containers failing an inspection would be recycled for a detailed assay and possibly repackaging or return to shipper. All data collected at the disposal site would be permanently stored and compared with corresponding shipper's data. The final decision on whether to accept a particular container for disposal would rest with a supervisor of safeguards and materials management.

A-20 Relevance: 2

Bishop, W. P, and J. Miraghi, Jr.

ENVIRONMENTAL SURVEY OF THE REPROCESSING AND WASTE MANAGEMENT PORTIONS OF THE LWR FUEL CYCLE, NUREG-0116 (Supp. 1 to WASH-1248)

Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D.C., October 1976.

This supplement deals with the reprocessing and waste management portions of the nuclear fuel cycle for uranium-fueled reactors. The scope of the report is limited to the illumination of fuel reprocessing and waste management activities, and examination of the environmental impacts caused by these activities on a per-reactor basis. One realistic reprocessing and waste management system is selected and treated in enough depth to illuminate the issues involved, the technology available, and their relationship to the nuclear fuel cycle in general and to its environmental impacts.

A-21 Relevance 2

Smith, T. H. and W. K. Winegardner

RISK ANALYSIS OF NUCLEAR WASTE MANAGEMENT SYSTEMS

Power Engineering, 79(2):35-37, February 1975.

This article describes a quantitative risk analysis study conducted by Battelle Pacific Northwest Laboratories for the safety of nuclear waste management systems. The analysis includes assessment of technical feasibility, R&D needs, costs, environmental impacts, and both the calculated and the publicly perceived safety. The risk assessment considers both the consequences of postulated releases of radioactive materials and estimated probabilities of such events.

A-22 Relevance: 2

McGrath, P. E.

RADIOACTIVE WASTE MANAGEMENT: POTENTIALS AND HAZARDS FROM A RISK POINT OF VIEW

Gesellschaft fur Kernforschung, Karlsruhe, Germany, EURFNR-1204, June 1974.

The problems of radioactive waste management are addressed in this paper. The magnitude of the problem identified primarily concerns the Federal Republic of Germany. Predictions are included of the characteristics of the wastes from the various activities of the nuclear fuel cycle, and their accumulation as a function of time until 2010. The methods for evaluating risk are reviewed, as well as possible extensions of the methods needed to evaluate risk from alternative radioactive waste management strategies. For input to risk evaluation a hazard index for radioactive isotopes is established. Proposed waste management strategies are reviewed and their potentials, in terms of risk reduction, are identified. An attempt is made to place the segments of the waste management strategies that contribute to risk in perspective.

A-23 Relevance: 2

Cohen, B. L.

ENVIRONMENTAL IMPACTS OF HIGH LEVEL RADIOACTIVE WASTE DISPOSAL

IEEE Transactions on Nuclear Sciences, 23(1):56-59, February 1976.

The potential hazards of the high level waste produced in 1 year by all nuclear power in the United States are calculated as a function of time for direct gamma radiation, inhalation, and ingestion. Scales are given for consequences of the worst credible handling. The probability for radioactivity from buried waste to be released into the environment by several

pathways is estimated. Some interesting comparisons are given for lethal effects produced by inhalation or ingestion of other materials found in the environment.

A-24 Relevance: 2

Lohse, G. E.

SAFETY ANALYSIS REPORT FOR THE ICPP HIGH-LEVEL SOLID RADIOACTIVE WASTE STORAGE FACILITIES

Allied Chemical Corporation, Idaho Falls, Idaho, UC-70, April 1972.

At the Idaho Chemical Processing Plant, radioactive solid wastes resulting from fluidized-bed calcination of extraction-column raffinates and nuclear facilities decontamination solutions are stored in stainless steel bins in buried concrete vaults. The report's analysis of the safety of the storage facilities indicates that they can withstand natural occurrences such as earthquakes, tornadoes, high winds, or floods without serious damage or spread of radioactive materials to the environment.

A-25 Relevance: 2

Bingham, G. E. and T. K. Evans

FINAL SAFETY ANALYSIS REPORT FOR THE IRRADIATED FUELS STORAGE FACILITY

Allied Chemical Corporation, Idaho Falls, Idaho, ICP-1052, January 1976.

A fuel storage facility has been constructed at the Idaho Chemical Processing Plant (ICPP) to provide safe storage for spent fuel from two commercial high-temperature gas-cooled reactors--Fort St. Vrain and Peach Bottom--and from the Rover nuclear rocket program. In this report the potential hazards associated with the storage at the facility are studied. The study indicates that the facility can withstand all credible combinations of internal accidents and pertinent natural forces--including design basis natural phenomena of a 10,000 year flood, a 175-mph tornado, or an earthquake having a bedrock acceleration of 0.33 g and an amplification factor of 1.3--without a loss of integrity or a significant release of radioactive materials. The results and methodology of this study pertain specifically to the ICPP facility and, for the most part, cannot be transferred to a risk analysis for the underground storage of nuclear waste.

A-26 Relevance: 2

de Marsily, G., E. Ledoux, A. Barbreau, and J. Margat

NUCLEAR WASTE DISPOSAL: CAN THE GEOLOGIST GUARANTEE ISOLATION?

Science, 197(4303):519-527, August 1977.

This article discusses the confining power of deep geologic formations over very long periods for highly toxic radionuclides with long half-lives (principally, ^{129}I , ^{237}Ne , and ^{239}Pu). Three barriers provided to stop the return toward the human environment are evaluated: (1) the material in which the waste is included--glass in this study, (2) the canisters containing the waste, and (3) the geologic system. In examining theoretical cases, it was found that if the integrity of the glass material is guaranteed indefinitely, the rate of waste release, which depends solely on the diffusion of the elements in the glass, is very slow. If the integrity of the glass matrix cannot be guaranteed, highly adsorbed elements such as Pu can be reclaimed in the geological environment, depending on the ion exchange of the surroundings for a radionuclide. If no sorption phenomena occur, the radioactivity will be released into the environment if a flow of water, even small, reaches the wastes.

A-27 Relevance: 2

Litchfield, J. W., J. V. Hansen, and L. C. Beck

A DECISION MODEL INCORPORATING UTILITY THEORY AND MEASURES OF SOCIAL VALUES APPLIED TO NUCLEAR WASTE MANAGEMENT

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-B-424, July 1975.

The goal of this research was to provide a decision analysis tool that could supply information useful in indicating future research needs for long-term storage of nuclear wastes. To make a choice based on technical estimates of the costs, short-term safety, long-term safety, and accident detection and recovery requires estimating the relative importance of each of these factors or attributes. These estimates primarily involve social values and are therefore characterized by subjective interpretations. Thus, various public groups were sampled to determine how the relative importance of each of the factors differed from group to group. These estimates of importance weights were combined in a decision analysis model with estimates of the degree to which each alternative concept achieves each of the criteria. The model then integrated the data that indicated the preferences and concerns of the public and the technical areas within each concept that needed further research.

A-28 Relevance: 3

Wolf, J.

ULTIMATE STORAGE OF SPENT FUEL ELEMENTS FROM THE AVR EXPERIMENTAL
NUCLEAR POWER PLANT IN THE ASSE SALT MINE

Gesellschaft mit beschränkter Haftung, Institute for Chemical Technology,
GERHTR-147, February 1975.

This report is intended to serve as the basis for licensing procedures, both in respect to the transportation and storage of nuclear wastes for the AVR reactor. Included are safety assessments for handling and decommissioning. The report concludes that the direct storage of the fuel elements in the salt mine at Asse is the recommended solution from the viewpoint of both safety and cost.

A-29 Relevance: 3

U.S. Congress

RADIOACTIVE WASTE MANAGEMENT

Hearings Before the Subcommittee on Environment and Safety of the Joint
Committee on Atomic Energy, Washington, D.C., May 10, 11, and 12, 1976.

These hearings assessed the policies, plans, and programs of the executive branch and the NRC for the safe storage and disposal of radioactive wastes produced in the commercial nuclear fuel cycle. Witnesses included representatives of ERDA, FEA, NAS, NRC, USGS, Battelle Memorial Institute, and Allied General Nuclear Services. Interesting discussions of the nuclear waste storage problem took place, but little information of direct use in a nuclear waste risk or safety analysis was provided.

A-30 Relevance: 3

U.S. House of Representatives

LOW-LEVEL RADIOACTIVE WASTE DISPOSAL

Hearings Before a Subcommittee of the Committee on Government Operations,
Washington, D.C., February 23, March 12, and April 6, 1976.

These hearings concerned U.S. intentions for dealing with the problem of shallow land disposal of low-level radioactive wastes, especially the role of federal agencies in that effort. Witnesses included representatives of GAO, EPA, USGS, NCR, ERDA, the Nuclear Engineering Co., and several states. The most useful information in this hearing for a risk assessment of a nuclear waste storage facility concerns the migration of radioactive material in the environment.

A-31 Relevance: 3

U.S. Congress

STORAGE AND DISPOSAL OF RADIOACTIVE WASTE

Hearings Before the Joint Committee on Atomic Energy, Washington, D.C.,
November 19, 1975.

This hearing assessed the policies, plans, and programs of the executive branch for the safe storage and disposal of radioactive wastes produced in the commercial nuclear fuel cycle. Representatives of ERDA, NRC, and EPA testified. Their testimony was oriented towards waste management plans and contains little information directly applicable to risk studies of nuclear waste storage.

A-32 Relevance: 3

U.S. House of Representatives

NUCLEAR WASTE DISPOSAL IN MICHIGAN

Oversight Hearings Before the Subcommittee on Energy and the Environment of the Committee on Interior and Insular Affairs, Washington, D.C.,
July 6, 1976.

At this hearing, ERDA plans regarding the possible locations of a radioactive waste storage site in Michigan were discussed. These hearings provide interesting testimony regarding public concern over the site selection of nuclear wastes.

A-33 Relevance: 3

U.S. House of Representatives

RADIOACTIVE WASTE DISPOSAL PROBLEMS

Hearing Before a Subcommittee of the Committee on Government Operations, Washington, D.C., September 17, 1976.

The testimony focused on two aspects of the waste disposal problem: (1) the environmental effects of abandoned ocean radioactive waste disposal sites and (2) the implications of a decision by the U.S. Court of Appeals, District of Columbia, requiring the NRC to perform an in-depth study of the environmental and health effects of various types of nuclear wastes before powerplants licensing could continue. Representatives of the Natural Resources Defense Council, the State of California Energy Resources Conservation and Development Commission, the California State Legislature Subcommittee on Energy, EPA, and NRC testified.

A-34 Relevance: 3

Inoue, Y. and S. Morisawa

ON THE SELECTION OF A GROUND DISPOSAL SITE FOR RADIOACTIVE WASTES:
AN APPROACH TO ITS SAFETY EVALUATION

Health Physics, 26:53-63, January 1974.

The disposal of radioactive solids or solidified wastes in the ground is not allowed in Japan, mainly because of the difficulties in estimating the migration of escaped radionuclides and their effect on the human body (internal dose). This report quantifies the action of radionuclides in an environment and estimates the dose rate of internal irradiation. Ten radionuclides contained in radioactive wastes and three paths of flow (i.e., drinking water, sea foods, and vegetables) by which they have escaped into the ground to migrate in an environment are discussed. It is concluded that (1) the most dangerous nuclides in this method of disposal are ^{90}Sr and $^{110\text{m}}\text{Ag}$, (2) the largest internal dose is absorbed through the intake of vegetables, (3) the method of ground disposal of radioactive wastes appears to be safe and promising because of the low internal dose estimated, and (4) the method of estimation discussed in this report is also applicable to other problems of the same type such as the sanitary land-fill of industrial wastes.

A-35 Relevance: 3

Zima, G. E.

A BRIEF ASSESSMENT OF SOME TECHNICAL AND RADIOLOGICAL HAZARD FACTORS
AFFECTING CLAD WASTE MANAGEMENT

Battelle-Pacific Northwest Laboratories, Richland, Washington, Report BNWL-2104, UC-70, 30 July 1976.

Various technical and hazard indices are compared for the light water, enriched uranium fueled, reactor to develop some measure of the importance of the high level waste (HLW) and clad waste (CW) streams within the context of a reasonable nuclear power scenario. Six indices--uncompacted volume, compacted volume, aggregate radioactivity, radiation hazard-air, radiation hazard-water, and thermal power--are estimated for the two waste streams for various points in time, ranging to 100,000 years. The ratio of the CW value to the HLW value is then calculated and compared. This provides a reasonably good and unambiguous measure of the relative importance of these waste streams. The statement that HLW is more hazardous than CW is well-supported by the results. The quantification of this statement into economic and public hazard terms poses substantial analytical problems at this time.

A-36 Relevance: 3

NRC Task Force

NRC TASK FORCE REPORT ON REVIEW OF THE FEDERAL/STATE PROGRAM FOR
REGULATION OF COMMERCIAL LOW-LEVEL RADIOACTIVE WASTE BURIAL GROUNDS,
NUREG-0219

Office of Nuclear Material Safety and Safeguards and Office of State
Programs, U.S. Nuclear Regulatory Commission, Washington, D.C., 1977.

The present system for low-level radioactive waste management lacks national organization and direction. The states have adequately protected the public health and safety, and no compelling health or safety reason exists for reasserting federal control. However, the states do not have the resources to provide necessary overall leadership or organization. The states' vested interest in protecting the health and safety of their citizens and in land use decisions can be satisfied by their participation in the site selection process and their monitoring of day-to-day operations. This document states that the development and implementation of a national waste management plan, which includes adequate capacity without site proliferation, can be more readily achieved if the NRC assumes regulatory control (with state participation). The federal government should assume responsibility for perpetual care of the sites through federal landownership.

A-37 Relevance: 3

National Research Council

THE SHALLOW LAND BURIAL OF LOW-LEVEL RADIOACTIVELY CONTAMINATED SOLID
WASTE

National Academy of Sciences, Washington, D.C., 1976.

This report presents the results of a study of the conditions, practices, and problems involved in the near-surface ground burial of solid waste contaminated with low levels of radioactive materials. Two of the chapters, "Problems of Potential Hazards from Waste Management Facilities Today" and "Hydrogeological Research," provide information that might be useful in assessing the underground storage of nuclear waste.

A-38 Relevance: 2.

Unruh, C. M.

A PRELIMINARY ANALYSIS OF NEAR SURFACE STORAGE OF RADIOACTIVE WASTE
AS SALT CAKES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1194, UC-41, January 1970.

This report examined the hazards of the in-tank-solidification (ITS) waste storage concept for the Hanford facility. Among the factors considered were weather, earth stability, ground-water, external explosions, and plant and animal activities. The report concluded that no natural hazards leading to the development of unsafe conditions were discovered and that the ITS concept offered improved long-term waste storage when compared with liquid storage-methods.

A-39 Relevance: 3

Logan, S. E.

WORKSHOP ON GEOLOGIC REQUIREMENTS FOR RADIOACTIVE WASTE MANAGEMENT
ASSESSMENT MODELS

Workshop held at Santa Fe, New Mexico, June 28-July 1, 1975, The University of New Mexico, Albuquerque, New Mexico. Y/OWI/SUB-76/81726, September 1976.

This workshop was held to facilitate exchange of information among persons (1) investigating geologic formations to determine their suitability for various emplacement techniques and (2) developing models for ERDA, NRC, and EPA to assess the long-term safety of terminal storage facilities. Presentations covered topics of: current geologic studies, methods for risk analysis, assessment models being developed, and descriptions of field observations of radionuclide migration.

A-40 Relevance: 3

Toffer, H.

FUEL STORAGE BASIN: CRITICALITY SAFETY ANALYSIS REPORT AND TECHNICAL
BASIS

Douglas United Nuclear, Inc., Richland, Washington, DUN-7824, December 1971.

The criticality discussed in this report assesses the feasibility of storing a full nuclear reactor fuel discharge in a storage basin with fully loaded cubicles. This would require storage on top of full concrete cubicles in the basin. Based on criticality control calculations that draw on Monte Carlo simulation, neutron transport theory, and neutron diffusion theory computer codes, it is estimated that basket loads of four tubes of Mark IV or Mark IC fuel or two tubes of Mark IVAA or Mark IA can be safely stored on top of fully loaded storage cubicles.

A-41 Relevance: 3

Lapp, Ralph E.

THE NUCLEAR CONTROVERSY

Fact Systems, A Public Education Division of Reddy Kilowatt, Inc.
537 Steamboat Road, Greenwich, Connecticut, 1974.

This book attempts to analyze the nuclear controversy in terms that the layman can understand. The book first presents a simple discussion of nuclear power technology and then addresses controversial issues. The issues discussed are:

- Adequacy of uranium resources as fuel for the future
- Routine releases from nuclear power plants
- Abnormal occurrences in reactor operations
- Emergency core cooling and reactor safety
- Major nuclear accidents
- Transportation risks
- Nuclear safeguards--the plutonium problem
- Radioactive waste disposal.

The final chapter attempts to put the issues in prospective. The author notes that the nuclear controversy has highlighted areas that needed attention and that responsible criticism should continue. He concludes that nuclear power presents risks but that they are small and are well worth taking, particularly in the context of existing energy and environmental constraints.

Directorate of Licensing, Fuels and Materials

ENVIRONMENTAL SURVEY OF THE NUCLEAR FUEL CYCLE

U.S. Atomic Energy Commission, Washington, D.C., November 1972.

This survey assessed the environmental considerations related to the currently predominant nuclear fuel cycle for UO_2 -fueled LWRs. In the United States, about 99% of the electric power generated from nuclear fuel incorporates this fuel cycle and most of the plants under consideration for construction permits or operating licenses will use this fuel cycle. In addition, estimates indicated that LWRs will predominate through most of the present decade. Alternative nuclear fuel cycles involving plutonium recycle in the present generation of LWRs will predominate through most of the present decade. Alternative nuclear fuel cycles involving plutonium recycle in the present generation of LWR power reactors and the fuel cycles for gas-cooled and fast breeder reactors will be considered in future documents. The specific components comprising the LWR supporting fuel cycle include the following:

- (a) Mining uranium ore.
- (b) Milling and refining ore to produce concentrated U_3O_8 .
- (c) Production of UF_6 from uranium concentrates to provide feed for isotopic enrichment.
- (d) Isotopic enrichment of UF_6 to attain reactor enrichment requirements using the gasoline diffusion process.
- (e) Fabrication of nuclear reactor fuel, including: converting UF_6 to UO_2 , pelletizing, encapsulating in rods and assembling fuel elements.
- (f) Reprocessing irradiated fuel and converting uranium to UF_6 for recycle through the gaseous diffusion plant for re-enrichment.
- (g) Radioactive waste management of high-level and low-level wastes, including their long-term storage.
- (h) Transportation activities associated with moving materials to and from each of these operations.

A-43 Relevance: 3

Office of Radiation Programs

ENVIRONMENTAL STATEMENT FOR A PROPOSED RULE-MAKING ACTION CONCERNING ENVIRONMENTAL RADIATION PROTECTION REQUIREMENTS FOR NORMAL OPERATIONS OF ACTIVITIES IN THE URANIUM FUEL CYCLE

U.S. Environmental Protection Agency, Washington, D.C., May 1975.

EPA proposed standards to limit radiation doses to the general public and quantities of long-lived radioactive materials in the environment. These doses and quantities are attributable to planned releases from operations that contribute to the generation of electrical power through the uranium fuel cycle. These standards are proposed to apply to all operations within the fuel cycle, including the operations of milling, conversion, enrichment, fuel fabrication, LWR operation, fuel reprocessing, and transportation of radioactive materials in connection with any of these operations.

A-44 Relevance: 3

Bell, M. J. and R. S. Dillon

THE LONG-TERM HAZARD OF RADIOACTIVE WASTES PRODUCED BY THE ENRICHED URANIUM, $\text{Pu-}^{238}\text{U}$, and ^{233}U -Th FUEL CYCLES

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-TM-3548, November 1971.

Long-term hazards of "high-level" and "alpha" radioactive wastes were evaluated. These wastes are generated by irradiating three fuels representative of those that will be used to generate electrical power in the next several decades. In this evaluation the composition and radioactivity of the wastes generated by typical LWR, LMFBR, and molten-salt breeder reactors using the enriched uranium, $\text{Pu-}^{238}\text{U}$, and ^{233}U -Th fuel cycles, respectively, have been computed for as many as 30 million years after discharge. The volumes of water necessary to dilute these high-level wastes to the radiation concentration guides (RCG) for ingestion in unrestricted areas have been computed as a function of waste age. The volumes required were similar when evaluated at the same age and exposure. The water necessary to dilute any of the three wastes aged 1000 years, as well as the associated salt in the proposed federal repository, to the RCG for unrestricted uses is less than that required to dilute the same amount of uranium ore tailings to the RCG. The high-level waste deposited in the federal repository will, when averaged over the total mass of the repository, result in an alpha activity of less than $10 \mu\text{Ci/kg}$ at 10,000 years after burial. The hazard from waste contaminated to $10 \mu\text{Ci/kg}$ (the upper limit assumed for surface burial) of initial parent alpha activity was also calculated as a function of time, and the time of maximum relative

hazard was determined. Transuranium or alpha wastes contaminated to this level will present a maximum ingestion hazard similar to naturally occurring uranium ores.

A-45 Relevance: 3

American Nuclear Society Transactions
1974 WINTER MEETING--WASHINGTON, D. C.
Volume 19, Hinsdale, Illinois, 1974.

This document abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- A New Approach for the Efficient Probabilistic Risk Analysis of Nuclear Power Plants, K. E. El-Sheikh, p. 232.
- A Probabilistic-Risk Modeling of Nuclear Radwaste Facilities, P. H. Lehman and A. A. El-Bassioni, p. 236.

A-46 Relevance: 3

American Nuclear Society Transactions
1975 ANNUAL MEETING--NEW ORLEANS, LOUISIANA
Volume 21, Hinsdale, Illinois, June 8-13, 1975.

This document abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- Techniques for Reliability and Availability Estimates, R. C. Erdmann and E. T. Rumble, p. 208.
- The Use of Empirical Bayes and Distribution Methods in Assessing Probabilities and Risks, W. E. Vesely, p. 209.
- A Reliability Assessment Method Including Human Factors, Donald E. Emon and Noel J. Becar, p. 211.

- A Dependent Event Model for Fault Trees, F. L. Levering, Jr., E. T. Rumble, and R. C. Erdmann, p. 212.
- Shielding Analysis of the Retrievable Surface Storage Facility, M. G. Zimmerman, p. 263.
- Inhibition of Nitrate Stress Corrosion Cracking Mild Steel in Nuclear Process Wastes, J. A. Donovan, p. 266.
- A Generalized Methodology for the Probabilistic Assessment of Aircraft Crash on Nuclear Power Plants, P. J. Godbout, J. L. Houle, M. Moore, and A. Braise, p. 349.
- Hazards to Nuclear Stations from Explosive Gas Mixtures--A Methodology, R. C. Iotti, D. R. de Boisblanc, R. Wiloy, and W. J. Krotuik, p. 350.
- Design Basis Velocities of Tornado-Generated Missiles, R. C. Iotti, p. 351.

A-47 Relevance: 3

American Nuclear Society Transactions

1975 WINTER MEETING--SAN FRANCISCO, CALIFORNIA

Volume 22, Hinsdale, Illinois, November 16-21, 1975.

This document contains abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- Decommissioning in the Mature Nuclear Fuel Reprocessing Industry, F. H. Anderson and Cyril M. Slansky, p. 350.
- How Should WASH-1400 Results and Methodology Be Used?, Eugene N. Cramer, p. 360.
- Hazards to Nuclear Plants from Off-Site Release of Toxic Vapors, Karl Hornyik, p. 363.
- Information Theory and Nuclear Risk, R. A. Bari, p. 364.
- Thermal Analysis of a Fuel Cladding Repository Pilot Plant in Salt, H. C. Claiborne, p. 352.

- The Chemistry and Physical Mechanics of Nuclear Wastes in Rocks, W. C. Luth, R. N. Anderson, and R. J. Johns, p. 354.
- Strengths and Limitations of Probabilistic Risk Assessment in the Regulatory Process, W. C. Gangloff, p. 455.
- State-of-the-Art in Probabilistic Risk Assessment, R. C. Erdmann and E. T. Rumble, p. 457.
- On the Automatic Construction of Fault Trees, S. L. Salem, G. E. Apostolakis, and D. Okrent, p. 475.
- On the Reliability of Redundant Systems, G. E. Apostokalis, p. 477.
- Site Population Evaluation, C. S. Kang, and R. P. Sie, p. 511.

A-48 Relevance: 3

American Nuclear Society Transactions

1976 ANNUAL MEETING--TORONTO, CANADA

Volume 23, Hinsdale, Illinois, June 14-18, 1976.

This document abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- A Pragmatic View of Risk Assessment and Reliability Engineering, W. E. Vesely and M. C. Cullingford, p. 68.
- Probabilistic Engineering and Risk Evaluation at the Idaho National Engineering Laboratory, E. P. Eales, F. J. Balkovetz, and R. R. Stiger, p. 68.
- Risk Assessment and Reliability Engineering, M. E. Lapidés and G. S. Lellouche, p. 69.
- Broadening the Application of Risk and Reliability Technology, B. John Garrick, p. 70.

A-49 Relevance: 3

American Nuclear Society Transactions

1976 WINTER MEETING--WASHINGTON, D.C.

Volume 24, Hinsdale, Illinois, November 14-19, 1976.

This document abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- New Concepts in Understanding Earthquake Occurrence in the Eastern United States, Joseph A. Fischer, p.88.
- Prediction of Stress Corrosion of Carbon Steel by Nuclear-Process Liquid Waste, R. S. Ondrejcin, p. 241.
- A New Methodology for the Automatic Construction of Fault Trees, S. L. Salcm, G. E. Apostokalis, and D. Okrent, p. 321.
- Use of Three-Valued Logic for Describing Reliability of Safety Systems, A. Banfi, S. Garribba, P. Mussio, F. Naldi, and G. Volta, p. 326.
- Quantitative Risk Analysis: The Promised But Not the Sacred, W. Vinck, G. Van Reijen, and J. Van Caeneghem, p. 334.

A-50 Relevance: 3

American Nuclear Society Transactions

1977 ANNUAL MEETING--NEW YORK, NEW YORK

Volume 26, Hinsdale, Illinois, June 12-16, 1977.

This document abstracts the papers presented at the meeting. The titles of those particularly relevant to risk assessment of long-term nuclear waste isolation follow:

- Benefit-Cost Analysis in the Nuclear Fuel Cycle, Allen V. Kneese, p. 134.
- The Ultimate Trade-Off Problem: Comparative Social Impacts of Electrical Energy Alternatives, Elizabeth Peele, p. 135.
- Leaching of Solidified Nuclear Waste, O. U. Anders and S. J. Altschuler, p. 142.

- The Relative Hazard of Nuclear Wastes and Naturally Occurring Toxic Minerals, K. A. Tonnessen and J. J. Cohen, p. 291.
- Criteria for Assessing Radioactive Waste Management Schemes, F. L. Perret, G. Yadigaroglu, and C. West Churchman, p. 295.
- Oceanic Processes and the Ultimate Disposal of High-Level Radioactive Waste, Charles D. Hollister and Peter B. Rhines, p. 299.
- Automatic Event Tree Construction, James R. Wilson and G. R. Bardick, p. 392.
- A Modular Approach to Fault Tree and Reliability Analysis, J. Olmos and L. Wolf, p. 395.

A-51 Relevance: 3

Finney, B. C., R. E. Blanco, R. C. Dahlman, G. S. Hill, F. G. Kitts, R. E. Moore, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL-REPROCESSING LIGHT-WATER REACTOR FUEL

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/NUREG/TM-6, January 1977.

A cost/benefit study determined the cost and effectiveness of radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from a model nuclear fuel reprocessing plant that processes light-water reactor (LWR) fuels, and the radiological impact (dose commitment) of the released materials on the environment. The study was designed to assist in defining the term "as low as reasonably achievable" in relation to limiting the release of radioactive materials from nuclear facilities. The base-case model plant was representative of current plant technology and had an annual capacity of 1500 metric tons of LWR fuel. Additional radwaste treatment systems were added to the base-case plant in a series of case studies to decrease the amount of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The cost for the added waste treatment operations and the corresponding dose commitments were calculated for each case. In the final analysis, radiological dose is plotted as a function of the annual cost for treatment of the radwastes. The status of the radwaste treatment methods used in the case studies was discussed. Much of the technology used in the advanced cases is in an early stage of development and was not suitable for immediate use. This report is a revision of the original study (ORNL/TM-4901).

A-52 Relevance: 3

Sears, M. B., R. E. Blanco, R. C. Dahlman, G. S. Hill, A. D. Ryon, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE FOR USE IN ESTABLISHING "AS LOW AS PRACTICABLE" GUIDES - MILLING OF URANIUM ORES

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/TM-4903, May 1975.

A cost-benefit study determined the cost and effectiveness of radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from model uranium ore processing mills, and to determine the radiological impact (dose commitment) of the released materials on the environment. The study was designed to assist in defining the term "as low as practicable" for limiting the release of radioactive materials from nuclear facilities. The base-case model mills were representative of those that will process a major fraction of the ore in the next 20 years. Each mill processed 2,000 short tons of ore per day. Additional radwaste treatment techniques were applied to the base-case mill and the waste tailings area in a series of case studies to decrease the amounts of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The cost for the added waste treatment operations and the corresponding dose commitment were calculated for each case. In the final analysis, radiological dose was plotted as a function of the annual cost for treatment of the radwastes. The status of the radwaste treatment methods used in the case studies was discussed. Much of the technology used in the advanced cases will require development and demonstration and is not suitable for immediate use.

A-53 Relevance: 3

Roddy, J. W., R. E. Blanco, B. C. Finney, G. S. Hill, R. E. Moore, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE - CONVERSION OF RECYCLE URANIUM TO UF

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/NUREG/TM-37, August 1977.

A cost/benefit study determined the cost and effectiveness of various radioactive waste (radwaste) treatment systems for decreasing the amount of radioactive materials released from a model recycle uranium conversion and uranium hexafluoride (UF₆) production plant and the radiological impact (dose commitment) of the released radioactive materials on the environment. The study was designed to assist the U.S. Nuclear Regulatory Commission in defining the term "as low as reasonably achievable" as it applies to these nuclear facilities. The base-case model plant was representative of a licensable UF₆ production plant and has an annual capacity of 1500 metric tons of uranium. Additional radwaste treatment systems were added to the base-case plant in a series of case studies to decrease the amount of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The cost for the added waste treatment operations and the corresponding dose commitments was calculated for each case. In the final analysis, radiological dose was plotted as a function of the annual cost for treatment of the radwastes. The status of the radwaste treatment methods used in the case studies was discussed.

