WASH-1400
(NUREG 75/014)

Reactor Safety Study

An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants

Executive Summary

United States Nuclear Regulatory Commission

October 1975

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REACTOR SAFETY STUDY

AN ASSESSMENT OF ACCIDENT RISKS IN U.S. COMMERCIAL NUCLEAR POWER PLANTS

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Section 1

Introduction and Results

The Reactor Safety Study was sponsored by the U. S. Atomic Energy Commission[1] to estimate the public risks that could be involved in potential accidents in commercial nuclear power plants of the type now in use. It was performed under the independent direction of Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The risks had to be estimated, rather than measured, because although there are about 50 such plants now operating, there have been no nuclear accidents to date resulting in significant releases of radioactivity in U.S. commercial nuclear power plants. Many of the methods used to develop these estimates are based on those that were developed by the Department of Defense and the National Aeronautics and Space Administration in the last 10 years and are coming into increasing use in recent years.

The objective of the study was to make a realistic estimate of these risks and, to provide perspective, to compare them with non-nuclear risks to which our society and its individuals are already exposed. This information may be of help in determining the future reliance by society on nuclear power as a source of electricity.

The results from this study suggest that the risks to the public from potential accidents in nuclear power plants are comparatively small. This is based on the following considerations:

a. The possible consequences of potential reactor accidents are predicted to be no larger, and in many cases much smaller, than those of non-nuclear accidents. The consequences are predicted to be smaller than people have been led to believe by previous studies which deliberately maximized estimates of these consequences.

b. The likelihood of reactor accidents is much smaller than that of many non-nuclear accidents having similar consequences. All non-nuclear accidents examined in this study, including fires, explosions, toxic chemical releases, dam failures, airplane crashes, earthquakes, hurricanes and tornadoes, are much more likely to occur and can have consequences comparable to, or larger than, those of nuclear accidents.

Figures 1-1, 1-2, and 1-3 compare the nuclear reactor accident risks predicted for the 100 plants expected to be operating by about 1980 with risks from other man-caused and natural events to which society is generally already exposed. The following information is contained in the figures:

a. Figures 1-1 and 1-2 show the likelihood and number of fatalities from both nuclear and a variety of non-nuclear accidents. These figures indicate that non-nuclear events are about 10,000 times more likely to produce large numbers of fatalities than nuclear plants.[1]

b. Figure 1-3 shows the likelihood and dollar value of property damage associated with nuclear and non-nuclear accidents. Nuclear plants are about 1000 times less likely to cause comparable large dollar value accidents than other sources. Prop-

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[1] The work, originally sponsored by the U.S. Atomic Energy Commission, was completed under the sponsorship of the U.S. Nuclear Regulatory Commission, which came into being on January 19, 1975.

[1] The fatalities shown in Figs. 1-1 and 1-2 for the 100 nuclear plants are those that would be predicted to occur within a short period of time after the potential reactor accident. This was done to provide a consistent comparison to the non-nuclear events which also cause fatalities in the same time frame. As in potential nuclear accidents, there also exist possibilities for injuries and longer term health effects from non-nuclear accidents. Data or predictions of this type are not available for non-nuclear events and so comparisons cannot easily be made.

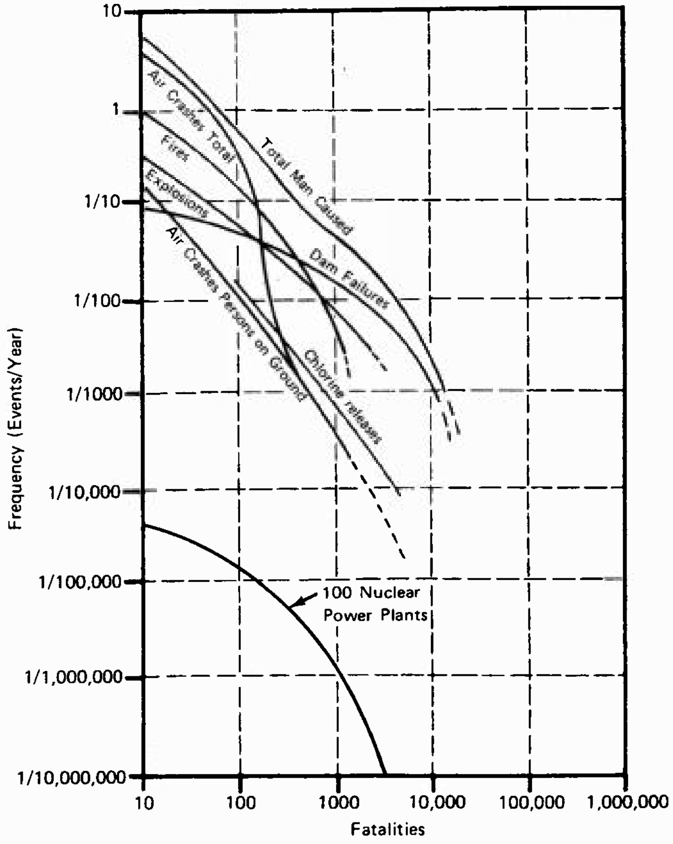

FIGURE 1-1 Frequency of Fatalities due to Man-Caused Events

Notes:
1. Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.
2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.
3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

