5.2 Offsite Dispersion and Doses

In order to assess the consequences of a severe accident, one must (1) estimate the source term, (2) characterize the transport of radionuclides in the environment, and (3) estimate the resulting doses to the public (accounting for protective actions that may be taken). This process is depicted in Figure 5.2-1. Source term estimates are treated in Section 5.1. This section discusses the transport of radionuclides in the environment and the doses that could potentially result from such transport. Offsite protective actions that could be taken to reduce doses to the public are discussed in section 5.3.

5.2.1 Radiation Dose and Health Effects

Radiation exposures can affect the health of exposed individuals. The type of effect, its severity, and the length of time until the effect appears are determined by the total dose received, the rate of exposure, the exposed organs, and the degree of medical treatment received.

Although the curie is an appropriate unit for quantifying amounts of radioactive materials (e.g., curies in the core), it is not an appropriate unit for quantifying the potential health effects that may result from the release of radioactive materials to the environment. The number of curies required to induce various health effects can vary considerably, depending on the types of radiation emitted by the decaying nuclei and how the radiation enters the body (i.e., the pathway). The term dose refers to radiation absorbed by a human body. A unit of dose is the rad. One rad corresponds to 100 ergs of energy deposited in a gram of material. The corresponding SI unit is the Grey (Gy), and 1 Gy = 100 rads (1 J/kg). A closely related unit, the rem, is a measure of dose equivalent in humans. The corresponding SI unit is the Sievert (Sv), and 1 Sv = 100 rems. The dose to the whole body or to a particular organ is a measure of potential biological damage induced by exposure of the body or organ to radiation.

5.2.1.1 Chronic (Latent) Effects

Small doses or moderately large doses received at low dose rates (e.g., long term exposure to low levels of ground contamination) can cause health effects such as cancer, which appear later in time and are not directly observable following the exposure. Such effects are called chronic effects.

Traditionally, the risk of cancer has been assumed to be proportional to dose, no matter how small. That is, we assume for regulatory purposes that a collective dose of about 2,000 person-rem (1 rem to 2,000 people, 0.1 rem to 20,000 people, etc.) will result in one radiation-induced cancer in the affected population.[1] This linear, no-threshold hypothesis is the subject of considerable debate, with some contending it is too conservative. Under this hypothesis, because the release is spread over a larger area and therefore over a larger population the farther it moves from the plant, a sizable fraction of the predicted radiation-induced cancers can result from very small exposures beyond 50 miles from the plant. This is illustrated in Figure 5.2-2.[2]

5.2.1.2 Acute Health Effects

Large doses received over short time periods threaten both the short- and long-term health of exposed individuals. If exposures are sufficiently intense, exposed organs are damaged causing radiation sickness or death within days or months. As a class, such early health effects are called acute. Radiation sickness includes vomiting, diarrhea, loss of hair, nausea, hemorrhaging, fever, loss of appetite, and general malaise.

Deaths can be caused by failures of the lungs, small intestine, or blood-forming bone marrow. Barring death or complications, recovery from radiation sickness occurs in a few weeks to a year depending on the dose received. Exposed individuals who survive radiation sickness are still subject to increased risk of latent effects such as cancers.

Because damage sufficient to impair organ functioning does not occur if exposures are small, short-term health effects usually have dose thresholds. That is, the effect does not appear until the dose received is greater than the threshold dose (D_{th}). Once the threshold dose has been exceeded, the fraction of the exposed population in which the health effect occurs (the health effect's incidence) rises rapidly with increasing dose until the effect appears in all of the exposed individuals. The dose at which a health effect is induced in half of the exposed population is called the D_{50} dose (LD_{50} if the dose is lethal).

Figure 5.2-3 depicts the average dose equivalents in millirems received from natural background, common medical procedures, and frequent human activities.[3] As indicated in the figure, early injuries generally would appear at doses above 50 to 100 rem to the whole body, and early deaths would be expected at much higher doses (e.g., 250 to 600 rem). It has been estimated that, with only minimal medical treatment, about 50% of the people who receive a whole-body dose (LD_{50}) of 300 rem would die within 60 days. LD_{50} has been estimated to increase to 450 rem with supportive medical treatment.[4]

5.2.2 Dose Pathways

As indicated in Figure 5.2-4, a person can receive a radiation dose from a plume in several ways, usually called pathways. First, dose can be received externally from the radiation given off by the passing plume or the ground contamination. Such doses are called cloud shine and ground shine, respectively. The dose due to radioactive particles that settle directly onto the skin or clothing of persons immersed in the cloud is called the skin dose. Dose can also be received by inhaling the radioactive material in the plume; this is called inhalation dose. Some of the inhaled material may concentrate in particular organs such as the lungs or thyroid and thus become a special threat to those organs. Cloud shine, ground shine, and inhalation are collectively considered parts of the plume exposure pathway.

Dose can also be received from the ingestion pathway, that is, from eating or drinking contaminated food or water. As in the case of inhaled material, ingested material can concentrate in various organs. Ingestion of milk receives special attention because radioiodine from a plume can contaminate grass eaten by dairy herds. This radioiodine, which can be greatly concentrated in the milk, can then concentrate in the drinker's thyroid gland.

The actual doses received by individuals offsite as a result of an accidental release would depend primarily on three factors:

1. The release (source term) characteristics,

2. The weather during and after the release, which would determine the concentrations of airborne radionuclides and ground contamination offsite, and

3. The protective actions taken by individuals located offsite.

Source terms are discussed in Section 5.1. The impact of weather on offsite consequences is discussed in the following subsections. The impact of protective actions on offsite-site health effects is discussed in Section 5.3. In considering offsite protective actions against releases from nuclear power plant accidents, both acute dose to the bone marrow and thyroid doses are important. Dose to the bone marrow (mostly from shine) is a dominant cause of early deaths for reactor accidents. Thyroid dose is important because inhalation or ingestion of small amounts of radioiodine can result in damage or destruction of the thyroid. However, unlike bone marrow dose, dose to the thyroid will not be fatal in the short term in most cases. There would, of course, be increased risk of death due to thyroid cancer.

5.2.3 Meteorology

In the absence of significant heat transfer with the ground or between adjacent layers of air, the temperature in a well-mixed atmosphere decreases linearly with altitude at a rate of about 5.4°F/1000 ft (1°C/100 m). This is called the adiabatic lapse rate (or adiabatic temperature distribution) because it is derived by treating the expansion of air with altitude as an adiabatic expansion.[5] As indicated in Figure 5.2-5, other temperature distributions such as isothermal, superadiabatic, and inversions may exist over particular ranges of altitudes. The actual temperature profile at any time is determined by a number of factors including heating and cooling of the earth's surface, the movements of large air masses (highs and lows), the existence of cloud cover, and the presence of large topographical obstacles. For example, on clear days with light winds, superadiabatic conditions may exist in the first few hundred meters of the atmosphere due to the heat transferred to the air from the hot surface of the earth. Conversely, on a cloudless night, when the earth radiates energy most easily, the earth's surface may cool down faster than the air immediately above it, and the result is a *radiation inversion*.

The degree to which pollutants are dispersed in the atmosphere depends to a large extent on the atmospheric temperature profile. Consider the case of dispersion in a superadiabatic atmosphere. If a small parcel of polluted air is released at some altitude h and the same temperature T as the atmosphere, as indicated in Figure 5.2-6a, the parcel will remain in equilibrium at that point if not disturbed. Suppose, however, that a fluctuation in the atmosphere moves the parcel upward. The parcel will cool adiabatically as it rises; that is, the temperature of the parcel will follow the adiabatic curve shown by the dashed lines in Figure 5.2-6a. Because the surrounding superadiabatic atmosphere cools more rapidly, the parcel becomes increasingly hotter than the atmosphere. This means the parcel becomes increasingly buoyant, causing it to move more rapidly upward. On the other hand, if the parcel is pushed downward, its temperature will fall more rapidly and it will become increasingly more dense than the surrounding superadiabatic air. This will accelerate the downward motion at the parcel. Clearly, the superadiabatic atmospheric conditions are inherently unstable and are highly favorable for dispersing pollutants.

In contrast, if the parcel is released into an isothermal or inversion profile, as indicated in Figure 5.2-6b, a fluctuation upward will make it cooler and hence more dense than the surrounding atmosphere, tending to return the parcel to its original position. Similarly, a downward fluctuation will make the parcel hotter and more buoyant than the surrounding air. This will also tend to return the parcel to its equilibrium point.

Atmospheres characterized by isothermal or inversion profiles are therefore said to be stable. This is undesirable for pollutant dispersal.

Frequently, the parcel is hotter than its surroundings when released, and it will initially rise due to its greater buoyancy. Various types of dispersal patterns can be observed depending on the conditions in the surrounding atmosphere, as illustrated in Figure 5.2-7. Plumes emitted into an inversion layer (stable atmosphere) disperse horizontally much more rapidly than they disperse vertically (vertical dispersion is inhibited in an inversion layer). Therefore, the plume spreads out horizontally but not vertically, which produces a fan shape when viewed from below (fanning). If a hot plume is emitted into an unstable atmosphere that is capped by an inversion layer, the plume rises to the inversion layer and then spreads rapidly downward, fumigating the ground below (fumigation). Plumes emitted into an uncapped unstable atmosphere tend to breakup because vertical displacements of plume parcels are enhanced (looping). Plumes emitted into a neutral atmosphere (lapse rate equal to the adiabatic lapse rate) are dispersed smoothly both vertically and horizontally, and therefore have a conical profile in the crosswind direction (coning). Plumes emitted into a neutral layer that overlies an inversion layer can spread upward but not downward (lofting).

It is possible to estimate the stability conditions in the lower atmosphere by simply measuring the temperature at two or more heights on a meteorological tower. The slope of the temperature profile can then be compared by dividing the temperature difference ΔT by the difference in height Δz of the measurements. Alternatively, stability can be estimated by monitoring fluctuations (standard deviation σ_Θ) in the angle of a wind vane. Based on experimental data on atmospheric dispersion, stability regions are often divided into the seven stability classes listed in Table 5.2-1[6] depending on the indicated ranges of $\Delta T/\Delta z$ or σ_Θ.

Other meteorological conditions that can have a strong impact on atmospheric dispersion or ground contamination include wind speed, precipitation and humidity. Data on these factors are also measured on the meteorological tower. The significance of such factors is discussed in the following section.

5.2.4 Dispersion of Effluents

Plumes disperse as they are transported downwind, which means that concentrations of released radionuclides would decrease with plume travel distance. Because dispersion causes plume materials (droplets, particles, gas molecules) to move away from the plume centerline in a random series of steps, plume concentrations tend to assume normal (Gaussian) distributions in both the vertical and horizontal directions. The rate of spreading depends on atmospheric stability and is usually not the same in the vertical and horizontal directions.

Models of atmospheric dispersion range in complexity from simple to sophisticated. Perhaps the simplest model is the straight-line Gaussian plume model. As illustrated in Figure 5.2-8, this model assumes a constant wind direction and a Gaussian-shaped spreading of the plume with distance. It also assumes a constant wind speed, and it does not account for the effects of local topography. According to this model, the released plume (or puff for a short duration release) moves downwind at the wind speed u. The plume spreads in all directions due to turbulent diffusions as it moves. This spreading is characterized by empirically determined standard deviations in vertical and cross wind pollutant concentrations.

These standard deviations increase with downwind distance and atmospheric instability.

The inhalation and immersion doses that would be received by an individual standing in the path of the plume increase with the magnitude of χ_T, the time-integrated concentration at the point in question. According to the straight-line Gaussian plume model

$$\chi_T \propto Q\frac{\Phi}{u}$$

where

χ_T = integrated radionuclide concentration at point in question (Ci•s/m^3)

Q = quantity of radionuclide released (Ci)

u = wind speed (m/s)

Φ = Gaussian shape function, which depends on the location, the stability class, and the release height (m^{-2})

Figure 5.2-9 shows the quantity χ_T/Q along the plume centerline at ground level for effluent released at a height of 100 ft under Pasquill stability classes B, C, and D for a 6 mile/hr wind. χ_T/Q is also shown for a 2 mile/hr wind speed for stability class D. It will be observed that, at reasonable distances from the plant, χ_T/Q decreases more or less exponentially. With the more unstable conditions (B), the maximum of χ_T/Q occurs nearer the release point (within a few hundred meters), then drops rapidly to very low values. On the other hand, under more stable conditions (D), the peak of χ_T/Q is located much further from the source. Concentrations in populated offsite locations are therefore usually greater under stable than under unstable conditions and stable conditions are often assumed in calculations of the atmospheric dispersion of releases from nuclear power plants.

The preceding discussion ignored the effects of radioactive decay and ground deposition on plume concentrations. Radioactive decay and deposition, both wet and dry, are each first order processes (i.e., their rates are proportional to the local concentration). Both processes cause atmospheric concentrations to decrease more rapidly with distance.

Changes in wind speed and atmospheric stability cause the rate at which plume concentrations decrease with distance to change but do not cause the preceding generalizations to be seriously violated. However, wind stagnation or rainfall can cause high local air or ground concentrations. Wind stagnation causes cloudshine, inhalation, and skin doses at the stagnation distance to increase because the exposure times for these doses all increase. In addition, prolonged stagnation can produce a hot spot on the ground at the stagnation distance because of the greatly increased time period during which deposition occurs at that distance. Rain can have a major impact on accident consequences. Rain decreases plume concentrations and associated cloudshine, inhalation, and skin doses, but rain can result in very high local ground concentrations (hot spots) distributed in very complex patterns as seen at Chernobyl (Figure 5.2-10).[7]

Wind stagnation causes cloudshine, inhalation, and skin doses at the stagnation distance to increase because the exposure times for these doses all increase. In addition, prolonged stagnation can produce a hot spot on the ground at the stagnation distance because of the greatly increased time period during which deposition occurs at that distance.

5.2.5 Dose Versus Distance

As indicated in Section 5.1.3, releases to the atmosphere from a very severe reactor accident involving both core melting and containment failure could result in offsite-site injuries or fatalities. This section presents dose versus distance calculations based on the straight-line Gaussian plume model for such a release, one resulting from a Surry (PWR) accident scenario in which containment fails early (2.5 hours after scram). The release duration is taken to be 0.5 hour. The release fractions are set at the median values depicted within the NUREG-1150 uncertainty ranges of Figure 5.1-4.

Two radiation-induced injuries with relatively low thresholds are prodromal vomiting (threshold stomach dose of ~50 rem) and hypothyroidism (threshold thyroid dose of ~200 rem). Figure 5.2-11 provides information regarding the stomach and thyroid doses versus distance for the postulated release under typical meteorological conditions (stability class D, 6 m/s wind speed).

It is evident from Figure 5.1-4 that the postulated release fractions are neither optimistic nor pessimistic. Nor are the postulated meteorological conditions particularly extreme. Doses resulting from an actual accident involving both core melting and containment failure could therefore be much higher or much lower depending on the actual source term characteristics and the weather at the time of the release.

In calculating the doses presented in Figure 5.2-11, evacuation, sheltering, and other possible offsite-site protective actions are not considered, and dose reduction factors representative of normal indoor activities are not applied. That is, the doses shown are for hypothetical persons on the plume centerline who remain outside during plume passage for the indicated time intervals measured from plume arrival.

The top left plot in Figure 5.2-11 shows the integrated stomach dose at 4 hours, 24-hours, and 7 days following initial exposure. It is evident that the stomach dose continues to increase after plume passage. This is due to continued exposure to radionuclides deposited on the ground and from inhalation of resuspended radionuclides. The top right plot shows the relative contribution of various pathways to the 24-hour stomach dose as a function of distance. The cloudshine and groundshine pathways contribute roughly equally, whereas the inhalation pathway is insignificant. The 4-hour stomach dose exceeds the ~50 rem threshold for radiation-induced injury to a distance of ~2.5 miles.

From the bottom figures, it can be seen that projected thyroid doses are dominated by inhalation doses. The ground and cloud shine contributions increase the thyroid dose only marginally within 24 hr. The 4-hr thyroid dose exceeds the ~200 rem threshold for radiation-induced hypothyroidism within about 5.25 miles.

The dose versus distance results clearly indicate that people close to the plant would have to take protective actions before or shortly after the start of the release to avoid injuries and fatalities. Actions taken after plume passage would be effective only in reducing additional dose from ground contamination. Beyond a certain radius, the direct dose from the plume (cloudshine and inhalation) is not sufficient to result in early injuries; but if people remain on contaminated ground, their dose can clearly increase to the point where injuries or fatalities become likely. Obviously, after a major release, areas of substantial ground contamination must be identified, and the population must be relocated.

For most LWR release scenarios, the greatest effluent concentrations occur within the first 2 to 3 miles. Therefore, independent of the size of the release, the greatest need for protective actions most likely will be within 2 to 3 miles of the plant. For large releases, these actions are taken to prevent early injuries and fatalities. For lesser releases, they are taken to keep doses below Environmental Protection Agency protective action guides, which are discussed in Appendix 5A.

Another point to be made from Figure 5.2-11 involves the plume exposure emergency planning zone, which is normally within a 10 mile radius of the plant (see Section 5.4.5.1). Many think that the public risk stops at the boundary of the emergency planning zone. But, it is clear that the postulated release could result in doses in excess of the Environmental Protection Agency whole body (1 to 5 rem) and thyroid (5 to 25 rem) protective action guides beyond 10 miles. At these levels, protective actions could be appropriate beyond the plume emergency planning zone.

5.2.6 Uncertainties in Dose Projections

In a 1981 study conducted at the Idaho National Engineering Laboratory, a nonradioactive tracer (SF_6) was released and the resulting air concentrations were compared with predictions made by various models to evaluate their potential use in emergency response situations. Figure 5.2-12 shows the actual air concentration (plume) pattern observed for one of the tests and the plume pattern predicted by three of the models tested under this program: (a) a simple, straight-line Gaussian plume model of the type used by many emergency response organizations, (b) a Gaussian-puff trajectory model, which accounts for wind shifts, and (c) a more sophisticated wind field and topographic model used in the DOE's Atmospheric Release Advisory Capability (ARAC) program. Even the most complicated ARAC model could not reproduce what actually occurred.

This result points out two concerns. First, only one meteorological tower is typically in the site vicinity. The initial transport of radioactive material from a site after it is released to the atmosphere will be dominated by local conditions (e.g., hills, valleys, lakes, and precipitation). This single source of weather and wind information cannot give a definitive indication of winds away from the plant. Nuclear power plants are typically located in very complex areas (e.g., in river valleys or on the coast), where wind direction and flows can vary considerably within a short distance of the plant. As an example, a 180° difference in wind direction could result from sea breeze effects at a coastal site. This is the basis for taking protective actions in all directions near (within 2 or 3 miles) of the plant. The events that occurred early in the TMI-2 incident (as discussed in Section 5.3.7), further illustrate the problems inherent in taking protective actions only in the downwind direction.

Second, differences should be expected in the estimates produced by various analysts. Various response organizations may be performing analyses based on different assumptions. For example, the NRC may be concentrating on dose projections based on possible additional plant failures, while the state is making dose projections based on estimates of actual releases. As Figure 5.2-12 indicates, even if the same input conditions (e.g., source terms and meteorology) are used, dose estimates may differ.

Unanticipated catastrophic containment failure is an example of a case where source term could be underestimated by a factor of 100,000. For lesser accidents (non-core damage) where the total release is through a monitored pathway and consists mostly of noble gases, the source term uncertainty can be reduced. However, the transport and dose uncertainties would remain. Overall, the best that should be expected in the early time frame is that projected dose estimates may be within a factor of 10 of the true dose value; more likely, they will be even less accurate.

It is clear that one should not expect close agreement when comparing various dose projections with each other or with early field monitoring data. Dose projections should be viewed only as rough estimates.

What may be more important than relying on a dose model in estimating plume movement is a knowledge of local meteorological conditions and trends (e.g., the winds shift every morning at about 9:00 a.m.).

The basic point here is that the analyst needs to understand the problem, the models, and the results. Indiscriminate use of technical aids such as dose projection models without access to staff who understand the unpredictability of local conditions can provide misleading input to protective action decision making.

5.2.7 Dispersion of the Chernobyl Release

As shown in Figure 5.2-10, the Chernobyl nuclear power plant is located between 51° and 52° north latitudes in the Ukraine in the Kiev region and is only 15 km from the south border of the Gomel region of Belarus. The western part of the Bryansk region of Russia is 150 km from the plant. The region is relatively flat, and elevations do not exceed 200 m. The climate is moderate, with warm summers, mild winters, and an average precipitation of 20 to 24 inches (500 to 650 mm).

