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The Effects of Natural Phenomena on the Exxon Nuclear Company Mixed Oxide Fabrication Plant at Richland, Washington

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Division of Fuel Cycle and Material Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

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This is the third in a series of documents to be published concerning the effects of natural phenomena on existing plutonium fabrication facilities. The first in the series, NUREG-0547, covered the Babcock and Wilcox Co. operations at Leechburg, Pennsylvania; the second, NUREG-0621, covered the Westinghouse Electric Corp. operations at Cheswick, Pennsylvania.

SUMMARY

DESCRIPTION OF THE PROPOSED ACTION

The proposed action is to issue a renewal to the full-term Special Nuclear Material License No. SNM-1227 (Docket No. 70-1257) authorizing the Exxon Nuclear Company (XN) to operate the Mixed Oxide Fabrication Plant (MOFP) located in Richland, Washington. The license renewal would authorize continued operation of development activities associated with plutonium-bearing fuel fabrication and the production of completed fuel rods and assemblies. The XN plutonium facilities have operated without significant offsite effect under license since early 1972.

Part 70 of Title 10 of the Code of Federal Regulations (10 CFR 70) defines and enumerates the Nuclear Regulatory Commission (NRC) policy and procedures for the issuance of licenses for possession and use of special nuclear material (SNM). Implicit in Sections 70.22 and 70.23 of 10 CFR 70 is a requirement that existing plutonium fabrication plants be examined with the objective of improving, to the extent practicable, their abilities to withstand adverse natural phenomena without loss of capability to protect the public.* In accordance with these regulations, the Division of Fuel Cycle and Material Safety (the staff) of the NRC initiated an analysis of the effects of natural phenomena on the XN MOFP. Following completion of the analysis, the staff has prepared a condensation of the effects of natural phenomena on the facility. The condensation, published herein, is based on information contained in or derived from the following reports, or in literature referenced in the following reports:

- T.T. Fujita. "Review of Severe Weather Meteorology at Exxon Nuclear Company, Inc., Richland, Washington." The University of Chicago, report submitted to Argonne National Laboratory under Contract No. 31-109-38-3731, 31 March 1977.

- "Seismic Risk Analysis for the Exxon Nuclear Plutonium Facility, Richland, Washington." TERA Corporation, Berkley, CA, report submitted to Lawrence Livermore Laboratory, 29 September 1978.

- "Assistance in Hydrologic Aspects - Analysis of the Effects of Natural Phenomena on Existing Plutonium Fabrication Facilities - Exxon." Transmitted by memorandum from L.G. Hulman of USNRC/DSE to Richard W. Starostecki of USNRC/FC, 3 July 1978

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*"*Statements of Consideration,*" *10 CFR 70; and 36 FR 17573, 2 September 1971.*

- "Description of the Site Environment - The Exxon Nuclear Site." Transmitted by letter from L.C. Rouse of USNRC/FC to Dr. R. Nilson of Exxon Nuclear Company, 13 March 1980.

- J. Mishima and L.C. Schwendiman, Battelle - Pacific Northwest Laboratory, and J.E. Ayer, USNRC. "Identification of Features Within Plutonium Fabrication Facilities Whose Failure May Have a Significant Effect on the Source Term." 24 April 1978.

- K.C. Mehta, J.R. McDonald, and D.A. Smith. "Response of Structures to Extreme Wind Hazard at the Exxon Nuclear Company Mixed Oxide Fuel Fabrication Plant, Richland, Washington." Texas Tech University, Institute for Disaster Research, Lubbock, TX, December 1979.

- "Structural Condition Documentation and Structural Capacity Evaluation of Exxon Nuclear Company Mixed Oxide Fabrication Plant at Richland, Washington, for Earthquake and Flood, Task II - Structural Capacity Evaluation." Engineering Decision Analysis Company, Inc., prepared for Lawrence Livermore Laboratory, April 1979.

- D.W. Pepper. "Calculation of Particulate Dispersion in a Design-Basis Tornadic Storm from the Exxon Nuclear Company, Richland, Washington." E.I. du Pont de Nemours and Co., Savannah River Laboratory, Aiken, SC, prepared for USDOE under Contract DE-AC09-76SR00001, DP-1544, November 1979.

- J. Mishima, L.C. Schwendiman, and J.E. Ayer. "Estimated Airborne Release of Plutonium from the Exxon Nuclear Mixed Oxide Fuel Plant at Richland, Washington as a Result of Postulated Damage From Severe Wind and Earthquake Hazard." Battelle - Pacific Northwest Laboratory, PNL-3340, February 1980.

- J. D. Jamison and E. C. Watson. "Environmental Consequences of Postulated Plutonium Releases from Exxon Nuclear MOFP, Richland, Washington, as a Result of Severe Natural Phenomena." Battelle - Pacific Northwest Laboratory, PNL-3315, Feburary 1980.

- Risk Analysis of Postulated Plutonium Releases from the Exxon Plant, Richland, Washington as a Result of Tornado Winds and Earthquakes, James W. Johnson, USNRC/PAS, August 1980

This summary is derived from the condensation and the above-listed reports.

THE PROBABLE EFFECTS OF NATURAL PHENOMENA ON THE EXXON MIXED OXIDE FABRICATION PLANT

In this summary of the probable effects of damage to the Exxon MOFP by tornadoes and earthquake, the consequence of damage is expressed as dose to several human receptors. Although dose from the more important pathways was considered, almost all the dose contribution comes from plutonium inhalation during cloud passage and resuspension of deposited material. The highest dose to organs of interest accrues to lungs and bone. Therefore, the dose is expressed in terms of the 50-year committed dose to lungs and bone from inhalation.

- The most likely 50-year committed dose to the nearest resident from the most severe tornado considered is 3.7 rem to lungs and 5.4 rem to bone. This consequence is caused by a tornado with a windspeed of 112 m/s and probability of occurrence of 3.0×10^{-9} per year. The most likely value of 50-year committed dose to the population within 80 km of the plant from the same event is 19 000 person-rem to lungs and 28 000 person-rem to bone. When this most severe tornado occurs, the most likely doses occur roughly 90% of the time, and there is also a probability that higher doses will occur. The highest calculated 50-year doses to the population within 80 km are 1.2 million person-rem to lungs and 1.7 million person-rem to bone. These highest doses occur roughly 0.25% of the time. These dose and occurrence-rate estimates have a factor of roughly 10 uncertainty either way (with about 90% confidence). Hence, the quoted numbers should not be interpreted as being precise--not even to one significant figure--but should be regarded as indicating values only of about an order of magnitude.

- The most likely 50-year committed dose to the nearest resident from damage caused by the most severe earthquake considered is 2.4 rem to lungs and 3.5 rem to bone. That earthquake has an annual occurrence rate of 1.0×10^{-5} and also causes a most likely 50-year committed dose to the population within 80 km of the plant of 16 000 person-rem to lungs and 23 000 person-rem to bone. These most likely doses occur roughly 90% of the time. The highest 80-km calculated doses are 360 000 person-rem to lungs and 520 000 person-rem to bone, which occur roughly 0.25% of the time. These numbers, like those given above for severe winds, have only an order-of-magnitude precision and, hence, should be interpreted as being quite imprecise.

To put the consequence from wind and earthquake hazard in perspective: if a worker is exposed for 50 years to the maximum permissible concentration of ^{239}Pu under present limits, at the end of that time he would have the maximum permissible body burden and would have received a dose commitment to bone of 750 rem. This compares with a 50-year dose commitment of 5.4 rem to bone, to the nearest resident, from wind hazard that is most likely to occur in the case of the most severe tornado evaluated, and 3.5 rem to bone of that same resident in the case of the most severe earthquake evaluated. In the case of population dose from these events, the most likely 50-year committed dose to bone of the population within 80 km of the plant is 28 000 person-rem from the tornado and 23 000 person-rem from the earthquake. The 50-year collective dose equivalent to the total body from natural-background radiation, to the same population, is estimated at 1 million person-rem. Thus, the most likely population dose to bone from the most severe tornado and earthquake hazard is about 3% of the total-body dose from natural-background radiation.

Of course, there are unlikely events that result in significantly greater doses, as described earlier. The unlikely events causing the greatest doses have probabilities that are reduced by a factor of roughly 400 compared with the most likely event.

The doses that result from facility damage due to severe weather and earthquake, when multiplied by the occurrence rate for the initiating event, yield the yearly risk. (Risk, as defined here, is the statistical average consequence. It should be recognized that many other definitions can be used for "risk," some of which incorporate public aversion to high-consequence accidents.)

The greatest risk from the severe weather considered is attributed to the tornado with an 85-m/s windspeed. The most likely radiological risk to the population within 80 km of the MOFP from this event is estimated to be 1.7 person-mrem/yr to the lungs and 2.4 person-mrem/yr to bone. This compares with an absolute risk of about 20 million person-mrem/yr from natural-background radiation to the total body of the same population. Similarly, the most likely radiological risk to the resident nearest the MOFP from the 85-m/s tornado is about 3×10^{-5} mrem/yr to the lungs and about 4×10^{-5} mrem/yr to bone. From natural background the nearest resident receives an annual dose rate of 100 mrem/yr to the total body. The above comparisons are conservative in that they all neglect that the consequence component of risk from natural phenomena is the 50-year dose commitment, whereas from natural background it is the annual dose.

The most likely radiological risk from earthquake to the population within 80 km of the MOFP is about 0.14 person-rem/yr to the lungs and 0.21 person-rem/yr to bone. The nearest resident would risk 0.02 mrem/yr to the lungs and 0.03 mrem/yr to bone from the same event. As discussed above, the consequence term of risk is the 50-year dose commitment.

The staff also analyzed the site from the standpoint of hazard due to flooding. This analysis showed a low ($\sim 6 \times 10^{-5}$/yr) likelihood of occurrence of damaging flood combined with a warning time of at least 30 days. Because Exxon has contingency plans for facility protection and disposition of in-process plutonium, no further consideration was given to deriving dose or risks associated with the flooding event.

RESULTS OF THE EFFECTS OF NATURAL PHENOMENA ON THE EXXON MIXED OXIDE FABRICATION PLANT

One of the aims of the analysis is to examine the plant with the objective of improving, to the extent practicable, its ability to withstand adverse natural phenomena without loss of capability to protect the public. The relatively small risk to the public from the unlikely events previously discussed would indicate that the public is not seriously threatened by the presence of the XN MOFP. Thus, it is the judgment of the staff that the benefits to be gained by substantial plant improvements to further mitigate against adverse natural phenomena are not cost effective.

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THE EFFECTS OF NATURAL PHENOMENA
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FABRICATION PLANT AT RICHLAND, WASHINGTON

1. INTRODUCTION

1.1 PREFACE[1]

The regulations that establish procedures and criteria for the issuance of licenses to possess and use (and, thereby, fabricate) special nuclear materials (SNM) are contained in Title 10 Part 70 of the Code of Federal Regulations, commonly denoted as 10 CFR 70. In part, 10 CFR 70 describes the content of license applications and supporting documents and requirements for approval of applications and issuance of licenses. Due to a change in the regulations that became effective on 2 September 1971, applications for licenses to possess and use SNM in a plutonium fuel fabrication plant are required to contain a description and safety assessment of the design bases of the principal structure, systems, and components of the plant, including provisions for protection against natural phenomena. Therefore, facilities for which the license application was filed after 2 September 1971 must be designed to provide protection against natural phenomena. This was not a requirement for facilities of this type that were licensed earlier.

Specific address to the problem of existing facilities and protection against the effects of natural phenomena was contained in the required preamble to the rulemaking that became effective on 2 September 1971. The Statement of Considerations stated that existing licensed plutonium fabrication plants would be examined with the objective of improving, to the extent practicable, their abilities to withstand adverse natural phenomena without loss of capability to protect the public. The NRC Office of Nuclear Material Safety and Safeguards has started the examination of existing licensed plutonium fabrication plants. This summary describes the analyses that support the examination and conclusions reached relative to the Exxon Nuclear Company (XN) Mixed Oxide Fabrication Plant (MOFP) at Richland, Washington.

1.2 TECHNICAL ANALYSIS

Experts in the fields of seismology/geology, surface hydrology, normal- and severe-weather phenomena, structural analysis, source-term characterization, meteorological dispersion, demography, ecology, and radiological impact have been engaged in the analyses. These experts, assembled in teams, have reviewed the facility and provided a realistic assessment of the range of credible consequences of natural phenomena and the likelihood thereof.

1.2.1 Severe-Weather Event

The site has been described with respect to credible severe weather. Tornado frequency of occurrence by Fujita scale on a historic, statistical basis constitutes the basic input to the review process.

Severe-weather characterization includes recurrent high-velocity non-tornadic winds that can have more serious consequences than tornadoes in the event of breach of confinement. Severe-weather characteristics are translated into transient and steady-state forces for application to structural analysis that determines the response of structure and confinement to storm-induced forces. Source terms and estimates of rate of release and quantity of material available for dispersion are estimated for each postulated breach of confinement. Analysis of dispersion, airborne concentration, and deposition by and from severe weather is coupled with demographic and land/water-use data to permit assessment of radiological impact of releases. Figure 1 is a graphic depiction of the input/output information flow from reviewer to reviewer in the analytical chain associated with the determination of the consequences of the severe-weather event.

1.2.2 Earthquake

For the seismic event, ground motion at the plant foundation is provided as input for the structural and component analysis. Response of the structure and confinement to seismic forces has been determined. For the event of breach of confinement, a description of the expected damage was provided to an expert on aspiration and levitation of heavy-metal compounds who estimated the rate of release and quantity of material available for dispersion. A meteorologist estimated deposition and airborne concentrations, which--when coupled with demographic and land- and water-use data--permitted an assessment of the radiological impact on man and his environment. Figure 2 is a schematic diagram of the flow of information that took place during the review of the consequences of seismic events.

1.2.3 Flood

The plant site has been characterized with respect to flooding potential. The low likelihood of occurrence of the probable maximum flood (about 6×10^{-5}/yr) combined with a long warning time (greater than one month) and planned disposition of in-process inventory dictate against further consideration of adverse radiological consequences due to flooding of the MOFP site.