erty damage is associated with three effects:

1. the cost of relocating people away from contaminated areas,
2. the decontamination of land to avoid overexposing people to radioactivity.
3. the cost of ensuring that people are not exposed to potential sources of radioactivity in food and water supplies.

In addition to the overall risk information in Figs. 1-1 through 1-3, it is useful to consider the risk to individuals of being fatally injured by various types of accidents. The bulk of the information shown in Table 1-1 is taken from the 1973 Statistical Abstracts of the U.S. and applies to the year 1969, the latest year for which these data were tabulated when this study was performed. The predicted nuclear accident risks are very small compared to other possible causes of fatal injuries.

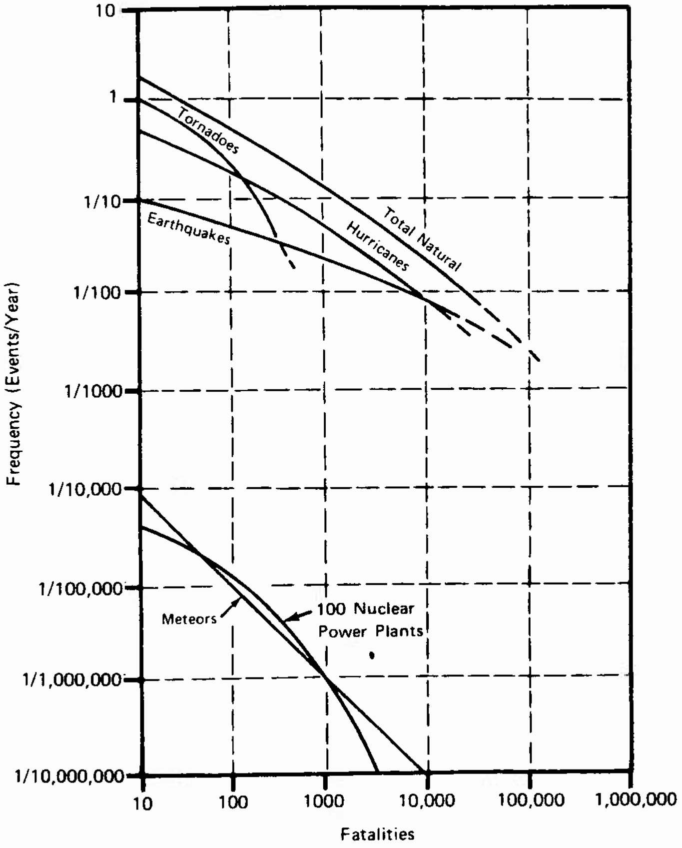

FIGURE 1-2 Frequency of Fatalities due to Natural Events

Notes:
1. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.
2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

In addition to fatalities and property damage, a number of other health effects could be caused by nuclear accidents. These include injuries and long-term health effects such as cancers, genetic effects, and thyroid gland illness. The early illness expected in potential accidents would be about 10 times as large as the fatalities shown in Figs. 1-1 and 1-2; for comparison there are 8 million injuries caused annually by other accidents. The number of cases of genetic effects and long-term cancer fatalities is predicted to be smaller than the normal incidence rate of these diseases. Even for a large accident, the small increases in these diseases would be difficult to detect from the normal incidence rate.

