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Report of
THE CLINCH VALLEY STUDY
May 15—June 2, 1972

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HEALTH PHYSICS DIVISION

Report of
THE CLINCH VALLEY STUDY

May 15 - June 2, 1972

Edited by
J. A. Auxier
and
R. O. Chester

NOTICE

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JANUARY 1973

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UNION CARBIDE CORPORATION
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THE CLINCH VALLEY STUDY

Edited by
J. A. Auxier and R. O. Chester

ABSTRACT

A number of topics are discussed which affect the handling of an accidental radioactivity release from a nuclear power plant. Principal attention is given to those matters that decrease the threat to the population surrounding the site of the power plant. Recommendations are made to improve existing emergency plans. Procedures and methods are listed which have proved useful in handling other types of emergencies and appear to have use during a radioactivity release. Also discussed are emergency control centers, construction modifications to the nuclear power plants, chemical prophylaxis, and improvised respiratory protection.

INTRODUCTION

This preliminary study of methods of coping with accidents that release radioactivity to the environment was conducted by the Oak Ridge National Laboratory at the request of the Division of Biomedical and Environmental Research, U. S. Atomic Energy Commission. A number of topics affecting decisions to be made and actions to be taken in the first hours following an accidental radioactivity release from a nuclear power plant were critically examined. The intent of the study was to provide practical suggestions to supplement existing emergency plans and procedures.

After discussions with the members of the Division of Biomedical and Environmental Research and the study participants, it was apparent that actions taken in the first few hours following an incident would influence the consequences of the incident, possibly to a major degree. Therefore, in this preliminary study available information was collected that might be used to minimize the radiation dose to the public, the financial loss, and contaminated land area resulting from a radiological incident. During this process, problem areas that need further investigation were identified. The Clinch Valley Study represents a synopsis of the views and recommendations of the study participants.

The Clinch Valley Study was not intended to cover all possible topics because it was a preliminary study, reflecting the interests of participants, and because no effort was made to duplicate efforts on the specific topics being examined by other study groups. Therefore, the inclusion of a topic in this study should not be interpreted as implying the greater importance of this subject but rather that it is a topic which the participants of this study decided should be further pursued in studies of emergency operations.

Although Federal agencies, the state and local governments, and the utility companies would all eventually be involved in dealing with a radioactivity release from an installation, the study focused primarily on actions that could be initiated by officials at the state and local levels with the technical analyses and advice provided by the utility company officers. Preincident planning and construction topics as discussed are concerned primarily with the utility company and the nuclear facility licensing procedure. Principal attention was given to those matters that decrease the threat to the general public.

Increasing attention has been brought to the problem of developing detailed, workable radiological emergency response plans at the state and local level. More extensive use of nuclear power generation in the future will require that even more detailed attention be given to the problem of handling accidental radioactivity releases. The excellent safety record of licensed nuclear installations has resulted in little opportunity to exercise many aspects of radiological emergency plans. No really serious or even potentially serious offsite emergency has occurred. Shipping accidents involving nuclear materials, while more numerous than reactor incidents affecting offsite property and population, have not been extensive enough to test the limits and therefore suggest major improvements of local and state response capabilities.

At present, the primary responsibility for handling requests for assistance from either civilian or military authorities at the Federal level is the Interagency Radiological Assistance Plan (IRAP). The IRAP is intended to integrate the Federal, state, and other capabilities to respond to requests for assistance in radiological incidents.

Much of the existing local and state capability is being coordinated in response to licensing requirements of nuclear facilities. The licensee is required to submit in both preliminary and final safety analyses a comprehensive radiological emergency plan. Agreements with local, state, and Federal authorities included in the plan must be confirmed in writing. The licensee is charged to assist offsite organizations in the development of appropriate plans. However, the utility is not required to evaluate how effectively other organizations can carry out the things they have agreed to do in an emergency. Special employee training, periodic drills, and updating of the emergency plans on an annual basis are also required as part of the licensing procedure.

Radiological emergency response planning at state and local levels, appropriately tied to licensee plans, is becoming increasingly important with the increase in the number of nuclear power reactors and public interest related to safety. This need is recognized, and various efforts have been initiated to step up and improve the planning by state and local governments. For example, a potentially very useful project of organizational interactions at all levels is being sponsored by the Office of Emergency Preparedness (OEP) assisted by the Atomic Energy Commission (AEC), the Defense Civil Preparedness Agency (DCPA), and the Environmental Protection Agency (EPA). The project is centered on the Arkansas Power and Light's Dardanelle Plant in Pope County, Arkansas. The expected product is a set of model complementary emergency plans covering the response to a radiological emergency by licensee, the county and state. This project should eventually provide to other localities and states valuable guidance in their nuclear incident planning as well as in the coordination of these activities at all levels.

In contrast, in the Clinch Valley Study a number of technical topics that could be utilized by organizations responding to a radiological emergency or participating in preincident planning have been examined.

The participation of representatives of the following organizations and Federal agencies is greatly appreciated.

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 EG&G, Inc.
 Florida Power and Light Company
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 Disaster Preparedness Division
 Tennessee Valley Authority
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J. A. Auxier
 Study Director

REPORT OF THE CLINCH VALLEY STUDY

" . . . for practical purposes, technological advances have all but eliminated routine radioactive emission . . . but we shall never be totally free of concern over reactor safety [and] transport of radioactive materials . . . "

A. M. Weinberg
Science 177, 27 (1972)

The following represents a synopsis of the views of the Study participants on the indicated topics. In this preliminary study, the topics covered reflect the interests and capabilities of the participants. Detailed discussions of each topic will be found in the Appendices.

THE EMERGENCY PLAN

Effective action to minimize the impact of an incident that releases radioactivity to the environment from a power reactor must be initiated promptly after the start of the incident. The Clinch Valley Study makes the following recommendations to improve and speed emergency response:

- I. A plan that establishes executive authority and areas of responsibility must exist prior to the emergency for prompt and effective response.

Fortunately, plans for coping with emergencies are required as part of the licensing procedure for nuclear power plants. The more recent plans, in particular, are thorough in delineating the responsibilities of the utility and of local and state governments. The utilities are not presently required, however, to evaluate the ability of organizations with which they have agreements to fulfill their commitments. A procedure for evaluating the emergency response should be developed and put into operation.

- II. The emergency plan should be exercised approximately once every year to maintain useable organizational function during an emergency.

Present emergency plans specify drills at least once a year. Experience in the United Kingdom has shown that a full scale site emergency exercise every 14 months with a six hour training course for involved personnel will keep the emergency procedures in good working order. Drills for the more frequently encountered minor incidents are held the most frequently. The use of complete scripts for all participants during some of the drills, as explained in Appendix II, appears to have merit. This procedure builds invaluable self-confidence in emergency personnel. A much more detailed list of the types of drills, emergency procedures, and sequencing of drills needs to be added to existing emergency plans.

- III. The emergency plan must specify clearly the formal mechanism for hazard assessment so that varying differences of scientific opinion are resolved quickly.

This aspect of emergency planning needs more attention. In particular, if experts are consulted who are outside the chain of authority specified in the emergency plan, there must be a rapid method of reconciling their opinions with those of the technical advisors specified by the existing emergency plans.

- IV. The plan should indicate the methods for prompt notification of the local civilian authorities of the status of the emergency.

Local civilian officials must be reminded immediately of their areas of responsibility and authority and areas in which they do not have authority. The mechanics of this notification need to be spelled out more clearly than it is in existing emergency plans.

- V. The plan should specify a procedure for supplying promptly information on the status of the emergency to the general public.

Full information must be supplied to the public to obtain understanding from the public, ensure cooperation from all involved parties, and to check the spread of misinformation. The Clinch Valley Study recommends a detailed procedure for informing the public be specified in all emergency plans.

DEMOGRAPHIC CONSIDERATIONS

Important data to be considered during realistic emergency planning are the population distributions around the power reactor sites. For example, in the event of radioactivity releases, the detailed population distribution would determine, in part, the action level at which population evacuation would be ordered. For a relatively lower projected dose, evacuation might be ordered at a later time for a low density population than for a high population density. An evacuation from a high population density area might require staging to remove the high risk population first before evacuation routes might be blocked. Chemical prophylaxis might be recommended in lower risk, high population density areas in lieu of total evacuation of that area.

The Clinch Valley Study recommends that a study be made of the required demographic accuracy around a power reactor site for effective decisions on emergency operations. Additionally, the demographic accuracy required as a function of time of day should be carefully specified.

Once the required demographic accuracy has been established, then the demographic information itself must be extracted from existing data or new, site related data must be obtained. The Clinch Valley Study recommends that the methods for

obtaining site specific demographic data to the required accuracy be investigated and demonstrated for several different sites.

A closely related topic that must also be examined in detail is the most useful manner of storage, retrieval, and display of the demographic information that is available at the time of a radiological incident. For example, the detail and sophistication of data presentation would depend on the computer facilities and data display mechanisms that would be available to the decision-making authorities during a crisis situation.

EMERGENCY OPERATIONS CONTROL CENTER

If a regional or national Emergency Operations Control Center were available to the decision-making authorities, more elaborate computer facilities and data display devices would be utilized than a single reactor site could justify.

Demographic information for each reactor, typical meteorological data by seasons, current meteorological data, and information on predetermined evacuation routes could be stored at the center in a readily accessible fashion. If the center were provided with an estimate of the isotope leak rate for the mixture of escaping isotopes, an estimate of the inhaled dose vs position could quickly be made. A computer connected to a display system could provide a visual presentation of dose vs position at the time of the request and estimates of dose vs position for any specified future time period.

An Emergency Operations Control Center would have additional advantages and disadvantages. Site meteorological, radiological, and water quality information could be telemetered daily to the center. Since radiological emergency episodes would be few and far between, routine work for each site, such as the required periodic meteorological, water quality, and radiological release summaries, could be prepared at the center. Routine work would insure that communication links were operational.

A single, multipurpose center nationwide in coverage and accessible to all through a single telephone number may be a very expeditious arrangement. A multipurpose center is one that handles incidents other than radiological releases. Technical advisors both at the center and the site could use the available information in providing technical advice and expert situation assessment for local officials.

There are disadvantages to a single center that must be weighed against the advantages. The single center requires installation and maintenance of often long communication links between the center and each site. Since the processing of data is remote, there might be additional chances for error and misinterpretation. A computer failure or any power outage at the center could not be allowed to completely halt emergency operations.

The Clinch Valley Study recommends that the feasibility of a regional or national Emergency Operations Control Center be studied. Single purpose as well as multipurpose centers should be evaluated. A cost estimate for each type of center should be made.

CHEMICAL PROPHYLACTIC MEASURES

A number of chemical compounds can be ingested before or shortly after exposure to radioactive aerosols and gases to prevent the biological assimilation of the inhaled radioisotopes. Chemical prophylaxis has been most studied for radioisotopes of iodine, strontium, and cesium.

Iodine prophylaxis has received more attention than that for other elements because it is the most serious inhalation hazard under many foreseeable circumstances. One reason for the seriousness of the radioiodine hazard is that iodine and iodine compounds are usually quite volatile and therefore a sizeable fraction of the core inventory can be released from the reactor. Another reason for considering iodine a major hazard is its unique biological effects. A large fraction of the inhaled iodine is in the soluble form and is quickly absorbed into the bloodstream. Iodine collects preferentially in the thyroid and is released with a relatively long biological half-life; so a small vital organ receives most of the dose from the radioactive iodine.

A number of chemical compounds are suitable as prophylactic agents for inhaled radioiodine; potassium iodide, potassium iodate, calcium iodate, and pentacalcium orthoperiodate are four of the most promising. Table I in Appendix IV summarizes their properties. Only potassium iodide, the least stable and strongest tasting, is approved for human consumption by the Food and Drug Administration (FDA) in the USA. Potassium Iodate is used as a table salt additive in other parts of the world, but the FDA requirements for USA use have not been fulfilled. The principle requirement not yet fulfilled is a two-year feeding study on two species of test animals. The cost would be approximately \$50,000. The Clinch Valley Study recommends that this study be carried out.

The Clinch Valley Study recommends that calcium iodate and pentacalcium orthoperiodate be further investigated as iodine prophylactic compounds. These compounds have the advantage of increased stability in the presence of light and moisture.

The Clinch Valley Study also recommends that methods of rapidly disseminating a prophylactic iodine compound be carefully evaluated. Both pre-emergency and post-emergency distribution systems should be evaluated. A pre-emergency distribution system using electric meters as storage points is discussed in Appendix IV.

Under some accident conditions, the long term effects of inhalation of radiostrontium, radiocesium, or other radioisotopes might prove more serious than the effects of inhalation of radioiodine. The possibility of using treatment to hasten the elimination of radiostrontium and radiocesium is discussed in Appendix IV.

However, prophylactic agents capable of reducing the uptake of radioactive strontium and cesium still need more detailed in vivo study before a workable prophylactic schedule for the general population can be suggested. The Clinch Valley Study recommends continued study of prophylactic chemicals for strontium and cesium.

