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Docket No.: 50-397

MEMORANDUM FOR: Robert L. Tedesco, Assistant Director for Licensing
Division of Licensing

FROM: William E. Kreger, Assistant Director for Radiation Protection
Division of Systems Integration

SUBJECT: PLANT ACCIDENT SECTION FOR DRAFT ENVIRONMENTAL STATEMENT WASHINGTON NUCLEAR PLANT UNIT 2

Enclosed is the Accident Section for Washington Nuclear Plant Unit 2 Draft Environmental Statement prepared by the Accident Evaluation Branch

Original signed by
W. E. Kreger

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5.8.2 POSTULATED ACCIDENTS

5.8.2.1 Plant Accidents

The staff has considered the potential radiological impacts on the environment of possible accidents at WNP-2 in accordance with a Statement of Interim Policy published by the Nuclear Regulatory Commission on June 13, 1980.[42] The following discussion reflects these considerations and conclusions.

The first section deals with general characteristics of nuclear power plant accidents including a brief summary of safety measures to minimize the probability of their occurrence and to mitigate their consequences if they should occur. Also described are the important properties of radioactive materials and the pathways by which they could be transported to become environmental hazards. Potential adverse health effects and impacts on society associated with actions to avoid such health effects are also identified.

Next, actual experience with nuclear power plant accidents and their observed health effects and other societal impacts are then described. This is followed by a summary review of safety features of the WNP-2 facilities and of the site that act to mitigate the consequences of accidents.

The results of calculations of the potential consequences of accidents that have been postulated in the design basis are then given. Also described are the results of calculations for the WNP-2 site using probabilistic methods to estimate the possible impacts and the risks associated with severe accident sequences of exceedingly low probability of occurrence.

5.8.2.1.1 General Characteristics of Accidents

The term "accident," as used in this section, refers to any unintentional event not addressed in Section 5.8.1 that results in a release of radioactive materials into the environment. The predominant focus, therefore, is on events that can lead to releases substantially in excess of permissible limits for normal operation. Such limits are specified in the Commission's regulations in 10 CFR Part 20.

There are several features which combine to reduce the risk associated with accidents at nuclear power plants. Safety features in the design, construction, and operation comprising the first line of defense are to a very large extent devoted to the prevention of the release of these radioactive materials from their normal places of confinement within the plant. There are also a number of additional lines of defenses that are designed to mitigate the consequences of failures in the first line. Descriptions of these features for the WNP-2 plant may be found in the applicant's Final Safety Analysis Report,[43] and in the staff's Safety Evaluation Report.[44] The most important mitigative features are described in Section 5.8.2.1.3 below.

These safety features are designed taking into consideration the specific locations of radioactive materials within the plant, their amounts, their nuclear, physical, and chemical properties, and their relative tendency to be transported into and for creating biological hazards in the environment.

5.8.2.1.1.1 Fission Product Characteristics

By far the largest inventory of radioactive material in a nuclear power plant is produced as a byproduct of the fission process and is located in the uranium oxide fuel pellets in the the reactor core in the form of fission products. During periodic refueling shutdowns, the assemblies containing these fuel pellets are transferred to a spent fuel storage pool so that the second largest inventory of radioactive material is located in this storage area. Much smaller inventories of radioactive materials are also normally present in the water that circulates in the reactor coolant system and in the systems used to process gaseous and liquid radioactive wastes in the plant.

These radioactive materials exist in a variety of physical and chemical forms. Their potential for dispersion into the environment is dependent not only on mechanical forces that might physically transport them, but also upon their inherent properties, particularly their volatility. The majority of these materials exist as nonvolatile solids over a wide range of temperatures. Some, however, are relatively volatile solids and a few are gaseous in nature. These characteristics have a significant bearing upon the assessment of the environmental radiological impact of accidents.

The gaseous materials include radioactive forms of the chemcially inert noble gases krypton and xenon. These have the highest potential for release into the atmosphere. If a reactor accident were to occur involving degradation of the fuel cladding, the release of substantial quantities of these radioactive gases from the fuel is a virtual certainty. Such accidents are very low frequency but credible events (cf Section 5.8.2.1.2). It is for this reason that the safety analysis of each nuclear power plant analyzes a hypothetical design basis accident that postulates the release of the entire contained inventory of radioactive noble gases from the fuel into the containment system. If further released to the environment as a possible result of failure of safety features, the hazard to individuals from these noble gases would arise predominantly through the external gamma radiation from the airborne plume. The reactor containment system is designed to minimize this type of release.

Radioactive forms of iodine are formed in substantial quantities in the fuel by the fission process and in some chemical forms may be quite volatile. For these reasons, they have traditionally been regarded as having a relatively high potential for release from the fuel. If released to the environment, the principal radiological hazard associated with the radioiodines is ingestion into the human body and subsequent concentration in the thyroid gland. Because of this, its potential for release to the atmosphere is reduced by the use of special systems designed to retain the iodine.

The chemical forms in which the fission product radioiodines are found are generally solid materials at room temperature, however, so that they have a strong tendency to condense (or "plate out") upon cooler surfaces. In addition, most of the iodine compounds are quite soluble in, or chemically reactive with, water. Although these properties do not inhibit the release of radioiodines from degraded fuel, they do act to mitigate the release from containment systems that have large internal surface areas and that contain large quantities of water as a result of an accident. The same properties affect the behavior of radioiodines that may "escape" into the atmosphere. Thus, if rainfall occurs during a release, or if there is moisture on exposed surfaces, e.g., dew, the radioiodines will show a strong tendency to be absorbed by the moisture.

Other radioactive materials formed during the operation of a nuclear power plant have lower volatilities and therefore, by comparison with the noble gases and iodine, a much smaller tendency to escape from degraded fuel unless the temperature of the fuel becomes very high. By the same token, such materials, if they escape by volatilization from the fuel, tend to condense quite rapidly to solid form again when transported to a lower temperature region and/or dissolve in water when present. The former mechanism can have the result of producing some solid particles of sufficiently small size to be carried some distance by a moving stream of gas or air. If such particulate materials are dispersed into the atmosphere as a result of failure of the containment barrier, they will tend to be carried downwind and deposit on surface features by gravitational settling or by precipitation (fallout), where they will become "contamination" hazards in the environment.

All of these radioactive materials exhibit the property of radioactive decay with characteristic half-lives ranging from fractions of a second to many days or years (see Table 5.8). Many of them decay through a sequence or chain of decay processes and all eventually become stable (nonradioactive) materials. The radiation emitted during these decay processes is the reason that they are hazardous materials.

5.8.2.1.1.2 Exposure Pathways

The radiation exposure (hazard) to individuals is determined by their proximity to the radioactive material, the duration of exposure, and factors that act to shield the individual from the radiation. Pathways for the transport of radiation and radioactive materials that lead to radiation exposure hazards to humans are generally the same for accidental as for "normal" releases. These are depicted in Section 5.8.1, Figure 5.1. There are two additional possible pathways that could be significant for accident releases that are not shown in Figure 5.1. One of these is the fallout onto open bodies of water of radioactivity initially carried in the air. The second would be unique to an accident that results in temperatures inside the reactor core sufficiently high to cause melting and subsequent penetration of the basemat underlying the reactor by the molten core debris. This creates the potential for the release of radioactive material into the hydrosphere through contact with ground water. These pathways may lead to external exposure to radiation, and to internal exposures if radioactivity is inhaled, or ingested from contaminated food or water.

It is characteristic of these pathways that during the transport of radioactive material by wind or by water, the material tends to spread and disperse, like a plume of smoke from a smokestack, becoming less concentrated in larger volumes of air or water. The result of these natural processes is to lessen the intensity of exposure to individuals downwind or downstream of the point of release, but they also tend to increase the number who may be exposed. For a release into the atmosphere, the degree to which dispersion reduces the concentration in the plume at any downwind point is governed by the turbulence characteristics of the atmosphere which vary considerably with time and from place to place. This fact, taken in conjunction with the variability of wind direction and the presence or absence of precipitation, means that consequences of accidental releases to the atmosphere would be very much dependent upon the weather conditions existing at the time.

5.8.2.1.1.3 Health Effects

The cause and effect relationships between radiation exposure and adverse health effects are quite complex,[45a] but they have been more exhaustively studied than for any other environmental contaminant.

Whole-body radiation exposure resulting in a dose greater than about 10 rem for a few persons and about 25 rem for nearly all people over a short period of time (hours) is necessary before any physiological effects to an individual are clinically detectable. Doses about ten to twenty times larger, also received over a relatively short period of time (hours to a few days), can be expected to cause some fatal injuries. At the severe, but extremely low probability end of the accident spectrum, exposures of these magnitudes are theoretically possible for persons in the close proximity of such accidents if measures are not or cannot be taken to provide protection, e.g., by sheltering or evacuation.

Lower levels of exposures may also constitute a health risk, but the ability to define a direct cause and effect relationship between a known exposure to radiation and any given health effect is difficult, given the backdrop of the many other possible reasons why a particular effect is observed in a specific individual. For this reason, it is necessary to assess such effects on a statistical basis. Such effects include randomly occurring cancer in the exposed population and genetic changes in future generations after exposure of a prospective parent. Cancer in the exposed population may begin to develop only after a lapse of 2 to 15 years (latent period) from the time of exposure and then continue over a period of about 30 years (plateau period). However, in the case of exposure of fetuses (*in utero*), cancer may begin to develop at birth (no latent period) and end at age 10 (i.e., the plateau period is 10 years). The health consequences model currently being used is based on the 1972 BEIR Report of the National Academy of Sciences.[46]

Most authorities are in agreement that a reasonable and probably conservative estimate of the randomly occurring health effects of low levels of radiation exposure to a large number of people is within the range of about 10 to 500 potential cancer deaths per million person-rem (although zero is not excluded by the data). The range comes from the latest NAS BEIR III Report[47] (1980) which also indicates a probable value of about 150. This value is virtually identical to the value of about 140 used in the current NRC health effects models. In addition, approximately 220 randomly occurring genetic changes per million person-rem would be projected by BEIR III over succeeding generations. That also compares well with the value of about 260 per million person-rem currently used by the NRC staff.

5.8.2.1.1.4 Health Effects Avoidance

Radiation hazards in the environment tend to disappear by the natural process of radioactive decay. Where the decay process is a slow one, however, and where the material becomes relatively fixed in its location as an environmental contaminant (e.g., in soil), the hazard can continue to exist for a relatively long period of time--months, years, or even decades. Thus, a possible consequential societal impact of severe accidents is the avoidance of the health hazard rather than the health hazard itself, by restrictions on the use of the contaminated property or contaminated foodstuffs, milk, and drinking water. The potential economic impacts that this can cause are discussed below.

5.8.2.1.2 Accident Experience and Observed Impacts

The evidence of accident frequency and impacts in the past is a useful indicator of future probabilities and impacts. As of mid-1981, there were 71 commercial nuclear power reactor units licensed for operation in the United States at 50 sites with power generating capacities ranging from 50 to 1130 megawatts electric (MWe). (WNP-2 is designed for 1145 MWe.) The combined experience with these units represents approximately 500 reactor years of operation over an elapsed time of about 21 years. Accidents have occurred at several of these facilities.[48] Some of these have resulted in releases of radioactive material to the environment, ranging from very small fractions of a curie to a few million curies. None is known to have caused any radiation injury or fatality to any member of the public, nor any significant individual or collective public radiation exposure, nor any significant contamination of the environment. This experience base is not large enough to permit a reliable quantitative statistical inference. It does, however, suggest that significant environmental impacts due to accidents are very unlikely to occur over time periods of a few decades.

Melting or severe degradation of reactor fuel has occurred in only one of these units, during the accident at Three Mile Island - Unit 2 (TMI-2) on March 28, 1979. In addition to the release of a few million curies of xenon-133, it has been estimated that approximately 15 curies of radioiodine was also released to the environment at TMI-2.[49] This amount represents an extremely minute fraction of the total radioiodine inventory present in the reactor at the time of the accident. No other radioactive fission products were released in measurable quantity.

It has been estimated that the maximum cumulative offsite radiation dose to an individual was less than 100 millirem.[49,50] The total population exposure has been estimated to be in the range from about 1000 to 3000 person-rem. This exposure could produce between none and one additional fatal cancer over the lifetime of the exposed population. The same population receives each year from natural background radiation about 240,000 person-rem and approximately a half-million cancers are expected to develop in this group over its lifetime,[49,50] primarily from causes other than radiation. Trace quantities (barely above the limit of detectability) of radioiodine were found in a few samples of milk produced in the area. No other food or water supplies were affected.

Accidents at nuclear power plants have also caused occupational injuries and a few fatalities but none attributed to radiation exposure. Individual worker exposures have ranged up to about 4 rems as a direct consequence of accidents, but the collective worker exposure levels (person-rem) due to accidents are a small fraction of the exposures experienced during normal routine operations that average about 500 person-rem per reactor year.

Accidents have also occurred at other nuclear reactor facilities in the United States and in other countries.(48) Due to inherent differences in design, construction, operation, and purpose of most of these other facilities, their accident record has only indirect relevance to current nuclear power plants. Melting of reactor fuel occurred in at least seven of these accidents, including the one in 1966 at the Enrico Fermi Atomic Power Plant Unit 1. This was a sodium-cooled fast breeder demonstration reactor designed to generate 61 MWe. The damages were repaired and the reactor reached full power in four years following the accident. It operated successfully and completed its mission in 1973. This accident did not release any radioactivity to the environment.

A reactor accident in 1957 at Windscale, England released a significant quantity of radioiodine, approximately 20,000 curies, to the environment. This reactor, which was not operated to generate electricity, used air rather than water to cool the uranium fuel. During a special operation to heat the large amount of graphite in this reactor, the fuel overheated and radioiodine and noble gases were released directly to the atmosphere from a 405-foot stack. Milk produced in a 200-square mile area around the facility was impounded for up to 44 days. This kind of accident cannot occur in a water-cooled reactor like WNP-2, however.

5.8.2.1.3 Mitigation of Accident Consequences

In accordance with the Atomic Energy Act of 1954, the Nuclear Regulatory Commission is conducting a safety evaluation of the application to operate WNP-2. Although the safety evaluation will contain more detailed information on plant design, the principal design features are presented in the following section.