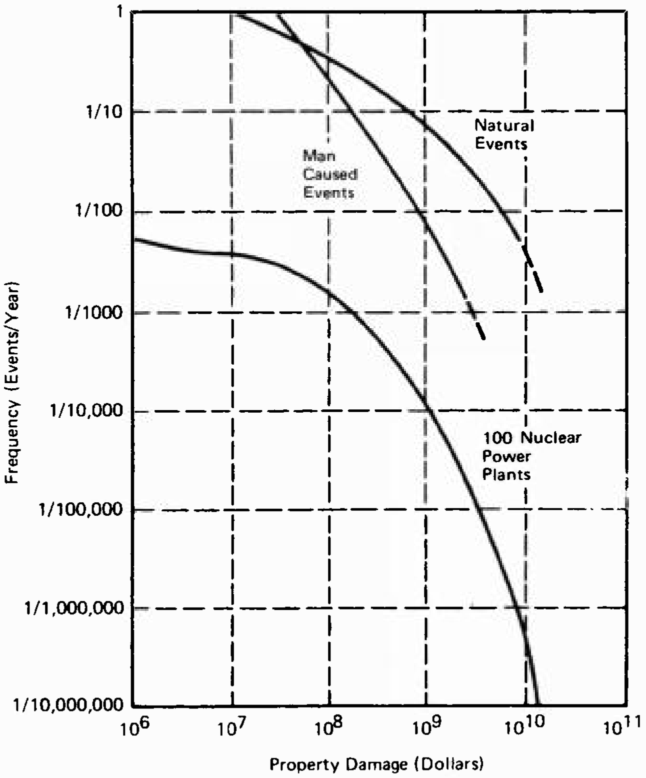

FIGURE 1-3 Frequency of Property Damage due to Natural and Man-Caused Events

Notes:
1. Property damage due to auto accidents is not included because data are not available for low probability events. Auto accidents cause about $15 billion damage each year.
2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/5 and 2 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.
3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

TABLE 1-1 AVERAGE RISK OF FATALITY BY VARIOUS CAUSES

Accident Type	Total Number	Individual Chance per Year
Motor Vehicle	55,791	1 in 4,000
Falls	17,827	1 in 10,000
Fires and Hot Substances	7,451	1 in 25,000
Drowning	6,181	1 in 30,000
Firearms	2,309	1 in 100,000
Air Travel	1,778	1 in 100,000
Falling Objects	1,271	1 in 160,000
Electrocution	1,148	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
All Accidents	111,992	1 in 1,600
Nuclear Reactor Accidents (100 plants)	-	1 in 5,000,000,000

Thyroid illnesses that might result from a large accident are mainly the formation of nodules on the thyroid gland; these can be treated by medical procedures and rarely lead to serious consequences. For most accidents, the number of nodules caused would be small compared to their normal incidence rate. The number that might be produced in very unlikely accidents would be about equal to their normal occurrence in the exposed population. These would be observed during a period of 10 to 40 years following the accident.

While the study has presented the estimated risks from nuclear power plant accidents and compared them with other risks that exist in our society, it has made no judgment on the acceptability of nuclear risks. The judgment as to what level of risk is acceptable should be made by a broader segment of society than that involved in this study.

Section 2

Questions and Answers About the Study

This section of the summary presents more information about the details of the study than was covered in the introduction. It is presented in question and answer format for ease of reference.

2.1 WHO DID THIS STUDY AND HOW MUCH EFFORT WAS INVOLVED?

The study was done principally at the Atomic Energy Commission headquarters by a group of scientists and engineers who had the skills needed to carry out the study's tasks. They came from a variety of organizations, including the AEC, the national laboratories, private laboratories, and universities. About 10 people were AEC employees. The Director of the study was Professor Norman C. Rasmussen of the Department of Nuclear Engineering of the Massachusetts Institute of Technology, who served as an AEC consultant during the course of the study. The Staff Director who had the day-to-day responsibility for the project was Mr. Saul Levine of the AEC. The study was started in the summer of 1972 and took three years to complete. A total of 60 people, various consultants, 70 man-years of effort, and about four million dollars were involved.

2.2 WHAT KIND OF NUCLEAR POWER PLANTS ARE COVERED BY THE STUDY?

The study considered large power reactors of the pressurized water and boiling water type being used in the U.S. today. Reactors of the present generation are all water cooled, and therefore the study limited itself to this type. Although high temperature gas cooled and liquid metal fast breeder reactor designs are now under development, reactors of this type are not expected to have any significant role in U.S. electric power production in this decade; thus they were not considered.

Nuclear power plants produce electricity by the fissioning (or splitting) of uranium atoms. The nuclear reactor fuel in which the uranium atoms fission is in a large steel vessel. The reactor fuel consists of about 100 tons of uranium. The uranium is inside metal rods about 1/2 inch in diameter and about 12 feet long. These rods are formed into fuel bundles of about 50-200 rods each. Each reactor contains several hundred bundles. The vessel is filled with water, which is needed both to cool the fuel and to maintain the fission chain reaction.

The heat released in the uranium by the fission process heats the water and forms steam; the steam turns a turbine to generate electricity. Similarly, coal and oil plants generate electricity using fossil fuel to boil water.