A-54 Relevance: 3

Pechin, W. H., R. E. Blanco, R. C. Dahlman, B. C. Finney, R. B. Lindauer, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE FOR USE IN ESTABLISHING "AS LOW AS PRACTICABLE" GUIDES - FABRICATION OF LIGHT-WATER REACTOR FUEL FROM ENRICHED URANIUM DIOXIDE

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/TM-4902, May 1975.

A cost-benefit study determined the cost and effectiveness of radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from a model enriched-uranium, light-water reactor (LWR) fuel fabrication plant, and the radiological impact (dose commitment) of the released materials on the environment. The study was designed to assist in defining the term "as low as practicable" in relation to limiting the release of radioactive materials from nuclear facilities. The base-case model plant was representative of current plant technology and has an annual capacity of 1500 metric tons of LWR fuel. Additional radwaste treatment equipment was added to the base-case plants in a series of case studies to decrease the amount of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The cost for the added waste treatment operations and the corresponding dose commitment were calculated for each case. In the final analysis, radiological dose was plotted as a function of the annual cost for treatment of the radwastes.

The status of the radwaste treatment methods used in the case studies was discussed. Some of the technology used in the advanced cases is in an early stage of development and is not suitable for immediate use.

A-55 Relevance: 3

Davis, W. Jr., R. E. Blanco, B. C. Finney, G. S. Hill, R. E. Moore, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE-REPROCESSING OF HIGH TEMPERATURE GAS-COOLED REACTOR FUEL CONTAINING U-233 AND THORIUM

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNO/NUREG/TM-4, May 1976.

A cost/benefit study determined the cost and effectiveness of various radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from a model high-temperature gas-cooled reactor (HTGR) fuel reprocessing plant and determined the radiological impact (dose commitment) of the released materials on the environment. The study was designed to assist the U.S. Nuclear Regulatory Commission in defining the term "as low as reasonably achievable" as it applies to this nuclear facility. The base-case was representative of conceptual, developing technology of head-end graphite-burning operations, and of extensions of solvent-extraction technology of current designs for light-water-reactor (LWR) fuel reprocessing plants. The model plant had an annual capacity of 450 metric tons of heavy metal (MTHM, when heavy metal is uranium plus thorium), as charged to about fifty 1000-MW(e) HTGRs. Additional radwaste treatment systems were added to the base-case plant in a series of case studies to decrease the amounts of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The capital and annual costs for the added waste treatment operations and the corresponding reductions in dose commitments were calculated for each case. In the final analysis, the cost/benefit of each case, calculated as additional cost of the radwaste system divided by the reduction in dose commitment, was tabulated or the dose commitment was plotted with cost as the variable. The status of each of the radwaste treatment methods used in the case studies was discussed. Much of the technology used in the advanced cases is in an early stage of development and is not suitable for immediate use in detailed designs of an HTGR fuel reprocessing plant.

A-56 . Relevance: 3

Groenier, W. S., R. E. Blanco, R. C. Dahlman, B. C. Finney, A. H. Kibbey, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE FOR USE IN ESTABLISHING "AS LOW AS PRACTICABLE" GUIDES - FABRICATION OF LIGHT-WATER REACTOR FUELS CONTAINING PLUTONIUM

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/TM-4904, May 1975.

A cost-benefit study determined the cost and effectiveness of radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from a model light-water plutonium recycle reactor fuel fabrication plant, and determined the radiological impact (dose commitment) of the released materials on the environment. The study is designed to assist in defining the term "as low as practicable" for limiting the release of radioactive materials from nuclear facilities. The base-case model plant was representative of current plant technology and had an annual capacity of 300 metric tons of LWR (light-water reactor) plutonium recycle fuel. Additional radwaste treatment equipment was added to the base-case plants in a series of case studies to decrease the amounts of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The cost for the added waste treatment operations and the corresponding dose commitment were calculated for each case. In the final analysis, radiological dose is plotted as a function of the annual cost for treatment of the radwastes. The status of the radwaste treatment methods used in the case studies was discussed. Some of the technology used in the advanced cases is in an early stage of development and is not suitable for immediate use.

A-57 Relevance: 3

Roddy, J. W., R. E. Blanco, G. S. Hill, R. E. Moore, R. D. Seagren, and J. P. Witherspoon

CORRELATION OF RADIOACTIVE WASTE TREATMENT COSTS AND THE ENVIRONMENTAL IMPACT OF WASTE EFFLUENTS IN THE NUCLEAR FUEL CYCLE FABRICATION OF HIGH-TEMPERATURE GAS-COOLED REACTOR FUEL CONTAINING URANIUM-233 AND THORIUM

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/NUREG/TM-5, September 1976.

A cost/benefit study determined the cost and effectiveness of various radioactive waste (radwaste) treatment systems for decreasing the release of radioactive materials from model High-Temperature Gas-Cooled (HTGR) fuel fabrication plants and the radiological impact (dose commitment) of the released materials on the environment. The study was designed to assist the U.S. Nuclear Regulatory Commission in defining the term "as low as reasonably achievable" as it applies to those nuclear facilities. The base cases of the two model plants, a fresh fuel fabrication plant and a refabrication plant, were representative of current proposed commercial designs or are based on technology being developed to fabricate uranium, thorium, and graphite into fuel elements. The annual capacities of the fresh fuel plant and the refabrication plant, respectively, were 450 and 245 metric tons of heavy metal (when heavy metal is uranium plus thorium), as charged to about fifty 1000-MW(e) HTGRs. Additional radwaste treatment systems were added to the base-case plants in a series of case studies to decrease the amounts of radioactive materials released and to reduce the radiological dose commitment to the population in the surrounding area. The capital and annual costs for the added waste treatment operations and the corresponding reductions in dose commitments were calculated for each case. In the final analysis, the cost/benefit of each case, calculated as additional cost of radwaste system divided by the reduction in dose commitment, was tabulated or the dose commitment was plotted with cost as the variable. The status of each of the radwaste treatment methods used in the case studies was discussed. Much of the technology included in the advanced case studies has been utilized in either pilot-plant or industrial-scale operations, although no existing fabrication plant has used all of the treatment methods.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION A

B-20, C-9, D-7, D-8, D-23, D-28, E-7, I-4, I-17, J-4, J-5, L-1, L-2,
L-3, L-7, L-8, L-10, L-13, L-14, L-15, L-17, L-18, L-19, L-20, M-1,
M-2, M-3, M-4, M-5, M-6, M-7

Section B

NUCLEAR REACTOR HAZARD STUDIES

B-1 Relevance: 1

U.S. Nuclear Regulatory Commission

REACTOR SAFETY STUDY: AN ASSESSMENT OF ACCIDENT RISKS IN
U.S. COMMERCIAL NUCLEAR POWER PLANTS

Washington, D.C., WASH-1400 (NUREG 75/014), October 1975.

This report presents what probably is the most comprehensive risk assessment to date. It is published in a main volume with 11 appendices. It is more commonly known as the Rasmussen Report after Professor Norman C. Rasmussen who was in charge of its production. The objective of the study was to estimate realistically the public risks that could be involved in accidents in commercial nuclear power plants and to compare them with non-nuclear risks to which society is already exposed. A variety of risk assessment methodologies were used, including fault trees and event trees. Risks from a number of internal and external causes were considered. The results from the study suggest that the risks to the public from potential accidents in nuclear power plants are comparatively small.

B-2 Relevance: 1 (Comments on WASH-1400)

U.S. House of Representatives

OVERSIGHT HEARING BEFORE THE SUBCOMMITTEE ON ENERGY AND THE ENVIRONMENT
OF THE COMMITTEE ON INTERIOR AND INSULAR AFFAIRS ON THE REACTOR SAFETY
STUDY (Rasmussen Report)

U.S. Government Printing Office, Washington, D.C., Serial No. 94-61, 1976.

This document presents hearings held before the House Committee on Interior and Insular Affairs regarding the Reactor Safety Study (WASH-1400, more commonly known as the Rasmussen Report). Included are 7 separate statements and 23 sets of additional material. Because pro and con discussions are given for both the methodology and the specific application of the methodology, the hearings provide interesting reading for anyone planning to use risk analysis or the approach or conclusions of the Rasmussen Report.

B-3 Relevance: 2 (Comments on WASH-1400)

Kamins, Milton

A RELIABILITY REVIEW OF THE REACTOR SAFETY STUDY

The Rand Corporation, Santa Monica, California, P-5413, April 1975.

This report presents comments on the reliability aspects of the Reactor Safety Study (WASH-1400). These comments were initially made in response to an investigation by the Chairman of the Energy Committee of the Sierra Club. Salient comments include the following:

- Fault tree methods were developed to predict rather than assess reliability.
- Fault trees are not the "latest" methodologies in use in the aerospace field. These methodologies include probabilistic design analysis, propagation of error techniques, reliability estimation from small sample sizes, and malfunction simulation models.
- It is impossible to identify all the important accident modes completely.
- Assuming that failures of components are independent is a serious oversimplification.
- The concept of comparison of reactor risks to other risks in everyday life is subject to considerable doubt.
- The assignment of failure rates to components for which failure data are lacking is a further weakness. These estimates may be considerably biased; thus, the random technique used for assessing system reliability is inaccurate.
- The use of seismic records of each fault to determine the maximum earthquake magnitude that might be expected on the fault is a flawed concept.
- The observed failure rate for the high-pressure coolant systems and diesel generators is much higher than the values used in the Reactor Safety Study.

B-4 Relevance: 2 (Comments on WASH-1400)

Office of Radiation Programs

REACTOR SAFETY STUDY (WASH-1400): A REVIEW OF THE FINAL REPORT

U.S. Environmental Protection Agency, EPA/520/3-76-009, June 1976.

This document presents EPA's review of the Reactor Safety Study (RSS). The review document states that the authors have tried to keep in perspective the original intent of RSS provision of a technically sound overall assessment of accident risks from commercial nuclear power plants in the United States. They have noted the limits to the RSS scope and limitations that the report attaches to the applicability of RSS's results and methodology. In providing a technically sound overall assessment of the

accident risks, EPA found several significant areas in the RSS report that were either deficient or contained unjustified assumptions. These include: (1) failure to address fully the health effects expected after an accident and to consider adequately a technical basis, including a broad range of perspectives, for estimating the incidence of the associated bioeffects; (2) the assumptions made in regard to evacuation as a remedial measure; (3) improper or incompletely evaluated parameters used in determining accident event-sequences and probabilities; and (4) inadequate description of the analysis of consequences of the release of radioactive materials to the environment.

B-5 Relevance: 2 (Comments on WASH-1400)

Lévérenz, F. L and R. C. Erdmann

CRITIQUE OF THE AEC REACTOR SAFETY STUDY (WASH-1400)

Science Applications, Inc., Palo Alto, California, June 1975.

This report contains a critical commentary of the Reactor Safety Study, WASH-1400 (commonly called the Rasmussen Report). The substance of this critique accumulated from using the methods and results contained in WASH-1400 for resolving other reactor safety issues. Generally, it was concluded that the original study group did a remarkable job in comprehensively assessing reactor risks and in documenting their procedures and results. Although slightly conservative at times, the study chose to carry out realistic estimates when possible. Contributions to risk from various failure initiators and sequences, common mode occurrences, multi-unit site effects, and certain consequence averaging procedures were often not documented clearly. Some accident sequences may also have been omitted in the study, although no major ones were found.

B-6 Relevance: 3 (Comments on WASH-1400)

U.S. Congress

INVESTIGATION OF CHARGES RELATING TO NUCLEAR REACTOR SAFETY

Hearings Before the Joint Committee on Atomic Energy, Washington, D.C., February 18, 23, and 24, and March 2 and 4, 1976.

These hearings investigated the concerns regarding the safety of nuclear power programs expressed by three former employees of the General Electric Co. and charges made against the NRC by one of its recent employees. In essence, the former GE employees charged that certain nuclear plants now licensed to operate are so plagued by design deficiencies and operational problems that they pose major safety concerns. The former NRC employee charged that safety information had been suppressed within the Commission. Some of the testimony concerned the accuracy of the Rasmussen Report.

B-7 Relevance: 3 (Comments on WASH-1400)

Shapley, Deborah

REACTOR SAFETY: INDEPENDENCE OF RASMUSSEN STUDY DOUBTED

Science, 197:29-31, July 1977.

This article charges that the Rasmussen study (WASH-1400) was conducted in an atmosphere and circumstances that were not conducive to obtaining impartial results. The article charges that Norman Rasmussen was selected to head the study not only for his technical knowledge and national stature but because he was regarded as a "friend" of nuclear power. It also charges that the study was conducted at AEC headquarters rather than MIT and that the project's staff was apparently poorly insulated from bureaucratic pressure.

B-8 Relevance: 3 (Comments on WASH-1400)

Rasmussen, Norman C.

NUCLEAR POWER: SAFE BY ANY MEASURE

Electric Perspectives, 5-9 February 1976.

As with most complex issues, emotion dominates much of the debate about the crucial issue of nuclear power, and with too little rational dialog taking place. As a result, many findings of scientific investigations of nuclear power have not reached the consumer, who is asked to decide the future of this power source. Therefore, Rasmussen reexamines WASH-1400 and presents in understandable terms study conclusions.

B-9 Relevance: 3 (Comments on WASH-1400)

Governor's Office of Emergency Services

RADIOLOGICAL DEFENSE OFFICER CONFERENCE

State of California, Conference held in South Lake Tahoe, October 23-25, 1974.

Three papers presented at this conference relate to reactor safety

1. "All Consequences of a Reactor Accident Will be Confined to the Reactor Site: Fact," David F. Pilmer.
2. "All Consequences of a Reactor Accident Will be Confined to the Reactor Site: Fiction," Robert W. Christopherson.
3. "A Review of the AEC Reactor Safety Study (Rasmussen Study)," B. John Garrick.

The first paper discusses what has been done at the San Onofre, California, nuclear power plant to determine types of possible accidents and to analyze their consequences. The second paper primarily criticizes the Rasmussen study, whereas the third paper defends the Rasmussen study.

B-10 Relevance: 1

Smith, T. H., P. J. Pelto, D. L. Stevens, G. D. Seybold, W. L. Purcell, and L. V. Kimmel

A RISK-BASED FAULT-TREE ANALYSIS METHOD FOR IDENTIFICATION, PRELIMINARY EVALUATION, AND SCREENING OF POTENTIAL ACCIDENTAL RELEASE SEQUENCES IN NUCLEAR FUEL CYCLE OPERATIONS

Battelle Northwest Laboratory, Richland, Washington, BNWL-1956, UC-70, January 1976.

This report describes a method for identification, preliminary evaluation, and screening of potential accident sequences that lead to uncontrolled release of radioactive materials. Included is a procedure for estimating the risk sum of all identified sequences. In addition, portions of the procedures have been developed to analyze the highest risk sequences screened. Existing methods, such as event trees or cause/consequence diagrams, could also be used for the detailed analysis. The method, which appears useful for analysis of most operations of the nuclear fuel cycle, begins with preliminary analyses. The facility and operation are described, and analysis bounds are established. SAR and related documents are reviewed, and a preliminary hazards analysis is performed. After reviewing several methods for systematic identification of accidental release sequences--a type of fault tree construction--the "to/through" approach, which resembles the "leak path" approach, was applied to several fuel cycle operations. The most undesirable event (accidental release of radioactive material from the facility) was postulated. Reviewing the process, the analyst determines how each containment barrier could have been breached. The material must move to each barrier and pass through it for release to occur. The process continues until initiating events have been reached and all conceivable release sequences of importance postulated.

B-11 Relevance: 1

American Physics Society

REPORT TO THE AMERICAN PHYSICS SOCIETY BY THE STUDY GROUP ON LIGHT WATER REACTOR SAFETY

Reviews of Modern Physics, 47(1):S1-S124, Summer 1975.

The issues of LWR safety have been the subject of a part-time, year-long study sponsored by the American Physical Society. The goal of the study was the assessment of some of the technical aspects of the safety of large nuclear LWRs typical of present commercial practice in the United States. The report examines issues related to safe operation of the LWRs; the research and development program responsible for establishing and enhancing safety; and the consequences of accidents for public health and welfare. The report does not deal with the need for nuclear power or its benefits, and does not give a net assessment of the risks versus benefits of nuclear reactors. Because the risks of ecological impacts of other energy technologies are not addressed, no recommendations are made concerning future specific reactor programs. Among the areas covered in this report are primary pressure-vessel integrity; quality assurance; accident initiation from operator error; transients; sabotage; the adequacy of present emergency core-cooling system designs; the calculation of long-term consequences to health from a particular low-probability accidental release of radioactivity; and the experimental and calculational aspects of the present reactor safety research program. The recommendations given mainly address how LWR safety can be improved or better understood.

B-12 Relevance: 2

Starr, C. and M. A. Greenfield

PUBLIC HEALTH RISKS OF THERMAL POWER PLANTS

University of California, Los Angeles, California, UCLA-ENG-7242, May 1972.

A study of the risks from urban oil-fired and nuclear power plants indicates the following findings (provided available technology is used to protect health and safety):

1. The public health risk from routine operations of electricity generating plants that use nuclear fuel or oil is similar to the very low hazard of being struck by lightning or bitten by a venomous animal or insect (i.e., about 1 death per year per million population).
2. Routine operation of a nuclear plant presents a significantly smaller public health risk than the routine operation of an oil-fired plant--typically 10 to 100.
3. The public health risks due to accidental releases from nuclear or oil-fired plants are of the same magnitude, and about 100,000 times smaller than the risk from routine operation of the plants.
4. The maximum hypothetical accidents associated with either plant type are unlikely to affect public health significantly when they are compared to the normal incidence of disease.
5. Both oil-fired and nuclear plant structures should be designed to meet the earthquake forces expected at a particular site.

6. The risk associated with transporting spent nuclear fuel can be made small enough so that the location of the associated fuel reprocessing installations is a separable factor in siting nuclear power plants.

B-13 Relevance: 2

Cohen, S. C. and K. D. Dance

SCOPING ASSESSMENT OF THE ENVIRONMENTAL HEALTH RISK ASSOCIATED WITH ACCIDENTS IN THE LWR SUPPORTING FUEL CYCLE

Teknekron, Inc., Washington, D.C., November 1975.

A framework is developed for assessing the health risk associated with postulated accidents in the fuel cycle that supports the annual operation of a 1000-MWe LWR. The methodology applied consists of a synthesis of nominal radiological source terms and corresponding likelihoods for postulated accidents at generic fuel cycling facilities in existence around 1980. The accident definitions, source terms, and likelihoods are compiled and evaluated from diverse studies. Risk is defined in this study as the product of the expected consequences of an accident and its likelihood of occurrence. The source terms are converted to 50-year dose commitments in accordance with recommendations of the International Commission on Radiological Protection. Dose commitments are converted to health effects by using the linear, nonthreshold dose-response relationship developed in the BEIR report and interpreted by EPA.

B-14 Relevance: 2

Godbout, P.

APPENDIX III--PROBABILISTIC SAFETY ANALYSIS OF A HYPOTHETICAL 1000 MWe LIQUID METAL FAST BREEDER REACTOR: PUBLIC HEALTH RISKS OF THERMAL POWER PLANTS

University of California, Los Angeles, California, UCLA-ENG-7242, May 1972.

The probable risk for a hypothetical 1000-MWe LMFBR was studied. Six types of potential major accidents were investigated: (1) loss of primary coolant flow, (2) pipe rupture, (3) reactivity insertion, (4) loss of heat sink, (5) fuel handling, and (6) sodium fire. The associated fault trees were generated and equipment failure data and other probabilistic data such as earthquakes and tornadoes were researched. A bibliographical research of radiation hazards to man was used to develop a series of

radiation risk curves in the low-dose domain. Two series of calculations were performed: one without the designed-in redundancy, fail-safe, or similar schemes to upgrade the reliability of the safety systems, and one with these schemes. The results gave upper limits, medians, and lower limits. Accident envelopes were generated for the following radioactivity releases: Pu, ^{131}I , Xe, and Kn. These results were coupled to meteorology and demography to develop curves for the mortality risk per distance and integrated mortality risks for the plant. The median integrated risk was found to be lower than existing similar analysis of median risk for PWR and BWR plants.

B-15 Relevance: 3

Otway, Harry J. and Robert C. Erdmann

REACTOR SITING AND DESIGN FROM A RISK VIEWPOINT

Nuclear Engineering and Design, 13:365-376, 1970.

This paper proposes a method for the assessment of reactor safety, based on the mortality risk, that allows the determination of necessary site exclusion radii and the evaluation of safeguards in terms of the risk reduction provided. An application to a 1000-MWe PWR indicates that for a maximum individual mortality risk of 10^{-7} per year (at the site boundary), an exclusion radius of 350 m is required. For a densely populated urban site the total risk was found to be 0.003 deaths over a 30-year reactor lifetime. Risk is reported to be not particularly sensitive to accident probabilities.

B-16 Relevance: 3

Otway, Harry J., Ronald K. Lohrding, and Morris E. Battat

A RISK ESTIMATE FOR AN URBAN-SITED REACTOR

Nuclear Technology, 12:173-184, October 1971.

A method for estimating the risk from reactor installations is presented and applied to the Omega West Reactor, a 8-MW(t) research reactor at Los Alamos, New Mexico. The method, which considers both accident probabilities and the probabilities of various wind and weather conditions, estimates individual risk as a function of direction and distance from the reactor, and estimates the total detriment to the community as a consequence of reactor accidents. The somatic risk due to thyroid carcinoma from ^{131}I uptake, the somatic risks of leukemia and other neoplasms from whole body irradiation, the genetic risk, and nonspecific life shortening are considered. The individual somatic risk at the nearest habitation is found to be $5 \times 10^{-10}/\text{y}$ and the total detriments to the community (all the above risks summed over the total population) was 4.5×10^{-4} deaths per year of reactor operation.

B-17 Relevance: 3

Argonne National Laboratory

LIQUID METAL FAST BREEDER REACTOR PROGRAM PLAN, VOLUME 10, SAFETY

Argonne, Illinois, WASH-1110, August 1968.

The general objective of the LMFRB safety program is an improved technological base needed: to provide realism and confidence in the understanding and analysis of accident situations; to develop and evaluate safety systems for the prevention of accidents and mitigation of their consequences; and to develop standards and codes for the safe design, siting, construction, and operation. The report includes results of evaluations and experimentation relative to abnormal operation, to potential accidents, and to safety systems designed to prevent accidents and to limit their consequences. Prevention, early detection, and control of accidents are emphasized. A review of the method of approach may provide some useful insights for a similar safety study applied to nuclear waste storage.

B-18 Relevance: 3

U.S. Atomic Energy Commission

GENERIC ENVIRONMENTAL STATEMENT: MIXED OXIDE FUEL

Washington, D.C., WASH-1327, August 1974.

This generic environmental statement on the use of mixed oxide fuel in LWRs provides a basis for informed discussion of using recycled Pu as mixed oxide fuel. It also provides a basis for rule-making decisions concerning such Pu recycling. The following topics were addressed generically:

- The impact of normal operations and accidents from recycling Pu on the environment.
- Nuclear materials safeguards.
- Alternative dispositions of Pu.
- The relationship between short-term environmental effects and long-term productivity.
- Irreversible and irretrievable commitments of resources.
- Cost-benefit analysis.

B-19 Relevance: 3

Babcock and Wilcox

ACCIDENT ANALYSIS AND SAFETY SYSTEM DESIGN STUDY FINAL REPORT

Lynchburg, Virginia, BAW-1365, May 1971.

The basic objective of this study was to develop a better understanding of the influence of safety requirements on commercial LMFBR plants. This work was only partially completed because all 1000-MWe LMFBR Study contracts were terminated in October 1970. Phase I and part of the Phase II effort were completed. In Phase I, component and system faults and malfunctions were identified, and fault trees were prepared. Phase II concerned the definition of initiating conditions, based on the faults and malfunctions identified in Phase I, and the subsequent analysis of potential reactor accidents to establish functional requirements for selected protective systems and safety features.

B-20 Relevance: 3

U.S. Congress

EXTENT AND SIGNIFICANCE OF THE IMPACT ON REACTOR LICENSING OF
RECENT COURT DECISIONS

Hearings Before the Joint Committee on Atomic Energy, Washington, D.C.,
August 27, 1976.

The U.S. Court of Appeals for the District of Columbia Circuit declared inadequate the justification for the mechanism for evaluating environmental impact of radioactive waste disposal. This invalidation resulted in a de facto moratorium on the construction or operation of new nuclear power plants. The congressional hearings were held to set forth clearly our ability to analyze the environmental impact of nuclear waste disposal. Witnesses from NRC testified.

B-21 Relevance: 3

U.S. House of Representatives

CORRESPONDENCE WITH THE NUCLEAR REGULATORY COMMISSION AND THE ENERGY
RESEARCH AND DEVELOPMENT ADMINISTRATION

The Subcommittee on Energy and the Environment of the Committee on
Interior and Insular Affairs, Washington, D.C., November 1976.

This document contains the correspondence between the Subcommittee and NRC, and between the Subcommittee and ERDA during 1976. Of particular interest to nuclear waste storage risks is correspondence dealing with sabotage and spent fuel, with worker exposure to ionizing radiation, security alert, and with radioactive waste migration in groundwater.

B-22 Relevance: 3

Harper, B. E. and R. S. Hart (editors)

1000-MWe LIQUID METAL FAST BREEDER REACTOR FOLLOW-ON STUDY CONCEPTUAL DESIGN REPORT, VOLUME III, PLANT SAFETY ANALYSES

Atomics International, AI-12793, 1971.

This document presents a safety analysis of a selected group of accidents applicable to the reference design for a 1000-MWe LMFBR. It is the first of several safety analyses that could lead to the final safety report. The objectives of these safety studies are identifying accidents and transients, analyzing them, and determining their effect on design.

B-23 Relevance: 3

U.S. Nuclear Regulatory Commission

SAFETY EVALUATION REPORT RELATED TO THE CONSTRUCTION OF PHIPPS BEND NUCLEAR PLANT UNITS 1 AND 2

Washington, D.C., NUREG-0101, April 1977.

This Safety Evaluation Report summarizes the results of the technical evaluation performed by NRC staff of the proposed Phipps Bend Nuclear Plant. It delineates the scope of the technical matters considered in evaluating the radiological safety aspects of the facility. Aspects of the environmental impact are considered in the review of the facility in accordance with 10 CFR 51, "Licensing and Regulatory Policy and Procedures for Environmental Protection," and are discussed in NRC's Final Environmental Statement issued in February 1977. This is an example of a typical reactor SAR.

B-24 Relevance: 3

U.S. Nuclear Regulatory Commission

SAFETY EVALUATION REPORT RELATED TO THE CONSTRUCTION OF PERKINS NUCLEAR STATION UNITS 1, 2, AND 3

Washington, D.C., NUREG-0188, March 1977.

This Safety Evaluation Report summarizes the results of the technical evaluation of the proposed Perkins Nuclear Station performed by NRC staff and delineates the scope of the technical matters considered in evaluating the radiological safety aspects of the facility. Aspects of the environmental impact are considered in the review of the facility in accordance with 10 CFR 51, "Licensing and Regulatory Policy and Procedures for Environmental Protection," and are discussed in NRC's Final Environmental Statement issued in October 1975. This is an example of a typical reactor SAR.

B-25 Relevance: 3

Doron, Z. J. and H. Albers

MEAN ANNUAL SEVERITY: AN EXTENSION OF THE QUANTITATIVE PROBABILISTIC APPROACH TO REACTOR SAFETY ANALYSIS

Nuclear Engineering and Design, 9:349-356, 1969.

The quantitative approach to reactor safety analysis introduced by F. R. Farmer is discussed and the analysis of each branch of an accident is extended, with the probable frequency and consequent radioactivity release assigned to it multiplied together. This product is termed Mean Annual Severity (MAS), and is useful in analyzing the safeguards and accident status of a reactor. In addition to determining the severity of an accident, this approach enables any weaknesses in the overall safety design to be pin-pointed for further analysis and action. As an example, a loss-of-coolant accident in a PWR is analyzed and the conclusions that can be thereby drawn are demonstrated. The MAS and the maximum credible accident (MCA) approaches are compared, and examples demonstrating weaknesses in the MCA approach by means of MAS analysis are presented.

B-26 Relevance: 3

Stevens, C. A. and F. L. Leverenz

ATWS: A REAPPRAISAL, PART II EVALUATION OF SOCIETAL RISKS DUE TO REACTOR PROTECTION SYSTEM FAILURE, VOLUME 4, THE PROBABILITY OF EXCEEDING 10 CFR 100 GUIDELINES FROM ATWS EVENTS IN LIGHT WATER REACTORS

Science Applications, Inc., Palo Alto, California, EPRI NP-265, January 1977.

This analysis here was based on the methods of WASH-1400. The results obtained there showed that Anticipated Transients Without Scram (ATWS) are responsible for less than 5% of the total LWR risk. This volume considers the probability of an ATWS releasing enough radiation to violate the radiation limits set by 10 CFR 100. The calculations shown that the probability is less than 3×10^{-7} per year (3 chances in 10 million). Because WASH-1270 stated the desirable probability would be 10^{-7} per year, it would appear that such a limit has already been met.

B-27 Relevance: 3

Fullwood, R. R., R. C. Erdmann, A. A. Garcia, F. L. Leverenz, E. T. Rumble, and G. S. Lellouche

ATWS: A REAPPRAISAL

Science Applications, Inc., Palo Alto, California, EPRI-NP-251, August 1976.

This series of reports examines the basis for the problem of Anticipated Transients Without Scram (ATWS). These documents evaluate risk due to ATWS in the light of developments subsequent to the publication of WASH-1270 and reevaluate the probabilistic basis for ATWS. The project's goals include estimates of: the actual probability of failure to scram and the probability of initiating events. This series of documents consists of four volumes:

1. An examination and analysis of WASH-1270, the "Technical Report on ATWS for Water Cooled Power Reactors."
2. Evaluation of Societal Risks Due to Reactor Protection System Failure (BWR Risk Analysis).
3. Evaluation of Societal Risks Due to Reactor Protection System Failure (BWR Fault Tree Evaluation).
4. Evaluation of Societal Risks Due to Reactor Protection System Failure (PWR Risk Analysis).

B-28 Relevance: 3

Raabe, P. H., W. J. Houghton, and V. Jaksimovic

HTGR ACCIDENT INITIATION AND PROGRESSION ANALYSIS STATUS REPORT,
VOLUME 1 INTRODUCTION AND SUMMARY

General Atomic, GA-A13617, January 1976.

Probabilistic risk assessment techniques have been applied to aid in choosing the most worthwhile nuclear safety research and development for HTGR nuclear power plants. The probabilistic techniques used are similar to those employed in WASH-1400. Recommendations for research include studies related to core heatup (even though this event poses a very low risk to the public). In fact, in the many conditions covered by the study to date, even very infrequent accidents in HTGRs (e.g., once in 10,000,000 years) will not produce fatalities. Potential cost reductions of alternative design options have been found that protect the public and meet regulation safety criteria. The study provides an interesting application of risk analysis, including treatment of common mode failures, uncertainties, and human operator reliability.