1.3 RESULTS

The completed work provides a description and safety assessment of the design of the principal structures, systems, and components of the plant with respect to its ability to withstand the effects of natural phenomena. The results include an assessment of the consequences to the public and the environment of exposure of the plant to potentially damaging natural phenomena.

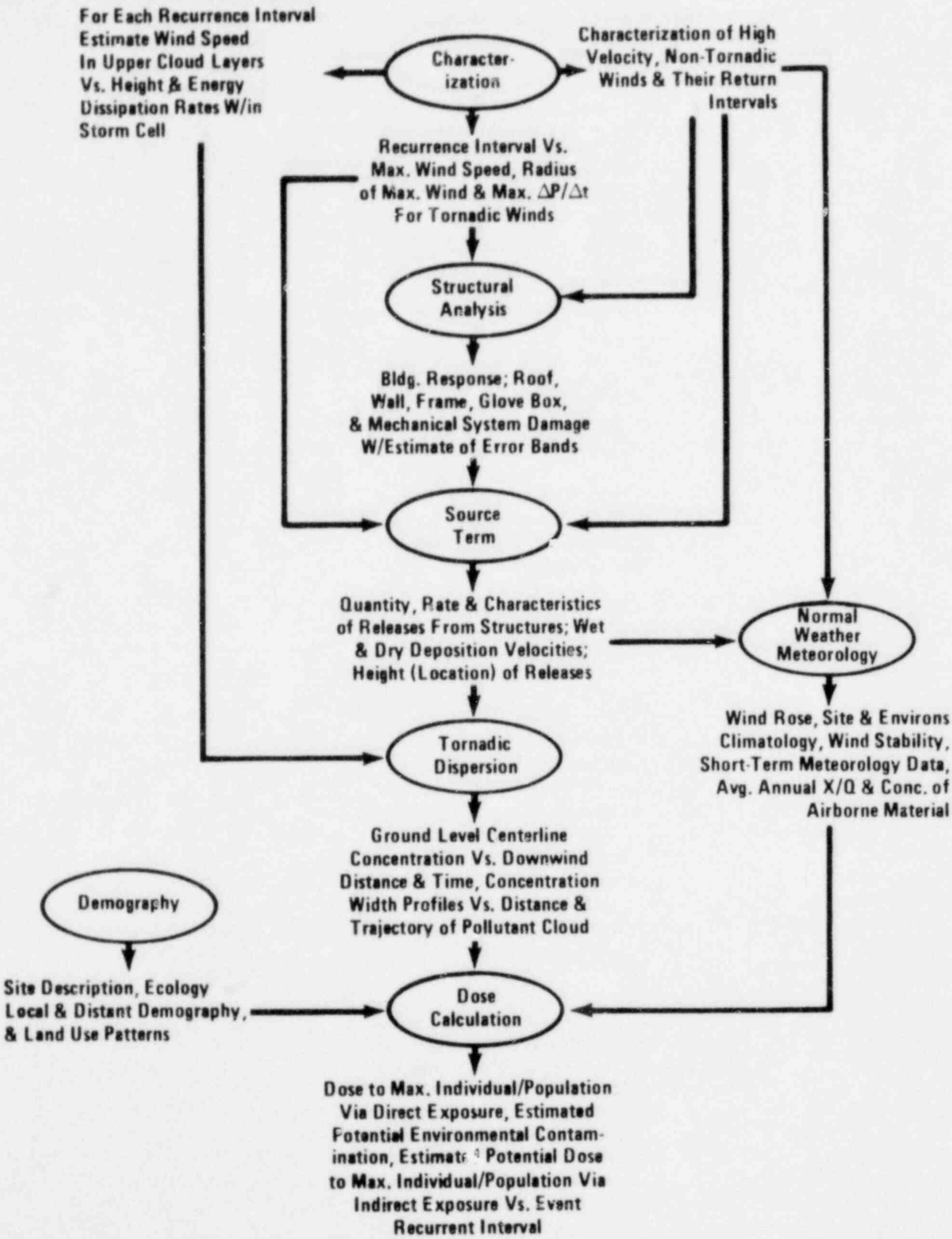


Fig. 1. Flow Diagram for Severe-Weather Aspects of Analysis of the Effects of Abnormal Natural Phenomena on Operating Plutonium Fabrication Facilities.

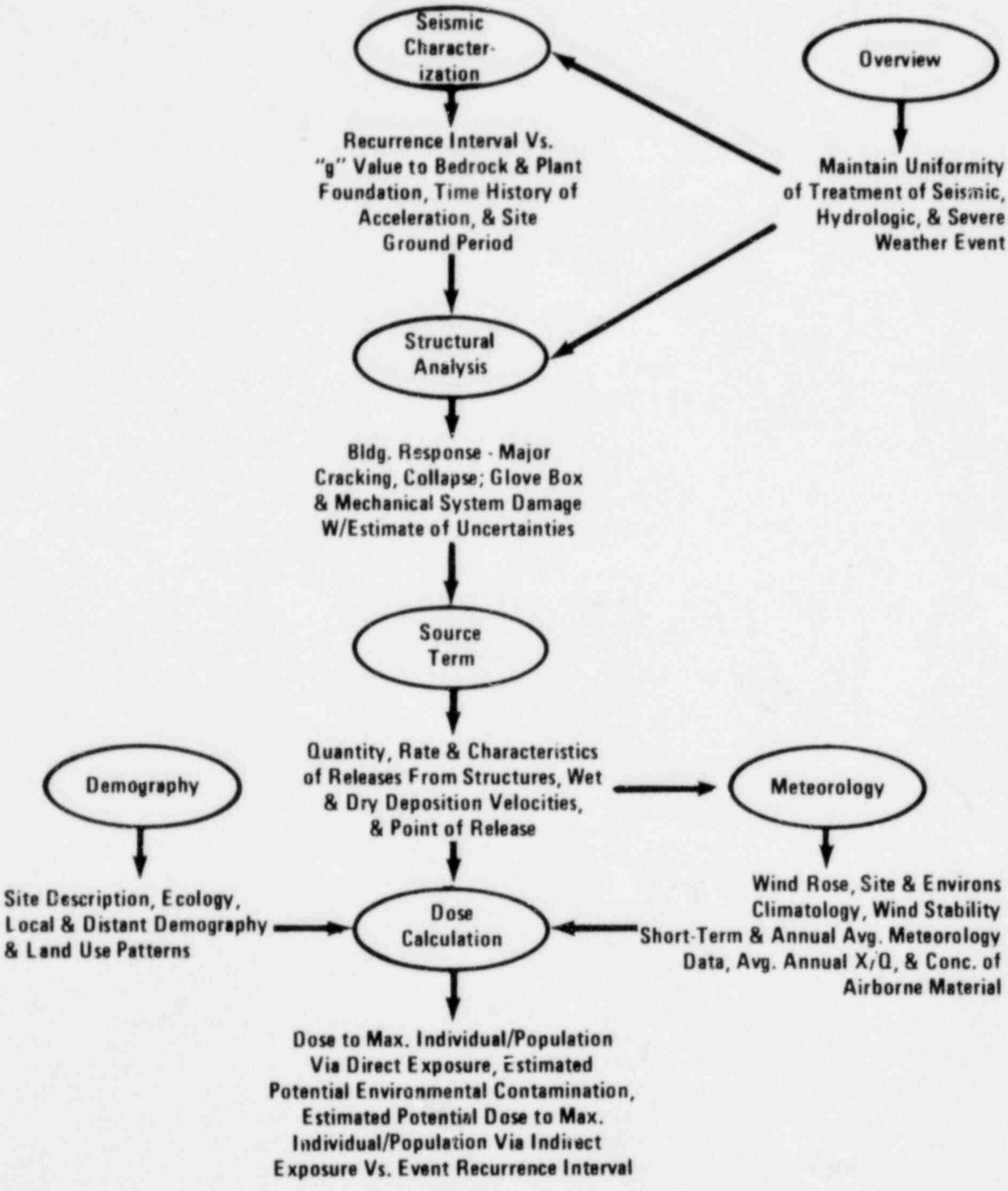


Fig. 2. Flow Diagram for Seismic Aspects of Analysis of the Effects of Abnormal Natural Phenomena on Operating Plutonium Fabrication Facilities.

This analysis is a part of both the safety assessment and the environmental review that normally precedes a licensing action. This is consistent with both Part 51 and Sections 10 CFR 70.22 and 10 CFR 70.23 of the regulations that establish procedures and criteria for the issuance of licenses to possess and use SNM. The analysis and results provide a basis for determining the modifications, to the extent practicable, necessary to improve the existing plant's ability to withstand adverse natural phenomena.

2. SITE CHARACTERIZATION

2.1 SEVERE-WEATHER METEOROLOGY[2]

The XN MOFP is located in the southeastern portion of the State of Washington in the Columbia River Valley at about 120 m (400 ft) MSL. It lies on a wedge of land between the Columbia and Yakima Rivers, as shown in Figure 3. The geographical coordinates are 46°22' N Lat. and 119°16' W Long. Both straight-line winds and tornadoes are considered in arriving at accurate wind-hazard probabilities for the site.

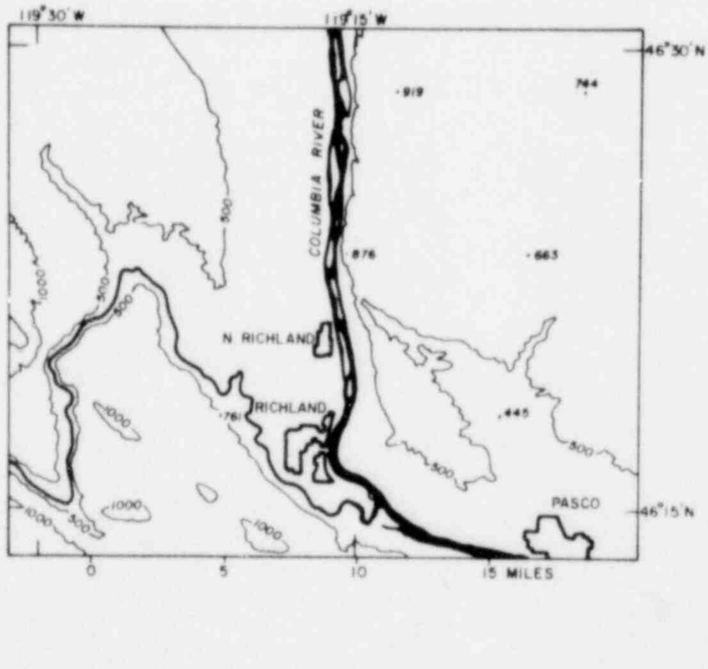


Fig. 3.

Exxon Nuclear Company Site and Vicinity. (Contour lines and elevations of selected locations are given in ft MSL.) (1000 ft = 300 m; 10 mi = 16 km.)

2.1.1 Straight-Line Winds

For straight-line winds, the annual extreme windspeed of the fastest-mile wind for a 26-year period, 1950-1975, is 30 m/s (67 mph) from the southwest, which occurred on 3 November 1958 at Walla Walla. The maximum fastest-mile winds occur in cold months, December through March. Apparently, they are caused by intense cyclones accompanied by strong westerly winds. Both August and September are months in which the fastest-mile wind of the year has not been recorded. The fastest-mile windspeed of 14 m/s (31 mph), or a corresponding peak gust of 17 m/s (39 mph), occurred every year in the period of record. Windspeeds of peak gusts are higher than those of the fastest-mile winds because the duration of the peak gust is considerably shorter than that of the fastest-mile wind. The peak gust is defined as 25% greater than the fastest-mile windspeed. In about half the years of the 26-year period, fastest-mile windspeeds greater than 19 m/s (42 mph) and corresponding peak gusts greater than 24 m/s (53 mph) were recorded.

2.1.2 Tornado Frequencies

During the 26 years, 1950-1975, 21 tornadoes were reported to have occurred within 230 km (144 mi) of the XN MOFP site. The average frequency was 0.8 tornado per year regardless of tornado size or intensity. With a mean damage path of 0.12 km^2 (0.05 mi^2) per tornado, the probability of any point within this radius experiencing any tornado damage is 5.9×10^{-6} per year. Figure 4 shows the distribution of tornadoes vs. distance from the XN MOFP.

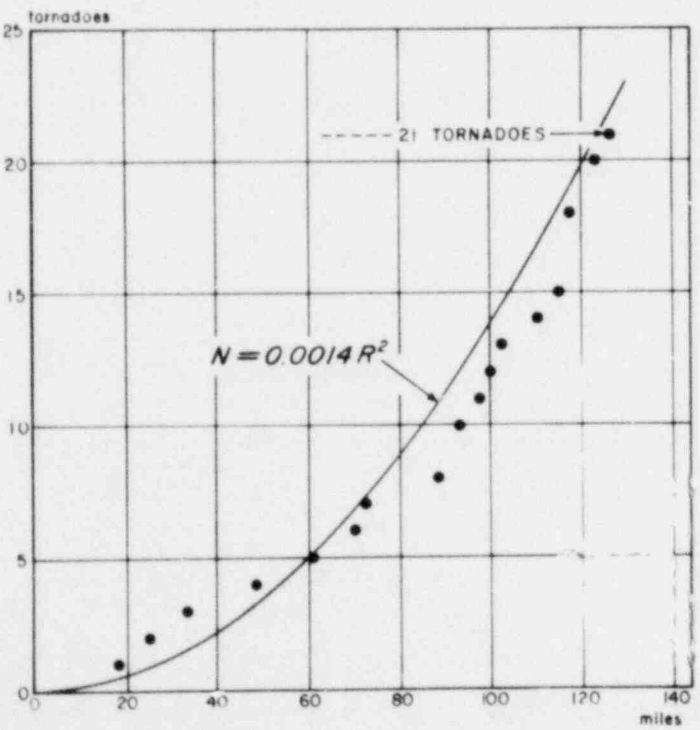


Fig. 4.

Cumulative Number of Tornadoes as a Function of Distance from the Exxon Nuclear Company Site. (Based on 21 tornadoes on the NSSFC tape -- 1950-1975.) (100 mi = 160 km.)

Reported tornadoes since 1950 were used to compute tornado-hazard probability. The recommended probabilities are shown in Figure 5. The figure shows tornado-hazard probabilities as a function of F-scale damage categories converted into windspeeds.