As discussed in Appendix IV, the Clinch Valley Study recommends against the dissemination of drugs that stop thyroid function to prevent iodine uptake. The Study recommends against the prophylactic use of radioprotective drugs for protection against external gamma ray and neutron radiation.

IMPROVISED RESPIRATORY PROTECTION

During a radiological emergency, there may be situations in which evacuation is not feasible or cannot be completed. In these situations, improvised respiration protection for the general population would be desirable. Enough work has been done to indicate that common household materials can be highly effective. The Clinch Valley Study recommends that more research be done on this. Among other things, an improvised tent of filter medium should be developed for infants.

DETAILS OF RADIOACTIVITY RELEASES

Basic to all the previously discussed considerations is the fission product release from the reactor containment. The Clinch Valley Study recommends realistic assessment of the potential airborne threat. A realistic calculation of releases under a variety of conditions should be made. More data on fission product release from highly irradiated fuel elements would be useful for quantitative calculations. Meteorological data for each site should be used to estimate the airborne threat. Diurnal variations in meteorological conditions should be considered and real sequences of conditions used in dose calculations.

Such calculations would give a realistic range of threats that might have to be dealt with at each site. Out of this work would come the time estimate for a specific release to build up to a given action level and hence the desirable emergency organization response time would have an estimated upper limit. The preliminary investigations of the Study indicate that a realistic offsite emergency team response time is about three hours. It is not true that emergency response in every situation at all sites has been drilled and thought through carefully enough to insure such rapid team response times. Fission product release calculations even for quite badly damaged reactor containment systems show that at three hours only a small fraction of the releasable fission product inventory has been released. The Clinch Valley Study recommends that fission product release and emergency response time comparisons be further examined. Then realistic but effective response times should be requested of emergency response teams.

REACTOR CONSTRUCTION MODIFICATIONS

Another emergency abating factor considered during the Clinch Valley Study was a major construction modification, berm containment. This type of containment should decrease the probability of some types of incidents that release radioactivity to the environment. Berm containment is basically above-ground construction that has been covered with crushed rock and then soil backfill. This type of construction provides an additional containment with a number of useful properties. A breach in a berm containment could be closed with earth moving equipment. Damaged locks designed

to admit personnel and equipment could be plugged after an incident to prevent further fission product release. An internally generated high pressure steam jet venting through the reactor building inside the berm containment would have much, if not essentially all, of its energy absorbed by the large volume of rock backfill. Much of the first puff of radioactivity release could be eliminated in this manner. Therefore, a berm containment breach should result in negligible radioactivity release under more different emergency conditions than a conventionally constructed additional containment building.

The impact resistance of a berm containment is much greater than a conventionally constructed containment. Hence, the containment provides immunity from unlikely but dangerous events such as tornadoes, hurricanes, plane crashes, and effects of conventional weapons. The management of other unlikely but potentially dangerous events such as a catastrophic meltdown, sabotage, and effects of nuclear weapons is greatly simplified because the reactor is already covered with soil and containment breaches can be plugged with soil and cement, if necessary.

This additional containment will involve additional costs for the utility. The Clinch Valley Study recommends that a detailed cost benefit analysis of earth berm construction as a nuclear power reactor containment system be made.

SUMMARY

The Study participants intended that the preceding report provide practical suggestions that, if adapted to existing emergency plans and procedures, would help minimize the impact of a radioactivity release to the environment. Principal attention was given to those technical topics that could decrease the threat to the general public from airborne radioactivity.

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APPENDIX I

PRE-EMERGENCY PLANNING

INTRODUCTION

Useful information concerning pre-emergency planning can be obtained from the response to non-nuclear incidents. For example, an objective and thorough critique of the "Chlorine Barge Incident" in Louisville, Kentucky, in March-April 1972 provides a description of both the strengths and weaknesses of the response mechanisms to this type of incident.¹ While these mechanisms are not identical to those that would be used in a radiological incident, there is some overlap and many points of similarity. Some of the conclusions of the critique should apply to a radiological incident.

The chlorine barge incident resulted when a tow of nine barges broke up on the Ohio River near Louisville, Kentucky. A barge loaded with four tanks, each containing 160 tons of chlorine, became lodged in the Bay of Tainter Gate No. 2 at the McA Alpine Dam. Until the chlorine was safely transferred to an empty barge, the threat of escaping gas extended over a populated area. Some of the threatened area was evacuated on a mandatory basis and some on a voluntary basis. The threat lasted nearly one month, allowing the full extent of Federal, state, and local organizational and technical preparedness and capability to become evident. The response of the news media and general population are noted in the critique.

PLANNING CONSIDERATIONS

Using the Chlorine Barge Critique, among other sources, the Clinch Valley Study suggests the following issues be given careful consideration in pre-emergency planning.

I. A plan must exist to deal with radioactivity release from a power reactor.

Experience has shown that prompt and effective response to an emergency situation is achieved most frequently when an emergency plan exists and emergency personnel are well versed in its procedures prior to the existence of a real emergency situation.

The critique pointed out the necessity to have pre-disaster planning at Federal, state, and local levels. At all levels it is necessary to establish executive authority and to have well-defined areas of responsibility in order to have rapid and effective response.

II. The emergency plan must be exercised regularly.

Gulf Coast hurricane evacuation experience shows that a full scale exercise approximately once every year is necessary to retain some organizational function

during an emergency.² One apparently effective set of procedures used at Harwell³ consisted of a full scale site emergency exercise once every 14 months for all plant personnel. Everyone who has a role in the site emergency organization each year has to go through a six hour training course that is spread over a week. The course consists of three hours of lectures in which procedure and the role of individuals is explained. One and one-half hours is devoted to a completely scripted exercise. The rationale for scripted accidents is that if the drill cannot run smoothly and efficiently with a script, then surely it would not go well without a script. Another objective of scripted drills is to build up the self-confidence of emergency personnel. One and one-half hours is devoted to an unscripted exercise and everyone taking part in it knows that the next full scale site emergency will be based on it. This ensures that all personnel will show a keen interest in the proceedings. Part of the effectiveness of this procedure lies in the drill content. More exercises simulating minor accidents are included in the drills than exercises simulating major accidents because minor accidents are more numerous than major accidents.^{4,5} Also, use of minor accident drills saves a great deal of supervisory time in dreaming up incidents.

III. The emergency plan must specify clearly the formal mechanism for the hazard assessment of a radioactivity release.

A formal mechanism would quickly resolve varying differences of scientific opinion so that effective action could be initiated with minimum delay. The chlorine barge incident critique indicates that part of the emergency response must be to inform rapidly local and state officials of the current technical assessment of the situation and discuss possible methods of handling the emergency. In some cases, local officials must be clearly informed of their authority or lack of it to insure rapid, effective decision making. This is particularly true when a population evacuation must be ordered.

IV. The plan should delineate the means by which local civilian authorities will be notified promptly of an emergency situation.

The chlorine barge incident showed need for early notification of civilian authorities so that they are aware of their areas of responsibility and authority and the proper response may proceed without delay.

If civilian authorities are alerted during a progressively deteriorating situation or at the onset of an accident, action can be taken promptly as the situation warrants. Decisive action taken early in such a situation can greatly mitigate the effects of a radioactivity release. Although the Clinch Valley Study is not recommending action levels, assume, for example, that each reactor scram could automatically initiate a "first level" alarm in the office of a properly designated non-utility civilian authority. After determining that no offsite hazard is involved, a phone call from the reactor control room or from a utility official could stop the civilian emergency preparations. Regular drills in this procedure would prevent undue alarm in the civilian population.

V. The plan should specify a procedure for promptly supplying accurate information on the status of the emergency to the public.

It is essential to inform but not to alarm the public. The news media can accomplish this by reporting in a manner devoid of sensationalism. For example, the media coverage of the chlorine barge incident by the Louisville newspapers, local TV, and local radio was extensive but was carried out in a matter-of-fact, low-key manner. In addition, the establishing of a rumor control office at the Louisville Emergency Operation Center and continually announcing that telephone number assisted in reducing rumors.

POPULATION RESPONSE

Various studies of population reaction during periods of emergency or crisis show that the most rapid and rational response is obtained if:

1. The public is fully informed in a factual non-sensational manner.
2. An emergency plan for the high risk population has been reviewed and rehearsed by this population.
3. The emergency procedures have been reviewed and publicly endorsed by well respected, local community officials.⁶
4. A recognized civil official such as the Mayor, City Manager, or Civil Defense Director makes the announcements concerning the emergency on the news media.²

In some legislation dealing with emergencies, full information to the public is specified. For example, according to Annex VI of the National Contingency Plan⁷ dealing with oil and hazardous materials spilled on waterways, "... it is imperative that the public be provided promptly with accurate information on the nature of the spill and what steps are being taken to correct the problems. This policy must be followed to obtain understanding from the public, ensure cooperation from all interested parties and to check the spread of misinformation. National Administration Policy and the Freedom of Information Act both call for maximum disclosure of information."

Currently approved emergency plans for nuclear power reactors contain good but very general press release examples. Press releases would have to be more numerous and more detailed as the radioactivity release becomes more extended or extensive.

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⁷ For example, see the list of Federal Statutes and Executive Orders from Annex I of Ref. 1. Also, see "National Oil and Hazardous Materials Pollution Contingency Plan," § 504.1, Federal Register 35, No. 106 (June 2, 1970), or "Toxic Substances Control Act of 1972," S1478 Sect. 110 (3), Congressional Record S8546-8552 (May 30, 1972).

APPENDIX II

EUROPEAN AND UNITED STATES POWER REACTOR EMERGENCY PROGRAMS

INTRODUCTION

A comparison of the U.S. emergency programs and proposed alternatives and the existing European emergency programs provides interesting background material for discussion of emergency planning. The importance of U.S. state government responsibilities for public health and safety virtually guarantees that U.S. plans will differ from reactor to reactor. The traditions of Europe tend toward uniformity and stronger central control. As a result, the emphasis in the two types of plans is different even though the plans are intended for similar emergency situations.

FOREIGN SYSTEMS

United Kingdom

All nuclear power reactors in the United Kingdom are operated by the Central Electricity Generating Board (CEGB), and the Nuclear Health and Safety Department of the Board is responsible for emergency planning as required by the Nuclear Installations Act of 1965.

A detailed emergency plan is required for each reactor. However, a basic emergency plan is provided by the CEGB.¹ Certain key functions will be discussed here.

Identification and Declaration

The British plan recognizes that an Emergency Alert can and will be declared by the nuclear power plant supervisor when a discharge of radioactive material which is likely to cause a hazard to the public has occurred, or whenever the circumstances demand such action. The offsite survey to measure hazard to the public is performed by plant health physics personnel in a specially equipped health physics vehicle (or vehicles).

Warning and Emergency Action

The offsite warning network is not well defined in the basic plan but consists in part of the emergency controller informing the local police of the accident and requesting any help needed. The details of an initial program of education and information are not discussed in the plan. However, emergency practice sessions do include local police and other outside authorities.

A central feature is the formation of a Local Liaison Committee, chaired by the plant superintendent with members from the local public organizations having emergency responsibilities. These include county and local authorities; representatives of police, fire, and ambulance services; national farmers union; meteorological office; and River Board and Water Undertakings.

The committee meets periodically to discuss the local emergency plan, and once a year the plan is practiced with observers from the Nuclear Installations Inspectorate of the Department of Trade and Industry who provide independent and competent criticism and evaluation.

Although the practice session involves emergency personnel including the local policemen, the public is not involved directly. The police expect to evacuate large groups of the public closest to the reactor and to issue potassium iodide pills together with written explanations of their purpose and dosage. Cards have been printed and pills in foil strips have been prepared and stocked at each operating reactor.

The police are capable of making an independent decision on what offsite emergency actions to take at the time of a reactor accident. This is because the police report through a chain of command to the Home Office, and the reactor emergency controller is not in the chain. Therefore, the reactor controller's recommended actions communicated to the police are suggestions only. However, prior practice sessions and discussions lead to a very cooperative attitude on the part of the police as well as other local authorities.

In summary, the British plan involves the plant supervisor as the local emergency director, his own staff as technical consultants, and the police as the principle emergency operating force.

Italy

The Comitato Nazionale Energia Nucleare (CNEN), a branch of the Italian Ministry of Industry, has the responsibility for approving the technical content of all plans for power reactor safety. On the other hand, the Ministry of Interior is responsible for the protection of the public from nuclear emergencies. This split has been bridged by the CNEN acting in an advisory function for approval of reactor emergency plans.

The exact requirements for these plans are spelled out in a 1964 decree of the Italian President.² A commentary on the plans was prepared in 1967 by Dr. Osvaldo Ilari of the CNEN.³ Again, certain functions of special significance to the present discussion will be presented here.

Identification and Declaration

Although the first steps of the Italian emergency plan for offsite hazards control originate with the power plant staff, the plan calls for very quick transfer of authority to the Prefect of the province in which the reactor is located. A Provincial Committee of Emergency (PCE), chaired by the Prefect, would have been formed before the reactor began emergency operations. Although the PCE has several parallel duties to the Local Liaison Committee in the U.K., it has prepared the plan rather than merely

reviewed it. Further, the PCE has an important operating capability which distinguishes it clearly from its U.K. counterpart.