B-29 Relevance: 3

U.S. Nuclear Regulatory Commission

COST-BENEFIT ANALYSIS FOR RADWASTE SYSTEMS FOR LIGHT-WATER-COOLED
NUCLEAR POWER REACTORS

Washington, D.C., Regulatory Guide 1.110, March 1976.

Each applicant for a permit to construct or a license to operate a light-water-cooled nuclear power reactor and each licensee with a license to operate such a reactor is required to provide reasonable assurance that the design objectives for effluent releases as low as reasonably achievable are satisfied by the liquid and gaseous radwaste system designs. This guide provides a method of performing cost-benefit analysis to demonstrate that plant design includes the technology for reducing the cumulative population dose from radioactivity released from the reactor to levels as low as reasonably achievable. As an interim measure NRC chooses values of \$1,000 per man-rem and \$1,000 per man-thyroid-rem to implement the cost-benefit analysis. In addition, NRC has outlined performance requirements for cost-benefit analysis and has provided cost parameters for estimating the costs of radwaste treatment equipment for light-water-cooled nuclear power reactors.

B-30 Relevance: 3

Gerrick, B. J., W. C. Gekler, R. H. Karcher, B. Shimizu and J. R. Wilson
RELIABILITY ANALYSIS OF NUCLEAR POWER PLANT PROTECTIVE SYSTEMS

Phillips Petroleum Company, Idaho Falls, Idaho, HN-190, UC-80, May 1967.

Data and analytical requirements for a nuclear power plant reliability monitoring program is identified. A data management system is defined that incorporates a method for the classification of equipment and events and a plan for data collection. The accuracy and flexibility of the automatic reliability mathematical modeling technique has been increased and a computer program (Systems Analysis by Fault Tree Evaluation) has been developed. The authors conclude that reliability analysis can contribute to a safety analysis of nuclear power plants.

B-31 Relevance: 3

Frigerio, Norman A., Keith F. Eckerman, and Ralph S. Stowe

THE ARGONNE RADIOLOGICAL IMPACT PROGRAM (ARIP), PART I. CARCINOGENIC HAZARD FROM LOW-LEVEL, LOW-RATE RADIATION, PART I

Argonne National Laboratory, Argonne, Illinois, ANL/ES-26, September 1973.

The entire Argonne Radiological Impact Program is briefly outlined, and part of the program that deals with radiation hazards from nuclear power plants is discussed in detail. Various models and predictions or carcinogenic hazards are examined and compared with actual experience in U.S. and foreign populations. All of the models predict a significant increment in malignant mortality with increasing background. Observation of the actual populations at risk shows not only no increment, but an actual decrement, so that the predictions are left quite without observational support. The authors conclude that extrapolation of high-rate and usually high dose-level studies to low rates and low levels is probably invalid, and that radiation at such levels and rates does not constitute an environmental carcinogen of significance.

B-32 Relevance: 3

Jacobs, I. M.

THE COMMON MODE FAILURE STUDY DISCIPLINE, IEEE Transactions on Nuclear Science, NS-17(1):594-598, February 1970.

A Common Mode Failure (CMF) study is described to support the design basis for the reactor protection system on a General Electric BWR. Ground rules are formulated that restrict the study to functional CMFs applied one at a time to a reactor plant subjected to initiating transients and accidents. Each outcome is traced to a stable condition, and the results are examined to determine their acceptability. CMF studies seem to parallel the development of reliability studies, with complementary results.

B-33 Relevance: 3

Office of Radiation Programs

ENVIRONMENTAL ANALYSIS OF THE URANIUM FUEL CYCLE

U.S. Environmental Protection Agency, Washington, D.C. EPA-520/9-73-003-(B, C, and D), 1973.

These analyses project the effects that the total uranium fuel cycle may have on public health, and indicate where, when, and how standards limiting environmental releases could be effectively applied to mitigate these effects. Considerable health consequences would result from radioactivity released from the various operations, especially in terms of its expected environmental persistence and from regional, national, or worldwide migrations that might occur. This complete analysis comprises three reports: The Fuel Supply, Light-Water Reactors, and Fuel Reprocessing. High-level waste disposal operations are not included.

B-34 Relevance: 3

U.S. Atomic Energy Commission

STANDARD FORMAT AND CONTENT OF SAFETY ANALYSIS REPORTS FOR NUCLEAR POWER PLANTS--LMFBR EDITION

Washington, D.C., February 1974.

Section 50.34 of 10 CFR 50 of AEC regulations requires that each application for a construction permit for a nuclear reactor facility include a PSAR, and that each application for a license to operate such a facility include an FSAR. Section 50.34 specifies in general terms the information to be supplied in these SARs. Further information was provided in a "Guide to the Organization and Contents of Safety Analysis Reports" issued by the AEC on June 30, 1966. This document was directed primarily at LWRs, but was also considered generally applicable to plants using other types of reactors.

B-35 Relevance: 3

U.S. Atomic Energy Commission

FINAL ENVIRONMENTAL STATEMENT CONCERNING PROPOSED RULE MAKING ACTION: ACCEPTANCE CRITERIA FOR EMERGENCY CORE COOLING SYSTEMS FOR LIGHT-WATER COOLED NUCLEAR POWER REACTORS

Washington, D.C., Docket No. RM-50-1, May 1973.

This environmental statement covers proposed adoption of acceptance criteria for emergency core cooling systems for LWRs. Adoption would provide general criteria and evaluation models for the AEC to use in evaluating the design of proposed emergency core cooling systems in regard to their ability to cool the reactor core following a postulated loss-of-coolant accident over the spectrum of postulated accident conditions.

B-36 Relevance: 3

Cottrell, William B.

AEC TESTIMONY AT THE 1973 JCAE HEARINGS ON REACTOR SAFETY

Nuclear Safety, 15(2):132-145, March-April 1974.

The testimony here was concerned with all aspects of AEC activities related to the nuclear power-reactor program, including (1) reactor safety research and development, (2) waste-management investigations, (3) the protection of materials and facilities, and (4) the AEC's regulatory activities as well as those of the Advisory Committee on Reactor Safeguards and the Atomic Safety and Licensing Board Panel. The presentation discussed actual and potential problems in detail, including needed safety research, the accident-risk study, waste-management experience, sabotage, diversion, reactor licensing, inspection, operating experience, and standards development.

B-37 Relevance: 3

Cave, L. and D. Ilberg

RELATIVE HAZARD POTENTIAL--THE BASIS FOR DEFINITION OF SAFETY CRITERIA FOR FAST REACTORS

University of California at Los Angeles, School of Engineering and Applied Science, Los Angeles, California, UCLA-ENG-7692, February 1977.

One of the main safety criteria for larger thermal reactors is that the probability of exceeding the dose limits imposed by 10 CFR 100 should not be greater than 10^{-6} per reactor year. The potential hazards presented by LMFBRs could be substantially greater than that posed by an LWR. The potential for harm of a reactor system can be judged by severe accident effects, including latent fatal cancers; deaths due to acute effects; thyroid tumors or nodules; property damage; and genetic effects. This paper employs analytical methods for comparison. A second important parameter reviewed is the radiotoxicity attributed to the various isotopes. The worst conceivable accident to a 1000-MW(e) LMFBR would affect an order of magnitude more than the worst accident usually considered for an LWR. Therefore, reconsideration of additional safety criteria for LMFBRs to guide designers in controlling the effects of very severe accidents is desirable.

B-38 Relevance: 3

Office of Nuclear Material Safety and Safeguards

FINAL GENERIC ENVIRONMENTAL STATEMENT OF THE USE OF RECYCLE PLUTONIUM
IN MIXED OXIDE FUEL IN LIGHT-WATER COOLED REACTORS

U.S. Nuclear Regulatory Commission, Washington, D.C., NUREG-0002, ES,
August 1976.

NRC is deciding whether or not to permit the widespread use of mixed oxide fuel in LWRs. This fuel has been used for many years in LWRs on a limited basis. Health, safety, and environmental impacts of widescale use are examined, and costs and benefits are weighed. An evaluation of the safeguards required for the widescale use of this fuel will supplement the study. The final safeguards supplement will include the overall cost-benefit balancing, including health, safety, environmental, economic, and safeguards factors. Public hearings will be conducted.

B-39 Relevance: 3

American Nuclear Society

TOPICAL MEETING ON WATER REACTOR SAFETY

Held in Salt Lake City, Utah, March 26-28, 1973.

This topical meeting's purpose was "to provide an open technical forum for the exchange of information on research and engineering problems related to water reactor safety." Most of the material presented at this meeting is specific to water reactor safety and has little utility for a risk assessment of nuclear waste storage. The two papers that would be the most useful are:

- Assessment of Risks in Reactor Safety, I. M. Jacobs
- The Fault Tree as a Safety Optimization Design Tool, C. W. Griffin.

B-40 Relevance: 3

U.S. Congress

NUCLEAR REACTOR SAFETY

Hearings Before the Joint Committee on Atomic Energy, Washington, D.C.,
January 25, September 22, 23, 24, and 28, 1974.

These hearings were conducted to obtain testimony about the status of nuclear reactor safety.

B-41 Relevance: 3

Fish, B. R., G. W. Keilholtz, W. S. Snyder, and S. D. Swisher

CALCULATION OF DOSES DUE TO ACCIDENTALLY RELEASED PLUTONIUM FROM AN LMFBR

Oak Ridge National Laboratory Operated by the Union Carbide Corporation, Oak Ridge, Tennessee, ORNL-NSIC-74, November 1972.

Experimental data and analytical models that should be considered in assessing the transport properties of Pu aerosols following a hypothetical reactor accident were examined. Behaviors of released airborne materials within the reactor containment systems, as well as in the atmosphere near the reactor site boundaries, were predicted from experimental data and analytical models. The chemistry of Pu applicable to biological systems was used to prepare models related to the intake and metabolism of PuO_2 --the fuel material of interest. Attempts were made to calculate the possible doses from Pu aerosols for a typical analyzed release; in this way, the magnitude of internal exposure hazards near the reactor after a hypothetical LMFBR accident can be evaluated. To the extent possible, dose-response data and models have been reviewed, and their adequacy has been assessed so that recommended or preferred practices can be developed.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION B

A-41, A-42, D-1, D-3, D-13, D-19, D-26, E-7, E-10, E-11, D-12, D-13,
E-15, E-16, E-17, E-18, G-3, G-4, G-7, G-8, G-9, G-13, G-15, G-19,
G-20, G-25, G-28, G-31, I-2, I-3, I-6, I-18, J-3, J-7, J-9, J-13,
J-15, J-16, J-17, J-18, J-22, L-6, K-13, M-8, M-9, M-10, M-11, M-15

Section C

HAZARD STUDIES FOR PHASES OF THE NUCLEAR FUEL CYCLE OTHER THAN WASTE AND REACTORS

C-1 Relevance: 2

Hodge, C. V. and A. A. Jarrett

TRANSPORTATION ACCIDENT RISKS IN THE NUCLEAR POWER INDUSTRY, 1975-2020

Nuclear and Systems Sciences Group, Anaheim, California, November 1974.

The accident risks associated with transporting radioactive material for the nuclear power industry to 2020 were quantitatively assessed. A scenario was developed for 1975 to 2020 for shipments among nuclear reactors, chemical reprocessing plants, fuel fabrication facilities, and waste repositories. Technical data from numerous sources were collected in regard to shipping spent fuel, recycled plutonium, high-level radioactive solid waste, and fission-product gases. Assumptions were developed regarding transport modes, shipping containers, transport pathways for dispersion of released radioactivity, population distribution, and health responses to radiological exposure.

C-2 Relevance: 2

U.S. Environmental Protection Agency

ENVIRONMENTAL ANALYSIS OF THE URANIUM FUEL CYCLE, PART III--NUCLEAR
FUEL REPROCESSING

U.S. Environmental Protection Agency, Washington, D.C., EPA-520/9-73-003-D,
October 1973.

This analysis examines technological, environmental, and biological factors in terms of the potential public health and environmental risks involved for fuel reprocessing requirements over the next several decades. This review has two objectives: (1) determining the population health risks and the cost-effectiveness of waste controls for the present and future nuclear fuel reprocessing industry, and (2) documenting the data base and techniques for assessing the environmental impact of the fuel reprocessing industry. Fuel reprocessing requirements through 2020 are forecast; effluent control systems are analyzed in detail; and the environmental transport of radionuclides, and resultant doses and health effects are considered. The data base and techniques used for these analyses are detailed in the appendices of this report.

C-3 Relevance: 3

Jones, George P., Robert W. Barrow, Linn C. Stuckenbruck, Eugene L. Holt, and Robert P. Keller

RISK ANALYSIS IN HAZARDOUS MATERIALS TRANSPORTATION

University of Southern California, Los Angeles, California, RAPO-73-7, March 1973.

This report contains a risk analysis of hazardous materials. The three tasks were to: (1) develop a conceptual model for risk analysis, (2) demonstrate the practicability of risk determination by examples, and (3) demonstrate the practicability of evaluating special permit petitions. The results are as follows: (1) a risk analysis model was developed that was provided with input from existing data bases, (2) 20 examples were shown that demonstrated the procedure, and (3) the petition evaluation showed a clear dominance of one alternative over the others in terms of risk, bodily injury, deaths, and normal and total cost.

C-4 Relevance: 2

Garrick, B. John, Orlino C. Baldonado, and Willard C. Gekler

ESTIMATING THE RISK INVOLVED IN THE TRANSPORT OF HAZARDOUS MATERIALS

Holmes and Narver, Inc., Manuscript of a Paper Presented at the Armed Services Explosives Safety Board Seminar, August 25-27, 1970.

This paper describes a model for quantitatively estimating the risk associated with handling and transporting hazardous materials. The estimated risk values can be used to evaluate the effectiveness of changing the container design, handling procedures, and method and path of transport, as well as testing and inspection procedures. The model's objective is minimizing public exposure during transport of hazardous materials such as industrial gases. The measure of risk calculated by the model is the expected number of people affected by the hazardous materials per trip. The model calculates the probability of release and the expected area affected by various dose levels or concentrations if a release of hazardous material occurs. Coupling the population density with the areas gives the risk measure.

C-5 Relevance: 2

McSweeney, T. I., and R. J. Hall

AN ASSESSMENT OF THE RISK OF TRANSPORTING PLUTONIUM OXIDE AND LIQUID PLUTONIUM NITRATE BY TRUCK

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1846, August 1975.

Radioactive materials, in a variety of physical and chemical forms, are routinely transported between nuclear facilities. The research described in this document is part of a continuing program to develop a methodology to assess the safety of transporting radioactive materials quantitatively and to apply that methodology to current and future shipping systems. The report presents both a methodology for assessing the risk in transporting radioactive materials and the results of the initial application of the methodology to truck shipments of plutonium. Based on the shipping assumptions, plutonium truck shipments are estimated to be involved in an accident about once in 1.5 years. Most accidents will result in no release of plutonium. For the shipping rate projected for the early 1980s, the likelihood of a release of plutonium as a result of shipment by truck is about one in 60 years for liquid nitrate in the L-10 container and one in 330 years for oxide powder in the 6M container. The consequences of these postulated releases were also estimated.

C-6 Relevance: 3

U.S. Atomic Energy Commission

ENVIRONMENTAL SURVEY OF TRANSPORTATION OF RADIOACTIVE MATERIALS TO AND FROM NUCLEAR POWER PLANTS

Washington, D.C., WASH-1238, December 1972.

This analysis assessed the potential impact on the environment of transporting fuel and solid radioactive wastes for nuclear power plants under existing regulations. The probability of an accident occurring in transportation is about 1 accident every 10^6 vehicle miles, with 1 severe accident every 100×10^6 vehicle miles, and 1 extremely severe accident every 10×10^{12} vehicle miles. For a typical nuclear reactor, it is estimated that the fuel or fuel waste shipped will be involved in 1 transportation accident every 10 years and that 1 of these accidents out of about 100 will be severe. When both probability of occurrence and extent of the consequences are taken into account, the risk to the environment due to radiological effects from transportation accidents is estimated to be small. Within the United States from 1947 to 1972, only about 300 reportable accidents occurred in transportation that involved radioactive material. Only about 30% of these involved any release of contents or increased radiation levels, and none resulted in perceptible injury or death attributable to the radiation aspects.

C-7 Relevance: 3

Yadigaroglu, George

SPENT FUEL TRANSPORTATION ON HIGHWAYS--THE RADIOACTIVE DOSE TO THE TRAFFIC
Nuclear Technology, 27(2):258-266, October 1975.

The radioactive exposure of traffic moving on the same highways with spent fuel shipments has been neglected in the past. Methods developed for calculating (1) peak exposures, (2) the number of individuals receiving a dose in excess of a certain limiting value, and (3) the cumulative population doses for vehicle occupants under a variety of highway and accident conditions allow comparisons with corresponding stationary-population doses. Considerations of both routine direct-radiation exposures and accidental releases indicate that the traffic dose can be of equal or greater importance than the stationary-population doses.

C-8 Relevance: 3

Shappert, L. B., W. A. Brobst, J. W. Langhaar, and J. A. Sisler

PROBABILITY AND CONSEQUENCES OF TRANSPORTATION ACCIDENTS INVOLVING
RADIOACTIVE MATERIAL SHIPMENTS IN THE NUCLEAR FUEL CYCLE

Nuclear Safety, 14(b):597-604, November-December 1973.

For 1980, the projected electrical generating capacity of nuclear power plants in the United States will generate thousands of shipments of radioactive materials annually. The probability of accidents involving these shipments within the public domain has been estimated for five severity categories. This study estimates that in 1980 such shipments would be involved in less than 20 accidents, most of which would result in only moderate damage to the shipping system and no significant nuclear-related hazard.

C-9 Relevance: 3

Reinking, A., M. Mishouie, G. Yadigaroglu, and V. E. Schrock

APPENDIX V, TRANSPORTATION OF NUCLEAR FUEL: PUBLIC HEALTH RISKS
OF THERMAL POWER PLANTS

University of California, Los Angeles, California, UCLA-ENG-7242, May 1972.

The appendix reviews transportation and reprocessing operations, and estimates the amount of radioactive releases expected to occur from steps in the nuclear fuel cycle in California. The safety and radioactive release aspects of irradiated fuel transportation are discussed, as are fuel reprocessing and waste disposal. The future needs for irradiated fuel transportation, reprocessing, and possible waste disposal in California and their consequences in terms of radioactive releases are analyzed.

C-10 Relevance: 3

Brobst, William A.

TRANSPORTATION ACCIDENTS: HOW PROBABLE?

Nuclear News, 48-54, May 1973.

On the basis of the analysis described in this paper, it may be stated that the theoretical probability of occurrence of almost any kind of transportation accident can be estimated with a reasonable degree of accuracy. The methodology shown may be extended to different types of accidents or different types of accident consequences in terms of damage to different types of packages. With regard to the probability of serious public consequences of transportation accidents involving radioactive materials, it appears that the probability of death, injury, or massive property loss because of the release of radioactive materials in an accident is (1) determinable; (2) not zero; and (3) very small. In projecting the total probability of an accident in the transportation of radioactive materials to and from nuclear power plants, the author concludes that the radiological consequences of the total accident spectrum will be several orders of magnitude below the more common non-radiological causes.

C-11 Relevance: 3

Australian Mineral Foundation Inc.

RADIATION CONTROLS IN URANIUM MINING

Health Session Papers, Adelaide, Australia, August 23, 1972.

The session papers contained are:

Watson, G. M., "The Biological Effects of Radiation"

Watson, G. M., "Lung Cancer in Uranium Miners"

Rathus, E. M., "Occupational Health Problems of Uranium
Mining and Milling"

Lander, H., "Radiation Damage: Mechanism and Factors Which
Influence It"

Stevens, D. J., and I. S. Leith, "Present and Possible Future
Radiation Protection Standards for Uranium
Mining and Milling."

C-12 Relevance: 3

Australian Atomic Energy Commission

PROCEEDINGS OF THE AAEC SYMPOSIUM ON ENVIRONMENTAL AND RADIOLOGICAL
ASPECTS OF THE MINING AND PROCESSING OF URANIUM

Symposium held at Lucas Heights, December 9-10, 1971.

This document contains papers of a symposium on environmental and radiological safety aspects of mining and processing uranium. The symposium was held to draw attention to the problems associated with protecting man and the environment in the vicinity of uranium mining. Papers presented were:

Review of World Trends in the Uranium Industry (A Summary),
R. K. Warner

Philosophy of Environmental Protection and Control, G. M. Watson

Philosophy of Pollution in Uranium Mining and Processing Activities
(A Summary), R. K. Warner

Environmental Studies for Uranium Provinces - Aims and Methods,
D. R. Davy

Methods of Control of Potential Pollutants (A Summary), C. J. Hardy

Introduction to Radiological Safety, J. C. E. Button

Radiological Health and Safety Aspects of Uranium Mining and Ore
Treatment - A Bibliography Compiled, J. C. E. Button

Biological Effects of Radiation, G. M. Watson

History of Radiation Effects and Control in Uranium Mining,
G. M. Watson

Uranium Mining - The Nature of the Dosimetry Problem, J. E. Cook

Practical Dosimetry in Uranium Mining, D. R. Davy and N. Conway

Prospects for Control of Radiological Hazards in Uranium Mining,
D. R. Davy.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION C

A-18, A-41, A-42, I-16

Section D

PERTINENT HAZARD STUDIES ASSOCIATED WITH NATURAL ENVIRONMENTAL CAUSES

D-1 Relevance: 1

Soloman, K. A., R. C. Erdmann, T. E. Hicks, and D. Okrent

ESTIMATE OF THE HAZARDS TO A NUCLEAR REACTOR FROM THE RANDOM IMPACT OF METEORITES

School of Engineering and Applied Science, University of California,
Los Angeles, California, UCLA-ENG-7426, March 1974.

A method and statistics given by V. E. Blake have been employed to estimate the probability per year that a nuclear reactor could be seriously damaged by a meteorite strike. The probability per year that a target area of 10,000 ft² will be struck by a meteorite weighing more than 1 lb is estimated to be 4.3×10^{-9} per reactor year. However, only a fraction of these meteorites corresponding to weights exceeding 100 lb are very likely to damage the reactor seriously enough for uncontrolled release of fission products to occur. For a target area of 10,000 ft², this probability is estimated to be 7×10^{-10} per reactor year. Also included are methods for estimating the probability that a coastal plant will suffer serious damage from a tidal wave induced by a meteorite. The equations and methods given in this report can be used to estimate the probability of impact of meteorites of a specified weight on a target of specified size.

D-2 Relevance: 1

Veneziano, Daniele

PROBABILISTIC AND STATISTICAL MODELS FOR SEISMIC RISK ANALYSIS

Massachusetts Institute of Technology, July 1975.

A number of models for engineering seismic risk analysis are proposed and compared. In all cases, uncertainties are included, both for the seismic demand at the site and for the seismic resistance of the facility. Particular attention is given to the effects of induced uncertainty on the model parameters, due to the limited information available. These parameters include the mean occurrence rate of seismic events, the "decay rate" of the frequency-site intensity law, the mean value, and the variance of the resistance distribution. The results from the model are compared with

currently used approximations, which are found not to be conservative. A numerical example is presented that deals with the estimation of seismic risk for nuclear power plants in Massachusetts.

D-3 Relevance: 1

Matthiesen, R., G. Howard, and C. B. Smith

APPENDIX IV--SEISMIC SAFETY OF POWER PLANTS: PUBLIC HEALTH RISKS
OF THERMAL POWER PLANTS

University of California, Los Angeles, California, UCLA-ENG-7242, May 1972.

This report outlines a methodology and provides preliminary guidelines for evaluating sites and designs for power plants subjected to strong vibratory ground motions from earthquakes in California. Methods are proposed for (1) estimating an upper bound to ground motion at a site, (2) determining the required response of selected nuclear power plant structures, piping, and equipment to this ground motion, and (3) estimating the capacity of typical reactor components for responding safely to earthquake ground motions. A comparison of the required response and the capacity of critical components determines the suitability of a particular site. Preliminary comparisons indicate that appropriately designed nuclear power plants could be safely located in most areas of the state.

D-4 Relevance: 1

Donovan, Neville C. and Ann E. Bornstein

A REVIEW OF SEISMIC RISK APPLICATIONS

Dames and Moore, San Francisco, California, 1975.

Seismic risk procedures have been available for several years in a form that has engineering applications. The authors have extended these procedures by using the results of the research in practical engineering situations. These are situations in which design decisions have been significantly guided by the results of the seismic risk analysis. The published procedures have had to be modified because of two requirements: (1) closer representation of the parameters used in the analysis, with particular emphasis on attenuation relationships, and (2) development of procedures that simplify the application of the analysis in areas where the seismic sources are relatively well-understood and can be included in the source modeling.

D-5 Relevance: 2

Okrent, D.

A SURVEY OF EXPERT OPINION ON LOW PROBABILITY EARTHQUAKES

University of California, Los Angeles, California, UCLA-ENG-7515,
February 1975.

Seismic history is generally much too short to provide an accurate statistical basis for determining low probability earthquakes at every potential site. Detailed knowledge of the cause or source of earthquakes is far from complete, particularly for the eastern United States. In examining uncertainties in the prediction of low probability earthquakes, a number of experts were invited to review 11 nuclear plant sites in the United States to provide their independent estimates on seismicity. The report summarizes correlations employed between seismic intensity and peak acceleration, and the estimates of uncertainty.

D-6 Relevance: 2

Algernisson, S. T.

SEISMIC RISK STUDIES IN THE UNITED STATES

Fourth World Conference on Earthquake Engineering, Santiago, Chile,
January 1969.

A new Seismic Risk Map of the United States was presented, together with strain release and maximum Modified Mercalli intensity maps of the country. Frequency of occurrence of damaging earthquakes was not considered in assigning ratings to the various zones on the risk map, but studies of earthquake frequency were included to aid in using the risk map.

D-7 Relevance: 2

Starfield, A. M. and W. C. McClain

PROJECT SALT VAULT: A CASE STUDY IN ROCK MECHANICS

International Journal of Rock Mechanics, Mining Science and Geomechanics:
Abstracts, 10:641-457, 1973.

This paper outlines the rock mechanics investigation associated with Project Salt Vault, a feasibility study of radioactive waste disposal in an underground salt formation in Lyons, Kansas. A theoretical model of creep and thermal effects in bedded salt was developed and correlated with laboratory and large-scale field experiments. The successful correlation indicated that the model can be applied to full-scale operations.

D-8 Relevance: 2

Gera, Ferruccio

REVIEW OF SALT TECTONICS IN RELATION TO THE DISPOSAL OF RADIOACTIVE WASTES
IN SALT FORMATIONS

Bulletin of the Geological Society of America, 83:3551-3574, December 1972.

The plastic deformation of salt formations is reviewed to evaluate the possibility of diapiric processes affecting the salt beds used for radioactive waste disposal. It is concluded that, in the final stage of salt intrusion, rates of diapir growth as high as a few millimeters per year are possible, and in the initial phase of plastic deformation of the salt bed, flow rates should be markedly lower. The risk of excessive deformation leading to release of radioactive wastes from the geological containment can be kept acceptably low if the disposal formation meets the following requirements: (1) the bedded salt is located in a geologically stable area; (2) the subhorizontal salt beds are exposed to very limited differential loading; (3) the thickness of the salt beds is on the order of 100 to 300 m; and (4) the depth of the salt beds is between 300 and 700 m.

D-9 Relevance: 2

Burton, Ian, Robert W. Kates, and Gilbert F. White

THE HUMAN ECOLOGY OF EXTREME GEOPHYSICAL EVENTS

University of Toronto, Department of Geography, Working Paper No. 1,
Toronto, Ontario, 1968.

This paper evaluates perceived risk resulting from natural hazards such as flood and earthquakes. For any given natural disaster, the public can make a wide range of theoretically possible adjustments. These adjustments range from technological improvements (or the "tech fix") to altered human behavior (e.g., moving out of hazardous areas). The authors found that public information has not led to rapid and solid adjustments because individuals perceive hazards very differently. Laymen have a higher degree of awareness than is commonly assumed by professionals, although their knowledge of the frequency and probability of a hazardous event often departs from the scientific description. On the other hand, although the professional view incorporates stochastic probabilities comfortably, the estimates of frequency and magnitude are not so good as the layman often assumes them to be. The fundamental difference between the two groups appears to be their tolerance of uncertainty. There is strong relationship between adoptions of ameliorative measures and frequency of hazard, and especially the perceived frequency of hazard. However, when the frequency of hazard is intermediate and a high variability exists in perceived frequency, wide variations are observed in the proportion of

the population that advocates adjustments. In addition, there is indication that the public develops anxiety to a significantly greater extent in dealing with nonnatural or man-made hazards than with natural ones.

D-10 Relevance: 2

Read, J.B.L. and L. W. Bell

AN ASSESSMENT OF THE BASES FOR SELECTING CRITERIA FOR PROTECTION
AGAINST TORNADO-ENTRAINED DEBRIS

Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission,
Washington, D.C., NUREG-0121, May 1977.

Tornado missiles have been identified as credible threats to nuclear power plants. To assess the risk of damage from tornado missiles, this report discusses the probabilities and consequences of the acceleration of solid objects by air motion within a tornado. Design criteria for protection against tornado missile risk are suggested. The work summarized in this report would be useful in assessing potential risks to aboveground nuclear waste storage operations from tornado damage.

D-11 Relevance: 2

Blake, V. E

A PREDICTION OF THE HAZARDS FROM THE RANDOM IMPACT OF METEORITES
ON THE EARTH'S SURFACE

Sandia Laboratories, Albuquerque, New Mexico, SC-RR-68-838, December 1968.

The probability of a person being injured or killed by a meteorite is estimated. It is concluded that there is a distinct possibility that someone will be seriously injured or killed by a meteorite within the next 50 years. In addition, there is a significant probability that a large meteorite will strike a populated area and kill a number of people. In addition, this report gives data relating meteorite weight characteristics to frequency of impacts; these data can be used in other damage assessments.

D-12 Relevance: 2

Twisdale, L. A., W. L. Dann, S. T. Lew, T. L. Davis, J. C. Hsu, and B. S. McConnell

TORNADO MISSILE RISK ANALYSIS

Carolina Power and Light, Raleigh, North Carolina, January 1976.

This preliminary report develops a probabilistic formula for characterizing the effects of tornado-generated missiles on nuclear plant safety. The types of analyses evaluated are: probability analysis and risk assessment; tornado windfield modeling; missile characterization and plant specification; and missile aerodynamics and trajectory analysis. Much of the methodology discussed is tentative and requires further investigation.

D-13 Relevance: 2

Ritchie, Lynn T., Warren D. Brown, and J. Robert Wayland

EFFECTS ON RAINSTORMS AND RUNOFF ON CONSEQUENCES OF NUCLEAR REACTOR ACCIDENTS

Sandia Laboratories, Albuquerque, New Mexico, SAND 76-0429, October 1976.