Today's nuclear power plants are very large. A typical plant has an electrical capacity of 1,000,000 kilowatts, or 1,000 megawatts. This is enough electricity for a city of about five hundred thousand people.

2.3 CAN A NUCLEAR POWER PLANT EXPLODE LIKE AN ATOM BOMB?

No. It is impossible for nuclear power plants to explode like a nuclear weapon. The laws of physics do not permit this because the fuel contains only a small fraction (3-5%) of the special type of uranium (called uranium-235) that must be used in weapons.

2.4 HOW IS RISK DEFINED?

The idea of risk involves both the likelihood and consequences of an event. Thus, to estimate the risk involved in driving an automobile, one would need to know the likelihood of an accident in which, for example, an individual could be 1) injured or 2) killed. Thus there are two different consequences, injury or fatality, each with its own likelihood. For injury, an individual's chance per year is about one in 130 and for fatality, it is about one in 4000. This type of data concerns the risk to individuals and can affect attitudes and habits that individuals have toward driving.

However, from an overall societal viewpoint, different types of data are of interest. Here, 1.5 million injuries per year and 55,000 fatalities per year due to automobile accidents represent the kind of information that might be of use in making decisions on highway and automobile safety.

The same type of logic applies to reactors. From the viewpoint of a person living in the general vicinity of a reactor, the likelihood of being killed in any one year in a reactor accident is one chance in 5 billion, and the likelihood of being injured in any one year in a reactor accident is one chance in 75,000,000.

2.5 WHAT CAUSES THE RISKS ASSOCIATED WITH NUCLEAR POWER PLANT ACCIDENTS?

The risks from nuclear power plants are due to the radioactivity formed by the fission process. In normal operation nuclear power plants release minute amounts of this radioactivity under controlled conditions. In the event of highly unlikely accidents, larger amounts of radioactivity could be released and could cause significant risks.

The fragments of the uranium atom that remain after it fissions are radioactive. These radioactive atoms are called fission products. They disintegrate further with the release of nuclear radiations. Many of them decay away quickly, in a matter of minutes or hours, to non-radioactive forms. Others decay away more slowly and require months, and in a few cases, many years to decay. The fission products accumulating in the fuel rods include both gases and solids. Included are iodine, gases like krypton and xenon, and solids like cesium and strontium.

2.6 HOW CAN RADIOACTIVITY BE RELEASED?

The only way that potentially large amounts of radioactivity could be released is by melting the fuel in the reactor core. The fuel that is removed from a reactor after use and stored at the plant site also contains considerable amounts of radioactivity. However, accidental releases from such used fuel were found to be quite unlikely and small compared to potential releases of radioactivity from the fuel in the reactor core.

The safety design of reactors includes a series of systems to prevent the overheating of fuel and to control potential releases of radioactivity from the fuel. Thus, for a potential accidental release of radioactivity to the environment to occur, there must be a series of sequential failures that would cause the fuel to overheat and release its radioactivity. There would also have to be failures in the systems designed to remove and contain the radioactivity.

The study has examined a very large number of potential paths by which potential radioactive releases might occur and has identified those that determine the risks. This involved defining the ways in which the fuel in the core could melt and the ways in which systems to control the release of radioactivity could fail.

2.7 HOW MIGHT A CORE MELT ACCIDENT OCCUR?

It is significant that in some 200 reactor-years of commercial operation of reactors of the type considered in the report there have been no fuel melting accidents. To melt the fuel requires a failure in the cooling system or the occurrence of a heat imbalance that would allow the fuel to heat up to its melting point, about 5,000°F.

To those unfamiliar with the characteristics of reactors, it might seem that all that is required to prevent fuel from overheating is a system to promptly stop, or shut down, the fission process at the first sign of trouble. Although reactors have such systems, they alone are not enough since the radioactive decay of fission fragments in the fuel continues to generate heat (called decay heat) that must be removed even after the fission process stops. Thus, redundant decay heat removal systems are also provided in reactors. In addition, emergency core cooling systems (ECCS) are provided to cope with a series of potential but unlikely accidents, caused by ruptures in, and loss of coolant from, the normal cooling system.

The Reactor Safety Study has defined two broad types of situations that might potentially lead to a melting of the reactor core: the loss-of-coolant accident (LOCA) and transients. In the event of a potential loss of coolant, the normal cooling water would be lost from the cooling systems and core melting would be prevented by the use of the emergency core cooling system (ECCS). However, melting could occur in a loss of coolant if the ECCS were to fail to operate.

The term "transient" refers to any one of a number of conditions which could occur in a plant and would require the reactor to be shut down. Following shutdown, the decay heat removal systems would operate to keep the core from overheating. Certain failures in either the shutdown or the decay heat removal systems also have the potential to cause melting of the core.