The executive secretary of the PCE is the Provincial commandant of the Fire Services. On a national basis, the fire brigades have general responsibility for radiological survey, including civil defense functions. Near each power reactor, special instruments and specially trained personnel of the brigade provide an alternate survey team to measure the hazards of an emergency release of radioactivity.

The plans call for health physics personnel from the reactor to survey from the plant borders downwind while the fire brigade personnel, under the direction of the Prefect, survey upwind in the same sector. Reports from the survey teams are to be the basis for emergency action, with the Prefect making the decision. In this arrangement, the plant director becomes a technical consultant in the writing of the plan and an advisor through the Committee in the emergency action decision.

Warning and Emergency Action

The details of warning the public and instructing them in appropriate emergency actions are quite unclear in the Italian documents. The police, with the aid of the military headquarters, are said to be responsible for the evacuation of the population and for control of traffic if necessary. At the present time, there are no plans to use potassium iodide tablets to control thyroid uptake of iodine.

Summarizing the Italian plan, the Provincial Prefect is the emergency supervisor, the fire brigade and the plant staff provide technical guidance, and the police perform operating functions.

CURRENT U. S. EMERGENCY OPERATIONS

The major difference between current U.S. and European offsite emergency organizations is diffuse central responsibility for U.S. vs strong local responsibility for European organizations.

In the United States, plans for coping with emergencies are required as part of the licensing procedure for nuclear power plants. The Atomic Energy Commission, Directorate of Licensing, has the responsibility of approving these emergency plans.

The atomic energy legislation lists the general requirements for emergency plans⁴ and a guide for the preparation of emergency plans prepared by the Atomic Energy Commission is available.⁵

The emergency plans for one nuclear power reactor site have been selected for discussion. The Tennessee Valley Authority's (TVA) Browns Ferry Plant⁶ in Alabama was chosen because of the thoroughness with which its organizational plans have been addressed.

The detailed emergency plans differ from reactor to reactor because of different local and state laws, population distribution near the reactor, and different topographical features near the reactor.

Identification and Declaration

The first notice of an offsite emergency would be available to the reactor staff. For determining what emergency action should be taken to protect the surrounding population, a classification of accidents by TVA has been established, as shown in Table I. A declaration of the emergency accident would be made by the State Department of Public Health in Montgomery based on a telephone call from TVA who supplies all necessary health physics data plus local meteorology from which exposure data can be determined.

If the normal health physics staff at the reactor site is not adequate for environmental surveillance during an accident, independent survey teams at Muscle Shoals, Alabama, 30 miles west of the plant will be assigned to offsite monitoring. The teams have three specially equipped vehicles which contain the necessary monitoring and radio equipment. The maximum response time to the Browns Ferry Plant is estimated to be about one hour, and its independence assures that onsite problems should not interfere with general area surveying.

After classification and declaration of an incident, the State Department of Public Health contacts the State Civil Defense Director who notifies the county civil defense directors who are affected. They carry out the necessary offsite emergency actions with the exception of radiological monitoring.

Warning and Emergency Action

The plan for Morgan County* (with Decatur the county seat), southeast of the reactor, is typical of those of the three counties (including Limestone and Lawrence). The public will be warned by loud speakers on police vehicles dispatched by the Civil Defense Director from the county Emergency Operations Center. If evacuation has been ordered, National Guard trucks will accompany the police cars to provide transportation. If the State Health Department has ordered an area evacuated, then evacuation is compulsory in Alabama. Other police cars will establish road blocks on all county roads cut by a seven-mile arc centered on the reactor site to prevent entry into the hazardous area and to direct all who leave to the relocation center in Decatur.

Welfare Services

A national Guard armory in Decatur has been selected as the collection center for evacuees. There the people leaving the hazardous area will be registered, checked for radiation exposure and contamination, provided with medical services as required, and given food and housing as needed. Since only 36 persons are expected to live within five miles from the reactor in 1985 (see Fig. 1), the staff and facilities for welfare services appear to be quite adequate. Twenty-eight hundred residents are projected for all three counties, and adequate reception centers have been designated.

* "Civil Defense Emergency Plan for Nuclear Incident Involving Browns Ferry Nuclear Power Plant," Morgan County, Alabama, January 1972.

Table I. Classification of Radiation Accidents of Browns Ferry

Classification	Lower Limit of exposure	Organ or Media Involved	Actions to be Taken
Class A Incident	5 rems 15 rems 30 rems 500 X MPC in 24 hrs.	Whole body Child's thyroid All other organs Liquid discharge	Evacuation of the population from exposure area; control of water usage to prevent expo- sure; all class B actions.
Class B Incident	1.25 rems 3.75 rems 7.5 rems 50 X MPC in 24 hrs.	Whole body Child's thyroid All other organs Liquid Discharge	Control of food and water supply to prevent exposure in excess of these values; all class C actions.
Class C Incident	0.5 rems 1.5 rems 3.0 rems 1 X MPC in 24 hrs.	Whole body Child's thyroid All other organs Liquid Discharge	Intensive environmental sampling to confirm that exposure not in excess of these levels.
Class D Incident	1 millirem 1 hr. at boundary 10 ⁻⁷ microcurie/cc water	Gas discharge Liquid discharge	Extra samples in reactor area to confirm that discharge is not in excess of these levels.

FIGURE 1

ORNL-DWG 72-6656

Population Distribution Near Brown's Ferry Nuclear Power Station

Special Organizational Problems

Residential density is quite low in the immediate vicinity of Browns Ferry. But TVA recreation experts have estimated that Wheeler Lake and its shoreline may contain as many as 30,000 transients within five miles of the reactor site during some summer weekends and holidays. Department of Conservation water patrols are theoretically capable of warning this large group of people using speedboats equipped with loud-speakers. But no detailed plan or organization exists to identify and direct the recreationers to relocation centers, and to provide the welfare services described earlier.

REFERENCES

¹ "Basic Emergency Plan," Central Electricity Generating Board, Nuclear Health and Safety Department, NH/HCO/3. 10.

² "Safety of Plants and Protection of Workers and the Population Against the Risk of Ionizing Radiations Arising from the Peaceful Uses of Nuclear Energy," Decree No. 185 of the 13th February, Gassetta Ufficiale No. 95 of 16th April, 1964, Articles 112 through 122.

³ O. Ilari, "Technical Criteria and Administrative Procedures for the Health Protection of Populations against the Hazards from Nuclear Plants," Division of Health and Protection Control, Rome, December 1967.

⁴ "Emergency Plans for Production and Utilization Facilities," 10 CFR Part 50, 450.34 and Appendix E, Federal Register, Vol. 35, No. 249 (December 24, 1970).

⁵ "Guide to the Preparation of Emergency Plans for Production and Utilization Facilities," Atomic Energy Commission, Washington, D. C. 20545 (December 1970)

⁶ "Tennessee Valley Authority - Radiological Emergency Plan, Browns Ferry Plant," AEC Docket No. 50-259/260/296.

APPENDIX III

DEMOGRAPHIC CONSIDERATIONS OF AN ACCIDENTAL RADIOACTIVITY RELEASE FROM A NUCLEAR POWER PLANT

INTRODUCTION

Safety considerations of today mandate a broad examination of the population risk within geographic proximity to the reactor site. Given the increase, however small, in background radiation, as well as the possibility, again however small, of a minor leakage or catastrophic failure of a nuclear power reactor, then the safety concerns of today have to go beyond the technical problems of reactor shut-down and the safety of the site workers. In fact, with the increasing fervor and sophistication of today's safety and licensing hearing protagonists, the delineation of that population at risk, as well as the extent of the risk, are becoming dominant factors in measuring environmental impact of the existing and proposed power plants.

There are two demographic aspects in nuclear power reactor safety considerations:

1. An awareness of the various levels of exposure to people and the numbers of people likely to be receiving those exposures in the event of a nuclear emergency at a reactor site, with a view towards evacuation or other countermeasure decisions; and
2. The ability to evaluate the risk entailed by the exposure as well as the risks entailed by any countermeasures.

Across both of these two aspects of risk evaluation are time considerations. First, whichever emergency is being explored, the population counts being used must be projections of the available data gathered in the past. The most likely data for estimation of the population at risk are the Decennial Census of Population and Housing, data current as of April 1, 1970, as well as more recent locally generated counts for portions of the exposure-risk area around the reactor site. Thus, figures for "today" can only be projections based on estimates of the various components of change.

CURRENT WORK

The "exposure-risk area" has been specified for safety and licensing purposes to be within a 70-mile radius of the nuclear power plant; this is divided into sub-areas defined by polar coordinates such that the sixteen "rays" of 22.5° centered on the major compass points are further segmented by the circles 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, and 70 miles from the reactor site. Figure 1 shows the 1, 2, 3, and 4 mile circles for the Newboid Island plant on the Delaware River.

FIGURE 1

PHOTO 3137-72

Site of Newbold Island Nuclear Power Plants
Units 1 and 2, Newbold Island, New Jersey.
The circles have 1, 2, 3 and 4 mile radius.

For the licensing process, population estimates are required for each of the above defined 192 sub-areas for the year the power plant is expected to come on stream, and then for the next four decennial census years.

For an accidental release of radioactivity of the types being considered by the Clinch Valley Study, the above defined areas should suffice. What is needed is a means of keeping the estimates reasonably current and available, so that in an emergency situation they can be retrieved, overlaid onto meteorological mappings, and used to provide guidance for civilian authorities who must make the countermeasure decisions, including area evacuation. For anticipative safety decisions, projections into the future may be needed to provide guidance for decisions such as zoning or construction permits which might have major demographic impacts on portions of the 70-mile circular area. For instance, a major industrial plant site or proposed housing development might be sited in other than prevailing downwind directions from the reactor.

In looking at the demographic aspects of safety planning, there is another time dimension which must be incorporated — the time of day variability of the population distribution. The census figures, and thus estimates based thereon, are for the population at rest, which might be referred to as a 2:00 a.m. population distribution. Unfortunately, we have no means of guaranteeing that an accident will occur at that "demographic-estimate" optimal point. Estimates at 2:00 p.m., when portions of the populace are likely to be at work, school, shopping, play, etc., are much more involved and more geographically unstable. Then, if you impose the possibility of an accident during either of the two rush hour periods, when there are major instabilities in the geographic dispersal of the populace, one can have considerable difficulties with the demographic aspects of immediate or short term response to a disaster situation.

The "2:00 a.m. - 2:00 p.m. problem" presumably could be solved, on a site by site basis, with varying uncertainly levels in the estimates derived, but only with the allocation of major resources to the study effort. Before that step is taken, an area of needed future study is the level of accuracy required in demographic estimates for disaster decision making. The Clinch Valley Study recommends that a study be made of the required accuracy level.

DATA SOURCES

The data source which is consistent across all reactor power plant sites is the Decennial Census of Population and Housing. An introductory description of the nature of the informational content of that census and the geographic areas for which the Bureau of the Census provides summary count figures is contained in the following Appendix. For these purposes, the major problem is that their tabulation areas are operationally defined and constrained by political boundaries — city blocks or block groups, and "enumeration districts" are the smallest tabulative areas. Enumeration districts (or block groups within cities) are defined by the census as the area one enumerator can cover within a reasonable time interval around the census date, April 1,

and includes approximately 250 households. There are other larger aggregation areas made up of enumeration districts which are described in Illustration 1 in the Appendix.

Earlier discussion indicated that for the purposes at hand, estimates were desired for 192 sub-area units within 70 miles of a reactor site, defined with polar coordinates. Census data are defined in terms of physical boundaries such as streets, streams, railroad tracks, etc., or political boundaries. The allocation of census-produced sub-area counts to the polar coordinate segments is somewhat eased by use of the Coordinate MEDList — a version of the Master Enumeration District Listing which gives the longitude and latitude of the population centroids of all ED's, as well as the total population counts. Thus, with a margin of error, the population residing (at 2:00 a.m.) within an ED can be assigned to the polar coordinate segment in which the centroid lies. At the outer ring, where the segments are about 250 square miles in area, the amount of error in this manner of assignment is slight. Most of the way into the center of the circular territory, computer assignments are reasonably accurate, for the census sub-area units are much smaller than the units of interest.

Starting near the reactor site, however, imposes major accuracy problems with the computer assignment of census ED's. At the center, the 16 pie slices within the one-mile circle have an area of approximately 0.2 square mile each, which is less than most block groups or enumeration districts. Depending on the density, other assignment methods must be used for the segments within either the five- or the ten-mile circles. Aerial photography can be used as a guideline in such assignments, but assignments made in this manner can be expensive. An assignment method which gives reasonably accurate population counts and is effective as well as inexpensive is to examine the close-in areas with census map overlays and allocate the census counts for blocks, block groups, enumeration districts, or minor civil divisions by hand. The census maps generally give some indications of housing units, and thus can be used rather effectively to proportion the population to the segments of interest.