A preliminary model describing the effects of washout and runoff on the consequences of a nuclear reactor accident is presented. The most important new feature of this stratified model in relation to the COMO model used in the reactor safety study (WASH-1400) is the spatial structure of rainstorms and runoff consisting of four levels of rain activity normalized by rain gage data. The predicted concentrations or radioactivity and resultant health consequences of the stratified model are compared with those of the model used in WASH-1400. For individual storms, runoff and the spatial structure of the rain in the new model can result in health consequences that are significantly different from those in the COMO model. The differences between the predictions of the two models are small for the stratified sample run.

D-14 Relevance: 2

Yegian, Mishal K.

RISK ANALYSIS FOR EARTHQUAKE-INDUCED GROUND FAILURE BY LIQUEFACTION

Massachusetts Institute of Technology, Seismic Design Decision Analysis Report No. 26, NTIS PB-256 793, May 1976.

A methodology is proposed to study the likelihood of ground failure by liquefaction. The two alternative probabilistic models developed consider uncertainties present in the methods of analysis employed and the parameters used. The first model is based on a new empirical method of analysis for liquefaction that employs earthquake magnitude and hypocentral distance. Current empirical methods, on the other hand, rely on ground acceleration for which there are poor historical measurements. The second probabilistic model is based on a modified version of a current method of analysis for liquefaction. These two models are incorporated into risk analysis for liquefaction and a case study performed for a nuclear power plant. This methodology may be useful in conducting a risk assessment for the above-ground near-surface facilities of a nuclear waste repository.

D-15 Relevance: 3

Cummings, G. E., J. E. Wells, H. E. Lambert, and G. St. Leger-Barter
ADVISABILITY OF SEISMIC SCRAM

Lawrence Livermore Laboratory, Livermore, California, UCRL-52156, June 1976.

This study assesses the value of seismic trip (scram) systems for commercial nuclear power plants. Five topics were addressed: (1) the likelihood that existing instrumentation would trip the plant, (2) the consequences of spurious trips, (3) the consequences of tripping during an earthquake, (4) the advantages of a controlled shutdown, and (5) the desirability of continuing operation. A comparative risk assessment, using fault tree analysis, was made to evaluate the risk of requiring seismic trip systems versus the risk of not requiring them. Two categories of risk were identified: core meltdown accidents resulting from earthquakes and other causes; and loss of emergency services during an earthquake. The study results indicate that seismic trip systems would have a small and undetermined effect on risk due to nuclear reactor accidents. The estimated risk due to earthquake-caused events is of the order 10^{-6} , which is greater than reported in the Reactor Safety Study. It was found that the seismic trip systems might increase the risk to society as a whole by denying a source of power during an earthquake emergency. Recommendations were included to improve existing instrumentation.

D-16 Relevance: 3

Anderson, R. P. and D. R. Armstrong

COMPARISON BETWEEN VAPOR EXPLOSION MODELS AND RECENT EXPERIMENTAL RESULTS

Heat Transfer-Research and Design, American Institute of Chemical Engineers Symposium Series, 70(138):31-47.

This paper traces the history and development of current understanding of vapor explosions, and discusses results of recent experiments and second-generation mechanistic models. The discussion of theory and the models presented may be useful for assessing risk of explosion in above-ground operations at a nuclear waste repository. In particular, the results of experiments are compared to theoretical models to explain the energy level of the explosions. One proposed model explains several apparently inconsistent results by making additional assumptions. This homogeneous nucleation model also suggests that some types of vapor explosions may be prevented by sufficient nucleation sites. This preventive measure has important ramifications for nuclear power plants, where the intense radiation field in reactors can produce many nucleation sites.

D-17 Relevance: 3

Murakami, Masaya and Joseph Penzien

NONLINEAR RESPONSE SPECTRA FOR PROBABILISTIC SEISMIC DESIGN AND DAMAGE ASSESSMENT OF REINFORCED CONCRETE STRUCTURES

Earthquake Engineering Research Center, University of California at Berkeley, Prepared for National Science Foundation, NTIS PB-259 530, November 1975.

In this study, 20 each of 5 different types of artificial earthquake accelerograms were generated for computing the nonlinear response spectra of 5 structural models representing reinforced concrete buildings. For probabilistic design and damage assessment, mean values and standard deviations of ductility factors that have a range of prescribed strength values and a range of natural periods were determined for each model. In investigating the strength levels required for each model, it was assumed that only minor damage is acceptable under moderate earthquake conditions and that total damage or complete failure should be avoided under severe earthquake conditions. Response ductility factors and coefficients of variation presented provide necessary data for probabilistic seismic-resistant designs.

D-18 Relevance: 3

Oliveria, Carlos S.

SEISMIC RISK ANALYSIS

Earthquake Engineering Research Center, University of California at Berkeley, Prepared for National Science Foundation, NTIS PB-235 920, January 1974.

This state-of-the-art report reviews the studies on the probability-statistical measure of seismic action at a site and the consequences for the structure. The following points include the main problems in seismic risk analysis and recommended research needs: (1) validity of the assumptions leading to the models of generation and intensity of earthquakes and mechanisms of ground motion propagation, based on records of earthquakes and on geological and morphological features of the area; (2) derivation of the extreme value distributions of the response of soil and structures to seismic events; (3) Bayesian approach as an alternative tool for cases in which imperfect or lacking data suggest the characterization of the mean rate of occurrence of earthquakes through conditional distribution; (4) for application of risk analysis to further theories of damage, structural safety, optimization, and the like, a better understanding of costs and resistance conditions is required; and (5) the influence of dispersion in the response cannot be ignored as long as inelastic excursion is allowed.

D-19 Relevance: 3

Chan, Conway, George Sliter, and Boyer Chu

NUCLEAR PLANT TORNADO SAFETY

EPRI Journal, 1(7):12-17, September 1976.

Because the probabilities and mechanics of tornado damage have never been determined quantitatively, research on this subject is of considerable importance. This paper describes research being conducted by EPRI in five related areas:

- Tornado wind fields.
- Trajectories of tornado-driven projectiles.
- Full-scale impact tests.
- Local response of concrete to impact.
- Missile risk analysis.

An interdisciplinary approach is taken in this integrated program to provide the power industry with useful tools based on realistic calculations and simulations.

D-20 Relevance: 3

Ayyaswamy, P., B. Hauss, T. Hseih, A. Moscati, T. E. Hicks, and D. Okrent
ESTIMATES OF RISKS ASSOCIATED WITH DAM FAILURE

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7423, March 1974.

The probabilities and potential consequences of dam failure in California, primarily due to large earthquakes, are estimated by examining 11 dams with relatively large populations downstream. Mortalities in the event of dam failure were found to range from 11,000 to 260,000, and damage to property could be as high as \$720 million. Predictions of dam failures were based on IX and X intensity earthquakes and their reoccurrence times. Damage estimates reflect losses incurred by structural damage to buildings and do not include loss of income.

D-21 Relevance: 3

Caputo, Michele

A MECHANICAL MODEL FOR THE STATISTICS OF EARTHQUAKES, MAGNITUDE, MOMENT, AND FAULT DISTRIBUTION

Bulletin of the Seismic Society of America, 67(3):849-861, June 1977.

This paper presents a model to explain the Ishimoto Iida empirical law for earthquake statistics. The model is shown to fit the statistics of earthquakes of all of the regions of the world for which reliable catalogs of earthquakes exist. The asymptotic behavior of the derived statistical law is studied, and the model is applied to estimate the number and dimensions of the faults in the central Apennines. If the rate at which the elastic energy is stored in a region of the earth's crust is known and if a catalog of earthquakes of the region is available, the model estimates the number and size of faults of the region, and the maximum magnitude and seismic moment possible in the region.

D-22 Relevance: 3

Epstein, B. and C. Lomnity

A MODEL FOR THE OCCURRENCE OF LARGE EARTHQUAKES

Nature, 211(5052):954-956, 27 August 1966.

This paper outlines a probability model that provides a basis for predicting the occurrence of the largest earthquake magnitudes. The validity of the model was checked by applying it to earthquakes in California from 1932 to 1962. Despite the known lack of homogeneity of earthquake occurrence there, the simplified approach presented provides reasonable estimates for the occurrence of large earthquakes--given uncertainty due to the short historical record. This paper is useful for comparison with current state-of-the-art papers on predicting earthquake occurrence.

D-23 Relevance: 3

Ekren, E. G., G. A. Dinwiddie, J. W. Mytton, William Thorderson, J. E. Weir, Jr., E. N. Hinrichs, and L. J. Schroder

GEOLOGIC AND HYDROLOGIC CONSIDERATIONS FOR VARIOUS CONCEPTS OF HIGH-LEVEL RADIOACTIVE WASTE DISPOSAL IN CONTERMINOUS UNITED STATES

U.S. Geological Survey, Open-File Report 74-158, 220, 1974.

This investigation evaluated and identified those geohydrologic environments in the conterminous United States that are best suited to underground disposal of high-level radioactive waste; it also established geologic and hydrologic criteria pertinent to high-level waste disposal. The investigation focused principally on the geohydrologic possibilities of several methods of disposal in rocks other than salt. Criteria were identified that assure hydrologic isolation of the waste and containment within a small radius of the emplacement zone. Areas and types of geologic formations were identified that satisfy most geohydrologic requirements for deep drill holes and matrix holes. Specific geohydrologic information required for each disposal site was listed.

D-24 Relevance: 3

Gates, W. Lawrence and John Imbrie

CLIMATIC CHANGE

The Rand Corporation, Santa Monica, California, May 1975.

This paper provides a state-of-the-art review of climate modeling, paleoclimatic studies, and related research. It is a very thorough treatment of the literature and of ongoing research.

D-25 Relevance: 3

Budyko, M. I.

ON PRESENT-DAY CLIMATIC CHANGES

Tellus, 29(3):193-204, 1977.

This paper evaluates the possibility of using the numerical models of climatic theory to study future climatic changes under the conditions of the increasing influence of man's economic activity on climate. The results show that, if major feedbacks among individual climatic elements are considered, simple models of semiempirical climatic theory are suitable for studying climatic changes after data on past climatic changes have been verified. The effect of economic activity on the global climate is determined by three factors: the growth of CO₂ concentration; the increase of the aerosol mass; and the growth of heat production by sources of energy additional to solar radiation. Using the semiempirical model of the atmospheric thermal regime, a rise in CO₂ concentration by 10% raises the mean temperature near the earth's surface by 0.3°. Thus, a temperature increase of 0.3-0.4° over the past 100 years can be estimated. It was also established that man-made aerosols under present conditions reduced the mean air temperature by 0.5°. Because this value is higher than the predicted temperature rise from increasing CO₂, the decrease in the mean global air temperature by some tenths of a degree in recent decades can be fully or partly explained by man-made factors.

D-26 Relevance: 3

Hsieh, T. and D. Okrent

SOME PROBABILISTIC ASPECTS OF THE SEISMIC RISKS OF NUCLEAR REACTORS

School of Engineering and Applied Science, University of California at Los Angeles, California, UCLA-ENG-76113, December 1976.

The potential for existing cracks in piping systems to grow to critical size and cause system failure during a severe earthquake was examined, and critical crack size based on calculations using linear elastic mechanics was reviewed. The potential importance of seismic events leading to a core-melt accident was examined by factoring the effect of design errors and system degradation into an estimate of the probability of a core-melt accident due to seismic events.

D-27 Relevance: 3

Shannon & Wilson, Inc. and Agbabian Associates

EVALUATION OF SOIL LIQUEFACTION POTENTIAL FOR LEVEL GROUND DURING
EARTHQUAKES--A SUMMARY REPORT

NTIS PB-257 232, October 1975.

This report evaluates the results of a 3-year research program conducted to investigate the settlement and liquefaction of sands under multidirectional shaking. The investigation indicated that the behavior of a saturated sand under cyclic loading conditions is a function of its geologic and seismic history, grain structure, and placement density. It was concluded that a sand deposit's resistance to liquefaction can best be estimated by laboratory testing on undisturbed samples. Cyclic triaxial tests used in conjunction with appropriate correction factors to account for multidirectional shaking, simple shear loading conditions, and overconsolidation effects can provide valid data on cyclic loading characteristics. The two basic methods for evaluating liquefaction potential and the effects of liquefaction were reviewed and updated.

D-28 Relevance: 3

Barnes, Harvey

GEOLOGIC AND HYDROLOGIC BACKGROUND FOR SELECTING SITE OF PILOT-PLANT
REPOSITORY FOR RADIOACTIVE WASTE

Bulletin of the Association of English Geologists, 11(1):83-92, 1974.

This paper assesses the geology and hydrology of various salt and argillaceous deposits in the United States as potential sites for underground emplacement of noxious or radioactive wastes. Conducted by the USGS, the areas investigated included the Permian salt basin, the Paradox basin in Utah and Colorado, the Supai salt basin and Luke salt body in Arizona, and northern Gulf Coast salt-dome province, and various impermeable argillaceous rocks. Of these rock types and areas, the bedded salt deposits of southeastern New Mexico and the Paradox basin seem to be the most promising sites.

D-29 Relevance: 3

Simin, Emil

WIND CLIMATE AND FAILURE RISKS

Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, 102(ST9):1703-1707, September 1976.

Relations among risk of failure, degree of wind sensitivity, type of wind climate, and mean recurrence intervals used in design are examined. The results suggest that the design wind maps based on a standard mean recurrence interval are incompatible with the purpose--implicit in building code provisions--of ensuring consistent levels of safety for structures subjected to wind loads. To achieve this purpose, research is required to develop regional design wind speed provisions that are based on reliability considerations. The results show that a strong correlation exists between probability of structural failure and type of wind climate, as defined quantitatively by the parameters of the extreme wind distribution. If all other relevant factors are equal, including the degree of sensitivity to the wind, the probability of failure of a structural member may increase considerably as a function of wind climate. The study also concluded that research is needed to develop effective design criteria that ensure more consistent safety levels for structural members with varying sensitivities to wind.

D-30 Relevance: 3

Salvatori, Romano

SYSTEMATIC APPROACH TO SAFETY DESIGN AND EVALUATION

IEEE Transactions on Nuclear Science, NS-18(1):495-504, February 1971.

The probabilistic approach to safety offers a mathematical means for dealing with a highly subjective problem. Therefore, it is proposed that goals be defined, establishing levels of risk tolerance not specifically related to biological effects. The proposed procedure is based on the following principles:

- (1) Failures or maloperations can be piled up to give the same "limit consequence."
- (2) The "limit consequence" status of a reactor can be classified in the category of natural disasters.
- (3) The acceptable frequency level for the "limit consequence" status of a plant can be apportioned among the events that push a reactor into the limit consequence status.

- (4) This systematic process for assessing acceptable probability levels for each event will assist the designer (or reviewer) in making decisions about: what accidents should not be postulated in the design and what steps should be taken to keep the likelihood of these accidents acceptable; and what redundancy, test programs, maintenance programs, and the like are required for the various categories of emergency systems.

Examples are given to illustrate the practical applications of the proposed approach.

D-31 Relevance: 3

Congressional Research Service

A PRIMER ON CLIMATIC VARIATION AND CHANGE

Prepared for the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, Government Printing Office, Washington, D.C., September 1976.

This document comprehensively evaluates current understanding about climate change. The topics discussed are: (1) effects on agriculture; (2) effects on energy consumption; (3) effects on man; (4) effects on water availability; (5) use of simulation models; and (6) factors governing climate change. In addition, many current research articles are attached to the report.

D-32 Relevance: 3

Congressional Research Service

A PRIMER ON CLIMATIC VARIATION AND CHANGE

Prepared for the Subcommittee on the Environment and the Atmosphere of the Committee on Science and Technology, U.S. House of Representatives, 94th Congress, U.S. Government Printing Office, Washington, D.C., September 1976.

This report describes the current predictive capabilities of climatologists and concludes that little is known about climate and its associated physical processes. So little is known, in fact, about whether predictions of climatic change are accurate that it is difficult to ascertain if long-term predictions are a realistic possibility. The report describes the state-of-the-art of atmospheric modeling and paleoclimatology. Possible implications of a changing climate are evaluated as they might effect agriculture, energy requirements, transportation, and water availability. The potential for man-made climatic change is also discussed.

D-33 Relevance: 3

Blasing, T. J. and H. C. Fritts

RECONSTRUCTING PAST CLIMATIC ANOMALIES IN THE NORTH PACIFIC AND WESTERN NORTH AMERICA FROM TREE-RING DATA

Quaternary Research, 6:563-579, 1976.

This paper is an excellent example of recent research that has been successful in extending the modern climatic record by the use of multivariate analysis techniques in conjunction with tree-ring analysis (dendrochronology). Winter climatic anomalies in the North Pacific sector and western North America were statistically calibrated with tree-ring data in western North America and reconstructed back to AD 1700. The climatic conditions reconstructed for the 18th and 19th centuries are summarized and compared with the 20th-century record, with significant differences over time indicated in the reconstructed records.

D-34 Relevance: 3

Fritts, Harold C., Terence J. Blasing, Bruce P. Hayden, and John E. Kutzbach

MULTIVARIATE TECHNIQUES FOR SPECIFYING TREE-RING GROWTH AND CLIMATE RELATIONSHIPS AND FOR RECONSTRUCTING ANOMALIES IN PALEOCLIMATE

Journal of Applied Meteorology, 10(5): 845-864, October 1971.

This classic paper described the emerging use of multivariate techniques in conjunction with tree-ring analysis to reconstruct past climates. Technical advances were described and evidence was presented to support the analytical method. Reconstructions of anomalous variations in atmospheric circulation for portions of the Northern Hemisphere to AD 1700 were presented.

D-35 Relevance: 3

Duke, C. M., and S. E. Jacobsen

OPTIMIZATION OF WATER RESOURCE SYSTEMS INCORPORATING EARTHQUAKE RISK: 1973 CONTRIBUTIONS

University of California, Water Resources Center Contribution No. 141, June 1973.

This report contains two papers of particular interest to risk assessment. The first, "On the Consideration of Earthquake Risk in the Design of Water Resource Systems," develops a theoretical model to evaluate the damage costs expected from earthquakes for a segment of a water distribution system located in a large seismic region. The second, "Earthquake Risk in Water Resource System Planning," develops a space distribution of earthquakes in size and time; when combined with site and intensity functions, this distribution establishes the probability of each level of intensity at any site. The report shows this method can be applied to optimizing the routing of aqueducts or other systems extending over large areas.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION D

M-15

Section E

PERTINENT HAZARD STUDIES ASSOCIATED WITH HUMAN NON-OCCUPATIONAL CAUSES

E-1 Relevance: 2

Bennett, Carl A., William M. Murphy, and Theodore S. Sherr
SOCIETAL RISK APPROACH TO SAFEGUARDS, DESIGN AND EVALUATION

Energy Research and Development Administration, Washington, D.C.,
ERDA-7, June 1975.

The safeguards problem is described in this report in terms of the events affecting societal risk and the adversary actions leading to the events. A methodology is illustrated for characterizing the problem in terms of the necessary sequence of adversary actions. The methodology uses fault tree terminology to construct adversary action trees as a systematic method of identifying all combinations that could lead to a nuclear incident. The societal risk approach suggests allocating available resources to minimize risks to the public, or alternatively, the allocation of resources to efficiently provide the protection required to achieve a given level of acceptable risk.

E-2 Relevance: 2

Gref, L. G. and J. W. Rosengren
AN ASSESSMENT OF SOME SAFEGUARDS EVALUATION TECHNIQUES

R&D Associates, Arlington, Virginia, NUREG-0141, February 1977.

This study provides the NRC with information on the availability and capability of current evaluation techniques to support safeguard regulations that emphasize performance requirements. Nine evaluation techniques were considered: four deal with material control, four with fixed-site physical protection, and one with transportation safeguards. All but one of the techniques (NBS-DPA) employ computer codes; most are closely tied to a data base associated with the technique. An overall appraisal of the nine techniques studied indicates that, although a significant and growing expertise exists, no one technique is sufficiently general to treat either the physical protection or material control evaluation problem comprehensively.

E-3 Relevance: 2

Boozer, D. D., B. L. Hulme, S. L. Daniel, G. B. Varnado, C. A. Bennett, L. D. Chapman, and D. Engi

SAFEGUARDS SYSTEMS EFFECTIVENESS MODELING

Sandia Laboratories, Albuquerque, New Mexico, SAND 76-0428, 1976.

A general methodology for the comparative evaluation of physical protection system effectiveness at nuclear facilities is currently under development. This approach also applies to problems of sabotage or theft at fuel cycle facilities. In this paper, the overall methodology and the primary analytic techniques used to assess system effectiveness are briefly outlined.

E-4 Relevance: 2

Chapman, Leon D.

EFFECTIVENESS EVALUATION OF ALTERNATIVE FIXED-SITE SAFEGUARD SECURITY SYSTEMS

Sandia Laboratories, Albuquerque, New Mexico, 1975.

An evaluation of a fixed-site physical protection system must consider the interrelationships of barriers, alarms, on-site and off-site guards, and their effectiveness against a forcible adversary attack intent on sabotage or theft. A computer model, Forcible Entry Safeguard Effectiveness Model (FESEM), has been developed at Sandia Laboratories to evaluate alternative fixed site protection systems. A hypothetical fixed-site protection system is defined, and relative evaluations from a cost-effectiveness perspective are presented to demonstrate how the model can be used. Trade-offs involving on-site and off-site response forces and response times, perimeter system alarms, barrier configurations, and varying levels of threat are analyzed. The computer model provides a framework for performing inexpensive experiments on fixed-site security systems, for testing alternative decisions, and for determining the relative cost-effectiveness associated with these decision policies.

E-5 Relevance: 2

Hornyik, Karl

HAZARDS TO NUCLEAR PLANTS FROM OFF-SITE RELEASE OF TOXIC VAPORS

Nuclear Technology, 28:199-207, February 1976.

This method for assessing the risk involved in shipping toxic compounds past nuclear power plants uses a postulated chain of events, starting with a traffic accident that causes instantaneous release of the compound as

vapor and leading to incapacitation of control operators in the nuclear plant. Deterministic and statistical models appropriate to the respective event are described. The statistical treatment of relevant atmospheric conditions is a major improvement over more conservative assumptions commonly made in current analyses of this problem. Consequently, the risk estimated, as expressed in usual terms of the annual probability of an unacceptable event, is substantially reduced, with no protective measures taken other than potential control room isolation.

E-6 Relevance: 2

Grund, J. E. and K. Hornyik

HAZARDS FROM AIRCRAFT

Proceedings Institute of Environmental Sciences, pp 1-5, 1974.

This article deals with the probability that an aircraft may crash near or directly into a nuclear power plant. Because of missile and/or fire effects, such a crash could be postulated to result in radioactive releases that could endanger public health and safety. A number of models are presented that, under given sets of conditions, permit evaluation of aircraft strike probability. They also permit assessments of the effects of varying conditions, such as plant location or changes in flight patterns. This allows the determination of the sensitivity of resulting probabilities to variations in certain parameters.

E-7 Relevance: 3

Chester, C. V.

ESTIMATES OF THREATS TO THE PUBLIC FROM TERRORIST ACTS AGAINST
NUCLEAR FACILITIES

Nuclear Safety, 17(6):659-665, November-December 1976.

The potential fatalities, or extent of potential lethal consequences, from terrorist acts against nuclear facilities are estimated. The most severe threat is from the theft of fissionable material and subsequent fabrication of a clandestine nuclear explosive. A nuclear explosive of efficient design exploded without warning in a crowded high-rise commercial district could produce a million fatalities. The uncontained meltdown of a power reactor and, to a lesser extent, the dispersal of plutonium are minor threats to human life if there is any warning, but they comprise potentially great and extremely coercive threats to property. The toxicity of plutonium is no worse than that of much more easily available nerve gas and requires weeks or months to kill as opposed to minutes for nerve gas. Attacks on spent fuel shipments, high-level waste shipments, reprocessing plants, or waste tanks present minimal threats to human life.

E-8 Relevance: 3

Parks, R. E., C. R. Condon, and R. J. Newmaker

SAFEGUARDS ASSURANCE ANALYSIS: A PRACTICAL APPLICATION OF THE FAULT TREE TECHNIQUE IN SAFEGUARD DESIGN

Nuclear Materials Management, 5(3):248-257, Fall 1976.

Safeguard assurance analysis was developed to provide early identification of potential problems in a physical security/safeguards system so that alternatives could be recommended to correct or reduce those problems. The analysis systematically reviews facility design, candidate safeguard features, and applicable regulatory requirements in light of credible threat scenarios. The qualitative results of the analysis are used to assess the capability of the system and to identify problem areas. The quantitative results are used in equipment selection and to eliminate inefficient safeguard redundancies.

E-9 Relevance: 3

U.S. Nuclear Regulatory Commission and U.S. Energy Research and Development Administration

JOINT ERDA-NRC TASK FORCE ON SAFEGUARDS

Washington, D.C., NUREG-0095, ERDA 77-34, July 12, 1976.

On March 12, 1976, managers from ERDA and NRC met to review safeguards investigations at nuclear fuel cycle facilities licensed by the NRC that process nuclear materials under ERDA contracts. A joint ERDA-NRC task force was created to propose an action plan for improving the control and protection of nuclear materials at NRC-licensed fuel cycle facilities that possess significant amounts of highly enriched uranium and plutonium. This report briefly summarizes the task force findings and proposed plan of action.

E-10 Relevance: 3

Rasmussen, Norman C.

PROBABILISTIC RISK ANALYSIS, ITS POSSIBLE USE IN SAFEGUARDS PROBLEMS

Nuclear Waste Management, 5(3):66-88, 1976.

The Reactor Safety Study report (WASH-1400) stimulated interest in the use of this methodology as a possible way of addressing the risk involved in other parts of the nuclear fuel cycle as well as for social activities. This paper briefly reviews the Reactor Safety Study methodology and briefly discusses its possible application to the safeguards problem. This paper is primarily a defense of the Reactor Safety Study. The paper

concludes that these methodologies may be applied to the development of effective safeguards. However, an overall quantitative risk assessment of the safeguards issue is at present beyond the capability of the methodology.

E-11 Relevance: 3

U.S. Nuclear Regulatory Commission

SUMMARY REPORT OF WORKSHOP ON SABOTAGE PROTECTION IN NUCLEAR POWER
PLANT DESIGN

Sandia Laboratories, Albuquerque, New Mexico, NRC-13, February 1977.

During the summer of 1976, Sandia Laboratories hosted a workshop on Sabotage Protection in Nuclear Power Plant Design in which 11 consultants from the nuclear power industry participated. The objective of the workshop was to identify practicable design measures that could be employed in future nuclear power plants to provide increased protection against sabotage. This report summarizes the conclusions and recommendations of the workshop. The applicability of this report to underground nuclear waste storage is that facility design should take sabotage into consideration.

E-12 Relevance: 3

Willrich, Mason and Theodore B. Taylor

NUCLEAR THEFT: RISKS AND SAFEGUARDS

A Report to the Energy Policy Project of the Ford Foundation, Ballinger Publishing Company, Cambridge, Massachusetts, 1974.

This book is one of a series of studies commissioned by the Energy Policy Project of the Ford Foundation to contribute to today's public discussion about nuclear energy. It analyzes the possibility of nuclear violence facilitated by using fissionable material that might be stolen from the U.S. nuclear power industry. Although this book does not specifically address the problem of theft of nuclear wastes, the information on safeguards and risks of nuclear theft are applicable to that problem.

E-13 Relevance: 3

Jenkins, Brian Michael

TERRORISM AND THE NUCLEAR SAFEGUARDS ISSUE

The Rand Corporation, Santa Monica, California, March 1976.

In this short paper, the author discusses the difference between nuclear safety and nuclear safeguards. On the issue of safeguards, he indicates that incidents in which terrorists have deliberately tried to kill large numbers of people or cause widespread damage are rare. Terrorists want a lot of people watching, not a lot of people dead. Mass casualties simply may not serve the terrorists' goals and could alienate the population. Terrorist actions have tended to be aimed at producing immediate dramatic effects, which might include taking over a large national radioactive waste storage facility.

E-14 Relevance: 3

Bennett, Carl A.

COMPARISON OF SOCIETAL RISKS

Nuclear Materials Management, 451-457, Fall 1976.

The utility of the social risk approach to the design and evaluation of safeguard systems is examined, with particular reference to the comparison of the relative effectiveness of various safeguard mechanisms. Research on threat evaluation is reviewed, and the need for further research on its consequences is discussed in terms of extending the definition of the safeguards objective from system capability to social consequences and of establishing public confidence.

E-15 Relevance: 3

Nuclear Fuel Cycle Program Staff, Sandia Laboratories

SAFETY AND SECURITY OF NUCLEAR POWER REACTORS TO ACTS OF SABOTAGE

Nuclear Safety, 17(6):665-670, December 1976.

This study considers the vulnerability of U.S. commercial LWR power plants to sabotage. The susceptibility of nuclear plants to sabotage and the consequences of a successful attack are compared with other industrial and civil targets. The study concludes that because of their safety-based design and construction, nuclear power plants have inherent resistance to sabotage. A highly determined, knowledgeable, planned, and skillful effort would be required for saboteurs to circumvent plant security measures and disable the engineered safety features in order to cause a radioactive release from the plant. Countermeasures involving plant design, protection

systems, administrative control, and emergency planning are recommended to provide increased protection against sophisticated efforts.

E-16 Relevance: 3

Soloman, Kenneth A.

ANALYSIS OF REACTOR HAZARDS DUE TO AIRCRAFT MISSILES

American Nuclear Society Transactions, 23:312-313, 1976.

This study develops and applied a generalized methodology to approximate both the best-estimate and pessimistic probabilities that an aircraft or missile will strike the effective plant area of a nuclear generating facility. Three sets of probability equations are given, one for each of the following conditions: vector airways, airport within five miles, a missile base more than five miles away. The equations can be used to calculate a crash probability and, hence, a crash consequence for each type of aircraft or missile hazard.

E-17 Relevance: 3

Clark, R. G.

A METHODOLOGY FOR COPING WITH SABOTAGE AND DIVERSION AT COMMERCIAL NUCLEAR FACILITIES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-SA-5043, July 1974.

This report claims that sabotage and diversion of nuclear materials at commercial nuclear facilities can be averted by using modern analytical methods and instrumentation. The analytical methods consist of: (1) using safety tree (fault and event trees) analysis for simulation, and (2) implementing a system of modern instrumentation and surveillance devices.

E-18 Relevance: 3

Kendrick, H., E. Lofgran, W. Runquist, and R. Fullwood

AN APPROACH TO THE EVALUATION OF SAFEGUARDS SYSTEMS EFFECTIVENESS

Nuclear Materials Management, 5(3):226-238, 1976.