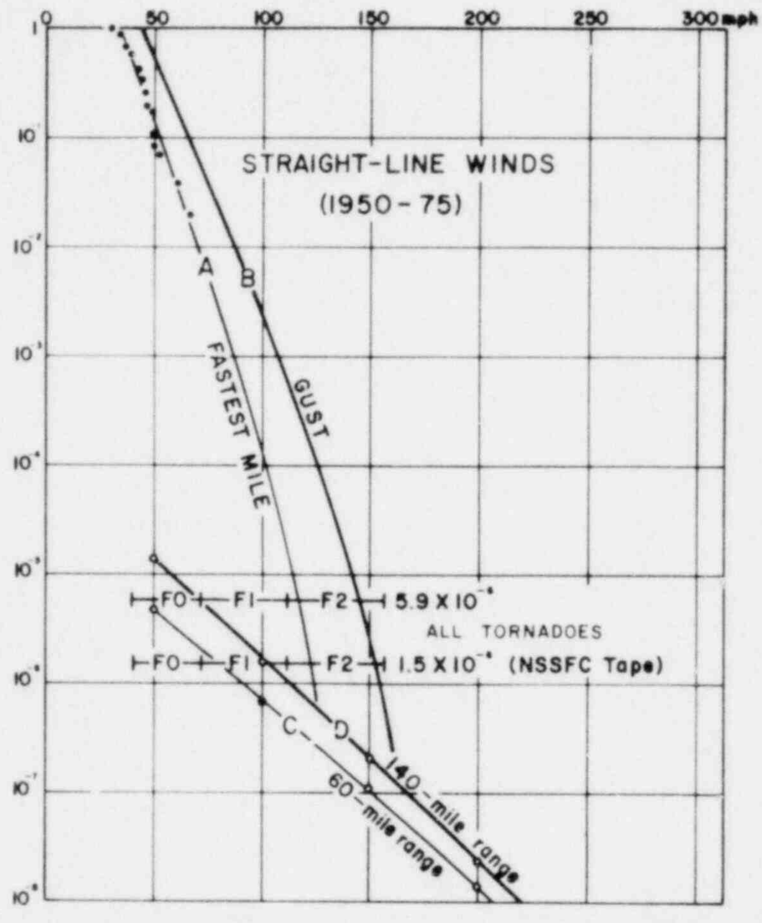


Fig. 5.

Windspeeds of Design-Basis Storms as a Function of Probability of Occurrence at the Site. (Probability per year of 10^{-3} is regarded as high, 10^{-6} as low, and 10^{-7} as remote. Straight-line winds dominate the high- and low-probability cases; tornadoes dominate the remote-probability case. The use of curves B and D combined is recommended.) (100 mph = 45 m/s.)

The Damage Area Per Path Length (DAPPLE) method was used to compute the tornado-hazard probabilities within given distances of the XN MOFP site. Two radii, 100 km (60 mi) and 225 km (140 mi), were selected as having representative homogeneous tornado data for use in calculating the site-specific tornado-hazard probabilities. The 100-km radius envelopes the Walla Walla tornado alley. Expanding the radius to 225 km increases the path length of strong tornadoes due to the inclusion of both the Spokane and Baker alleys, thus increasing the probability of occurence of strong tornadoes. Because the computed probability for 110-m/s (250-mph) windspeeds was one in ten million per year, no computations were performed for windspeeds greater than 130 m/s (300 mph).

2.1.3 Summary and Conclusions

Results of the foregoing computations of windspeed probabilities are summarized in Figure 5, which includes four curves:

(1) Probability of fastest-mile windspeed,
(2) Probability of peak gust (assumed to be 1.25 times the fastest-mile speed),
(3) Tornado probability within the 100-km (60-mi) range, and
(4) Tornado probability within the 225-km (140-mi) range.

The figure reveals that the speeds of straight-line winds are higher than those of tornado winds when the probability is greater than about 10^{-6} per year. Tornadoes become important when the probability decreases below 10^{-7} per year.

2.2 SEISMIC ANALYSIS[3]

A detailed seismic-risk analysis of the XN MOFP site at Richland, Washington has been completed. To ensure credible results, sophisticated but well-accepted techniques were employed in the analysis. The calculational method that was used has been previously applied to safety evaluations of major projects.

The historical seismic record was established after a review of available literature, consultation with operators of local seismic arrays, and examination of appropriate seismic-data bases including those of the World-Wide Network, the University of Washington, the Puget Sound and Hanford Networks, and the Dominion Observatory in British Columbia.

Input to the probabilistic seismic-risk assessment is comprised of earthquake occurrence frequency relations, attenuation functions, and specification of local source regions. Earthquakes in the source region containing the site dominate the risk at the site; thus, particular attention was directed to the validity of the statistics associated with this region. Paramount to the seismic analysis is the specification of attenuation, or decay of peak acceleration with distance from the earthquake. Therefore, an attenuation relation was developed that considered data in the range of 20 to 100 km to estimate the far-field attenuation, data at about 10 km to fix near-field trends, and data within 10 km to establish very-near-field accelerations. These input data were used to calculate, for circular sectors within each source region at the site, the expected annual number of earthquakes producing accelerations greater than a specified value for each source region. The expected numbers were summed for each region and the resulting risk calculated.

Uncertainties in the input were explicitly considered in the analysis. For example, allowance was made for uncertainty in predicting the maximumpossible earthquake in each source zone, the magnitude of the data dispersion about the mean acceleration-attenuation relationship, and the recurrence relation for the source region containing the site.

The results of the risk analysis, which include a Bayesian estimate of the uncertainties, are presented in Figure 6 expressed as return-period accelerations. The best-estimate curve indicates that the XN facility will experience 0.10 g every 600 years and 0.15 g every 2500 years. The bounding curves roughly represent one-standard-deviation confidence limits about the best estimate, reflecting uncertainty in certain portions of the input.

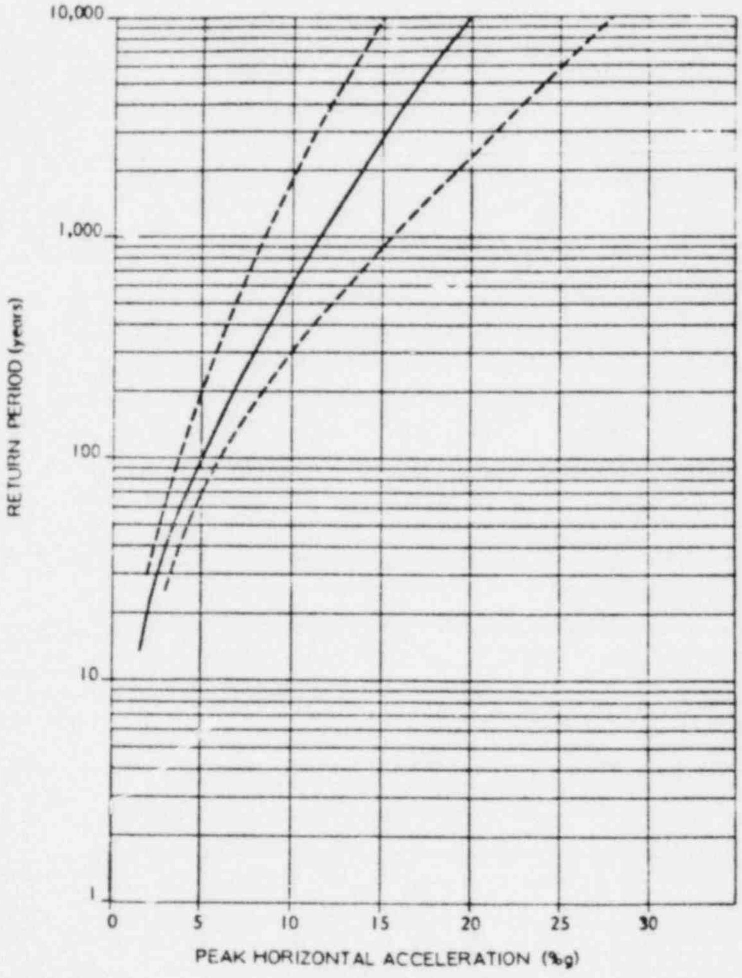


Fig. 6.
Return Period vs. Peak Acceleration for the Exxon Nuclear MOFP.

2.3 HYDROLOGIC ANALYSIS[4]

The XN MOFP site has been reviewed with respect to potential flooding up to and including the probable maximum flood (PMF). A river level of 115.5 m (379 ft) MSL is ascribed to the regulated PMF peak discharge of 2.45 million m^3/min (1.44 million cfs) in the Columbia River at Mile 340 and at the MOFP.

Plant grade is 113.2 m (371.5 ft) MSL; thus, the PMF will flood the site to a depth of 2.3 m (7.5 ft). The recurrence probability for the PMF is about 6×10^{-5}/yr and advance warning of one month of the flood potential can be expected.

Ample time exists to remove essentially all plutonium in actual process to higher elevation. The second floor of the MOFP vault is above PMF stage and has been designed for emergency storage. The vault has been designed and constructed to withstand horizontal hydrostatic pressure resulting from a 3-m (10-ft) head of water (either from within or without the vault) and the vault will not float from vertical uplift due to hydrostatic pressure (USAEC, "Final Environmental Statement Related to Operation of Mixed Oxide Fabrication Plant, Exxon Nuclear Company," Docket No. 70-1257, June 1974). The low likelihood of occurrence of the PMF combined with a long warning time and planned disposition of in-process plutonium dictate against further consideration of radiological risks due to flooding of the MOFP site.

2.4 ECOLOGICAL CHARACTER[5]

2.4.1 Topography and Land Use

The XN MOFP site lies just inside the northern boundary of the City of Richland in the southeastern portion of the State of Washington, and is about 180 km (110 mi) west of the Idaho-Washington border, 290 km (180 mi) south of the Canadian border, and 360 km (225 mi) east of the Pacific Ocean. It is bordered on the north by the 1448-km^2 (559-mi^2) Hanford Reservation. The site consists of the entire southwest quarter of Section 15, Township 10 North, Range 28 East, Willamette Meridian in Benton County. Geographical coordinates are given in Section 2.1.

The site is basically flat, but covered with a series of parallel windswept ridges that extend to the northeast and southwest and range from 1.5 to 10 m (5 to 30 ft) in height. The surface soil of the area supports typical desert vegetation dominated by bitterbrush and sagebrush. The general topographic trend is an upward slope from the site, which is at an elevation of about 113 m (372 ft) MSL, toward the north and northwest.

The site lies on a wedge of land between the Columbia and Yakima Rivers. The Columbia River is about 105 m (340 ft) MSL in the vicinity of the site. About 5 km (3 mi) northeast of the site on the eastern bank of the Columbia is a continuous outcropping, known as the White Bluffs, which vary in elevation between 205 and 280 m (670 and 930 ft) MSL. To the west and south are the Rattlesnake Hills, which reach an elevation of about 1100 m (3600 ft). These features, cut by the Yakima River near Benton City, merge into the Horse Heaven Hills near Kennewick, about 23 km (14 mi) southeast of the site.

The MOFP site is the sole development on a 2500-ha (6100-acr) parcel of land known as the Horn Rapids Triangle. This land was acquired by the USAEC in 1942 as part of the Hanford Reservation and was subsequently annexed to the City of Richland in 1967. The City of Richland owns two-thirds of the land in the Triangle; the remaining third, arranged in a checkerboard pattern, is owned by the Bureau of Land Management. At present, a portion of the Triangle is zoned for light industry and the remainder is zoned agricultural. The 65-ha (160-acr) XN MOFP site lies in the northeastern portion of the 320-ha (800-acr) rectangle, which is zoned industrial. It is planned that roughly 10%-20% of the Triangle will be developed for industry, and that the industrial development will take place to the south and west of the existing MOFP site.

The land use in Benton County within an 8-km (5-mi) radius of the MOFP comprises rural residential southwest of the plant, high-density residential southeast of the plant, and unoccupied desert northeast and northwest of the plant. About 75 ha (180 acr) of land are being farmed for alfalfa east-southeast of the plant, and an additional alfalfa field of about 25 ha (65 acr) lies southeast of the plant. Because the soil is salty, land close to the MOFP is not well suited for cash crops. However, a number of hectares of irrigated pasture supports horses, beef cattle, and a few sheep and milk cows. It is estimated that there are a few hundred head of cattle within 8 km (5 mi) of the plant in Benton County. The closest herd of about 50 beef cattle is located about 5 km (3 mi) southwest of the plant.

That portion of Franklin County lying within an 8-km (5-mi) radius of the MOFP is primarily an agricultural area. The principle crops are alfalfa, hay, and potatoes. There are two commercial dairy herds in this area comprising roughly 150 cows. There are, perhaps, an equal number of beef cattle.

In 1978, the value of crops grown in the Columbia Basin area was about $230 million, and livestock, poultry, and associated products were valued at about $71 million. Much of the area devoted to crops is irrigated and planted with wheat, hay, and other small grains; also potatoes, to a lesser extent vineyard, and orchard crops are grown. There are essentially no forest products harvested in this part of the State.

The major commercial activities in the Tri-Cities area (Richland, Pasco, and Kennewick) are nuclear energy research, development, and application; and agriculture. An industrial park directly east of the XN MOFP site is populated mostly by U.S. Department of Energy contractors employing more than 1200 individuals.

The 1448-km^2 (559-mi^2) Hanford Reservation has served as a national nuclear center since 1943, when construction of the plutonium production reactors was initiated. The reservation is still a center for nuclear energy research and development and some production activities. At present, about 3500 people are employed at Hanford.

In 1967, there were about 60 manufacturing establishments employing about 5300 individuals in Benton and Franklin Counties. Chemical products, food products, and printing and publishing constituted the majority of the manufacturing establishments. A number of these plants are located along the Columbia River, southeast of the Tri-Cities.

The area between the Port of Benton Airport and Hanford Road, about 4 km (2.5 mi) south of the MOFP, is the site of some recent industrial developments. A large food-packaging plant, specializing in the processing of potatoes, has been located there. Additionally, a new airport terminal including a restaurant has been built. Nearby, computer-software manufacturing and office facilities have been built.