REACTION CONSIDERATIONS

At the instant of notification of an emergency, the decisions would depend on the most current demographic information readily available. This suggests that the segment demographic information for each reactor site be stored on-line in an accessible computer system. Then, when needed, it could be called out either in toto or for a given directional sector. The information might be provided in terms of a compass heading, and the numeric counts for each segment starting at the center, or a computer-driven plotter might overlap the meteorological information on wind strength and directions onto the demographic density information. Either of these two approaches could be called forth on a visual display device, as well as on paper.

In addition to this data bank covering all reactor sites, there might need to be an accessible data set at an emergency operations control center for each individual site served by the center. There a map could be maintained showing evacuation mechanisms such as roadways, or commercial transportation routes as well as topographical features which might affect the dispersion of the radioactivity. The maps

could also indicate major demographic changes — sub-divisions, apartments, factories, schools, etc. — which have occurred since the estimates were prepared. As an alternative to maps, aerial photographs could serve the same purpose if their cost could be brought down to an acceptable, cost-effective level.

APPENDIX

THE 1970 CENSUS — AND YOU

A General Introduction to Census Data ¹

Can Census Data Help Me?

Probably. Census data are put to a wide variety of uses. Housing authorities study information about characteristics of housing in their cities as an aid in selecting neighborhoods which should benefit from improvement programs. County and regional officials are interested in population shifts, change in the average family size, concentrations of the very young or very old and other characteristics of their areas which affect requirements for public services. Businessmen also find a knowledge of such characteristics helpful in marketing their products.

In the 1970 census, information was collected on such subjects as age, race, education, income, ownership or rental of houses and apartments, and number of rooms in houses and apartments. While you cannot obtain information from the Census Bureau about specific individuals or homes because this is forbidden by law, you can obtain summary information about geographic areas such as city blocks, groups of blocks, cities, counties, and States. By summary information we mean counts of persons or housing units with particular characteristics, such as the number of men 25 to 34 years old, families headed by females, housing units renting for \$150 to \$200 per month, or persons residing in a certain city.

Consider a few examples of the use of summary data:

- A businessman interested in locating a new store will want to find an area with a high proportion of likely customers, such as families with moderate incomes, single young adults, or college graduates.
- A school administrator may want figures for different parts of his city on the number of children under 5 years old for use in planning adequate future facilities, or the number of adults who have not completed high school in order to choose neighborhoods for adult education classes.
- A neighborhood citizens' group, interested in improving services provided by the city, may want data on the number of children in various age groups to support requests for recreational facilities or on the number of working mothers with children under 6 to indicate the need for child day-care centers.

So, if you need to know the characteristics of the people and housing units within an area or want to know where people or housing units with particular characteristics are located, more than likely there are census data that can help.

What Information Does the Census Provide?

The information becoming available from the 1970 census is derived from either questions asked of the entire population or a sample of the populations. The questions asked of everyone or about every housing unit are called 100 percent or complete-count questions. They concern basic information on such subjects as age, sex, race, property value or rent, and number of rooms. This information is needed to count everyone accurately and to make possible the publication of some data for very small areas such as city blocks.

One household in every five throughout the country answered sample questions in addition to the 100 percent questions answered by everyone. The exact questions which were asked depended on which one of two sample questionnaires the household received. One type of sample questionnaire went to 15 percent of all households; the other went to 5 percent of all households. In some cases, the same question appeared on both, resulting in a 20 percent sample, otherwise, 15 or 5 percent sample responses were obtained. The information requested concerned such subjects as income, number of school years completed, occupation, place of work, heating fuel used, and number of automobiles.

To insure the validity of sample data and prevent disclosure of information about any individual, tabulations of information from the sample questions are only released for types of areas which generally have a population of at least two to three thousand. Thus, if you need information for very small areas such as city blocks, you will only be able to obtain statistics derived from the 100 percent questions. In general, the larger the population of an area, the greater the amount of data, both 100 percent and sample, which is available.

Table 1 shows all the subjects covered in the 1960 and 1970 censuses and indicates whether they were asked on a complete-count or sample basis. There was little difference in questionnaire content between 1960 and 1970 because of the importance of having comparable data for assessing changes in population and housing characteristics which occurred during the decade.

For What Areas Are Census Data Reported?

Data are presented for the entire country in printed reports and computer tapes. But the Census Bureau does not tabulate data for all the blocks, streets, or other small areas in the exact combinations which might be desired. For example, data for school districts or police precincts are not prepared in regular Census Bureau operations.

Through its regular tabulation program, the Bureau prepares data summaries, presented in printed reports and/or computer summary tapes, for the following areas (also see illustration 1):

Table 1. Content and Coverage Comparison, 1960-1970

The sample percentages for population and housing items included in the 1970 census in comparison with the items in the 1960 census are shown below.

POPULATION ITEMS			HOUSING ITEMS		
	1960	1970		1960	1970
Relationship to head of household	100%	100%	Number of units at this address	---%	* 100%
Color or race	100	100	Telephone	25	⁷ 100
Age (month and year of birth)	100	100	Access to unit	100	100
Sex	100	100	Kitchen or cooking facilities	100	---
Marital status	100	100	Complete kitchen facilities	---	100
			Condition of housing unit	100	---
			Rooms	100	100
State or country of birth	25	20	Water supply	100	100
Years of school completed	25	20	Flush toilet	100	100
Number of children ever born	25	20	Bathup or shower	100	100
Employment status	25	20	Basement	25	100
Hours worked last week	25	20	Tenure	100	100
Weeks worked last year	25	20	Commercial establishment on property	100	100
Last year in which worked	25	20	Value	100	100
Occupation, industry, and class of worker	25	20	Contract rent	100	100
Activity 5 years ago	---	20	Vacancy status	100	100
Income last year			Months vacant	25	100
Wage and salary income	25	20	Components of gross rent	25	20
Self-employment income	25	¹ 20	Heating equipment	25	20
Other income	25	² 20	Year structure built	25	20
			Number of units in structure and whether a trailer	20	20
Country of birth of parents	25	15	Farm residence (acreage and sales of farm products)	25	20
Mother tongue	25	15	Land used for farming	24	---
Year moved into this house	25	15	Source of water	20	15
Place of residence 5 years ago	25	³ 15	Sewage disposal	20	15
School or college enrollment (public or private)	25	15	Bathrooms	20	15
Veteran status	25	15	Air conditioning	5	15
Place of work	25	⁴ 15	Automobiles	20	15
Means of transportation to work	25	15	Stories, elevator in structure	20	5
			Fuel— heating, cooking, water heating	5	5
Mexican or Spanish origin or descent	---	5	Bedrooms	5	5
Citizenship	---	5	Clothes washing machine	5	5
Year of immigration	---	5	Clothes dryer	5	5
When married	25	⁵ 5	Dishwasher	---	5
Vocational training completed	---	5	Home food freezer	5	5
Presence and duration of disability	---	5	Television	5	5
Occupation—industry 5 years ago	---	5	Radio	5	5
			Second home	---	5

¹ Single item in 1960; two-way separation in 1970 by farm and nonfarm income.

² Single item in 1960; Three-way separation in 1970 by social security, public welfare, and all other receipts.

³ This item is also in the 5-percent sample but limited to State of residence 5 years ago.

⁴ Street address included in 1970.

⁵ In 1960, whether married more than once and date of first marriage; in 1970, also includes whether first marriage ended by death of spouse.

⁶ Collected primarily for coverage check purposes.

⁷ Required on 100-percent for field followup purposes.

COMMON CENSUS GEOGRAPHIC AREAS

AREA

**STANDARD METROPOLITAN
STATISTICAL AREA AND
COMPONENT AREAS**
(central city of 50,000+ population
and the surrounding metropolitan
county(s))

POPULATION SIZE

At least 50,000

CENSUS TRACT (small, homogeneous,
± relatively permanent area; all SMSA's
are entirely tracted)

Average 4,000

**BLOCK GROUP OR ENUMERATION
DISTRICT** (subdivisions of census tracts,
places, and minor civil divisions)

Average 1,000

BLOCK (identified in all urbanized areas
and some selected areas)

Average 100

Political units of the Nation, including States, congressional districts, counties, minor civil divisions (e.g., towns, precincts, and townships),* incorporated places (e.g., cities and villages), and wards in some cities. Both 100 percent and sample data summaries are prepared for these areas, except for wards (population counts only).

Statistical areas, (listed in order according to diminishing average population size), such as:

- standard metropolitan statistical areas (SMSA's — comprising a county containing a central city of 50,000 or more plus contiguous counties socially and economically integrated with the central county. Both 100 percent and sample data.)
- urbanized areas (UA's — comprising a central city plus the surrounding closely settled urban fringe. Both 100 percent and sample data.)
- unincorporated places (a concentration of population which is not incorporated. Only unincorporated places of 1,000 or more inhabitants are shown in the reports. Both 100 percent and sample data.)
- census tracts (subdivisions of SMSA's, averaging 4,000 population, covering all SMSA's for 1970. Both 100 percent and sample data.)
- enumeration districts (ED's — administrative divisions set up by the Bureau to take the census in areas where enumerators were used, averaging 800 population. Only 100 percent data.)
- block groups (groups of city blocks, averaging 1,000 population, which are the equivalent of enumeration districts in 145 of the large metropolitan areas where the census was taken by mail in 1970. Only 100 percent data.)
- blocks (city blocks, generally rectangular areas bounded by four streets, defined in cities of 50,000 and over plus their suburbs and in additional cities which contracted with the Bureau for block tabulations. Only 100 percent data.)

How are Census Data Released?

Printed Reports

Printed reports have long been the most common means of releasing census data. If you do not require information in great detail for a large number of areas, the printed reports will probably be the most convenient and readily available source for you.

* In 21 States minor civil divisions (MCD's) are not adequately defined for reporting census statistics. To take their place, Census and local officials have designed census county divisions (CCD's).

The data being presented in 1970 census reports are similar in kind and quantity to the data contained in reports resulting from the 1960 census. Your local library may have the reports you need, or you may purchase copies, usually for less than \$2, from the U.S. Superintendent of Documents or from the nearest U.S. Department of Commerce field office. Order forms should be obtained from the Census Bureau (see page 11).

The census data contained in printed reports are arranged in tables. Population and housing characteristics for specified areas are reported, such as the number of rented housing units in a block, the number of families below specified income levels in a census tract, or the number of persons who have had vocational training in a city or county.

The Census Bureau releases several different series of reports, and in most series, there is one report for each State. The reports in each series are released over several months on a State-by-State basis. Some contain data principally about people and families; others contain data primarily about housing.

REFERENCES

¹ Prepared by Gary M. Young, Data Access and Use Laboratory, Data User Services Office, August 1971 (revised February 1972).

APPENDIX IV

PROPHYLACTIC MEASURES TO LIMIT THE UPTAKE OF INHALED RADIOACTIVE MATERIALS

INTRODUCTION

Inhaled radioactive materials are transferred to the bloodstream by absorption that takes place on the lung surfaces or in the GI tract. Gases and particles soluble in lung fluids are absorbed primarily in the respiratory tract. Less soluble materials or soluble compounds that can be leached out of insoluble particles are absorbed in both the lungs and the GI tract. GI tract absorption arises because particles retained on the ciliated lung surfaces, with a half-life of about one day, are swept into the trachea, coughed up, and may be swallowed.¹ Once in the GI tract, the residence time of particles is somewhat over one day. Particles on the unciliated lung surfaces clear to either the GI tract, pulmonary lymph nodes, or directly to the bloodstream with an approximate 500 day half-life.* As long as the particles are in the body the leaching process and the absorption of radioactive material will continue.

Several methods are used to prevent the uptake of soluble radioactive materials. For example, for iodine, a soluble gas, the thyroid capacity can be saturated with stable iodine at any time from one hour before exposure to 12 hours after exposure to radioiodine. For cesium, a prophylactic agent is used to adsorb the element in the GI tract and inhibit its absorption into the bloodstream.

RESPIRATORY PROTECTION

In addition to chemical prophylaxis, much protection against ingestion during a release of radioactivity can be obtained by breathing filtered air. In industrial practice this is commonly accompanied by the use of dust filter respirators, gas masks, or self-contained breathing apparatus. Unfortunately, very little of this equipment is distributed or available to the general public.

However, experiments carried out at Fort Detrick in 1958 have shown that surprisingly effective respiratory protection can be improvised from household materials.⁴ The test aerosol was the spore of the bacterium B. globigii with mass median diameter

* Inhaled particles from an accidental release of the type being considered by the Clinch Valley Study are assumed to be uranium or mixed uranium and plutonium oxides. Many of the fission products will be incorporated in or absorbed on the uranium oxide particles. For these particles, the biological half-life for the slow clearance pathways from the lungs is not well known and probably depends upon solubility as well as particle size.² Estimates for the half-life range from 150 to 1400 days,³ but it is assumed to be about 500 days for a single acute exposure.¹

of 2.1 microns. Of the materials tried, the most effective at an acceptable pressure drop were 8 layers of a man's cotton handkerchief, 89% efficiency, and 2 layers of bath towel, 85% efficiency. All respiratory protection devices require air to be forced through a filtration medium. The result is usually that the person wearing a protection device must put extra effort into exhaling and inhaling. The extra effort is commonly measured as a pressure drop across the protection device. An acceptable pressure drop is 20 mm water at 10 l/min flow rate on 12.5 cm² area. With the thicknesses indicated for the handkerchief, the pressure drop was 18 mm and the towel, 11 mm. Most respiratory protective masks are designed for a pressure drop of 10 mm water.