A methodology for considering safeguards systems effectiveness is described. Adversary action sequences are delineated by event and fault tree techniques. Two variations in this type of graphic book-keeping are presented, and the adversary action sequences identified are quantified by a system simulation model. A Monte Carlo computer code has been written to evaluate time distribution or probability as a function of time of the adversary action sequences.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION E

M-12, M-13

Section F

SELECTED OCCUPATIONAL HAZARD STUDIES

F-1 Relevance: 2

Brooks, D. B. and D. R. Berry

MINE HEALTH AND SAFETY AS AN ANALYTIC PROBLEM

Department of Energy, Mines, and Resources, Ottawa, Canada, MR 125,
February 1972.

The human and economic losses due to accidents and occupational illness in the mineral industry require increased effort in the area of health and safety. Economics can be of great assistance in such efforts through analyses of the costs of accidents and disease, and of the cost-effectiveness of preventive measures. The necessary tools of analysis exist, but suitable data on health and safety are often unavailable. This paper reviews the theory and methodology of analysis, describes data availability in Canada and the United States, and compares the accident rates in the two countries. Finally, estimates of the costs of mine accidents in Canada are presented as an example of the approach and conclusions that can be derived from such analyses.

F-2 Relevance: 2

Miller, Wayne K.

ANALYSIS OF TRUCK RELATED FATALITIES AND DISABLING INJURIES AT METAL AND NONMETAL SURFACE MINES

U.S. Department of the Interior, Mining Enforcement and Safety Administration, Washington, D.C., IR 1022, 1975.

Hauling accidents involving trucks at metal and nonmetal mines resulted in 24 fatalities during 1973. This is the greatest number of fatal injuries attributed to a single agent during the year for both surface and underground metal and nonmetal mining. In 1973, there were 643 disabling injuries involving truck haulage.

F-3 Relevance: 2

Ditto, R. H. and R. R. McLellan

ANALYSIS OF FATAL ACCIDENTS INVOLVING FRONT-END LOADERS AT METAL AND NONMETAL MINES, 1972-1974

U.S. Department of Interior, Mining Enforcement and Safety Administration, Washington, D.C., IR 1019, 1975.

A critical accident trend has been identified that involves the front-end loader widely used in metal and nonmetal mines. In 1972, 18 fatal accidents occurred, with 20 in 1973, and 15 in 1975. The analysis indicates that the installation of roll-over protection on the machines and provision of adequate training for loader operators will substantially reduce the accident rate.

F-4 Relevance: 3

Ankenbruck, H. O., S. L. Blackman, H. J. Billmeyer, W. J. Hargreaves, and M. Perlman

HAZARD ANALYSIS OF UNDERGROUND COAL MINE HAULAGE SYSTEMS

The Bendix Corporation, Denver, Colorado, OFR 100-75, June 1975.

Analysis of statistical data indicates that haulage accidents are a leading cause of injuries and fatalities in underground coal mines and that the rate of accidents in transportation has been increasing during the past few years. Previous statistical analyses had been performed by correlating accident or fatality data at a rather high level of miner activity. To understand factors contributing to hazards specific situations, this investigation surveyed underground conditions and activities in some detail at a rather low level of activity. The study's aim was to derive preventive measures that might obviate the hazardous conditions and unsafe acts observed, and following this, to recommend additional research and development to reduce accident potential in underground transportation. In-mine surveys were made in 35 underground coal mines in 10 different coal seams believed to be representative of U.S. mines.

F-5 Relevance: 3

Warner, Barry L.

EVALUATION OF POTENTIAL FIRE HAZARD CAUSED BY EXPOSED TIMBER IN MINE
PASSAGEWAYS

Walter Kidde and Company, Inc., Belleville, New Jersey, March 1975.

This document reports testing to determine whether a fire hazard exists when the exposed wood surface of timber in a mine passageway equals 40% of the surrounding strata surface, excluding the sill. Twelve full-scale fire tests were conducted in simulated passageways. The results show air velocity to be an important factor in the occurrence of fire propagation and that the 40% surface area ratio appears to be a valid criterion for safety at 150 ft/min, but not at 350 ft/min.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION F

C-11, C-12, M-10

Section G

SELECTED RISK METHODOLOGY STUDIES

G-1 Relevance: 1

Apostolakis, George

MATHEMATICAL METHODS OF PROBABILISTIC SAFETY ANALYSIS

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7464, September 1974.

The aim of this report is to present systematically the mathematical methods that are useful in reliability and safety studies. These methods are built on the following bases: probability theory, statistics, and logic. In general, the methods deal with the prediction of the probability that a specified function will be performed satisfactorily within a given period or per demand, and the identification of events and their probabilities that may lead to unfavorable circumstances endangering the health of the public. Topics covered include elements of probability theory and statistics, the failure component, simple systems, maintenance models, logic diagrams, common mode failures, human factors and software reliability, and analysis without logic diagrams.

G-2 Relevance: 1

Okrent, D. (editor)

RISK-BENEFIT METHODOLOGY AND APPLICATION: SOME PAPERS PRESENTED AT THE ENGINEERING FOUNDATION WORKSHOP, SEPTEMBER 22-26, 1975, ASILOMAR, CALIFORNIA

School of Engineering and Applied Science, University of California, Los Angeles California, UCLA-ENG-7598, December 1975.

The goal of this workshop was to assess quantitatively the state of the art on risk-benefit methodology. Two large-scale technology areas were considered: (1) nuclear reactors and (2) shipment and storage of liquefied natural gas. Both of these technologies can provide incidents of large consequence should failures occur. Many of the papers presented are on subjects applicable to a potential risk assessment of the underground storage of nuclear wastes. These include papers dealing with risk assessment methodology, and political, legal, and acceptance aspects of risks.

G-3 Relevance: 1

Ott, Karl O.

RISK-ASSESSMENT METHODOLOGY FOR FAST BREEDER REACTORS

Argonne National Laboratories, Argonne, Illinois, ANL-76-39, April 1976.

The methods applied or proposed for risk assessment of nuclear reactors are reviewed, particularly with respect to their applicability for risk assessment of future commercial fast breeder reactors. Among the concepts reviewed are the maximum credible accident approach, design based accident approach, Farmer's limit-line approach, accident-risk envelope, probability distribution of consequences, the Rasmussen approach, line-limit and envelope integrations, event trees, fault trees, accident-progression diagrams, and simulation. A generalized and improved risk-assessment methodology is outlined and proposed (accident-spectra-progression). The generalization consists primarily of an explicit treatment of uncertainties throughout the accident progression.

G-4 Relevance: 1

Rumble, E. T., F. L. Leverenz, Jr., and R. C. Erdmann

GENERALIZED FAULT TREE ANALYSIS FOR REACTOR SAFETY

Science Applications, Inc., Palo Alto, California, June 1975.

This report describes methods for constructing detailed logic sequences that relate individual faults to one another along an entire accident chain. The methods allow for detailed evaluation of system interaction, and include explicit consideration of mutually exclusive, dependent, and common-mode events. The mathematical development of the AND-OR-NOT logic operations and their incorporation into a computer code (BAN) for logic tree evaluation based on a truth table approach are discussed. Two examples are analyzed that indicate how the methodology can handle certain types of common-failure modes: a portion of the consequence limiting control system for a PWR and a redundant water supply pump system. A brief comparison with other logic codes is given.

G-5 Relevance: 1

Lambert, Howard E.

FAULT TREES FOR DECISION MAKING IN SYSTEMS ANALYSIS

Dissertation, University of California at Berkeley, California, 1975.

The main objective of this thesis is to make fault trees a tool for decision making in systems analysis. One goal is to bridge the gap between mathematical theory and applications. It shows what bounding

procedures are necessary for making the solutions to real world problems tractable. It points out (1) the distinguishing features of systems currently being analyzed by fault-tree analysis and (2) how the application of reliability calculations differ from system to system. Chapter One places fault tree analysis in a system-safety perspective with other system safety modeling techniques. Chapter Two discusses the methods of probabilistic evaluation of fault trees in terms of coherent structure theory. Chapter Three presents the theory of probabilistic importance and the mathematical expressions that are required to compute importance. Chapter Four applies the concept of probabilistic importance to system design. Chapter Five shows how the concept of probabilistic importance can be applied to areas of system diagnosis and simulation, and how repair checklists can be generated on the basis of fault tree logic. This dissertation gives the most comprehensive discussion of fault tree analysis available and should be quite useful in the risk analysis for the storage of radioactive waste.

G-6 Relevance: 1

Lambert, H. E.

SYSTEMS SAFETY ANALYSIS AND FAULT TREE ANALYSIS

Lawrence Livermore Laboratory, Livermore, California, UCID-16238, May 1973.

This document was written to supplement a course in systems safety analysis given at Lawrence Livermore Laboratory in 1971-72. It describes systems safety analysis methodology from its basic concepts to its application. The author describes systems safety analysis as a systematic process of identifying the hazardous conditions within a system. The two principal methods of safety analysis are listed as inductive and deductive analysis. Inductive techniques given include preliminary hazards analysis, failure mode and effects, criticality analysis, fault hazards analysis, decision trees, and Markovian processes. They are best applied to generic equipment hazards. The development of subsystem functional faults are said to require deductive analysis, specifically fault tree analysis. The risk analysis methods and approach presented provide useful background information for conducting a risk analysis of a nuclear waste storage facility.

G-7 Relevance: 1

Smith, T. H.

PROBABILISTIC RISK ANALYSIS OF NUCLEAR SYSTEMS

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1848, September 1974.

Evaluation of event frequency and severity, and of dispersed radionuclides requires treatment of several probability spectra because initiating events vary in severity and releases vary in quantity and rate. The report stresses the need for including probabilistic considerations in nuclear risk analyses. Although report findings' potential application is general, certain aspects of the treatment are of special interest for studies of transportation and waste management. Previous methods of quantitative risk calculation for nuclear systems are reviewed. A method of accounting for probabilistic considerations is derived, drawn from literature review. The approach is considered to be more important than the particular equations derived. The equations could be changed to suit different requirements without sacrificing the basic intent of the method. Special effort is directed toward an approach compatible with existing fault tree and radionuclide transport methodology. Calculated accident frequencies and release quantities, including frequency distributions of the most important parameters, are weighted to give a measure of risk. Ways are discussed of simplifying the complete equations into more readily usable forms for preliminary studies.

G-8 Relevance: 2

Fleming, K. M., P. H. Raabe, G. W. Hannaman, W. J. Houghton, R. D. Pfemmer, and F. S. Dombek

HTGR ACCIDENT INITIATION AND PROGRESSION ANALYSIS STATUS REPORT,
VOLUME II: AIPA RISK ASSESSMENT METHODOLOGY

General Atomic, San Francisco, California, GA-A13617, October 1975.

Advances in probabilistic safety analysis applied to HTGRs have been reported by several authors as well as in papers presented at the 1969 British Nuclear Energy Society Conference. Rasmussen has also reviewed the approach and general results of the application of probabilistic safety methods to the analysis of LWRs. These sources were used in formulating a methodology for the systematic probabilistic analysis of the HTGR in the AIPA program. This methodology substantially agrees with the probabilistic methods reported in WASH-1400. Methodological differences reflect two major differences between WASH-1400 and the AIPA program: the objectives of the two studies are different, and WASH-1400 is based on analyses of currently operating LWRs, whereas the AIPA program is based on the designs of HTGRs to be built relatively soon. Methodology discussed includes event trees, fault

G-9 Relevance: 2

Nuclear Power Engineering Committee

IEEE GUIDE FOR GENERAL PRINCIPLES OF RELIABILITY ANALYSIS OF NUCLEAR
POWER GENERATION STATION PROTECTION SYSTEMS

The Institute of Electrical and Electronic Engineers, Inc., New York, N.Y.,
IEEE Standard 35201975, 1975.

This document is basically tutorial and was prepared to provide the user with basic principles needed to analyze the reliability of protection systems. It is not expected or intended that an individual or organization will need to employ all of the principles presented. For example, an organization may be concerned only with the qualitative analysis procedure discussed in Section 4. Another organization may be concerned with the quantitative analysis and mathematical modeling procedures discussed in Section 5. The problem of failure data is discussed in Section 6. The principles given are not necessarily limited to protection systems.

G-10 Relevance: 2

Van Slyke, W. J. and D. E. Griffing

ALLCUTS, A FAST COMPREHENSIVE FAULT TREE ANALYSIS CODE

Atlantic Richfield, Hanford Company, Richland, Washington, ARH-57-112,
July 1975.

The FORTRAN computer code, ALLCUTS, which is discussed and presented in this report, was developed to identify fault tree cutsets faster and more completely. A companion program, BRANCH, was developed to determine input data gate and bottom event interrelationships.

G-11 Relevance: 2

Lowrance, William W.

OF ACCEPTABLE RISK: SCIENCE AND THE DETERMINATION OF SAFETY

William Kaufmann, Inc., Los Altos, California, 1976.

This book was sponsored by the National Academy of Sciences to "popularize" the complex issues involved in the determination of public safety and of the role of scientists in this process. Topics in the book include a discussion of the safety problem, a presentation of methods of measuring risk and judging safety, a description of safety issues and public problems, a description of what is required for safety, and a discussion of DDT as an archetypal modern problem.

G-12 Relevance: 2

Kastenbergl, W. E., T. E. McKone, and D. Okrent

ON RISK ASSESSMENT IN THE ABSENCE OF COMPLETE DATA

School of Engineering and Applied Science, University of California,
Los Angeles, California, UCLA-ENG-7677, July 1976.

A major problem in assessing risks in advanced systems is that:
(1) all of the potential consequences are not known or anticipated and
(2) even when risks are anticipated the data are uncertain. Several
mathematical risk assessment theories are summarized in this report, and
their deficiencies that are related to incomplete data, are discussed.
The mathematical basis of risk assessment is considered, and the basic
problems of moving from a discrete to a continuous consequence-frequency
distribution are discussed. The application of these concepts to waste
disposal and storage of high level radioactive waste, risk to ground
populations due to airline crashes, and nuclear power plant risks are
reviewed and discussed.

G-13 Relevance: 2

Jennings, R. H., J. K. Rawlins, and M. E. Stewart

TEST REACTOR RISK ASSESSMENT METHODOLOGY

Aerojet Nuclear Company, Idaho Falls, Idaho, ANCR-1271, UC-78, April 1976.

A methodology developed for use in quantitatively evaluating the risks
of test reactors is directly applicable to other areas. Three major areas
exist in which departures have been made from the methods used in the
Reactor Safety Study (WASH-1400): (1) accident initiating event identifica-
tion; (2) system fault model construction, including the treatment of
common mode events; and (3) radiological consequence determination. The
methods are exemplified by determining the risks related to a loss of
primary coolant flow in the engineering test reactor.

G-14 Relevance: 2

Fussell, J. B., D. M. Rasmuson, J. R. Wilson, G. R. Burdick, and
J. C. Zipperer

A COLLECTION OF METHODS FOR RELIABILITY AND SAFETY ENGINEERING

Aerojet Nuclear Company, Idaho Fall, Idaho, ANCR-1273, UC-79h, April 1976.

This document contains five reports, each of which describes a method of reliability and safety engineering. Report I provides a conceptual framework for the study of component malfunctions during systems evaluations. Report II provides methods for locating groups of critical component failures so that all the component failures in a given group can be caused to occur by the occurrence of a single separate event. These groups of component failures are called common cause candidates. Report III provides a method for acquiring and storing system-independent component failure logic information. The information stored is influenced by the concepts presented in Report I and also includes information useful in locating common cause candidates. Report IV sets forth methods for analyzing situations that involve systems that change character in a predetermined time sequence. These phased mission techniques are applicable to the hypothetical "accident chains" frequently analyzed for nuclear power plants. Report V presents a unified approach to cause-consequence analysis, a method of analysis useful during risk assessments. This approach, developed by the Danish Atomic Energy Commission, is modified to reflect the format and symbols conventionally used for other types of analysis of nuclear reactor systems.

G-15 Relevance: 2

General Atomic

HTGR ACCIDENT INITIATION AND PROGRESSION ANALYSIS STATUS REPORT

San Francisco, California, GA-A13617, Volume II, October 1975.

This volume comprehensively summarizes the methods and techniques used in accident initiation and progression analysis. Because probabilities and consequences must be as realistic as possible, it was necessary to expand and improve existing methods in several areas. For example, system reliability modeling had to be improved to account for common mode failures and system-operated interactions. In the biological consequence evaluation area, existing methods and assumptions had to be modified so that realistic assessments could be made in contrast to other methods that usually yield ultraconservative results.

G-16 Relevance: 2

Lee, Y. T. and G. E. Apostolakis

PROBABILITY INTERVALS FOR THE TOP EVENT UNAVAILABILITY OF FAULT TREES

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7663, June 1976.

This work deals with estimating probability intervals for the existence of the top event of a fault tree. Given the uncertainties of the primary input data, a method is described for the evaluation of the first four moments of the top event occurrence probability. These moments are then used to estimate confidence bounds by several approach based on standard inequalities (e.g., Tchebycheff and Cantelli) or on empirical distributions (the Johnson family). Several examples indicate that the Johnson family of distributions yields results that are in good agreement with those produced by Monte Carlo simulation. These techniques could be useful in a risk assessment of the underground storage of nuclear waste in establishing confidence limits for the estimated risks.

G-17 Relevance: 2

Wu, S., S. L. Salem, and G. E. Apostolakis

DECISION-TABLE DEVELOPMENT FOR USE WITH THE CAT CODE FOR THE AUTOMATED FAULT-TREE CONSTRUCTION

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7711, January 1977.

The CAT code implements a methodology that uses decision tables for the construction of fault trees. To generate a fault tree, two major tasks must be completed by the user: (1) development of decision tables for the components used in the system, and (2) development of a system chart. For the first category, it is helpful to have a well-developed library containing decision tables for components that are often used. This report contains a library of decision tables for components that describes the output of each component in terms of its inputs and its internal states. In addition, a modification of the CAT code that couples it with a fault tree analysis is presented. Many of the components described are of the type that would be used in a radioactive waste storage facility.

G-18 Relevance: 2

Salem, S. L., G. E. Apostolakis, and D. Okrent

A COMPUTER-ORIENTED APPROACH TO FAULT-TREE CONSTRUCTION

School of Engineering and Applied Science, University of California, Los Angeles, California, EPRI NP-228, November 1976.

A methodology for systematically constructing fault trees for general complex systems is developed, and via the computer program CAT it is applied to several systems. First, a means of representing component behavior by decision tables is presented. To use the tables described, a procedure for constructing and editing fault trees, either manually or by computer, is described. CAT was developed to verify the methodology and has been used to construct fault trees for two systems. By analyzing and comparing these trees, several conclusions are reached. This approach is shown to be a useful tool for the analyst, especially when employed thoughtfully and carefully.

G-19 Relevance: 2

Mazumdar, M., J. A. Marshall, P. A. Awate, S. C. Clay, and D. K. McLain
REVIEW OF THE METHODOLOGY FOR STATISTICAL EVALUATION OF REACTOR
SAFETY ANALYSIS

Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, WCAP-8555,
September 1975.

This report reviews the state of the art of statistical methodology for estimating the probability of a specified outcome, given the uncertainties associated with the initiating events and the relationship between the outcome and the initiating variables. The work is directed toward methodology that might be useful in assessing the probabilities of accident sequences within nuclear power reactor systems and the consequences of these accidents. Methods described include sensitivity analysis, Monte Carlo analysis, stratified sampling, control variates, importance sampling, numerical integrations, and response surface. These methods may have some application in assessing probabilities associated with risks in the underground storage of radioactive wastes.

C-20 Relevance: 2

Mazumdar, M., J. A. Marshall, and S. C. Clay
METHODOLOGY DEVELOPMENT FOR STATISTICAL EVALUATION OF REACTOR SAFETY ANALYSIS
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, EPRI NP-194,
July 1976.

This report documents the results of two tasks aimed at the development of a methodology for statistical evaluation of nuclear-safety-related engineering analysis. The two tasks are (1) an investigation of the relative efficiencies and accuracies of various Monte Carlo and analytical techniques for estimating probability distributions of output variables

for a simple thermal hydraulic problem, whose output variable of interest is given in a closed-form relationship of the input variables; and (2) a repetition of the above study on a thermal hydraulic problem in which the relationships between the predicted variable and the inputs are described by a short-running computer program. The methods used in this study may be useful in assessing the probabilities of risks associated with the underground storage of radioactive wastes.

G-21 Relevance: 2

Spetzler, Carl S. and Carl-Axel S. Staël Von Holstein

PROBABILITY ENCODING IN DECISION ANALYSIS

Management Science, 22(3):340-358, November 1975.

This paper presents a philosophy of probability encoding. Probability encoding, the process of extracting and quantifying individual judgments about uncertain quantities, is one of the major functions required in the performance of decision analysis. The paper discusses the setting of the encoding process, including the use of sensitivity analysis to identify crucial state variables for which extensive encoding procedures are appropriate. The importance of balancing modeling and encoding techniques is emphasized, and examples of biases and unconscious modes of judgment are reviewed. A variety of encoding methods is presented, and their applicability is discussed.

G-22 Relevance: 2

Nuclear Reactor Safety Division

ROLE OF PROBABILISTIC RISK ASSESSMENT IN THE REGULATORY PROCESS

American Nuclear Society Transactions, 22:455-458, November 1975.

This document contains six short papers that deal with the role of probabilistic risk assessment in the regulatory process. The six papers are:

1. Probabilistic Risk Assessment in the Nuclear Regulatory Process in the United States--History and Perspective--Stephen H. Hunter.
2. Strengths and Limitations of Probabilistic Risk Assessment in the Regulatory Process--W. C. Gangloff.
3. Current Plans of the Regulatory Staff for the Use of Probabilistic Assessments--Darrell G. Eisenhut and Richard C. DeYoung.
4. Current Marginal Safety Issues Amenable to Probabilistic Risk Assessment--Joseph R. Penland.

5. State-of-the-Art in Probabilistic Risk Assessment--R. E. Erdmann and E. T. Rumble.
6. Status of the Reactor Safety Study and a Look to the Future--Saul Levine.

G-23 Relevance: 3

Arnett, L. M.

QUALITATIVE SAFETY ANALYSIS--II

E. I. DuPont de Nemour and Company, Savannah River Laboratory, Aikem, South Carolina, DP-1420, September 1976.

Several examples of probabilistic models often used to analyze fault trees, common mode failures, and decision trees are discussed to show that each is a special case of a general model. The general model is termed Probabilistic Analysis of Risks (PAR), and is used to enhance the understanding and interpretation of this type of analysis. The PAR method was flexibly designed to ease data assembly and review. The model's generality is intended to prevent a false sense of security that a single numerical answer or a restricted view of the problem might give.

G-24 Relevance: 3

Barlow, R. E. and H. E. Lambert

INTRODUCTION TO FAULT TREE ANALYSIS

Reliability and Fault Tree Analysis, Society for Industrial and Applied Mathematics, Philadelphia, Pennsylvania, 1975.

This paper is an elementary, engineering-oriented introduction to fault tree analysis. The basic concepts, techniques, and applications of fault tree analysis are described. The two major steps of fault tree analysis are identified as (1) the construction of the fault tree and (2) its evaluation. The evaluation of the fault tree can be qualitative or quantitative, depending on the scope, extensiveness, and use of the analysis. The advantages, limitations, and usefulness are discussed.

G-25 Relevance: 3

Erdmann, R. C., R. R. Fullwood, A. A. Garcia, J. E. Kelly, F. L. Leverenz, E. T. Rumble, and C. A. Stevens

PROBABILISTIC SAFETY ANALYSIS

Science Applications, Inc., Palo Alto, California, July 1975.

This document briefly presents a summary and critique of the Reactor Safety Study (WASH-1400). It also sets forth additional work performed in regard to the Reactor Safety Study, including a sensitivity analysis, consequence analyses, accident sequence calculations, the development of a BAM code for analyzing logic diagrams, and a failure gathering activity. Of particular importance to a risk assessment of underground nuclear waste storage is the BAM computer code. It can quantify accident logic sequences that include common mode, dependent, and disjoint events.

G-26 Relevance: 3

Sather, H. N.

STATISTICAL MODELS FOR COMPETING RISK ANALYSIS

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7676, August 1976.

This report describes research results on three new models for potential applications in competing risk problems. One section covers the basic statistical relationships underlying the subsequent model development for competing risks. Another discusses the problem of comparing cause-specific risk structures by competing risk theory and the use of two homogeneous populations. The use of concomitant information for modeling single-risk survival is extended in this document to the multiple-failure mode domain of competing risks. A life table model is used to illustrate this methodology. Two parameteric models for bivariate dependent competing risks are proposed and examined.

G-27 Relevance: 3

Feiler, A. M.

PROJECT MANAGEMENT THROUGH SIMULATION

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENGR-76-119, December 1976.

This study discusses the role of critical path network analysis in project management. It outlines specific shortcomings of conventional, deterministic network analysis techniques and gives examples of factors that contribute to the overall optimism of deterministic analysis. Computer simulation is offered as a means of developing realistic schedules, budgets, and resource requirements for projects in which uncertainty and performance variability are significant.

G-28 Relevance: 3

Rubel, P.

BONSAI: CULTIVATING THE LOGIC TREE FOR REACTOR SAFETY

Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1975.

Practical aspects of adapting tree logic to the analysis of reactor plant safety are discussed. Emphasized is the desirability of incorporating fundamental and engineering information into trees of accident events to improve general understanding of accident risks and to simulate dialogue on safety issues. The organization strategy combines decision and fault trees, and proposes substituting a matrix format for the decision trees in some applications. Example diagrams consider the HTGR cooling interruption accident.

G-29 Relevance: 3

Hebert, John A., Michael K. Lindell, William S. Maynard, and Stanley M. Nealey

SOCIALLY WEIGHTED LINEAR COMPOSITES IN ENVIRONMENTAL DECISION MAKING

Battelle Pacific Northwest Laboratories, BNWL-B-467, November 1975.

This document reviews methods for combining social values and technical information. Specifically, it presents a method by which the factors can be weighted by social values, with the resulting scores summed for each option. Interpretation, scaling, weight definition and influence, and implications for social weighting are important discussion areas in this report. The chief purpose of the report is to analyze special problems associated with the weighted linear composites used in sociotechnical evaluation.

G-30 Relevance: 3

Rubel, Paul

TIGER IN THE FAULT TREE JUNGLE

Oak Ridge National Laboratory, Oak Ridge, Tennessee, Submitted for Presentation at the Seventh Annual Pittsburgh Conference on Modeling and Simulation, April 26-27, 1976.

This document states that formal reliability analysis methods have not been seriously applied in evaluating, or even in identifying, potential common-mode failures (CMF) of reactor safety systems. The prospects for event logic modeling are examined by reviewing actual CMF experience in terms of what the analyst might have perceived a priori. Further insights of the probability and risks aspects of CMFs are sought through consideration of three key likelihood factors: (1) the prior probability of the cause's existence; (2) opportunities for removing the cause; and (3) probability that a CMF cause will be activated by conditions associated with a real system challenge. To decrease CMF-related risks, the principal needs for formal logical discipline are discovering and accounting for strong dependency couplings that could arise in major hypothetical accidents.

G-31 Relevance: 3

Schleicher, R.

STOCHASTIC DECISION MAKING APPLIED TO NUCLEAR REACTOR SAFETY

Ph.D. Thesis, Cornell University, Ithaca, New York, 1972.

A methodology is proposed for making optimum engineering decisions regarding the design and operation of a nuclear power plant with respect to public safety. By employing the principle of stochastic decision making, an optimum safety strategy may be determined by a quantitative trade-off between the economic cost (a deterministic function of the design and operating procedures) and the risk (a quantitative measure of safety). This strategy is the expected value over the random occurrences of accidental consequences. It will take some imagination to apply this technique to radioactive waste storage.

G-32 Relevance: 3

Fussell, J. B.

SYNTHETIC TREE MODEL: A FORMAL METHODOLOGY FOR FAULT TREE CONSTRUCTION

Aerojet Nuclear Company, Idaho Falls, Idaho, ANCR-1098, UC-32, March 1973.

This report provides a formal methodology (Synthetic Fault Tree Model) for constructing fault trees for electrical systems so that identifiable primary component failures will directly produce the required fault events. Although the model was developed solely for electrical systems, its implications extend to all fault tree constructions. The Synthetic Fault Tree Model is a synthesis technique for piecing together, with proper editing, a fault tree from small segments called component failure transfer functions. These functions are obtained from a system-independent failure mode analysis of individual components.

G-33 Relevance: 3

Sather, H. N.

BIOSTATISTIC ASPECTS OF RISK-BENEFIT: THE USE OF COMPETING RISKS ANALYSIS

University of California, Los Angeles, California, UCLA-ENG-7477, September 1974.

In studying risk for a given population, risk profiles for the population should be examined. One approach is using the theory of competing risks. Competing risk provides an analytic technique for studying the individual and combined effects of risks on a particular population, and their relation to other risks present. Biometry and engineering are the most prominent disciplines in applying the theory of competing risks (e.g., clinical trials, controlled laboratory experiments on animals, longitudinal risk factor studies, life table analysis, studies of component failure for the life of certain engineering systems, and reliability analysis). The theory of competing risks and its relationship to risk-benefit analysis are developed.

G-34 Relevance: 3

Atkinson, John W.

MOTIVATIONAL DETERMINANTS OF RISK-TAKING BEHAVIOR

Psychological Review, 64(6):359-371, 1957.

A theoretical model is presented to explain how the motives to achieve success and to avoid failure influence behavior when performance is evaluated against a standard of excellence. A conception of motivation in which strength of motivation is a joint multiplicative function of motive, expectancy (subjective probability), and incentive is set forth. It accounts for selecting one task from alternatives that differ in difficulty and it also accounts for varying performance levels when only one task is concerned. The incentive value of success is assumed to be a positive linear function of difficulty, as inferred from the subjective probability of success; and the negative incentive value of failure is assumed to be a negative linear function of difficulty. The major implications of the theory are: (1) that performance level should be greatest where uncertainty about the outcome is greater (i.e., when subjective probability of success is 0.50, whether the motive to achieve or the motive to avoid failure is stronger within an individual); but (2) that persons for whom the achievement motive is stronger prefer intermediate risk, whereas persons for whom the motive to avoid failure is stronger avoid intermediate risk. They prefer very easy and safe undertakings or extremely difficult and speculative undertakings. Results of experiments are cited, and the implications of the theoretical model for research on probability preferences in gambling and studies of social mobility aspirations are briefly discussed.

The paper is related to individual subjective probability and utility that might be ascribed to employers of a waste isolation facility and potential saboteurs. The incentive for winning as winning or losing as losing, presumably developed early in life, can be generalized to the gambling situation in which winning is not contingent on a person's skill and competence.

G-35 Relevance: 3

Howard, Ronald A.