2.4.2 Regional Demography

The XN MOFP site is on the northern border of the City of Richland, which, along with Pasco and Kennewick, constitutes a metropolitan area known as the Tri-Cities. The projected population of the Tri-Cities in 1980 is about 78 500. The projected 1980 population distribution within 22.5° sectors is given in Figure 7. Table 1 gives population projections, supplied by the Battelle Pacific Northwest Laboratories, through the year 1990.

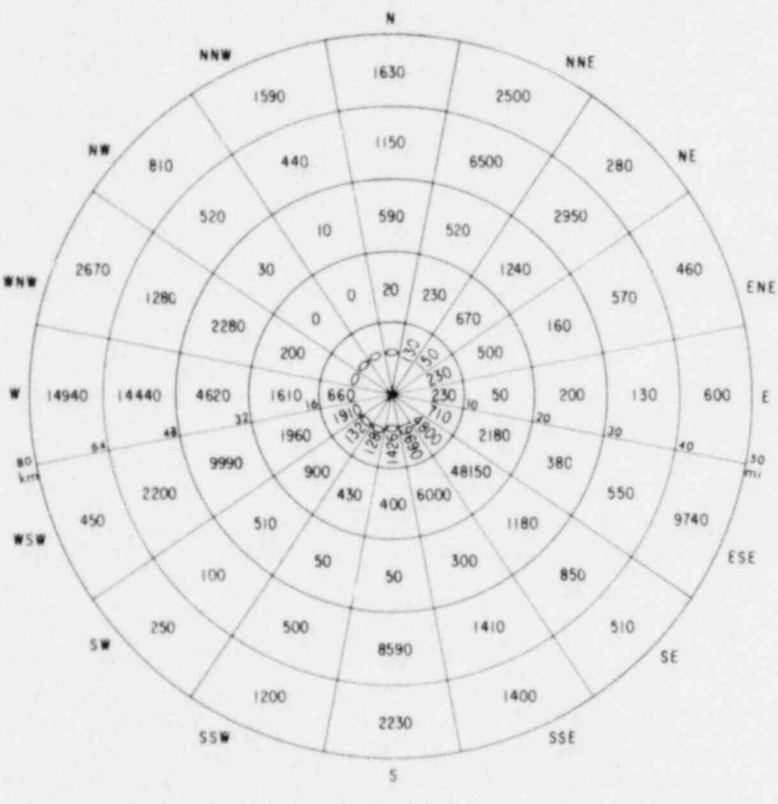


Fig. 7.
Projected 1980 Population Distribution Within 80 km (50 mi) of the Exxon Nuclear MOFP Site.

2.4.3 Flora and Fauna

2.4.3.1 Terrestrial

The XN MOFP site is located in a relatively flat, desert steppe. Sagebrush and antelope bitterbrush predominate among the pristine plant communities in the area. Cheatgrass, brome, and Sandberg bluegrass prevail in the understory. The annual herbage production of dry matter has been estimated to be roughly 100 g/m^2.

Table 1. Population Projections in Annuli Surrounding the Exxon Nuclear MOFP Site

Radius (mi)	*1980*	*1990*
0-10	45 370	54 440
10-20	63 300	67 680
20-30	22 110	27 010
30-40	42 180	55 660
40-50	41 260	47 200
Total	214 220	251 990

Throughout the years, the local vegetation has been disturbed by homesteading, fire, and grazing, leaving areas exposed to wind erosion and dune formation. As a result, vegetation such as Russian thistle, mustard, and rabbitbrush have encroached on the native flora. A few barely surviving locust trees testify to the homesteading history. A severe wildfire in 1970 encompassed an area of about 7700 ha (19 000 acr) of the Hanford Reservation north of the MOFP site, but it did not spread into the Horn Rapids Triangle. The fire destroyed a majority of the established shrubs, forbs, and grasses in its path. Initial revegetation of disturbed areas is dominated by annual grasses and forbs, such as cheatgrass, with little or no perennial plant recovery.

The most abundant mammals in the vicinity of the site are pocket mice and deermice. Jackrabbits and coyotes are also scattered throughout the area. By far the most abundant mammal is the pocket mouse, which subsists largely on the seeds of grasses. Larger and more mobile mammals, such as mule deer, prefer the shores and islands of the Columbia River, with limited use of the more barren, inland steppe. However, in the fall and winter the mule deer may wander inland to forage on the shoots of cheatgrass and the leaves and smaller twigs of bitterbrush. In the summer, the deer are frequently found in the distant Rattlesnake Hills.

The most abundant reptile is the side-blotched lizard. Snakes, especially the gopher snake and the Pacific rattlesnake, are occasionally encountered.

Birds are not abundant in the sagebrush-bitterbrush type of vegetation. The most common resident birds are meadowlarks and horned larks. The loggerhead shrike, although not an abundant bird, is conspicuous. During periods when food and cover are adequate, game birds, such as the chukar partridge, quail, ringneck pheasant, and mourning dove may be found in the vicinity of the site. The region is used as a hunting ground for birds of prey, such as the marsh hawk and golden eagle in the winter and the burrowing owl and Swainson's hawk in the summer. The bald eagle is occasionally observed in the area, and the southern bald eagle is the only wildlife species in the vicinity that is on the list of endangered species. During the fall and winter, migrating flocks of Canada geese forage on the cheatgrass and alfalfa in the vicinity of the site.

2.4.3.2 Aquatic

Waterfowl are of major importance in the area. About 200 pairs of Canada geese reside on the river islands in the vicinity of the site, and produce an average of roughly 700 goslings annually. An estimated 100 pairs of ducks also rest on these islands. Two islands, one near Ringold and another near Coyote Rapids, are used as rookeries by colonies of California and ring-billed gulls. About 6000 nesting pairs produce 10 000 to 20 000 young annually.

2.4.4 Climatology and Meteorology

2.4.4.1 Climatology

The climate of the Hanford area is relatively mild and dry and is controlled in part by the seasonal and synoptic variations in the strength and position of the Pacific high-pressure center. The area has the characteristics of both maritime and continental climates, modified by the Cascades and Rocky Mountains. The maritime influence of the ocean is strongest in winter due to the prevailing westerlies. Occasionally, very cold Canadian air enters the region from the east and north, resulting in very cold conditions. In summer, airflow from the Pacific is reduced, and the area is subject to clear skies, high temperatures, and low humidities during the afternoons, but the clear, dry air permits rapid radiation cooling after sundown, producing cool nights. Rainfall in summer is very light. Winters are cloudy and relative humidities are high, although total precipitation is quite low. Wind direction is strongly influenced by the terrain; windspeeds are moderate, with occasional calms and gales. The prevailing wind direction is southeast.

Unless otherwise indicated, the climatological data used in this summary were collected at the Hanford Meteorological Station (HMS), which is located about 32 km (20 mi) northwest of the site. Temperature and precipitation records were collected by a U.S. Weather Bureau cooperative observer from 1912 to 1943 at a site about 16 km (10 mi) ENE of the HMS. Hourly observations at the HMS are continuous since December 1944. (There are small gaps in the record in 1943 and 1944.)

Thunderstorms are quite rare, averaging 11 days per year, mostly in summer. Hail has been observed on 16 days in 12 years of record. Dust has been recorded at the HMS on 2% of all days of observation (84 days in 14 years of record), with a distinct maximum frequency during the summer months.

Surface winds in the area are controlled in part by local topographic features. The long-term (1945-1970) average annual windspeed at 15.2 m at the HMS site is 3.4 m/s (7.6 mph). Monthly averages vary from 2.7 m/s (6.0 mph) in November to 4.0 m/s (9.0 mph) in June. This unusual annual cycle of windspeeds is caused by strong drainage winds from the nearby mountain ridges during clear summer evenings and nights. The prevailing wind direction for all months at HMS is either NW or WNW, reflecting drainage winds at night. Winds from the W, WNW, and NW occur 42.4% of the time, compared to only 10.8% from the SSW, SW, and WSW. Strong winds from the NW sectors are relatively rare; 88.9% of all winds 13.9 m/s (31 mph) or faster come from the SSW, SW, and WSW, whereas only 6.8% are associated with flow from the W, WNW, and NW.

The strongest wind ever observed at Hanford occurred on 11 January 1972. A peak gust of 35.8 m/s (80 mph) was recorded at the 15.2-m height of the HMS meteorological tower; the average windspeed for the hour ending at 0900 PST was 22.8 m/s (51 mph).

2.4.4.2 Dispersion Meteorology

The average annual relative-concentration (χ/Q) and relative-deposition (D/Q) values for the XN facility were calculated using one year (April 1975-March 1976) of wind-velocity and stability data collected at the Hanford-2 reactor site and the XOQDOQ model developed by NRC. Table 2 provides χ/Q values at selected distances for 16 directions from the plant for continuous ground-level releases. The model includes an allowance for plume meander during light winds and stable atmospheric conditions.

The accident-case (short-term, up to 2-h) relative concentrations have been computed, using the NRC accident dispersion model, and are given in Tables 3 and 4. The model is direction-dependent and calculates the χ/Q values out to a distance of 5.0 km (3.1 mi) immediately following the natural destructive event. The calculation computes the χ/Q values that are exceeded 5% and 50% of the time as a function of distance and direction. This model also includes allowance for plume meander during light winds and stable atmospheric conditions.

Most dispersion models are applicable only to continuous releases during periods of light to moderate steady-state winds, with numerous experiments averaged to yield dispersion parameters. Concentrations and dimensions of a particulate cloud have been calculated for conditions when the release time is short, the windspeed is very high, and the time the particulate cloud travels across the area is very short.

The values of the dispersion parameters were extrapolated from values for unstable conditions and puff releases. As is standard for instantaneous releases, it is assumed that $\sigma_x = \sigma_y$. The release height for this calculation is assumed to be 8 to 10 m (25 to 30 ft). It was arbitrarily assumed that the centerpoint of the cloud of particulates released from the facility traveled

Table 2. Annual Average Relative Concentrations (s/m^3) Based on Continuous Ground-Level Release and One Year of Hanford-2 Meteorological Data, Exxon Facility, Richland, Washington

	Distance (mi)						
Sector	*0.5*	*1.0*	*2.0*	*4.0*	*10.0*	*25.0*	*50.0*
N	6.1-6[a]	1.9-6	6.5-7	2.4-7	6.7-8	2.1-8	8.3-9
NNE	5.1-6	1.6-6	6.3-7	1.9-7	5.4-8	1.6-8	6.4-9
NE	3.9-6	1.2-6	4.2-7	1.5-7	4.2-8	1.2-8	5.1-9
ENE	3.6-6	1.1-6	3.8-7	1.4-7	3.9-8	1.2-8	4.7-9
E	3.4-6	1.0-6	3.6-7	1.3-7	3.6-8	1.1-8	4.4-9
ESE	5.9-6	1.8-6	6.2-7	2.3-7	6.3-8	1.9-8	7.5-9
SE	7.6-6	2.4-6	8.1-7	3.0-7	8.4-8	2.5-8	1.0-8
SSE	7.3-6	2.3-6	7.8-7	2.9-7	8.2-8	2.5-8	1.0-8
S	5.8-6	1.8-6	6.3-7	2.3-7	6.7-8	2.0-8	8.6-9
SSW	4.8-6	1.5-6	5.2-7	1.9-7	5.6-8	1.7-8	1.2-9
SW	4.2-6	1.3-6	4.6-7	1.7-7	5.1-8	1.6-8	6.6-9
WSW	3.2-6	1.0-6	3.5-7	1.3-7	3.7-8	1.1-8	4.8-9
W	2.8-6	8.8-7	3.1-7	1.1-7	3.3-8	1.0-8	4.2-9
WNW	2.9-6	8.9-7	3.1-7	1.1-7	3.2-8	9.7-9	4.0-9
NW	3.6-6	1.1-6	3.8-7	1.4-7	3.9-8	1.2-8	4.8-9
NNW	5.7-6	1.8-6	6.0-7	2.2-7	6.2-8	1.9-8	7.6-9

[a]*Scientific notation: 6.1-6 =* 6.1×10^{-6}.

downwind with the gust-front with no deposition at speeds of 42.5 m/s (95 mph) and 67.0 m/s (150 mph). Centerline-centerpoint concentrations are given in Table 5.

To determine the area impacted by the particulate cloud and the time it takes to pass, concentration limits are set at two-sigma, or 0.135, of the centerline-centerpoint concentration. The dimensions of a particulate cloud at a point and time of its passage are given in Table 6.

Table 3. Five Percentile Short-Term (2-h) Relative Concentrations (s/m^3) for the Exxon Facility, Richland, Washington

	Distance in Miles (meters)				
Sector	*0.09 (145)*	*0.31 (500)*	*0.62 (1000)*	*1.24 (2000)*	*3.1 (5000)*
N	9.6-3[a]	1.5-3	5.6-4	2.0-4	7.5-5
NNE	8.5-3	7.6-4	2.8-4	1.8-4	6.4-5
NE	9.4-3	6.5-4	2.3-4	2.0-4	7.2-5
ENE	8.4-3	6.9-4	2.5-4	1.8-4	6.6-5
E	7.9-3	6.2-4	2.2-4	1.7-4	6.1-5
ESE	1.1-2	7.7-4	2.8-4	2.2-4	8.1-5
SE	1.4-2	1.0-3	3.8-4	3.0-4	1.0-4
SSE	1.8-2	8.1-4	3.0-4	2.7-4	1.3-4
S	1.9-2	7.0-4	3.2-4	2.2-4	1.4-4
SSW	1.9-2	6.8-4	3.0-4	2.1-4	1.4-4
SW	2.0-2	6.6-4	2.4-4	2.3-4	1.5-4
WSW	1.3-2	5.8-4	2.1-4	1.8-4	1.0-4
W	1.1-2	5.5-4	2.3-4	1.8-4	8.7-5
WNW	9.1-3	5.0-4	2.3-4	1.8-4	7.1-5
NW	8.9-3	6.0-4	2.2-4	1.9-4	6.9-5
NNW	9.3-3	1.2-3	4.3-4	2.0-4	7.3-5

[a]*Scientific notation:* $9.6\text{-}3 = 9.6 \times 10^{-3}$.