Wetting the filter media causes no significant increase in filtration efficiency but very large increases in pressure drop.

To keep the hands free, the filter can be tied over the open mouth directly, using a torn towel, or, if a handkerchief is used, a second one can serve to attach it. Inhaling through the mouth and exhaling through the nose minimizes dead air volume and wetting of the filter by saliva.

Infants cannot tolerate filter media held over the nose and mouth. They must be enclosed in an improvised tent of the filter medium, and have air forced through the medium by manually collapsing and expanding part of the tent volume. Some development of convenient improvisations of this equipment would make this protection more effective. The Clinch Valley Study recommends that more work be done in the area of improvised respiratory protection.

IODINE

Iodine prophylaxis has received more attention than other elements because it is the most serious inhalation hazard under many circumstances. One reason for the seriousness of the iodine hazard is that iodine and iodine compounds are usually quite volatile and therefore a sizeable fraction of the core inventory can be released from the reactor. Another reason for considering iodine a major hazard is its unique biological effects. A large fraction of the inhaled iodine is in the soluble form and is quickly absorbed into the bloodstream. Inhaled iodine is in equilibrium with body fluids in about $\frac{1}{2}$ hour.⁵ Five to 35% of the ingested iodine collects in the thyroid⁶ and is released with a relatively long, 138 day, biological half-life.⁷ Using the biological half-life and the radioactive decay half-life an effective half-life for each isotope involved can be calculated.⁷ The relative amounts of each isotope for various power reactor types are available.⁸ The remainder of the ingested iodine is excreted fairly rapidly and is essentially gone in 48 hours.⁹ So a small vital organ receives most of the damage from the radioactive iodine.

If the radiation damage is enough to permanently destroy the thyroid function (1×10^5 to 5×10^5 rem),⁹ the condition is called thyroid burnout. Without administration of a thyroxine compound on a regular basis, thyroid burnout is fatal. Doses to the thyroid less than the burnout dose can eventually result in thyroid cancer or other abnormal conditions.

If body fluids are saturated with stable iodine before exposure to radioiodine, the ultimate thyroid absorption of radioiodine is 1% or less of the available amount.⁵ In this condition the uptake of radioiodine by the thyroid is said to be blocked.

Experiments with adult human volunteers indicate that 100 mg of stable iodine* taken one-half hour to approximately one day before exposure to radioiodine produces thyroid blocking.⁵ In any event, 100 mg stable iodine should be administered as soon as possible after exposure. As a rough guide, the final uptake is halved if stable iodine is administered 6 hrs after exposure. Very little is gained by taking stable iodine more than 12 hrs after exposure and nothing is achieved after the first day. Therefore, in a suspected exposure, it is probably better to administer a prophylactic stable iodine dose immediately rather than spend time in any assessment of the release or probable intake.

Normally, iodine taken up by the thyroid is released into the body fluids at a slow rate and some of it is eventually localized again in the thyroid gland. This reabsorption of the radionuclide can be prevented by continued low doses (≈ 30 mg) of the stable element given over at least the next 8 days. Chronic exposure requires a stable iodine dose of 100 mg/day to maintain a blocked thyroid.

It may be noted that the addition of 400 mg KIO_3 to each gallon of local milk would ensure blocking for a population drinking about 1 pint of milk per day.

A number of possible prophylactic compounds are available. Table I gives their properties.

Suggestions have been made that drugs such as carbimazole that stop the functioning of the thyroid be used to prevent uptake of radioiodine.¹¹ Such drugs have much more serious side effects than the iodides and iodates previously discussed and are potential bone marrow depressants.¹² There is no apparent advantage in the use of this drug over the use of stable iodine. Therefore, the Clinch Valley Study recommends against the use of carbimazole or similar drugs.

Since prophylactic iodine should be administered before exposure to radioiodine, or as soon after as possible, it would be highly desirable to have iodide or iodate pills at the residences and places of work of the population. The problem is to protect the pills from loss, misplacement, and misuse.

One way to make the pills available to private residences is to incorporate them in a suitably designed tag attached to the seal wire on the latch of the electric meter housing. Public health officials and utility companies could also have stockpiles of these pills. As many as forty 200 mg potassium iodate pills might be sealed in a tag $1 \times 3 \times \frac{1}{8}$ inches. The outside of the tag might bear a legend something like, "Unauthorized tampering with this seal can result in discontinuation of electric service to these premises." Underneath the weather-proof, sealed plastic outer cover would be instructions for taking the pills.

* The smallest amount of stable iodine required to produce blocking of the thyroid is about 30 mg. The time taken to achieve the blocked state decreases from about two hours after the oral administration of 30 mg. of iodine to 30 minutes after 100 mg. Amounts of iodine larger than 100 mg. do not appear to reduce the time any further.⁹

Table I. Possible Prophylactic Iodine Compounds

Compound ^{a,b,c}	Solubility in Cold Water g/100 ml	Single Thyroid Blocking Dose	Toxicity Probable Lethal Dose 70 kg Adult	Taste	Stability in Storage	Current Use
KI, Potassium Iodide	127.5	100 mg ^d	35,000 to 350,000 mg ^e (similar to NaCl and sodium bicarbonate).	Strong, nauseating. May be difficult to give to infants and children.	Slightly deliquescent in moist air. Decomposes and discolors with long exposure to air, light, and moisture. ^{f,g}	Table salt additive in the USA (used in about 50% of iodized table salt).
KIO ₃ , Potassium Iodate	4.74	130 mg	80,000 mg ^h	Nearly tasteless	Iodates are much more stable in air, light, and moisture than iodides. The iodates are listed in order of increasing stability. ⁱ	Recommended by World Health Organization for table salt additive (used in about 50% of iodized table salt ^{g,j}).
Ca (IO ₃) ₂ , Calcium Iodate	0.427 ^c	120 mg	25,000 mg ^h This toxicity group is similar to aspirin and ruinine. ^e			Salt additives for farm animals. ^{i,j}
Ca ₅ (IO ₆) ₂ , Pentacalcium Orthoperiodate ^k	0.0063 ^c	200 mg	50,000 mg ^h			

^aAll the listed compounds make iodine available to the thyroid equally rapidly.^{b,c}

^bJ. K. Miller, IT-AEC Agricultural Research Laboratory, Oak Ridge, Tennessee (personal communications).

^cH. W. Fiedelman, Morton Salt Company, Woodstock, Illinois (personal communications).

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^gAs a table salt additive, KI is stabilized by adding 0.04% dextrose and a trace of bicarbonate. With the additives the iodide is still not as stable as the iodate.

^hE. J. Kuhajek and G. F. Andelfinger, J. Animal Sci. **31**, 51-58 (1970).

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^jIodates are not yet approved for human use in the USA by the FDA. The main objection the FDA has to the use of KIO₃ is that the required two-year feeding studies on two species of animals have not been carried out. The approximate cost of the studies would be \$50,000.^c

^kPatent applied for by the Morton Chemical Co., Division of Morton International, Inc.

Authorization and instructions for opening the tag would be transmitted to the population by radio and television in conjunction with whatever warning system is installed.

By attaching the tag to the electric meter, the pills remain under the control of the power company, and can be routinely inspected (and replaced, if necessary) by the meter reader. Initial distribution would be by the power company as a requirement for licensing reactors in the area.

For schools, factories, apartment houses, and offices, a sufficient number of pills can be sealed in a suitable steel cabinet adjacent to the electric meter.

STRONTIUM

Strontium is chemically similar to calcium and, if present in the diet, is incorporated in bone and other tissue. The biological half-life of material incorporated in bone is about 50 years.⁷ As a result of the long half-life, even small amounts of incorporated radiostrontium could have serious consequences.

Although the efficiency of calcium absorption by the intestinal epithelium is greater than that of strontium, the discrimination is not enough to prevent the absorption of undesirably large quantities of strontium from contaminated food. A decrease in strontium uptake by the blood plasma and presumably the bone has been demonstrated if the calcium intake is increased or aluminum phosphate gel¹⁵ is administered. The results presented to date are discussed below.

Studies have shown that intestinal absorption of strontium decreases¹⁴ and urinary excretion of strontium increases¹⁶ with an increase in dietary calcium. Extra calcium results in a decrease in the total amount of strontium in the blood plasma and an increase in the calcium-to-strontium ratio. Presumably either of these conditions produces a decrease in strontium in the bones. Hodgekinson et al. have shown that increasing the calcium intake from 50 mg to 1500 mg decreases the plasma levels of Sr by a factor of 4.¹⁴

Another method of preventing strontium assimilation is to absorb it with a cation binding agent while it is still in the stomach and small intestine. Alginate, a major polysaccharide present in brown seaweeds and used as a stabilizer in ice cream manufacture, has been shown to bind Sr and Ca using an ion-exchange mechanism. The alginate, which consists of mixed polymers of L-guluronic and D-mannuronic acids, preferentially binds Sr. This preferential binding is enhanced if the ratio of guluronic to mannuronic acids is greater than 3 or 4. Experiments have shown that if the alginate is given simultaneously with the strontium dose, the strontium in the blood plasma decreases to 5% of the levels without alginate therapy and the Ca to Sr ratio increases by a factor of 6.

Both these methods of reducing Sr absorption can be utilized simultaneously. However, comparatively larger doses would be required. The alginate does bind some of the calcium, and the strontium binding capacity of the alginate decreases as the calcium concentration increases.

Aluminum phosphate gel, an aqueous suspension of 3.4 to 4.5 percent AlPO_4 , has been shown to markedly inhibit the absorption of strontium by the stomach and small intestine.¹⁵ A single 100 ml dose of the gel causes an 80 to 98 percent decrease in strontium absorption with only a 30 percent decrease in calcium absorption.

However, much experimental work on Sr prophylaxis still needs to be done. The effect of calcium, sodium alginate, and aluminum phosphate gel on the amount of Sr that goes into the bone needs to be quantified. The effect of simultaneous calcium and sodium alginate administration should be examined as a function of time after inhaling the Sr. Prophylaxis must be studied for chronic ingestion. Due to these uncertainties, the Clinch Valley Study does not recommend dissemination of prophylactic substances for strontium.

CESIUM

Prophylactic action of several materials for cesium has been demonstrated.^{17,18} The most promising material so far, nickel ferrocyanide-anion exchange resin (NiFC)R, selectively adsorbs cesium.¹⁷

Recent studies demonstrated the low toxicity of the resin. This resin is formed by mixing a nickel chloride solution and the chloride form of Amberlite IRA-904, a macro reticular anion exchange resin. The resin is then washed and dried before use.

Prophylactic action seems to rely on adsorption of the ingested cesium while it remains in the GI tract. The amount of cesium retained in the body after 24 hrs was reduced to 60% of the amount normally retained by giving 1 gm of resin 10 min after exposure and 0.5 gm at 4 and 8 hrs. Even as long as 20 to 30 days after dosing, the excretion of cesium can be accelerated by administering 2 gm/day of the resin. Apparently cesium reappears in the GI tract where it can be adsorbed by the resin.

More detailed work needs to be done on the size and timing of doses before a really workable prophylactic dose schedule can be proposed. The Clinch Valley Study recommends that work be continued on (NiFC)R as a prophylactic agent for radiocesium.

EXTERNAL GAMMA RAY AND NEUTRON RADIATION

In some situations the radiation dose from gamma rays and neutrons originating outside the body can be a serious threat. This situation is not anticipated to be the case in any foreseeable power reactor incident; however, this section is included for completeness and to prevent the spread of misinformation about the nature of these radioprotective drugs. The work on protective chemicals in mammals for this situation is summarized below.

The acute radiation syndrome may be divided into four main categories: (1) sublethal, <200 rads whole body dose; (2) hematopoietic, >200 rads; (3) gastrointestinal, >500 rads; and (4) central nervous system, >5000 rads.

Many agents have been found which tend to control the early nausea and vomiting after radiation. These include pyridoxine, psyquil, thiethylperazine, metoclopramide, trifluoperazine, and haloperidol.¹⁹ However, these agents do not protect against the biologically damaging effects of radiation. They merely control many of the early symptoms of a lethal dose or symptoms following a sub-lethal dose of radiation.

The agents studied so far for protection against the biologically damaging effects of radiation show protection mainly against hematopoietic syndrome death, with less protection against gastrointestinal syndrome death and little protection against central nervous system syndrome death. Of the 33 recently developed drugs studied by Yuhas,²⁰ only one was effective against central nervous system death while all were effective against hematopoietic and gastrointestinal death.