From the time the accident began on April 26, 1986, a stream of hot air carried radioactive materials from the destroyed reactor into the atmosphere. Volatile iodine and cesium radioisotopes were discovered at heights up to 6 to 9 km. The exposure rate in the stream at a distance of 5 to 10 km and a height of 200 m was approximately 1 rad/h on April 27 and 0.5 rad/h on April 28.[8]

When the plume of radioactive material first rose on April 26, the winds carried it northwest into Latvia, Scandinavia, Lithuania, and Northern Poland. On the second day, the winds changed, blowing to the west and southwest and passing over Southern Poland, Switzerland, Italy, Austria, Southern Germany, and France. On the fifth day the wind changed back to the northwest and the cloud moved into Central Germany, the Netherlands, and Great Britain. Eventually, the winds blew northeast spreading the fallout into Central Russia. Some radioactive material road the jet-stream over the United States and other countries. Trace levels of I-131 were measured in Japan and the United States by May 5.[9]

In all, more than 20 countries received fallout from Chernobyl, exposing nearly 400 million people. Deposition patterns were complex and diverse. They depended on both particle densities and the weather. The largest particles, which were primarily fuel particles, were deposited within 100 km of the reactor. Both in this near zone and across the former Soviet Union and Europe, levels of contamination depended on whether it was raining when the cloud passed over. Outside the former Soviet Union, the Lap people of northern Sweden were perhaps hardest hit. Their reindeer herds were so contaminated they were unfit for human consumption.

Ukraine, Belarus, and Russia were subjected to the most intense radioactive contamination (see Figure 5.2-10).[10,11] The three main regions of contamination have been designated the Central, Bryansk-Belarus and Kaluga-Tula-Orel hot spots. The following information regarding these hot spots and other contamination is taken from Reference 12 and summarized in Table 5.2-2.

The central hot spot was formed during the initial active stage of the release, predominantly to the west and northwest. Cs-137 soil surface activities in excess of 1.0 $\mu Ci/m^2$ covered large areas of the territory of the Kiev, Zhitomir, Chernigov, Rovno, and Lutsk regions of the Ukraine; as well as the Gomel and Brest regions of Belarus. The most highly contaminated area was the 30-km radius surrounding the reactor, where Cs-137 surface activities generally exceeded 40 $\mu Ci/m^2$. Outside the 30-km zone, such areas were also present to the west and northwest of the reactor in the Gomel, Kiev, and Zhitomir regions. The initial gamma dose rate (1 m above the ground) from deposited radionuclides ranged from 1 to 200 mrad/h. By 1991, these dose rates had decreased to 0.005 to 1 mrad/h.

The Bryansk-Belarus hot spot, centered 200 km to the north-northeast of Chernobyl, was formed on April 28-29, 1986 as a result of rainfall at the interface of the Bryansk region of Russia and the Gomel and Mogilev regions of Belarus. The soil surface activities of Cs-137 in the most highly contaminated areas in this hot spot were comparable to the levels in the central hot spot and exceeded 130 $\mu Ci/m^2$ in some villages of the Mogilev region and 110 $\mu Ci/m^2$ in the village Zaborye of the Bryansk region. The initial dose rates in air ranged form 0.3 mrad/hr to 30 mrad/hr. By 1991, these dose rates had fallen to 0.005 to 0.5 mrad/hr. The Bryansk-Belarus spot was called a "cesium hot spot" because of the predominance of long-lived Cs-137.

The Kaluga-Tula-Orel spot in Russia, centered approximately 500 km northeast of the reactor, was also a "cesium hot spot." It was formed from the same radioactive cloud that produced the Bryansk-Belarus spot, as a result of rainfall on April 28-29. However, Cs-137 contamination levels were lower, less than 0.16 $\mu Ci/m^2$. The initial dose rates over this hot spot ranged from 0.3 to 3.0 mrad/hr. By 1991 these dose rates had fallen to 0.005 to 0.05 mrem/hr.

Outside the three main hot spots in the greater part of the European territory of the former Soviet Union, there were many areas of radioactive contamination with Cs-137 levels mainly in the range 1 to 5 $\mu Ci/m^2$. Overall, the contaminated land areas of the former Soviet Union included approximately

3,100 km^2 with >40 $\mu Ci/m^2$ Cs-137,
7,200 km^2 with 16 to 40 $\mu Ci/m^2$ Cs-137,
17,600 km^2 with 5 to 16 $\mu Ci/m^2$ Cs-137,
103,000 km^2 with 1 to 5 $\mu Ci/m^2$ Cs-137.[11]

The total Cs-137 activity in areas where Cs-137 levels exceeded 1 $\mu Ci/m^2$ is estimated to be approximately 1.0 MCi, including 0.3 MCi within a radius of 40 km around the reactor.[10,11] Accounting for the large area with Cs-137 contamination levels less than 1.0 $\mu Ci/m^2$, the total Cs-137 deposition in the former Soviet Union is estimated to be 1.3 MCi, 95% of which was deposited in the European part and 5% outside this part (east of the Ural mountain range).

Most of the Sr-90 released was deposited in the near zone of the accident. In fact, areas with Sr-90 surface activity levels on the soil exceeding 3.0 $\mu Ci/m^2$ were almost entirely within the 30-km zone. Areas with Sr-90 levels exceeding 1.0 $\mu Ci/m^2$ were almost entirely within the 100-km zone. Only a few separate sites with Sr-90 levels in the range 1.0 to 3.0 $\mu Ci/m^2$ were found in the Bryansk-Belarus hot spot.

Information on areas contaminated with plutonium isotopes is not extensive because of the difficulty in detecting these isotopes. The only hot spot with plutonium (Pu-239 and Pu-240) surface activity on the soil exceeding 0.1 $\mu Ci/m^2$ was located completely within the 30-km zone. In the regions of the Bryansk-Belarus and Kaluga-Tula-Orel hot spots, plutonium activity levels ranged from 0.002 to 0.02 $\mu Ci/m^2$ and 0.002 to 0.008 $\mu Ci/m^2$, respectively. Although Cs-137 and Sr-90 levels were well correlated in these regions, there was no apparent correlation between plutonium and Cs-137 or Sr-90 levels.

5.2.8 Perspective on Dose Projections

In the past, considerable attention has been given to the use of real-time dose projections as the primary basis for initiating offsite protective actions. Section 5.1 highlights the difficulty of predicting the source term with sufficient accuracy to justify this use of real-time dose projections during a severe accident. This section explains why significant uncertainties would still be associated with projecting offsite doses, even if one could accurately predict the timing, energetics, composition, and amount of radioactive material that may be or is being released from a plant during a severe accident. As a result, decisions regarding early protective actions should be based on plant conditions, which demonstrate the potential for a large release, not on dose projections for some assumed source term and weather. Nevertheless, both pre-calculated and real-time dose projections in conjunction with early field monitoring would play a useful role in responding to a severe accident.

Precalculated dose projections may be useful in comparing the consequences of various plant response options (e.g., venting the containment versus allowing later containment failure). During the initial phase of a severe core damage accident, precalculated and real-time dose projections would be helpful in establishing priorities for the use of limited resources in the implementation of offsite actions such as deployment of field-monitoring teams. In an actual uncontrolled release of radioactive material to the environment, it would be imperative to obtain offsite monitoring team data as quickly as possible.

After implementation of protective actions near the plant (based on an assessment of plant conditions), dose projections may assist in determining whether these actions should be extended. The model projections may indicate the maximum distance from the plant where further actions are required. Another role of dose projections is to provide feedback regarding the magnitude and composition of a release based on the analysis of offsite samples and field monitoring results.

Table 5.2-1 Relationship between Pasquill category and $\Delta T/\Delta z$ and σ_θ*

Pasquill category	$\Delta T/\Delta z$ (°C/100 m)	σ_θ (degrees)
A - Extremely unstable	$\Delta T/\Delta z \leq -1.9$	$\sigma_\theta \geq 22.5$
B - Moderately unstable	$-1.9 < \Delta T/\Delta z \leq -1.7$	$22.5 > \sigma_\theta \geq 17.5$
C - Slightly unstable	$-1.7 < \Delta T/\Delta z \leq -1.5$	$17.5 > \sigma_\theta \geq 12.5$
D - neutral	$-1.5 < \Delta T/\Delta z \leq -0.5$	$12.5 > \sigma_\theta \geq 7.5$
E - Slightly stable	$-0.5 < \Delta T/\Delta z \leq 1.5$	$7.5 > \sigma_\theta \geq 3.8$
F - Moderately stable	$1.5 < \Delta T/\Delta z \leq 4.0$	$3.8 > \sigma_\theta \geq 2.1$
G - Extremely stable	$4.0 < \Delta T/\Delta z$	$2.1 > \sigma_\theta$

*From Regulatory Guide 1.23, U.S. Nuclear Regulatory Commission, 1980.

Table 5.2-2 Characteristic of hot spots resulting from Chernobyl accident*

Hot Spot	Direction	Cs-137 Soil Surface Activity (μCi/m^2)	Initial Dose Rate (mrad/hr)	1991 (5 yr) Dose Rate (mrad/hr)
Central	W-NW	to >40	1 to 200	0.005 to 1
Byransk-Belarus	Centered ~200 km N-NE	>130	0.3 to 30	0.0005 to 0.5
Kaluga-Tula-Orel	Centered ~500 km NE	<0.16	0.3 to 3	0.0005 to 0.05

* From Reference 12.

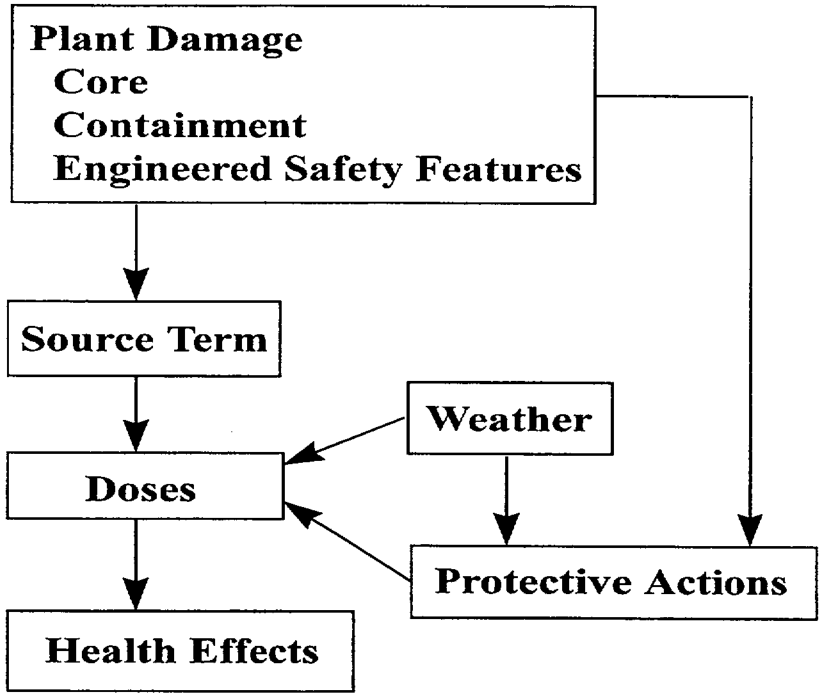

Figure 5.2-1 Steps in projecting offsite consequences

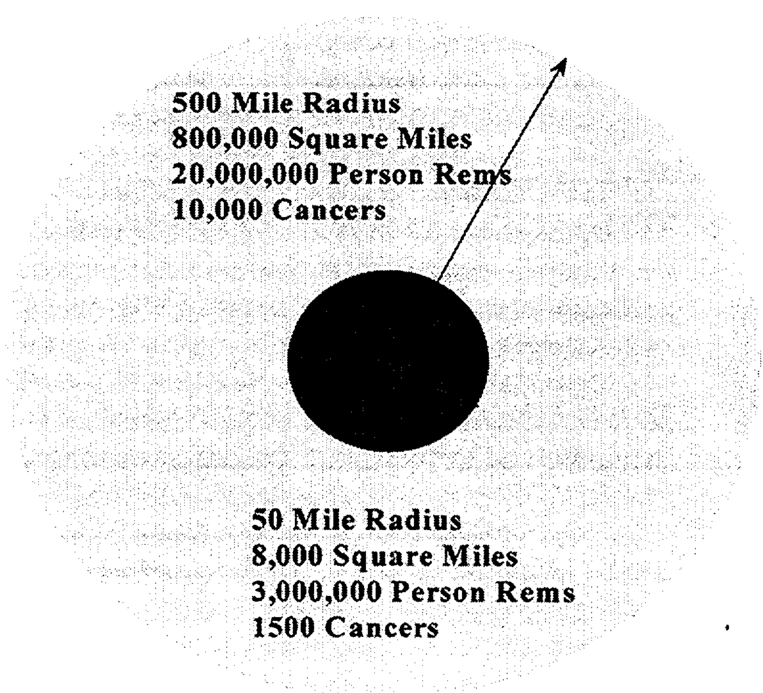

Figure 5.2-2 Illustration of person-rems and cancers within 50 and 500 mile radii

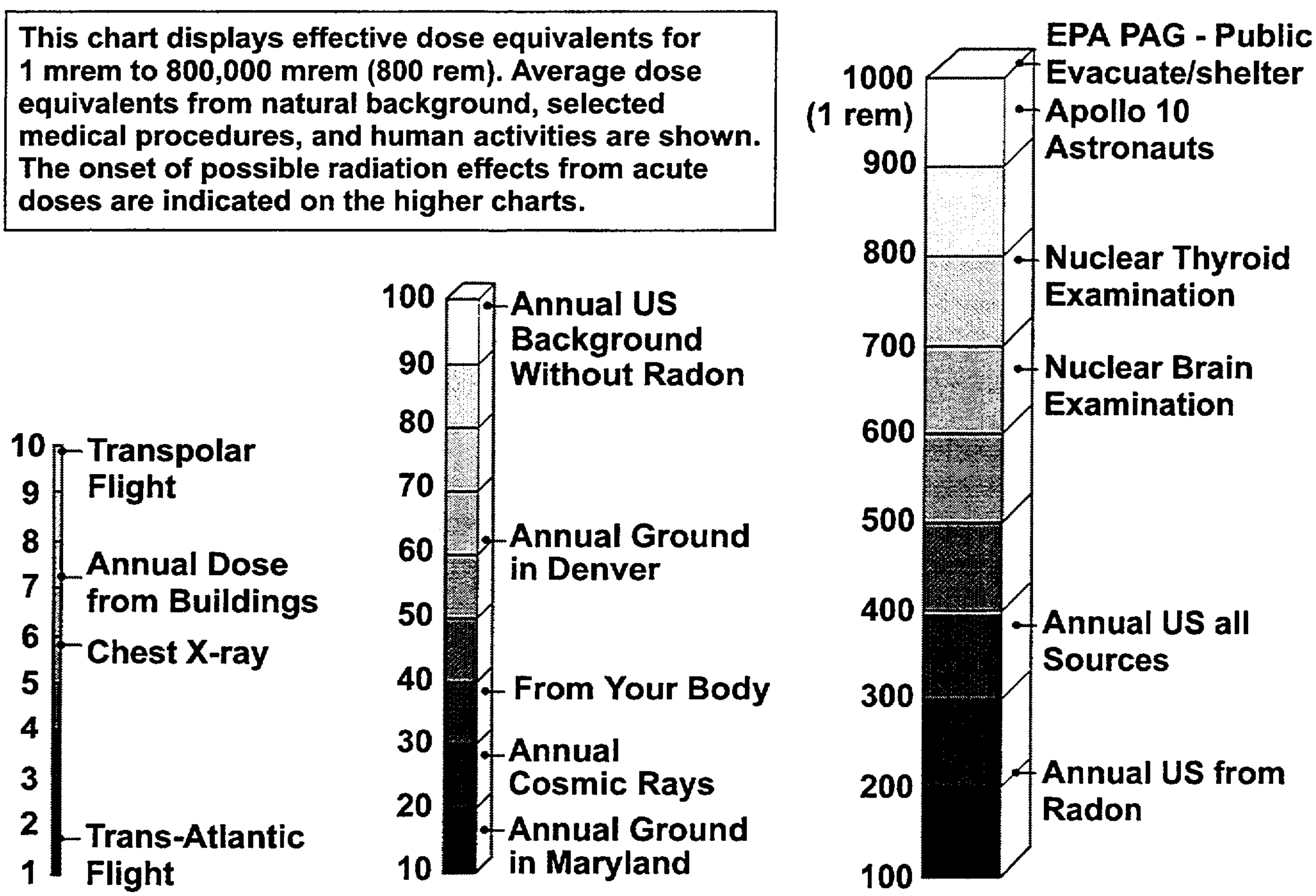

Figure 5.2-3a Putting radiation in perspective for the public (mrem)

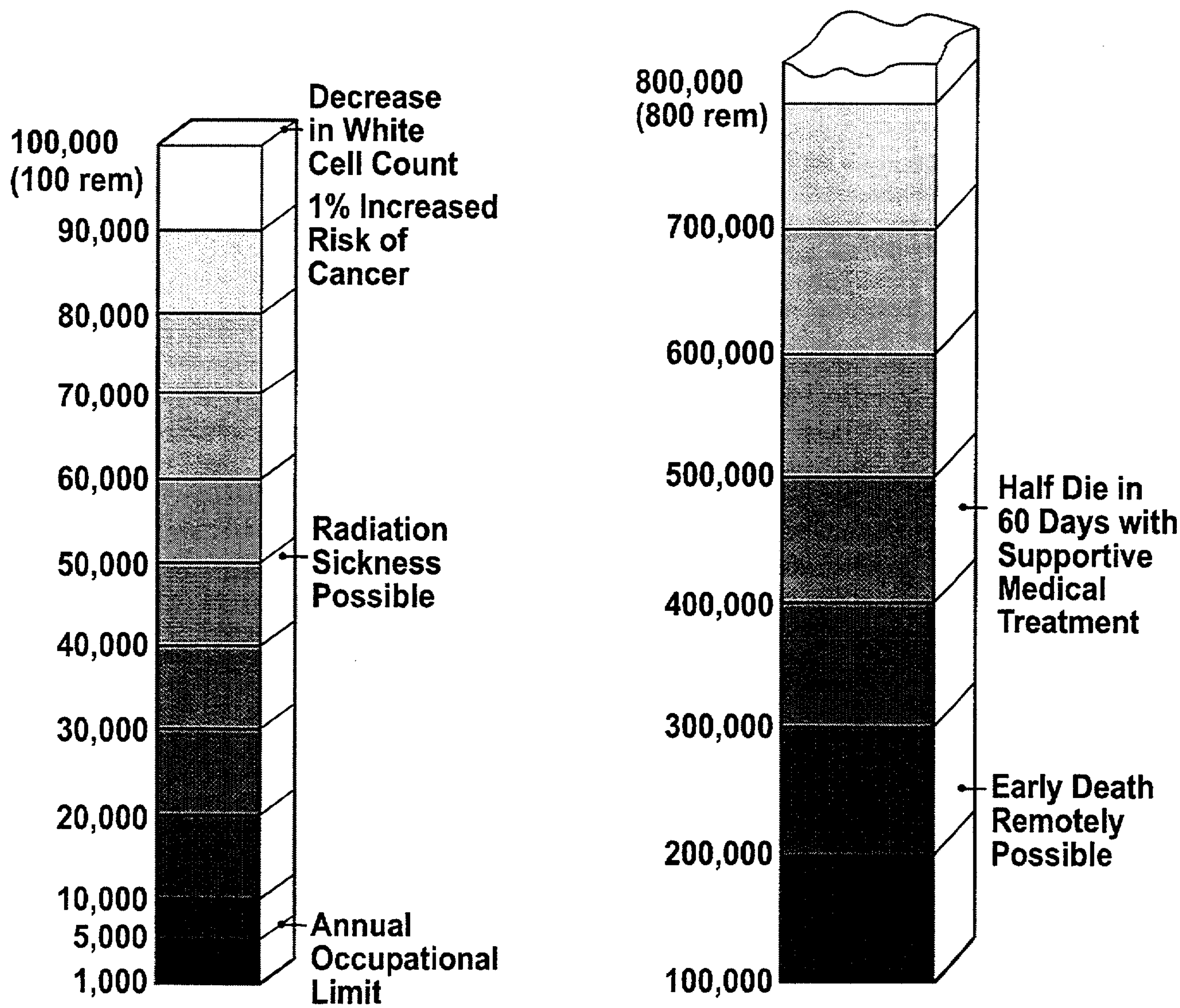

Figure 5.2-3b Putting radiation in perspective for the public (mrem)