5.8.2.1.3.1 Design Features

The design includes features that are for preventing accidental release of radioactive fission products from the fuel and to lesson the consequences should such a release occur. Many of the design and operating specifications of these features are derived from the analysis of postulated events known as design basis accidents. These accident preventive and mitigative features are collectively referred to as engineered safety features (ESF). The possibilities or probabilities of failure of these features is incorporated in the assessments discussed in Section 5.8.2.1.4.

The ESF of this plant can be divided into four general groups: Containment systems, emergency core cooling systems, habitability systems, and fission product removal and control systems.

The containment systems consist of five subsystems: Primary containment, secondary containment (or reactor building), containment heat removal system, containment isolation system, and combustible gas control. These five subsystems can provide a physical barrier as well as containment isolation for accidental radioactivity releases to the environment. They also assure containment integrity following a postulated loss-of-coolant accident (LOCA).

The Emergency Core Cooling System (ECCS) is designed to provide cooling water to the reactor core during an accident to prevent or minimize fuel damage. The system includes the high pressure core spray (HPCS), low pressure core spray (LPCS), low pressure coolant injection (LPCI) and automatic depressurization system (ADS).

In the event of a LOCA, operating personnel within the control room are protected from airborne radioactivity by the control room habitability systems which will pressurize the control room with filtered air drawn from either of two separate remote fresh air intakes. Redundant radiation monitors at each of the two remote intake headers are provided.

The Standby Gas Treatment System (SGTS) is designed to establish and maintain a negative pressure in the secondary containment following the signal for its isolation in the event of release of radioactivity to this building in an accident. Negative pressure, with respect to the outside atmosphere, would prevent out-leakage of radioactivity from this building to the environment except along the release path controlled by the SGTS. Radioactive iodine and particulate fission products would be substantially removed from the flow stream by safety-grade activated charcoal and high-efficiency particulate air filters.

The main steam isolation valve leakage control system is designed to control the release of fission products through the main steam isolation valves. This system directs the leakage through these valves to the area served by the SGTS. The spent fuel storage pool is located in the secondary containment where potential radioactive leakage from the stored fuel can be directed through the SGTS.

The mechanical systems mentioned above are supplied with emergency power from onsite diesel generators in the event that normal offsite station power is interrupted.

Much more extensive discussions of the safety features and characteristics of WNP-2 may be found in the applicant's Final Safety Analysis Report.[43] The staff evaluation of these features will be addressed in a forthcoming Safety Evaluation Report. In addition, the implementation of the lessons learned from the TMI-2 accident, in the form of improvements in design and procedures, and operator training, will significantly reduce the likelihood of a degraded core accident which could result in large releases of fission products to the containment. Specifically, the applicant will be required to meet those TMI-related requirements specified in NUREG-0737. As noted in Section 5.8.2.1.4.7 no credit has been taken for these actions and improvements in discussing the radiological risk of accidents in this supplement.

5.8.2.1.3.2 Site Features

The NRC's reactor site criteria, 10 CFR Part 100, require that the site for every power reactor have certain characteristics that tend to reduce the risk and potential impact of accidents. The discussion that follows briefly describes the site for the WNP-2 reactor and how it meets these requirements.

First, the site has an exclusion area as required by 10 CFR Part 100. The boundary of the exclusion area is a circle with its center at the reactor and a radius of 1950 meters (6400 feet). There are no residents within the exclusion area. Industrial facilities located in the site area are the H. J. Ashe Substation and the Washington Public Power Supply systems (WPPSS) Nuclear Projects No. 1 and 4. A highway and a railroad traverse the exclusion area. Other than these facilities there are no activities unrelated to the operation of WNP-2 within the exclusion area. Both WNP-1 and 4 and their respective access roads will be owned and operated by WPPSS. The 1950 meter radius exclusion area extends outside the plant property. All land outside the plant property but within the exclusion area is owned by the United States and is managed by the U.S. Department of Energy (DOE) as part of the Hanford Site. The applicant has obtained a long-term lease from DOE over this area which gives it the authority, required by Part 100, to determine all activities in this area. In case of emergency, the applicant has made arrangements with federal and state authorities to control traffic on the routes traversing the exclusion area, including possible removal of personnel at the Ashe substation.

Second, beyond and surrounding the exclusion area is a low population zone (LPZ), also required by 10 CFR Part 100. The LPZ for the WNP-2 reactor is defined as all land within 4.8 kilometers (three miles) of the site. Within this zone the applicant must assure that there is a reasonable probability that appropriate and effective measures could be taken on behalf of the residents and other members of the public in the event of a serious accident. There are no residents presently within the LPZ. In case of a radiological emergency, the applicant has made arrangements to carry out protective actions, including evacuation of personnel in the vicinity of the nuclear plant. For further details, see the following section on Emergency Preparedness.

Third, Part 100 also requires that the nearest population center of about 25,000 or more persons be no closer than one and one-third times the outer radius of the LPZ. Since accidents of greater potential hazards than those commonly postulated as representing an upper limit are conceivable, although highly improbable, it was considered desirable to add the population center distance requirement in Part 100 to provide for protection against excessive exposure doses to people in large centers.

The nearest population center is the City of Richland, Washington (1980 estimated population of 33,512), located about 19 kilometers (12 miles) S to SSE of the site. This distance is at least 1 1/3 times the low population zone distance, as required by Part 100.

The nearest significant transient population are located at DOE area 400 (HEDL) located about 5 to 6 kilometers (3 to 4 miles) SW of the plant. Th employment level at area 400 is currently 1187.

The safety evaluation of the WNP-2 site has also included a review of potential external hazards, i.e., activities offsite that might adversely affect the operation of the plant and cause an accident. This review encompasses nearby industrial, transportation, and military facilities that might create explosive, missile, toxic gas, or similar hazards. The staff has concluded that the hazards from nearby industrial, military, mining, pipelines, air transportation, waterways, and highways are negligibly small. The evaluation of the DOE railway which passes through the site has not yet been completed. The results will be reported in the staff's forthcoming Safety Evaluation Report or supplement thereto.

5.8.2.1.3.3 Emergency Preparedness

The applicant has submitted an upgraded Emergency Plan[51] for Washington Nuclear Project 2 (WNP-2) dated April 1981. The Emergency Plan represents a consolidation of the three Emergency Plans for WNP-1, 2, and 4 into one document and is based on WNP-2 being in an operational status and WNP-1/4 under construction. Revisions will be made in the Plan as WNP-1 and WNP-4 become operational. The WNP-2 Emergency Plan was developed in response to the requirements of Appendix E to 10 CFR Part 50, "Emergency Planning and Preparedness for Production and Utilization Facilities", which established minimum requirements for an acceptable state of onsite emergency preparedness, and 10 CFR 50.47, "Emergency Plans" which specifies standards which must be met for both onsite and offsite emergency response.

The staff has initiated a review of the Emergency Preparedness Plan for the WNP-2 site. This review is part of a comprehensive staff effort to evaluate the overall adequacy and effectiveness of the applicant's total emergency preparedness program. The review effort will include an onsite appraisal of the emergency preparedness program and a fullscale exercise involving both onsite and offsite response agencies.

NRC and the Federal Emergency Management Agency (FEMA) have agreed that FEMA will make a finding and determination as to the adequacy of State and local government Emergency Response Plans. NRC will determine the adequacy of the applicant's Emergency Response Plans with respect to the standards listed in Section 50.47(b) of 10 CFR Part 50, the requirements of Appendix E to 10 CFR Part 50, and the guidance contained in NUREG-0654/FEMA-REP 1, Revision 1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Prepared in Support of Nuclear Power Plants," dated November 1980. After the above determinations by NRC and FEMA, the NRC will make a finding in the licensing process as to the overall and integrated state of preparedness. In accordance with Section 50.47(a) of 10 CFR Part 50, an operating license will not be issued unless the overall finding is such that the state of onsite and offsite emergency preparedness provides reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency.

5.8.2.1.4 Accident Risk and Impact Assessment

5.8.2.1.4.1 Design Basis Accidents

As a means of assuring that certain features of WNP-2 meet acceptable design and performance criteria, both the applicant and the staff have analyzed the potential consequences of a number of postulated accidents. Some of these could lead to significant releases of radioactive materials to the environment, and calculations have been performed to estimate the potential radiological consequences to persons offsite. For each postulated initiating event, the potential radiological consequences cover a considerable range of values depending upon the particular course taken by the accident and the conditions, including wind direction and weather, prevalent during the accident.

In the safety analysis and evaluation of WNP-2, three categories of accidents have been considered by the applicant and the staff. These categories are based upon their probability of occurrence and include (a) incidents of moderate frequency, i.e., events that can reasonably be expected to occur during any year of operation, (b) infrequent accidents, i.e., events that might occur once during the lifetime of the plant, and (c) limiting faults, i.e., accidents not expected to occur but that have the potential for significant releases of radioactivity. The radiological consequences of incidents in the first category, also called anticipated operational occurrences, are discussed in Section 5.8.1. Initiating events postulated in the second and third categories for WNP-2 are shown in Table 5.6. These are collectively designated design basis accidents in that specific design and operating features as described above in Section 5.8.2.1.3.1 are provided to limit their potential radiological consequences. Approximate radiation doses that might be received by a person at the nearest site boundary (1950 meters (6400 feet) from the plant) are also shown in the table, along with a characterization of the time duration of the releases. The results shown in the table reflect the expectation that engineered safety and operating features would function as intended.

An important implication of this expectation is that the radioactive releases considered are limited to noble gases and radioiodines and that any other radioactive materials e.g., in particulate form, are not expected to be released. The results are also quasi-probabilistic in nature in the sense that the meteorological dispersion conditions are taken to be neither the best nor the worst for the site, but rather at an average value determined by actual site measurements. In order to contrast the results of these calculations with those using more pessimistic, or conservative, assumptions described below, the doses shown in Table 5.6 are sometimes referred to as "realistic" doses. These dose calculations are still estimates, but the doses are not of highest concern since the resultant risks are small compared to the risks associated with the more severe "class 9 accidents."

Calculated population exposures for these events range from a small fraction of a person-rem to about 3 person-rem for the population within .80 kilometers (50 miles) of WNP-2. These calculations for both individual and population exposures indicate that the risk of incurring any adverse health effects as a consequence of design basis accidents is exceedingly small. By comparison with the estimates of radiological impact for normal operations shown in Section 5.8.1, we also conclude that radiation exposures from design basis accidents are roughly comparable to the exposures to individuals and the population from normal station operations over the expected lifetime of the plant.

The staff has also carried out calculations to estimate the potential upper bounds for individual exposures from the same initiating accidents in Table 5.6 for the purpose of implementing the provisions of 10 CFR Part 100, "Reactor Site Criteria." For these calculations, much more pessimistic (conservative or worst case) assumptions are made as to the course taken by the accident and the prevailing conditions. These assumptions include much larger amounts of radioactive material released by the initiating events, additional single

Table 5.6

Approximate Radiation Doses† from
Design Basis Accidents

Infrequent Accidents	Duration of Release**	Dose (rem) at 6400 feet* Whole Body
Radioactive Waste System Failure:		
Equipment Leakage or Malfunction	< 2 hr	0.01
Release of Waste-Gas Storage Tank Contents	< 2 hr	0.04
Release of Liquid-Waste Storage Contents	< 2 hr	< 0.0005
Small-Break LOCA	hours-days	< 0.0005
Fuel Handling Accident (Fuel-Cask Drop)	< 2 hr	0.014
Limiting Faults		
Main Steam Line Break	< 2 hr	0.0015
Control Rod Drop	hrs-days	0.0005
Large-Break LOCA	hrs-days	0.004

*The nearest site (or exclusion area) boundary.

**< means "less than".

†The doses are from the Final Environmental Statement (Construction Permit stage) for Hanford Number Two Nuclear Power Plant (WNP-2), USAEC, December, 1972.

failures in equipment, operation of ESF's in a degraded mode,* and very poor meteorological dispersion conditions.

The results of these calculations show that, for these events, the limiting whole-body exposures are not expected to exceed 9 rem to any individual at the site boundary. They also show that radioiodine releases have the potential for offsite exposures ranging up to about 120 rem to the thyroid. For such an exposure to occur, an individual would have to be located at a point on the site boundary where the radioiodine concentration in the plume has its highest value and inhale at a breathing rate characteristic of a person jogging, for a period of two hours. The health risk to an individual receiving such a thyroid exposure is the potential appearance of benign or malignant thyroid nodules in about 4 out of 100 cases, and the development of a fatal cancer in about 2 out of 1000 cases.

None of the calculations of the impacts of design basis accidents described in this section take into consideration possible reductions in individual or population exposures as a result of taking any protective actions.

5.8.2.1.4.2 Probabilistic Assessment of Severe Accidents

In this and the following three sections, there is a discussion of the probabilities and consequences of accidents of greater severity than the design basis accidents identified in the previous section. As a class, they are considered less likely to occur, but their consequences could be more severe, both for the plant itself and for the environment. These severe accidents, heretofore frequently called Class 9 accidents, are different from design basis accidents in two primary respects: they involve substantial physical deterioration of the fuel in the reactor core, including overheating to the point of melting; and involve deterioration of the capability of the containment system to perform its intended function of limiting the release of radioactive materials to the environment.

The assessment methodology employed is that described in the Reactor Safety Study (RSS) which was published in 1975.[52]** However, the sets of accident sequences that were found in the RSS to be the dominant contributors to the risk in the prototype BWR (Peach Bottom Unit 2) have recently been updated[53] ("rebaselined"). The rebaselining has been done largely to incorporate peer group comments[54], and better data and analytical techniques resulting from research and development after the publication of the RSS. Entailed in the rebaselining effort was the evaluation of the individual dominant accident sequences as they are understood to evolve. The earlier technique of grouping a number of accident sequences into the encompassing Release Categories as was done in the RSS has been largely eliminated.

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*The containment system, however, is assumed to prevent leakage in excess of that which can be demonstrated by testing, as provided in 10 CFR Part 100.11(a).