With administration of radioprotective drugs, the LD₅₀ radiation dose is at most 2.6 to 2.7 times the unprotected LD₅₀ dose. For the two drugs that achieve this much protection S-2-(3-aminopropylamino) ethyl phosphorothioic acid and 3-(2-mercaptoethylamino) propionamide, the drug dose required is 500 mg/kg and 2,000 mg/kg, respectively. These doses are close enough to the toxic LD₅₀ doses of 700 mg/kg and 3,000 mg/kg that the drugs themselves in the amounts required could cause severe sickness and even death. In addition, the drugs must be administered before irradiation to be most effective. For example, the first drug listed must be administered 30 minutes before irradiation to be effective.

Because of the high toxicity of radioprotective drugs and the low protection factors obtained, the Clinch Valley Study recommends against drug distribution to the public for protection against external gamma ray and neutron radiation.

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APPENDIX V

A RADIOLOGICAL EMERGENCY CONTROL CENTER

The implementation of emergency plans might be greatly facilitated by the use of a regional or national emergency operations control center (EOCC). The center would not replace any of the existing emergency operations procedures but rather provide additional technical advice more rapidly than it is presently available.

For this discussion an EOCC similar to EPA's national EOCC in Research Triangle Park, North Carolina, which monitors air pollution episodes, is assumed.¹ Specific power reactor site information is assumed added to the EOCC data banks. Site meteorological, radiological, and water quality information would be telemetered daily to the EOCC.

There is some precedent for radiological accidents being handled at least partially through non-radiological centers. The Chemical Transportation Emergency Center (CHEMTREC)² provides advice for those at the scene of chemical shipping emergencies. In some cases radioactive materials have been involved in transportation emergencies, and CHEMTREC has given on the spot advice and notified the proper federal agencies for further action. When CHEMTREC was formed, having a single, multipurpose EOCC nationwide in coverage and accessible to all through a single telephone number was judged the most expeditious arrangement.

There are a number of advantages of having a multipurpose regional or national EOCC.

Continuing funding for a multipurpose EOCC might be more certain than for a single purpose radiological incident EOCC. The excellent safety record of operating nuclear installations would indicate a low use factor for a single purpose EOCC, and there might be a tendency for funds to be put on apparently more pressing projects.

Since radiological emergency episodes would be few and far between, routine work for each site, such as the required periodic meteorological, water quality, and radiological release summaries, could be prepared at the EOCC. This routine work would insure that data gathering procedures and communication lines are in operating condition.

A single center that is multipurpose would get regularly exercised during real, although non-radiological, emergencies rather than during drills alone.

A multipurpose EOCC can usually justify, obtain, and man terminals for the nationwide and regional National Weather Service forecasting, reporting, and warning networks. The cost of these services may be excessive for individual nuclear reactor sites.

A multipurpose center could justify more extensive computer facilities and a larger programmer and maintenance staff than a single installation. In particular, a real-time video display system using data input from several lines takes a larger computer capability.

If there is stored in a readily accessible fashion demographic information for each reactor, typical meteorological data by seasons, current meteorological data, and predetermined evacuation routes, the facility of an EOCC could be used to advantage during a radiological emergency. Provided with an estimate of the isotope leak rate

and mixture of escaping isotopes, an estimate of the inhaled dose vs position could be made. A computer connected to a real-time display system could provide quick estimates of dose to the present time and estimates of dose for some specified future time period. A time period of interest, for example, would be the time elapsed from the start of the release to the present time plus an estimated population reaction time plus the time required for the population to evacuate crosswind on specified evacuation routes.³ The Clinch Valley Study recommends against extrapolating a dose rate to a 30-day dose with the wind from just one compass point since it is extremely unlikely that a wind direction will persist for so long. In many localities there are at least differences between the daytime and nighttime wind and meteorological conditions.⁴ Areas of dangerous or potentially dangerous inhaled dose could be indicated on the appropriate quadrangle of the Geological Survey maps and larger scale maps of the reactor sites already at the EOCC. Either a backlighting or a projection method, such as used in the Weapons Effects Display System developed by the Lawrence Livermore Laboratory, could be used.⁵ Possible safe evacuation routes could be illuminated. When contamination reaches or is projected to reach within some specified time interval a predetermined action level, illumination intensity could be altered. This information would be quickly transmitted via conventional telephone or telegraph lines or possibly a "hot line" to the designated decision-making officials near the site. Federal advisors both at the EOCC and the site could use this information in providing technical advice and expert situation assessment for local officials.

An example illustration of the type that could have computer-directed illumination is shown in Fig. 1. The radioactivity release occurs at the center of the map and threatened areas are indicated by the striped regions. Possible evacuation routes and possible road blocks to prevent cross-sector travel are indicated. The number and location of the evacuation routes would be selected in part after examining demographic data. The geometric outlines shown in Fig. 1 would be altered, of course, either by computer or local officials to conform to community and block outlines.

There are disadvantages to a single center that must be weighed against the advantages.

The single center requires installation and maintenance of communication links between the center and each site. This cost should be evaluated carefully.

Since the processing of data is remote, there might be additional chances for error and misinterpretation. Some of these problems could be minimized by frequent pre-emergency drills and checkouts. While the EOCC capability would be a very desirable addition to emergency procedures, it would have to be implemented so that it is not absolutely essential for performing emergency operations. For this reason, the center should always be in an advisory and not in a controlling capacity for emergency operations. A computer failure or power outage at the center could not be allowed to completely halt emergency operations.

FIGURE 1

ORNL-DWG 72 6656A

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APPENDIX VI

FISSION PRODUCT RELEASE FROM WATER-COOLED REACTORS

INTRODUCTION

Releases from reactor accidents are considered because a realistic calculation of a fission product release as a function of time will indicate the speed and type of response necessary. Meteorological data observed as the accident progresses combined with radioactivity data from the release could be used in an iterative procedure with calculations of the type described here to predict the destinations and concentrations of released isotopes.

The model used is one in which the rate of fission product release from the core is proportional to the fission product decay heating rate. The fission products then make their way through a sequence of containments with constant leak rates.

The release model assumes that a constant fraction of the decay heat, from 60 seconds after shutdown onward, vaporizes UO_2 and fission products. Each fission product vaporization rate was assumed to be proportional to the ratio of the vapor pressure of the fission product to that of UO_2 . The release rate was assumed to be zero during a heatup period of ten seconds and to increase linearly from zero at ten seconds after shutdown to the value at 60 seconds.

Containment vessels and reactor buildings are commonly characterized in terms of volumes and leak rates.¹ Gaseous fission products, which do not adsorb, can be expected to gradually leak from one containment to the next and eventually to the environment. The release will depend on the leak rates and the gaseous fission product half-life. Solid fission products can be expected to become associated with UO_2 aerosol particles; they will leak from one containment to the next; they will undergo decay and they will also deposit as a consequence of agglomeration and settling. The general behavior of aerosols in closed vessels due to agglomeration, settling, and other processes has been described.² Several experimental studies have also been made; one study in particular provided data from fairly large tank experiments with UO_2 aerosols at high concentration.³ Several calculations of aerosol concentration vs time in a closed vessel have been proposed. One in particular is mathematically simple and was shown to predict with reasonable accuracy the experimental UO_2 aerosol concentration vs time behavior noted above.⁴ This aerosol calculation was adapted to the present need.

In the calculations four classes of fission products (refractories, noble gases, volatiles, halogens) were employed and sample calculations for one member of each class were made. One isotope was selected to represent each class: ^{90}Y with a 58-day half-life represents the refractory group, ^{133}Xe with a 5.3-day half-life represents the noble gases, ^{90}Sr with a 28-year half-life represents the volatile group, and ^{131}I with an 8.0-day half-life represents the halogen group. Refractory fission products, Zr, Nb, and the rare earths, were assumed to condense, along with UO_2 , soon after vaporization, hence to be particulate in each containment, including the

pressure vessel. Noble gases were assumed to be molecular throughout the containment system. The volatile fission products were presumed to include all others except the halogens. The volatile fission products were assumed to be molecular in the pressure vessel and particulate in each successive containment. Half of the halogens were presumed to remain molecular throughout like the noble gases; the other half was assumed to be molecular in the pressure vessel and particulate in each successive containment, like the volatile fission products.

MATHEMATICAL MODEL

List of Symbols

- A constant in particle size distribution equation, cm^3
- B total inventory of one fission product airborne in the reactor building, curies
- C total inventory of one fission product airborne in the containment, curies
- D_b deposition rate constant in the reactor building, sec^{-1}
- D_c deposition rate constant in the containment, sec^{-1}
- D_p deposition rate constant in the pressure vessel, sec^{-1}
- D_t deposition rate constant in the access tunnel, sec^{-1}
- E_b fractional removal efficiency of the reactor building filter-absorber
- E_c fractional removal efficiency of the containment filter-absorber
- F' ratio of vapor pressures: fission product/ UO_2
- F_b flow rate through the reactor building filter absorber, cm^3/sec
- F_c flow rate through the containment filter absorber, cm^3/sec
- F_{tp} ratio of vaporized and undecayed fission product to the initial inventory in the core
- F_u fraction of core which has vaporized
- H fraction of fission product decay heat available to vaporize UO_2
- ΔH_{sub} heat of sublimation of UO_2 , joules/g
- K constant in aerosol agglomeration term, cm^3/sec
- K^* constant in aerosol settling term, sec^{-1}
- K^{**} constant in aerosol formation term, $\text{cm}^{-3} \text{sec}^{-1}$
- L_b leakage rate of gas between the reactor building and the next containment, cm^3/sec
- L_c leakage rate between the containment and the reactor building, cm^3/sec
- L_p leakage rate of gas in and out of the pressure vessel, cm^3/sec
- L_t leakage rate of gas between the access tunnel and the environment, cm^3/sec
- M_0 M_u at reactor shutdown, g
- M_p mass concentration of UO_2 aerosol in the pressure vessel, g/cm^3
- M_u mass of the core, g
- n particle number concentration, cm^{-3}
- n_p particle number concentration in the pressure vessel, cm^{-3}
- P total inventory of one fission product airborne in the pressure vessel, curies
- P' amount of heat available to vaporize UO_2 , watts
- P_{DH} fission product decay heating rate, watts

- P_0 reactor operating power level, watts
 Q inventory of one fission product in the fuel, curies
 Q_0 Q at reactor shutdown
 R total inventory of one fission product airborne in the environment, curies
 t time after shutdown, sec
 T total inventory of one fission product airborne in the access tunnel, curies
 v particle volume, cm^3
 V rate of one fission product vaporization from the core, curies/sec
 V_b volume of the reactor building, cm^3
 V_c volume of the containment, cm^3
 V_p volume of pressure vessel, cm^3
 V_t volume of the access tunnel, cm^3
 V_U rate of vaporization of UO_2 , g/sec
 λ one fission product decay constant, 1/sec

Heat Generation

The fission product decay heating rate was taken to be approximately that for a core which has operated for infinite time,⁵

$$P_{DH} = 0.140 P_0 t^{-0.291}. \quad (1)$$

Equation (1) is empirical and is approximately correct in the time range from 60 seconds after shutdown to 10^7 seconds after shutdown.

Vaporization of UO_2 and Fission Products

During the first 10 seconds after cessation of fissioning, no vaporization was assumed to occur

$$P' = 0 \text{ for } t < 10. \quad (2)$$

It is assumed that heatup of the core takes about one minute.⁶ Therefore, from 60 seconds after shutdown onward, it was assumed that a constant fraction of the decay heat generated in that fraction of the core which had not yet vaporized, went to vaporize UO_2 and fission products. Hence,

$$P' = 0.140 H P_0 (1 - F_U) t^{-0.291} \text{ for } t > 60. \quad (3)$$

For times between 10 and 60 seconds after shutdown, it is assumed that the decay heating to cause vaporization of UO_2 increased linearly from zero at 10 seconds to the heating rate given in equation (1) at 60 seconds. Hence,

$$P' = 0.140 \times 60^{-0.291} H P_0 (1 - F_U) (t - 10)/50 \text{ for } 10 \leq t \leq 60. \quad (4)$$

The rate of vaporization of UO_2 is

$$V_U = P'/\Delta H_{\text{sub}} . \quad (5)$$

The heat of sublimation of UO_2 at 1800°K is $137.1 \text{ kcal/mole}^7$ or 2150 joules/g . V_U is the rate of decrease in the mass of the core, M_U . Hence,

$$-V_U = dM_U/dt \quad (6)$$

and F_U is simply related to the mass of the core at any time, M_U and the total or original mass of the core,

$$F_U = 1 - M_U/M_0 . \quad (7)$$

Solving for M_U as a function of time and integrating gives

$$M_U = M_0 \quad \text{for } t < 10 \quad (8)$$

$$M_U = M_0 \exp \left(- \left(\frac{0.140 H P_0 60^{-.291}}{\Delta H_{\text{sub}} M_0 100} (t-10)^2 \right) \right) \quad \text{for } 10 \leq t \leq 60 \quad (9)$$

$$M_U = M_0 \exp \left(- \left(\frac{0.140 H P_0}{\Delta H_{\text{sub}} M_0} \right) \left(60^{-.291} 25 + \frac{(t^{.709} - 60^{.709})}{.709} \right) \right) \quad \text{for } 60 < t. \quad (10)$$

F_U and V_U are given as functions of time in each case by equations (7) and (6).