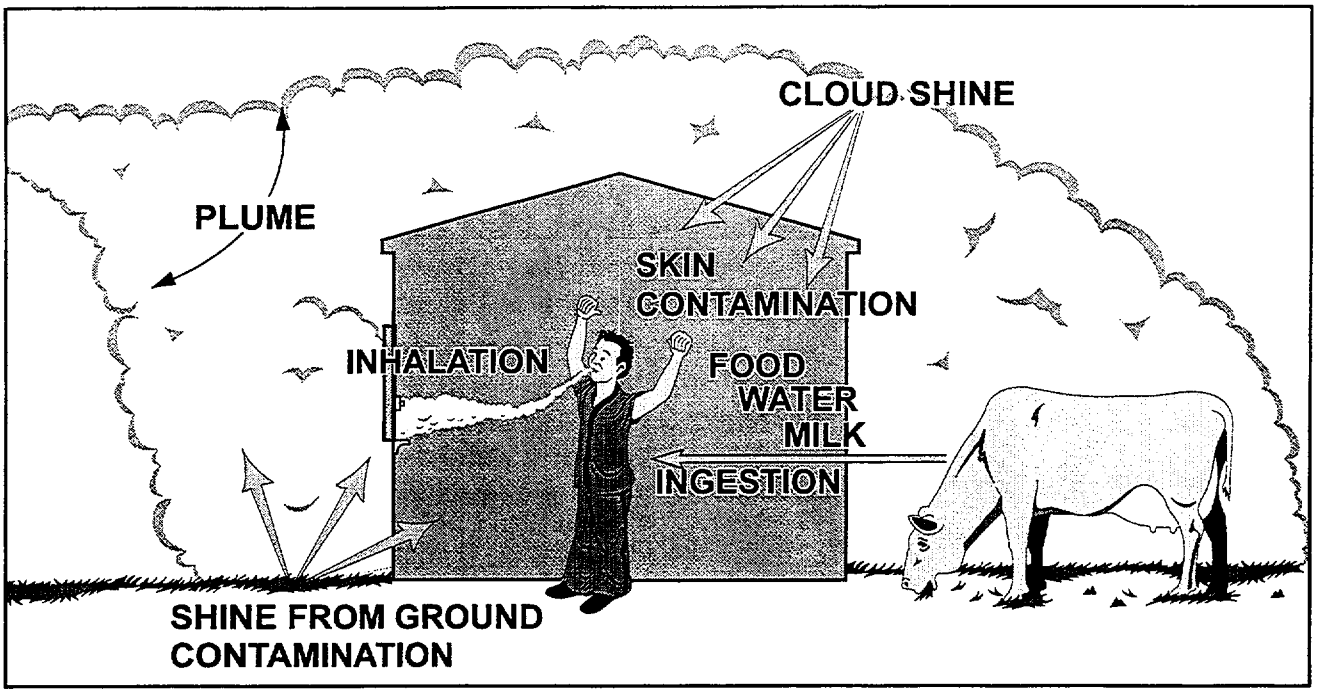

Figure 5.2-4 Radiation dose pathways

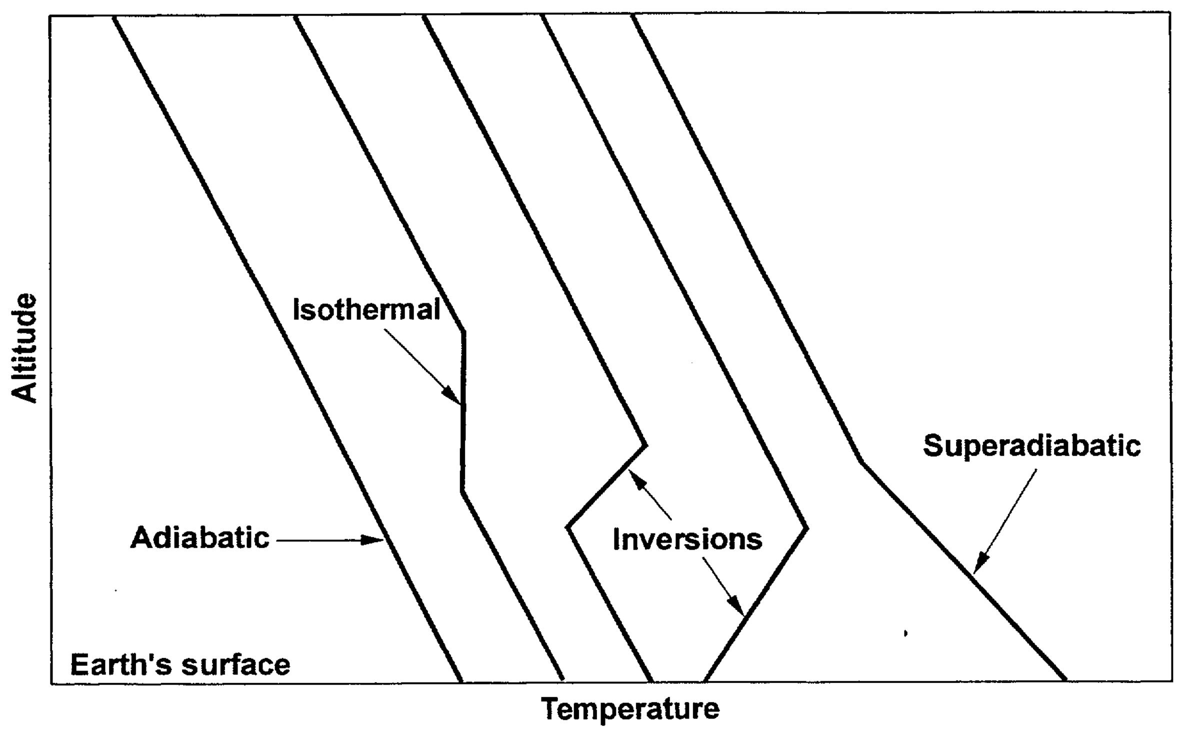

Figure 5.2-5 Examples of low-level temperature distribution in the atmosphere

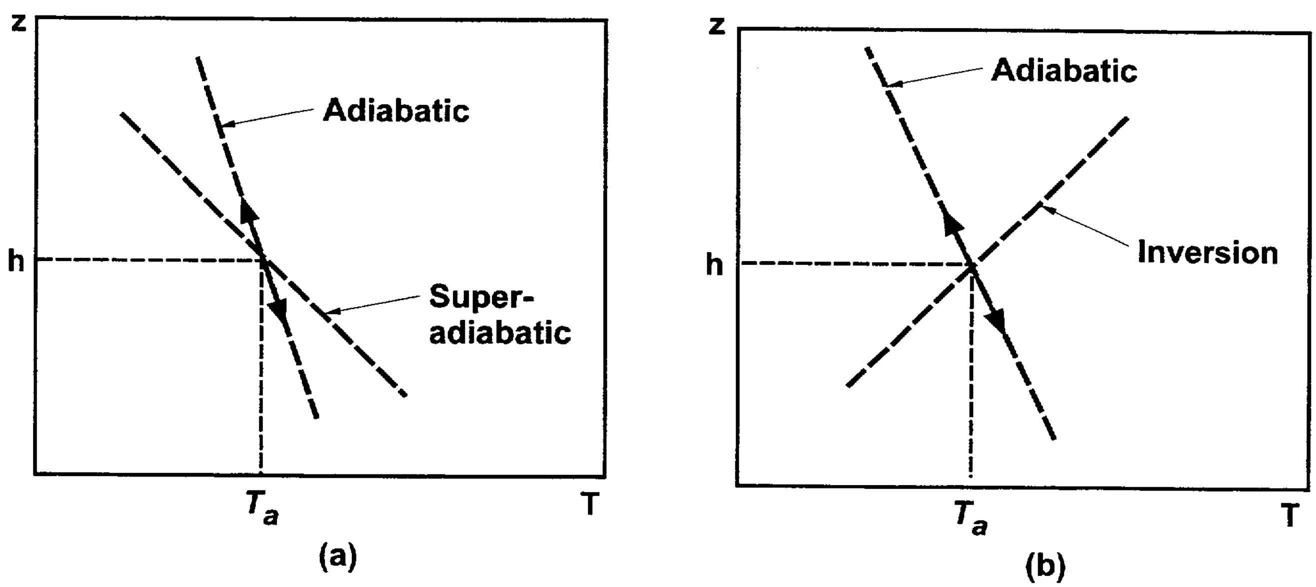

Figure 5.2-6 Movement of a parcel of air in (a) a superadiabatic profile and (b) an inversion profile

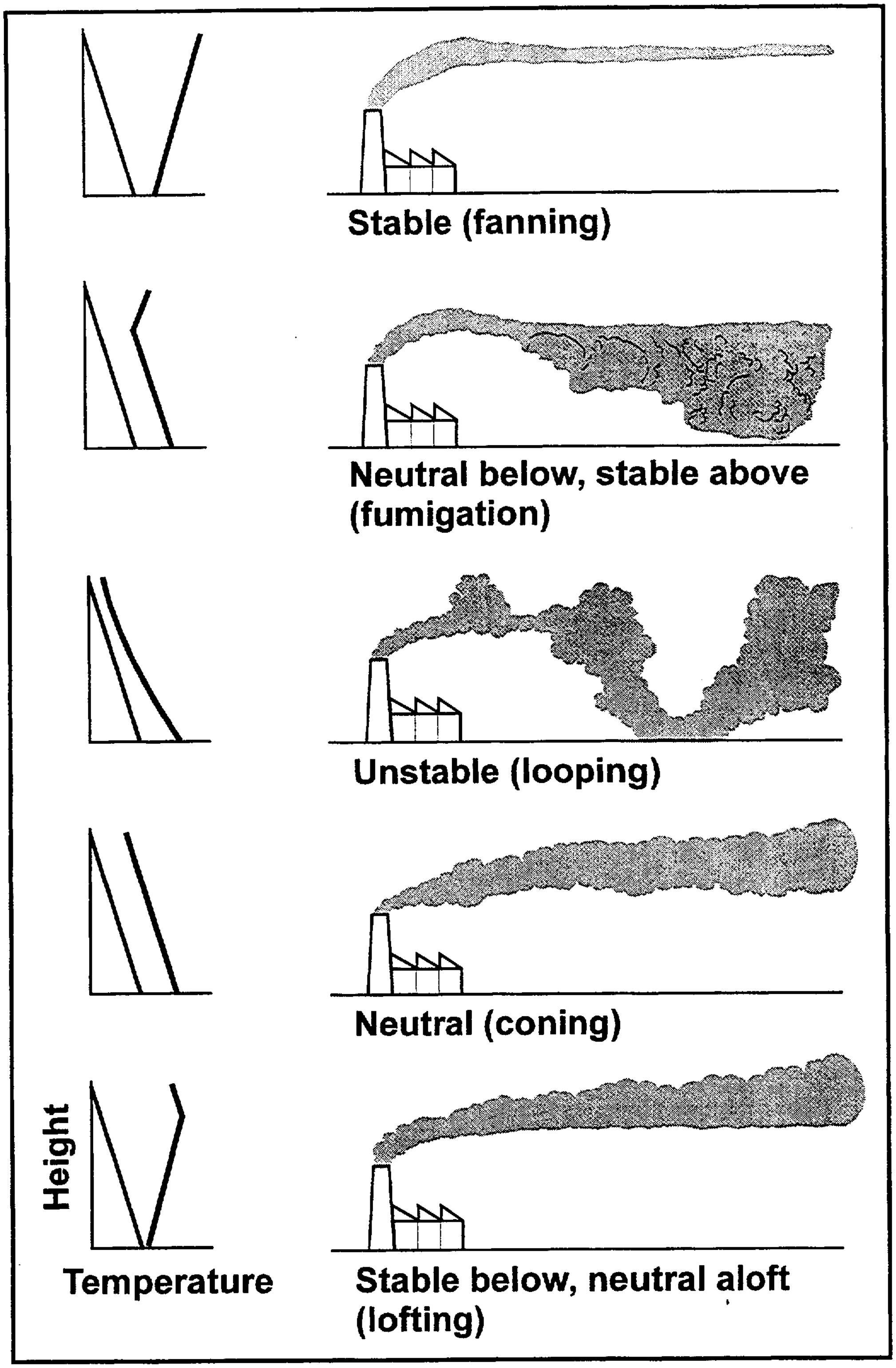

Figure 5.2-7 Various types of smoke plume patterns

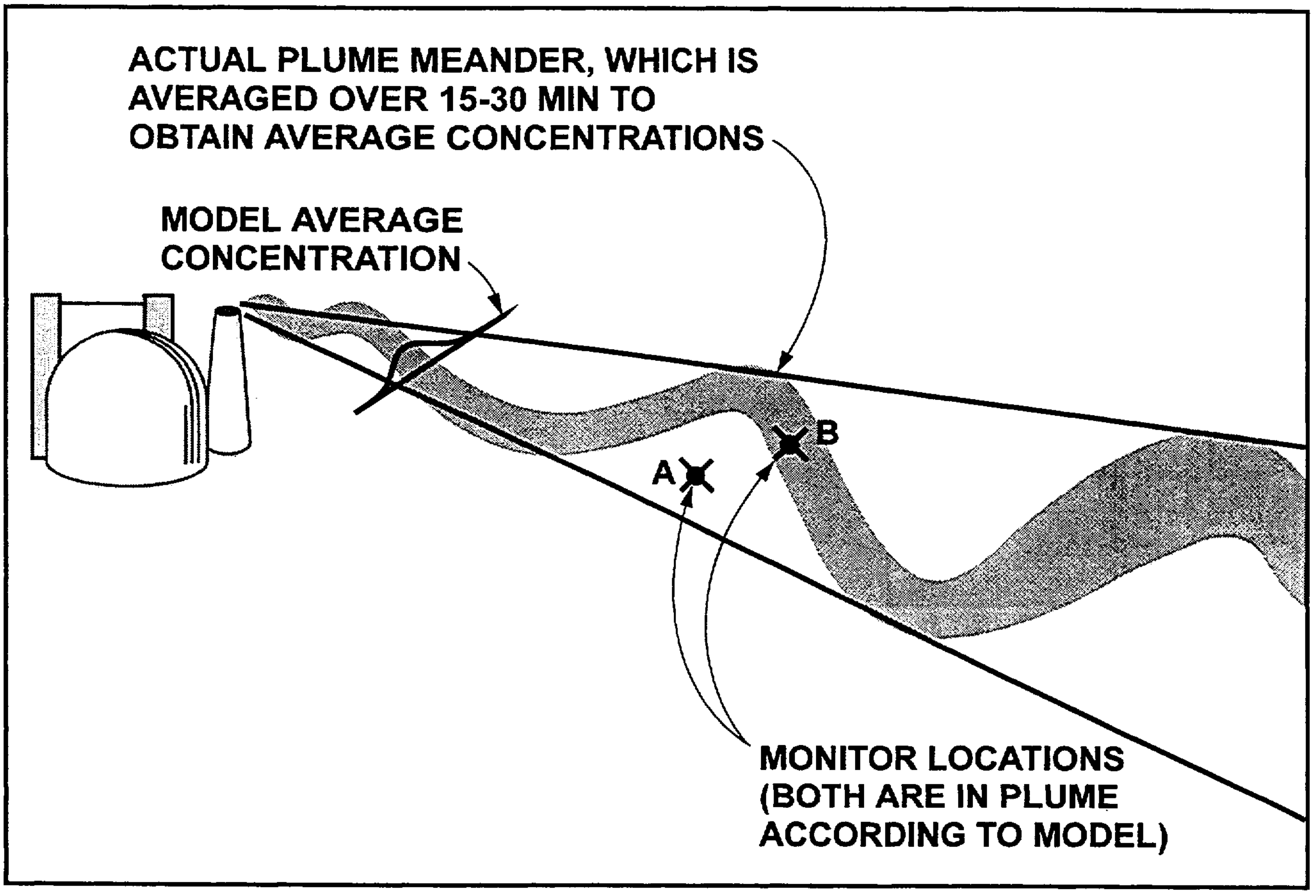

Figure 5.2-8 Relationship between actual plume and model projections

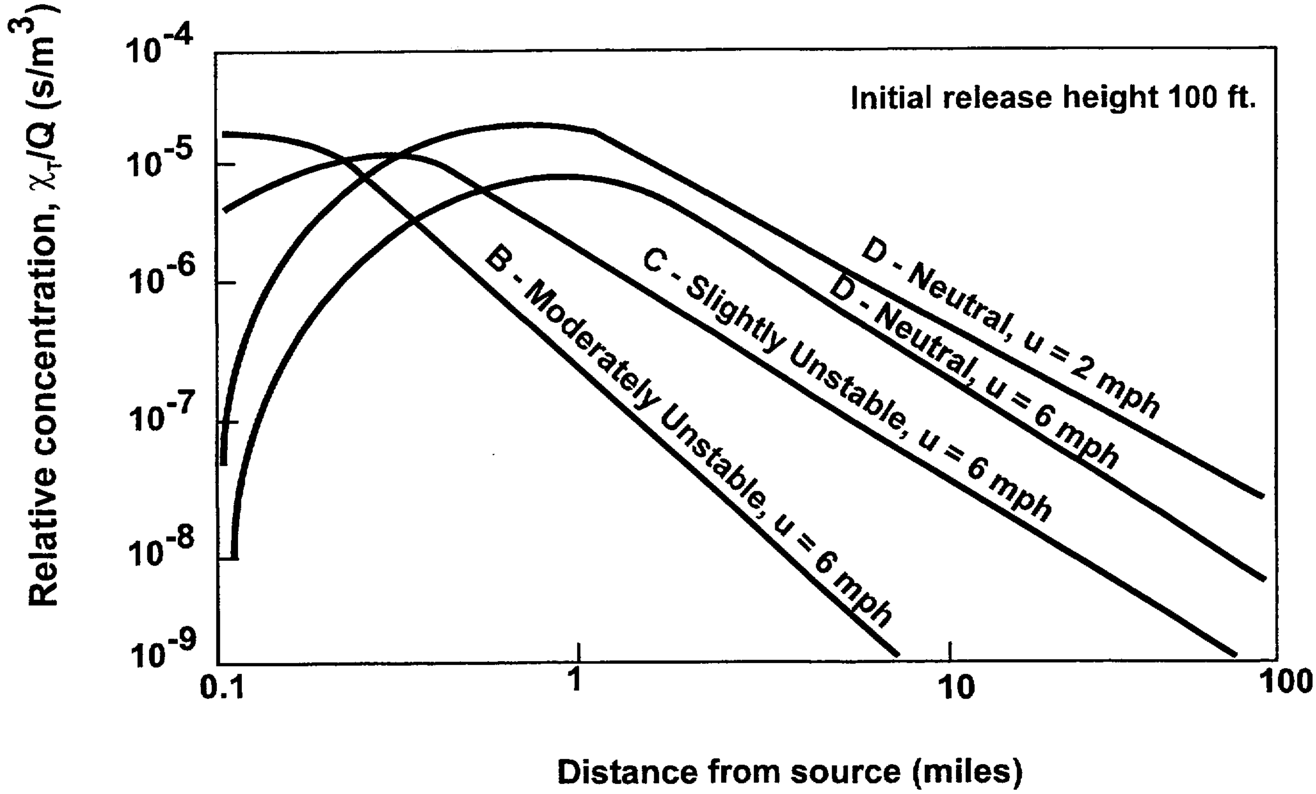

Figure 5.2-9 The quantity χ_T/Q at ground level for effluents emitted at a height of 30 m, as a function of distance from the source

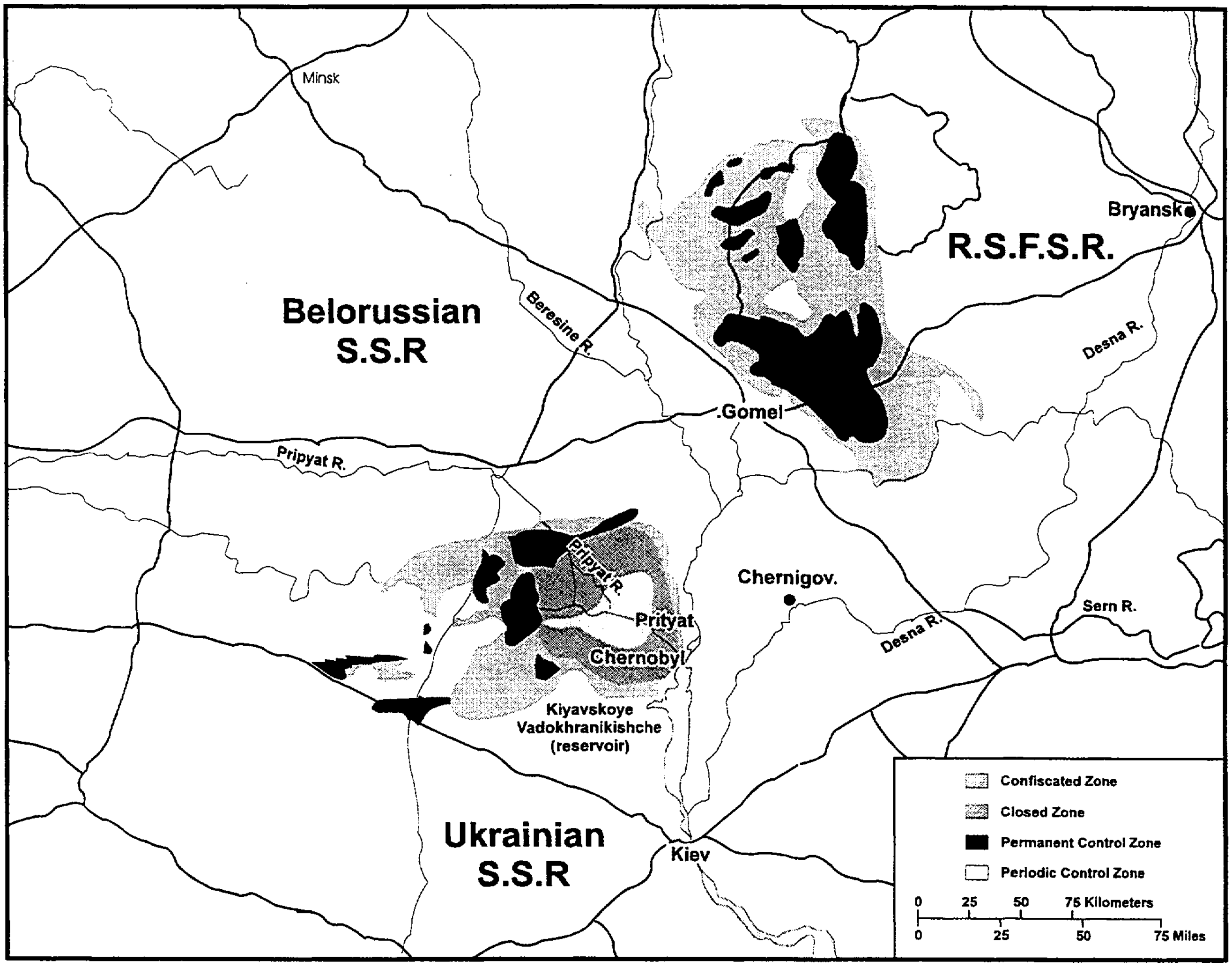

Figure 5.2-10 Radiation hot spots resulting from Chernobyl nuclear power plant accident