Table 4. Fifty Percentile Short-Term (2-h) Relative Concentrations (s/m^3) for the Exxon Facility, Richland, Washington

	Distance in Miles (meters)				
Sector	*0.09 (145)*	*0.31 (500)*	*0.62 (1000)*	*1.24 (2000)*	*3.1 (5000)*
N	8.4-4[a]	1.4-4	4.7-5	1.8-5	4.8-6
NNE	7.0-4	9.8-5	3.3-5	1.1-5	3.0-6
NE	8.0-4	9.9-5	3.3-5	1.2-5	3.5-6
ENE	8.9-4	1.3-4	4.7-5	1.8-5	4.8-6
E	8.6-4	1.4-4	4.7-5	1.8-5	4.8-6
ESE	8.6-4	1.4-4	4.7-5	1.8-5	4.8-6
SE	8.6-4	1.6-4	4.7-5	2.0-5	5.0-6
SSE	1.2-3	1.6-4	5.0-5	2.0-5	6.0-6
S	1.2-3	1.4-4	4.9-5	2.0-5	6.0-6
SSW	1.2-3	1.4-4	4.9-5	2.0-5	6.0-6
SW	1.9-3	2.0-4	7.0-5	3.3-5	1.3-5
WSW	1.3-3	1.8-4	6.5-5	2.8-5	9.0-6
W	1.3-3	1.6-4	6.5-5	2.9-5	8.0-6
WNW	1.3-3	1.5-4	5.2-5	2.1-5	7.0-6
NW	1.2-3	1.5-4	4.8-5	2.0-5	6.0-6
NNW	1.2-3	1.7-4	5.5-5	2.0-5	6.5-6

[a] *Scientific notation:* $8.4\text{-}4 = 8.4 \times 10^{-4}$.

Table 5. Centerline-Centerpoint Concentrations Resulting from Straight-Line Wind Dispersion of a 1-kg Source (42.5 m/s and 67.0 m/s)

Distance (km)	*Concentration ($\mu g/m^3$)*
0.8	381
2.4	23
4.0	6
5.6	3
7.2	2
12.1	0.4
24.1	0.1
40.2	0.02
56.3	0.01
72.4	0.004
80.0	0.003

Table 6. Dimensions of a Particulate Cloud at a Point and Time of Passage of the Cloud

		Time (s)	
Distance (km)	*y,x (m)*	*42.5 m/s*	*67.0 m/s*
0.8	140	7	4
2.4	380	18	11
4.0	610	29	18
5.6	820	39	24
7.2	1 025	48	31
12.1	1 700	80	51
24 1	3 200	151	96
40.2	5 200	245	155
56.3	6 800	320	203
72.4	8 400	395	251
80	10 300	485	307

3. STRUCTURAL ANALYSIS

The analysis of the response of structures that house plutonium-handling operations at the XN MOFP site was done in several steps. The features within the facility, the failure of which may have a significant effect on the quantity of material released, were identified for analysts who were involved in assessing the structural responses of the plant and its equipment. The present structural condition was documented to provide the engineering basis for subsequent structural evaluations. Finally, the structural response of the building and its components was expressed in terms of threshold values of windspeed and ground-shaking levels necessary to produce postulated damage. The following sections summarize the above steps.

3.1 AREAS OF CONCERN[6]

The consequence of concern in this study is the generation and release of an aerosol composed of particles of about 5-μm aerodynamic equivalent diameter (AED).* In the XN plant finely divided PuO_2 powders are starting materials. Powders are of more concern because, under comparable conditions, less work is required to aerosolize a highly subdivided material than is required for bulk solids and liquids. The areas of principal concern are glove boxes where large quantities of Pu-bearing powder are free in the glovebox atmosphere at some point in the process (i.e. during pouring, weighing, sieving, etc.).

The specific features that warrant individual attention at each location where dispersible plutonium compounds are held in significant quantities were identified, as were other features that may contribute to plutonium release through interaction or secondary effects.

3.2 STRUCTURAL-CONDITION DOCUMENTATION[7]

The purpose of this effort was to document the present condition of the XN facility to provide the engineering basis for subsequent structural evaluations. The documents related to the original design and construction of the building structure and critical equipment components were surveyed, including the following:

(1) Construction drawings and specifications,
(2) Design computations,
(3) Codes and standards in effect at the time of design,
(4) Soils reports and other relevant soils data, and
(5) Test data and/or material specifications on materials used in construction.

**A particle exhibiting the aerodynamic behavior of a unit-density sphere of the stated size.*

It was necessary for structural engineers to conduct an extensive site inspection to field check the construction plans and to obtain details on connections and other information that were not shown on the plans.

The areas that were structurally evaluated were those identified as areas of concern. However, the areas adjacent to those listed were investigated to identify their effects on the critical areas.

The results of the construction-data review, facility inspection, and structural-data organization were documented in a form that was used in subsequent evaluations. The following information was given in the report and shown on schematic plans:

(1) Line drawings showing plans and sections;
(2) Connection details between building elements;
(3) Member properties;
(4) Masses (based on a detailed weight takedown);
(5) Construction details;
(6) Equipment locations, support details, and connecting pipes, ductwork, etc.;
(7) Recommendations for materials testing and/or additional probing inspections; and
(8) Summary of soils data.

3.3 RESPONSE OF STRUCTURES TO NATURAL PHENOMENA

3.3.1 Wind Hazard[8]

Damage scenarios for selected probabilities of occurrence of windspeed were established from the threshold values of windspeed for various calculated failure modes. Four damage scenarios for selected windspeed values are presented to establish a trend of increasing damage with diminishing probability of occurrence. The specific windspeed values chosen provide a gradation from minimum damage to extensive damage to the areas of concern in the XN MOFP facility. The windspeed range associated with each damage scenario is based on the variability in the damage pattern. These windspeed ranges may be used to provide error bands on potential damage to the facility.

3.3.1.1 Damage Scenario for a Nominal Windspeed of 42.5 m/s (95 mph)

Probability of Occurrence

Probability of 6×10^{-3} per year.

Windspeed Range

Range of 37 to 49 m/s (83 to 109 mph) based on failure of door.

Mixed-Oxide Preparation Area

The small door at the southeast corner of the building could fail outward. Wind circulation in the vicinity of the failed door could damage the exterior filters on glove box 4a. The other glove boxes or filters in the mixed-oxide preparation area are not likely to sustain damage. No significant missile-induced damage is expected at this windspeed.

Cold-Lab Area

No damage of consequence.

Mass-Spec Area

No damage of consequence.

Poison-Rod Fab Area

No damage of consequence.

Vault

No damage of consequence.

3.3.1.2 Damage Scenario for a Nominal Windspeed of 67 m/s (150 mph)

Probability of Occurrence

Probability of 3×10^{-6} per year.

Windspeed Range

Range of 59 to 75 m/s (133 to 169 mph) based on failure of doors.

Mixed-Oxide Preparation Area

Failure of the small door in the southeast corner of the building would permit some wind circulation in the area. Because the opening is small, only the glove box closest to the door is likely to be affected. The filter outside the glove box is likely to be damaged and the glove box could be perforated by a small wooden plank.

Cold-Lab Area

No damage of consequence.

Mass-Spec Area

No damage of consequence.

Poison-Rod Fab Area

The outside door in the south wall could fail allowing wind to circulate in that area of the building. The interior wall could collapse in the poison-rod fab area, causing damage to equipment located within 5 m (15 ft) of the wall. The best estimate of the number of pieces of equipment crushed is one-third as the median value, with upper- and lower-bound values being one-half and one-fifth, respectively.

Vault

No damage of consequence.

3.3.1.3 Damage Scenario for a Nominal Windspeed of 85 m/s (190 mph)

Probability of Occurrence

Probability of 6×10^{-8} per year.

Windspeed Range

Range of 76 to 95 m/s (170 to 212 mph) based on failure of walls.

Mixed-Oxide Preparation Area

A 6-m (20-ft) section of the south wall at the southeast corner can fail. This failure will cause a 6-m (20-ft) section of the roof to collapse. The roof joists and metal deck are likely to remain together and the north end of the roof may not slip from its support. The best estimate is that three-fourths of the glove boxes in this 6-m (20-ft) -wide section close to the east wall will be crushed; upper- and lower-bound values are all and one-half, respectively. In the remaining area, one-half the glove boxes may be perforated by debris; upper- and lower-bound values are three-fourths and one-third, respectively.

Cold-Lab Area

No damage of consequence because it is distant from the wall opening.

Mass-Spec Area

No damage of consequence because it is distant from the wall opening.

Poison-Rod Fab Area

Portions of the west and east interior walls are likely to collapse and could cause damage to equipment located within 5 m (15 ft) of the walls. The best estimate of the number of pieces of equipment crushed is one-half as the median value, with upper- and lower-bound values being three-fourths and one-third, respectively.

Vault

No damage of consequence.

3.3.1.4 Damage Scenario for a Nominal Windspeed of 112 m/s (250 mph)

Probability of Occurrence

Probability of 3×10^{-9} per year.

Windspeed Range

Range of 89 to 139 m/s (200 to 312 mph) based on collapse of walls.

Mixed-Oxide Preparation Area

Portions of the outside walls collapse. The interior wall between the poison-rod fab area and the mixed-oxide preparation area collapses allowing wind to circulate through the building. The roof collapses along with the inplane truss. All glove boxes and filters are likely to be crushed. The roof deck and the inplane truss cover the glove boxes and prevent some material from being blown from the building.

Cold-Lab Area

Interior walls collapse. The roof and the inplane roof truss collapse. The 25-cm (10-in) concrete wall is likely to remain standing. All glove boxes and filters will be crushed. The roof deck is likely to cover the crushed boxes and prevent some material from being blown from the building.

Mass-Spec Area

Damage is similar to that in the cold-lab area.

Poison-Rod Fab Area

The south wall collapses. The roof and inplane roof truss collapse, crushing all glove boxes in the area. The roof deck, for the most part, is likely to remain intact with the roof joists. This provides a covering over the boxes and prevents some of the material from being blown away.

Vault

No damage of consequence.

3.3.2 Seismic Hazard[9]

The purpose of this analysis is to evaluate the structural capacity of those building structures and critical equipment components that could potentially release hazardous chemicals into the environment from the MOFP facility as a result of damage or failure during an earthquake.

The effort focused primarily on the building structure as representing the final confinement barrier for release of hazardous chemicals. The designated process equipment, such as glove boxes and exhaust ducting, were also evaluated for structural capacity. The loss of primary confinement due to direct glovebox failure or from indirect glovebox damage caused by interaction with adjacent equipment and connections is identified as the ultimate mode of release resulting from extreme earthquake hazard. The structural capacity of the building and associated equipment systems as related to the ultimate mode of release are addressed in this summary, but operational and functional aspects of the facility are not addressed.

The MOFP is a windowless one-story high-bay (with attached two-story office area) precast/cast-in-place concrete building constructed in 1971. The building has a length-to-width ratio of 1.14:1. Fuel manufacturing and processing are conducted within the one-story high-bay area, which is separated from the two-story office and locker areas of the building by a 25-cm (10-in) reinforced-concrete wall. The second-story floor area is a concrete/metal-deck composite slab supported by beam and column framing. A one-story high-bay reinforced-concrete vault, with a wall thickness of at least 45 cm (18 in), is located in the northeast corner of the building. The building roof is insulated metal decking supported on steel open-web joists.

The seismic lateral-force resistance of the MOFP building structure is provided by a shear-wall box system tied together by a steel roof diaphragm and a redundant horizontal roof truss. The diaphragm consists of a steel deck welded to the main roof beams and connected to shear walls by welds to the peripheral steel chord members, which are anchored to the walls at the roof line. The horizontal roof truss is a unique structural feature of the MOFP building. This structure is external from (above) the deck diaphragm and does not support any roof dead load. The function of this truss is to act as a redundant roof diaphragm that ties the high-bay area walls together and allows an alternate path for shear transfer between wall elements. The building structure may be considered to resist seismic forces as two independent systems; one for each major building direction, north-south and east-west. Because of the diaphragm and truss flexibility and general configuration of the MOFP building with regard to mass and structural rigidity, torsional coupling of the two systems will be negligible. For both systems, inertia of the roof and the tributary wall is transferred to the active panel shear walls by the diaphragm and roof truss. The exterior walls are precast tilt-up reinforced-concrete panels, which are joined by cast-in-place columns between each panel. A cast-in-place roof-edge beam joins the columns and panels around the entire periphery of the building. Panel reinforcing steel is extended and hooked within the column and beam reinforcing cages. Each panel is placed upon the footing walls with a mortar bed. No positive connection exists between the footing wall and each panel. Shear transfer is effected through panel friction and dowels with shear keys at each column footing. The inplane wall seismic shear forces are transferred to grade through the combination wall and spread concrete footings. Floor slabs are supported at grade without ties to the wall footings.

The evaluation of the structure, in terms of ground-acceleration capacity, used equivalent finite-element dynamic models to assess the component stress levels associated with a given level of ground motion. The controlling collapse capacities (1.37 to 1.80 g) were all associated with loss of diaphragm and truss support for the panel walls. The values of ground-acceleration capacity were based on the uncoupled response of the structure in each principal direction as determined from the independent dynamic models. The actual behavior of the structure for ground accelerations in excess of 1.3 g will involve joint slippage at the panel/foundation-wall interface. Beyond this level of ground acceleration, the two lateral-force systems will become coupled due to torsional effects. However, further refinement of the MOFP collapse capacity, to establish a precise value within the range of 1.3 to 1.8 g, appears to be unwarranted when the associated return periods ($> 10^5$ yr) are taken into account. Thus, for purposes of the natural-hazard study, the median collapse capacity of the MOFP building may be estimated by assuming the median seismic capacity of the north-south force-resisting system (1.37 g) as the controlling seismic capacity. Based on the statistical uncertainty-bound analysis, the estimated standard-deviation upper- and lower-bound seismic capacities are 1.09 g and 1.72 g, respectively.

The interior partitions and secondary architectural systems in the critical areas do not sustain major damage prior to diaphragm failure and, therefore, are not themselves critical in terms of release of hazardous material. The equipment items exhibit a higher structural capacity than the structural system and are generally affected only by total facility collapse or by the large relative displacements between the floor and the roof that occur just prior to collapse.