**Because this report has been the subject of considerable controversy, a discussion of the uncertainties surrounding it is provided in Section 5.8.2.1.4.7.

WNP-2 is a General Electric designed BWR having similar design and operating characteristics to the RSS prototype BWR. Therefore, the present assessment for WNP-2 has used as its starting point the rebaselined accident sequences and sequence groups referred to above, and more fully described in Appendix D. Characteristics of the sequences (and sequence groups) used (all of which involve partial to complete melting of the reactor core) are shown in Table 5.7. Sequences initiated by natural phenomena such as tornadoes, floods, or seismic events and those that could be initiated by deliberate acts of sabotage are not included in these event sequences. The radiological consequences of such events would not be different in kind from those which have been treated. Moreover, it is the staff's judgment; based upon design requirements of 10 CFR Part 50, Appendix A, relating to effects of natural phenomena; and safeguards requirements of 10 CFR Part 73; that these events do not contribute significantly to risk.

Calculated probability per reactor year associated with each accident sequence (or sequence group) used is shown in the second column in Table 5.7. As in the RSS there are substantial uncertainties in these probabilities. This is due, in part, to difficulties associated with the quantification of human error and to inadequacies in the data base on failure rates of individual plant components that were use to calculate the probabilities.[54] (See Section 5.8.2.1.4.7 below.) The probability of accident sequences from the Peach Bottom plant were used to give a perspective of the societal risk at WNP-2 because, although the probabilities of particular accident sequences may be substantially different or even improved for WNP-2, the overall effect of all sequences taken together is likely to be within the uncertainties (see Section 5.8.2.1.4.7 for discussion of uncertainties in risk estimates.

The magnitudes (curies) of radioactivity releases for each accident sequence or sequence group are obtained by multiplying the release fractions shown in Table 5.7 by the amounts that would be present in the core at the time of the hypothetical accident. These are shown in Table 5.8 for the WNP-2 plant at the core thermal power level of 3468 megawatts.

The potential radiological consequences of these releases have been calculated by the consequence model used in the RSS[55] and adapted to apply to a specific site. The essential elements are shown in schematic form in Figure 5.3. Environmental parameters specific to the WNP-2 site have been used and include the following:

(1) Meteorological data for the site representing a full year of consecutive hourly measurements and seasonal variations.

(2) Projected population for the year 2000 extending throughout regions of 80 and 563 kilometers (50 and 350 miles) radius from the site (the latter region includes parts of Canada).

(3) The habitable land fraction within the 563 kilometers (350-mile) radius, and

(4) Land use statistics, on a state-wide basis, including farm land values, farm product values including dairy production, and growing season information, for the State of Washington and each surrounding state within the 563 kilometer (350-mile) region.

Table 5.7

Summary of Atmospheric Releases in Hypothetical Accident Sequences in a BWR (Reb. lined)

Accident Sequence or Sequence Group[b]	Probability ($reactor\text{-}yr^{-1}$)	Fraction of Core Inventory Released[a]						
		Xe-Kr	I	Cs-Rb	Te-Sb	Ba-Sr	Ru[c]	La[d]
TCγ'	2.0×10^{-6}	1.0	0.45	0.67	0.64	0.073	0.052	0.0083
TWγ'	3.0×10^{-6}	1.0	0.098	0.27	0.41	0.025	0.028	0.005
TQUVγ' AEγ' $S_1E\gamma'$ $S_2E\gamma'$	3.0×10^{-7}	1.0	0.095	0.3	0.36	0.034	0.027	0.005
TCγ	8.0×10^{-6}	1.0	0.07	0.14	0.12	0.015	0.01	0.002
TWγ	1.0×10^{-5}	1.0	0.003	0.11	0.083	0.011	0.007	0.001
TQUVγ AEγ $S_1E\gamma$ $S_2E\gamma$	1.0×10^{-6}	1.0	0.02	0.055	0.11	0.006	0.007	0.0013

(a) Background on the isotope groups and release mechanisms is presented in Appendix VII, WASH 1400 (Ref. 52).

(b) See Appendix D for description of the accident sequences and sequence groups.

(c) Includes Ru, Rh, Co, Mo, Tc.

(d) Includes Y, La, Zr, Nb, Ce, Pr, Nd, Np, Pu, Am, Cm.

NOTE: Please refer to Section 5.8.2.1.4.7 for a discussion of uncertainties in risk estimates.

Table 5.8

Activity of Radionuclides in the WNP-2 Reactor Core at 3468 MWt

Group/Radionuclide	Radioactive Inventory in Millions of Curies	Half-Life (days)
A. NOBLE GASES		
Krypton-85	0.61	3,950
Krypton-85m	26	0.183
Krypton-87	51	0.0528
Krypton-88	74	0.117
Xenon-133	184	5.28
Xenon-135	37	0.384
B. IODINES		
Iodine-131	92	8.05
Iodine-132	130	0.0958
Iodine-133	184	0.875
Iodine-134	206	0.0366
Iodine-135	163	0.280
C. ALKALI METALS		
Rubidium-86	0.028	18.7
Cesium-134	8.1	750
Cesium-136	3.2	13.0
Cesium-137	5.1	11,000
D. TELLURIUM-ANTIMONY		
Tellurium-127	6.4	0.391
Tellurium-127m	1.2	109
Tellurium-129	34	0.048
Tellurium-129m	5.7	34.0
Tellurium-131m	14	1.25
Tellurium-132	130	3.25
Antimony-127	6.6	3.88
Antimony-129	35	0.179
E. ALKALINE EARTHS		
Strontium-89	102	52.1
Strontium-90	4.0	11,030
Strontium-91	119	0.403
Barium-140	173	12.8
F. COBALT AND NOBLE METALS		
Cobalt-58	0.85	71.0
Cobalt-60	0.31	1,920
Molybdenum-99	173	2.8
Technetium-99m	152	0.25
Ruthenium-103	119	39.5
Ruthenium-105	78	0.185
Ruthenium-106	27	366
Rhodium-105	53	1.50

Table 5.8 (Continued)

Group/Radionuclide	Radioactive Inventory in Millions of Curies	Half-Life (days)
G. RARE EARTHS, REFRACTORY OXIDES AND TRANSURANICS		
Yttrium-90	4.2	2.67
Yttrium-91	130	59.0
Zirconium-95	163	65.2
Zirconium-97	163	0.71
Niobium-95	163	35.0
Lanthanum-140	173	1.67
Cerium-141	163	32.3
Cerium-143	141	1.38
Cerium-144	92	284
Praseodymium-143	141	13.7
Neodymium-147	65	11.1
Neptunium-239	1780	2.35
Plutonium-238	0.062	32,500
Plutonium-239	0.023	8.9×10^6
Plutonium-240	0.023	2.4×10^6
Plutonium-241	3.7	5,350
Americium-241	0.0018	1.5×10^5
Curium-242	0.54	163
Curium-244	0.025	6,630

NOTE: The above grouping of radionuclides corresponds to that in Table 5.7.

Table 5.9

Summary of Environmental Impacts and Probabilities

Probability Of Impact Per Reactor-Year	Persons Exposed over 200 rem	Persons Exposed over 25 rem	Acute Facilities	Population Exposure Millions of person-Rem 50 mi/Total	Latent* Cancers 50 mi/ Total	Cost of Offsite Mitigating Actions Millions of Dollars
10^{-4}	0	0	0	0/0	0/0	0
10^{-5}	0	180	0	.5/3.1	27/170	60
5×10^{-6}	0	1,4000	0	1.3/4.8	93/270	130
10^{-6}	70	23,000	0	4.8/9.0	440/660	480
10^{-7}	11,000	53,000	350	11/20	1,920/21,000	1,100
10^{-8}	25,000	88,000	6,000	20/36	3500/3500	1,100
Related Figure	5.4	5.4	5.6	5.5	5.7	5.8

*Includes cancers of all organs. Thirty times the values shown in the Figure 5.7 are shown in this column reflecting the thirty-year period over which cancers might occur. Genetic effects might be approximately twice the number of latent cancers.

NOTE: Please refer to Section 5.8.2.1.4.7 for a discussion of uncertainties in risk estimates.

(5) Land use statistics including farm land values, farm product values including dairy production, and growing season information for the adjoining regions of Canada, within 563 kilometers (350 miles), based on comparison with the values for the nearby states of the U.S.

To obtain a probability distribution of consequences, the calculations are performed assuming the occurrence of each accident release sequence at each of 91 different "start" times throughout a one-year period. Each calculation utilizes the site-specific hourly meteorological data and seasonal information for the time period following each "start" time. The consequence model also contains provisions for incorporating the consequence reduction benefits of evacuation and other protective actions. Early evacuation of people would considerably reduce the exposure from the radioactive cloud and the contaminated ground in the wake of the cloud passage. The evacuation model used (see Appendix E) has been revised from that used in the RSS for better site-specific application. The quantitative characteristics of the evacuation model used for the WNP-2 site are estimates made by the staff and based upon preliminary evacuation time estimates prepared by the applicant. Actual evacuation effectiveness could be greater or less than that characterized but is not expected to be very much less.

The other protective actions include: (a) either complete denial of use (interdiction), or permitting use only at a sufficiently later time after appropriate decontamination, of food stuffs such as crops and milk, (b) decontamination of severely contaminated environment (land and property) when it is considered to be economically feasible to lower the levels of contamination to protective action guide (PAG) levels, and (c) denial of use (interdiction) of severely contaminated land and property for varying periods of time until the contamination levels reduce to such values by radioactive decay and weathering so that land and property can be economically decontaminated as in (b) above. These actions would reduce the radiological exposure to the people from immediate and/or subsequent use of, or living in, the contaminated environment.

Early evacuation within the plume exposure pathway Emergency Planning Zone (EPZ) and other protective actions as mentioned above are considered to be essential sequels to serious nuclear reactor accidents involving a significant release of radioactivity to the atmosphere. Therefore, the results shown for the WNP-2 reactor include the benefits of these protective actions.

There are also uncertainties in the estimates of consequences, and the error bounds may be as large as they are for the accident probabilities. It is the judgment of the staff, however, that it is more likely that the calculated results are overestimates of consequences rather than underestimates.

The results of the calculations using this consequence model are radiological doses to individuals and to populations, health effects that might result from these exposures, costs of implementing protective actions, and costs associated with property damage by radioactive contamination.

5.8.2.1.4.3 Dose and Health Impacts of Atmospheric Releases

The results of the calculations of dose and health impacts performed for the WNP-2 facility and site are presented in the form of probability distributions in Figures 5.4 to 5.7 and are included in the impact Summary Table 5.9. All of the six accident sequences and sequence groups shown in Table 5.7 contribute to the results, the consequences from each being weighted by its associated probability.

Figure 5.4 shows the probability distribution for the number of persons who might receive whole-body doses equal to or greater than 200 rem and 25 rem, and thyroid doses equal to or greater than 300 rem from early exposure,* all on a per-reactor-year basis. The 200-rem whole-body dose figure corresponds approximately to a threshold value for which hospitalization would be indicated for the treatment of radiation injury. The 25-rem whole-body (which has been identified earlier as the lower limit for a clinically observable physiological effect in nearly all people) and 300-rem thyroid figures correspond to the Commission's guideline values for reactor siting in 10 CFR Part 100.

The figure shows in the left-hand portion that there is less than two chances in 100,000 per year (i.e., 2×10^{-5}) that one or more persons may receive doses equal to or greater than any of the doses specified. The fact that each of the three curves approaches a horizontal line shows that if one person were to receive such doses the chances are about the same that several tens to hundreds would be so exposed. The chances of larger numbers of persons being exposed at these levels are seen to be considerably smaller. For example, the chances are less than 2 in 10,000,000 (2×10^{-7}) per reactor year that 10,000 or more people might receive whole body doses of 200 rem or greater. A majority of the exposures reflected in this figure would be expected to occur to persons within a 32 kilometer (20-mile) radius of the plant. Virtually all would occur within a 161-kilometer (100-mile) radius.

Figure 5.5 shows the probability distribution for the total population exposure in person-rem, i.e., the probability per year that the total population exposure will equal or exceed the values given. Most of the population exposure up to 200,000 person-rem would occur within 80 kilometers (50 miles), but the more severe accident sequences or sequence groups such as the first three in Table 5.7 would result in exposure to persons beyond the 80-kilometer (50-mile) range as shown.

For perspective, population doses shown in Figure 5.5 may be compared with the annual average dose to the population within 80 kilometers (50 miles) of the WNP-2 site due to natural background radiation of 26,000 person-rem, and to the anticipated annual population dose to the general public from normal station operation of about 3.5 person-rem (excluding plant workers)--see Section 5.8.1.

Figure 5.6 shows the probability distributions for acute fatalities, representing radiation injuries that would produce fatalities within about one year after exposure. All of the acute fatalities would be expected to occur within a 40-kilometer (25-mile) radius and the majority within a 20-kilometer (12.5-mile) radius. The results of the calculations shown in this figure and in Table 5.9 reflect the effect of evacuation within the 16-kilometer (10-mile) plume exposure

*Early exposure to an individual includes external doses from the radioactive cloud and the contaminated ground, and the dose from internally deposited radionuclides from inhalation of contaminated air during the cloud passage. Other pathways of exposure are excluded.

pathway EPZ only. For the very low probability accidents having the potential for causing radiation exposures above the threshold for acute fatality at distances beyond 16 kilometers (10 miles), it would be realistic to expect that authorities would evacuate persons at all distances at which such exposures might occur. Acute fatality consequences would therefore reasonably be expected to be very much less than the numbers shown. (Figure E.1 of Appendix E illustrates the potential benefits of evacuation within 24 kilometers (15 miles), and within 32 kilometers (20 miles). Calculations predict zero acute fatalities for complete evacuation within 40 kilometers (25 miles).)

Figure 5.7 represents the statistical relationship between population exposure and the induction of fatal cancers that might appear over a period of many years following exposure. The impacts on the total population and the population within 80 kilometers (50 miles) are shown separately. Further, the fatal, latent cancers have been subdivided into those attributable to exposures of the thyroid and all other organs.