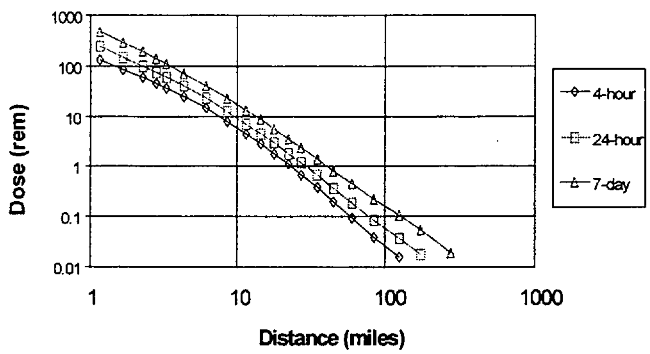

Figure 5.2-11a Stomach dose by exposure time: no sheltering, stability class D, 2.68 m/s wind

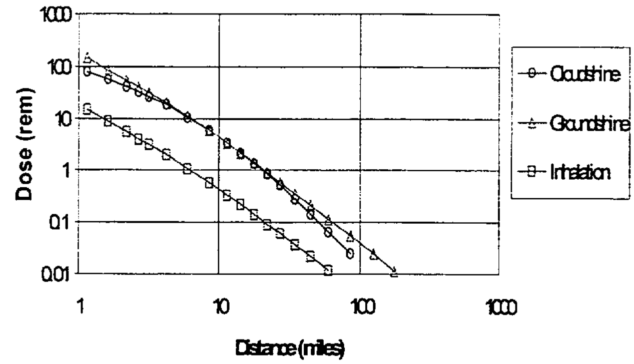

Figure 5.2-11b Plume centerline stomach dose by pathway: no sheltering, 24-hour exposure, class D, 2.68 m/s wind

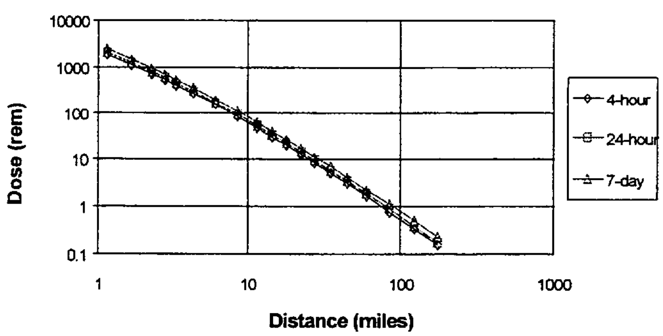

Figure 5.2-11c Thyroid dose by exposure time: no sheltering, stability class D, 2.68 m/s wind

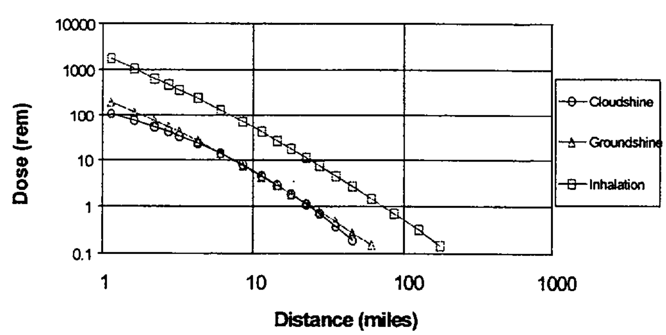

Figure 5.2-11d Plume centerline thyroid dose by exposure pathway, no sheltering, 24-hour exposure, class D, 2.68 m/s

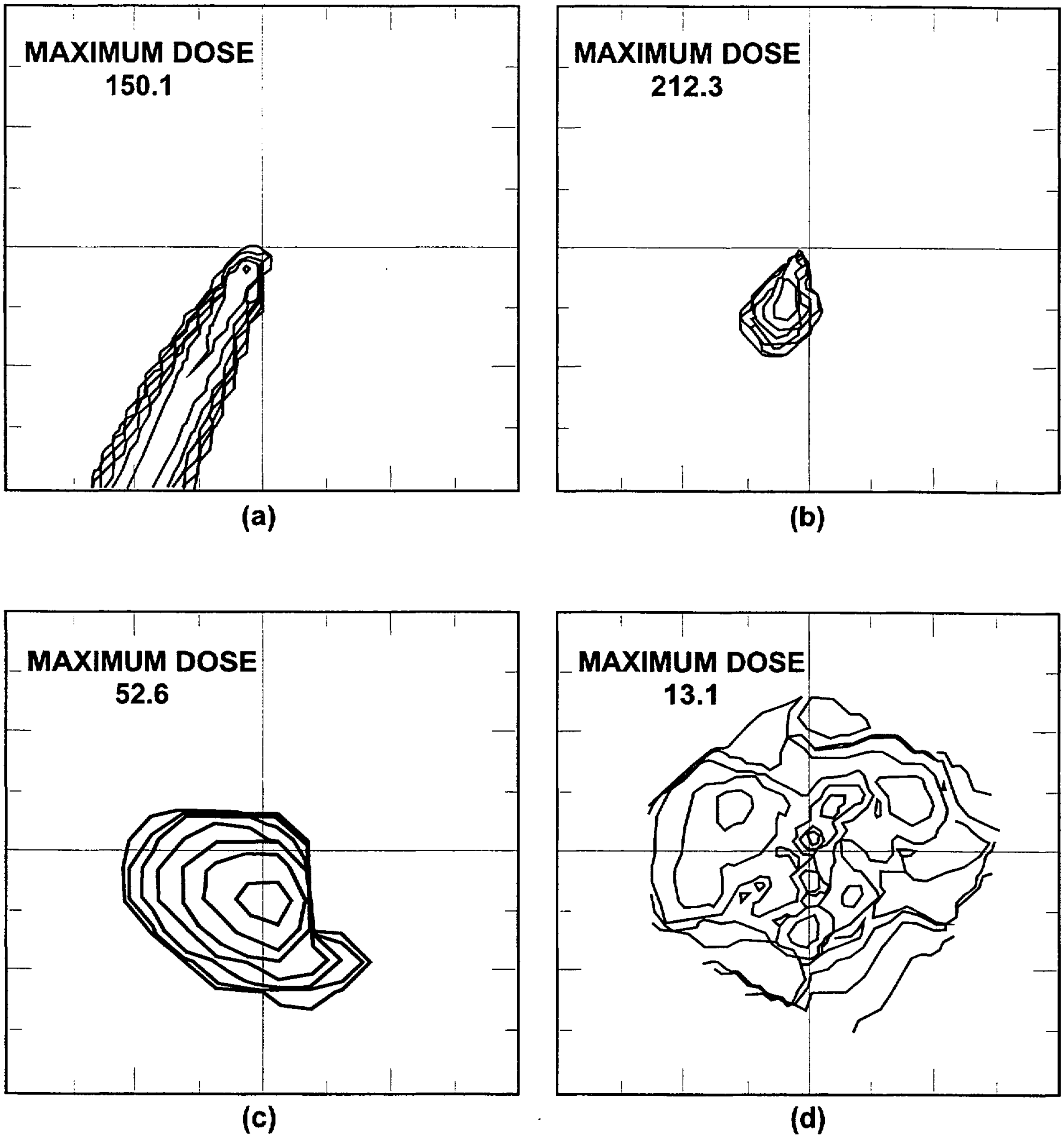

Figure 5.2-12 **One-hour surface doses predicted by (a) Gaussian plume model, (b) puff-trajectory model, (c) complex numerical model, and (d) doses actually observed**

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2. NUREG-1150, Table 11.7, Plant 3, exceedance frequency 10^{-6} yr^{-1}, mean complementary cumulative distribution function (CCDF), adjusted to one cancer per 2000 person-rem, June 1989.

3. U.S. Nuclear Regulatory Commission, "RTM-96 Response Technical Manual," Vol. 1, Rev. 4, March 1996, pp. O-6 to O-9.

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5.3 Protective Actions

The public can usually be protected from an uncontrolled release of radiological material only by some form of intervention (e.g. evacuation) that disrupts normal living. Such intervention is termed protective action. This section presents information regarding the appropriate timing and potential effectiveness of various protective actions. Emergency preparedness, that is, the process of preparing to take effective actions to protect the public in the case of a U.S. reactor accident, is the subject of Section 5.4.

5.3.1 Basic Concepts

5.3.1.1 Early, Intermediate, and Late Phases

In discussing protective actions, it is convenient to identify three time phases: early, intermediate, and late. Although the time intervals associated with these phases may overlap, different considerations apply within each phase.

The early phase (also referred to as the emergency phase) is the period at the beginning of a reactor accident when immediate decisions for the effective use of protective actions are required. This phase may last from hours to days.

The intermediate phase is the period beginning after the radiological releases have been brought under control and reliable environmental measurements are available to provide a basis for decisions on additional protective actions. It extends until these additional protective actions are terminated. This phase may overlap the early and late phases and last from weeks to many months.

The late phase (also referred to as the recovery phase) begins with recovery actions designed to reduce radiation levels in the environment and ends when all recovery actions have been completed. This period may extend from months to years.

The protective actions available to avoid or reduce radiation dose can be categorized as a function of exposure pathway and incident phase, as shown in Table 5.3-1. Evacuation and sheltering are the principal protective actions available to protect the public from exposure during the early phase. It may also be appropriate to take actions to protect against contamination of milk (primarily by radioactive iodine) or to issue stable iodine to reduce thyroid doses. The use of simple, ad hoc respiratory protection may also be appropriate.

It is necessary to distinguish between evacuation and relocation with regard to incident phases. Evacuation is the urgent removal of people from an area to avoid or reduce high-level, short-term exposure, usually from the plume or deposited activity. Relocation, on the other hand, is the removal or continued exclusion of people (households) from contaminated areas to avoid chronic radiation exposure. Conditions may develop in which some groups who have been evacuated in an emergency may be allowed to return, while others may be converted to relocation status.

Relocation and decontamination are key protective actions for the intermediate and late phases. Decisions would be made during the intermediate phase concerning whether areas from which the public has been relocated should be decontaminated and reoccupied, or condemned and the occupants permanently relocated. Another protective action for the intermediate and late phases is the imposition of restrictions on the use of contaminated food and water.

5.3.1.2 Basic Radiation Protection Objectives

Protective actions taken in response to a severe accident at a nuclear power plant have the following objectives:

1. To avoid (prevent) doses sufficient to cause early health effects (injuries or deaths) that would be seen at specific organ (e.g., bone marrow or thyroid) doses above 50 rem;

2. to reduce early off-site doses that would otherwise exceed federal protective action guidelines (see Appendix 5A); and

3. to reduce the risk of long-term health effects (e.g., cancers).

These objectives are listed in decreasing order of importance. Initial protective actions should be directed toward meeting the first objective by keeping the acute doses from the passing plume (cloud shine, ground shine, and inhalation doses) below levels that could result in early injuries or deaths. Federal protective action guides (PAG) dose levels are well below the levels that would cause early health effects (see Appendix 5A).

5.3.1.3 Early Protective Action Guidance

Guidance regarding early protective actions has evolved from numerous severe accident studies. This guidance has been incorporated into response procedures and training manuals for the NRC staff, the latest edition of which is Response Technical Manual (RTM)-96.[1] Figures 5.3-1 and 5.3-2 depict the current strategy. In short, the early protective action guidance says, given a severe core damage accident, people should immediately evacuate areas near the plant (within a 2 to 3-mile radius) and remain in shelter elsewhere for the immediate future. Let us now examine the rational for this guidance.

5.3.1.4 Timing of Initial Actions

First, consider the need for the immediate implementation. As discussed in Section 5.1, core damage and containment failure are both required for a large release. Control room indicators of core damage should be numerous. On the other hand, it would be virtually impossible to predict the occurrence or time of containment failure in most severe accidents. A major release would be very intense with most of the radioactive material being released within 0.5 to 2.0 hr of containment failure. Relying on predictions of containment failure or waiting for indications of containment failure could delay an evacuation during the period when it would be the most effective action for avoiding offsite health effects.

The best way to ensure that protective actions are started before a major release is to initiate the actions as soon as core damage is detected. If the decision to take action awaits dose projections or field monitoring results, the population close to the plant could be exposed to the large radioactive plume. This is one of the primary reasons for establishing emergency action levels that tie the declaration of a General Emergency (see Section 5.4) to clear indications of core damage.

5.3.2 Evacuation

Early evacuation of the area near the plant has several benefits in terms of public safety:

1. Cloud shine dose from all or at least part of the plume can be avoided (if the evacuation begins before or shortly after the release).

2. Dose from contaminated ground and other surfaces can be avoided.

3. Inhalation of contaminated air can be avoided.

4. The highest-risk areas would be cleared early, thereby permitting emergency response teams to focus on other areas.

Immediate evacuation of people near the plant could well prove to be precautionary because most severe accidents (like the Three Mile Island accident) would not be expected to lead to a major release. On the other hand, core damage accidents are expected to be extremely rare; so that precautionary evacuations would also be rare, and the results of not taking immediate protective actions could be tragic. As illustrated in Section 5.3.2.2, for a severe accident resulting in a large release, evacuation near the plant (within 2 to 3 miles) may be the only action that can prevent early health effects.

5.3.2.1 Effectiveness of Evacuation

A concern is sometimes raised that, once a release from a severe reactor accident starts, an evacuation should not be recommended because the evacuees may run into or be overtaken by the plume. However, as illustrated in Section 5.2.4, plume concentrations decrease exponentially with distance from the source.

As a result, large reductions in doses to individuals may be achieved by evacuation. Evacuation also precludes the possibility of long term exposure to hot spots. In contrast, sheltering in a typical farm house reduces a person's dose by no more than a factor of 2, and does not preclude long term exposure to hot spots. Consequently, public officials must continue to be concerned about people in shelters.

Studies consistently indicate that evacuation during plume passage does not increase risk over sheltering in a typical residential home. Conversely, delaying evacuation can considerably increase risk. These finding are, for example, consistent with NUREG-1150 results that compare the following six protective action scenarios:

1. Normal activity, which assumes that no protective actions are taken during the release but that people are relocated within 6 hours of plume arrival.

2. Home sheltering, which assumes (a) shielding typical of masonry houses or basements of wood frame houses, (b) inhalation protection consistent with such homes, and (c) relocation within 6 hours of plume arrival;

3. Large building shelter, which assumes sheltering in a large building such as an office building, hospital, apartment building, or school, indoor protection for inhalation of radionuclides, and relocation within 6 hours of plume arrival;

4. Radial evacuation at 2.5 miles/hr starting 1 hour before release;

5. Radial evacuation at 2.5 miles/hr starting at the time of release;

6. Radial evacuation at 2.5 miles/hr starting 1 hour after the start of release.

Figures 5.3-3 and 5.3-4 show the conditional probabilities of exceeding 50-rem and 200-rem red bone marrow doses for the six scenarios assuming an early containment failure at Zion with source term magnitudes varying from low to high.[2] These figures indicate a large probability of doses exceeding 200 rems (and the associated risk of fatalities) within 1 to 2 miles of the plant. With no protective actions, the probability of doses exceeding 50 rems (and the associated risk of radiation-induced injuries) is significant even 10 miles away. Sheltering in a typical house does not significantly lower these probabilities.

As indicated, evacuation before release (scenario 4) provides the greatest risk reduction. Evacuation at time of release (scenario 5) evacuation 1 hour after release (scenario 6) both result in exceedance probabilities that are lower than or, at large distances, comparable to those for basement sheltering. Therefore, if a large release can occur, it is prudent to consider prompt evacuation.

At 3 miles and beyond, it is possible to avoid doses exceeding 200 rems by sheltering in large buildings even in the case of a large release. People in large buildings such as hospitals would therefore not necessarily have to be immediately evacuated, but could shelter instead. Of course, further reductions in dose are possible by prompt evacuation.

At 10 miles, no protective actions except relocation would be necessary to avoid 200-rem doses. Sheltering in large buildings or evacuation prior to release would keep doses below 50 rem.

Calculations also indicate the importance of monitoring ground contamination following plume passage and quickly relocating sheltered individuals away from hot spots. In calculations like those performed for NUREG-1150, people are typically assumed to relocate if the ground contamination is 1 rem/h (about 100,000 times the normal background dose rate).

Few people live close to most nuclear power reactors. Figure 5.3-5 illustrates the number of people within 1 and 5 miles of 111 nuclear power plant sites (actual or proposed in 1979).[3] Well below 10,000 people live within a 1 to 5 mile radius. In fact, at most sites, fewer than 300 people live within 2 miles of the site. Indeed, the area within a 2- to 3-mile radius encompasses the low-population zone around most reactor sites. There would normally be few impediments to immediate evacuation of the population within a 2- to 3-mile radius.

The basic conclusion is that, even for a large release, large numbers of early fatalities can be prevented if (a) areas near the plant (2 to 3 miles) are evacuated before or shortly after the release and (b) prompt monitoring is conducted to locate ground contamination that would result in expeditious relocation of people sheltered outside the evacuation zone.

5.3.2.2 Evacuation Risks

Objections have been raised to evacuation because of fears of panic or injuries during the evacuation. Evacuations of up to a few thousand people from areas up to about several square miles are not uncommon. Evacuations of significant size occur about every week to ten days in the United States. (Keep a mental note every time you hear of an evacuation.)

The historical fatality risk is about 1/500,000 per person during evacuations. This evacuation risk is considerably less than PRA estimates of a 1/10 to 1/100 risk of fatality given a core melt accident with no evacuation. Although the comparison says nothing definitive about the risk for any particular core melt accident, it does indicate strongly that, on the average, it would be far less risky for a person to evacuate than to remain within 2 to 3 miles of a nuclear power plant experiencing a severe core damage accident. Conversely, on a predetermined basis, an evacuation should not be recommended unless a core melt accident sequence is actually under way.

The practice of basing emergency plans for nuclear facility accidents on information regarding public behavior during nonnuclear emergencies has been questioned. Although the data base is limited, several nuclear-related incidents involving public response have occurred and can be compared to the nonnuclear experience. Some of these incidents (excluding weapons-related incidents) are presented in Table 5.3-2. The Environmental Protection Agency found no reason to expect that people would react differently to a nuclear accident than they would to a flood, fire, or similar emergency.[4]

The accident that appears to be of the greatest relevance is the one at Three Mile Island Unit 2 (TMI-2), which occurred at 4:00 a.m. on March 28, 1979. By 8:00 a.m., the national television networks were broadcasting the news. A small percentage of the local population left the area during the first two days. On the third day (Friday), the governor of Pennsylvania recommended the evacuation of children and pregnant women. By the end of the weekend, about half of the population within 20 miles had left the area. Throughout this time, the people were subjected to intense stress and (to them) conflicting opinions and advice. Despite these conditions, the evacuations that occurred were orderly.

Some observers have stated that the evacuations represented panic. Conversely, it could be argued that the public's behavior was perfectly understandable considering the intense pressures to which they were subjected (e.g., various authorities expressed diametrically opposed positions, and some authorities even reversed their own positions during the course of the accident). In fact, if the current protective action guidance had been in place at the time of the accident, evacuation of the area near the plant would have been recommended.

5.3.2.3 Entrapment Scenarios

Scenarios can be hypothesized in which evacuation may not be practical. For example, if an ice storm is in progress, if major transportation arteries are blocked, or if a major population center is involved, ordering an evacuation may result in entrapment of persons outside, where they may be more vulnerable than in their original locations (a car is not as good a shelter as a house). If early evacuation is simply not possible, local officials must use common sense in providing the best shelter and/or evacuation possible. Emergency personnel should monitor for ground contamination following a release, and motivate people to leave any highly contaminated areas (i.e., hot spots). It would, most likely, not be necessary for people to move very far from such heavily contaminated areas to significantly reduce their exposures. Expedient shelter of some sort is almost always available.

Entrapment problems are expected to be rare at most reactor sites in the United States, especially rare in conjunction with a severe accident. Fewer than 300 people live within 2 to 3 miles of most nuclear power plants in the United States. Within this distance there are few facilities such as hospitals that would require special attention in the event of an evacuation. At a few reactor sites where these conditions are not met, the emergency planner (and responder) must recognize that evacuation would be more difficult. Emergency plans must be prepared and decisions made accordingly.