2.8 WHAT FEATURES ARE PROVIDED IN REACTORS TO COPE WITH A CORE MELT ACCIDENT?

Nuclear power plants have numerous systems designed to prevent core melting. Furthermore, there are inherent physical processes and additional features that come into play to remove and contain the radioactivity released from the molten fuel should core melting occur. Although there are features provided to keep the containment building from being damaged for some time after the core melts, the containment would ultimately fail, causing a release of radioactivity.

An essentially leaktight containment building is provided to prevent the initial dispersion of the airborne radioactivity into the environment. Although the containment would fail in time if the core were to melt, until that time, the radioactivity released from the fuel would be deposited by natural processes on the surfaces inside the containment. In addition, plants are provided with systems to contain and trap the radioactivity released within the containment building. These systems include such things as water sprays and pools to wash radioactivity out of the building atmosphere and filters to trap radioactive particles prior to their release. Since the containment buildings are made essentially leaktight, the radioactivity is contained as long as the building remains intact. Even if the building were to have sizable leaks, large amounts of the radioactivity would likely be removed by the systems provided for that purpose or would be deposited on interior surfaces of the building by natural processes.

Even though the containment building would be expected to remain intact for some time following a core melt, eventually the molten mass would be expected to eat its way through the concrete floor into the ground below. Following this, much of the radioactive material would be trapped in the soil; however, a small amount would escape to the surface and be released. Almost all of the nongaseous radioactivity would be trapped in the soil.

It is possible to postulate core melt accidents in which the containment building would fail by overpressurization or by missiles created by the accident. Such accidents are less likely but could release a larger amount of airborne radioactivity and have more serious consequences. The consequences of these less likely accidents have been included in the study's results shown in Figs. 1-1 through 1-3.

2.9 HOW MIGHT THE LOSS-OF-COOLANT ACCIDENT LEAD TO A CORE MELT?

Loss of coolant accidents are postulated to result from failures in the normal reactor cooling water system, and plants are designed to cope with such failures. The water in the reactor cooling systems is at a very high pressure (between 50 to 100 times the pressure in a car tire) and if a rupture were to occur in the pipes, pumps, valves, or vessels that contain it, then a "blowout" would happen. In this case some of the water would flash to steam and blow out of the hole. This could be serious since the fuel could melt if additional cooling were not supplied in a rather short time.

The loss of normal cooling in the event of a LOCA would stop the chain reaction, so that the amount of heat produced would drop very rapidly to a few percent of its operating level. However, after this sudden drop the amount of heat being produced would decrease much more slowly and would be controlled by the decay of the radioactivity in the fuel. Although this decrease in heat generation is helpful, it would not be enough to prevent the fuel from melting unless additional cooling were supplied. To deal with this situation, reactors have emergency core cooling systems (ECCS) whose function is to provide cooling for just such events. These systems have pumps, pipes, valves, and water supplies which are capable of dealing with breaks of various sizes. They are also designed to be redundant so that if some components fail to operate, the core can still be cooled.

The study has examined a large number of potential sequences of events following LOCAs of various sizes. In almost all of the cases, the LOCA must be followed by failures in the emergency core cooling system for the core to melt. The principal exception to this is the massive failure of the large pressure vessel that contains the core. However, the accumulated experience with pressure vessels indicates that the chance of such a failure is small. In fact the study found that the likelihood of pressure vessel failure was so small that it did not contribute to the overall risk from reactor accidents.

2.10 HOW MIGHT A REACTOR TRANSIENT LEAD TO A CORE MELT?

The term "reactor transient" refers to a number of events that require the reactor to be shut down. These range from normal shutdown for such things as refueling to such unplanned but expected events as loss of power to the plant from the utility transmission lines. The reactor is designed to cope with unplanned transients by automatically shutting down. Following shutdown, cooling systems would be operated to remove the heat produced by the radioactivity in the fuel. There are several different cooling systems capable of removing this heat, but if they all should fail, the heat being produced would be sufficient to eventually boil away all the cooling water and melt the core.

In addition to the above pathway to core melt, it is also possible to postulate core melt resulting from the failure of the reactor shutdown systems following a transient event. In this case it would be possible for the amounts of heat generated to be such that the available cooling systems might not cope with it and core melt could result.