Fission Product Vaporization and Inventory

The rates of vaporization of fission products were assumed to be proportional to the fractional rate of vaporization of UO_2 , the ratio of vapor pressure of the fission product to that of UO_2 , the amount of fission product not yet vaporized. Hence,

$$V = V_U F' Q/M_U . \quad (11)$$

In general, the inventory of any fission product in the fuel will be given by integration of an equation of the form

$$dQ/dt = -V - \lambda Q. \quad (12)$$

Solving for Q and integrating gives

$$Q/Q_0 = \exp [-\lambda t] (1 - F_U)^{F'} \quad (13)$$

By definition

$$F_{fp} = \int_0^{x=t} \frac{V}{Q_0} \exp(-\lambda(t-x)) dx = (Q_0 \exp[-\lambda t] - Q)/Q_0 \quad (14)$$

The agreement between this model and the observed fission product releases observed by Parker et al⁸ can be checked. Parker measured UO_2 and fission product release on melting UO_2 fuels. In the experiments $\lambda \approx 0$. Therefore,

$$F_{fp} \approx 1 - (1 - F_u)^{F'}$$

We have finally, in equation (15), an approximate relationship between the fraction of UO_2 vaporized in an experiment, F_u , the fraction of fission product vaporized, F_{fp} , and the ratio of the vapor pressure of the fission product to that of UO_2 , F' . In Table 1 are tabulated, calculated and observed⁸ values of F_{fp} , the fraction of fission product vaporized. The calculated values used the F' values listed which were obtained from thermodynamic calculations.⁹ The observed values for reducing conditions are from Parker's experiments with Zr-clad fuel and the observed values for oxidizing conditions are from experiments with SS-clad fuel.⁸

The agreement between observed and calculated release fractions (i.e., F_{fp} values) is reasonably good for several isotopes. One exception is the value for Te under reducing conditions; the reason for this discrepancy has been suggested, namely that the Te dissolves in the Zr cladding and reduces the Te vapor pressure. Hence,

Table 1. Evaluation of Vapor Pressure Ratios

Fission Product	Reducing Conditions			Oxidizing Conditions		
	F'	$F_{fp, calc}$	$F_{fp, obs}$	F'	$F_{fp, calc}$	$F_{fp, obs}$
Xe	High	1	1	High	1	1
I	High	1	0.83	High	1	0.93
Te	High	1	0.018	High	1	0.55
Cs	High	1	0.65	5	0.02	0.83
Ru	3.5×10^{-2}	6×10^{-6}	4×10^{-3}	0.1	4×10^{-4}	9×10^{-3}
Sr	8×10^2	0.74	0.22	4×10^{-3}	2×10^{-6}	2×10^{-2}
Ba	2×10^6	1	0.20	4×10^{-1}	2×10^{-3}	7×10^{-2}
Ce	8	0.014	0.012	1×10^{-6}	4×10^{-9}	5×10^{-3}

for Te with Zr-clad fuel, one would choose the observed value for comparison with the present calculations. Under oxidizing conditions, the observed F_{fp} for Cs is much higher than the calculated value. This is believed to be due to decomposition of cesium oxide in the helium atmosphere used in the experiments; hence for Cs under oxidizing conditions, one could choose the calculated F_{fp} for comparison.

Release of Vaporized Fission Products

The vaporized fuel and fission products are released into the pressure vessel and, if they do not deposit, find their way into the containment, the reactor building, any access tunnel associated with the power plant and finally the environment.

The inventory in the pressure vessel increases due to vaporization from the core at a rate of V curies per second. The inventory will decrease due to leakage from the pressure vessel to the containment and radioactive decay. A constant leakage flow from the pressure vessel to the containment and an equal flow from the containment to the pressure vessel was assumed.

Finally, in the case of refractory fission products, loss of airborne material was assumed to occur due to agglomeration and settling of aerosol particles. It was assumed that particulate fission products would be associated with UO_2 particles and therefore that the fractional rate of deposition of particulate fission products would equal that of UO_2 particles. More precisely, it was assumed that the rate of deposition was $D_p P$. The deposition rate constant,

$$D_p = (1/M_p) (dM_p/dt) \quad (16)$$

was evaluated by means of a system of equations previously reported.⁴ In this previously reported work, a calculation of aerosol mass concentration in a closed vessel as a function of formation rate and other parameters was developed. The calculation method was shown to fit observed values of concentration vs time for UO_2 aerosols.³ The calculation presumed a steady-state particle size distribution of the form;

$$(1/n) dn/dv = A v^{-2} \quad (17)$$

between sharply defined maximum and minimum particle sizes, where n is the particle number concentration, v is the particle volume and A is a term which depends⁴ on the maximum and minimum particle sizes in the distribution. Maximum and minimum particle radii of 10 and 0.09 microns were assumed; these are the values previously employed which led to a fit of calculated to observed concentration of UO_2 aerosols vs time.^{3,4} The equation for the change in aerosol particle number concentration with time has the form,

$$dn/dt = -K n^2 - K^* n + K^{**}. \quad (18)$$

The first two terms on the right hand side of equation (18) account for deposition due to agglomeration and settling; the third term is the rate of aerosol formation. Since

a steady-state particle size distribution was assumed, the fractional change in particle number concentration will equal the fractional change in particle mass concentration, hence,

$$(1/M_p) dM_p/dt = (1/n_p) dn_p/dt. \quad (19)$$

We can now write an expression for the rate of change in the inventory in the pressure vessel:

$$dP/dt = V_u F' Q/M_u - L_p (P/V_p - C/V_c) - \lambda P - D_p P. \quad (20)$$

As mentioned earlier, D_p is zero for those fission products which are molecular in the pressure vessel; i.e. for all except the refractory fission products which include Zr, Nb and the rare earths.

Analogously, gas is assumed to leak out of the containment into the reactor building and vice-versa. Provision is made to account for removal of particles by filtration or of iodine by charcoal adsorption and the loss rate by filtration-adsorption is $(F_c E_c/V_c)C$. Of course, this term is zero for noble gas isotopes. Finally, particulate fission products (except the noble gas isotopes and half of the halogens) will be removed by agglomeration and settling. The differential equation for the fission product inventory in the containment can therefore be written;

$$\frac{dC}{dt} = L_p(P/V_p - C/V_c) - L_c(C/V_c - B/V_b) - \lambda C - (F_c E_c/V_c)C - D_c C. \quad (21)$$

If the containment is enclosed by a building and if the reactor building is enclosed as with a berm containment, then the equation which describes the inventory in the reactor building and any access tunnel is entirely analogous to those above for the containment.

$$\frac{dB}{dt} = L_c(C/V_c - B/V_b) - L_b(B/V_b - T/V_t) - \lambda B - (F_b E_b/V_b)B - D_b B. \quad (22)$$

$$\frac{dT}{dt} = L_b(B/V_b - T/V_t) - (L_t/V_t)T - \lambda T - (F_t E_t/V_t)T - D_t T. \quad (23)$$

Consider these cases: an unenclosed containment, a containment enclosed in a reactor building and a containment enclosed in a building which is enclosed in an underground or berm containment so that the building leaks only to an access tunnel which in turn leads to the environment.

With an unenclosed containment, the release R changes according to

$$\frac{dR}{dt} = (L_c/V_c)C - \lambda R. \quad (24)$$

With a containment enclosed in a building, the differential equation becomes

$$\frac{dR}{dt} = (L_b/V_b)B - \lambda R. \quad (25)$$

If the building is enclosed, then the leak to the environment from the access tunnel of the underground containment becomes

$$\frac{dR}{dt} = (L_t / V_t) T - \lambda R. \quad (26)$$

The three equations are analogous to one another; they pertain respectively to single, double and triple containment systems. Equations (20) through (26) were solved by means of a finite difference technique.

VALUES OF PARAMETERS USED

Fission Product Inventory in the Core at Time Zero

The core size and fission product inventories were taken from Penna. Power and Light Co's Susquehanna Power Reactor, which is a modern BWR and which is designed to generate about 1000 MW of electricity. The full power heat generation rate is 3440 MW. The core contains 148 metric tons of uranium.

Fission product inventories were calculated¹⁰ on the basis of one-third of the core having operated for 1.3 years, one-third having operated for 2.7 years, and one third having operated for four years. This is a more-or-less worst case assumption; this is approximately the maximum inventory which is attained just prior to refueling.

Containment System Geometry

The values of geometric parameters used in the calculation cases are listed in Tabel 2. These values are reasonable estimates of those for actual containments. The pressure vessel volume employed for all cases was estimated from the dimensions of the Susquehanna pressure vessel; that vessel is 9 ft in diameter and 69 ft high. The volume of a cylinder of these dimensions is about $5 \times 10^8 \text{ cm}^3$. It was presumed that the main loop piping to the isolation valves and the volume of the recirculating system was approximately equal to the volume of the core and other apparatus in the pressure vessel; hence the free volume was taken to be $5 \times 10^8 \text{ cm}^3$.

The containment or pressure suppression chamber for Susquehanna has a free volume of 155,750 cu ft; this is approximately $5 \times 10^9 \text{ cm}^3$. The reactor building volume was simply estimated (on the basis of visual observations at Browns Ferry, a similar BWR) to be a factor of 10 larger than that of the containment, hence $5 \times 10^{10} \text{ cm}^3$. In one of the calculation cases, the reactor building was assumed to be underground and to leak to an access tunnel. The tunnel volume was estimated to be similar to that of the reactor building.

One has to assume values for the fall distances of aerosol particles in each vessel. This is the vertical distance which a particle must traverse to find a horizontal surface on which to deposit. The values listed were simply estimated from general observations.

The leak rate from the pressure vessel was taken to be 10^{-4} pressure vessel volumes per second (or about 10 volumes per day). Two sets of values were employed for

Table 2. Parameters Used in Calculation

Case Number --	I	II	III	IV	V	VI
Description --	Damaged BWR Containment and Bldg. with High Core Vaporiz- ation Rate	Damaged BWR Containment and Bldg.	Design Basis BWR	Damaged BWR Containment, Bldg. and Access Tunnel	Damaged PWR Containment, without Filter	Design Basis PWR with Filter
<u>Containment Volumes (cm³)</u>						
Pressure Vessel	5×10^8	5×10^8	5×10^8	5×10^8	5×10^8	5×10^8
Containment	5×10^9	5×10^9	5×10^9	5×10^9	6×10^{10}	6×10^{10}
Reactor Building	5×10^{10}	5×10^{10}	5×10^{10}	5×10^{10}	--	--
Access Tunnel	--	--	--	5×10^{10}	--	--
<u>Particle Fall Distances (cm)</u>						
In Pressure Vessel	1×10^2	1×10^2	1×10^2	1×10^2	1×10^2	1×10^2
In Containment	2×10^2	2×10^2	2×10^2	2×10^2	1×10^3	1×10^3
In Reactor Building	1×10^3	1×10^3	1×10^3	1×10^3	--	--
In Access Tunnel	--	--	--	6×10^2	--	--
<u>Leak Rates (volumes/sec)</u>						
From Pressure Vessel	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
From Containment	1×10^{-4}	1×10^{-4}	6×10^{-8}	1×10^{-4}	1×10^{-4}	6×10^{-8}
From Reactor Building	1×10^{-4}	1×10^{-4}	1×10^{-5}	1×10^{-4}	--	--
From Access Tunnel	--	--	--	1×10^{-4}	--	--
<u>Fraction of Decay Heat which Vaporized UO₂</u>						
	1×10^{-2}	1×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}
<u>Filter-Adsorber</u>						
	No	No	No	No	No	Yes*

*Recirculating filter-adsorber in the containment with a flow rate of 10^{-2} containment volumes per second and removal efficiencies for particles and for ²³⁵U of 95%.

the leak rates from the other containments. One set of leak rates was 10^{-4} containment volumes per second for each containment; this was to simulate badly damaged containment and building. The other set of leak rates, 6×10^{-8} volumes per second from the containment and 1×10^{-6} volumes per second from the reactor building, are design basis values.

Containment Filter-Adsorber

A recirculating filter-adsorber in the containment was included in Case VI of the calculations. Filtration efficiencies of 95% for particles and iodine were assumed. The flow rate through the filter-adsorber was 10^{-2} volumes per second (or about 100,000 cfm). No reactor building is assumed present in cases V and VI as would be true for a PWR containment system.

Rates and Amount of Vaporization

In the calculations the vaporization rate was related to the decay heat. The fraction of decay heat which vaporized UO_2 was, in most cases, assumed to be 10^{-3} ; in Case I, a value of 10^{-2} was employed to demonstrate the effect of this parameter.