5.8.2.1.4.4 Economic and Societal Impacts

As noted in Section 5.8.2.1.1, various measures for avoidance of adverse health effects including those due to residual radioactive contamination in the environment are possible consequential impacts of severe accidents. Calculations of the probabilities and magnitudes of such impacts for the WNP-2 facility and environs have also been made. Unlike the radiation exposure and adverse health effect impacts discussed above, impacts associated with adverse health effects avoidance are more readily transformed into economic impacts.

The results are shown as the probability distribution for costs of offsite mitigating actions in Figure 5.8 and are included in the impact Summary Table 5.9. The factors contributing to these estimated costs include the following:

- Evacuation costs
- Value of crops contaminated and condemned
- Value of milk contaminated and condemned
- Costs of decontamination of property where practical
- Indirect costs due to loss of use of property and incomes derived therefrom.

The last named costs would derive from the necessity for interdiction to prevent the use of property until it is either free of contamination or can be economically decontaminated.

Figure 5.8 shows that at the extreme end of the accident spectrum these costs could approach ten billion dollars but that the probability that this would occur is exceedingly small, much less than one chance in 100 million per reactor-year.

Additional economic impacts that can be monetized include costs of decontamination of the facility itself and the costs of replacement power. Probability distributions for these impacts have not been calculated, but they are included in the discussion of risk considerations in Section 5.8.2.1.4.6 below.

5.8.2.1.4.5 Releases to Groundwater

A pathway for public radiation exposure and environmental contamination that would be unique for severe reactor accidents was identified in Section 5.8.2.1.1.2 above. Consideration has been given to the potential environmental impacts of this pathway for WNP-2. The principle contributors to the risk are the core melt accidents associated with the rebaselined Boiling Water Reactor release categories in WASH-1400. The penetration of the basemat of the containment building can release molten core debris to the geologic strata beneath the plant. The soluble radionuclides in the debris can be leached and transported with groundwater to downgradient domestic wells used for drinking water or to surface water bodies used for drinking water, aquatic food and recreation. Releases of radioactivity to the groundwater underlying the site could also occur via depressurization of the containment atmosphere or radioactive ECCS and suppression pool water through the failed containment.

An analysis of the potential consequences of a liquid pathway release of radioactivity for generic sites was presented in the "Liquid Pathway Generic Study"[56] (LPGS). The LPGS compared the risk of accidents involving the liquid pathway (drinking water, irrigation, aquatic food, swimming and shoreline usage) for four conventional, generic land-based nuclear plants and a floating nuclear plant, for which the nuclear reactors would be mounted on a barge and moored in a water body. Parameters for the each generic land-based site were chosen to represent averages for a wide range of real sites and were thus "typical," but represented no real site in particular. The discussion in this section is a summary of an analysis performed to determine whether or not the liquid pathway consequences of a postulated accident at the WNP-2 site would be a unique problem with respect to offsite contamination when compared to the generic "large river" land-based site considered in the LPGS. The method of comparison consists of a direct scaling up or down of the LPGS population doses based on the relative values of key parameters characterizing the LPGS large river site and the subject site. The parameters evaluated here include the amounts and rate of release of radioactive materials to the ground, groundwater travel time and sorption on geological media.

All of the reactors considered in the LPGS were Westinghouse pressurized water reactors (PWR) with ice condenser containments. There are likely to be significantly different mechanisms and probabilities of releases of radioactivity for the WNP-2 boiling water reactor (BWR). The staff is not aware of any studies which indicated the probabilities or magnitudes of liquid releases for boiling water reactors. It is unlikely, however, that the liquid release for a BWR would be any larger than that conservatively estimated for simlarly sized PWR's in the LPGS. The source term used for WNP-2 in this comparison therefore is assumed to be equal to that used in the LPGS.

Doses to individuals and populations were calculated in the LPGS without consideration of interdiction methods such as isolating the contaminated groundwater or denying use of the water. In the event of surface water contamination, alternative sources of water for drinking, irrigation and industrial uses would be expected to be found, if necessary. Commercial and sports fishing, as well as many other water-related activities could be restricted. The consequences would, therefore, be largely economic or societal, rather than radiological. In any event, the individual and population doses for the liquid pathway range from fractions to very small fractions of those that can arise from the airborne pathways.

The WNP-2 site is located in the Hanford reservation about 5 kilometers (3 miles) west of the Columbia River. Groundwater at the site exists in both a water table aquifer and several confined, artesian aquifers largely in unconsolidated alluvial and glacial sediments. The water table aquifer at the site is about 18 meters (60 feet) below the surface and is 37 to 49 meters (120 to 160 feet) thick. Flow in the unconfined aquifer is toward the Columbia River, which is its sink. There is no recharge of the water table at the site.

The plant buildings are located on highly permeable glaciofluvial outwash sands and gravels. Contaminated water released from the plant would travel vertically until it reached the water table, and would then move downgradient toward the Columbia River. Although there are many wells on the site, they are closely monitored and are not used for public water consumption. In the event of a core melt accident, use of water from affected wells would, presumably, be halted. Therefore, our analysis focused on potential contamination of the Columbia River by way of contaminated ground water from the site.

Large releases to the ground of radioactive water resulting from chemical reprocessing of reactor fuel have occurred at the Hanford reservation. From 1944 to 1972, over 490 billion liters (130 billion gallons) of waste water and millions of curies of fission products have been discharged from seepage pits to the ground. There have been extensive measurements of the ground water plumes of several radioactive isotopes and other chemicals released from the seepage pits. Because of this large body of information obtained over the years, the movement of radionuclides in groundwater at the site is relatively well understood. Several constituents of leached waste have migrated up to about 24 kilometers (15 miles) in the direction of the Columbia River in the timespan 1944 to 1975. On the basis of the observed plume migration we have estimated the ground water velocity in the unconfined aquifer under the site to be about 2 meters (7 feet) per day toward the Columbia River. Contaminated water released from the plant in the event of a core melt accident could migrate to the river in a minimum of about 6 years. This compares to a minimum groundwater travel time of about 0.6 years used for the LPGS site.

For holdup times on the order of years the LPGS showed that the only significant contributors to population dose to surface water users would be the isotopes Cs-137 and Sr-90. Acutal observation of the movement of Cs-137 and Sr-90 in site soil columns and in situ measurements at the seepage pits indicate that these two isotopes are strongly bound to the soil.(57) While the plumes of substances not easily sorbed, such as tritium and nitrate, can be seen to extend tens of miles, most of the cesium and strontium has remained within a few tens of feet from the points of release. Based upon these data, the staff has estimated retardation factors, which reflect the effects of sorption of the radionuclides within the aquifer, to be about 8400 for Cs and 1400 for Sr. Using these values of the retardation factors, we estimate that it would take a minimum of 50,400 years for Cs-137 and 8400 years for Sr-90 to reach the Columbia River. These travel times compare to 51 years for Cs-137 and 5.7 years for Sr-90 employed in the LPGS. Because their half-lives are approximately

30 years, virtually all the Cs-137 and Sr-90 would decay in the groundwater before it could reach the Columbia River. Since nearly all of the population dose for a liquid pathway release can be shown to be due to these two isotpoes, the staff concludes that the liquid pathway consquences at the Hanford site, resulting from a postulated Class 9 accident, would be significantly less than that calculated for the LPGS large river site and would present no unique contribution to risk.

Finally, there are measures which could be taken, if necessary, to isolate liquid contaminants such as tritium before they could contaminate the river. The staff's estimate of a 6 year minimum travel time would allow ample time for engineering measures such as slurry walls and dewatering to isolate the radioactive contamination near the source.

5.8.2.1.4.6 Risk Considerations

The foregoing discussions have dealt with both the frequency (or likelihood of occurrence) of accidents and their impacts (or consequences). Since the ranges of both factors are quite broad, it is useful to combine them to obtain average measures of environmental risk. Such averages can be particularly instructive as an aid to the comparison of radiological risks associated with accident releases and with normal operational releases.

A common way in which this combination of factors is used to estimate risk is to multiply the probabilities by the consequences. The resultant risk is then expressed as a number of consequences expected per unit of time. Such a quantification of risk does not at all mean that there is universal agreement that people's attitudes about risk, or what constitutes an acceptable risk, can or should be governed solely by such a measure. At best, it can be a contributing factor to a risk judgment, but not necessarily a decisive factor.

In Table 5.10 are shown average values of risk associated with population dose, acute fatalities, latent fatalities, and costs for early evacuation and other protective actions. These average values are obtained by summing the probabilities multiplied by the consequences over the entire range of the distributions. Since the probabilities are on a per-reactor-year basis, the averages shown are also on a per-reactor-year basis.

The population exposure risk due to accidents may be compared with that for normal operations. These are shown in Section 5.8.1, for WNP-2. The radiological dose to the population from normal operation of each unit may result in about 3.5 person-rem per year which may result in about 0.0005 latent cancer in the exposed population. The comparison of 0.0005 latent cancer death for normal operation with about 0.005 latent cancer death from Table 5.10 shows that the accident risks are comparable to those for normal operation.

There are no acute fatality nor economic risks associated with protective actions and decontamination for normal releases; therefore, these risks are unique for accidents. For perspective and understanding of the meaning of the acute fatality risk of about 0.0003 per year, however, we note that to a good approximation the population at risk is that within about 32 kilometers (20 miles) of the plant, about 140,000 persons in the year 2000. Accidental fatalities per year for a population of this size, based upon overall averages

Table 5.10

Average Values of Environmental Risks
Due to Accidents Per Reactor-Year

Population exposure	
person-rem within 50 miles	25
person-rem total	77
Acute Fatalities	0.00032
Latent cancer fatalities	
all organs excluding thyroid	0.0042
thyroid only	0.C0067
Cost of protective actions and decontamination	$2,600

NOTE: Please see Section 5.8.2.1.4.7 for discussions of uncertainties in risk estimates.

for the United States, are approximately 31 for motor vehicle accidents, 11 from falls, 4 from drowning, 4 from burns, and 2 from firearms.[45b]

Figure 5.9 shows the calculated risk expressed as whole-body dose to an individual from early exposure as a function of the distance from the plant within the plume exposure pathway EPZ. The values are on a per-reactor-year basis and all accident sequences and sequence groups in Table 5.7 contributed to the dose, weighted by their associated probabilities.

Evacuation and other protective actions reduce the risks to an individual of acute and latent cancer fatalities. Figures 5.10 and 5.11 show curves of constant risk, as a function of distance, per reactor-year, to an individual living in the WNP-2 plume exposure pathway EPZ, of acute death and death from latent cancer, respectively, due to potential accidents in the reactor. Directional variation of these curves reflect the variation in the average fraction of the year the wind would be blowing into different directions from the plant. For comparison the following risks of fatality per year to an individual living in the U.S. may be noted[45b]; automobile accident 2.2×10^{-4}, falls 7.7×10^{-5}, drowning 3.1×10^{-5}, burning 2.9×10^{-5}, and firearms 1.2×10^{-5}.

The economic risk associated with protective actions and decontamination could be compared with property damage costs associated with alternative energy generation technologies. The use of fossil fuels, coal or oil, for example, would emit substantial quantities of sulfur dioxide and nitrogen oxides into the atmosphere, and, among other things, lead to environmental and ecological damage through the phenomenon of acid rain.[45c] This effect has not, however, been sufficiently quantified to draw a useful comparison at this time.

There are other economic impacts and risks that can be monetized that are not included in the cost calculations discussed in Section 5.8.2.1.4.4. These are accident impacts on the facility itself that result in added costs to the public, i.e., ratepayers, taxpayers, and/or shareholders. These costs would be associated with decontamination, repair or replacement of the facility, and for replacement power.

No detailed methodology has been developed for estimating the contributions of an accident to the economic risk to the licensee for decontamination and restoration of the plant. Experience with such costs is currently being accumulated as a result of the Three Mile Island accident. If an accident occurs during the first year of the WNP-2 (1984) operation, the economic penalty associated with the initial year of the unit's operation is estimated at \$1.0 billion for decontamination and \$600 million for restoration, including replacement of the damaged nuclear fuel. Staff considers the estimate as conservative (high) in that the total costs are assumed to occur during the first year of the accident whereas in reality the costs would be spread over several years thereafter. Although insurance would cover \$300 million of the \$1600 million, the insurance is not credited against the \$1600 million because the \$300 million times the risk probability should theoretically balance the insurance premium. In addition, staff estimates additional fuel costs of \$300 to \$400 million for replacement power during each year the plant is being restored. This estimate assumes that the energy that would have been forthcoming from WNP-2 unit (assuming 60% capacity factor) will be replaced primarily by oil-fired generation in California through reduced exports from the Northwest during part of the year, and increased imports to the Northwest during other parts of the year. The exact amount of displacement by oil and the distribution of the additional fuel costs will depend, among other things, on the hydro condition during the year, the contractual arrangements among the various electric utilities involved, and the load growth throughout the Pacific area. Assuming the high side estimate of $400 million per year for replacement power costs and inoperation of the nuclear unit for 8 years, the total additional replacement power costs would be approximately $3.2 billion.

If the probability of sustaining a total loss of the original facility is taken as the sum of the occurrence of a core melt accident (the sum of the probabilities for the categories in Table 5.7), then the probability of a disabling accident happening during each year of the unit's service life is 2.43×10^{-5}. Multiplying the previously estimated costs of $4.8 billion for an accident to WNP-2 during the initial year of its operation by the above 2.43×10^{-5} probability results in an economic risk of approximately $117,000 applicable to the WNP-2 unit during its first year of operation. This is also approximately the economic risk during the second and each subsequent year of its operation. Although nuclear units depreciate in value and may operate at reduced capacity factors such that the economic consequences due to an accident become less as the units become older, this is offset by higher costs of decontamination and restoration of the unit in the later years due to inflation.

5.8.2.1.4.7 Uncertainties

The foregoing probabilistic and risk assessment discussion has been based upon the methodology presented in the Reactor Safety Study (RSS) which was published in 1975.

In July 1977, the NRC organized an Independent Risk Assessment Review Group to (1) clarify the achievements and limitations of the Reactor Safety Study Group, (2) assess the peer comments thereon and the responses to the comments, (3) study the current state of such risk assessment methodology, and (4) recommend to the Commission how and whether such methodology can be used in the regulatory and licensing process. The results of this study were issued September 1978.[54] This report, called the Lewis Report, contains several findings and recommendations concerning the RSS. Some of the more significant findings are summarized below.