5.3.3 Sheltering and Relocation from Hot Spots

Early sheltering is an appropriate protective action measure

1. for areas where the risk of exceeding the doses required for early health effects is relatively low,

2. for lesser events (e.g., Site Area Emergencies) where a major release is not expected,

3. if outside entrapment problems are likely to occur should an evacuation be attempted.

Table 5.3-3 provides factors that can be used to indicate the relative amount by which exposures may be reduced for various pathways as a result of sheltering. These sheltering factors should be used for comparison purposes only, not for predictive purposes. They can be used to determine the type of structure to recommend if a choice of structures is available. For cloudshine and groundshine, small farmhouses provide very little protection; but, if a farmhouse has a basement, protection can be improved. Large concrete structures can provide a great deal of protection.

Enclosed structures can offer protection from the inhalation pathway. The degree of inhalation protection provided depends on the "openness" or ventilation rate of the shelter and on how long the plume remains outside. Small dwellings with closed windows and doors ventilate at a rate of about one air turnover per hour. Based on risk assessments, life-threatening releases from U.S. plants would be expected to last less than two hours. Less-severe (in quantity) releases could last much longer. For a one-hour release, a protection factor of about three (two-thirds reduction in dose commitment) can be achieved in such a dwelling. For longer releases, the inhalation protection factor would be lower (assuming that the wind does not shift).

Numerous studies indicate that beyond some distance (typically 2 to 3 miles from the plant) sheltering followed by post-release monitoring and relocation from "hot spots" would be as effective as evacuation for many severe accident scenarios. This might not be the case under certain meteorological conditions, in particular, if the radioactive plume passes through rainfall or if severe inversion conditions trap and confine the plume near the ground. Such conditions cannot be predicted with any useful degree of accuracy, and offsite radiological monitoring after the release must be relied upon to determine when evacuation at greater distances is warranted.

Doses from ground contamination may become very important within a few hours of a major release. Therefore, after implementing initial protective actions near the plant, dose projections and field monitoring should be performed. Dose projections would be used to estimate whether protective actions should be expanded according to the Environmental Protection Agency Protective Action Guides. As discussed in Section 5.2, large uncertainties are associated with dose projections. Therefore, as soon as possible after a release, field monitoring data should be the preferred basis for expanding initial protective actions.

In the event of an actual major release, anyone sheltered in an area of high ground-level contamination (e.g., >1 R/hr) would be asked to leave, whether or not an emergency plan calls for it. The predetermined level of 1 R/hr conforms to the Environmental Protection Agency Protective Action Guide of 1 to 5 rems projected whole-body dose. As noted earlier, evacuation at lower dose rates could be recommended on an ad hoc basis, but for a very severe accident, the 1 R/hr level may be suitable as an initial predetermined "trip" level.

5.3.4 Improvised Respiratory Protection

Improvised respiratory protection, such as placing a towel over the mouth and nose, reduces only the dose associated with inhalation of fine aerosols (less than about 10 microns in diameter). It does not impact the dose received from cloud shine or contaminated ground and other surfaces. As a result, improvised respiratory protection is a secondary protective action (i.e., it may be recommended in conjunction with evacuation or sheltering). Implementation of improvised respiratory protection should never delay implementation of other protective actions such as sheltering or evacuation.

Table 5.3-4 shows the results of experiments conducted using different types of improvised respiratory protection.[5] Military personnel used various household items for protection and measured their efficiency in removing particles. Some results are remarkable. Use of a tight-fitting heavy towel over the nose and mouth can reduce the inhalation exposure from small particulates by a factor of 10. A loose-fitting towel can be used to reduce particulate inhalation by a factor of 2 to 5. Similar reduction factors would apply to babies lightly wrapped in blankets, such as they are for protection from wind and cold. Note, however, that exposure received through inhalation of radioactive gases is not reduced by these techniques. Basically, improvised respiratory protection is a secondary protective action that can be used to provide a nontrivial level of additional protection.

5.3.5 Use of Potassium Iodide (KI)

The Food and Drug Administration has recommended that potassium iodide tablets be administered for projected thyroid doses greater than 25 rem.[5] Ingestion of potassium iodide (KI) tablets reduces the dose to the thyroid caused by the intake of radioiodine. It must be understood, however, that use of the thyroid-blocking agent potassium iodide (KI) is not an adequate substitute for prompt evacuation or sheltering by the general population near a plant in response to a severe accident. The immediate risk to the population from a severe reactor accident is bone marrow dose, not the dose to the thyroid from radioiodine.

To be effective, potassium iodide must be taken just before or shortly after exposure to radioiodine (within 1 to 2 hr). Thus, to be potentially effective, it must be readily available.[6] Taking the recommended dosage of KI (130 mg) just before or at the time of exposure could block more than 90% of radioactive iodine uptake by the thyroid as indicated in Figure 5.3-6. If taken approximately 3 to 4 hr after acute exposure, only about 20% blocking would occur in some persons. Note that a small percentage of people could react adversely to KI, but the risk of a severe reaction is very small.

The NRC and the Federal Emergency Management Agency (FEMA) recommend predistribution of KI to predesignated emergency workers, site personnel, and institutionalized individuals who might find it difficult to evacuate during an emergency. FEMA has stated the position that predistribution of KI to the general public should not be required for a state or local emergency plan to be acceptable.[7] NRC emergency preparedness regulations (10 CFR 50.47(b)(10)), however, require that States with population within the 10-mile emergency planning zone of commercial nuclear power plants consider including KI as a protective measure for the general public to supplement sheltering and evacuation. The NRC will provide funding for a supply of potassium

5.3.6 Early Protective Action Decisions During the TMI-2 Accident

To highlight some of the points discussed in this section, certain aspects of the assessments of the TMI-2 accident merit discussion. Figure 5.3-7 presents the hourly wind vector as measured by the site meteorological system during the first day of the accident. Actually, these measurements were not available to the NRC until three days later because the plant computer crashed early in the accident. It is evident that wind direction at the site varied dramatically throughout the 12-hr period.

A Site Emergency was declared at 6:56 a.m., followed by a General Emergency at 7:24 a.m. Between 7:30 and 8:00 a.m., the State of Pennsylvania did issue warnings of imminent evacuation to the west of the site. At 8:15 a.m., the evacuation alert was called off when the results of onsite and offsite radiation monitoring showed that there had been no major radiological release. Coincident with this decision, molten material existed in the reactor vessel and containment radiation levels were very high (see Table 2.1-1 and Section 3.5).

If an evacuation to the west of the site had been initiated around 8:00 a.m., local wind conditions would have shifted the potentially affected area to the north by 9:00 a.m., and then to the east by 11:00 a.m. Thus, the wrong people would have been told to evacuate. As the NRC Special Inquiry Group noted later, based on in-plant observations as set forth in the emergency plans and as emphasized in NRC emergency planning guidance in place even at the time (R.G. 1.101), omnidirectional evacuation of the total low-population zone (2.5-mile-radius area surrounding the site) would have been warranted no later than 7:30 a.m.

Although not diagnosed, by 9:00 a.m. indications of severe core damage were indisputable. Some of the core thermocouple showed temperatures over 2000°F (800°F beyond that required for cladding failures, and the containment dome monitor increased from 600 to 6000 R/hr between 8:20 and 9:00 a.m. However, as indicated, the decision not to take action was made based on field-monitoring results. The NRC Special Inquiry Group found that the state offices should have been advised at 9:00 a.m. that

> *the core has been badly damaged and has released a substantial amount of radioactivity. The plant is in a condition not previously analyzed for cooling system performance.*

The Inquiry Group went on to state:

> *The difficult question in this situation is whether to advise precautionary evacuation of the nearby population or to advise only an alert for possible evacuation. The recommendation to evacuate is consistent with what we think would then be the case, a prudent doubt that the core-cooling passages were still sufficient for cooldown. In addition, the containment building was now filling with intensely radioactive*

> *gas and vapors, leaving the nearby public protected by only one remaining barrier, the containment, a barrier with a known leak rate that needed only internal pressure to drive the leakage.*

Finally, the Inquiry Group stated:

> *Present emergency plans are inadequate because they do not provide a clear requirement to evaluate the need for protective actions based on deterioration of plant conditions.*

This example illustrates the importance (for core melt accidents) of implementing protective actions in the nearby areas as soon as core damage is detected and without regard for wind direction or detection of actual major releases. These are two of the foundations of current NRC staff emergency planning guidance. Early precautionary evacuation of the immediate area (approximately 2-mile radius) should not be recommended in only "downwind" directions because of the inability to determine where downwind will be when the protective actions are actually implemented or when a significant release occurs. In addition, when core damage is detected, the early recommendation to evacuate should not be based on early real-time dose projections but on the status of the core. Indeed, the predetermined, early, initial evacuation for a severe core damage accident is called "precautionary" because a major release may never actually occur, as was the case at TMI-2. On the other hand, no immediate, early evacuation would be warranted for sequences less serious than core-melt accidents.

5.3.7 Other Protective Actions

Other protective actions such as decontamination of evacuees, milk contamination control, and reservoir (water) protection may also be part of the emergency response; however, very early implementation of these actions (within 0 to 4 hr of the release) would not be crucial to their effectiveness. They would, however, be important in reducing the number of latent health effects.

For radiation protection purposes, it is assumed that, no matter how low the dose, some percentage of the population will eventually suffer from cancer because of the radiation exposure. As indicated in Section 5.2, consequence models predict that many of the radiation-induced cancers would occur due to doses received by people tens to hundreds of miles from the plant. This is the result of a great number of people receiving a very low dose. Thus, as a practical matter, emergency-phase protective actions available to reduce these effects are very few. In the early time frame of a response, sheltering to long distances might be advised--much as for an air pollution alert.

If a severe reactor accident occurred during the growing season, crops and pasture within the 50-mile ingestion-pathway emergency planning zone (EPZ) might need to be decontaminated or temporarily quarantined to allow radioactivity to decay. This means that very soon after the accident, surveys of pastures, milk, fruits, and leafy vegetables would need to be conducted, dairy and meat animals would have to moved from contaminated to uncontaminated pastures or fed from uncontaminated stored forage. Contaminated crops would have be prevented from reaching market (entering the food distribution system), and residents of the 50 mile EPZ would have to be carefully warned not to eat contaminated food they had privately grown.

5.3.8 Protective Actions Following The Chernobyl Accident

After the Chernobyl accident, plant workers and individuals who helped mitigate the accident were exposed to beta and gamma radiation from the reactor ruins, the core fragments expelled by the explosion, the plume, and the radionuclides deposited on the ground. The majority of acute radiation injuries occurred from the doses received during the night of the accident (April 26, 1986), when the reactor staff (not knowing the degree of destruction) tried to restore the reactor to operational mode. Shortly thereafter, firemen responding to the emergency were unprotected from the radiation. The dosimeters they wore were either damaged or incapable of measuring the extremely high dose rates they encountered (up to thousands of rads per hour). Clinical treatment for acute radiation sickness was delivered to 134 individuals; 37 of these cases were life threatening. Of these 37, 28 died within days or weeks. Thermal- and beta-induced skin burns affected more than 50% of the total body surface area of 26 of the 28 patients who died. Two more persons died at the site as a result of the initial explosions, and one person died of cardiac infarction. Thus, a total of 31 people died during the first three months.[8]

After the initial exposures, protective actions were implemented to reduce doses to the remaining Chernobyl workers, persons who helped mitigate the accident, and inhabitants of contaminated regions. No additional cases of acute radiation sickness were observed. In part, this is due to the protective actions including evacuations that are discussed in the following subsections. It is, however, also a result of the energetic lofting of the release and the winds and rains that existed during the release. These factors resulted in deposition patterns that were not as bad as they might otherwise have been in major population centers like the city of Kiev.

The information regarding protective actions and their effectiveness, which is presented in the following sections, is drawn from an overview which appears in a 1993 book entitled *The Chernobyl Papers*.[9]

5.3.8.1 Workers

Approximately 600,000 individuals took part in mitigation activities at the reactor and within the 30-km zone surrounding the reactor. These workers were all adults, most of whom were males between the ages of 20 and 45. About half were servicemen who were brought in from all territories of the former Soviet Union.

The effective dose equivalent limit established for individuals working in the 30-km zone was 25 rem in accordance with the Soviet standards of radiation safety. Upon reaching this limit, a worker was suspended from work in the 30-km zone and was required to undergo a medical evaluation. In 1987 this limit was reduced to 10 rem, and in 1988 to 5 rem per year.

As time progressed, especially while a protective shell (the "sarcophagus") was built around the destroyed reactor, workers continued to receive doses up to 25 rem and even higher in a few cases from exposure to external beta and gamma radiation. The composition of radionuclides contributing to these exposures varied continuously due to decay. Inhalation of radionuclides also occurred. These included volatile forms of I-131 in May 1986 and resuspended fuel particles in the hot, dry summer of 1986. Doses from ingestion were negligible because uncontaminated food products were made available to the workers.

To decrease beta and gamma radiation levels in the 30-km zone, activities included decontamination of buildings and roads using water and special decontamination solutions, removal of radioactive soil, and covering contaminated sites with up to 1.5 m of crushed rock and/or concrete. These activities were performed using heavy equipment with highly shielded cabins and remotely operated tools. Additional countermeasures included decontamination of roofs of buildings at the Chernobyl site using robotic machinery and the application of water and a fixing polymer to the ground to suppress dust.

Additional worker protection was provided through the use of special clothing and footwear, and both filter and supplied-air respirators. External gamma radiation doses were limited by restricting stay times in high exposure-rate areas and through the use of remotely operated tools. Also, stable iodine was administered to workers through June 1986.

5.3.8.2 Evacuees

To avoid acute radiation sickness, 49,000 inhabitants of the town of Pripyat, located 3 km from the Chernobyl nuclear power plant, were evacuated on April 27, 1986. Additionally, 11,000 inhabitants of 15 villages in the 10-km zone around the plant were evacuated on May 2 and 3, and 42,000 additional inhabitants of 83 villages in the 30-km zone were evacuated between May 4 and May 7. During June through September 1986, after data on the areas contaminated by long-lived radionuclides were refined, the inhabitants of 57 villages in Belarus, 1 village in the Ukraine, and 4 villages in the Bryansk region of Russia were resettled. No cases of acute radiation sickness were observed in any of the 116,000 evacuated individuals.

Although rumors were rampant, the population of Pripyat was not officially notified of the accident until approximately noon on April 27, at which time they were ordered to prepare to evacuate. Evacuation took place by buses mainly between 1 p.m. and 5 p.m. on April 27. The remainder of the population of the 30-km zone learned about the accident from television on the evening of April 28. Stable iodine was administered to approximately 60% of the population of Pripyat on April 26 and 27, but 65% of the population did not undertake any other countermeasures prior to evacuation. Rural residents of the 30-km zone did not significantly change routines, nor did they apply any personal countermeasures prior to evacuation.

The evacuees were subjected to external radiation from the plume and to beta and gamma radiation from radionuclides deposited on the ground before evacuation was completed. Ingestion of radionuclides occurred in a number of Belarus villages (in the southern portion of the Gomel region) because notifications of the accident were late and therefore ineffective in preventing consumption of contaminated foods. Consequently, thyroid doses to children in these villages exceeded a thousand rems.

External exposures and the intake of radionuclides essentially ceased after evacuation. The average and maximum effective dose equivalents from external gamma radiation to inhabitants of Pripyat were 1 rem and 10 rem, respectively. The values for the rural population of the 30-km zone were approximately 2 rem and 40 rem, respectively. The average thyroid dose to Pripyat inhabitants was approximately 20 rad for both children and adults. Administration of stable iodine is estimated to have decreased thyroid doses in Pypriat evacuees by a factor of 10.

5.3.8.3 Residents of Significantly Contaminated Areas

About 4 million people were, and many continue to be, subjected to external and internal exposures in the 131,000-km^2 area, with Cs-137 surface activity levels exceeding 1 $\mu Ci/m^2$. Approximately 270,000 of these individuals resided in the controlled area, which consisted of 10,300 km^2 with Cs-137 surface activity levels exceeding 16 $\mu Ci/m^2$. For these individuals, external exposures from the plume were insignificant compared to the external exposures from deposited radionuclides. According to available data, less than 10% of the external doses received during the first year were attributed to the plume. Inhalation doses from the plume and from resuspended radionuclides were also insignificant for these individuals compared to the ingestion of I, Cs, and Sr isotopes.

Dose limits were developed for the protection of people who continued to reside in significantly contaminated areas. The adopted limits were 10 rem for the first year after the Chernobyl accident, then 3 rem in the second year and 2.5 rem in each year of 1988 and 1989. Overall, through January 1, 1990 the maximum effective dose equivalent allowed was 13 rem per inhabitant. In 1991 a new criterion for relocation of residents to uncontaminated areas was set: for annual effective dose equivalents greater than 0.5 rem, relocation was required. To ensure that the effective dose equivalent limitations were met and to limit internal doses to critical organs, temporary permissible levels of radionuclide activities in food products and drinking water were instituted. Along with the standards for food products, many other standards were introduced including standards for contamination of various surfaces.

In the early and intermediate phase, protective actions taken for inhabitants of significantly contaminated areas included administration of stable iodine, temporary relocation, delivery of uncontaminated meat and dairy products, decontamination of villages, and measures to decrease radionuclide content in agricultural products. The inhabitants of villages with the highest levels of radioactive contamination were gradually resettled to uncontaminated areas. The most effective protective actions for reducing person-rems were temporary and permanent relocation and the supply of uncontaminated food products. Administration of stable iodine was only effective in Pripyat, where short-term (1.5 day) radioiodine intakes were very high and stable iodine was administered in a timely manner. There were no observations of cases of acute radiation sickness in the population of the controlled areas, although radiation-related thyroid cancers may be observed.

In many towns and villages, numerous countermeasures for protection of the population were performed simultaneously. Temporary resettling of children, monitoring of milk contamination and administration of stable iodine together decreased the collective thyroid dose to the 3 million inhabitants of Kiev by an estimated 11 million person-rem, or approximately 40%.

5.3.8.4 Residents of Less Contaminated Areas

The remainder of the population of the former Soviet Union numbered approximately 280 million in 1991. These individuals resided in territories with Cs-137 surface activity levels below 0.04 MBq/m^2 and were subjected to relatively insignificant exposures from local contamination. An important factor was the distribution throughout the country of meat and dairy products produced in the contaminated area. Although concentrations of radionuclides in these products were within permissible levels, the content of Cs radionuclides in the bodies of inhabitants of the former Soviet Union increased compared to the pre-accident levels as a result of the consumption of the products. In many regions both individual and collective population doses from these products were higher than those received from the local deposition of radioactive material.

Outside the former Soviet Union, protective actions in countries that received fallout from Chernobyl varied. In many countries, contamination levels in milk and other food products were monitored and sale of contaminated produce was banned. In some countries KI was distributed to children to protect against thyroid cancer.

5.3.9 Long-Term Health Effects From The Chernobyl Accident

In April of 1996, almost ten years after the Chernobyl accident, an international conference was held in Vienna to discuss the radiological, environmental, and psychosocial consequences of the Chernobyl accident.[8] One major conclusion of the conference was that the psychological impact of the accident has been extensive and long-lasting. The mental stress caused by what is and is not known about the accident is real. The population is inclined to mistrust official statements and attribute an increase in any kind of illness to radiation. Yet, at the time of the conference, clear evidence regarding the impact of Chernobyl on the incidence rates of various illnesses was sparse.

There is one notable exception. A large number of child thyroid tumors are clearly attributable to the consumption of milk contaminated with radioiodine. At the time of the conference, over 550 cases of thyroid cancer had been diagnosed in children below the age of 15--about 330 in Belarus, 200 in Ukraine, and 25 in Russia. In Belarus, the number of cases diagnosed between 1990 and 1995 was about 50 times greater than in the United Kingdom. This incidence rate is almost an order-of-magnitude greater than would have been predicted based on pre-existing models, and the reason for the discrepancy is not clearly understood. Children may be much more sensitive to radioactive iodine than anticipated, or iodine deficiency may have been a factor, or some genetic predisposition to the disease may have existed in the region. If detected sufficiently early, thyroid cancer can be treated with surgery, iodine-131 therapy, and thyroid hormone replacement. Some 10 to 15% of those treated develop complications that could result in death at a later date.

Data regarding other health effects is less clear. Studies of the overall incidence of cancer among cleanup workers and residents of contaminated areas were undertaken in Ukraine, Belarus, and Russia. Some of these studies indicated no increase in comparison with the general population whereas others reported increases as large a 11% for cleanup workers and 3% for inhabitants of contaminated areas. No consistent increase has been validated for leukemia in any of the three countries. After 10 years, an increase in the incidence of leukemia among the cleanup workers was anticipated based on studies of atomic bomb survivors. It may be that atomic bomb survivor studies are not directly applicable to Chernobyl because the doses to cleanup workers and residents in contaminated areas were delivered over comparatively long time periods.