SOCIAL DECISION ANALYSIS

Proceedings of the IEEE, 63(3):359-371, March 1975.

Decision analysis offers promise as a valuable procedure in making social decisions. The decision analyst creates a model of the decision under consideration, incorporating information about possible alternatives, uncertainties, relationships, or preferences that come from different groups. The implications for the decision are thus apparent to all. Decision making can thus be decentralized, with bodies responsible for creating social alternatives, for assessing the probabilities of various outcomes for each alternative, and for setting the preferences of society. Once the alternatives, information, and preferences were established, society would make the decision by using only the principles of logic. Applications to automotive pollution, hurricane seeding, and nuclear safety demonstrate the approach. This methodology of highlighting alternatives, determining probabilities, and arraying values could enable decision makers to reach the most rational decision regarding waste isolation.

G-36 Relevance: 3

Arrow, Kenneth J.

ALTERNATIVE APPROACHES TO THE THEORY OF CHOICE IN RISK-TAKING SITUATIONS

Econometrica, 19(4):404-437, October 1951.

This paper surveys the literature in economics, philosophy, mathematics, and statistics on choosing among alternatives whose consequences are uncertain. Attention centers on describing uncertainty and on theories of rational and actual behavior of individuals in making choices. The discussion touches on many aspects of risk-taking in geologic waste isolation.

G-37 Relevance: 3

Tversky, Amos and Daniel Kahneman

JUDGMENT UNDER UNCERTAINTY: HEURISTICS AND BIASES

Science, 185:1124-1131, 27 September 1974.

This article describes three heuristic approaches employed in making judgments under uncertain conditions: (1) representativeness, visually employed when people are asked to judge the probability that an object or event belongs to class or process B; (2) availability of instances or scenarios, often employed when people are asked to assess the frequency of a class or the plausibility of a particular development; and (3) adjustment from an anchor, usually employed in numerical prediction when a relevant value is available. These approaches are highly economical and usually effective, but they lead to systematic and predictable errors. A better understanding of these approaches and of the biases they lead to could improve judgments and decisions in situations of uncertainty.

G-38 Relevance: 3

Beattie, J. R., G. D. Bell, and J. E. Edwards

METHODS FOR THE EVALUATION OF RISK

U.K. Atomic Energy Authority, Authority Health and Safety Branch,
AHSB(S) R. 159, 1969.

The mathematical methods presented were used in estimating the risk to the population surround a hypothetical large power reactor. The reactor was assumed to satisfy a control curve of the Farmer type; the activity released was related--in a given range of curies on a logarithmic scale--to the probability of release occurring. Results for cases in which iodine was released, took the form of curves that related numbers of cases of thyroid cancer to the probability that the number lay in a given range on a logarithmic scale. After a mathematical solution had been derived, particular solutions were examined that illustrated the effect of the release control curve, of the dose-risk curve for the individual, and of the population distribution for the site, on the form of the frequency-casualty curve (in the case, the f-N curve, where N is the number of cases). A practical method for computing risk using the population figures and meteorological data for a site was given, including an outline of the "STRAP" program for this purpose; f-N curves derived in this way are given for seven population distributions, with general conclusions regarding comparative risks discussed.

trees, common mode failures, human error, earthquake risk, consequence evaluation, and interpolation of results.

G-39 Relevance: 3

Semanderes, Stavros, N.

"ELRAFT" A COMPUTER PROGRAM FOR THE EFFICIENT LOGIC REDUCTION ANALYSIS OF FAULT TREES

IEEE Transactions on Nuclear Science, NS-18(1):481-487, February 1971.

In fault tree analysis, component failures or conditions (basic events) are graphically depicted in the combinations necessary for causing subsystem or system failures (secondary events). Application of probability theory to this logic scheme permits computation of system failure probability when the probabilities of the basic events are known. The major problem in this quantitative analysis has been inability to compute the secondary event probabilities economically when the fault trees are complex and the components reliable. ELRAFT is a FORTRAN program that formulates the simplest logic expression for each secondary event in a fault tree in terms of the basic events that combine to cause it. Each secondary event is expressed as the union of intersections of basic events; dependencies are eliminated by ensuring (1) that in a particular intersection, a basic event can appear only once and (2) that a particular intersection of basic events is unique and not a subset of another intersection of events. The property of prime numbers expressed in the unique factorization theorem of number theory is used to eliminate dependencies. Each basic event is assigned a prime number, and a particular combination of basic events can be expressed uniquely by a single number that equals the product of their prime numbers.

G-40 Relevance: 3

Vesely, W. E.

A TIME-DEPENDENT METHODOLOGY FOR FAULT TREE EVALUATION

Nuclear Engineering and Design, 13:337-360, 1970.

In this methodology, called "kinetic tree theory," exact and detailed probabilistic information is obtained for any fault tree. The first assumption of this theory is that the primary failures, or components, of the fault tree are independent. Interdependent primary failures can be handled by extension of the methods presented. The second and last assumption of this theory is that the mode failures (critical paths) of the fault tree are known. This procedure handles fault trees of any structure and complexity, and general failure and repair distributions, with no limitation to these distributions.

Complete probabilistic information is first obtained for each primary failure of the fault tree, then for each mode failure, and finally for the top failure itself. The information is obtained as a function of time, and hence, with regard to reliability and safety, complete kinetic behavior is obtained.

G-41 Relevance: 3

Singpurwalla, Nozer D.

STATISTICAL FATIGUE MODELS: A SURVEY

IEEE Transactions on Reliability, R-20(3):185-189, August 1971.

This paper attempts to bring together both well-known and lesser known probability distributions that are candidates for failure models in reliability studies. Each probability distribution is discussed in regard to the physical process that causes it. A user who must choose a failure distribution can determine which of the physical causes discussed here best fits into his situation. The results presented in this paper enable the reliability analyst to view failure distribution in a more complete context.

G-42 Relevance: 3

Colombo, A. G.

CADI: A COMPUTER CODE FOR SYSTEM AVAILABILITY AND RELIABILITY EVALUATION

Joint Nuclear Research Center, Ispra Establishment, Italy, 1973.

This report describes a computer code for evaluating the availability of systems with elements for which binary states of functioning or nonfunctioning are assumed. First, it finds the minimum cut sets and then calculates the availability of each primary event. It evaluates the system availability as a function of the most significant minimum cut sets and also of the availability of the primary events appearing in these critical sets. It also supplies a table, oriented towards sensitivity analysis.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION G

B-1, B-30, B-32

Section H

OTHER SELECTED RISK ASSESSMENTS

H-1 Relevance: 3

Frenkel, L. and W. Hathaway

RISK ANALYSIS METHODS FOR DEEPWATER PORT OIL TRANSFER SYSTEMS

U.S. Department of Transportation, Transportation Systems Center,
Cambridge, Massachusetts, CG-D-7-76, June 1976.

This report deals with the risk analysis methodology for oil spills from oil transfer systems in deepwater ports. Failure mode and effects analysis in combination with fault tree analysis are identified as the methods best suited for assessing comparative risks posed by different technical alternatives. The necessary methodology and analytical expressions are developed, and their application is demonstrated in general, simple calculations. Basic data sources are listed, and the quality of the data is discussed. It is shown that available data are not sufficiently complete for quantitative calculations of risk for the entire system. Because comparative calculations are made, however, a systematic qualitative examination of the system is possible. This report provides an example of a risk analysis application that would be instructive in preparing a risk assessment for the underground storage of nuclear waste.

H-2 Relevance: 3

Clarke, R. K., J. T. Foley, W. F. Hartman, and D. W. Larson

SEVERITIES OF TRANSPORTATION ACCIDENTS

Sandia Laboratories, Albuquerque, New Mexico, SLA-74-0001, July 1976.

This document quantitatively describes the severities of the environments that small hazardous-material containers can be exposed to in transportation accidents. The descriptions, which constitute an important component of the risk analysis of hazardous material shipments, are necessary in determining the adequacy of protection provided by the uniquely designed shipping containers. Aircraft, truck, and train accidents are examined.

H-3 Relevance: 3

National Academy of Sciences

ANALYSIS OF RISK IN THE WATER TRANSPORTATION OF HAZARDOUS MATERIALS

Washington, D.C., U.S. Coast Guard Report CG-D-39-76, January 1976.

This report was prepared to assess the utility and feasibility of risk analysis as a set of techniques to assist in deciding how water transportation of bulk hazardous materials should be regulated. A number of risk analysis studies were surveyed, with barge transportation on inland waterways selected for special study, along with designation of a probabilistic model of risk. However, to develop a completely general risk model requires an impractical amount of time and resources. Therefore, the greatest utility of the methodology, and perhaps its only practical one, lies in answering specific questions with output of a predetermined nature. The report should thus be considered solely as an assessment of the utility of risk analysis to aid in decision-making for transport of hazardous materials.

H-4 Relevance: 3

Simmons, John A.

RISK ASSESSMENT OF STORAGE AND TRANSPORT OF LIQUEFIED NATURAL GAS AND LP-GAS

Science Applications, Inc., McLean, Virginia, EPA-520/3-75-015, November 1974.

This study describes a method for assessing the social risk of transporting liquefied petroleum gas (LPG) and liquefied natural gas (LNG), with application to the transport of LPG by tank truck and LNG by tanker ship in the United States. Data from experience and projected future handling of these liquefied gases are used with analysis of flammable plume formation, ignition, and population distributions to estimate the risks of fatalities from tank truck and tanker ship accidents. From an estimated 52 significant accidents per year with LPG tank trucks at the present truck-associated transportation rate of 20×10^9 gallons of LPG per year, a fatality rate of 1.2 per year is calculated. For the projected 1980 importation of 33×10^9 gallons by tanker ship, a fatality rate of 0.4 per year is calculated, using a conservatively high 1 chance in 20,000 of a significant accident per trip. Comparison with fires and explosions from all causes in the United States and Canada leading to 10 or more fatalities shown that these are 100 times more frequent than the predicted frequency of LPG and LNG accidents.

H-5 Relevance: 3

Joks, Hans C.

TRANSPORTATION SAFETY ANALYSIS

The Center for the Environment and Man, Inc., Cambridge, Massachusetts,
DOT-TSC-OST-76-24, November 1976.

A conceptual structure was developed for a model that expresses transportation accident deaths as a function of transportation activity levels. The literature and data bases were reviewed. A first-level model was developed for the following modes: highway transport, air transport--scheduled and general aviation, and rail transport. The first-level model was used to project the number of transportation accident deaths by mode to 1990. The results of this study can be used in estimating accidents associated with the transportation of nuclear wastes and comparing the risks from the accidents to the risks associated with the underground storage of radioactive waste.

H-6 Relevance: 3

Simmons, John A., Robert C. Erdmann, and Barry N. Naft

THE RISK OF CATASTROPHIC SPILLS OF TOXIC CHEMICALS

School of Engineering and Applied Science, University of California,
Los Angeles, California, UCLA-ENG-7425, May 1974.

This report describes the results of a study to assess the risk to the general population posed by the transportation of chlorine. Here risk means the probability of a single, catastrophic accident that would have a large adverse impact. This study was part of a larger program to provide a basis for comparing those risks now existing to the general population with the risks of catastrophic accidents occurring in nuclear power plants. The deaths resulting from all such accidents have numbered less than 20 in the last 50 years in the United States. A catastrophic event is predicted at least once in every 10 years through 1990. This implies an annual average mortality rate of 13 persons per year.

H-7 Relevance: 3

Pouliquen, Louis Y.

RISK ANALYSIS IN PROJECT APPRAISAL

World Bank Staff Occasional Papers Number 11, Washington, D.C., 1970.

The purpose of this paper, which the World Bank prepared to aid in tackling the problem of uncertainty, is three-fold: First, it describes three case studies in the use of risk analysis in project appraisal that

illustrate different aspects of the practical problem. Second, it describes and illustrates methodological problems. Third, it makes some general observations on the utility of the approach. Although not directly related to risks associated with nuclear waste storage, the paper provides useful insights into the application of risk analysis.

H-8 Relevance: 3

Oceanographic Commission of Washington

RISK ANALYSIS OF THE OIL TRANSPORTATION SYSTEM

Seattle, Washington, September 8, 1972.

This report develops a framework for a risk analysis of the transportation of oil on Washington State water. Statistics and probability, combinatorial logic, systems engineering, physical and behavioral sciences, reliability, maintainability, and systems safety analysis are integrated in this framework. It describes three phases: risk identification and definition that includes gross hazards analysis, and failure modes and effects analysis; risk analysis that use mathematical modeling and fault tree analysis; and risk reduction that discusses alternative selection, decision making, and methods for taking action. It includes recommendations to the State Legislature. This is a fairly extensive effort, and the framework developed is applicable to other environmental management matters.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION H

B-12, C-1, D-20

Section I

STUDIES DEALING WITH RURAL COMMUNITY ENVIRONMENTAL/SOCIAL/ECONOMIC EFFECTS

I-1 Relevance: 1

Gilmore, John S. and Mary K. Duff

BOOMTOWN GROWTH MANAGEMENT: A CASE STUDY OF ROCK SPRINGS--
GREEN RIVER, WYOMING

Westview Press, Boulder, Colorado, 1975.

This book describes the boomtown growth of Sweetwater County, Wyoming. The county population in 1970 was 18,391; by the end of 1974, it was estimated at 36,900--reflecting an annual growth rate of 19%. Among the problems created by the boomtown are: a deterioration in the quality of life, a 25 to 40% per capita decline in industrial productivity, and a failure of local services to meet needs. The book describes the boom problems and their interdependence, the growth process, boomtown growth management, a hierarchy of objectives for decision making, and concepts and remedies. Many of the problems associated with the Sweetwater County boomtowns are similar to those that would be encountered by a boomtown resulting from the establishment of a radioactive waste storage facility in a rural area.

I-2 Relevance: 1

Policy Research Associates

SOCIOECONOMIC IMPACTS: NUCLEAR POWER STATION SITING

State College, Pennsylvania, NUREG-0150, June 1977.

Literature on rural industrial development is used to gain insights to the socioeconomic effects of nuclear power stations. Previous studies of large industrial facilities in small towns have important implications for attempts to understand and anticipate the impacts of nuclear stations. A review of the nuclear development literature has revealed that research about industrialization in rural sociology, economic geography, and agricultural economics has been largely ignored. The goal of this research was not solely to review the literature, but rather to interpret the implications of these studies for NRC programs and research. This report contains a bibliography of more than 250 entries that deal with socioeconomic impacts.

I-3 Relevance: 1

U.S. Atomic Energy Commission

ENVIRONMENTAL STATEMENT, LIQUID METAL FAST BREEDER REACTOR PROGRAM

Washington, D.C., WASH-1535, December 1974.

This environmental statement for the LMFBR program has been prepared in seven volumes. Of particular interest to a nuclear waste storage risk or environmental analysis are Volumes II and IV. Volume II describes the direct environmental impact of each element of the LMFBR fuel cycle. It examines power reactors, fuel fabrication plants, and fuel reprocessing plants. For each, it discusses siting considerations, plant characteristics, effects on the environment from construction and normal operation, and environmental monitoring programs that together entail a complete environmental evaluation. It also evaluates the potential environmental impacts of various accidents, transportation of radioactive materials, management of radioactive wastes, the behavior of Pu in the environment, and the resulting health effects. Volume IV provides a broad overview of the many implications of LMFBR program implementation, up to and encompassing a fully developed LMFBR power plant economy. Included are secondary impacts, unavoidable adverse environmental impacts, cumulative environmental impacts, and cost-benefit analysis. Also covered are the cumulative environmental effects of LMFBR operations to 2020, the decommissioning of LMFBRs and fuel cycle facilities on completion of their useful life, the irreversible and irretrievable commitments of resources, and an analysis of costs and benefits.

I-4 Relevance: 1

U.S. Atomic Energy Commission

DRAFT ENVIRONMENTAL STATEMENT: WASTE MANAGEMENT OPERATIONS, HANFORD RESERVATION, RICHLAND, WASHINGTON

Washington, D.C., WASH-1538, September 1974.

This statement reassesses the environmental impact of the Hanford Waste Management Operations program. It was undertaken to assure that further major actions would minimize adverse environmental consequences and to account for those environmental consequences that were not fully evaluated at the outset or at each stage of the waste management program. This statement serves as a base for evaluating the environmental impact of future actions in relation to the existing environment at Hanford.

I-5 Relevance: 1

Booz, Allen & Hamilton, Inc.

A PROCEDURES MANUAL FOR ASSESSING THE SOCIOECONOMIC IMPACT OF THE CONSTRUCTION AND OPERATION OF COAL UTILIZATION FACILITIES IN THE OLD WEST REGION

Washington, D.C., 1974.

The Old West Region--Montana, Nebraska, North Dakota, South Dakota, and Wyoming--is the site of the Fort Union Formation, which accounts for 40% of the total U.S. coal resources and as much as 73% of the low sulfur resources. Present price and technology factors indicate that more than 60 billion tons of these resources are economically feasible to mine. A single coal gasification plant, with its attendant mining operation, can generate 800 to 1000 basic jobs in a community; secondary employment resulting from the basic jobs can add many thousands of persons to a local community. None of the counties of potential development had more than 20,000 population in 1970. This manual was written to aid in developing socioeconomic impact studies in these regions. It provides methods for assessing the following categories of impacts:

- Sociological impacts, such as changes in population characteristics.
- Economic impacts, including the creation of new employment and income.
- Capital costs for infrastructure, housing, public facilities, and commercial facilities.
- Public operation costs for county, municipal, and school functions.
- Potential revenues to cover public capital and operating costs.
- Cost/revenue analysis for public operations.
- Impact on existing industry.

I-6 Relevance: 2

U.S. Atomic Energy Commission

FINAL ENVIRONMENTAL STATEMENT CONCERNING PROPOSED RULE MAKING ACTION: NUMERICAL GUIDES FOR DESIGN OBJECTIVES AND LIMITING CONDITIONS FOR OPERATING TO MEET THE CRITERION "AS LOW AS PRACTICABLE" FOR RADIOACTIVE MATERIAL IN LIGHT-WATER-COOLED NUCLEAR POWER EFFLUENTS

Washington, D.C., EIS-AA-73-1252-F-1, WASH-1258, July 1973.

This environmental statement provides numerical guidance on the design objectives and limiting conditions of operation to assist applicants for, and holders of, licenses for LWRs in meeting the requirements set forth in AEC regulations. Those regulations stipulate that radioactive materials in effluents released from those facilities to unrestricted areas be kept "as low as practicable." This environmental statement is published in three volumes: (1) the statement, (2) analytical models and calculations, and (3) comments on the statement and staff responses thereto. Cost-benefit analyses indicate that it appears feasible to attain the design objective of 5 mrem/y to any organ of an individual offsite from radioactive material in liquid effluents. It appears feasible to attain the same design objective in gaseous effluents. However, for individual organs (e.g., thyroid and skin) this design objective may not be practicable with existing technology. An alternative design objective of 15 mrem/y for radioactive material in gaseous effluents for single organs is discussed.

I-7 Relevance: 2

Doran, Richard K., Mary K. Duff, and John S. Gilmore

SOCIOECONOMIC IMPACTS OF PROPOSED BURLINGTON NORTH AND CHICAGO WESTERN
RAIL LINE IN CAMPBELL-CONVERSE COUNTIES, WYOMING

University of Denver Research Institute, Denver, Colorado, May 1974.

This report describes socioeconomic impacts arising from construction of a rail line and the resulting extensive development of coal deposits along that line. Because rail construction necessarily precedes immediate coal development, railroad construction and coal development are considered to be part of the same economic activity or process. Thus, actual railroad construction and operations make up only a small portion of the reported impacts. Because the area considered is relatively rural, correlations can be drawn in regard to the potential socioeconomic impacts of a radioactive waste storage facility in a similarly rural area.

I-8 Relevance: 3

Bureau of Land Management

DRAFT ENVIRONMENTAL STATEMENT: PROPOSED DEVELOPMENT OF OIL SHALE
RESOURCES BY THE COLONY DEVELOPMENT CORPORATION IN COLORADO

Department of Interior, December 1975.

This statement analyzes environmental impact that may result from proposed federal actions in connection with development of an oil shale plant, mine, service corridor, land exchange, products pipeline, water use contracts, and powerline corridor. The statement discusses the socioeconomic and environmental effects that would result from increased population in a five-county Colorado region.

I-9 Relevance: 3

Department of Interior, Washington, D.C.

KAIPAROWITS ENVIRONMENTAL IMPACT STATEMENT

Chapter III: Environmental Impacts of Proposed Action, March 1976.

This environmental impact statement of the proposed Kaiparowits power plant includes an assessment of the potential socioeconomic and environmental impacts associated with a significantly increased population in a rural area. About 75% of the workers and their families were expected to live in a proposed new town.

I-10 Relevance: 3

Dickson, Edward M., Irving W. Yabroff, Cynthia A. Kroll, Ronald K. White, Barry L. Walton, Mary E. Ivory, Robert E. Fullen, Leo W. Weisbecker, and Roy L. Hays

SYNTHETIC LIQUID FUELS DEVELOPMENT: ASSESSMENT OF CRITICAL FACTORS

Volume III: Regional Industry, Social Impact, and Coal Resource Depletion, Stanford Research Institute, Menlo Park, California, ERDA 76-129/3, May 1977.

Chapter 4 of this volume assesses potential urbanization impacts and boomtowns associated with synthetic liquid fuels development in regions typified by small, rural, mainly agricultural communities. The chapter first treats the relationship of industrial growth and community development. It then outlines characteristics of the boomtown phenomenon as a prelude to illustrating its effects on a rural community that has undergone the process because of energy resource development. The variation of impacts as a function of community size is then explored. Considerations that can go into site selection to minimize deleterious effects of industrial development on communities are discussed.

I-11 Relevance: 3

Northern Great Plains Resources Program

EFFECTS OF COAL DEVELOPMENT IN THE NORTHERN GREAT PLAINS

Denver, Colorado, April 1975.

This report provides information useful in developing a perspective of the issues and consequences of expanded development of coal in the northern great plains region. The reported studies are expected to be helpful in the decision-making processes of federal, state, and local governments; industry; and other public and private groups. Part V analyzes the economic, social, and cultural impacts of coal development in the region. This type of analysis applies to similar impacts associated with the underground storage of nuclear wastes because both are expected to occur primarily in rural areas.

I-12 Relevance: 3

Wyoming Department of Economic Planning and Development

COAL AND URANIUM DEVELOPMENT OF THE POWDER RIVER BASIN--
AN IMPACT ANALYSIS

Cheyenne, Wyoming, June 1974.

The purpose of this study is to help the people of the Powder River Basin and the State of Wyoming deal with a future made uncertain by the prospects of large-scale mineral development. The study concentrated on four counties--Campbell, Converse, Johnson, and Sheridan. Employment and population impacts are estimated for three alternative futures postulated for the basin. This method of assessing potential impacts on a relatively rural area and the alternative futures approach could be used in assessing the impacts of a radioactive waste storage facility.

I 13 Relevance: 3

Department of Interior

EXCESS COST BURDEN, PROBLEM, AND FUTURE DEVELOPMENT IN THREE
ENERGY IMPACTED COMMUNITIES OF THE WEST

Washington, D.C., September 1975.

Some governors have felt that certain communities within their states have had "excessive" costs imposed on them because of national energy development policies. Implicit is the feeling that if energy development is taking place on leased federal land or with direct federal encouragement, then communities affected by this development ought to be reimbursed for their direct and indirect costs. Rock Springs, Wyoming; Vernal, Utah; and

Farmington, New Mexico are examples of such energy-impacted communities. These three communities were chosen as the focal point for this study. Parallels can be drawn between the problems of these three communities and similar problems for a community near a large radioactive waste storage facility.

I-14 Relevance: 3

Bureau of Reclamation

EL PASO COAL GASIFICATION PROJECT

Draft Environmental Statement, U.S. Department of Interior, July 1974.

El Paso Natural Gas Company proposes to construct and operate two coal gasification plants; the surface mining operation to supply the plants with coal and the necessary support facilities will be located in northwestern New Mexico on the Navajo Indian Reservation 35 miles southwest of Farmington, New Mexico. El Paso also proposed to operate a small development coal gasifier project and mine for 3 years before the complexes are built within the lease area for the large complexes. Section 3 of this environmental impact statement gives the environmental effects of the proposed action. Because this operation would involve a rural area, some correlations can be drawn with the construction and operation of a radioactive waste storage facility.

I-15 Relevance: 3

Luken, Ralph A.

ECONOMIC AND SOCIAL IMPACTS OF COAL DEVELOPMENT IN THE 1970s FOR MERCER COUNTY, NORTH DAKOTA

Thomas E. Carroll Associates, Washington, D.C., October 1974.

This report describes the economic impact of coal development in Mercer County, North Dakota, on the private and public sectors of the temporary construction force and on the permanent operating personnel of the new facilities. It focuses on aspects of development that can be quantitatively analyzed. The report also discusses boom town experience in Rock Springs, Wyoming, Gillette, Wyoming, and Langdon, North Dakota. The experiences in Gillette and Rock Springs provide evidence that a boom can disrupt the private sector. The experience in Langdon, however, suggests that a constructive boom does not have to disrupt the private sector; there, advanced planning for the new population and availability of construction funds to build the necessary facilities minimized the disruptive impact.

I-16 Relevancc: 3

Office of Standards Development

DRAFT ENVIRONMENTAL STATEMENT ON THE TRANSPORTATION OF RADIOACTIVE
MATERIAL BY AIR AND OTHER MODES

U.S. Regulatory Commission, Washington, D.C., NUREG-0034, March 1976.

This draft environmental statement assesses the environmental impact from air transportation of radioactive materials into, throughout, and out of the United States. It is intended to serve as background material for a NRC review of regulations dealing with transportation of radioactive materials. The impetus for this review resulted not only from a general need to examine regulations to ensure their continuing consistency with the goals of minimum radiological impact, but also from a need to respond to current national discussions of the safety and security aspects of nuclear fuel cycle materials.

I-17 Relevance: 3

U.S. Atomic Energy Commission

ENVIRONMENTAL STATEMENT: RADIOACTIVE WASTE EVAPORATOR AND AUXILIARIES,
RICHLAND, WASHINGTON

Washington, D.C., WASH-1521, April 1972

This environmental statement was prepared to cover the construction and operation of a radioactive waste evaporator and auxiliaries at the Hanford plant at Richland, Washington. The evaporator was to be used to convert highly radioactive liquid waste into a solid, retrievable salt cake residue. Environmental impacts would result primarily from the release of effluents from the facility. The material, which will contain some radionuclides, will be discharged in an open trench and waste waters containing heat will percolate through the soil to the ground water.

I-18 Relevance: 3

International Atomic Energy Agency

ENVIRONMENTAL ASPECTS OF NUCLEAR POWER STATIONS

Proceedings of a Symposium Held in New York on August 10-14, 1970,
Vienna, Austria, 1971.

This sumposium provided a forum to discuss and compare activities in the production of nuclear power that might affect the environment. Two papers of interest to a nuclear waste risk program are:

Benefit-Cost Relationships on Socio-Technical Systems, C. Starr

Some Risks in Modern Life, F. D. Sowby

)
ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION I

A-6, A-8, A-9, A-13, A-23, A-43, A-51, A-52, A-53, A-54, A-55, A-56,
A-57, B-18, B-33, B-35, B-38, C-2

Section J

APPLICABLE STUDIES DEALING WITH THE CONSEQUENCES OF RISKS

J-1 Relevance: 1

National Research Council

THE EFFECTS ON POPULATIONS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION

National Academy of Sciences, Washington, D.C., November 1972.

This report of the Committee on the Biological Effects of Ionizing Radiations (BEIR Committee) deals with the scientific basis for establishing radiation protection standards; it reviews and re-evaluates scientific knowledge concerning radiation exposure of human populations. Information is provided to assist in developing standards for major categories of radiation exposure, based insofar as possible on risk estimates and on cost-benefit analyses that compare activity involving radiation with the alternative options.

J-2 Relevance: 1

Hart, J. C., R. H. Ritchie, and B. V. Varnadore (editors)

POPULATION EXPOSURES

Proceedings of the Eighth Midyear Topical Symposium of the Health
Physics Society, Knoxville, Tennessee, October 1974.

This document contains 55 papers presented at the symposium. Technical material was presented in the following areas: (1) potential adverse effects that nuclear power may have on the environment, (2) pathways that various radionuclides follow in the biosphere when released in air or water, (3) the relationship of such information to other radiological hazards, and (4) environmental problems associated with the alternative fossil-fuel production of electricity.

J-3 Relevance: 1

Buchanan, J. R.

NUCLEAR POWER AND RADIATION IN PERSPECTIVE: SELECTIONS FROM NUCLEAR SAFETY

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-NSIC-100,
March 1974.

The risks of nuclear power and radiation are described to place them in perspective with other potential hazards faced by the public on a day-to-day basis in our complex industrial society. Although our lives are enriched by electricity, airplanes, automobiles, chemicals, and the like, these elements also produce hazards that can neither be ignored nor exaggerated. Included in the report are 20 articles on such topics as the effects of radiation, risk-benefit concepts, radiation risks relative to other risks, nuclear plant risks relative to fossil plant risks, licensing requirements, nuclear insurance, nuclear industry safety record, and public attitudes.

J-4 Relevance: 1

Streng, D. L., E. C. Watson, and J. G. Droppo

REVIEW OF CALCULATIONAL MODELS AND COMPUTER CODES FOR ENVIRONMENTAL DOSE ASSESSMENTS OF RADIOACTIVE RELEASES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-B-454,
June 1976.

The development of technological bases for siting nuclear fuel cycle facilities requires calculational models and computer codes for evaluating risks and assessing the environmental impact of radioactive effluents. A literature search and review of available computer programs revealed that no single program could perform the great variety of calculations required (e.g., external dose, internal dose, population dose, chronic release, and accidental release). Available literature on existing computer programs has been reviewed and each program reviewed is described.

J-5 Relevance: 1

Hoffman, F. O., C. W. Miller, D. L. Shaeffer, and C. T. Garten, Jr.

COMPUTER CODES FOR THE ASSESSMENT OF RADIONUCLIDES RELEASED TO THE ENVIRONMENT

Nuclear Safety, 18(3):343-354, May-June 1977.

This article presents a compilation of computer codes useful in assessing accidental or routine releases of radioactivity to the environment from nuclear power facilities. The capabilities of 83 computer codes in the areas of environmental transport and radiation dosimetry are summarized in tabular form. This preliminary analysis clearly indicates that the initial efforts in assessment methodology development have concentrated on atmospheric dispersion, external dosimetry, and internal dosimetry via inhalation. The incorporation of terrestrial and aquatic food-chain pathways has been a more recent development and reflects the need for satisfying the current requirements of environmental legislation and the needs of regulatory agencies. The article also reviews the characteristics of the conceptual models employed by these codes.