(1) A number of sources of both conservatism and nonconservatism in the probability calculations in RSS were found, which were very difficult to balance. The Review Group was unable to determine whether the overall probability of a core melt given in the RSS was high or low, but they did conclude that the error bands were understated.

(2) The methodology, which was an important advance over earlier methodologies that had been applied to reactor risk, was sound.

(3) It is very difficult to follow the detailed thread of calculations through the RSS. In particular, the Executive Summary is a poor description of the contents of the report, should not be used as such, and has lent itself to misuse in the discussion of reactor risk.

On January 19, 1979, the Commission issued a statement of policy concerning the RSS and the Review Group Report. The Commission accepted the findings of the Review Group.

The accident at Three Mile Island occurred in March 1979 at a time when the accumulated experience record was about 400 reactor years. It is of interest to note that this was within the range of frequencies estimated by the RSS for an accident of this severity.[45d] It should also be noted that the Three Mile Island accident has resulted in a very comprehensive evaluation of reactor accidents like that one, by a significant number of investigative groups both within NRC and outside of it. Actions to improve the safety of nuclear power plants have come out of these investigations, including those from the President's Commission on the Accident at Three Mile Island, and NRC staff investigations and task forces. A comprehensive "NRC Action Plan Developed as a Result of the TMI-2 Accident," NUREG-0660, Vol. I, May 1980 collects the various recommendations of these groups and describes them under the subject areas of: Operational Safety; Siting and Design; Emergency Preparedness and Radiation Effects; Practices and Procedures; and NRC Policy, Organization and Management. The action plan presents a sequence of actions, some already taken, that will result in a gradually increasing improvement in safety as individual actions are completed. The WNP-2 plant is receiving and will receive the benefit of these actions on the schedule indicated in NUREG-0660. The improvement in safety from these actions has not been quantified, however, and the radiological risk of accidents discussed in this chapter does not reflect these improvements.

5.8.2.1.5 Conclusions

The foregoing sections consider the potential environmental impacts from accidents at the WNP-2 facility. These have covered a broad spectrum of possible accidental releases of radioactive materials into the environment by atmospheric and ground-water pathways. Included in the considerations are postulated design basis accidents and more severe accident sequences that lead to a severely damaged reactor core or core melt.

The environmental impacts that have been considered include potential radiation exposures to individuals and to the population as a whole, the risk of near- and long-term adverse health effects that such exposures could entail, and the potential economic and societal consequences of accidental contamination of the environment. These impacts could be severe, but the likelihood of their occurrence is judged to be small. This conclusion is based on (a) the fact that considerable experience has been gained with the operation of similar facilities without significant degradation of the environment; (b) that, in order to obtain a license to operate the WNP-2 facility, it must comply with the applicable Commission regulations and requirements; and (c) a probabilistic assessment of the risk based upon the methodology developed in the Reactor Safety Study. The overall assessment of environmental risk of accidents shows that it is roughly comparable to the risk for normal operational releases, although accidents have a potential for acute fatalities and economic costs that cannot arise from normal operations. The risks of acute fatality from potential accidents at the site are small in comparison with the risks of acute fatality from other human activities in a comparably-sized population.

We have concluded that there are no special or unique features about the WNP-2 site and environs that would warrant special mitigation features for the WNP-2 plant.

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43. "Final Safety Analysis Report (FSAR) for the Washington Nuclear Power Plant Unit 2, Docket Number 50-397, Washington Public Power Supply System, March 24, 1978, as amended.

44. "Safety Evaluation Report (SER) for WNP-2, Docket Number 50.-397 (to be published).

45a. "Energy in Transition 1985 - 2010, "Final Report of the Committee on Nuclear and Alternative Energy Systems (CONAES), National Research Council, 1979, Chapter 9, pp. 517-534; also C. E. Land, Science 209, 1197, September 12, 1980.

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54. "Risk Assessment Review Group Report to the U.S. Nuclear Regulatory Commission," H. W. Lewis et al., NUREG-CR-0400, September 1978.

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56. "Liquid Pathway Generic Study," NUREG-0440, February 1978.

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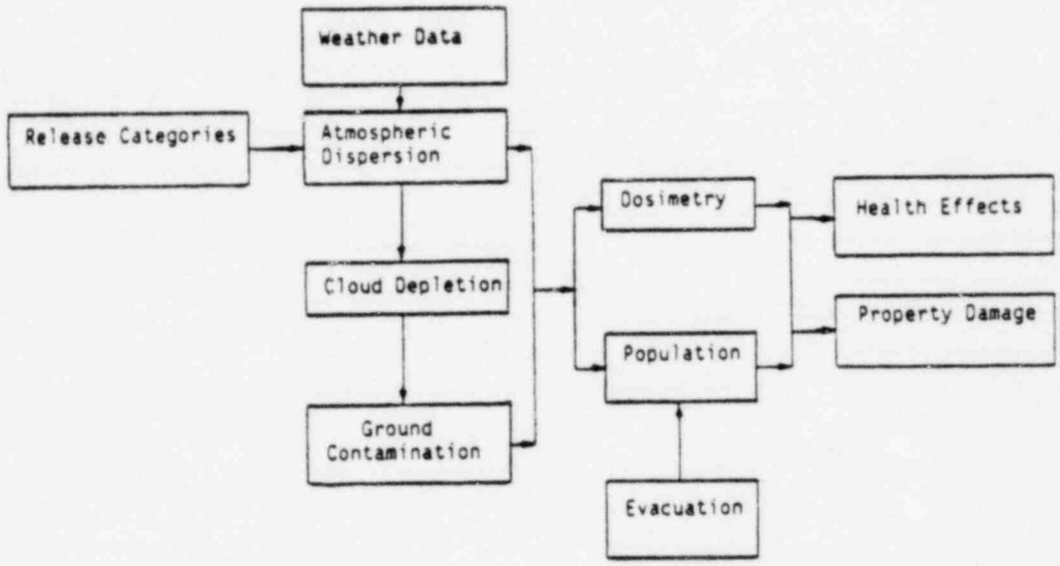


Figure 5.3 Schematic Outline of Consequence Model.

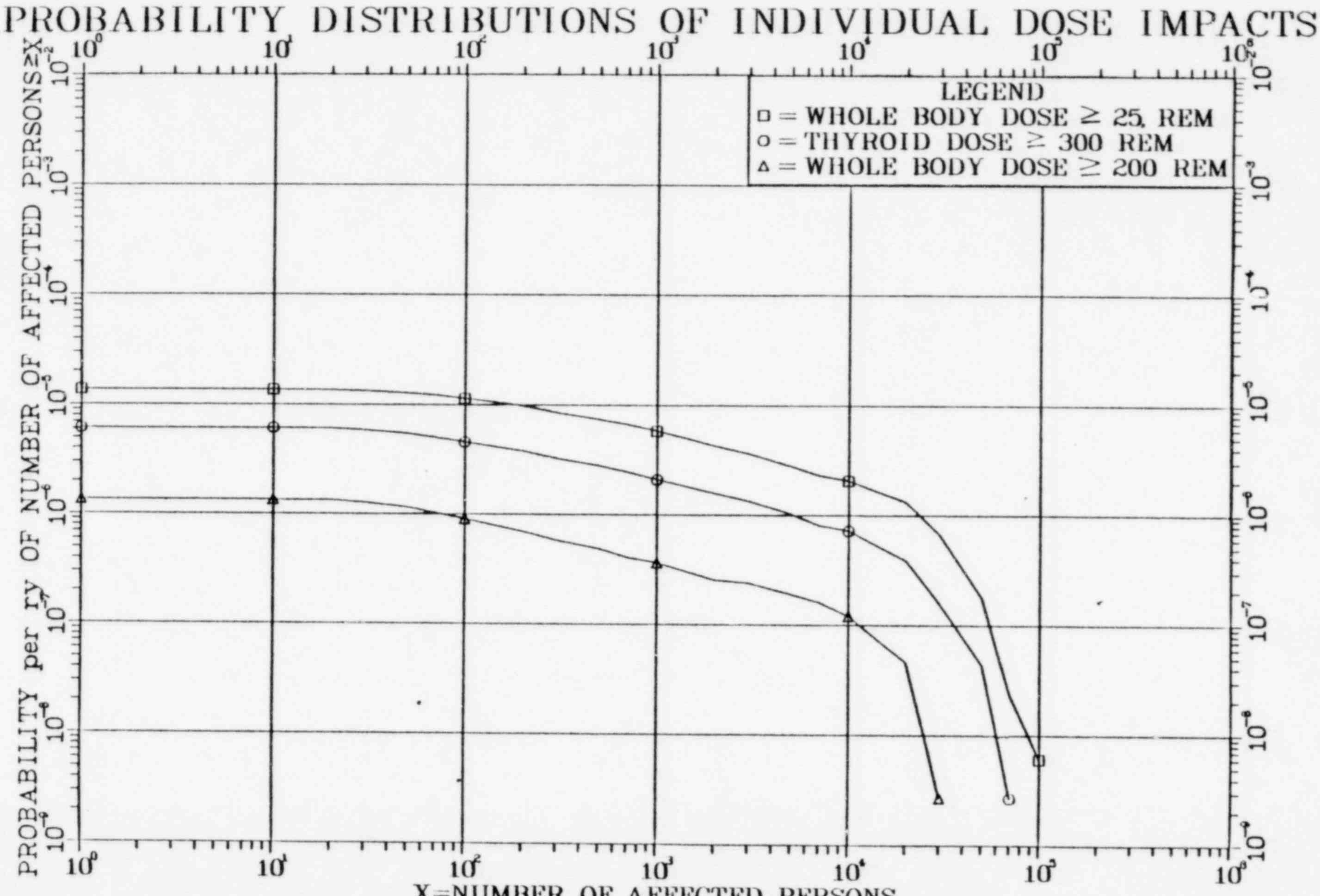
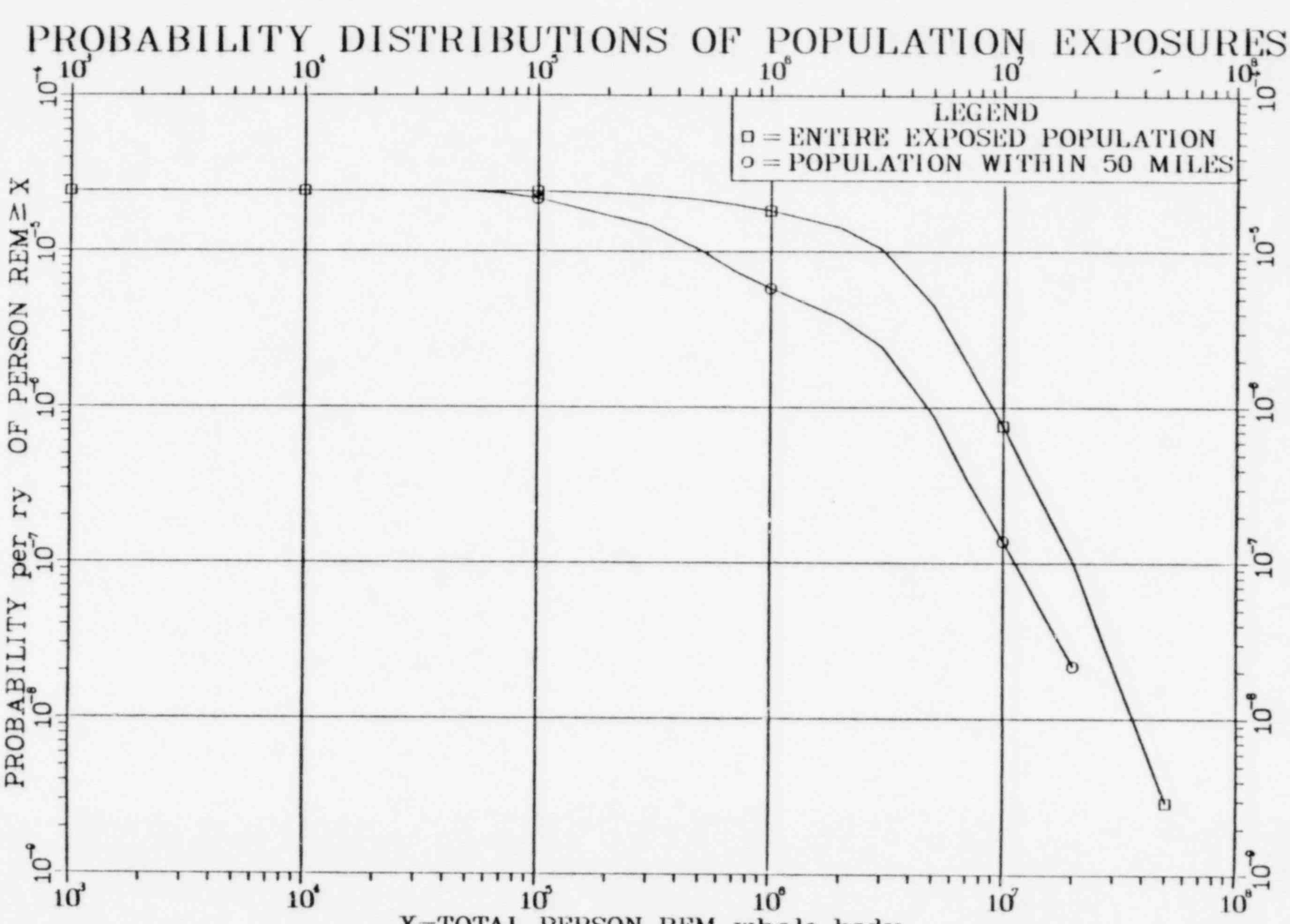


Figure 5.4

Note: Please See Section 5.8.2.1.4.7 for Discussion of Uncertainties in Risk Estimates


PROBABILITY DISTRIBUTIONS OF POPULATION EXPOSURES
LEGEND
□ = ENTIRE EXPOSED POPULATION
○ = POPULATION WITHIN 50 MILES
PROBABILITY per ry OF PERSON REM ≥ X
X=TOTAL PERSON REM whole body
Figure 5.5