Because additional thyroid cancers are anticipated, information regarding leukemia incidence rates is inconclusive, and the latency period for many other forms of cancer (in particular solid tumors) exceeds 10 years, it is important that studies of the disease incidence rates continue. Unfortunately, key pieces of information are often missing, such as data on the amount and type of radiation to which individuals were exposed. Also, records of the incidence of disease and causes of death for people in the affected areas before and after the accident often are often deficient. As a result, the long-term health effects of the Chernobyl accident may never be known with great accuracy. But major strides have been made in the treatment of children with thyroid cancer, the quality of cancer registries, health studies and research infra-structures, and training of epidemiologists and medical personnel.

Table 5.3-1 Exposure pathways, nuclear incident phases, and protective actions

Potential Exposure Pathways	Incident Phases	Potential Protective Actions
1. External radiation from facility		Sheltering Evacuation Control of access
2. External radiation from plume		Sheltering Evacuation Control of access
3. Inhalation of activity in plume	Early	Sheltering Use of potassium iodide Evacuation Ad hoc respiratory protection Control of access
4. Contamination of skin and clothes		Sheltering Evacuation Decontamination of persons
5. External radiation from ground deposition	Intermediate	Evacuation Relocation Decontamination of land and property
6. Ingestion of contaminated food and water	Late	Food and water controls
7. Inhalation of resuspended activity		Relocation Decontamination of land and property

Note: The use of stored animal feed and uncontaminated water to limit the uptake of radionuclides by domestic animals in the food chain can be applicable in any of the phases.

Table 5.3-2 Public response to nuclear-related incidents

Date	Location	Incident	Public reaction
1957	Windscale, England	Accident at a graphite reactor caused the release of 20,000 Ci of radioiodine	Typical, no panic
1977	Ft. St. Vrain, Colo.	Erroneous reports of a release of 20 Ci/sec from a nuclear power reactor	Normal, no panic despite blizzard conditions
1978	Rocky Flats, Colo.	Major fire at a plutonium plant	Normal, no panic or widespread flight
1980	Crystal River, Fla.	20,000 gal of primary water was spilled into the containment	Normal, no panic or widespread flight
1979	Three Mile Island, Pa	Nuclear power plant accident	Half of population within 20 miles evacuated within 5 days
1982	Rochester, N.Y.	Primary coolant released to the atmosphere from R.E. Ginna nuclear power plant	Normal, no panic or widespread flight
1981	Indian Point, N.Y.	Power transformer exploded when lightning struck a nuclear power station	Small-scale evacuation

Table 5.3-3. Factors by which radionuclide exposure may be reduced by sheltering for different types of shelters and pathways of exposure

Type of shelter	Cloud shine	Ground shine	Inhalation
Small, frame building			
Without basement	1	2	2[a]
With basement	3	5-10	3[a]
Multiple-story concrete structure	5	10	5

[a]Puff release only.

Table 5.3-4. Respiratory protection provided by common household and personal items against aerosols of 1- to 5-μm particle size

Item	Number of thicknesses	Geometric mean efficiency (%)
Toilet paper	3	91
Handkerchief, man's cotton	Crumpled	88
Bath towel, Turkish	2	85
Bath towel, Turkish	1	74
Bed sheet, muslin	1	72
Handkerchief, man's cotton	1	27

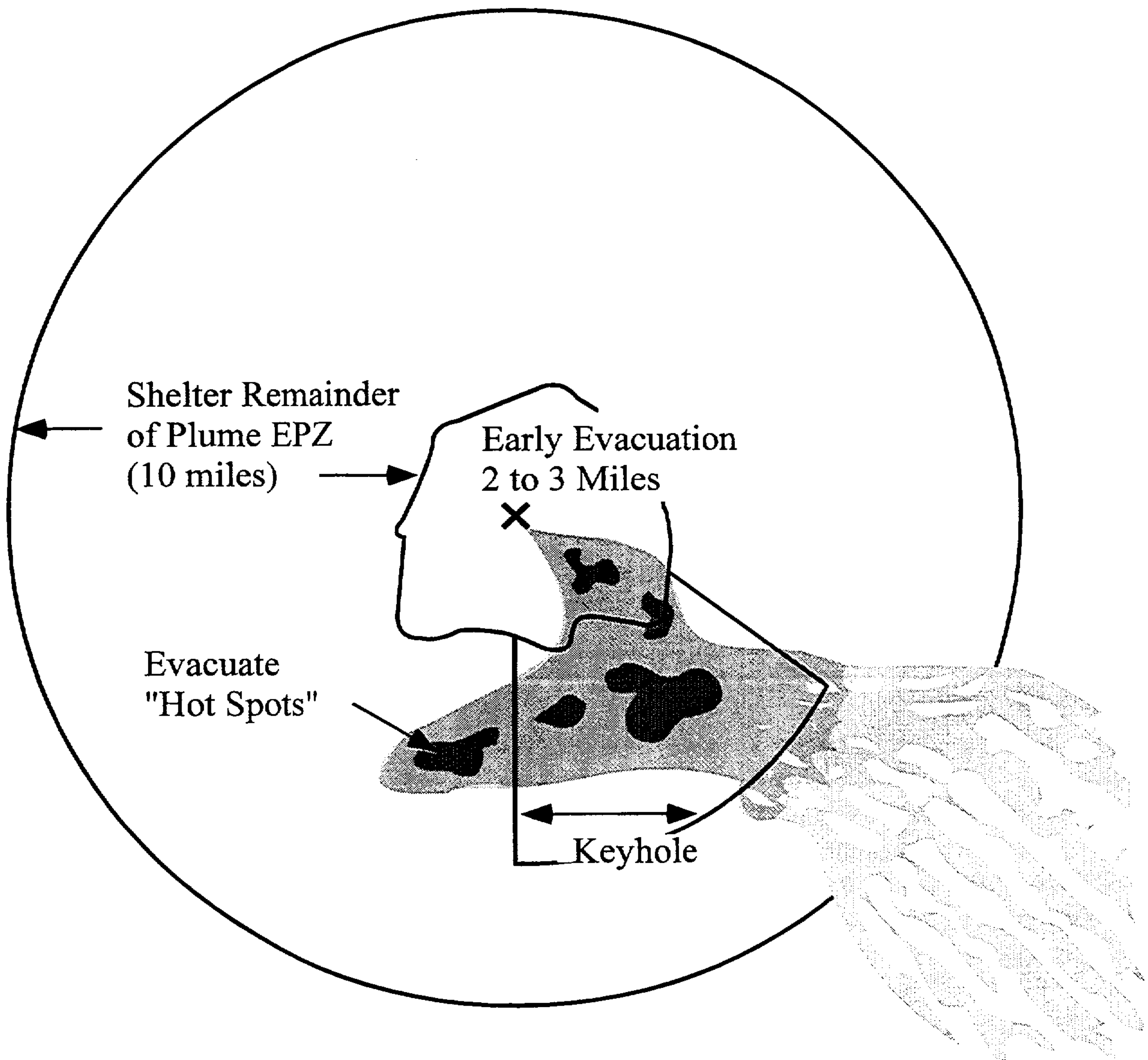
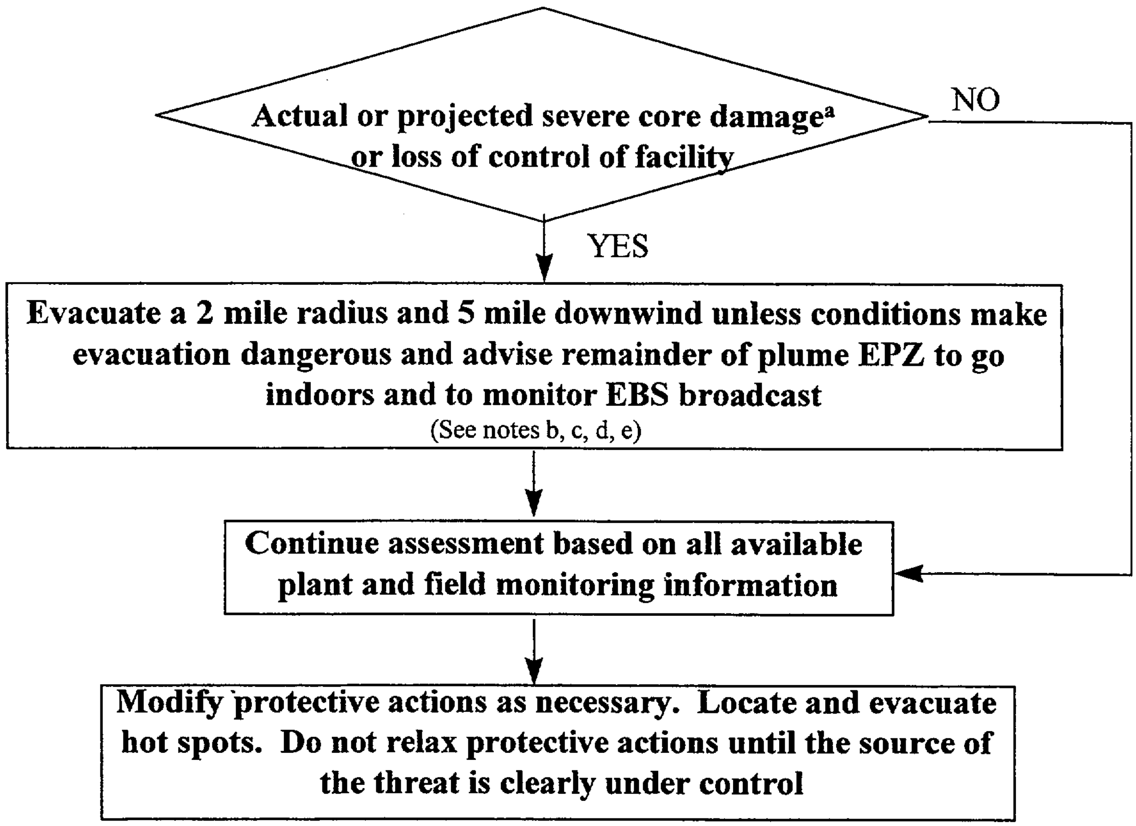


Figure 5.3-1 Early protective actions for core melt accidents



[a] Severe core damage is indicated by (1) loss of critical functions required for core protection (e.g., loss of injection combined with loss of cooling accident); (2) high core temperatures (PWR) or partially uncovered core (BWR); or (3) very high radiation levels in area or process monitors.

[b] Distances are approximate - actual distances will be determine by the size of the preplanned sub-areas, which are based on geopolitical boundaries.

[c] If there are very dangerous travel conditions, initially shelter rather than evacuate the population until condition improve.

[d] Transit-dependent persons should be advised to remain indoors until transportation resources arrive, if possible.

[e] Shelter may be the appropriate action for controlled releases of radioactive material from the containment if there is assurance that the release is short term (puff release) and the area near the plant cannot evacuated before plume arrives.

Figure 5.3-2 Protective action flow chart for severe core damage or loss of control facility

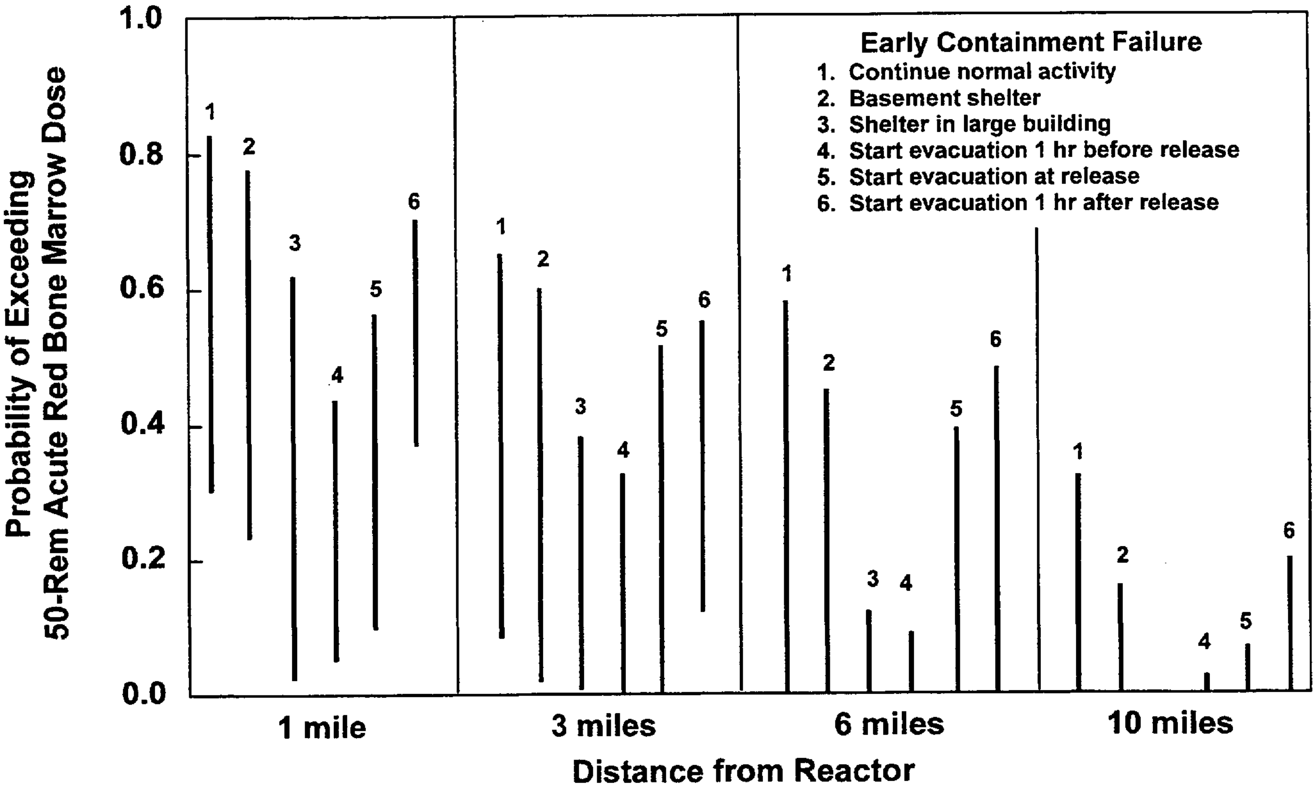


Figure 5.3-3 **Relative effectiveness of early protective actions given early containment failure (Source: NUREG-1150, Figure 13.5)**

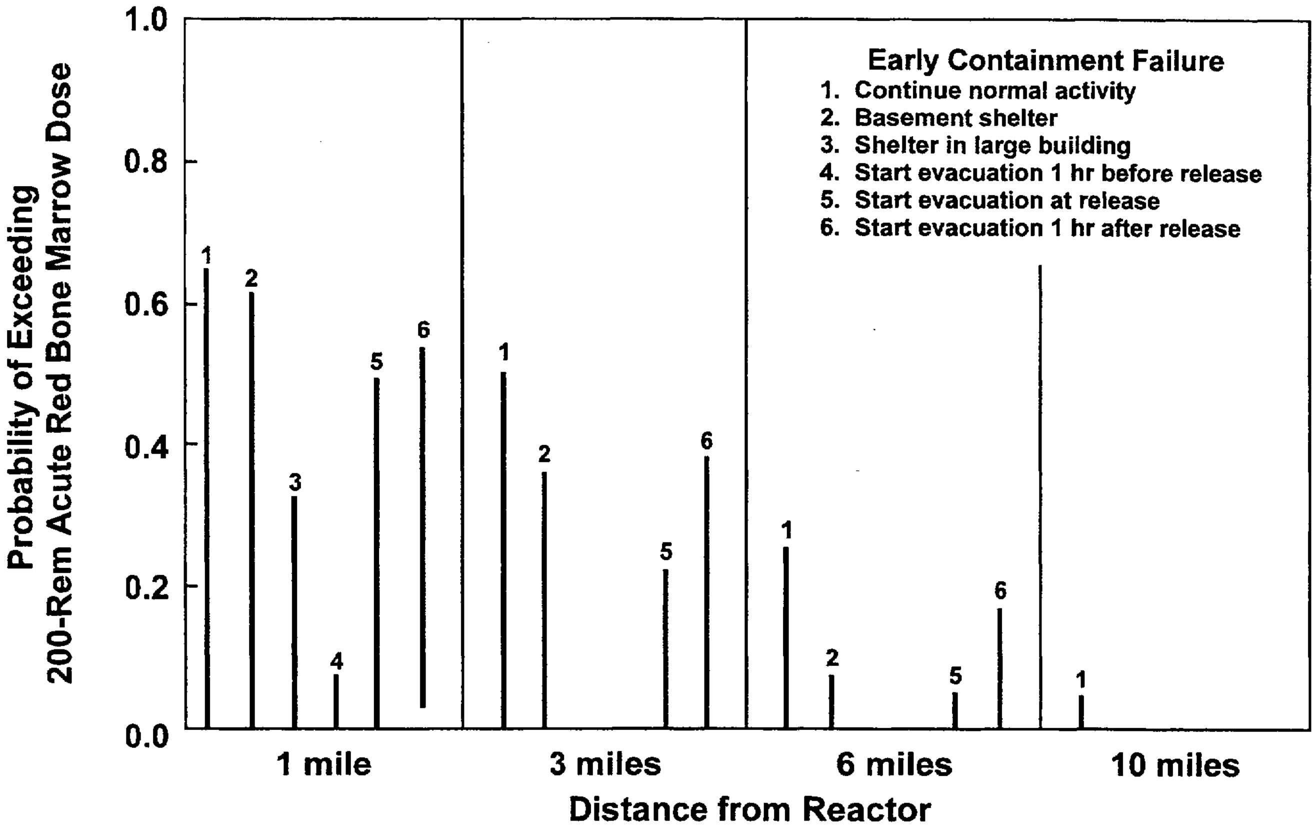


Figure 5.3-4 Relative effectiveness of emergency response actions assuming early containment failure with high and low source terms

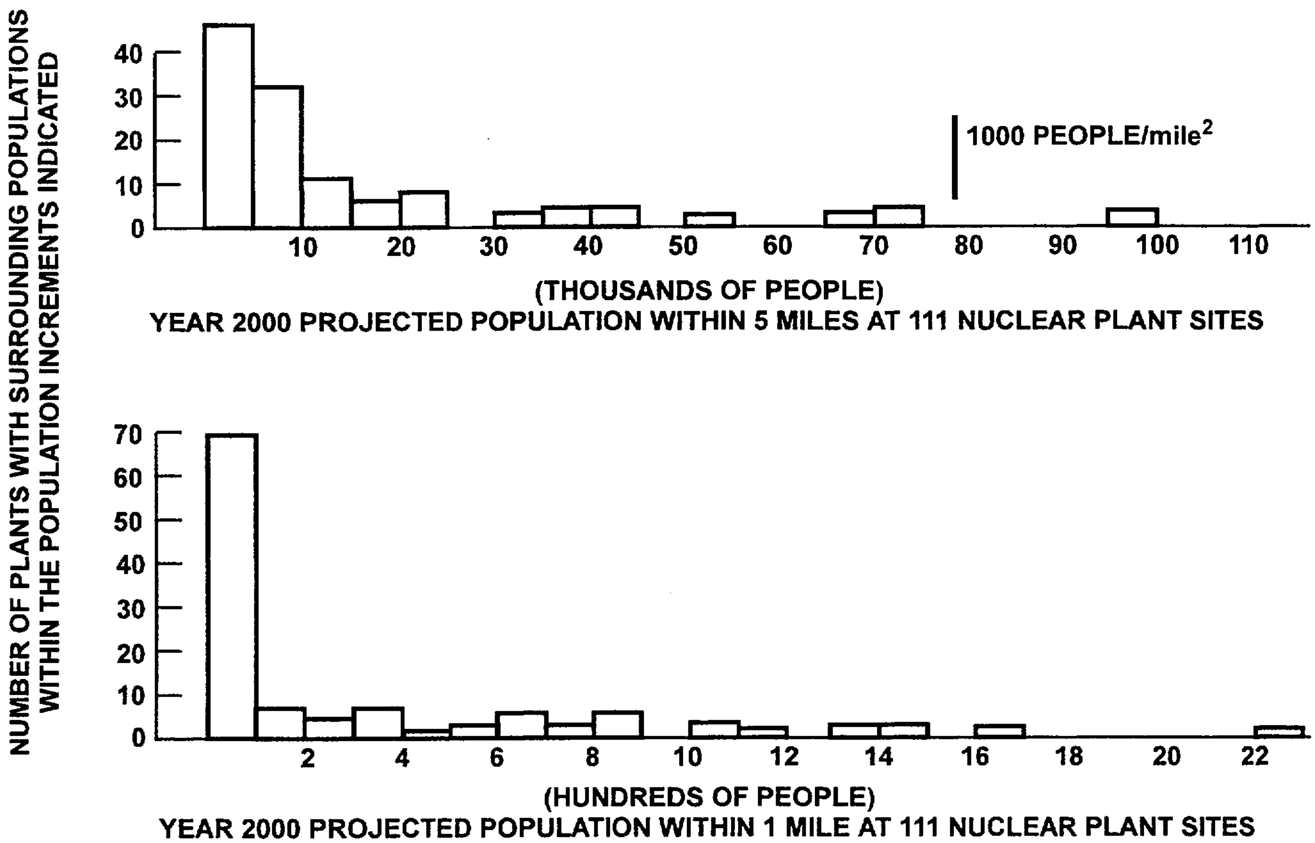


Figure 5.3-5 Number of people within 1 and 5 miles of 111 nuclear power plants, actual or proposed in 1979