4. SEVERE-WEATHER DISPERSION

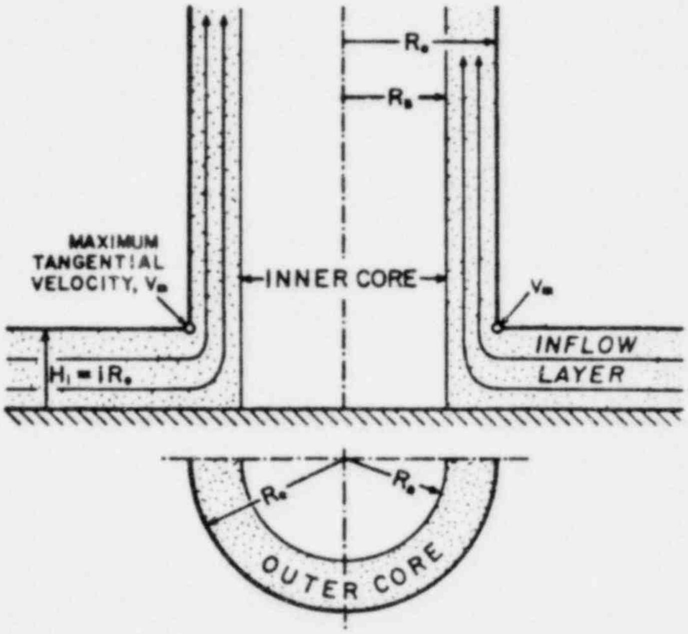
4.1 TORNADO STRUCTURE[10]

A model has been developed to represent the windspeed and pressure distribution in and around a tornado vortex. The model tornado DBT-77 was developed to provide more realistic estimations of tornadic features than has been available in earlier models. Input data is derived from vast experience with actual tornado-damage estimates, and represents the state-of-the-art in tornado modeling.

The model incorporates an axially symmetric vortex with a cylindrical core. The inner core rotates like solid discs stacked in a cylinder, whereas the outer core has air currents spiraling upward. A shallow layer, directly above the earth's surface, provides inflow air to the vortex. A schematic diagram of DBT-77 is shown in Figure 8. The depth of the inflow layer is related to the radius of the outer core; large tornadoes have larger inner cores and deeper inflow layers than do small tornadoes.

Fig. 8.

Schematic Diagram of Tornado Model DBT-77. (In this simplified model, the core is divided into inner and outer portions. Vertical motions are concentrated in the outer core and the inner core is assumed to rotate like a stack of solid discs in a cylinder.)



The horizontal windspeed of a tornado is the vector sum of tangential, radial, and translational velocities. Tangential velocity is treated as a function of both height and radius, whereas radial velocity varies with the crossing angle of inflow air relative to the vortex streamlines. The crossing angle is assumed to be constant at a given height, with airflow outside the core following logarithmic spirals toward the vortex center. Vertical velocity is a function of divergence in the air column and varies with height. It reaches a maximum at the top of the inflow layer. Vertical accelerations in the inflow layer vary with radius and core size. For a given tangential velocity, small vortices induce greater vertical accelerations than do large ones. Furthermore, the height at which the maximum vertical acceleration exists decreases with core radius. As a result, it is postulated that small vortices are capable of picking up objects near the ground. The "damage height" of a tornado is the height throughout which maximum damage caused by a given vortex will occur. Due to variations in inflow-layer depths of tornadoes with different core sizes, tall objects are most affected by large-core tornadoes, whereas objects near the ground receive the full impact of small-core tornadoes.

Extremely large pressure gradients must exist inside the tornado vortex to generate the large vertical velocities computed with the model. Because buoyancy alone is incapable of inducing such accelerations, nonhydrostatic-pressure gradients must be present. Nonhydrostatic pressure is assumed to be a function only of height and radial velocity. What causes nonhydrostatic-pressure gradients is poorly understood. In this model, the inertia of the inflow air is assumed to act as a radial compressor to induce nonhydrostatic pressures in the outer core. Thus, air moves against the horizontal pressure gradients, from low pressure to high pressure, while losing kinetic energy. Total pressure is the pressure generated by the swirling motions of the vortex added to the nonhydrostatic pressure. The total-pressure field is represented in Figure 9.

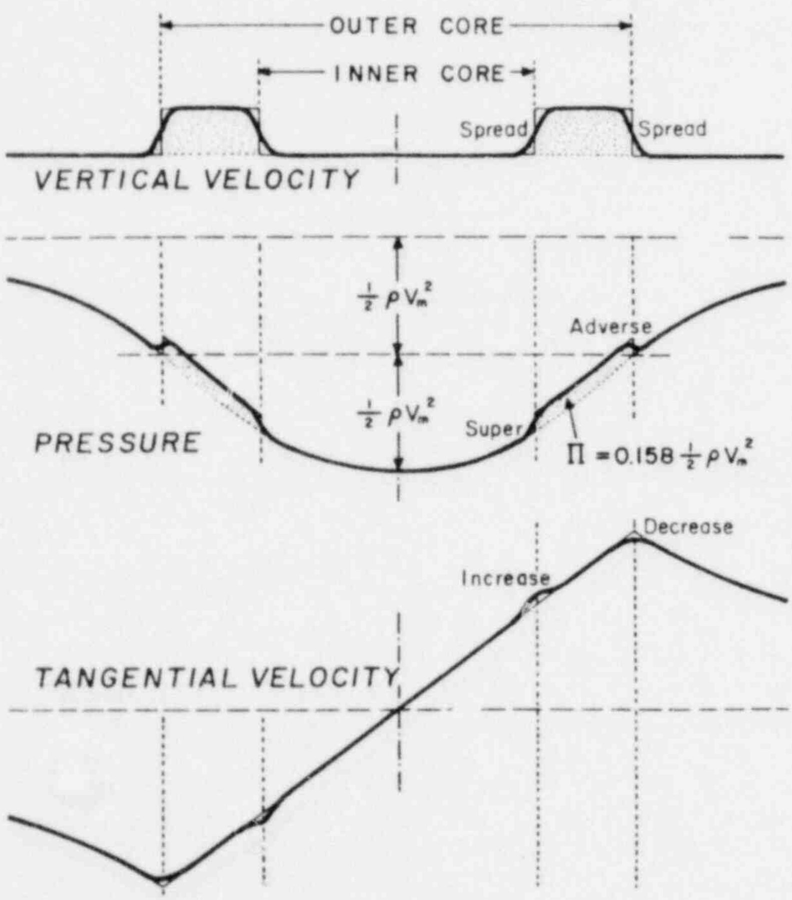


Fig. 9.

Pressure Field Inside the Model Tornado. (Pressure jumps and vertical-velocity changes characterize the boundaries of the outer core. Similar observations have been noted in data inferred from real tornadoes.)

Meteorological parameters such as pressure, windspeed, and temperature vary with time as a tornado passes over a fixed point. In particular, pressure tendencies vary significantly with the ratio of core size to translational velocity. A fast-moving small-core tornado induces extremely large pressure changes.

The total mass of air transported upward by a tornado is proportional to the maximum tangential velocity and to the square of the core radius. A "mini-tornado" (V_{max} = 25 m/s or 56 mph and R = 10 m or 33 ft) may transport about 3 Mg/s (about 3 ton/s) of air, whereas a "maxi-tornado" (V_{max} = 100 m/s or 220 mph and R = 150 m or 500 ft) may transport about 2100 Mg/s (about 2320 ton/s) of air.

The model DBT-77 was developed to provide a mathematical representation of the motions associated with a tornado. The equations appear to simulate actual tornado features well. The model is used as input to predict the ultimate fate of particles entrained by a tornado.

4.2 DISPERSION IN A TORNADIC STORM[11]

A three-dimensional numerical model is used to calculate the dispersion of small particulates in a tornadic storm. The model is designed to allow various meteorological parameters to be updated as more precise information becomes available. The three-dimensional transient equation of concentration transport is solved by a quasi-Lagrangian method of second moments in an Eulerian mesh centered over the assumed trajectory of the storm.

The horizontal-wind field varies with height over a one-hour period after the XN MOFP is breached. The updrafts and downdrafts associated with the tornadic storm are calculated from initial empirical estimates,[10] and then advected with the storm. The horizontal rotational-wind field within the storm cell is also advected with the vertical-velocity field. As the storm cell spreads horizontally, the wind field within the storm cell spreads accordingly.

Because of the lack of precise information regarding turbulence within severe storms, the turbulence-diffusion coefficients are obtained from empirical estimates. These estimates are based on sparse data measured within storms and on theoretical equations appearing in the literature.

Scavenging is calculated as a sink term to the governing equation. Washout scavenging below the cloud base acts on large particles; rainout scavenging acts on small particles within the cloud. However, limited knowledge of scavenging in severe storms necessitates the use of a single general expression based on rainfall rates, droplet size, and 100% collision efficiency. The effect of topography downwind of the XN MOFP is introduced through specification of roughness heights used in determining turbulent diffusion below the cloud. The effect of topography on advection is not considered.

The pollutant is assumed to be dispersed throughout the thunderstorm cell. A skewed log-normal distribution is used to initialize the concentration field. About 35% of the material is dispersed within the upper regions of the cloud, 15% within the middle section of the storm, and 50% within the lower layers and cloud base of the storm. Once the concentration field is established, scavenging and downdraft velocities begin to bring the concentration to the ground.

The updraft and downdraft vertical-velocity distributions and wet deposition account for most of the material being deposited at the surface one hour after initial uptake of the material. Scavenging accounts for about 50% of the particle removal from the cloud within 15 minutes. A constant rainfall rate of 20 mm/h is used throughout the calculation. The deposition of concentration at the surface consists primarily of plutonium particles suspended within waterdrops. As additional information on rainfall rates and velocities in tornadic storms becomes available, deposition will likely become highly nonuniform.

Ground-level air concentration begins to reach the surface within five minutes. Results show values of ground-level concentrations to begin occurring within 20 to 45 km of the XN MOFP. Peak centerline concentrations occur within 15 km of the point of initial dispersion within the cloud. Ground-level χ/Q values are shown in Figure 10 for each of four translational velocities. The concentration decreases significantly with distance after peak ground-level values are reached. The lateral spread of ground-level concentration is governed principally by the size of the thunderstorm cell directly overhead. Downdrafts and scavenging have more influence on bringing the concentration directly from the storm cell to the surface than does turbulent diffusion. Concentration reaching the anvil portion of the cloud is advected at a faster velocity than concentration in the lower levels of the storm. About 5% of the concentration is advected out of the anvil into the stratosphere.

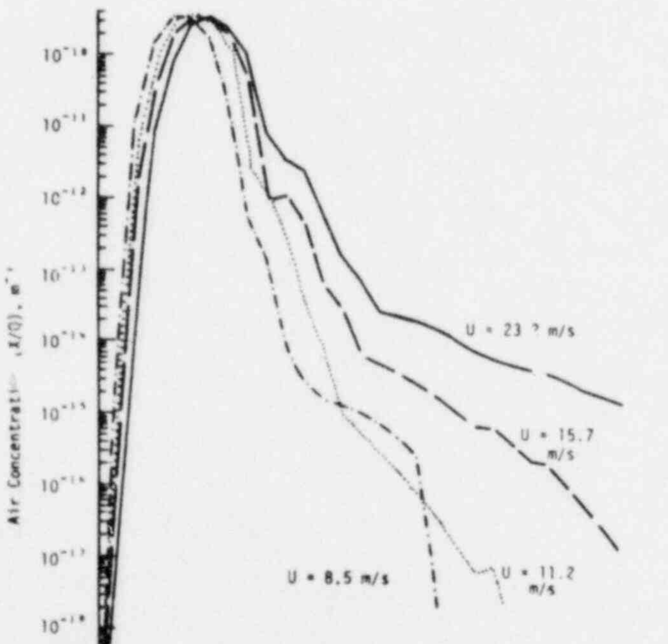


Fig. 10.

Maximum Ground-Level Centerline Air Concentration from Initialization Point in Storm.

Results obtained with a modified Gaussian puff model were considered to be low and showed the inflexibility of the analytical solution to account for the transient nature of the vertical-wind field. Ground-level χ/Q values were several orders of magnitude less in value than χ/Q values obtained from the numerical method.

5. RELEASES[12]

The objective of this section is to provide "realistic" estimates of the quantity of plutonium made airborne, as a result of the postulated damage scenarios, and released to the ambient atmosphere around the facility. Estimates of airborne releases are necessary for the calculation of dose, which is one component of the ultimate risk analysis. Inhalation is the only important pathway for acute atmospheric releases of plutonium; therefore, emphasis is on the estimation of released plutonium particulate material of a size range that can be carried downwind and inhaled.[13] Particles of 10-μm AED or less are conservatively assumed to be the respirable fraction. Such an assumption overstates the potential effect by a factor of 1.5 to greater than an order of magnitude, depending on the lung-deposition model chosen.[14]

The estimated source terms are based on potential damage to enclosures and the resulting airborne release. The damage scenarios are derived from the structural analysis. To provide a range of potential source terms to include the vast majority of normal processing conditions, a "best estimate" and "upper" and "lower" limits are provided. The range of source terms was calculated by combining ranges of damage with the airborne release determined from ranges of inventory of dispersible materials at risk.

The largest postulated airborne releases from the building are for the maximum wind hazard (112 m/s or 250 mph) and seismic hazard (ground acceleration greater than 1.0 g). Both hazard scenarios postulate virtually complete destruction of the facility. Wind hazard at higher velocities and earthquakes with higher ground accelerations should not result in significantly greater source terms. The source terms are expressed as mass of airborne plutonium particles, AED of 10 μm or less, released with time. From 0.5% to 91% of the source term is generated from two hours to four days after the event. The overall building source terms from the damage scenarios evaluated are shown in Table 7 in order of increasing severity of wind hazard and earthquake.

6. DOSE TO MAN[13]

This section presents estimates of the potential environmental consequences in terms of radiation dose to people resulting from postulated plutonium releases accidentally caused by severe weather or other natural phenomena. The accident scenarios considered include earthquakes, tornadoes, and high winds.