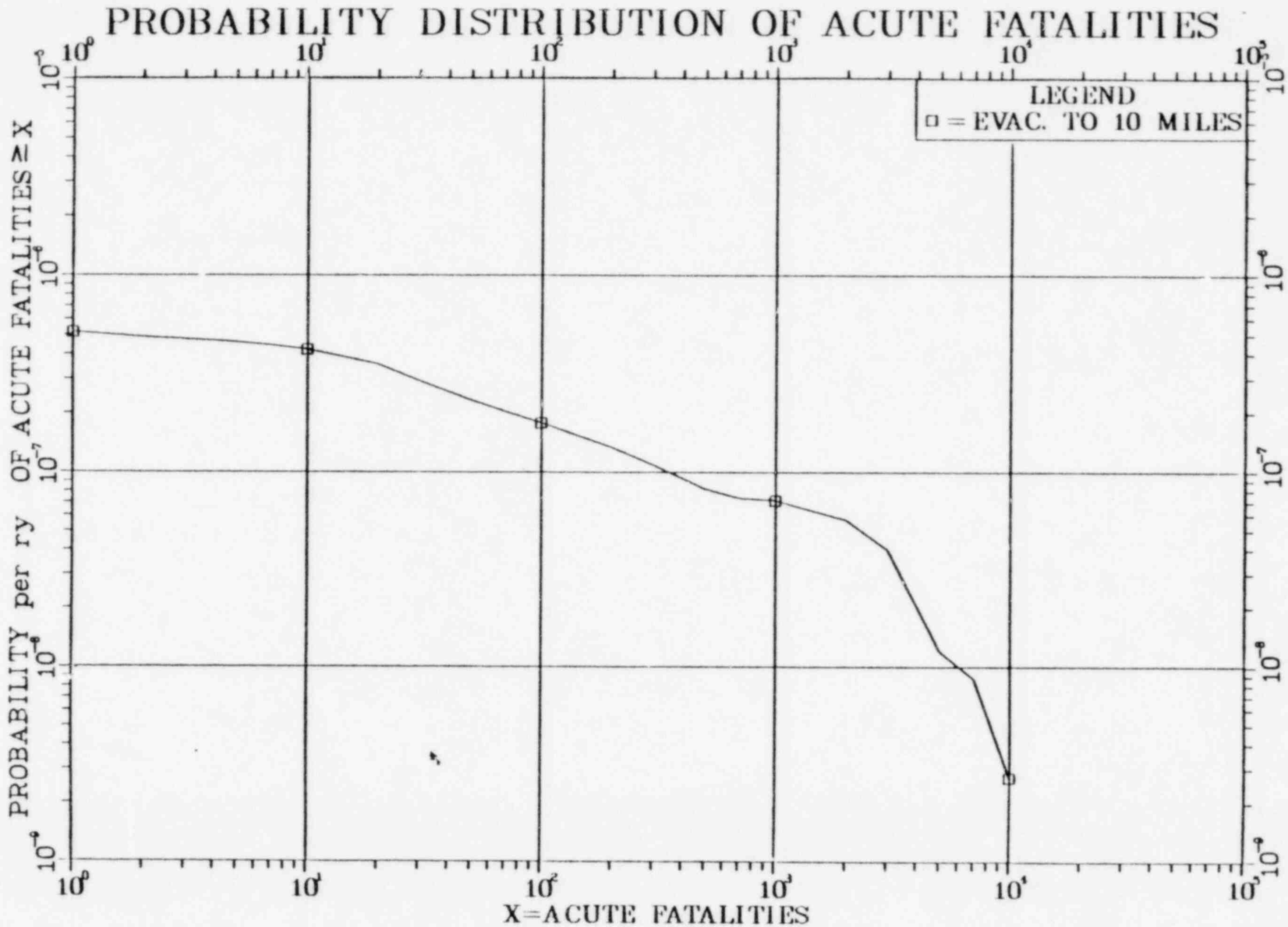

PROBABILITY DISTRIBUTION OF ACUTE FATALITIES
LEGEND
□ = EVAC. TO 10 MILES
PROBABILITY per ry OF ACUTE FATALITIES ≥ X
X=ACUTE FATALITIES

Figure 5.6

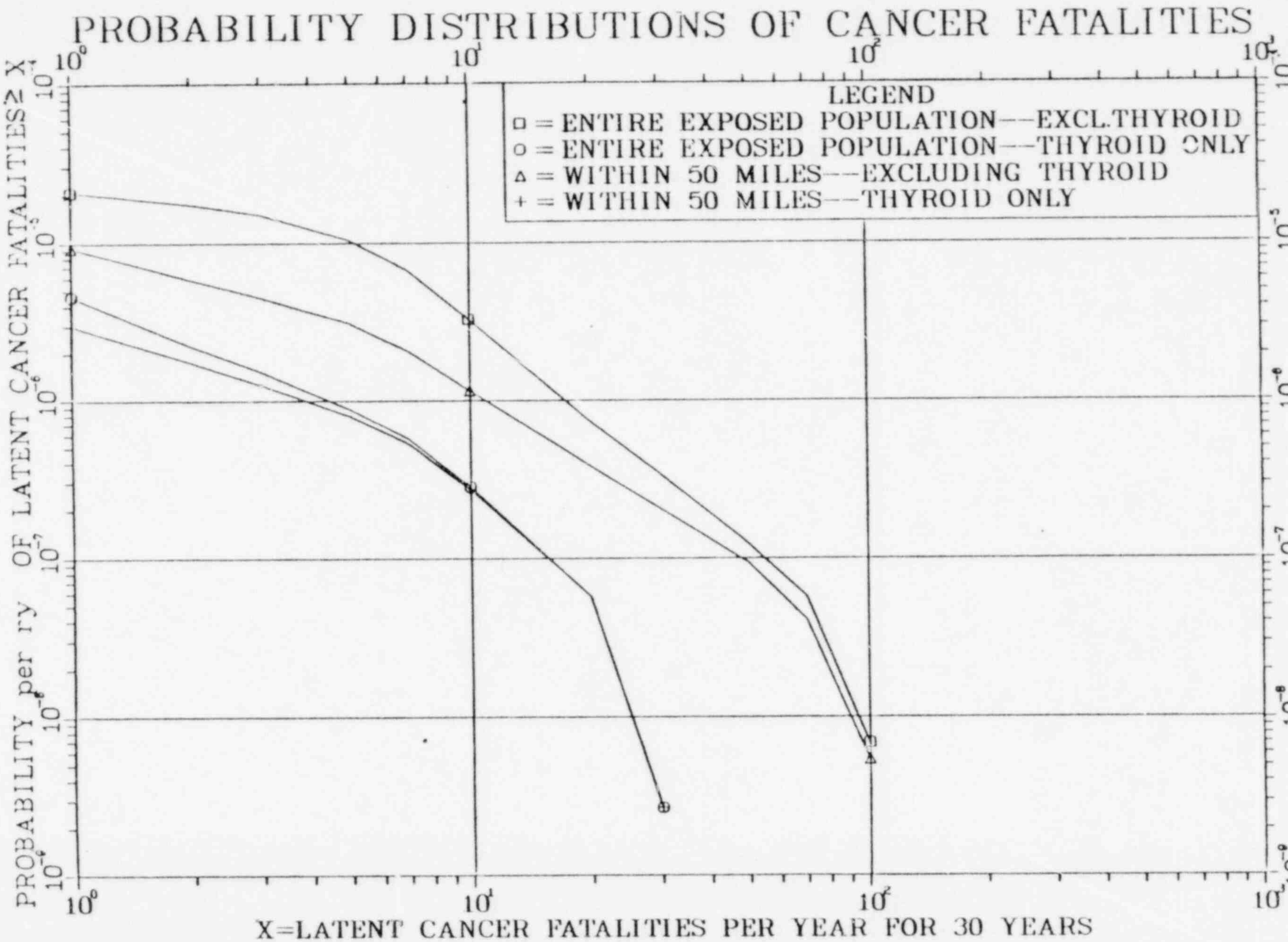


Figure 5.7

Note: Please See Section 5.8.2.1.4.7 for Discussion of Uncertainties in Risk Estimates.

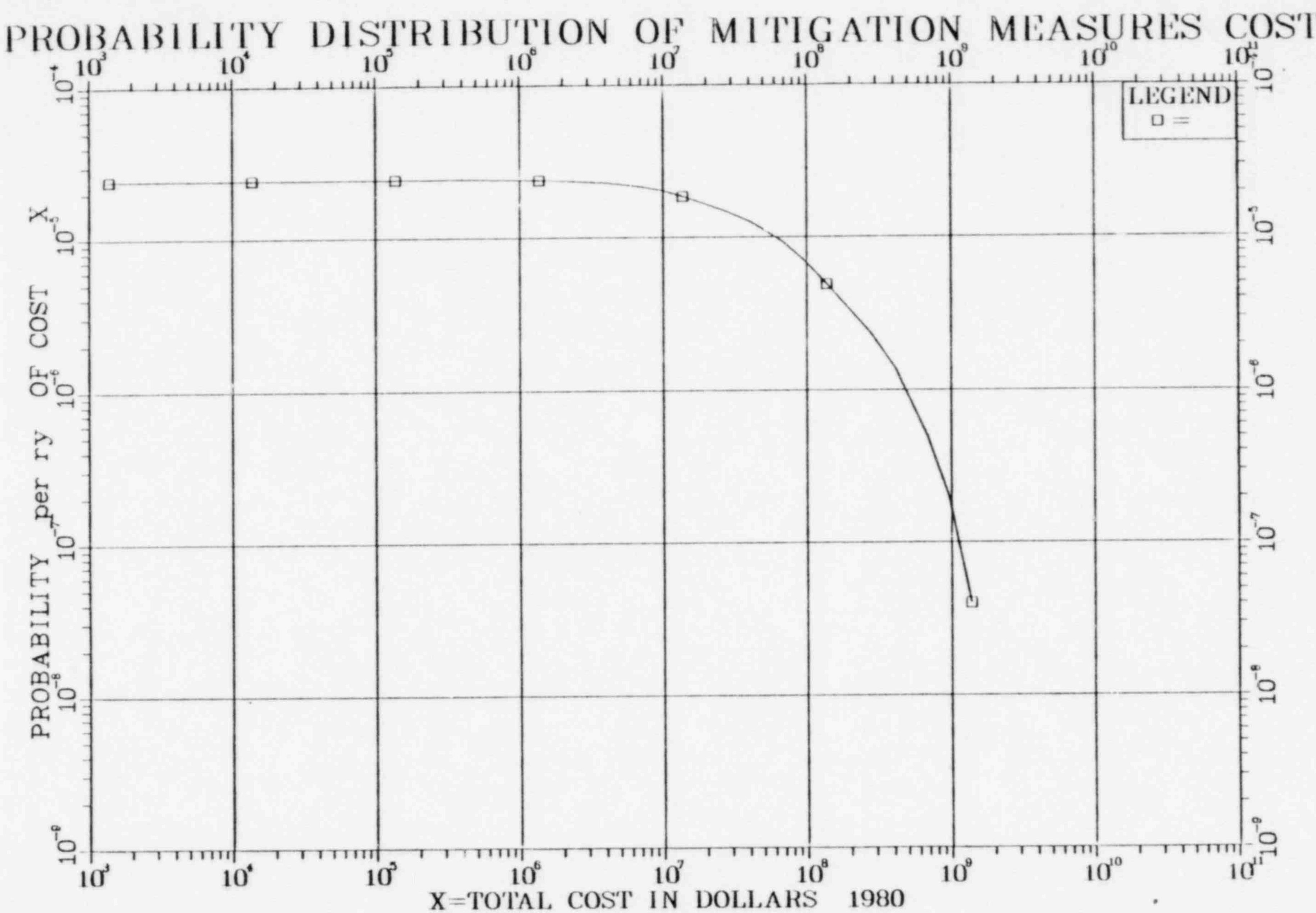


Figure 5.8

Note: Please see Section 5.8.2.1.4.7 for discussion of uncertainties in risk estimates.