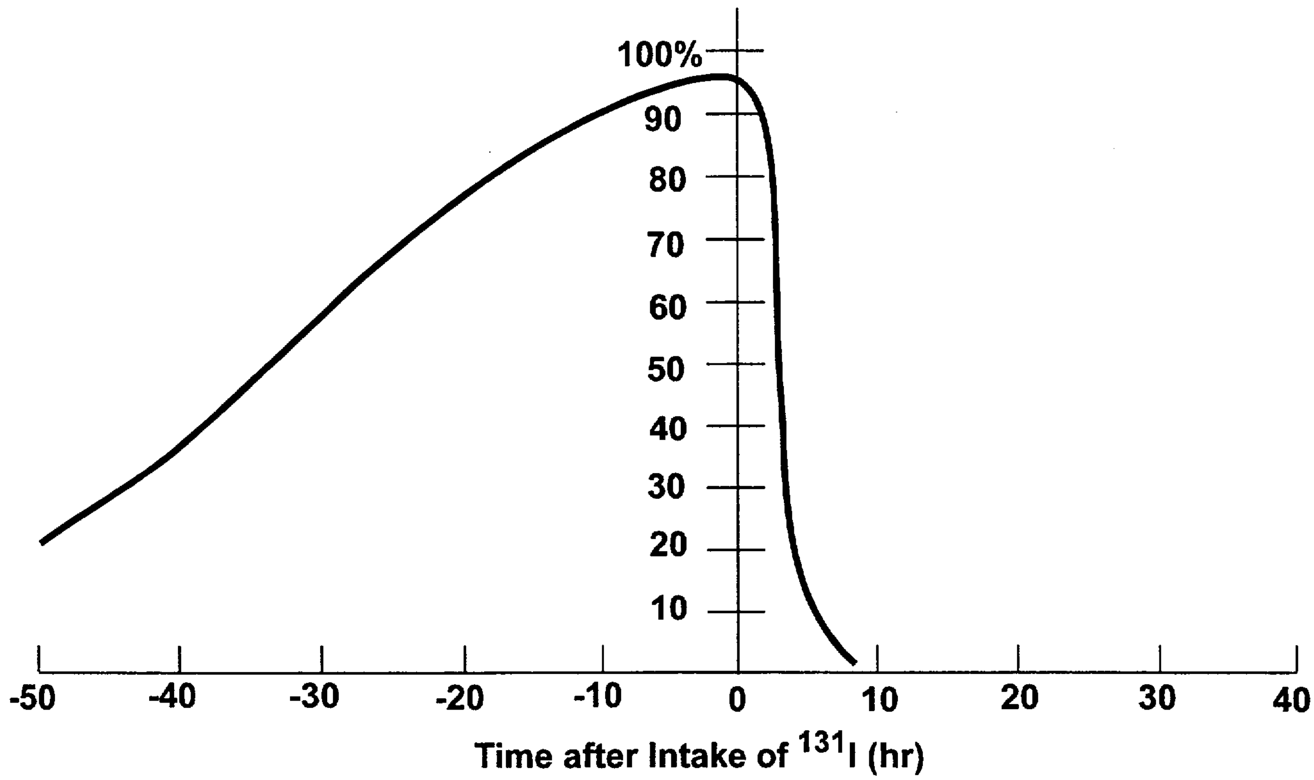
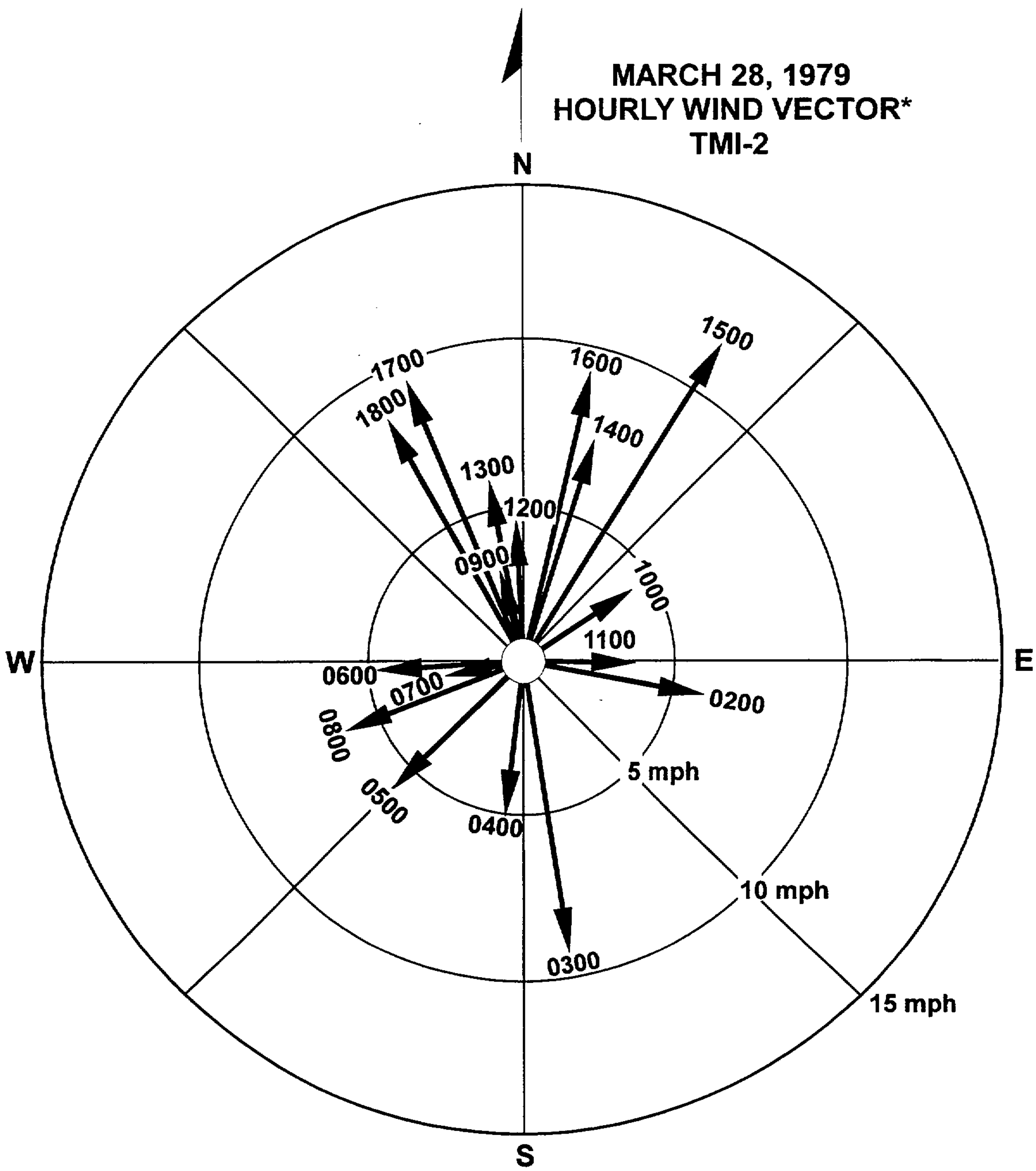


Figure 5.3-6 **Percent of thyroid blocking afforded by 100 mg of stable iodine (130 mg of potassium iodide) as a function of time of administration before or after a 1-μCi intake of ^{131}I**



*Arrows indicate direction toward which the on-site wind was blowing at the local time indicated. Circles represent varying wind speeds.

Figure 5.3-7 Hourly wind vector at Three Mile Island on March 28, 1979

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1. T. McKenna, et al., "RTM-96 Response Technical Manual," NUREG/BR-0150, Vol. 1, Rev. 4, March 1996, Figure G-1.

2. U.S. Nuclear Regulatory Commission, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, p. 13-12, December 1990.

3. U.S Nuclear Regulatory Commission, "Demographic Statistics Pertaining to Nuclear Power Reactor Sites," NUREG-0348, October 1979.

4. J. M. Hans, Jr. and T. C. Sell, "Evacuation Risks--An Evaluation," Environmental Protection Agency report EPA-520/6-74-002, Office of Radiation Research, National Environmental Research Center, Las Vegas, Nevada, June 1974.

5. J. A. Martin, Jr., et al., "Pilot Program: NRC Severe Reactor Accident Incident Response Training Manual, Public Protective Actions -- Predetermined Criteria and Initial Actions," NUREG-1210, Volume 4, 1987.

6. J. A. Martin, "Potassium Iodide: Predistribution or Not? The Real Emergency Preparedness Issue," *Health Physics*, 49(2):287-289, August 1985.

7. U.S. Food and Drug Administration, "Radioactive Contamination of Human and Animal Feeds and Potassium Iodide as a Blocking Agent in a Radiation Emergency," Federal Register, 43:242, Part VII, December 15, 1978.

8. A. Kaul, H. Landfermann, and M. Thieme, "One Decade After Chernobyl: Summing Up the Consequences," *Health Physics*, Vol. 71, No. 5 (November 1996) 634-640.

9. M. I. Balonov, "Overview of Doses to the Soviet Population from the Chernobyl Accident and the Protective Actions Applied," in The Chernobyl Papers, Vol. I, Doses to the Soviet Population and Early Health Effects Studies, Steven E. Merwin and Michail I. Balonov editors, Research Enterprises Publishing Segment, Richland, WA, 1993.

5.4 Emergency Preparedness

Preparations for potential nuclear power plant emergencies are extensive. The discussion in this section is limited to those aspects of preparedness that affect the NRC's role of monitoring protective actions. This includes organizational responsibilities, emergency detection and classification, Emergency Planning Zones, licensee response centers, and the response of state and local organizations.

5.4.1 Regulatory Basis

Licensees have developed plans and procedures for emergency response in accordance with the requirements and guidelines presented in the following documents:

1. Title 10, Code of Federal Regulations (CFR) Pt. 50.47 and Appendix E, which contain the basic requirements for emergency preparedness.

2. NUREG-0654 [Regulatory Guide (R.G.) 1.101, rev. 2],[1] which contains the criteria to be used in developing and assessing an emergency plan.

3. NUREG-0396,[2] NUREG-1131,[3] and Information Notice 83-28,[4] which discuss the foundation for the current emergency preparedness concepts.

4. NUREG-0737, Supplement 1,[5] which clarifies the requirements for the emergency organization and emergency centers.

5. NUREG-1210 and RTM-96,[6,7] which update the guidance in NUREG-0654 and Information Notice 83-28 based on results of severe accident research and experience gained in emergency preparedness exercises.

The licensee emergency plans and procedures are available at NRC Headquarters (HQ) and at the regional offices for each operating reactor.

5.4.2 Roles in an Emergency

5.4.2.1 Role of Licensee

In the event of an emergency, the primary responsibilities of the licensee are to protect the core, to prevent or limit offsite consequences, and to notify predesignated state and local officials promptly (within 15 minutes) of the emergency declaration.

The licensee's first priority is to protect the core by maintaining the following critical safety functions:

1. making the core subcritical and keeping it there,

2. keeping the water flowing through the core,

3. keeping the core covered with water,

4. providing makeup for water boiled off, and

5. removing decay heat from the core to an outside heat sink.

The licensee must also take action to prevent or limit offsite consequences by

1. maintaining reactor containment and the Engineered Safety Feature (ESF) systems,

2. controlling radionuclide releases,

3. recommending appropriate protective actions to offsite officials.

Licensees have developed Emergency Operating Procedures for use by the control room staff in responding to emergency conditions. These Emergency Operating Procedures are discussed in Section 5.4.3.1.

In parallel with attempts to correct the problem, the licensee must notify offsite officials of an emergency declaration promptly (within 15 min). The licensee recommends initial protective actions to offsite officials because the licensee has the best early understanding of core and containment conditions. Furthermore, if an actual offsite radionuclide release occurs, the licensee is responsible for monitoring that release to ensure that actions recommended off site are appropriate (i.e., that initial protective action recommendations/decisions continue to be valid based on current, actual monitoring data). Section 5.3 discusses role and efficacy of specific protective actions.

5.4.2.2 Role of State and Local Agencies

State and local agencies are charged with protecting the public from the offsite consequences that might result from a power plant accident. These organizations have the ultimate responsibility for notifying the public to take protective actions in the event of a severe accident. State and local officials base their decisions on the recommendations of the licensee. The licensee cannot order an evacuation of areas surrounding the plant; the licensee can only make such a recommendation to the appropriate offsite officials. Those officials must make the decision to notify the public to implement any protective actions. The response of state and local organizations is discussed in Section 5.4.6.

5.4.2.3 Role of the NRC

The NRC role should be one of monitoring the licensee's actions and providing assistance to the licensee. It is important that the NRC response personnel understand that extensive preplanning has been completed to assist in early decision making. When prompt protective action is dictated by plant conditions in a serious accident, it is not appropriate for the licensee or the responsible state or local agency to seek NRC concurrence prior to initiating the action. The NRC should intervene only if there is a serious lack of appropriate action.

5.4.3 Emergency Detection and Classification

5.4.3.1 Emergency Operating Procedures

Prior to the accident at Three Mile Island, plant emergency operating procedures were "event-oriented." They described the steps which the operator should take given the occurrence of certain preselected, pre-analyzed events. These procedures were typically limited to transient events or loss-of-coolant events followed by successful operation of all safety systems designed to respond to these events.

Since the Three Mile Island accident, considerable effort has been devoted to the development of "symptom-based" procedures to replace (or at least significantly augment) the event-specific procedures. The basic premise underlying these symptom-based procedures is that there is a limited set of critical safety functions (CSFs), which, if successfully performed by either automatic plant response or manual action, result in a "safe" condition for the plant. The basic goal of the plant safety systems and the ultimate goal of operator actions is to ensure the performance of these critical safety functions. Symptom-based operating procedures relate critical safety function performance to specific plant/control room instruments.

The attractiveness of the "critical safety functions" concept evolves from the implication that the operator need only monitor a relatively few pieces of information to ascertain the safety of the plant. While there are a limited number of critical functions (or parameters) which indicate the performance of these functions, there are virtually an unlimited number of events (with a wide variety of symptoms) that can affect the performance of these functions. The operator can carry out his duties by focusing on these critical functions without regard to the specific events that have occurred.

It is important to note that, in general, the Emergency Operating Procedures address actions that lead up to but do not include actions to be taken after core damage. Therefore, the operators may not have procedures to help them once the core has been damaged. However, as a result of shortcomings identified in the Three Mile Island accident, licensees have installed additional instrumentation to detect inadequate core cooling, developed core condition assessment procedures, and conducted training on core condition assessment. These assessments are based on the relationship of various plant instruments (e.g., containment radiation monitor, reactor water level indicator, core thermocouples, etc.). These relationships must be used with caution, but they do provide gross indicators of the extent of core damage.

5.4.3.2 Emergency Action Levels

Licensees have established Emergency Action Levels based on control room instrument readings (e.g., 1000 R/h containment monitor reading or 2000°F thermocouple) that indicate the scope of an emergency. NRC guidance requires that Emergency Action Levels be established for a full range of events from situations that indicate just a potential problem to actual core damage (General Emergency).

Emergency Action Levels are extremely important. They are trigger levels for the declaration of emergencies and the initiation of predetermined activities that lead to immediate, early actions (e.g., activation of organization, notifications, and protective actions).

Each licensee's emergency action plan contains a list of Emergency Action Levels which are used by the operators in assessing the level of response needed. Most licensees originally established their Emergency Action Levels for each of the 60 example initiating conditions provided in NUREG-0654. In many cases, this results in a very long list of diagnostic control room parameters, as can be seen from the sample shown in Table 5.4-1. Some licensees have streamlined this approach by using flow charts and other visual aids. A newer symptomatic EAL classification scheme has been developed by NUMARC and adopted many licensees. In the NUMARC methodology, generic recognition categories replace individual analyses of multiple NUREG-0654 initiating conditions.

Table 5.4-2 shows several examples of the timing of boiling water reactor (BWR) core damage accidents. These examples illustrate that core damage could occur within a few minutes or many hours. These are only examples to show what might be typical of the timing during an event and to demonstrate how the ability to take early action based on the exceeding of Emergency Action Levels could provide sufficient time to implement protective actions.

5.4.3.3 Emergency Classification System

Four classes of emergencies (Unusual Event, Alert, Site Area Emergency, and General Emergency) have been established by NRC regulations. The class of emergency that is declared is based on conditions that trigger the Emergency Action Levels (EALs). Typically, licensees have established for each emergency class specific Emergency Plan Implementation Procedures (EPIPs) that are to be implemented by the control room staff. The importance of correct classification cannot be overemphasized. The event classification initiates all appropriate actions for that class. Both over- and under-reaction could have serious adverse consequences. The classification procedures (i.e., Emergency Action Levels) for specific nuclear power plants are included in the emergency plans, which are located in the Region Incident Response Centers (IRCs) and the Headquarters Operations Center.

Each class requires specific initial actions. The classes and the appropriate initial actions are discussed in more detail in the following subsections.

5.4.3.3.1 Unusual Event

The rationale for establishing notification of an "Unusual Event" as an emergency class is to provide early and prompt notification of minor events that could possibly lead to more serious conditions. The purpose of offsite notification is to:

1. ensure that the first step in any response later found to be necessary has been carried out,
2. bring the operating staff to a state of readiness,
3. provide systematic handling of unusual events information and decision making, and
4. control rumors.

5.4.3.3.2 Alert

An alert is declared if events are in progress or have occurred that involve an actual (or potential) substantial degradation of the level of safety at the plant. Any radiological releases are expected to be limited, so that resulting exposures would be small fractions of the U.S. Environmental Protection Agency (EPA) Protective Action Guides.

The purpose of an alert is to:

1. ensure that the onsite Technical Support Center is activated so that licensee emergency personnel are readily available to respond,
2. provide offsite authorities with information on the current status of the event, and
3. provide assistance to the control room staff.

5.4.3.3.3 Site Area Emergency

A site area emergency is declared if events are in progress or have occurred that involve actual or likely major failures of plant functions needed for protection of the public. Radiological releases, if any, are not expected to result in doses exceeding Environmental Protection Agency Protective

Action Guide levels, except possibly near the site boundary.

The purpose of the Site Area Emergency declaration is to:

1. ensure that all emergency response centers are manned,
2. ensure that radiological monitoring teams are dispatched,
3. ensure that personnel required to aid in the evacuation of near-site areas are at duty stations should the situation become more serious,
4. provide consultation with offsite authorities,
5. provide updates for the public through offsite authorities, and
6. ensure that nonessential personnel are evacuated.

5.4.3.3.4 General Emergency

A general emergency is declared if events are in progress or have occurred that involve actual or imminent substantial core degradation or melting. Risks of exceeding Environmental Protection Agency Protection Action Guide exposure levels in more than the immediate area are considerably elevated. This is a very special case. A General Emergency indicates that plant conditions are well beyond design and early protective actions are warranted.

The purpose of the General Emergency declaration is to:

1. initiate predetermined protective action notification to the public, and
2. bring the full available resources of government and industry to bear on the situation.

5.4.3.3.5 Class Summaries and NUMARC Recognition Categories

Summary descriptions of the four emergency classes are provided in Table 5.4-3. A summary of emergency classification actions for the three major classes is presented in Table 5.4-4. The number of emergencies typically reported to the NRC in a year is 200 unusual events, 10 alerts, and 1 or 2 site area emergencies. No general emergencies have been declared since TMI-2.

Table 5.4-5 displays the relationship between the four emergency classes and the NUMARC recognition classes. By matching the observed plant condition with the recognition category descriptions on the left, the applicable emergency class can be determined. If the recognition category is "Fission Product Barriers Failure or Challenge," plant-specific measurable values indicating loss or potential loss of the cladding, reactor coolant system, and containment barriers are developed by the licensee.

5.4.3.4 Protective Action Recommendations

As discussed earlier, within 15 min of identifying a situation requiring urgent action (General Emergency), the licensee must recommend protective actions to offsite officials. For situations requiring urgent actions, recommended protective actions should have been predetermined based on discussions between the licensee and offsite officials considering plant and local conditions.

It is important to note that applications of protective actions are site-specific. For example, one plan may call for initial evacuation out to 5 miles, while another calls for initial evacuation out to 3 miles, but the basic concept of prompt evacuation of the area near the plant for a severe core damage accident is met.

No predetermined actions are established for site area emergencies and lesser events. The specific actions for these lesser events would be based on projected plant conditions, offsite dose projections, and monitoring conducted at the time.

5.4.4 Emergency Response Centers

5.4.4.1 Control Room

Authority to take action in the event of an emergency must reside in the plant control room until the Technical Support Center (see Section 5.4.4.2) or the Emergency Operations Facility (see Section 5.4.4.4) is activated. This includes the authority to declare emergencies, to notify offsite officials within 15 minutes of general emergency declaration, and to provide any appropriate protective action recommendations. The NRC must be notified after the appropriate state and local officials are notified and no later than one hour after declaring the emergency.