J-6 Relevance: 2

Taylor, C. I. (editor)

ENVIRONMENTAL SCIENCES DIVISION ANNUAL PROGRESS REPORT FOR PERIOD ENDING SEPTEMBER 30, 1977

Union Carbide Corporation, ORNL-5016, March 1975.

This report describes the work conducted by the Environmental Sciences Division of the Oak Ridge National Laboratory during 1974. Areas researched are grouped under the following topics: Pu in the environment; environmental assessments; aquatic studies; terrestrial analyses, effects, and material transport; and analysis and evaluation.

J-7 Relevance: 2

Chester, R. O.

RADIOLOGICAL DOSE AND RADIOLOGICAL ACTIVITY FROM NUCLEAR REACTOR OR NUCLEAR WEAPON FISSION PRODUCTS

Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-4996, UC-32, December 1974.

This report describes a computer code, YIELDS, that performs rapid, accurate calculation of dose and activity from the fission products of a nuclear reactor core or a nuclear weapon. For example, if a dispersal model is assumed, calculations can be made of the contaminated area; the dose from inhaled or ingested fission products to each part of a biological system; or the dose from external fission products, from a dispersed reactor core, or nuclear weapon fallout. Individual beta and gamma ray energies for each isotope are included and permit detailed calculation of biological dose or other functions of these energies versus time. The calculation method facilitates the handling of complicated radiological decay chains coupled with multisection biological systems. The option of sorting the output by isotopes or chemical species is available.

J-8 Relevance: 2

Hub, K. A., J. G. Asbury, W. A. Buehring, P. F. Gast, R. A. Schlenker, and J. T. Wehls

A STUDY OF SOCIAL COSTS FOR ALTERNATE MEANS OF ELECTRICAL POWER GENERATION FOR 1980 AND 1990

Argonne National Laboratories, Argonne, Illinois, ANL-8092, February 1973.

This study was one in a continuing series sponsored by the AEC to assist in defining the role of nuclear energy in our society. The research reported here addressed the subject of costs, risks, and benefits of the various means of using energy materials to produce electricity. The future scenario depicted the flow of events for the "snapshot" years of 1980 and 1990. Sufficient information was obtained to conclude that external costs, including cumulative genetic and ecological effects from fuel cycle operations in 1980 and 1990, will be a small part of the cost of obtaining electrical energy in those years.

J-9 Relevance: 2

Gavankar, Roger, Patricia W. Durbin, and Thomas H. Pigford

A BASIS FOR ASSESSMENT OF RADIATION RISKS FOR A HYPOTHETICAL RELEASE OF PLUTONIUM DIOXIDE FROM A FAST REACTOR ACCIDENT

Conference on Fast Reactor Safety, Beverly Hills, California, April 2, 1974.

This paper presents a method of assessing emergency radiation risks from a single inhalation of a $^{239}\text{PuO}_2$ aerosol. The ICRP Lung Model was used to calculate organ burdens and doses resulting from a single intake. Tumor risks have been estimated from experiments in which beagle dogs inhaled $^{239}\text{PuO}_2$ particles or were injected with $^{239}\text{PuO}_2$ citrate; tumor risks can be related directly to organ burdens. Lifetime tumor risks were extrapolated and expressed as (1) tumor risk/person/rem of organ dose accumulated over 50 years, and (2) tumor risk/person/mCi of organ burden.

J-10 Relevance: 2

Lee, Hong, T. O. Peyton, R. V. Steele, and R. K. White

POTENTIAL RADIOACTIVE POLLUTANTS RESULTING FROM EXPANDED ENERGY PROGRAMS

SRI International, Final Report for EPA Environmental Monitoring and Support Laboratory, Contract 68-03-0375, April 1977.

The radionuclide releases and the resulting population exposure doses from several energy systems for four projected energy use scenarios were calculated and compared. The energy system components examined were: coal mining, processing, combustion, and ash disposal; coal gasification and liquefaction; oil shale mining, processing, residue disposal, and product utilization; geothermal development and operations; uranium mining, conversion, enrichment and fabrication; nuclear reactor operations; and fuel reprocessing and waste disposal. The energy use scenarios included one that projected a high level of synthetic fuel production; one that projected high electrical power utilization--mostly derived from nuclear power developments beyond 1985; and one that assumed moderate developments in all energy systems, along with energy conservation measures. For nonnuclear energy systems, the dominant radionuclide contributing to population exposure doses is ^{222}Rn , whose major sources are coal ash piles created from burning coal to produce electricity. On a per unit energy basis, the geothermal energy system is a comparable contributor of ^{222}Rn exposure doses. Exposure doses derived from other radionuclides and from other nonnuclear energy systems are comparatively insignificant. For nuclear energy systems, the radionuclides contributing to population exposure doses are ranked as follows: (1) ^3H , (2) ^{238}U , (3) ^{222}Rn , (4) ^{85}Kr , (5) ^{106}Ru , (6) ^{133}Xe , (7) ^{131}I and ^{129}I , (8) actinides, and (9) other fission and activation products. Population exposure doses of ^3H are released from spent-fuel reprocessing operations and from nuclear reactor operations. The ^{238}U releases, mostly during milling operations, also contribute to relatively significant population exposure doses. The population exposure doses derived from ^{222}Rn releases from uranium mine and mill sites, however, are about the same order of magnitude as that derived from the release of ^{222}Rn from coal ash piles.

J-11 Relevance: 2

Soldat, J. K., N. M. Robinson, and D. A. Baker

MODELS AND COMPUTER CODES FOR EVALUATING ENVIRONMENTAL RADIATION DOSES

Battelle Northwest Laboratories, Richland, Washington, BNWL-1754, UC-11, February 1974.

To compute the environmental radiation dose and evaluate the radiological impact required for the environmental impact statements for nuclear plants, a simplified model for calculating radiation doses from radioactive effluents was developed. The new model is divided into four independent parts, each written as a separate program:

- ARRRG calculates individual and population doses from liquid effluents.
- CRITR calculates internal radiation doses to four common classes of aquatic organisms and to organisms that consume them.
- FOOD calculates doses from consumption of food crops and animal products produced on irrigated farms.

- GRONK calculates doses from gaseous effluents to individuals and to population within 50 miles.

The model can calculate doses to the total body, to selected organs of individuals and population groups, and to organisms other than man. It includes all air and liquid exposure pathways for which reasonable supporting data exist. Internal doses to man are based on a 1-year radionuclide intake, assuming no prior accumulation in the body. The radionuclide content of ingested food is assumed to be at equilibrium with the environment. The question-and-answer format of these programs allows them to be used by nonprogrammers. The programs are applicable to any nuclear facility that releases radioactive effluents to air or water.

J-12 Relevance: 3

Brewer, Shelby T.

COMPARATIVE RISK-COST-BENEFIT STUDY OF ALTERNATIVE SOURCES
OF ELECTRICAL ENERGY

U.S. Atomic Energy Commission, Washington, D.C., WASH-1224, December 1974.

This study attempts to quantify the social costs associated with the production of electrical energy by currently available alternative systems that operate under routine conditions. Motivating the study was an awareness that social costs of a given system cannot be judged in a vacuum: costs of alternatives must be compared. The word "risk" as used in this study connotes rather severe unplanned events, such as large-scale low-probability accidents. Risk are translated into costs by extrapolating frequencies and consequences of events from experience. Benefit is defined as a quantity of electrical energy.

J-13 Relevance: 3

Eicholz, Geoffrey G.

COST-BENEFIT AND RISK-BENEFIT ASSESSMENT FOR NUCLEAR POWER PLANTS

Nuclear Safety, 17(5):525-539, September-October 1976.

This article reviews cost-benefit and risk-benefit assessment for nuclear power plants. The review demonstrates that the radiological impact of the plant on the surrounding population from the release of low-level effluents can be quantified and treated as a financial "cost." Alternatively, it can be treated as a "risk" and related to other risks modern man is subjected to and can be used as a means to establish site boundaries. Both cost-benefit and risk-benefit analyses essentially represent optimization approaches to making nuclear power plants economically competitive, socially and politically acceptable, and as safe or innocuous as one can reasonably make them.

J-14 Relevance: 3

Tihansky, Dennis P. and Harold V. Kibby

A COST-RISK-BENEFIT ANALYSIS OF TOXIC SUBSTANCES

Journal of Environmental Systems, 42(2):117-134, 1974.

Hundreds of new toxic substances are produced each year to satisfy consumer demand, and many of them also enter the environment, thereby subjecting the exposed population and ecosystems to risk. The most logical criterion for their control is a net comparison of product gains and risk losses from using these substances, with the objective of maximizing the overall welfare of society. The operational framework presented attempts to synthesize cost-benefit and risk information into a decision-making setting to identify the optimal control level. Both quantitative and qualitative value systems are merged into a single framework, and sequential stages of the analysis are outlined in detail. Several decision-making approaches are recommended, the appropriate choice depending on the extent of risk-benefit data available as well as the preference for monetary versus nonmonetary values. Uncertainty in the data base complicates the assessment because its inclusion requires the application of special statistical measures of confidence.

J-15 Relevance: 3

Rudman, Richard L.

COST-BENEFIT CONSIDERATIONS OF NUCLEAR POWER

Nuclear Technology, 24:309-313, December 1974.

This article reports on a cost-benefit analysis used in an attempt to place the societal costs associated with nuclear power into perspective by comparing them with the costs associated with coal-fired plants. Generation of electricity from coal is assumed to represent an acceptable risk to our society. The results indicate that nuclear power compares favorably with coal for the following costs: resource depletion, environmental effects, cost of power generation, voluntary occupational health risks, and involuntary public health risks associated with routine plant operation. Plant accidents, waste disposal techniques for both nuclear and coal-fired stations, and the nuclear safeguards issues are identified as the major areas requiring further risk evaluation.

J-16 Relevance: 3

Barrager, Stephen M., Bruce R. Judd, and D. Warner North
THE ECONOMIC AND SOCIAL COSTS OF COAL AND NUCLEAR ELECTRIC GENERATION
A FRAMEWORK FOR ASSESSMENT AND ILLUSTRATIVE CALCULATIONS FOR THE COAL
AND NUCLEAR FUEL CYCLES

Stanford Research Institute, Menlo Park, California, March 1976.

This report presents a method for extending economic comparisons of nuclear and coal-fired electrical power to include health, safety, and environmental impacts in the same quantitative framework. This method is illustrated by considering the decision between a LWR and a conventional coal-fired power plant to satisfy a 1000 MWe increase in electrical demand in the northeastern United States. For both alternatives, preliminary calculations were made of the economic and social costs. Economic costs are those faced by the utility, including capital charges, operating expenses, and fuel cycle costs. Social costs for each plant and its associated fuel cycle include routine environmental impacts, such as air pollution, as well as risk to the public from reactor accidents or sabotage. The sum of these economic and coal costs are used as the criterion for comparison of nuclear and coal.

J-17 Relevance: 3

Sagan, L. A.
HUMAN COSTS OF NUCLEAR POWER
Science, 177:487-493, 11 August 1972.

This article treats the human cost of producing and using nuclear fuel to generate electricity, as well as the question of whether the price of such electricity compensates for these costs. The analysis is based on estimates of the value of human life, lost productivity, and potential effects of radiation. The author concludes that major inequities exist.

J-18 Relevance: 3

Maaz, I.
INCREMENTAL NET SOCIAL BENEFIT ASSOCIATED WITH USING NUCLEAR-FUELED
POWER PLANTS

School of Engineering and Applied Science, University of California,
Los Angeles, California, UCLA-ENG-76117, December 1976.

This paper assesses the "incremental net social benefit" (INSB) resulting from nuclear fueled electrical power generation. INSB is defined as the difference between the incremental social benefit caused by the cheaper technology of electrical power generation and the incremental social cost associated with an increased power production induced by cheaper technology. The methodology used in this report has some utility in assessing the net social benefit associated with the underground storage of radioactive waste.

J-19 Relevance: 3

Peskin, Henry M. and Eugene P. Seskin (editors)

COST BENEFIT ANALYSIS AND WATER POLLUTION POLICY

Papers prepared for a symposium sponsored by the Environmental Protection Agency, and conducted in Annapolis, Maryland, September 5, 6, and 7, 1973, published by the Urban Institute, Washington, D.C., 1973.

Although it focuses on water pollution, this book also presents much of the methodology found useful in cost-benefit analysis. The editors approach cost-benefit analysis as a formal procedure for comparing the costs and benefits of alternative policies. They list cost-benefit analysis as a component of policy evaluation. The following papers are contained in this book:

- Introduction and Overview--Henry M. Peskin and Eugene P. Seskin.
- The Concept of Benefits in Cost-Benefit Analysis: With Emphasis on Water Pollution Control Activities--Robert H. Haveman and Burton A. Weisbrod.
- A Survey of the Techniques for Measuring the Benefits of Water Quality Improvement--A. Myrick Freeman III.
- Some Institutional and Conceptual Thoughts on the Measurement of Indirect and Intangible Benefits and Costs--John Bishop and Charles Cicchetti.
- A Survey of Empirical Benefit Studies--Dennis Tchansky.
- Costs of Water Quality Improvement, Transfer Functions, and Public Policy--Allen V. Kneese.
- Environmental Policy Costs: Definition, Measurement, and Conjecture--Ralph C. deAnge.
- Estimates of Industrial Waterborne Residuals Control Costs: A Review of Concepts, Methodology, and Empirical Results--Steve H. Hanke and Ivars Gulmanis.
- Valuing Long-Run Ecological Consequences and Irreversibilities--Anthony C. Fisher and John V. Krutilla.
- Voting, Cost-Benefit Analysis, and Water Pollution Policy--Paul R. Portney.
- Cost-Benefit Analysis, Property-Right Specifications, and Distribution--John A. Stockfish.

- Project-by-Project Analysis versus Comprehensive Planning--Fred H. Abel.
- Cost-Benefit Analysis of Cost-Benefit Analyses--Thomas D. Crocker.
- The Role of Cost-Benefit Analysis in Policy Making--Henry Rowen.

J-20 Relevance: 3

Mushkin, Selma J. and Francis d'A. Collings

ECONOMIC COSTS OF DISEASE AND INJURY

Public Health Reports, 74(9):795-809, September 1959.

This paper sets forth a tentative classification of the economic costs of disease, based on their effects on the use, distribution, and quantity of economic resources. The information available for measurement is discussed and additional information requirements are summarized. The economic cost of disease and injury are of three types: (1) costs that use a share of the nation's resources of manpower and materials to supply health services and their commodity components; (2) costs represented by the public and private transfer of income and resources from the well to the sick to mitigate the burdens of illness; and (3) costs reflected in a reduced national production of all goods and services.

J-21 Relevance: 3

Lave, Lester B. and Eugene P. Seskin

AIR POLLUTION AND HUMAN HEALTH

Science, 169(3947):723-733, 21 August 1970.

Because pollutants caused by plants, animals, and natural activity are natural constituents of the air, some pollution cannot be removed from the air. Instead, human polluters' need to vent residuals must be balanced by the damage suffered by society as a result of the increased pollution. To find an optimum level, we must know the marginal costs and marginal benefits associated with abatement. This article investigates the effects of air pollution on human health; it characterizes the problem of isolating health effects; it quantitatively estimates the effect of air pollution on various diseases and points out reasons for viewing some early estimates with caution; it discusses the economic costs of ill health; and it estimates the costs of effects attributed to air pollution.

J-22 Relevance: 3

Auerbach, Stanley I.

ECOLOGICAL CONSIDERATIONS IN SITING NUCLEAR POWER PLANTS:
THE LONG-TERM BIOTIC EFFECTS PROBLEM

Nuclear Safety, 12(1):25-34, January-February, 1971.

A current concern about increasing nuclear power stations is the potential impact of radioactive waste releases for local ecosystems. In particular, waste releases at maximum permissible concentration (MPC) levels may cause ecological problems because of radioactivity. Hypothetical annual submersion dose rates from water assumed to be maintained at the occupational MPC x 1/30 were calculated for organisms living in these waters. These doses were then used in comparing ecological studies of low doses of ionizing radiation and were analyzed and evaluated for detectability of biological effects at MPC levels. Data based on these and similar studies consistently indicate that possible biological effects would be undetectable.

J-23 Relevance: 3

Wolfe, Bertram

LOW-LEVEL RADIATION: PREDICTING THE EFFECTS

Science, 196:1387-1389, 24 June 1977.

The author questions predictions of cancer incidence based on the linear theory used by the American Physical Society in its reactor study. He refutes arguments in support of the linear theory by von Kippel, Morgan, and Brown in response to his original letter.

J-24 Relevance: 3

Morgan, M. Granger, Barbara R. Barkovich, and Alan K. Meier

THE SOCIAL COST OF PRODUCING ELECTRIC POWER FROM COAL:
A FIRST-ORDER CALCULATION

Proceedings of the IEEE, 61(10):1431-1442, October 1973.

A methodology is discussed for quantitatively computing the social costs or external diseconomies that result from the production of electric power in coal-fired plants. From available data, preliminary numbers place this cost for the technology of the mid- and late-1960s at $\geq 11.5 \pm 2$ mills/kWh, somewhat more than the price of bulk power at the plant bus bar. In applying controls to limit the social costs, control costs are incurred. Costs for the optimum level of control is the level at which the sum of the social costs and the control costs is minimum, are

estimated at $\geq 4.5 \pm 1.5$ mills/kWh and the costs of controlling to that level as $\geq 3 \pm 1$ mills/kWh. These values will probably be reduced, and the optimum levels for control increased, as new technologies are developed. More accurate estimates of these social costs will require improved data, especially in the areas of air pollution and land use costs, as well as conceptual progress in techniques for treating value orientation.

J-25 Relevance: 3

Solow, Robert M.

THE ECONOMIST'S APPROACH TO POLLUTION AND ITS CONTROL

Science, 173:498-503, 6 August 1971.

In the present environment, the assimilative capacity of air and water is decreasing. Because it is still free to anyone with waste to dispose of, this scarce resource will be overused. The normal system of incentives is biased: This costly resource carries no price to reflect its scarcity, and piecemeal regulation may simply transfer pollution from one medium to another. A system of taxes and effluent changes is more likely to achieve a cheaper solution than direct regulation. A scheme worth considering is government collection of a fee from the original producer or importer of raw materials. This fee would be set for each material to equal the environment social cost if the material were returned to the environment in the most harmful way possible. The fees would be refunded to those who could certify that they had disposed of the material, with the size of the refund dependent on the method of disposal.

J-26 Relevance: 3

Eisenbud, Merrill

ENVIRONMENTAL RADIOACTIVITY, Second Ed.

Academic Press, 1973.

The first edition of this book was published early in 1963 (McGraw-Hill, New York), when worldwide concern was focused on radioactive fallout from testing nuclear weapons. In that year, the principal nuclear powers agreed to ban open-air testing, and the environmental level of radioactivity from that source has diminished accordingly, despite occasional tests by

countries that did not participate in the test ban. Environmental radioactivity, however, has been more than sustained by the rapid growth of the nuclear power industry and the use of radioactive materials in medicine, research, space exploration, and industry. The author has attempted to provide an objective account of the relevant biological and physical information that has been accumulated in the 30 years since fission was first controlled. The book was written as a reference source for the scientist, engineer, or administrator with a professional interest in the subject, but may also be of value to the reader who wishes to understand the technical facts behind the public debate. Though not an exhaustive treatise, the book does present a useful review of what is now known.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION J

A-4, A-39, B-1, B-12, B-31, C-8, C-9, G-11, K-5, K-9, K-12, L-8

Section K

SELECTED STUDIES PRESENTING COMPARATIVE HAZARD ESTIMATES

K-1 Relevance: 1

Baldewicz, W., G. Haddock, Y. Lee, Projototo (sic), R. Whitley, and V. Denny

HISTORICAL PERSPECTIVES ON RISK FOR LARGE-SCALE TECHNOLOGICAL SYSTEMS

School of Engineering and Applied Science, University of California, Los Angeles, California, UCLA-ENG-7485, November 1974.

This empirical study considers historical trends in the risks sustained by populations affected by various large-scale technological systems. It reports results for three system categorizations: natural hazards, man-made hazards, and occupational hazards. In introducing a new model for risk assessment, it avoids the problems associated with assessing the value of a human life in risk-benefit decision making by treating risk in terms of loss of life expectancy. From historical trends in the rate of loss of life expectancy for the systems studied, it is concluded that: (1) appreciable disparities exist among occupational hazards, despite nearly similar technological benefits for the population at risk; (2) federal legislators can act to significantly abate risk; (3) federal safety legislation appears to be more responsive to highly publicized, disastrous accidents rather than to chronic, low-level hazards; (4) the introduction of a new technology as well as lack of maintenance of an old technology can increase risk levels; and (5) natural hazard risk levels are extremely low and can further be reduced in some cases, either by collective or individual precautions.

K-2 Prelevance: 1

Starr, Chauncey

SOCIAL BENEFIT VERSUS TECHNOLOGICAL RISK

Science, 165:1232-1238, 19 September 1969.

This paper provides a useful methodology for answering the question "How safe is safe enough?" Although the study is exploratory, it reveals several interesting points: (1) the public seems willing to accept "voluntary" risks roughly 1000 times greater than "involuntary" risks; (2) the statistical risk of death from disease appears to be a psychological

yardstick for establishing the level of acceptability of other risks; (3) the acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined); (4) the social acceptance of risk is directly influenced by public awareness of the benefits of an activity, as determined by advertising, utility, and the number of people participating; and (5) in a simple application of these criteria to atomic power plant safety, an engineering design objective determined by economic criteria would result in a design-target risk level very much lower than the present socially accepted risk for electric power plants. This methodology could be used to determine waste isolation facility design criteria that are based on the concept of "involuntary risk."

K-3 Relevance: 2

Bliss, C., P. Clifford, G. Goldgraben, E. Graf-Webster, K. Krickenger, H. Mahar, and N. Zimmerman

ACCIDENTS AND UNSCHEDULED EVENTS ASSOCIATED WITH NON-NUCLEAR ENERGY RESOURCES AND TECHNOLOGY

The Mitre Corporation, METREK Division, McLean, Virginia, EPA-600/7-77-016, December 1976.

Accidents and unscheduled events associated with non-nuclear energy resources and technology are identified for each step in the energy cycle. These include human error, structural or mechanical failure, sabotage, and natural phenomena such as hurricanes and earthquakes. These accidents can cause environmental damage, economic loss, fatalities, injuries, and health impairment. The frequency and severity of representative accidents for the coal, crude oil, natural gas, LNG, hydroelectric, geothermal, oil shale, and solar energy systems are summarized. The results given in this report can be used to compare and assess the risks of the underground storage of radioactive waste.

K-4 Relevance: 2

U.S. Environmental Protection Agency

A SUMMARY OF ACCIDENTS RELATED TO NON-NUCLEAR ENERGY

Washington, D.C., EPA-600/9-77-012, May 1977.

This report summarizes accidents and unscheduled events associated with non-nuclear energy resources and technology to provide data to help choose intelligently among available alternative energy resources. Coal, crude oil, natural gas, LNG, hydroelectric, oil shale, geothermal, and solar energy systems are considered. Accidents in each energy cycle element (i.e., exploration; extraction; processing; transportation, including transmission and distribution; and end-use technologies) are considered.

K-5 Rélevance: 2

Starr, C., M. A. Greenfield, and D. F. Haisknecht

A COMPARISON OF PUBLIC HEALTH RISKS: NUCLEAR VERSUS OIL-FIRED POWER PLANTS

Nuclear News, pp. 37-45, October 1972.

This article describes the comparative public health aspects of oil-fired and nuclear power plants, and their associated activities in a typical urban setting. In both types of plants, public risk of continuous plant operation at regulatory limits is in the range of those due to other human activities that have general social acceptance. They are estimated to be in the "low" part of this socially acceptable range for the oil-fired plant (60 deaths per year in a population of 10 million) and in the "negligible" part of the range of the nuclear plant (1 death per year in a population of 10 million). In both cases, the integrated accident risk (averaged over time and all episodic events) was found to be 10^{-5} of the continuous exposure for both the nuclear and the oil-fired plants. For the analyzed accident with equal probability of occurrence, the oil-fired plant has a substantially worse public health impact than the nuclear.

K-6 Relevance: 2

Libby, L. M.

TECHNOLOGICAL RISK VERSUS CATASTROPHE

The Rand Corporation, Santa Monica, California, March 1971.

The risk of death from unavoidable natural catastrophes is compared with the risk of death posed by activities of the electrical industry (including risk from nuclear power). The unavoidable natural catastrophes considered are death from meteor falls, from climatic deterioration caused by changes in the amount of sunlight reaching the earth, and from supernovas. Comparison of these risks to nuclear storage waste risks may help provide a perspective for risk acceptance.

K-7 Relevance: 3

Kletz, Trevor A.

THE RISK EQUATIONS--WHAT RISKS SHOULD WE RUN?

New Scientist, 74(1051):320-322, May 1977.

This article discusses how we designate those hazards that require immediate remedial attention and those that can be accepted, at least for the time being. The article contains data on the probabilities of voluntary and involuntary risks that can be used as a basis for comparing the risks associated with nuclear waste storage.

K-8 Relevance: 3

Eisenbud, Merrill and Henry G. Petrow

RADIOACTIVITY IN THE ATMOSPHERIC EFFLUENTS OF POWER PLANTS THAT USE FOSSIL FUELS

Science, 144:288-289, 17 April 1964.

Analysis of the fly ash produced by combustion of pulverized Appalachian coal has shown that a 1000-MW coal-burning power plant will discharge from about 20 mCi to nearly 1 Ci per year of ^{226}Ra and ^{228}Ra into the atmosphere. An oil-burning plant of similar size will discharge about 0.5 mCi of Ra per year. Comparison of these data with data on the release of fission products from nuclear-powered generating stations shows that when the physical and biological properties of the various radio-nuclides are considered, fossil-fueled plants discharge relatively greater quantities of radioactive materials into the atmosphere than nuclear-powered plants of comparable size.

K-9 Relevance: 3

Cohen, Bernard L.

IMPACTS OF THE NUCLEAR ENERGY INDUSTRY ON HUMAN HEALTH AND SAFETY

American Scientist, 64:550-559, September-October, 1976.

The principal health effects of radiation are acute radiation sickness, cancer, and genetic defects. Cancer induction by radiation is the much broader threat. It is usually assumed that cancer risk is proportional to the total exposure in rem. This "linear-no threshold" hypothesis involves a large extrapolation: Cancer is delayed by 15 to 45 years after exposure. This latent period increases with decreased exposures, and for small exposures it may well exceed life expectancy. This paper discusses routine and accidental emissions from all significant aspects of the fuel cycle. It develops the estimated hazard from the corresponding radiation exposures and compares them to natural disasters and other hazards normally faced by society. The paper concludes that, even with conservative assumptions concerning health effects, the hazards faced by society from a nuclear economy are a small fraction of those that society routinely accepts from other sources.

K-10 Relevance: 3

Office of Radiation Programs, U.S. Environmental Protection Agency

RADIOLOGICAL QUALITY OF THE ENVIRONMENT

Washington, D.C., EPA-520/1-76-010, May 1976.

The Office of Radiation Programs (ORP) of the U.S. EPA is responsible for establishing radiation protection guidance and for interpreting existing guides for federal agencies; included is the responsibility for monitoring and assessing the impact of radiation from all sources in the United States on public health and the environment. This report, which is part of ORP's program for evaluating the quality of the environment, summarizes information available in the open literature. The primary effort has been to identify source categories of radiation, which have been considered in two general categories: (1) ionizing radiation and (2) nonionizing radiation. In category (1), sources were further grouped under ambient environmental radiation, technologically enhanced radiation, fallout, uranium fuel cycle, federal facilities, medical, occupational, and other sources. Category (2) is mainly concerned with environmental sources.

K-11 Relevance: 3

Farmer, F. R., C. Starr, H. L. Ley, Jr., R. Lowenstein, A. Z. Raisman, J. Simpson, and R. E. Lapp

HOW SAFE IS SAFE ENOUGH--AND WHY?

Transactions American Nuclear Society, 15(2):823-825, November 1972.

A series of invited papers are given on the subject. An argument is developed leading to a proposition that the risk of release of radioactivity occurring at any time, anywhere, from the reactors now being built or commissioned in this decade should be less than 1 in 10, and preferably 1 in 100 (i.e., a risk from any reactor, in any year, of less than 10^{-6}). (F. R. Farmer)

A study of public acceptance of the risk of death from exposure to sociotechnical systems (such as motor vehicle transportation) indicates that society has accepted a range of risks as a normal part of life. It is shown that there is an approximate relation between the per capita benefits of a system and the acceptable risk as expressed in deaths per exposure year (i.e., time of exposure in units of a year). The highest level of acceptable risks that may be regarded as a reference level is determined by the normal U.S. death rate from disease (about 1 death/y/100 people). The lowest level for reference is set by the risk of death from natural events (e.g., lightning, flood, earthquakes, insect, and snake bites)--about 1 death/y/1,000,000 people. In between these two bounds, the public is apparently willing to accept those "involuntary" risks that are imposed by beneficial social systems and that are not easily modified by the individual (Chauncey Starr).

Significant parallels exist between reactor safety, and food safety. Both nuclear power sources and the national food supply are served by major distribution systems that conveniently provide electric power and food to the public. The parallels run much more deeply than the distribution systems. For both electric power/nuclear reactors and food supply/food additives, maximum benefits are sought with minimal risks. If it is decided to take no risk at all, power and food will only be available under rigid restrictions. If risks are ignored, the public will have what it expects, but at a high price. The proper answer is balancing risks and benefits. (Herbert L. Ley, Jr.)

This paper identifies principal elements of a regulatory safety decision. They include: (a) engineering information (e.g., safety analyses, accident and operating experience, probabilistic studies, and test data); (b) economic or cost data for eliminating or reducing identified risks; and (c) a significant policy or social element. This paper is concerned with (c). (Robert Lowenstein)

The two questions, "How Safe is Safe Enough and Why?" can be answered differently. For a lawyer the questions demand essentially legal answers. "Safe enough" is as safe as the law requires. The reason for that amount of safety is found in the legislative history of the Atomic Energy Act of 1954 and its amendments. (Anthony Zell Roisman)

The degree of safety incorporated into a system can be dictated by the demands of the public or based on the informed judgement of the engineers who design and build the system. For the public, the degree of requisite safety is not readily susceptible to quantitative measure; rather, it is whatever will convince the public that its worst fears cannot be realized. The engineer necessarily deals in margins of safety--mean time between failures, statistical probability, properties of materials, stress, and the like--and therefore strives for a realistic balance between risk and benefit. (John W. Simpson)

The "how" in the question "How Safe is Safe Enough--and Why?" implies some form of quantitative answer. Certainly, no one will be satisfied with a "half-safe" solution or a qualitative answer. The question is problematic because an accidental release of radioactivity has a low probability of occurrence. Such an event with severe consequences makes the "Why" redundant because a nuclear catastrophe, improbable as it may appear to many nuclear experts, could curse the nuclear industry for a long time to come. (Ralph E. Lapp)

K-12 Relevance: 3

Beckman, Peter

THE HEALTH HAZARDS OF NOT GOING NUCLEAR

The Golem Press, Boulder, Colorado, 1976

This book compares the risks of nuclear power with the risks of fossil, hydro, and solar power per units of energy produced in regard to deaths, injuries, and disease incidence. Chapter 4 discusses and compares risks due to waste disposal. Although the book presents little, if any, new information, the presentation and comparisons provide interesting reading.