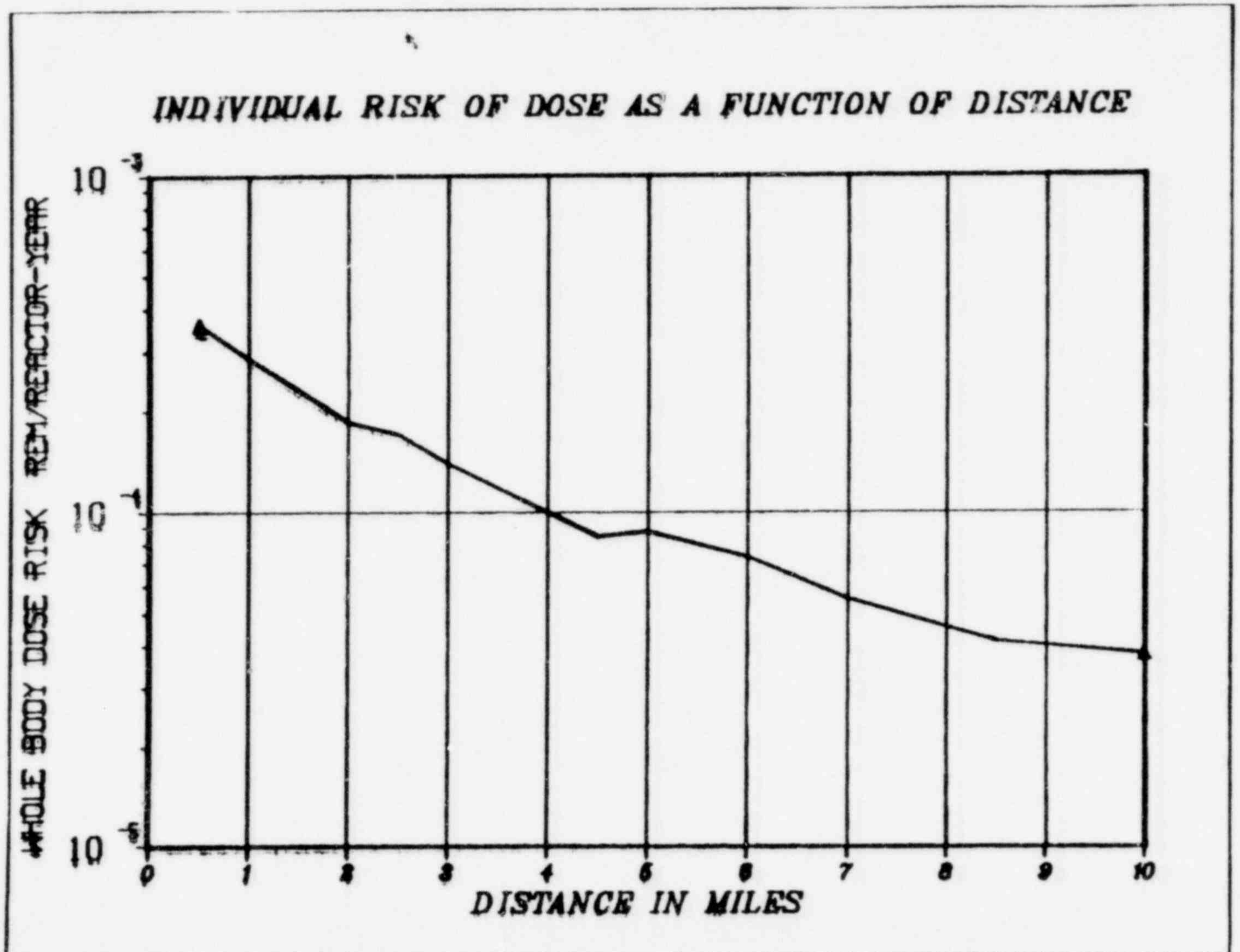
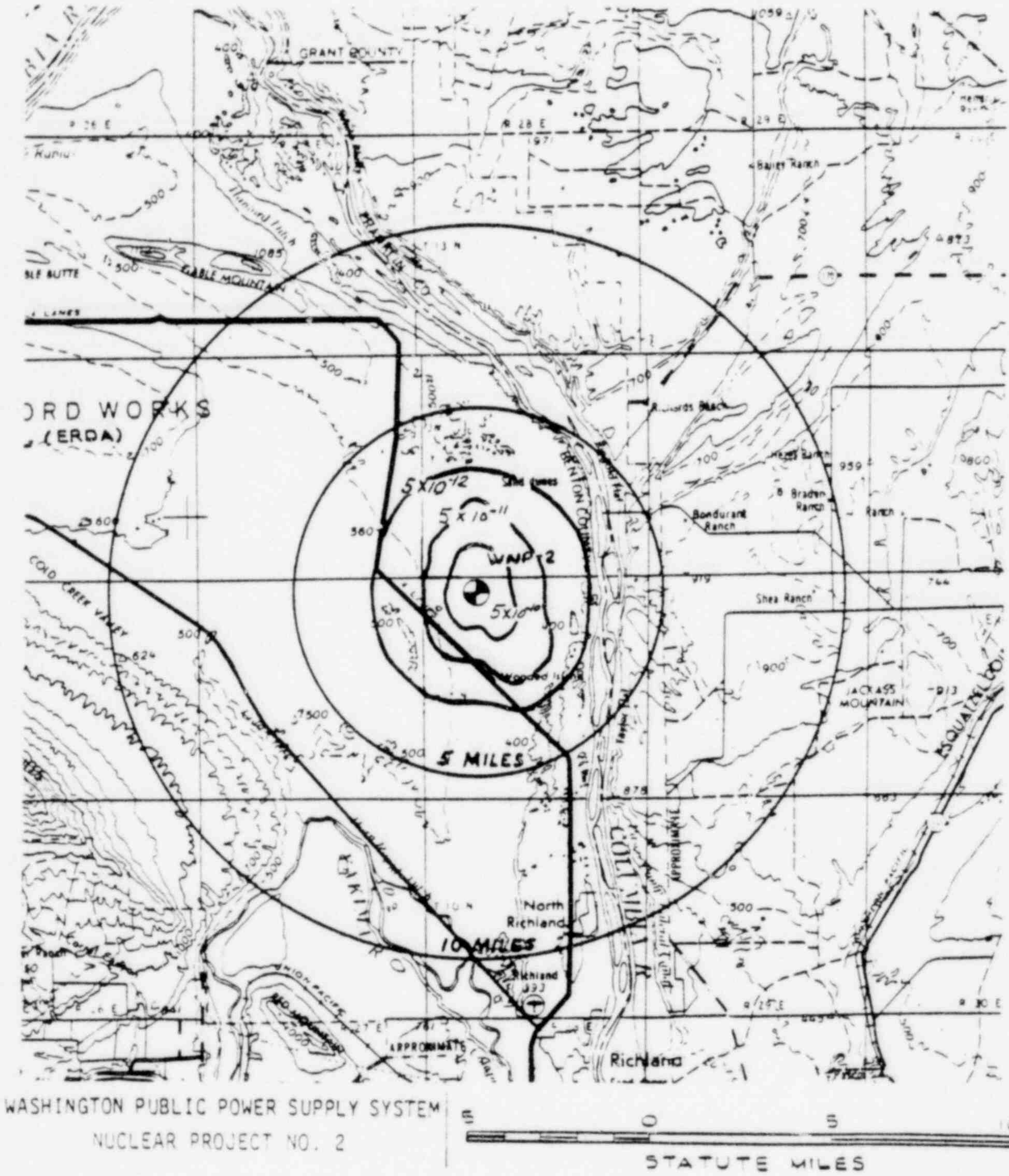


Figure 5.9

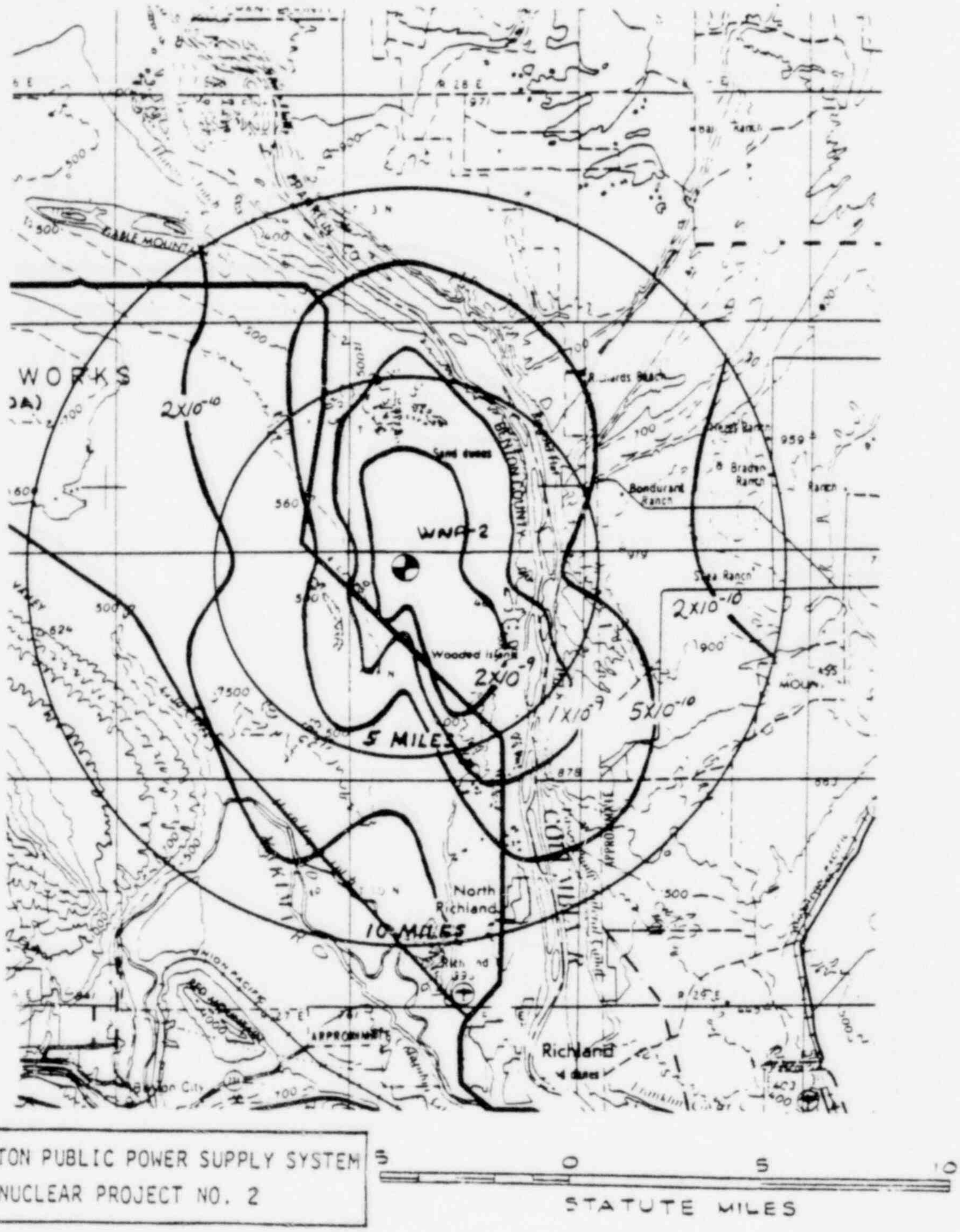
Note: Please see Section 5.8.2.1.4.7 for discussion of uncertainties in risk estimates.



Isopleths of Risk of Acute Fatality
Per Reactor Year to an Individual

Figure 5.10

Note: Please see Section 5.8.2.1.4.7 for a discussion of uncertainties in risk estimates.



WASHINGTON PUBLIC POWER SUPPLY SYSTEM
NUCLEAR PROJECT NO. 2

Isopleths of Risk of Latent Cancer Fatality
Per Reactor Year to an Individual

Figure 5.11

Note: Please see Section 5.8.2.1.4.7 for a discussion of uncertainties in risk estimates.

APPENDIX D

REBASELINING OF THE RSS RESULTS FOR BWRs

The results of the Reactor Safety Study (RSS) have been updated. The update was done largely to incorporate results of research and development conducted after the October 1975 publication of the RSS and to provide a baseline against which the risk associated with various LWRs could be consistently compared.

Primarily, the rebaselined RSS results reflect use of advanced modeling of the processes involved in meltdown accidents, i.e., the MARCH computer code modeling for transient and LOCA initiated sequences and the CORRAL code used for calculating magnitudes of release accompanying various accident sequences. These codes* have led to a capability to predict the transient and small LOCA initiated sequences that is considerably advanced beyond what existed at the time the Reactor Safety Study was completed. The advanced accident process models (MARCH and CORRAL) produced some changes in our estimates of the release magnitudes from various accident sequences in WASH-1400. These changes primarily involved release magnitudes for the iodine, cesium and tellurium families of isotopes. In general, a decrease in the iodines was predicted for many of the dominant accident sequences while some increases in the release magnitudes for the cesium and tellurium isotopes were predicted.

Entailed in this rebaselining effort was the evaluation of individual dominant accident sequences as we understand them to evolve rather than the technique of grouping large numbers of accident sequences into encompassing, but synthetic, release categories as was done in WASH-1400. The rebaselining of the RSS also eliminated the "smoothing technique" that was criticized in the report by the Risk Assessment Review Group (sometimes known as the Lewis Report; NUREG/CR-0400).

In both of the RSS designs (PWR and BWR), the likelihood of an accident sequence leading to the occurrence of a steam explosion (α) in the reactor vessel was decreased. This was done to reflect both experimental and calculational indications that such explosions are unlikely to occur in those sequences involving small size LOCAs and transients because of the high pressures and temperatures expected to exist within the reactor coolant system during these scenarios. Furthermore, if such an explosion were to occur, there are indications that it would be unlikely to produce as much energy and the massive missile-caused breach of containment as was postulated in WASH-1400.

For rebaselining of the RSS BWR design, the sequence $TC\gamma'$ (described later) was explicitly included into the rebaselining results. The accident processes associated with the TC sequence had been erroneously calculated in WASH-1400. In general, the rebaselined results led to slightly increased health impacts

*It should be noted that the MARCH code was used on a number of scenarios in connection with the TMI-2 recovery efforts and for post-TMI-2 investigations to explore possible alternative scenarios that TMI-2 could have experienced.

being predicted for the RSS BWR design. This is believed to be largely attributable to the inclusion of TCγ'.

In summary, the rebaselining of the RSS results led to small overall differences from the predictions in WASH-1400. It should be recognized that these small differences due to the rebaselining efforts are likely to be far outweighed by the uncertainties associated with such analyses.

The accident sequences identified in the rebaselining effort which are expected to dominate risk of the RSS-BWR design are briefly described below. These sequences are assumed to represent the approximate accident risks from the WNP-2 BWR design.

Each of the accident sequences is designated by a string of identification characters in the same manner as in the RSS (See the table of these symbols in page D-4). Each character represents a failure in one or more of the important plant systems or features. For example, in sequences having a γ' at the end of the string, it means a particular failure mode (overpressure) of the containment structure (and a rupture location) where a release of radioactivity takes place directly to the atmosphere from the primary containment. In the sequence having a γ at the end of the string, the containment failure mode is again by overpressure but this time, the rupture location is such that the release takes place into the reactor building (secondary containment) before discharging to the environment. In this latter (γ) case, the overall magnitude of radioactivity release is somewhat diminished by the deposition and plateout processes that take place within the reactor building.

TCγ' and TCγ

These sequences involve a transient event requiring shutdown of the reactor while at full power, followed by a failure to make the reactor subcritical (i.e., terminate power generation by the core). The containment is assumed to be isolated by these events; then, one or the other of the following chain of events is assumed to happen:

(a) High pressure coolant injection system would succeed for some time in providing makeup water to the core in sufficient quantity to cope with the rate of coolant loss through relief and safety valves to the suppression pool of the containment. During this time, the core power level varies, but causes substantial energy to be directed into the suppression pool; this energy is in excess of what the containment and containment heat removal systems are designed to cope with. Ultimately, in about 1-1/3 hours, the containment is estimated to fail by overpressure and it is assumed that this rather severe structural failure of the containment would disable the high pressure coolant makeup system. Over a period of roughly 1-1/2 hours after breach of containment, it is assumed the core would melt. This has been estimated to be one of the more dominant sequences in terms of accident risks to the public.