2.11 HOW LIKELY IS A CORE MELT ACCIDENT?

The Reactor Safety Study carefully examined the various paths leading to core melt. Using methods developed in recent years for estimating the likelihood of such accidents, a probability of occurrence was determined for each core melt accident identified. These probabilities were combined to obtain the total probability of melting the core. The value obtained was about one in 20,000 per reactor per year. With 100 reactors operating, as is anticipated for the U.S. by about 1980, this means that the chance for one such accident is one in 200 per year.

2.12 WHAT IS THE NATURE OF THE HEALTH EFFECTS THAT A CORE MELT ACCIDENT MIGHT PRODUCE?

It is possible for a potential core melt accident to release enough radioactivity so that some fatalities might occur within a short time (about one year) after the accident. Other people may be exposed to radiation levels which would produce observable effects which would require medical attention but from which they would recover. In addition, some people may receive even lower exposures, which would produce no noticeable effects but might increase the incidence of certain diseases over a period of many years. The observable effects which occur shortly after the accident are called early, or acute, effects.

The delayed, or latent, effects of radiation exposure could cause some increase in the incidence of diseases such as cancer, genetic effects, and thyroid gland illnesses in the exposed population. In general these effects would appear as an increase in these diseases over a 10 to 50 year period following the exposure. Such effects may be difficult to notice because the increase is expected to be small compared to the normal incidence rate of these diseases.

The study has estimated the increased incidence of potentially fatal cancers over the 50 years following an accident. The number of latent cancer fatalities are predicted to be relatively small compared to their normal incidence. Thyroid illness refers mainly to small lumps, or nodules, on the thyroid gland. The nodules are treated by medical procedures that sometimes involve simple surgery, and these are unlikely to lead to serious consequences. Medication may also be needed to supplement the gland function.

Radiation is recognized as one of the factors that can produce genetic effects which appear as defects in a subsequent generation. From the total population exposure caused by the accident, the expected increase in genetic effects in subsequent generations can be estimated. These effects are predicted to be small compared to their normal incidence rate.

2.13 WHAT ARE THE MOST LIKELY CONSEQUENCES OF A CORE MELT ACCIDENT?

As stated, the probability of a core melt accident is on the average one in 20,000 per reactor per year. The most likely consequences of such an accident are given below.

MOST LIKELY CONSEQUENCES OF A CORE MELT ACCIDENT

	Consequences
Fatalities	<1
Injuries	<1
Latent Fatalities per year	<1
Thyroid Nodules per year	<1
Genetic Defects per year	<1
Property Damage[(a)]	<$1,000,000

(a) This does not include damage that might occur to the plant or costs for replacing the power generation lost by such damage.

2.14 HOW DOES THE AVERAGE ANNUAL RISK FROM NUCLEAR ACCIDENTS COMPARE TO OTHER COMMON RISKS?

Considering the 15 million people who live within 25 miles of current or planned U.S. reactor sites, and based on current accident rates in the U.S., the annual numbers of fatalities and injuries expected from various sources are shown in the table below.

ANNUAL FATALITIES AND INJURIES EXPECTED AMONG THE 15 MILLION PEOPLE LIVING WITHIN 25 MILES OF U.S. REACTOR SITES

Accident Type	Fatalities	Injuries
Automobile	4,200	375,000
Falls	1,500	75,000
Fire	560	22,000
Electrocution	90	--
Lightning	8	--
Reactors (100 plants)	2	20

2.15 WHAT IS THE NUMBER OF FATALITIES AND INJURIES EXPECTED AS A RESULT OF A CORE MELT ACCIDENT?

A core melt accident is similar to many other types of major accidents such as fires, explosions, dam failures, etc., in that a wide range of consequences is possible depending on the exact conditions under which the accident occurs. In the case of a core melt, the consequences would depend mainly on three factors: the amount of radioactivity released, the way it is dispersed by the prevailing weather conditions, and the number of people exposed to the radiation. With these three factors known, it is possible to make a reasonable estimate of the consequences.

The study calculated the health effects and the probability of occurrence for 140,000 possible combinations of radioactive release magnitude, weather type, and population exposed. The probability of a given release was determined from a careful examination of the probability of various reactor system failures. The probability of various weather conditions was obtained from weather data collected at many reactor sites. The probability of various numbers of people being exposed was obtained from U.S. census data for current and planned U.S. reactor sites. These thousands of computations were carried out with the aid of a large digital computer.

These results showed that the probability of an accident resulting in 10 or more fatalities is predicted to be about 1 in 3,000,000 per plant per year. The probability of 100 or more fatalities is predicted to be about 1 in 10,000,000, and for 1000 or more, 1 in 100,000,000. The largest value reported in the study was 3300 fatalities, with a probability of about one in a billion.