6.1 ENVIRONMENTAL EXPOSURE PATHWAYS FOR PLUTONIUM

Experience has shown that the more important pathways for exposure to plutonium and daughter products released to the atmosphere are inhalation,

Table 7. Source-Term Estimates for the Exxon Nuclear MOFP as a Result of Wind and Seismic Hazard

Event	Mass Airborne Release of Plutonium in Respirable Size Range, ≤ 10 μm AED (mg)					
	36-kg/d MO Throughput			72-kg/d MO Throughput		
	Upper Limit	*Best Estimate*	*Lower Limit*	*Upper Limit*	*Best Estimate*	*Lower Limit*
Wind hazard						
Nominal windspeed of 42.5 m/s (95 mph), 6×10^{-3} per year probability of occurrence						
Instantaneous	–	–	– < 0.1 μg	–	–	–
Additional mass released in next 2 hours	–	–	–	–	–	–
6 hours	–	–	–	–	–	–
16 hours	–	–	–	–	–	–
3 days	–	–	–	–	–	–
Nomi: windspeed of 67 m/s (150 mph), 3×10^{-6} per year probability of occurrence						
Instantaneous	10		0.04	100	80	0.006
Additional mass released in next 2 hours	0.004		0.003	0.01	0.008	0.004
6 hours	0.01		0.01	0.03	0.02	0.01
16 hours	0.03		0.03	0.08	0.06	0.04
3 days	0.1		0.1	0.4	0.3	0.2
Nominal windspeed of 85 m/s (190 mph), 6×10^{-8} per year probability of occurrence						
Instantaneous	300 (300)[a]	200 (200)	20	900 (1 000)	600 (800)	60
Additional mass released in next 2 hours	100	60	0.6	300	100	2
6 hours	400	200	2	800	400	5
16 hours	1 000	500	5	2 000	1 000	10
3 days	5 000	2 000	20	10 000	5 000	60
Nominal windspeed of 112 m/s (250 mph), 3×10^{-9} per year probability of occurrence						
Instantaneous	1 000 (2 000)	1 000 (1 000)	100	2 000 (3 000)	2 000 (3 000)	300
Additional mass released in next 2 hours	200	100	10	400	300	20
6 hours	600	400	30	1 000	800	100
16 hours	2 000	1 000	80	3 000	2 000	200
3 days	7 000	5 000	400	14 000	9 000	700
Seismic hazard						
Ground acceleration of 0.3 to 1.0 g, 1×10^{-5} per year probability of occurrence at 0.3 g	No significant structural damage postulated					
Ground acceleration greater than 1.0 g						
Instantaneous	1 000 (2 000)	1 000 (1 000)	100	2 000 (3 000)	2 000 (3 000)	300
Additional mass released in next 2 hours	200	100	10	400	300	20
6 hours	600	400	30	1 000	800	100
16 hours	2 000	1 000	80	3 000	2 000	200
3 days	7 000	5 000	400	14 000	9 000	700

[a]Parenthetical entries indicate total mass Pu estimated to be released from facility.

POOR ORIGINAL

cloud submersion, ingestion, and direct ground irradiation. Of these four pathways, almost all the dose contribution comes from inhalation. Therefore, the radiation doses from inhalation during initial cloud passage and from inhalation of resuspended environmental residual contamination are calculated. For liquid releases, the important exposure pathways are aquatic-food ingestion, water consumption, and shoreline exposure. However, it is estimated that any flood that would threaten the XN MOFP would be preceded by a warning period of at least 30 days, during which dikes could be constructed and the plutonium inventory relocated above the projected flood level. As a result, this release scenario was not considered further. The significant potential exposure pathways that have been considered are shown in Figure 11.

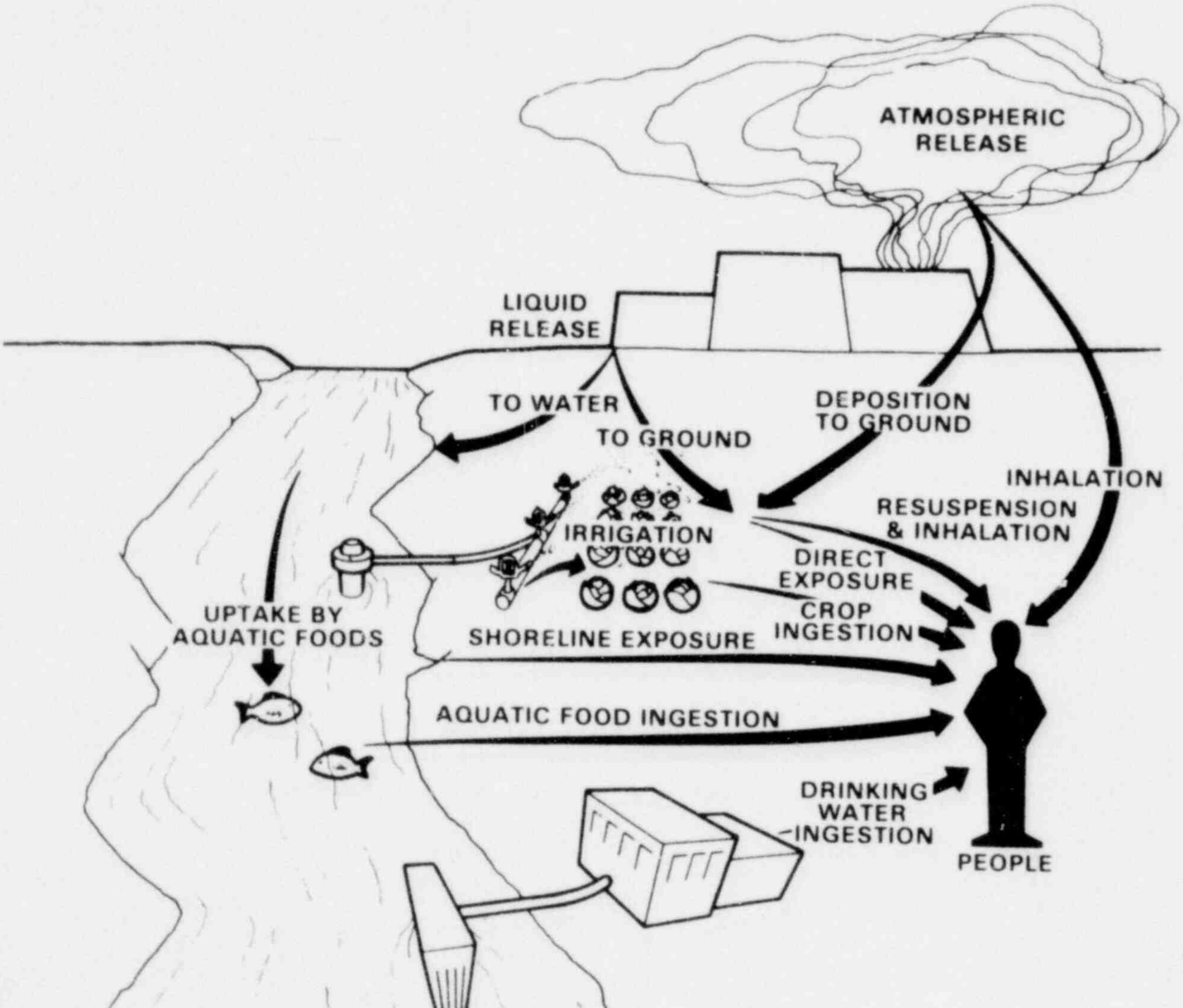


Fig. 11. Significant Potential Exposure Pathways Through Which People May Be Exposed from an Accidental Release of Plutonium.

6.2 RADIATION-DOSE MODELS FOR AN ATMOSPHERIC RELEASE

Fifty-year committed-dose-equivalent factors for acute inhalation were calculated using the computer code DACRIN.[15] This code incorporates the ICRP Task Group lung model to calculate the dose commitment to lungs and other organs of interest. The translocation of americium from the blood to the organs of interest has been changed to the values suggested in ICRP-19. In plutonium dosimetry, the organs of interest are the total body, kidneys, liver, bone, and lungs. Doses only to the lungs and bone are included in this discussion, because these two organs receive the highest doses.

Plutonium particulates that deposit onto the ground surface from the plume can be resuspended to the atmosphere by natural processes, and subsequently inhaled by people. Resuspension rates for material deposited on the ground are time dependent and tend to diminish after initial deposition. Local conditions can be expected to affect the rate strongly; rainfall, winds, and surface characteristics are predominant. The exact relationships are not well enough understood to account for these effects. However, the airborne concentration from resuspended material can be estimated using a resuspension factor. The resuspension factor is defined as the resuspended air concentration divided by the surface deposition. A simple time-dependent model, recommended by Anspaugh et al.,[16] was used to predict the average airborne concentration of a resuspended contaminant. This model estimates values for the resuspension factor between 10^{-4} m^{-1} at initial deposition and 10^{-9} m^{-1} about 20 years later. About 99% of the total 50-year exposure from resuspension occurs in the first five years. Chronic 50-year committed-dose-equivalent factors for inhalation of resuspended material were calculated using DACRIN.[15]

6.3 RADIATION DOSES

The plutonium postulated to be released to the atmosphere is in the form of plutonium oxides. Lung retention, as described by the ICRP Task Group lung model, depends on the chemical nature of the compound inhaled. Compounds of plutonium fall largely into Class Y (retained for years) or Class W (retained for weeks). There is no evidence of plutonium existing in the environment as Class D material. Actinides in the oxide form are currently classified as Class Y, which is assumed in this study. Only that plutonium released in the respirable-particle size range was considered (median AED less than 10 μm).

The isotopic composition by percent weight used in the calculations is given in Table 8.

6.3.1 Earthquakes

Committed radiation-dose equivalents to bone and lungs of the human body were calculated for two earthquake events. For one, peak ground-acceleration levels from 0.3 to 1.0 g were assumed; for the other, greater than 1.0 g was assumed. Significant damage was not postulated for the former earthquake (< 1.0 g).

For the zero-to-two-hour period, accident atmospheric-dispersion values for 5% and 50% conditions, calculated by NRC for the XN MOFP site, were used

Table 8. Isotopic Composition of the Plutonium Mixture

Isotope	*Percent Weight*
^{238}Pu	1.9
^{239}Pu	63.9
^{240}Pu	18.8
^{241}Pu	10.5
^{242}Pu	3.5
^{241}Am	1.4
	100

to estimate potential committed dose equivalents to the population and a maximum individual. Annual average atmospheric-dispersion and deposition values, given in Section 2.4.4, were used for all other time periods. For the 5% condition, the annual dispersion and deposition values were multiplied by four. Four combinations of release and dispersion were considered, referred to as cases I through IV. The calculated committed dose equivalents via inhalation are listed in Table 9, as are descriptions of the four dispersion/deposition cases. The estimated maximum plutonium ground depositions at the site boundary, nearest residence, and farm are listed in Table 10.

6.3.2 High Winds

One straight-line high-wind condition was considered: 67 m/s (150 mph). For the zero-to-two-hour period following an event, best-estimate atmospheric-dispersion values were calculated as discussed in Section 2.4.4. The wind was assumed to blow from westerly directions; i.e. into the ENE, E, ESE, and SE sectors. Significant deposition downwind is presumed not to occur during the zero-to-two-hour period. Committed radiation-dose equivalents calculated for bone and lungs are given in Table 9.

6.3.3 Tornadoes

Average tornado atmospheric-dispersion and deposition values are discussed in Section 4.2. Values for three windspeeds of 67, 85 and 112 m/s (150, 190, and 250 mph respectively) were calculated. These values were assumed to apply during the first two hours after the event. During this time, the tornadoes were assumed to move in an easterly direction. Annual average atmospheric-dispersion and deposition values were used for all other time periods. Committed radiation-dose equivalents are given in Table 9 for Class Y plutonium. The estimated maximum plutonium ground-contamination levels at the significant locations are listed in Table 10.

Table 9. Fifty-Year Best-Estimate Committed Dose Equivalents from Inhalation Following Severe-Wind and Earthquake Events (Class Y material)

		Population Dose[a] (person-rem)				Dose at Nearest Residence (rem)			
Event	Organ	Case[b] I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
67-m/s wind	Lungs	8.2-1[c]	6.8+0	8.2-1	6.2+1	1.4-4	1.4-3	1.4-4	1.4-3
	Bone	1.2+0	9.9+0	1.2+0	9.0+1	2.0-4	2.0-3	2.0-4	2.0-3
67-m/s tornado	Lungs	1.7+3	1.7+4	1.7+3	1.7+4	3.4-2	3.4-1	3.4-2	3.4-1
	Bone	2.5+3	2.5+4	2.5+3	2.5+4	5.0-2	5.0-1	5.0-2	5.0-1
85-m/s tornado	Lungs	3.1+4	2.8+5	5.1+4	4.2+6	5.0-1	5.0+0	7.8-1	7.8+0
	Bone	4.5+4	4.1+5	7.4+4	6.1+6	7.3-1	7.3+0	1.1+0	1.1+1
112-m/s tornado	Lungs	1.9+4	1.3+5	2.6+4	1.2+6	3.7+0	3.7+1	4.1+0	4.1+1
	Bone	2.8+4	1.8+5	3.7+4	1.7+6	5.4+0	5.4+1	5.9+0	5.9+1
Earthquake > 1.0 g	Lungs	1.6+4	1.1+5	2.2+4	3.6+5	2.4+0	2.8+1	2.7+0	3.1+1
	Bone	2.3+4	1.5+5	3.2+4	5.2+5	3.5+0	4.1+1	3.9+0	4.5+1

[a] *Population within an 80-km radius of the plant.*

[b] *Case (parenthetical values are approximate probabilities):*
I - Most likely release (0.95) and most likely dispersion (0.95).
II - Most likely release (0.95) and conservative dispersion (0.05).
III - Conservative release (0.05) and most likely dispersion (0.95).
IV - Conservative release (0.05) and conservative dispersion (0.05).

[c] *Scientific notation.* $8.2\text{-}1 = 8.2 \times 10^{-1}$.