The values of the ratios of the fission product vapor pressures to the UO_2 vapor pressure (F' values) which were employed were as follows:⁸

^{91}Y	0.3
^{133}Xe	1×10^6
^{90}Sr	8×10^2
^{131}I	1×10^6

RESULTS

Four fission products were chosen, one to represent each of the four classes of behavior. ^{133}Xe was chosen to represent the noble gases, ^{91}Y was chosen to represent the refractory fission products, ^{131}I was chosen as a halogen, and ^{90}Sr was chosen to represent the volatile fission products. Several calculations of inventories (in the fuel, pressure vessel, containment, and reactor building) and release were done to illustrate the calculation capability. Figure 1 is a plot of the curves of inventory of ^{91}Y in the pressure vessel, in the reactor containment, in the reactor building and the curves of ^{91}Y released for Case III which represents a BWR with design basis containment and building. These results are presented to illustrate the format of the results and, as can be seen by referring to Fig. 1, the calculated inventory in the pressure vessel built up quickly in the first two minutes after shutdown; it went through a maximum value at about five minutes at which time about 10^{-6} of the total core inventory was airborne in the pressure vessel; it then gradually declined. It appears that the airborne inventory in the pressure vessel largely reflects the core vaporization rate; the inventory built quickly in the approximate time range 10 to 60 seconds in which the vaporization

rate was assumed to build quickly; the inventory then falls gradually with time similar to the assumed vaporization rate. The inventory buildup in the containment followed that in the pressure vessel; it reached a maximum at about 3×10^{-6} of the initial total core inventory. The inventory in the reactor building is always several orders of magnitude lower than that in the pressure vessel because a low leakage containment was assumed. The reactor building inventory built up slowly and only reached a value of about 1×10^{-8} of the total initial core inventory about one day after shutdown. The calculated release also was delayed and was small; a value of only 0.48 Ci was estimated at about one day after shutdown.

Figures 2 through 5 are summary presentations of calculated releases for each of several assumed containment systems and degrees of damage or malfunction. Figure 2 presents such a summary for ^{91}Y , which is the representative refractory fission product. Figure 3 pertains to ^{133}Xe , which represents noble gases. Figure 4 presents the calculated releases of ^{90}Sr , which represents volatile fission products; and Figure 5 pertains to ^{131}I , the representative for halogens. Note that Fig. 2 for ^{91}Y contains a curve labeled "Design Basis BWR"; this is the same curve which appears on Fig. 1 and is labeled "Release."

Consider Fig. 2; it is convenient further to compare each release curve with the one for a "Damaged Containment and Damaged Reactor Building." The release with the same containment system but for a factor of 10 higher vaporization rate is larger (by a factor of 3 at early times and about a factor of 2 at 1 day). The release went up approximately as the square root of the increase in vaporization rate; the increase in aerosol deposition rate with vaporization rate prevented the release from going up in proportion to the vaporization rate. A damaged containment without a building resulted in a larger release, whereas a damaged access tunnel in addition to a damaged containment and building resulted in a smaller release. A design basis BWR containment with a reactor building or a design basis PWR containment with recirculating filter-adsorbers was estimated to release a very small quantity of ^{91}Y .

Figure 3 is a presentation of the calculated ^{133}Xe releases. In the case of the "Damaged Containment and Damaged Reactor Building," releases were calculated for two values of core vaporization rates, one value being 10 times the other. The calculated releases were almost identical to each other and are therefore not shown as separate curves. This finding presumably resulted because, in either case, the ^{133}Xe was released from the core much faster than it leaked through the containment shells; the vaporization rate did not exert any control on the release rate. The release is faster through a damaged containment without a building (than through the damaged containment plus building). It is slower through a damaged containment plus building plus access tunnel. Although the releases are slower or faster depending on the number of containment shells, the total releases are about the same; namely, all of the noble gas which has not undergone radioactive decay eventually gets out. The Design Basis BWR containment plus Reactor Building slows the release more effectively than the Design Basis PWR containment because the filter-adsorber in the PWR system has no effect on the noble gas.

Figure 4 pertains to ^{90}Sr , which was assumed to be in the form of gaseous molecules in the pressure vessel and later associated with UO_2 aerosol particles. Also, it is noted that ^{90}Sr was assumed to vaporize relatively faster than UO_2 by a factor of 800.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

If we compare the "Damaged Containment and Damaged Reactor Building Cases" at the two vaporization rates, we see that the release at early times is higher if the source term from the vaporization is higher. The release is higher by only a factor of about 3, whereas the vaporization rate was increased 10-fold; this is because the aerosol washout increases by more than the first power of the vaporization rate. At later times (after 2.5×10^4 sec) the release was actually smaller at the higher vaporization rate; apparently at these times the effect of the UO_2 vaporization rate on the rate of ^{90}Sr release becomes small because most of the ^{90}Sr is already vaporized, but the aerosol washout is still effective because UO_2 is continuing to be vaporized to keep the aerosol concentrations high.

As with the other isotopes, we find that the absence of a reactor building increased the release and an added access tunnel decreased the release. Also, the design basis release values for a BWR containment plus building or a PWR containment with filter-adsorbers were quite small.

On Fig. 5 we find calculated releases of ^{131}I . The effect of a 10-fold increase in core vaporization rate on the iodine release is small. Apparently the effect due to a faster vaporization of I_2 is negligible, as indicated by the two curves being together at early times, because the iodine release occurred at a rate much faster than the leakage rates at either value of core vaporization rates; hence the I_2 vaporization rate did not control the release rate in any case. At longer times the release is slightly larger at the lower UO_2 vaporization rate than at the higher one; this apparently resulted from the faster washout of I_2 with the higher UO_2 aerosol concentration. This effect is smaller with ^{131}I than with ^{90}Sr , probably because only half of the iodine was particulate and hence was affected by washout. The other release curves appear to be straightforward; the damaged containment without a building resulted in higher releases whereas the addition of an access tunnel reduced the release. The design basis releases were much smaller than those calculated for damaged containments.

SUMMARY

A scoping effort has been made with regard to expressing the fission product releases and release rates from possible reactor accidents, in terms of several parameters. There were two objectives; the first was to show that the quality and quantity of fission product releases can vary over several orders of magnitude, hence that the most rapid and rational responses to reactor accidents will require the capability of quickly using observations during the actual progress of the accident to predict the eventual release, i.e., the isotope mix, the amounts and the rates. The results clearly show such a need. Releases could vary by several orders of magnitude depending on the quality of the containment system and the amounts of fission products vaporized.

The second objective was to suggest the probable complexity and usefulness of estimations of releases with real time data. The predicted release values seem to be reasonable but some additional complexities in the calculation would probably be desirable. For instance, the vaporization model should include the sudden, partial release when clad failure occurs. The leak rates should probably be expressed in terms of sizes of holes in each containment and in terms of the pressure in each containment which in turn would require additional decay heat transfer modeling.

At any rate, it is hoped that this effort might lead to a more thorough effort which would estimate releases in terms of parameters which could be measured during the initiation and development of an accident, hence to allow prediction of the quantity and rate of actual releases.

The calculations suggest that a poor containment is much less beneficial than a good one but much better than none. The calculations suggest that even with a poor

containment the release occurs in a few hours or more; a longer period is available with better containment. The release of refractory fission products is predicted to be low (perhaps $<10^{-3}\%$) but very dependent on the rate and amount of core vaporization. Noble gas releases are reduced by containment as a consequence of holdup during which decay occurs; a large fraction of the longer half-life isotopes could be released. The volatile fission products, like ^{90}Sr , are washed out by aerosol deposition; the greatest calculated release was 77%, and this would be drastically reduced by a good containment and/or a filter. The greatest iodine release calculated was 83%; it, too would be greatly reduced by good containment, a filter and/or an adsorber.

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APPENDIX VII

BERM CONTAINMENT

The magnitude of a release of airborne radioactivity could be greatly mitigated by underground siting of a power reactor and in some cases the probability of a release is significantly reduced. For example, properly designed underground siting incorporates among other features an additional containment. Conservatively assuming that it is a very leaky containment that allows 10 complete air changes a day, the total fission product inventory released is decreased about an order of magnitude. If the underground siting is designed to have the same low leakage rate as the reactor containment*, the fission product inventory released is decreased between three and four orders of magnitude. **

Underground siting has been criticized as an uneconomic investment with current licensing requirements. Cost estimates for underground siting vary, but a recent estimate is $\$20.00 \times 10^3$ for designs putting a plant 200 to 500 feet underground.¹ The Clinch Valley Study recommends that earth berm construction as a nuclear power reactor containment system be carefully examined as an alternative to underground siting. As discussed below, this containment system appears to have many of the advantages of underground siting without many of the disadvantages, including high additional cost.

We propose a reactor containment scheme based on covering above-grade buildings with about 3×10^6 cubic yards of earth fill (berm construction). Savings could be achieved by using fill with an angle of internal friction greater than 30° , and designing all buried structures to support the fill by arching. The weight of the fill would poststress the containment structures to resist internal pressure, reducing the requirement for prestressing steel.

Exterior design could be simplified to the extreme. First cost savings on exterior architectural requirements would be considerable and the associated construction costs and delay effects would be eliminated. If we could assume that the restricted or exclusion area would be considerably reduced by the nature of construction for this nuclear plant, the total land purchase requirements should be much less than for conventional plants. The possibility of siting closer to the load center may be increased by the inherent safety features of underground siting. In this case, transmission line length would be decreased with a corresponding decrease in land acquisition cost. Improved aesthetics might lead to reduced public opposition to siting and result in a decrease in cost and time for the licensing procedure.

$$* \frac{dV}{dt} \frac{1}{V} = 0.635\%/day \text{ for a BWR.}$$

** The released inventory was calculated by R. J. Davis using the methods described in "Fission Product Release from a Typical BWR System of Containment" (in manuscript, 1972). The fission products are assumed to leak through the personnel and equipment locks. The rate of percolation through the rock and soil covering the reactor is assumed negligible.

Construction above the water table eliminates the danger of accidental flooding from failure of cooling water lines or structure and permits easy control of drainage. In addition to immunity from tornadoes, hurricanes, plane crashes, and effects of conventional weapons, the management of other unlikely but potentially dangerous events such as a catastrophic meltdown, sabotage, and effects of nuclear weapons is greatly simplified. By using a dilatant backfill (e.g., crushed rock) around the buildings, and designing the buildings as concrete cylinders and hemispheres, protection to more than 100 psi overpressure can be obtained. And if the overpressure limit of the construction is exceeded, the debris will be covered by 100 ft of loose earth, virtually eliminating the respiratory hazard from airborne radioactivity. Destruction or circumvention of the containment by sabotage or other means can be easily rectified by plugging all the openings to either the reactor building or, under worst conditions, to the entire facility, with earth.

The reactor building and other building requirements are taken from a loop type design of 1000 MWe LMFBR. See Figures 1 and 2.

The reactor building is a right circular cylinder approximately 100 ft ID with a hemispherical top. The building extends about 60 ft below original grade and 100 ft above grade. In the concept suggested here, an identical separate building is indicated for the intermediate heat exchangers (IHx) and steam generators. All other buried buildings can be horizontal cylinders or hemicylinders 40 to 60 ft in diameter, assembled from precast sections. The connecting vehicle tunnel can be a 20-ft diameter cylinder.

Those buildings requiring direct connection to the reactor building, or handling radioactive materials should be buried. Included are fuel handling, contact maintenance, rad waste, and the turbine hall. From the standpoint of aesthetics and safety, it would be desirable to put all the other buildings, transformers, and switchgear underground.

The cover of all the construction would be an earth and crushed rock mound 200 ft high and 600 ft radius, containing about 3×10^6 cubic yards, and costing about $\$3.00 \times 10^6$. The 3:1 slope of the surface will permit rubber-tire machinery on the surface. While attractive landscaping of the earth fill will greatly improve the aesthetics of power plants, the fill is part of the plant exclusion area. Some thought must be given to not making the place so attractive that there is continual pressure on the utility to make the area available to the public as a recreation area. One solution is to use the area for grazing cattle. The 30-acre surface can support up to 20 cattle depending on climate, and more with irrigation. A conspicuous herd of large animals thriving on the surface of the site ought to be good public relations, reassuring the surrounding community. It certainly should forestall nuisance suits from unexplained deaths of livestock in the surroundings.

Construction Method

The construction would be essentially by the "cut and cover" method. The buildings would be constructed on a suitably prepared site, and then covered with fill. The fill could be obtained from a nearby hill, or from the excavation of a cooling lagoon or discharge canal.

FIGURE 1

ORNL-DWG 72-1704R

FIGURE 2

ORNL-DWG 72-1522R

The reactor containment building can be constructed according to present practices, but with the important saving of omitting all prestressing steel to resist internal pressure. The vessel would be poststressed by the weight of the backfill.

The other buildings would have to be designed for burial, which could be more expensive than conventional above grade construction. However, imaginative use of advanced concrete construction techniques such as precasting, guniting airbags, or pour-and-inflate should make the costs competitive.

The control of ground water and arching ability that appropriately designed backfill permits can be exploited to greatly reduce buried construction costs. Elimination of windows and requirement for exterior maintenance, and great reduction of heating and cooling loads will provide savings over the life of the plant.

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