The above estimates are derived from a consequence model which includes statistical calculations to describe evacuations of people out of the path of airborne radioactivity. This evacuation model was developed from data describing evacuations that have been performed during non-nuclear events.

If a group of 100 similar plants are considered, then the chance of an accident causing 10 or more fatalities is 1 in 30,000 per year. For accidents involving 1000 or more fatalities the number is 1 in 1,000,000 per year. Interestingly, this value coincides with the probability that a meteor would strike a U.S. population center and cause 1000 fatalities.

The table shown below can be used to compare the likelihood of a nuclear accident to non-nuclear accidents that could cause the same consequences.

AVERAGE PROBABILITY OF MAJOR MAN-CAUSED AND NATURAL EVENTS

Type of Event	Probability of 100 or More Fatalities	Probability of 1000 or More Fatalities
Man-Caused		
Airplane Crash	1 in 2 years	1 in 2000 years
Fire	1 in 7 years	1 in 200 years
Explosion	1 in 16 years	1 in 120 years
Toxic Gas	1 in 100 years	1 in 1000 years
Natural		
Tornado	1 in 5 years	very small
Hurricane	1 in 5 years	1 in 25 years
Earthquake	1 in 20 years	1 in 50 years
Meteorite Impact	1 in 100,000 years	1 in 1,000,000 years
Reactors		
100 plants	1 in 100,000 years	1 in 1,000,000 years

These include man-caused as well as natural events. Many of these probabilities are obtained from historical records, but others are so small that no such event has ever been observed. In the latter cases the probability has been calculated using techniques similar to those used for the nuclear plant.

In regard to injuries from potential nuclear power plant accidents, the number of injuries that would require medical attention shortly after an accident is about 10 times larger than the number of fatalities predicted.

2.16 WHAT IS THE MAGNITUDE OF THE LATENT, OR LONG-TERM, HEALTH EFFECTS?

As with the short-term effects, the incidence of latent cancers, treatable latent thyroid illness, and genetic effects would vary with the exact accident conditions. The table below illustrates the potential size of such events. The first column shows the consequences that would be produced by core melt accidents, the most likely of which has one chance in 20,000 per reactor per year of occurring. The second column shows the consequences for an accident that has a chance of 1 in a million of occurring. The third column shows the normal incidence rate.

In these accidents, only the induction of thyroid nodules would be observable, and this only in the case of larger, less likely accidents. These nodules are easily diagnosed and treatable by medical or surgical procedures. The incidence of other effects would be low and should not be discernible in view of the high normal incidence of these two diseases.

INCIDENCE PER YEAR OF LATENT HEALTH EFFECTS
FOLLOWING A POTENTIAL REACTOR ACCIDENT

Health Effect (per year)	Chance per Reactor per Year		Normal(b) Incidence Rate in Exposed Population (per year)
	One in 20,000(a)	One in 1,000,000(a)	
Latent Cancers	<1	170	17,000
Thyroid Illness	<1	1400	8000
Genetic Effects	<1	25	8000

(a) The rates due to reactor accidents are temporary and would decrease with time. The bulk of the cancers and thyroid modules would occur over a few decades and the genetic effects would be significantly reduced in five generations.

(b) This is the normal incidence that would be expected for a population of 10,000,000 people who might receive some exposure in a very large accident over the time period that the potential reactor accident effects might occur.

2.17 WHAT TYPE OF PROPERTY DAMAGE MIGHT A CORE MELT ACCIDENT PRODUCE?

A nuclear accident would cause no physical damage to property beyond the plant site but may contaminate it with radioactivity. At high levels of contamination, people would have to be relocated from their homes until decontamination procedures permitted their return. At levels lower than this, but involving a larger area, decontamination procedures would also be required, but people would be able to continue to live in the area. The area requiring decontamination would involve a few hundred to a few thousand square miles. The principal concern in this larger area would be to monitor farm produce to keep the amount of radioactivity ingested through the food chain small. Farms in this area would have their produce monitored, and any produce above a safe level could not be used.

The core melt accident having a likelihood of one in 20,000 per plant per year would most likely result in little or no contamination. The probability of an accident that requires relocation of 20 square miles is one in 100,000 per reactor per year. Eighty per cent of all core melt accidents would be expected to be less severe than this. The largest accident might require relocation from 290 square miles. In an accident such as this, agricultural products, particularly milk, would have to be monitored for a month or two over an area about 50 times larger until the iodine decayed away. After that, the area requiring monitoring would be very much smaller.