K-13 Relevance: 3

Bell, C. D. and J. R. Beattie

ASSESSING RISKS IN THE NUCLEAR AND NON-NUCLEAR INDUSTRIES

Presented at the First International Loss Prevention Conference at The Hague, Holland, 1974.

The risk to the individual and to the community arising from nuclear and nonnuclear industry are assessed. The derivation of standards of safety are discussed against the background of risk in human society. Lifetime risk of death is given for the following occupations: trawler fishing, civilian aircraft crew, coal mining, pottery, construction, all manufacturing, all industries. U.S. AEC estimates were used for risks not included by radiation. Also given are general population risks from motor vehicle accidents, falls, drowning, accidental electrocution, lightning, deaths by venemous animals/insects, deaths by leukemia, and thyroid cancer. Most of these estimates are for risks in the United Kingdom.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION K

B-1, B-12, J-8, J-10, J-12, J-16, J-21, J-24

Section L

OTHER SELECTED STUDIES THAT WOULD PROVIDE USEFUL INFORMATION FOR A RADIOACTIVE RISK ASSESSMENT

L-1 Relevance: 2

Kelley, J. A. and R. M. Wallace

PROCEDURE FOR DETERMINING LEACHABILITIES OF RADIOACTIVE WASTE FORMS

Nuclear Technology, 30(1):47-51, July 1976.

This paper presents a new and improved procedure for determining leachabilities of proposed radioactive waste forms. Previous methods using stagnant water, which is changed periodically, gave results that vary by as much as a factor of 10. In addition, leachant pH exceeded 9, and anomalous increases in leachability were observed. In this method, glass samples are leached in flowing deionized water, with leached ions continuously sorbed on ion exchange resins to control ionic quality. Sorbed ions are elicited from the resin columns for atomic absorption analyses. The leachabilities measured by this procedure are lower and more consistent than those made in stagnant water without continuous ionic control. However, this paper presents results obtained from only three samples analyzed in two types of apparatus. These data are insufficient for evaluating the replicability of the procedure. The results do indicate that further investigation is warranted.

L-2 Relevance: 2

Burkholder, Harry C. and Michael O. Cloninger

THE RECONCENTRATION PHENOMENON OF RADIONUCLIDE CHAIN MIGRATION

Battelle Pacific Northwest Laboratories, Richland, Washington, Paper Presented at the 69th Annual Meeting of the American Institute of Chemical Engineers, November 28-December 2, 1976.

The report analyzes the potential reconcentration of radionuclide decay products during their transport by flowing groundwater from underground geologic nuclear waste disposal sites to the biosphere. The calculations show that the predicted maximum (but not the average) nuclide discharge rates to the biosphere for certain nuclides in particular disposal environments can increase above their corresponding values for surface storage. Both the magnitude and range of occurrence of the

phenomenon are complex functions of the adsorption properties of the geologic medium, the migration path length to the biosphere, the leach rate of the waste form, and the half-lives of the nuclides. The results of this study emphasize the importance of performing a thorough and comprehensive safety analysis of nuclear waste management systems, and the need to establish the acceptability criteria for geologic isolation systems with great care.

L-3 Relevance: 1

Gera, Ferruccio

GEOCHEMICAL BEHAVIOR OF LONG-LIVED RADIOACTIVE WASTES

Oak Ridge National Laboratory Operated by Union Carbide Corporation,
Oak Ridge, Tennessee, ORNL-TM-4481, UC-70, July 1975.

This report puts the long-term hazard potential of high-level wastes into perspective by following the changes in the isotopic composition of waste for as long as 10,000,000 years after generation. It also includes an extensive review of the available information on the geological and environmental behavior of long-lived nuclides. The change of the hazard potential associated with the heavy nuclides present in high level solid waste is shown to be an exceedingly slow process; particularly after about 1,000,000 years of decay. In the period from 100,000 to 5,000,000 years, the hazard potential of high-level waste is decreased by a factor of 10-20.

L-4 Relevance: 2

Platt, Robert B., H. L. Ragsdale, and D. J. Shure

ECOLOGICAL BEHAVIOR AND EFFECTS OF RADIONUCLIDES IN SOUTHEASTERN ECOSYSTEMS

Contract No. E-(40-1)-2412, Emory University, Atlanta, GA., ORO-2412-65, May 31, 1976.

This past year was the third of a three-year program commitment and was also the twentieth year of continuous AEC-ERDA support. Researchers concentrated in 1976 upon the behavior of radionuclides released by the nuclear industry. The initial hypotheses regarding the Lower Three Runs Creek are essentially intact; the stream, representative of low gradient streams of the coastal plain, does laterally displace ^{137}Cs into floodplains. The upstream-downstream gradient of decreased ^{137}Cs cycling is apparently real and related to microtopography of floodplains, increased C.E.C. and clays downstream, and increased potassium concentrations, also downstream. The documentation of 15 nCi/m^2 , $\sim 12\%$ of the total

system ^{137}Cs burden, in the biotic phase of the sandy low potassium content turkey oak, and measurement of a 3% root uptake of soil ^{134}Cs within forests suggest that unusually high bioaccumulation of ^{137}Cs can occur in terrestrial systems as well. The role of fungi in concentrating ^{137}Cs and in maintaining it in decomposing leaf litter suggest two mechanisms, food chains and elemental recycling, by which ^{137}Cs could remain mobile in the ecological systems of the Southeast. Although these conclusions must remain tentative, it seems that the coastal plain ecosystems studied in this project are different from those of other land provinces in the extent of system bioaccumulation of ^{137}Cs and in that those differences are strongly related to soils, nutrient concentrations, and processes of material transport within and through water sheds.

L-5 Relevance: 2

Champlin, J. B. F.

THE TRANSPORT OF RADIOISOTOPES BY FINE PARTICULATE MATTER IN AQUIFERS

Ph.D. Thesis, Georgia Institute of Technology, Atlanta, GA., 1970.

This thesis contains both theoretical and experimental investigations of the various phenomena that pertain to the long-range movement of radioisotopes in the environment. The theoretical section deals with the interactions between solids in water that result from thermal forces, electrostatic charges, and van der Waals forces. The relationship between suspended particles and "massive" granules making up the model aquifer is explored in some depth. In the experimental section, the author considers factors that influence either retention of radioactivity by the sand bar or transport of the activity through such a bed by micro-particles. The author seeks a correlation between the phenomena observed experimentally and those predicted in the theoretical section.

L-6 Relevance: 2

American Nuclear Society and American Institute of Chemical Engineers

TOPICAL MEETING: CONTROLLING AIRBORNE EFFLUENTS FROM FUEL CYCLE PLANTS

Sun Valley, Idaho, August 5-6, 1976.

This meeting considered airborne effluents; topics ranged from source terms to dose to the public. Regulatory action requires "as low as reasonably achievable" dose to the public. The overview of technology given in these proceedings is directed to what is "practicable" or "achievable." Papers of special interest to the risks associated with nuclear waste isolation include:

- Source Terms for Airborn Effluents, J. O. Blomeke
- Release of Tritium from Fuel and Collection for Storage, L. L. Burger and L. E. Trevorow
- Preparation of Collected Radionuclide Wastes for Storage, M. J. Steindler and B. Kullen
- Local and Global Transport of Airborne Effluents, S. R. Hanna
- Transport of Airborne Effluents to Man Via the Food Chain, B. E. Vaughn, R. E. Wildung, and J. J. Fuquay
- Dose Consequences from Airborne Radioisotopes, B. L. Cohen
- EPA--Regulatory Role in Radioactive Airborne Effluents, A.C.B. Richardson
- Public Concern for Airborne Effluents from the Nuclear Fuel Cycle, B. E. Watt

L-7 Relevance: 3

Bertram, Lee A.

THERMOMECHANICS IN NUCLEAR WASTE DISPOSAL

Sandia Laboratories, Albuquerque, New Mexico.

This paper presents a "worst case" analysis of the thermal stress problem related to the storage of nuclear waste materials in deep geologic formations. The results indicate that: (1) waste must be aged for 5-10 years before it can be stored in a repository; (2) both the tensile and compressive stress magnitudes must be controlled by proper choice of waste age and void space to guarantee confinement; and (3) substantial void space must be made available by costly additional drilling and modification of the borehole. Further investigations by detailed models are required and will necessitate collection of data on the local lithospheric stresses of particular sites, constitutive relations for rock over a wide range of pressures and temperatures, and sophisticated numerical schemes to solve the combined fluid-solid-thermomechanical governing equations.

L-8 Relevance: 3

Larson, N. M. and M. Reeves

ANALYTICAL ANALYSIS OF SOIL-MOISTURE AND TRACE-CONTAMINANT TRANSPORTATION

Oak Ridge National Laboratory Operated by Union Carbide Corporation,
Oak Ridge, Tennessee, ORNL S/NF/EATC-12, March 1976.

A transport model is presented that predicts the coupled movement of water and trace contaminants through a layered and unsaturated soil-moisture zone. To achieve computation speeds suitable for watershed implementations, moisture properties are approximated as exponential functions of pressure head, and lateral flows are treated as sinks in a basically vertical one-dimensional analysis. In addition, only advection by the Darcy-flow velocities and linear absorption by the soil matrix are considered in depicting movement of the trace contaminant. A program written in FORTRAN IV solves numerical problems. Two example calculations illustrate both strengths and weaknesses of the model.

L-9 Relevance: 3

Robertston, J. B.

DIGITAL MODELING OF RADIOACTIVE AND CHEMICAL WASTE TRANSPORT IN THE SNAKE RIVER PLAIN AQUIFER AT THE NATIONAL REACTOR TESTING STATION, IDAHO

USGS Open File Report IDO-22054, May 1974.

This report describes the results of monitoring studies and digital modeling of radionuclide migration through the Snake River Plain aquifer at the National Reactor Testing Station (now the Idaho National Engineering Laboratory). Monitoring studies have indicated that the movement of cationic wastes, particularly ^{90}Sr and ^{137}Cs , has been significantly retarded by sorption phenomena, principally ion exchange. Digital model techniques have been applied successfully to the analysis of the complex waste-transport system by numerically solving the coupled equations of groundwater motion and mass transport. The model includes the effects of convective transport, flow divergence, two-dimensional hydraulic dispersion, radioactive decay, and reversible linear sorption. For the assumed conditions, the model indicates that ^{90}Sr will move 2 to 3 mi (3 to 5 km) downgradient by 2000, A.D., whereas detectable concentrations of waste chloride and tritium could move as much as 15 mi (24 km). This model may be modified to estimate radionuclide migration from accidental spills or from disposal sites in other locations.

L-10 Relevance: 3

Barraclough, J. T., J. B. Robertson, and V. J. Janyer

HYDROLOGY OF THE SOLID WASTE BURIAL GROUND, AS RELATED TO THE
POTENTIAL MIGRATION OF RADIONUCLIDES

Idaho National Engineering Laboratory, USGS Open-File Report 76-471,
August 1976.

This report describes the results of a study conducted by USGS to (1) evaluate the geohydrological and geochemical controls on subsurface migration of radionuclides from pits and trenches in the Idaho National Engineering Laboratory (INEL) solid waste burial ground and (2) determine the existence and extent of radionuclide migration from the burial ground. About 1700 sediment, rock, and water samples were collected from 10 observation wells drilled in and near the burial grounds of INEL. Low levels of radioactivity were detected in one-half of the sedimentary samples and some of the water samples. The levels detected where, in most cases, less than the amounts found in surface soils in this region resulting from world-wide fallout. The radioactivity is not expected to migrate to the Snake River Plain aquifer. Although some of the observed concentrations might result from statistical variance or from artificial sample concentration, some migration of nuclides from the burial ground has apparently resulted from infiltration of precipitation and runoff water which, on occasion, flooded burial ground pits and trenches. Monitoring of the site will continue.

L-11 Relevance: 3

Emery, Richard M. and Donald C. Klopfer

THE DISTRIBUTION OF TRANSURANIC ELEMENTS IN A FRESHWATER POND ECOSYSTEM

Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms,
Ann Arbor Science Publishers, Ann Arbor, Michigan, 1976.

During the past 2 years, a unique study has been initiated on the Hanford Reservation concerning the ecological behavior of Pu and Am in a freshwater environment. This study involves a waste pond that has been receiving occasional low-level Pu processing wastes for about 30 years. The major sink for Pu and Am in this system is sediment. Seston (30% diatoms) appears to be the principal concentrator of transuranics in the pond system. Organic floc, overlaying the pond sediments, is also a major concentrator of transuranics in this system. Apart from the seston and floc, no other ecological components of the pond appear to have concentrations significantly greater than those of the sediment. Thus, Pu and Am seem to be relatively immobile in the aquatic ecosystem.

L-12 Relevance: 3

Nelson, D. J., S. V. Kaye, and R. S. Booth

RADIONUCLIDES IN RIVER SYSTEMS

River Ecology and Man: Proceedings of the International Symposium on River Ecology and the Impact of Man, 1971, pp. 367-387, 1972.

This paper indicates that the transport and fate of radionuclides in streams depends on hydrodynamic processes as well as on geochemical conditions and characteristics. Several models are discussed that describe the transport processes. The state-of-the-art knowledge of bioaccumulation and metabolism is reviewed, with discussion of monitoring programs near Oak Ridge National Laboratory and the Hanford Works. The Specific Activity Concept is discussed as a technique for predicting radionuclide uptake.

L-13 Relevance: 3

Borg, I. Y., R. Stone, H. B. Levy, and L. D. Ramspott

INFORMATION PERTINENT TO THE MIGRATION OF RADIONUCLIDES IN GROUNDWATER AT: THE NEVADA TEST SITE--PART 1: REVIEW AND ANALYSIS OF EXISTING INFORMATION

Lawrence Livermore Laboratory, Livermore, California, 25 May 1976.

This report comprehensively reviews the known data concerning migration of radionuclides in groundwater at the Nevada Test Site (NTS). A history of NTS is given; the geologic and hydrologic setting is described; and the amount of radioactivity deposited within and near the main aquifers is estimated. The laboratory and field investigations into the general processes that retard the movement of radioactivity from its source and that disperse its concentrations are described, together with results of programs designed to monitor the source terms and the movement of radioactivity at the site. The main conclusions indicate that: (1) current information is insufficient to state that radioactivity will never be carried off NTS by groundwater movement; (2) however, such a migration at levels above the maximum permissible concentration to existing wells and springs is considered unlikely; (3) tritium is the most mobile radionuclide and may be the only long-lived isotope of concern; and (4) predictions of migration both within and without NTS are hampered by a lack of values for fundamental parameters used in transport calculations. Recommendations for future studies to minimize uncertainties are described and given priority rankings.

L-14 Relevance: 3

Knox, J. B. and R. C. Orphan

PROGRAM REPORT--FY1976, ATMOSPHERIC AND GEOPHYSICAL SCIENCES DIVISION,
PHYSICS DEPARTMENT

Lawrence Livermore Laboratory, Livermore, California, UCRL-5144-76,
September 1976.

This report describes the atmospheric modeling activities of the lab, and the specific global and regional models developed to predict dispersion of radionuclides and other compounds. This dispersion is useful for identifying the capabilities of each type of model. Such models could be used to assess the risk of atmospheric dispersion of radionuclides from waste operations.

L-15 Relevance: 3

Merritt, W. F.

THE LEACHING OF RADIOACTIVITY FROM HIGHLY RADIOACTIVE GLASS BLOCKS
BURIED BELOW THE WATER TABLE: FIFTEEN YEARS OF RESULTS

Atomic Energy of Canada Limited, Chalk River Nuclear Laboratories,
Chalk River, Ontario, March 1976.

This paper presents the results of monitoring at an experimental nuclear waste disposal site at the Chalk River National Laboratories in Canada. Twenty-five nepheline syenite glass blocks containing about 300Ci of aged fission products were buried in a 5 x 5 block grid below the water table in August 1958. Leach rates and migration for ^{90}Sr were monitored. Extrapolations to a 30,000-MWe nuclear power industry were made, based on the CANDU heavy water reactor. Under the assumed conditions, it was estimated that 5 mCi would be released to the surface water system. It was concluded that this method can be used for disposal of nuclear waste without harm to the environment.

L-16 Relevance: 3

Moore, J. G., H. W. Godbee, and A. H. Kibbey

LEACH BEHAVIOR OF HYDROFRACTURE GROUT INCORPORATING RADIOACTIVE WASTES
Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1976.

This paper presents results from studies made to determine the leachability of various radionuclides from cementitious grouts similar to those used in the Hydrofracture Facility at Oak Ridge National Laboratory for disposal of intermediate-level nuclear waste. The rates at which Sr, Cs, Pu, and Cm are leached were measured. Several experimental methods were used. In general, the isotope leach rate followed the order: Cs>Sr>Cm>Pu. A comparison of the leach data for the grout with the results reported by other investigators for other products indicates that the grout can provide leach rates comparable to those obtained for wastes incorporated into borosilicate glass.

L-17 Relevance: 3

Ahlstrom, S. W., R. J. Serne, R. C. Routson, and D. B. Cearlock

METHODS FOR ESTIMATING TRANSPORT MODEL PARAMETERS
FOR REGIONAL GROUNDWATER SYSTEMS

Battelle Pacific Northwest Laboratories, Richland, Washington, 1974.

Risk assessment must include an analysis of the potential release of radionuclides to the groundwater system from spills, discharge, or disposal. This paper provides a methodology for estimating dispersion and sorption coefficients from correlations with characteristic regional soil properties, rather than the detailed and costly transmissivity measurements that comprise the current procedure. The method is used to derive the dispersion coefficient relationship and strontium sorption correlation for the saturated zone of the Hanford Reservation groundwater system. Preliminary functional relationships for the transport parameters are formulated and contour plots of the computed distributions are shown.

L-18 Relevance: 3

Routson, R. C. and R. J. Serne

ONE-DIMENSIONAL MODEL OF THE MOVEMENT OF TRACE RADIOACTIVE SOLUTE
THROUGH SOIL-COLUMNS: THE PERCOL MODEL

Battelle Pacific Northwest Laboratories, Richland, Washington,
BNWL-1718, 1972.

A one-dimensional mathematical model, PERCOL, has been developed to predict the movement of radionuclides through porous media as a function of measurable chemical parameters of the media. Laboratory studies were conducted to verify the model. System parameters considered include soil type, radionuclide type, waste composition, flow rate, column length, and soil saturation. The agreement between measured radionuclide movement and that predicted by the model is considered good. This model may be useful in predicting radionuclide migration from spills or discharge at nuclear waste repositories.

L-19 Relevance: 3

Mendel, J. E.

A REVIEW OF LEACHING TEST METHODS AND THE LEACHABILITY OF
VARIOUS SOLID MEDIA CONTAINING RADIOACTIVE WASTES

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-1765,
UC-70, July 1973.

This paper reviews state-of-the-art experimental techniques that have been used to measure the leachability of solidified radioactive wastes in the United States and elsewhere. Factors that affect leachability are described. The need for two different kinds of leach tests is emphasized: (1) a rapid comparison test and (2) a more comprehensive performance test that simulates the actual exposure environment.

L-20 Relevance: 3

Walton, R. D. and G. A. Cowan

THE RELEVANCE OF NUCLIDE MIGRATION AT OKLO TO THE PROBLEM
OF GEOLOGIC STORAGE OF RADIOACTIVE WASTE

Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Paper Submitted to IAEA International Symposium on the Oklo Phenomenon, Libreville, Gabon, June 23-27, 1975.

Analyses of available data indicate that escape of radioactive products from the Oklo reactor zones was quite limited. Estimates of radionuclide release are given. Relevance of these tentative conclusions to other geologic formations must await further study of comparative geochemistry and geology.

L-15 Relevance: 3

Huff, Dale D. and Paul Kruger

SIMULATION OF THE HYDROLOGIC TRANSPORT OF RADIOACTIVE AEROSOLS

Advances in Chemistry Series 93, American Chemical Society, Washington, D.C., 1970.

A model for the hydrologic transport of radioactive aerosols simulated watershed radioaerosol hydrographs. The hydrologic transport model (HTM-1) was based on the anticipated physical and chemical interactions of fallout-deposited radioaerosols with watershed media during runoff. A numerical simulation of the watershed moisture balance, computed with the Stanford Watershed Model, estimated resulting effects on radioaerosol transport. Transport calculations considered the effects of vegetal interception, soil surface interactions (included erosion), and stream channel movement to predict a continuous radioaerosol hydrograph for the two biologically important radionuclides: 27.7-year ^{90}Sr and 30.0-year ^{137}Cs . Experimental radioaerosol hydrographs obtained for the Saratoga Creek, California, watershed were used to evaluate the several processes considered in preparing HTM-1.

ADDITIONAL REFERENCES THAT MAY HAVE ALSO BEEN LISTED UNDER SECTION L

J-4, J-5, M-14

Section M

RELATED BIBLIOGRAPHIES

M-1

Asher, J. M. (editor)

NATIONAL WASTE TERMINAL STORAGE PROGRAM BIBLIOGRAPHY

Office of Waste Isolation, Union Carbide Corporation, Oak Ridge, Tennessee, Y/OWI/TM-26, April 1977.

This bibliography lists many of the documents authored since 1958 by Union Carbide Corporation--Nuclear Division's technical personnel, consultants, and subcontractors as part of the geologic waste disposal programs that Oak Ridge National Laboratory is conducting for the current National Waste Terminal Storage Program.

M-2

Powell, J. A.

BIBLIOGRAPHY OF PNL PUBLICATIONS IN MANAGEMENT OF RADIOACTIVE WASTES, SUBJECT-INDEXED (ALPHABETICALLY) AND LISTED CHRONOLOGICALLY (LATEST ISSUES FIRST)

Battelle Pacific Northwest Laboratories, Richland, Washington, BNWL-2201, July 1976.

The citations are arranged under the following topics: actinides, alpha particles, americium, beta particles, calcination, cements, ceramics, cesium, containers, decontamination, disposal, evaporation, fluidized bed, glass, ground release, high-level wastes, incinerators, liquid wastes, marine disposal, melting, nonradioactive waste disposal, processing, Pu, radiation doses, radiation protection, radionuclide migration, Ru, safety, separation processes, soils, solidification, solid wastes, stack disposal, temperature, thermal conductivity, transmutation, tritium, underground disposal, U, volatility, and waste disposal/management/processing, storage/transportation.

M-3

U.S. Atomic Energy Commission

RADIOACTIVE WASTE MANAGEMENT: A BIBLIOGRAPHY OF PUBLICLY AVAILABLE LITERATURE PERTAINING TO THE USAEC'S OAK RIDGE, TENNESSEE SITE

Oak Ridge, Tennessee, TID--3343, September 1973.

This bibliography contains abstracts of 448 technical reports and journal articles pertaining to radioactive waste management at the Oak Ridge site that appeared in Nuclear Science Abstracts from 1948 through 1973. The abstracts are grouped in 10 categories.

M-4

U.S. Atomic Energy Commission

RADIOACTIVE WASTE MANAGEMENT: A BIBLIOGRAPHY OF PUBLICLY AVAILABLE LITERATURE PERTAINING TO THE USAEC'S SAVANNAH RIVER, S.C., PRODUCTION SITE Oak Ridge, Tennessee, TID-3341, August 1973.

This bibliography contains abstracts of 197 technical reports and journal articles pertaining to radioactive waste management at the Savannah River site that appeared in Nuclear Science Abstracts from January 1951 through January 1973. The abstracts are grouped in 10 categories.

M-5

U.S. Atomic Energy Commission

RADIOACTIVE WASTE MANAGEMENT: A BIBLIOGRAPHY OF PUBLICLY AVAILABLE LITERATURE PERTAINING TO THE USAEC'S NATIONAL REACTOR TESTING STATION, IDAHO

Oak Ridge, Tennessee, TID-3342, August 1973.

This bibliography contains abstracts of 272 technical reports and articles pertaining to radioactive waste management at the National Reactor Testing Station that appeared in Nuclear Science Abstracts from January 1951 through July 1973. The abstracts are grouped in 10 categories.

M-6

U.S. Atomic Energy Commission

RADIOACTIVE WASTE MANAGEMENT: A BIBLIOGRAPHY OF PUBLICLY AVAILABLE LITERATURE PERTAINING TO THE USAEC'S HANFORD, WASHINGTON PRODUCTION SITE

Oak Ridge, Tennessee, TID-3340, August 1973.

This bibliography contains abstracts of 1098 technical reports and journal articles pertaining to radioactive waste management at the Hanford site that appeared in Nuclear Science Abstracts from January 1951 through July 1973. The abstracts are grouped in 10 categories.

M-7

U.S. Energy Research and Development Administration
RADIOACTIVE WASTE PROCESSING AND DISPOSAL
Washington, D.C. (ten documents), 1958 through 1976.

These bibliographies relate to radioactive waste announced in Nuclear Science Abstracts. The documents are as follows:

TID-3311 containing 698 citations, issues 1958
TID-3533 containing 696 citations, issued 1960
TID-3555-S1 containing 874 citations, issued 1962
TID-3311-S1 containing 989 citations, issued 1964
TID-3311-S2 containing 1012 citations, issued 1966
TID-3311-S3 containing 2249 citations, issued 1972
TID-3311-S4 containing 464 citations, issued 1973
TID-3311-S5 containing 345 citations, issued 1974
TID-3311-S6 containing 2140 citations, issued 1975
TID-3311-S7 containing 1841 citations, issued 1976.

M-8

Nuclear Safety Information Center

NUCLEAR POWER: ACCIDENTS PROBABILITIES, RISKS, AND BENEFITS: A
BIBLIOGRAPHY

Union Carbide Corporation, Oak Ridge, Tennessee, ORNL/NSIC-123,
February 1976.

This bibliography contains 396 documents pertaining to nuclear accident probability and nuclear risk. Abstracts of selected documents with keywords are included, followed by a keyword, author, and permuted title index.

M-9

Raleigh, Henry D.

REACTOR SAFETY: A LITERATURE SEARCH

U.S. Atomic Energy Commission, Oak Ridge, Tennessee, TID-3525-R5-S8,
December 1973.

This bibliography includes 267 citations to references issued from January 1972 through June 1973 on safety analysis of nuclear reactor design, siting, materials, engineered safeguards, and operating procedures. Reports cited concern hazards analyses of entire facilities to satisfy

construction and operation permit requirements, evaluation of the reactor systems and components, and analyses of the consequences of potential accident situations. Subject, author, corporate author, and report number indexes are included.

M-10

Grooms, David W. (editor)

ACCIDENT RISKS IN NUCLEAR FACILITIES (A BIBLIOGRAPHY WITH ABSTRACTS)

National Technical Information Service, Springfield, Virginia, NTIS/PS-76/0786, October 1976.

This bibliography presents risk analysis and hazards evaluation of design effects, construction, and operation of nuclear facilities, including the risk and hazards of transporting radioactive materials to and from these facilities. Radiological calculations for environmental effects of nuclear accidents are included. This bibliography covers 1964 to September 1976 and contains 195 abstracts.

M-11

Buchana, J. R. and G. W. Keilholtz

LMFBR SAFETY: 2. REVIEW OF CURRENT ISSUES AND BIBLIOGRAPHY OF LITERATURE (1970-1972)

Union Carbide Corporation, Oak Ridge, Tennessee, ORNL/NUREG/NSIC-129, December 1976.

This report discusses the status of LMFBR development and one of the principal safety issues--a hypothetical core-disruptive accident (HCDA). Worldwide bibliographic information about the development of the LMFBR as a safe source of nuclear power is presented for 1970 through 1972. The bibliography consists of approximately 1620 abstracts that cover early research and development and operating experiences leading up to the present design practices that are necessary for the licensing of LMFBRs. Key-word, author, and permuted-title indexes are included for completeness.

M-12

Groom, David W. (editor)

NUCLEAR MATERIALS SAFEGUARDS. VOLUME I. 1964-1974: A TITLE BIBLIOGRAPHY

National Technical Information Services, Springfield, Virginia,
NTIS/PS-76/0200, March 1976.

The research covers the methods of safeguarding nuclear materials through effective management, accountability, nondestructive assays, instrumentation, and automated continuous inventory systems. Studies on problem areas and recommendations for improving the management of nuclear materials are included. Because AEC abstracts were unavailable during the period covered by this bibliography, these citations are not included. The bibliography contains 287 titles.

M-13

Groom, David W. (editor)

NUCLEAR MATERIALS SAFEGUARDS. VOLUME 2. 1975 - FEBRUARY 1977. A
BIBLIOGRAPHY WITH ABSTRACTS

National Technical Information Center, Springfield, Virginia, NTIS/PS-
77/0175. April 1977.

Citations cover the methods of safeguarding nuclear materials through effective management, accountability, nondestructive assays, instrumentation, and automated continuous inventory systems. Problem areas and recommendations for improving the management of nuclear materials are included. (This updated bibliography contains 143 abstracts, 56 of which are new entries to the previous edition.) See also, NTIS/PS-76-0200, Nuclear Materials Safeguards. Vol. 1. 1964-1974: A Title Bibliography.

M-14

Borg, I. Y., R. Stone, H. B. Levy, and L. D. Ramspott

INFORMATION PERTINENT TO THE MIGRATION OF RADIONUCLIDES IN GROUND WATER
AT THE NEVADA TEST SITE. PART 2: ANNOTATED BIBLIOGRAPHY

Lawrence Laboratory, Livermore, California, UCRL-52078 Part 2, August 1976.

This bibliography contains abstracts compiled from a search of the literature for information on the migration of radionuclides at the Nevada test site. Included are abstracts on the distribution and transport of radioactivity and on sorption and leaching studies. A key word index is provided.

M-15 Relevance: 2

Cottrel, William B.

PROTECTION OF NUCLEAR POWER PLANTS AGAINST EXTERNAL DISASTERS

Nuclear Safety Information Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL-NSIC-117, April 1975.

This report is both a bibliography and a compilation of articles on the protection of nuclear power plants from external disasters. It includes material on tornadoes and high winds, floods and high waves, earthquakes, plane crashes, sabotage and diversion, acts of war, and other disasters. The articles included in this compilation are primarily review articles on various topics selected from Nuclear Safety. Relevant AEC regulations, rulings, and regulatory guides are also included. The bibliography with each section includes all recent literature on each topic, each with its own key-word, author, and permuted title index. In addition, a brief commentary introduces the report and places its varied contents in perspective.

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