(b) A variant to the above sequence is one where the high pressure coolant injection system fails somewhat earlier and prior to containment overpressure failure. In this case, the earlier melt could result in a reduced magnitude of release because some of the fission products discharged to the suppression pool, via the safety and relief valves, could be more effectively retained if the pool remained subcooled. The overall accident consequences would be somewhat reduced in this earlier melt sequence but ultimately, the processes accompanying melt (e.g., noncondensibles, steam, and steam pressure pulses during reactor vessel melt-through) could cause overpressure failure (γ or γ') of the containment.

<u>$TW\gamma'$ and $TW\gamma$</u>

The TW sequence involves a transient where the reactor has been shut down and containment has been isolated from its normal heat sink (i.e., the power conversion system). In this sequence, the failure to transfer decay heat from the core and containment to an ultimate sink could ultimately cause overpressure failure of containment. Overpressure failure of containment would take many, many hours, allowing for repair or other emergency actions to be accomplished; but, should this sequence occur, it is assumed that the rather severe structural failure of containment would disable the systems (e.g., HPI, RCIC) providing coolant makeup to the reactor core. (In the RSS design, the service water system which conveys heat from the containment via RHR system to the ultimate sink was found to be the dominant failure contribution in the TW sequence.) After breach of containment, the core is assumed to melt.

<u>[$TQUV\gamma'$, $AE\gamma'$, $S_1E\gamma'$, $S_2E\gamma'$] and [$TQUV\gamma$, $AE\gamma$, $S_1E\gamma$, $S_2E\gamma$]</u>

Each of the accident sequences shown grouped into the two bracketed categories above is estimated to have quite similar consequence outcomes and these would be somewhat smaller than the $TC\gamma',\gamma$ and $TW\gamma'$ sequences described above. In essence, these sequences, which are characterized as in the RSS, involve failure to deliver makeup coolant to the core after a LOCA or a shutdown transient event requiring such coolant makeup. The core is assumed to melt down and the melt processes ultimately cause overpressure failure of containment (either γ' or γ). The overall risk from these sequences is expected to be dominated by the higher frequency initiating events (i.e., the small LOCA (S_2) and shutdown transients (T)).

KEY TO BWR ACCIDENT SEQUENCE SYMBOLS

A - Rupture of reactor coolant boundary with an equivalent diameter of greater than six inches.

B - Failure of electric power to ESFs.

C - Failure of the reactor protection system.

D - Failure of vapor suppression.

E - Failure of emergency core cooling injection.

F - Failure of emergency core cooling functionability.

G - Failure of containment isolation to limit leakage to less than 100 volume per cent per day.

H - Failure of core spray recirculation system.

I Failure of low pressure recirculation system.

J - Failure of high pressure service water system.

M - Failure of safety/relief valves to open.

P - Failure of safety/relief valves to reclose after opening.

Q - Failure of normal feedwater system to provide core make-up water.

S_1 - Small pipe break with an equivalent diameter of about 2"-6".

S_2 - Small pipe break with an equivalent diameter of about 1/2"-2".

T - Transient event.

U - Failure of HPCI or RCIC to provide core make-up water.

V - Failure of low pressure ECCS to provide core make-up water.

W - Failure to remove residual core heat.

α - Containment failure due to steam explosion in vessel.

β - Containment failure due to steam explosion in containment.

γ - Containment failure due to overpressure - release through reactor building.

γ' - Containment failure due to overpressure - release direct to atmosphere.

δ - Containment isolation failure in drywell.

ε - Containment isolation failure in wetwell.

ζ - Containment leakage greater than 2400 volume percent per day.

η - Reactor building isolation failure.

θ - Standby gas treatment system failure.

APPENDIX E

EVACUATION MODEL

"Evacuation," used in the context of offsite emergency response in the event of substantial amount of radioactivity release to the atmosphere in a reactor accident, denotes an early and expeditious movement of people to avoid exposure to the passing radioactive cloud and/or to acute ground contamination in the wake of the cloud passage. It should be distinguished from "relocation" which denotes a post-accident response to reduce exposure from long-term ground contamination. The Reactor Safety Study(1) (RSS) consequence model contains provision for incorporating radiological consequence reduction benefits of public evacuation. Benefits of a properly planned and expeditiously carried out public evacuation would be well manifested in reduction of acute health effects associated with early exposure; namely, in number of cases of acute fatality and acute radiation sickness which would require hospitalization. The evacuation model originally used in the RSS consequence model is described in WASH-1400(1) as well as in NUREG-0340.(2) However, the evacuation model which has been used herein is a modified version(3) of the RSS model and is, to a certain extent, site emergency planning oriented. The modified version is briefly outlined below:

The model utilizes a circular area with a specified radius (such as a 10 mile plume exposure pathway Emergency Planning Zone (EPZ)), with the reactor at the center. It is assumed that people living within portions of this area would evacuate if an accident should occur involving imminent or actual release of significant quantities of radioactivity to the atmosphere.

Significant atmospheric releases of radioactivity would in general be preceded by one or more hours of warning time (postulated as the time interval between the awareness of impending core melt and the beginning of the release of radioactivity from the containment building). For the purpose of calculation of radiological exposure, the model assumes that all people who live in a fan-shaped area (fanning out from the reactor), within the circular zone with the down-wind direction as its centerline -- i.e., those people who would potentially be under the radioactive cloud that would develop following the release -- would leave their residences after lapse of a specified amount of delay time* and then evacuate. The delay time is reckoned from the beginning of the warning time and is recognized as the sum of the time required by the reactor operators to notify the responsible authorities; time required by the authorities to interpret the data, decide to evacuate, and direct the people to evacuate; and time required for the people to mobilize and get underway.

While leaving the area, the model assumes that each evacuee would move radially out and in the downwind direction with an average effective speed* (obtained by dividing the zone radius by the average time taken to clear the zone after the delay time) over a fixed distance* from the evacuee's starting point.

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*Assumed to be of constant values which would be the same for all evacuees.

This distance is selected to be 24 kilometers (15 miles), which is 8 kilometers (5 miles) more than the 16-kilometer (10-mile) plume exposure pathway EPZ radius. After reaching the end of the travel distance the evacuee is assumed to receive no further radiation exposure. (An important assumption incorporated in the RSS conseqeunce model is that if the calculated ground dose to the total marrow over a 7-day period would exceed 200 rems in the regions beyond the evacuation zone, then this high dose rate would be detected by actual field measurements following the accident and people from those regions would be relocated immediately. Therefore, the model limits the period for ground-dose calculation to only 24 hours for those regions. When no evacuation at all is assumed, this manner of ground-dose calculations applies to all regions, beginning from the reactor's location. CRAC code implements this feature irrespective of the evacuation model used.)

The model incorporates a finite length of the radioactive cloud in the downwind direction which would be determined by the product of the duration over which the atmospheric release would take place and the average windspeed during the release. It is assumed that the front and the back of the cloud formed would move with an equal speed which would be the same as the prevailing windspeed; therefore, its length would remain constant at its initial value. At any time after the release, the concentration of radioactivity is assumed to be uniform over the length of the cloud. If the delay time would be less than the warning time, then all evacuees would have a head-start, i.e., the cloud would be trailing behind the evacuees initially. On the other hand, if the delay time would be more than the warning time, then depending on initial locations of the evacuees, there are possibilities that (a) an evacuee will still have a head-start, or (b) the cloud would be already overhead when an evacuee starts out to leave, or (c) an evacuee would be initially trailing behind the cloud. However, this initial picture of cloud-people disposition would change as the evacuees travel depending on the relative speed and positions between the cloud and people. It may become possible that the cloud and an evacuee would overtake one another zero, or one or more times before the evacuee would reach his or her destination. In the model, the radial position of an evacuating person, while stationary or in transit, is compared to the front and the back of the cloud as a function of time to determine a realistic period of exposure to airborne radionuclides. The model calculates the time periods during which people are exposed to radionuclides on the ground while they are stationary and while they are evacuating. Because radionuclides would be deposited continually from the cloud as it passed a given location, a person while under the cloud would be exposed to ground contamination less concentrated than if the cloud had completely passed. To account for this, at least in part, the revised model assumes that persons are exposed to the total ground contamination concentration, calculated to exist after complete passage of the cloud, when completely passed by the cloud; to one-half the calculated concentration when anywhere under the cloud; and to no concentration when in front of the cloud. The model provides for use of different values of the shielding protection factors for exposure from airborne radioactivity and contaminated ground, and of the breathing rates for stationary and moving evacuees during delay and transit periods.

It is realistic to expect that authorities would evacuate persons at distances from the site where exposures above the threshold for causing acute fatalities could occur regardless of the plume exposure pathway EPZ distance. Figure E-1 illustrates the reduction in acute fatalities that can occur by extending evacuation to larger distances, such as 24 kilometers (15 miles), and 32 kilometers (20 miles). If it is assumed that all people within a distance of 40 kilometers (25 miles) are evacuated, the model predicts that there would be no acute fatalities at any probability level for this site. It should be noted, however, that the evacuation model becomes more inaccurate as larger distances, and larger numbers of people, are involved. Also illustrated in Figure E-1 is a pessimistic case for which no early evacuation is assumed and all persons are assumed to be exposed for the first 24 hours following an accident, and are then relocated.

The model has the same provision for calculation of the economic cost associated with implementation of evacuation as in the original RSS model. For this purpose, the model assumes that for atmospheric releases of durations three hours or less, all people living within a circular area of a 5-mile radius centered at the reactor plus all people living within a 45° angular sector within the plume exposure pathway EPZ and centered on the downwind direction would evacuate and temporarily relocate. However, if the duration of release would exceed three hours, the cost of evacuation is based on the assumption that all people within the entire plume exposure pathway EPZ would evacuate and temporarily relocate. For either of these situations, the cost of evacuation and relocation is assumed to be $125 (1980 dollar) per person, which includes cost of food and temporary sheltering for a period of one week.

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3. "A Model of Public Evacuation for Atmospheric Radiological Releases," SAND78-0092, June 1978.

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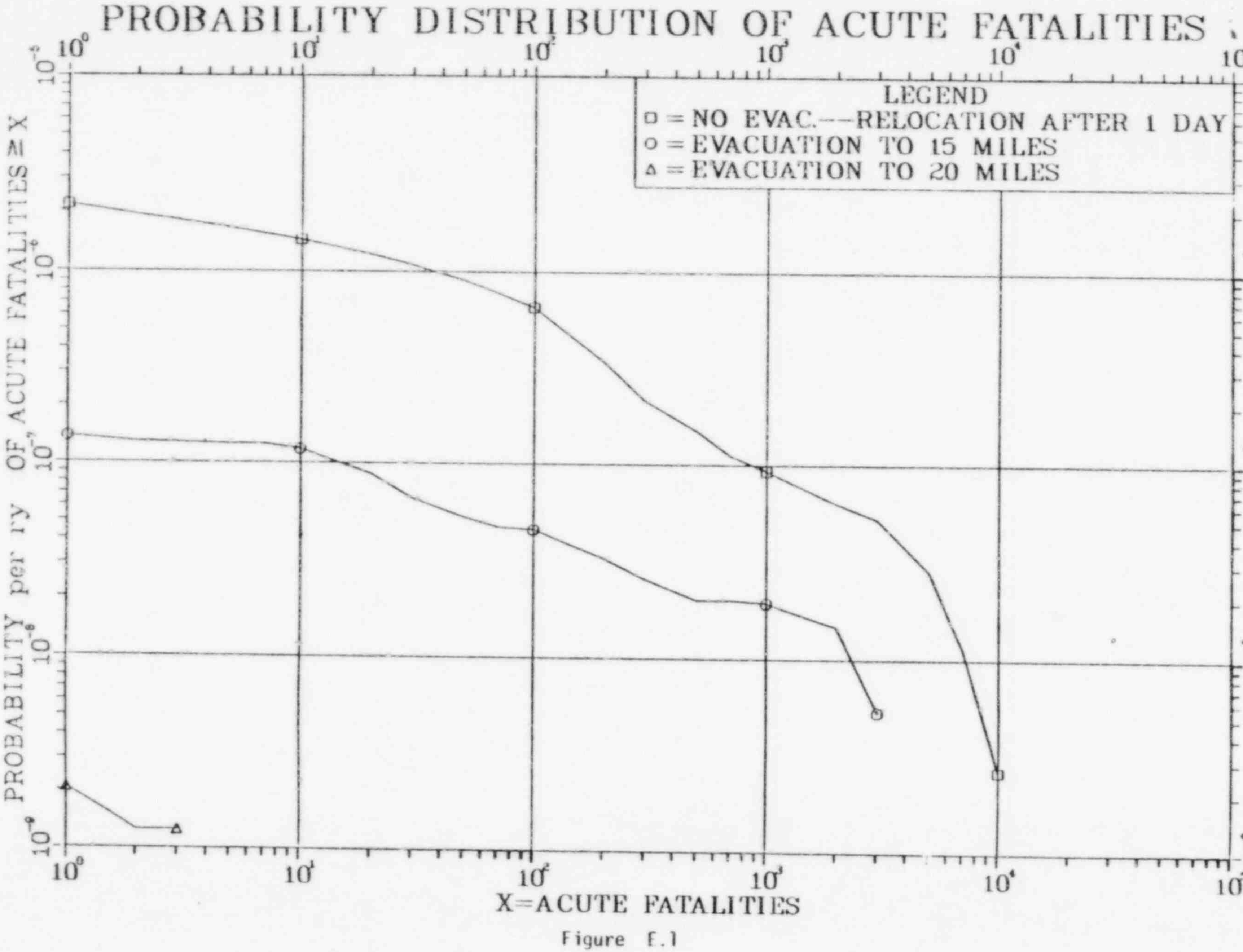

Figure E.1

Note: Please See Section E.9.2.1.4.7 for Discussion of Uncertainties in Risk Estimates