2.18 WHAT WOULD BE THE COST OF THE CONSEQUENCES OF A CORE MELT ACCIDENT?

As with the other consequences, the cost would depend upon the exact circumstances of the accident. The cost calculated by the Reactor Safety Study included the cost of moving and housing the people that were relocated, the cost caused by denial of land use and the cost associated with the denial of use of reproducible assets such as dwellings and factories, and costs associated with the cleanup of contaminated property. The core melt accident having a likelihood of one in 20,000 per reactor per year would most likely cause property damage of less than $1,000,000. The chance of an accident causing $150,000,000 damage would be about one in 100,000 per reactor per year. The probability would be about one in 1,000,000 per plant per year of causing damage of about one billion dollars. The maximum value would be predicted to be about 14 billion dollars, with a probability of about one in 1,000,000,000 per plant per year.

This property damage risk from nuclear accidents can be compared to other risks in several ways. The largest man-caused events that have occurred are fires. In recent years there have been an average of three fires with damage in excess of 10 million dollars every year. About once every two years there is a fire with damage in the 50 to 100 million dollar range. There have been four hurricanes in the last 10 years which caused damage in the range of 0.5 to 5 billion dollars. Recent earthquake estimates suggest that a one billion dollar earthquake can be expected in the U.S. about once every 50 years.

A comparison of the preceding costs shows that, although a severe reactor accident would be very costly, the costs would be within the range of other serious accidents experienced by society and the probability of such a nuclear accident is estimated to be smaller than that of the other events.

2.19 WHAT WILL BE THE CHANCE OF A REACTOR MELTDOWN IN THE YEAR 2000 IF WE HAVE 1000 REACTORS OPERATING?

One might be tempted to take the per plant probability of a particular reactor accident and multiply it by 1000 to estimate the chance of an accident in the year 2000. This is not a valid calculation, however, because it assumes that the reactors to be built during the next 25 years will be the same as those being built today. Experience with other technologies, such as automobiles and aircraft for example, generally shows that, as more units are built and more experience is gained, the overall safety record improves in terms of fewer accidents occurring per unit. There are changes in plants now being constructed that appear to be improved as compared to the plants analyzed in the study.

2.20 HOW DO WE KNOW THAT THE STUDY HAS INCLUDED ALL ACCIDENTS IN THE ANALYSIS?

The study devoted a large amount of its effort to ensuring that it covered those potential accidents of importance to determining the public risk. It relied heavily on over 20 years of experience that exists in the identification and analysis of potential reactor accidents. It also went considerably beyond earlier analyses that have been performed by considering a large number of potential failures that had never before been analyzed. For example, the failure of reactor systems that can lead to core melt and the failure of systems that affect the consequences of core melt have been analyzed. The consequences of the failure of the massive steel reactor vessel and of the containment were considered for the first time. The likelihood that various external forces such as earthquakes, floods, and tornadoes could cause accidents was also analyzed.

In addition there are further factors that give a high degree of confidence that the important and significant accidents affecting risk have been included. These are: 1) the identification of all significant sources of radioactivity located at nuclear power plants, 2) the fact that a large release of radioactivity can occur only if the reactor fuel were to melt, and 3) knowledge of the physical phenomena which can cause fuel to melt. This type of approach led to the screening of thousands of potential accident paths to identify those that would essentially determine the public risk.

While there is no way of proving that all possible accident sequences which contribute to public risk have been considered in the study, the systematic approach used in identifying possible accident sequences makes it unlikely that an accident was overlooked which would significantly change the overall risk.

2.21 WHAT TECHNIQUES WERE USED IN PERFORMING THE STUDY?

Methodologies developed over the past 10 years by the Department of Defense and the National Aeronautics and Space Administration were used in the study. As used in this study, these techniques, called event trees and fault trees, helped to define potential accident paths and their likelihood of occurrence.

An event tree defines an initial failure within the plant. It then examines the course of events which follow as determined by the operation or failure of various systems that are provided to prevent the core from melting and to prevent the release of radioactivity to the environment. Event trees were used in this study to define thousands of potential accident paths which were examined to determine their likelihood of occurrence and the amount of radioactivity that they might release.

Fault trees were used to determine the likelihood of failure of the various systems identified in the event tree accident paths. A fault tree starts with the definition of an undesired event, such as the failure of a system to operate, and then determines, using engineering and mathematical logic, the ways in which the system can fail. Using data covering 1) the failure of components such as pumps, pipes and valves, 2) the likelihood of operator errors, and 3) the likelihood of maintenance errors, it is possible to estimate the likelihood of system failure, even where no data on total system failure exist.

The likelihood and the size of radioactive releases from potential accident paths were used in combination with the likelihood of various weather conditions and population distributions in the vicinity of the reactor to calculate the consequences of the various potential accidents.