Table 10. Best-Estimate Maximum Plutonium Deposition at Significant Locations[a]

	Plutonium Deposition ($\mu Ci/m^2$)		
Event	Site Boundary[b]	Residence	Farm
Earthquake > 1.0 g	2.7+1[c]	2.3-1	8.8-1
67-m/s tornado	1.4-4	8.8-3	8.8-3
85-m/s tornado	2.8+0	1.3-1	2.3-1
112-m/s tornado	6.6+0	9.5-1	9.5-1

[a] *Case I - most likely release and most likely dispersion.*

[b] *Located 125 m W of the plant.*

[c] *Scientific notation.* $2.7+1 = 2.7 \times 10^{1}$.

6.4 DISCUSSION

For the tornado, the majority of the radionuclide intake occurs after the first two hours. At this time, historical site-specific meteorological conditions are considered to resume.

The calculated committed dose equivalents are based on the ICRP Publication 2 metabolic model, the ICRP Task Group lung model, and standard-man parameter values. To the best of the staff's knowledge, there are no reported assessments of the accuracy of dose calculations using these models and parameter values. Dose results are usually presented with no indication of the error associated with their use. Present insights into the degree of uncertainty involved are very limited and qualitative. Dose results presented in this section are probably accurate within a factor of ten.

The 50-year collective-dose equivalent to the total body from natural-background radiation within an 80-km (50-mi) radius of the XN plant is one million person-rem. The natural-background dose rate in the vicinity of Richland, Washington, is reported to be 100 mrem/yr to the total body. An individual receives a total-body dose of about 5 rem from natural-background radiation during a 50-year period. The average annual dose to the total body of an individual from medical X-ray examinations is about 20 mrem, which corresponds to a 50-year collective-dose equivalent of 200 000 person-rem. The dose contribution from exposure to fallout is negligible when compared with natural-background and medical X-ray exposure. If a radiation worker were involved in an occupational accident and received a maximum permissible bone burden of ^{239}Pu, his 50-year committed dose equivalent to bone would be greater than 1000 rem.

Existing guidelines on acceptable levels of soil contamination from plutonium can be found to range from 0.01 to 270 μCi/m^2. The EPA has proposed a guideline of 0.2 μCi/m^2 for plutonium in the general environment.[17] This guideline is based on an annual dose of 1 mrad to lungs from inhalation and 3 mrad to bone from ingestion. If other reported guidelines are normalized to these doses, and the same resuspension factor is used, they are all in reasonable agreement with 0.2 μCi/m^2.

The predicted levels of maximum residual plutonium contamination on the ground following the earthquake and the 85-m/s (190-mph) and 112-m/s (250-mph) tornadoes are above the EPA proposed guideline at some or all of the significant locations. The estimated contamination levels that are most likely to occur at these locations range from about 0.1 to 30 μCi/m^2. The predicted ground-contamination levels for the other severe natural phenomena are below the EPA proposed guideline. These data are summarized in Table 10.

7. RISK ANALYSIS[18]

Occurrence rates (probability per year) and associated approximate confidence bounds for the wind and earthquake events that were considered in the risk analysis are given in Table 11.

The 50-year committed dose equivalents resulting from tornado and earthquake at the XN facility are given in Table 9.

Table 11. Phenomena Probability and Associated Uncertainties

Windspeed (m/s)	*Peak Ground Acceleration*	*Probability per Year*	*Approximate 90% Bounds on the Probability*
67		3.0-7[a]	(3.0-8, 3.0-6)
85		6.0-8	(6.0-9, 6.0-7)
112		3.0-9	(3.0-10, 3.0-8)
	> 1.0 g	1.0-5	(1.0-6, 1.0-4)

[a] *Scientific notation. 3.0-7 = 3.0×10^{-7}.*

Figures 12 through 15 are graphs of complementary distribution functions, with approximate 90% bounds, for tornadoes and earthquakes. The curves are adequate to show general behavior. Other curves, including those obtained using isotonic regression analysis, have been provided by Johnson.[18] Table 12 indicates the risks resulting from the various tornado and earthquake events, in terms of dose rate, where "risk" is the probability of the event multiplied by the dose rate associated with it.

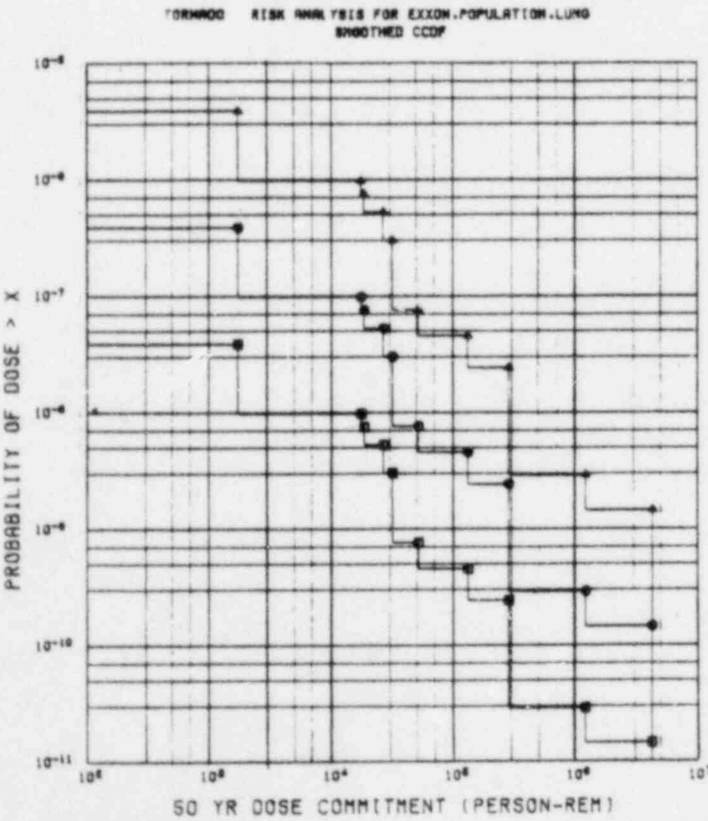


Fig. 12.

Complementary Cumulative Distribution for Dose to Lungs of Population Due to Damage from Tornadoes.

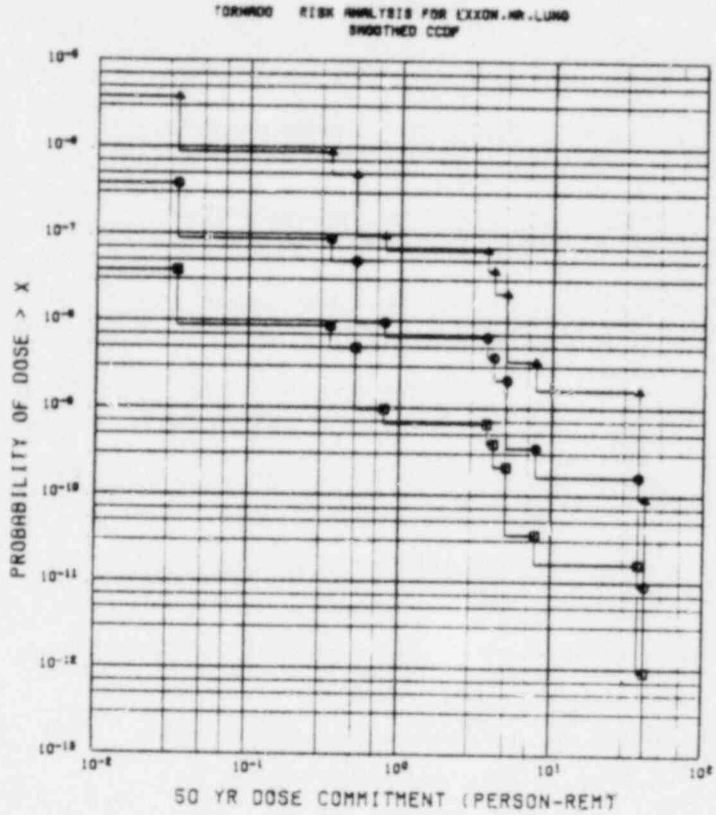


Fig. 13.

Complementary Cumulative Distribution for Dose to Lungs at the Nearest Residence Due to Damage from Tornadoes.

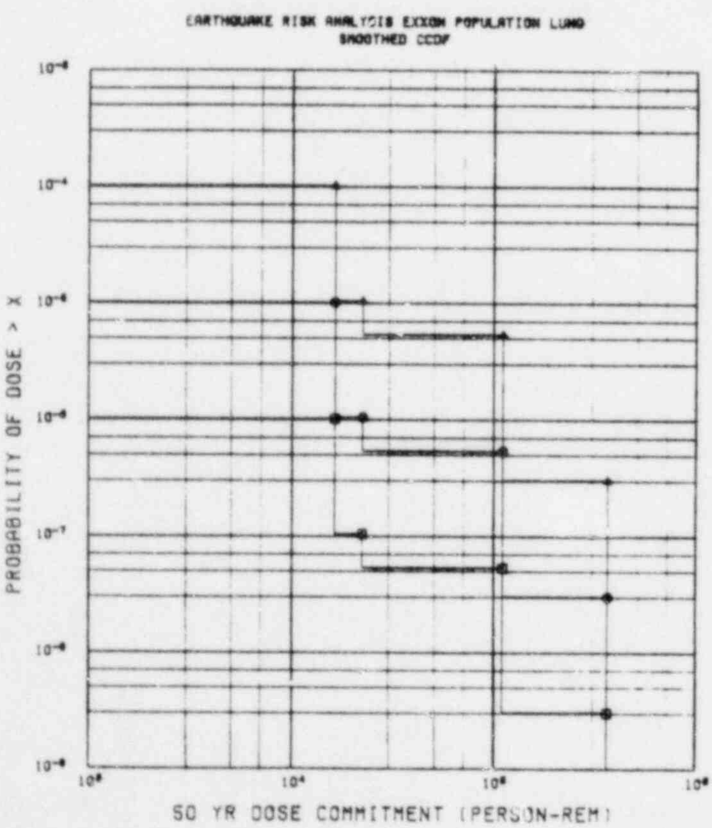


Fig. 14.

Complementary Cumulative Distribution for Dose to Lungs of Population Due to Damage from Earthquake.

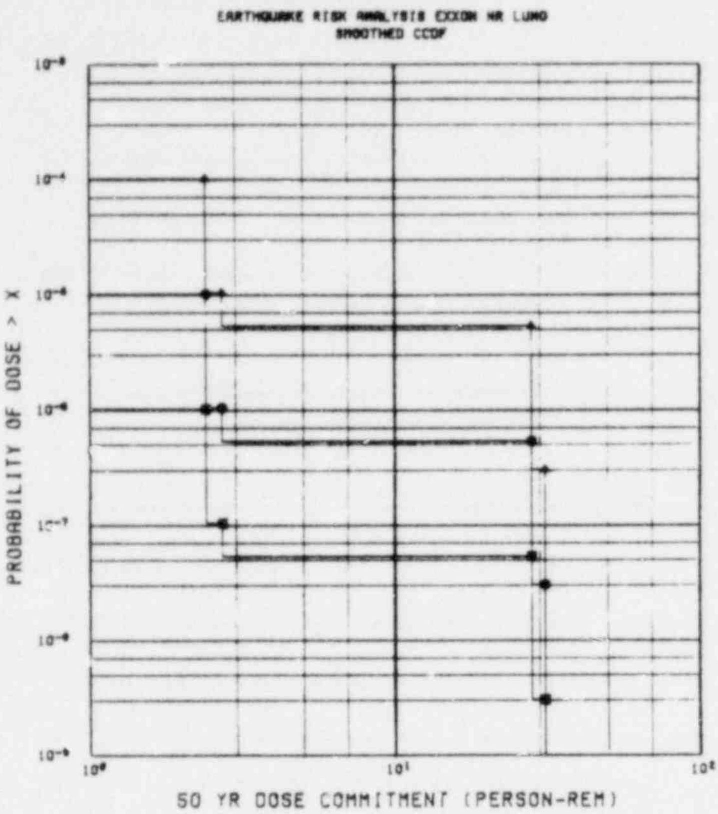


Fig. 15.

Complementary Cumulative Distribution for Dose to Lungs at the Nearest Residence Due to Damage from Earthquake.

Table 12. Risk to Nearest Resident and Nearby Population from Postulated Damage Due to Natural Phenomena

		Population Dose[a] (person-rem/yr)				Dose at Nearest Residence (rem/yr)			
Event	Organ	Case[b] I	Case II	Case III	Case IV	Case I	Case II	Case III	Case IV
67-m/s tornado	Lungs	4.6-4[c]	2.6-4	2.6-5	1.5-5	9.2-9	5.1-9	5.1-10	3.1-10
	Bone	6.8-4	3.8-4	3.8-5	2.3-5	1.4-8	7.5-9	7.5-10	4.5-10
85-m/s tornado	Lungs	1.7-3	8.4-4	1.5-4	7.6-4	2.7-8	1.5-8	2.3-9	1.4-9
	Bone	2.4-3	1.2-3	2.2-4	1.1-3	3.9-8	2.2-8	3.3-9	2.0-9
112-m/s tornado	Lungs	5.1-5	2.0-5	3.9-6	1.1-5	1.0-8	5.6-9	6.2-10	3.7-10
	Bone	7.6-5	2.7-5	5.6-6	1.5-5	1.5-8	8.1-9	8.9-10	5.3-10
Earthquake > 1.0 g	Lungs	1.4-1	6.0-2	1.0-2	1.0-2	2.2-5	1.4-5	1.4-6	9.3-7
	Bone	2.1-1	8.0-2	2.0-2	2.0-2	3.2-5	2.1-5	2.0-6	1.5-6

[a] *Population within an 80-km radius of the plant.*

[b] *See corresponding footnote, Table 9.*

[c] *Scientific notation.* $4.6\text{-}4 = 4.6 \times 10^{-4}$.

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An Analysis of the Effects of Natural Phenomena on the Exxon Nuclear Company Mixed Oxide Fabrication Plant at Richland, Washington has been prepared by the Office of Nuclear Material Safety and Safeguards. The analysis is in support of the Special Nuclear Materials License held by the subject company. It addresses the probable effects of damage to the Exxon Nuclear Company Mixed Oxide Fabrication Plant by severe weather and earthquake and expresses the consequence of damage as dose to several human receptors. The doses that result from facility damage are multiplied by the occurrence rate for the initiating event yielding the yearly risk.

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