Upon declaration of an emergency, most sites designate an onsite Emergency Director, who is in charge of the plant's total response. During night and weekend hours, this typically is the Shift Supervisor. Once the appropriate augmentation staff arrive following declaration of an emergency, this responsibility (and title) normally transfers to the Technical Support Center and then to the Emergency Operations Facility.

5.4.4.2 Technical Support Center

There were indications from the events at Three Mile Island that numerous personnel in the control room acted to congest and confuse the reactor operators' control room activities. Review of this accident also shows that there existed a lack of reliable technical data and other records on which to base accident recovery decisions. As a result, today licensees are required to establish Technical Support Centers whose staff have access to plant technical information and who are responsible for engineering support of reactor operations during an accident. Personnel in the Technical Support Center must be able both to assist the control room when needed and to diagnose and mitigate an event. Until the Emergency Operations Facility is activated, the Technical Support Center will also perform the functions of the Emergency Operations Facility. The Technical Support Center is located close to the control room inside a protected and shielded area to allow fast access for face-to-face discussions with control room personnel.

5.4.4.3 Operations Support Center

The establishment of an Operations Support Center was introduced to help relieve the influx of shift/operational support personnel in the control room. The function of the Operations Support Center is to provide a place to which shift personnel report to receive further instructions from the operations staff. The Operations Support Center can be a locker room with capability for reliable communications with supervisory and decision-making personnel.

5.4.4.4 Emergency Operations Facility

Personnel with primary responsibility for the licensee's response to a severe accident situation are located in the Emergency

Operations Facility once it is activated. The Emergency Operations Facility is an offsite facility, which is usually near the site, with hardening/shielding or a backup facility if necessary. Figure 5.4-1 depicts the relative locations of the licensee emergency response centers.

The Emergency Operations Facility is generally where protective action recommendations would be formulated and where the Emergency Director would be located. Space is also provided for state and local agencies. The Emergency Operations Facility enables effective coordination of onsite actions with those off site, and provides a central location from which to direct all offsite actions by the licensee (e.g., monitoring, sampling, and dose assessment).

5.4.4.5 Flow of Authority and Responsibility

The responsibility and authority for licensee actions during a severe nuclear power plant accident start in the control room and then flow out as people arrive to man the Technical Support Center and the Emergency Operations Facility. The licensee will typically start transferring functions/ responsibilities/authorities out of the control room as soon as possible so that control room personnel can concentrate on bringing the situation under control. Staffing the Technical Support Center would typically require about 30 minutes. About one hour would be required to staff the Emergency Operations Facility. NRC staff initially attempting to contact licensee personnel must be aware of how long the accident has been under way to determine where their contacts should be made. The Emergency Network System (ENS) and Health Physics Network (HPN) lines can be used to determine where the appropriate licensee representative is located.

5.4.5 Emergency Planning Zones

Plume and ingestion Emergency Planning Zones have been established around each nuclear reactor plant site. These Emergency Planning Zones were established so that the public can be notified to implement appropriate protective actions in an efficient and a timely manner in the event of a real emergency.

5.4.5.1 Plume Exposure Emergency Planning Zone

The plume exposure Emergency Planning Zone is that area requiring possible immediate action to reduce risk to the public in the event of an accident. It is an area approximately 10 miles in radius around the power plant. This size is based primarily on the following considerations:

1. Projected doses from the traditional design basis accidents would not exceed Environmental Protection Agency Protective Action Guide (PAG) levels outside the zone.

2. Projected doses from most core melt sequences would not exceed Protective Action Guide upper levels outside the zone.

3. For the worst-case core-melt sequences, immediate life-threatening doses would generally not occur outside the zone. (For most hypothesized severe accidents, life-threatening doses are not predicted beyond 2 to 3 miles from the plant.)

4. Detailed planning within 10 miles provides a substantial base for expansion of response efforts in the event that this proves necessary.

It is unlikely that any immediate protective actions would be required beyond the plume exposure pathway Emergency Planning Zone. The zone is sufficiently large that protective actions within it provide for substantial reduction in early health effects (injuries or deaths) in the event of a worst-case core melt accident.

The boundaries of the plume Emergency Planning Zone take into account local features such as roads, rivers, lakes, peninsula, etc. that may extend the zone beyond 10 miles. The boundaries are selected to assure the existence of adequate evacuation routes as illustrated in Figures 5.4-2 and 5.4-3.

Extensive provisions are made for action within the Emergency Planning Zone. These include:

1. provisions for prompt decision making on protective actions for the public by all responsible parties,

2. development of evacuation plans,

3. provisions for informing the public of emergency plans and procedures (i.e., a public education program),

4. provisions for promptly (within 15 min of the time that state and local officials are notified) alerting and informing the public of the actions to be taken (e.g., siren system and radio messages),

5. provisions for maintaining 24-hr communication between the licensee and state and local officials,

6. provisions for radiological monitoring in the event of an offsite radioactivity release, and

7. provisions for activating and maintaining emergency operations centers.

5.4.5.2 Ingestion Pathway Emergency Planning Zone

The ingestion pathway Emergency Planning Zone is the area in which plans exist for protecting the public from the consumption of food contaminated with radioactive material and for which there is considerable time (hours to days) for action to reduce risks. Thus, the level of preparation is much less in this Emergency Planning Zone than it is in the plume exposure pathway Emergency Planning Zone. Also, the preparations that are made for this Emergency Planning Zone are typically effected at the state level rather than at the local level.

In this Emergency Planning Zone, the concern is for the interdiction of foodstuffs rather than the avoidance of exposure to the plume itself. Protective actions within this zone would generally include the restriction of grazing animals to stored feed and restrictions on crop consumption and water usage. The area of this Emergency Planning Zone generally encompasses a 50-mile radius around the plant site. The size of the ingestion exposure Emergency Planning Zone (about 50 miles in radius, which also includes the 10-mile radius plume exposure Emergency Planning Zone) was selected for the following reasons:

1. The downwind range within which contamination will generally not exceed the Protective Action Guides is limited to about 50 miles from a power plant because of wind shifts during the release and travel periods.

2. There may be conversion of atmospheric iodine (i.e., iodine suspended in the atmosphere for long time periods) to chemical forms that do not readily enter the ingestion pathway.

3. Much of any particulate material in a radioactive plume would be deposited on the ground within about 50 miles of the facility.

4. The likelihood of exceeding ingestion pathway Protective Action Guide levels at 50 miles is comparable to the likelihood of exceeding plume exposure pathway Protective Action Guide levels at 10 miles.

Except for the most severe accidents, immediate action is not critical for food and agricultural produce because of the additional time involved when compared to the time frame associated with the plume exposure Emergency Planning Zone. Preplanned actions for the ingestion pathway Emergency Planning Zone ordinarily will be implemented by local agencies at the direction of state agencies.

5.4.6 Response of State and Local Organizations

5.4.6.1 Emergency Response Plans

States and local agencies have formulated written emergency response plans in response to NRC and Federal Emergency Management Agency (FEMA) requirements. These documents (1) describe the procedures that state and local officials will follow in the event of a nuclear power plant emergency and (2) list the responsibilities of each state and local agency involved. In most states, the authority to recommend protective actions to the public resides with local not state authorities.

5.4.6.2 Public Notification

The licensee must notify offsite state and local organizations responsible for implementing protective actions within 15 minutes of the declaration of an emergency. This permits offsite officials to make prompt protective action decisions, to provide an alerting signal (e.g., a siren), and to follow the signal by a message via the local radio station as to what actions the public should take. State and local officials have predetermined the criteria that they will use to make protective action decisions. These criteria should have been coordinated with the recommendations made to local agencies by the licensee.

In most cases, the specific protective action criteria for severe core damage accidents have been developed after consideration of plant and local conditions. For example, the areas planned to be evacuated may be confined to a valley around the site, or the specific evacuation sector boundaries may be determined by local roads. This delineation is done so that the local population can understand the evacuation instructions.

As discussed in Sections 5.2.6 and 5.4.3, current NRC guidance calls for prompt offsite protective actions on detection of actual or imminent core damage (before dose assessment). Earlier guidance caused many state and local agencies to rely primarily on projected dose assessments. The currently envisioned role for dose assessment during an emergency is discussed in Section 5.2.8.

A flow chart showing the typical steps from detection of an event in the power plant control room (CR) to notification of the public is shown in Figure 5.4-4. Note that the offsite officials generally make decisions based on licensee recommendations, which are, in turn, based on criteria discussed and agreed to in advance. However, conditions that exist off-site (e.g., ice storm, blocked highway, bridge out, etc.) might alter implementation of the licensee's recommendation.

5.4.6.3 Evacuation Time Estimates

Licensees are required to develop evacuation time estimates for the plume-exposure Emergency Planning Zone (10-mile radius). These estimates are based on various models and must be used with caution. These models have not been validated against evacuations and are subject to large uncertainties.

Often, the evacuation time estimates are dominated by assumptions of how long it will take to notify people and for them to get ready to leave. Sometimes it is assumed that it will take an hour or more for pre-evacuation preparation. Actual experience has shown, however, that, if people are told and motivated to "go now," most will follow instructions and most will evacuate very rapidly. Except for special cases where there is a large population near the site (i.e., Zion and Indian Point) or where there is some special population (e.g., hospital patients), it should be possible to evacuate the area near the site in 1 hour or less. Because of the NRC's siting criteria, there is a limited population (<300 people) within 2 miles of most sites. In these cases, the capacity of the local roads will be great enough so as not to delay an evacuation.

5.4.6.4 Dose Projections and Field Monitoring

Dose projection models used by offsite officials are generally similar to those used by the licensee and have the same limitations as other dose models. The only source of release estimates is from the licensee. Therefore, while offsite officials can confirm (check) licensee transport calculations, they must rely on the licensee's release estimates. Because of the complex processes involved in a core melt scenario, the source term (release) estimate would be highly uncertain early in an event. Offsite monitoring capabilities vary markedly, from excellent to marginal depending on the state's emphasis on developing an independent capability. In some situations, offsite officials rely on the licensee or the responding federal agencies (e.g., DOE, EPA, and NRC) for monitoring information.

5.4.6.5 Location of Authority and Responsibility

During the initial phase of the event, the specific location of the local offsite officials with the authority and responsibility to take action varies. The communications system between the licensee and offsite officials should accommodate this need. This is very site- and/or state-specific. In some cases, there are duty officers and 24-hr manned centers, and in others there are local police stations. Once the local emergency organization has been activated, it will establish a local Operations Center. It should be noted that at some sites there are several (2 to 20) local governments within the plume Emergency Planning Zone and that each might have a center.

At the state level, there are typically two levels of activity of interest: (1) an organization that is responsible for conducting technical assessments (e.g., dose assessment) of the situation and (2) decision makers (e.g., governor). These functions may be performed at two separate locations (centers). The NRC must coordinate its contact with offsite officials to avoid considerable confusion resulting from carrying out discussions with both groups. The licensee or state emergency plans should be consulted to determine the specific emergency organization's locations.

Table 5.4-1 Sample initiating condition and examples of accompanying Emergency Action Levels

Initiating condition No. 1	Emergency Action Levels
Known loss of coolant accident (LOCA) greater than makeup pump capacity	Low reactor water level (-134 in.) on level/pressure recorder 1B21-R623B panel 1H12-P601
	or
	High drywell pressure (+1.8 lb) on pressure indicators CM010 and/or CM021, panel 1PM06J **with** Water level below (and failure to return to) top of active fuel as indicated on fuel zone level indicator 1B21-R6210, panel 1H13-P601 (-150in. +50 in. range with "0" corresponding to top of active fuel), following a time delay of 3 min

Table 5.4-2 Example of timing for BWR general emergency sequences

	Timing of event (hr)			
	TW[a]	TQUV[b]	AE[c]	SJ[d]
Unusual event	0.017			
Alert	0.33			0.17
Site Area Emergency	1			0.5
General Emergency (protective actions recommended)	1 to 3	0.17	0.17	3+
Core damage	18	1	0.17	29
Containment failure[e]				
Leak	16	3	0.25	
Major	21	5	3	20

[a]Reactor shutdown followed by loss of decay heat removal.
[b]Reactor shutdown followed by loss of ability to provide coolant water.
[c]Large loss of coolant and failure of system to replace water.
[d]Small loss of coolant and loss of long-term heat removal.
[e]Assuming isolation.

Table 5.4-3 Emergency class descriptions

Class[a]	Core status	Radiation
Unusual Event	No threat to irradiated fuel	No release above technical specification (or annual limits)
Alert	Actual (or potential for) substantial degradation of safety	Release is small fraction of EPA Protection Action Guidelines (PAGs) beyond the site boundary
Site Area Emergency	Major failures of functions needed for public protection	Release is less than EPA PAGs beyond the site boundary
General Emergency	Actual or imminent core degradation	Dose may exceed EPA PAGs beyond the site boundary

[a]Classifications are based on plant instrument levels (i.e., Emergency Action Levels).

Table 5.4-4 Emergency class response

Class[a]	Plant action	Local and state agency action
Unusual event	Provide notification	Be aware
Alert	Mobilize plant resources; man centers (help for control room)	Stand by[a]
Alert	Activate Technical Support Center (TSC)	
Site Area Emergency	Full mobilization; nonessential site personnel evacuate	Mobilize; Man emergency centers and dispatch Monitoring Team
	Activate TSC, Operations Support Center, and Emergency Operations Facility	Inform public, activate warning system
	Dispatch monitoring team Provide dose assessments	Take protective actions in accordance with PAGs or on an ad hoc basis
General Emergency	Full mobilization; recommend predetermined protective actions (within 15 min) after declaring emergency	Recommend predetermined protective actions to the public based on plant conditions
		Precautionary evacuation (2 to 5 miles)

[a]The NRC will typically begin staffing its response centers at the Alert level and may be expected to go to "stand by" or "initial activation."

Table 5.4-5 Emergency Class vs. Recognition Categories

Recognition Categories

Emergency Class	Abnormal Rad Level or Effluents (All OP Modes)	Fission Product Barriers Failure or Challenge (PWR Op)	Hazards/Other Conditions Affecting Plant Safety (All Op Models)	System Malfunctions (Various Op Modes - See NUMARC/NESP-007)
NOUE	Unplanned Gas or Liq. Release to Environment >2X TS for ≥ 60 min. Unexpected Increase in Plant Radiation or Airborne Levels	Any Loss or Potential Loss of Containment	Natural & Destructive Phenomena in the Protected Area. Fire in the P.A. Not Out W/I 15 Min. of Detection. Release of Toxic or Flam. Gas Detrimental to Plt Safe Ops. Confirmed Security Event w/Potential Degradation Safe Op. of Plt. Other Conditions Warrant Declaration by ED.	Loss of Offsite Pwr to Essential Busses for > 15 min. Inability to Reach Req'd S/D within T/S Limits. Unplanned Loss of Safety Sys. Annunciators for > 15 min. Fuel Clad Degradation. RCS Leakage. Unplanned Loss of All Communication Capability. Unplanned Loss Essen. DC Pwr. During Cold S/D or Refueling.
Alert	Unplanned Gas or Liq. Release to Environment > 200 X TS for ≥ 15 min. Major Damage to Irradiated Fuel. Loss of Water Level Uncovers Fuel Outside RV. Increase in Plt Rad or Airborne Levels Impedes Sys. Ops or Ability to Maintain cold S/D.	Any Loss or Potential Loss of Either Fuel Clad or RCS.	Natural & Destructive Phenomena in Plt. Vital Areas. Safety Sys. Req'd. For Safe S/D Affected By Fire or Explosion. Release of Toxic/Flammable Gas Jeopardizes Sys. Op. Safe S/D. Security Event in P.A. Control Room Evac Initiated. Other Conditions Warrant Declaration by ED.	Loss of All On/Offsite AC to Essential Busses, Cold S/D, Refueling. Failure RPS to Scram & Manual Scram Successful. Inability to Maintain Cold S/D. Unplanned Loss of All Safety Sys. Annun., Transient in Progress. AC Pwr. Loss, Only One Source Feed Essen. Busses, > 15 min.
SAE	Site Boundary Dose (actual or projected) Exceeds 100 mRem W.B. or 500 mRem Child Thryoid.	Loss of Fuel Clad and RCS. Potential Loss of Fuel Clad and RCS. Potential Loss of Fuel Clad or RCS + Loss of Any Additional Barrier.	Security Event, Plt. Vital Area. CR Evac. Initiated, Plt. Control Cannot be Established. Other Conditions Warrant Declaration By ED.	Loss of All AC Pwr. Failure EPS to Scram & Manual Scram Unsuccessful. Loss of all Vital DC Pwr. Loss of functions Req'd to maintain Hot S/D. Loss of RV Water Level Req'd to Cover Fuel. Inability to Monitor Significant Transient in Progress.
GE	Site Boundary Dose (actual or imminent) Exceeds 1 Rem.W.B or 5 Rem Child Thyroid for Actual/Proj. Duration Release, Actual Meteorology.	Loss of Any Two Barriers and Potential Loss of Third Barrier. Any core melt sequence.	Security Event, Cannot Reach/Maintain Cold S/D. Other Conditions Warrant Declaration by ED.	Prolonged Loss of AC Pwr. Failure RPS to Scram & Manual Scram Unsuccessful & Extreme Challenge to Core Cooling.

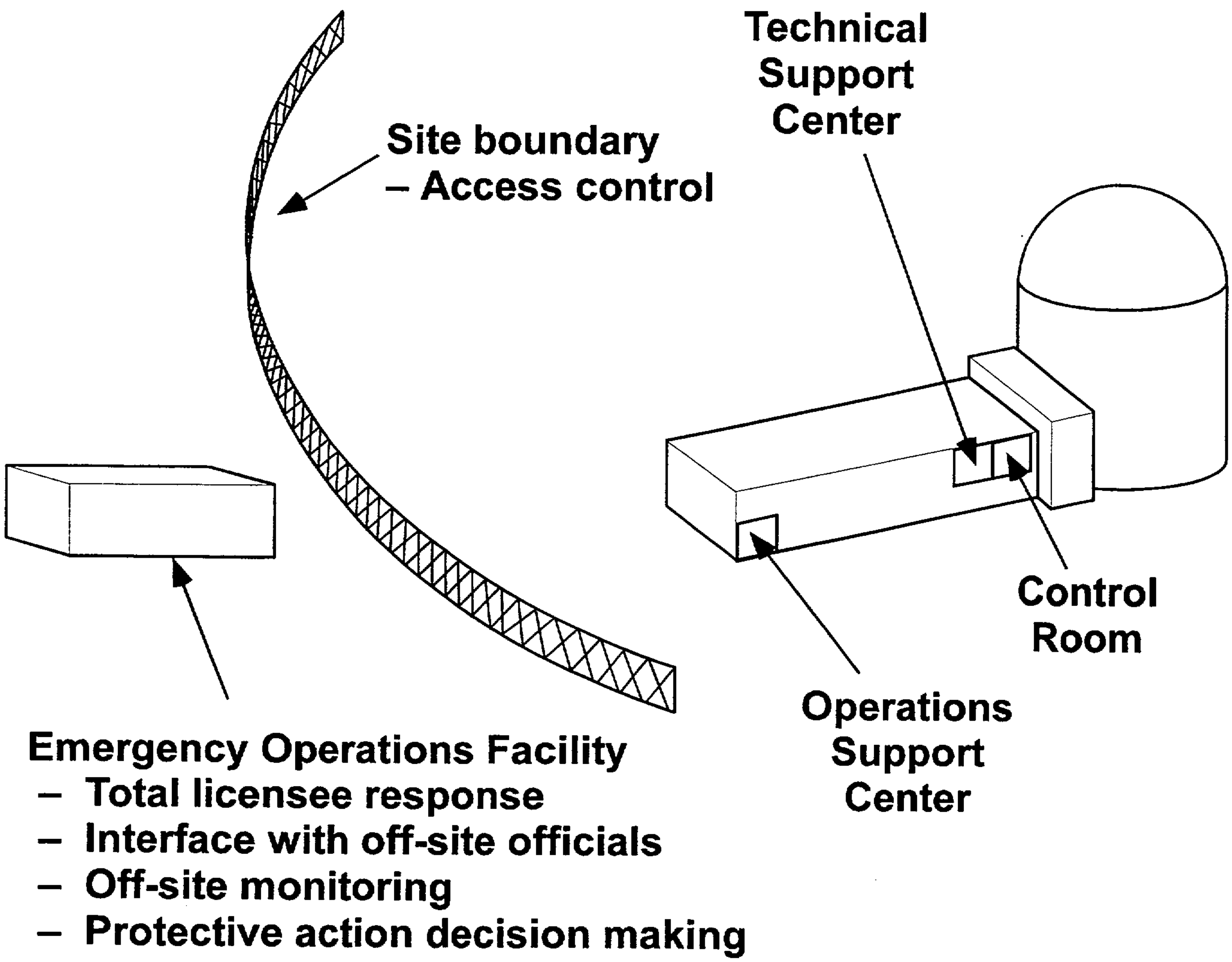


Figure 5.4-1 Relative locations of licensee emergency response centers

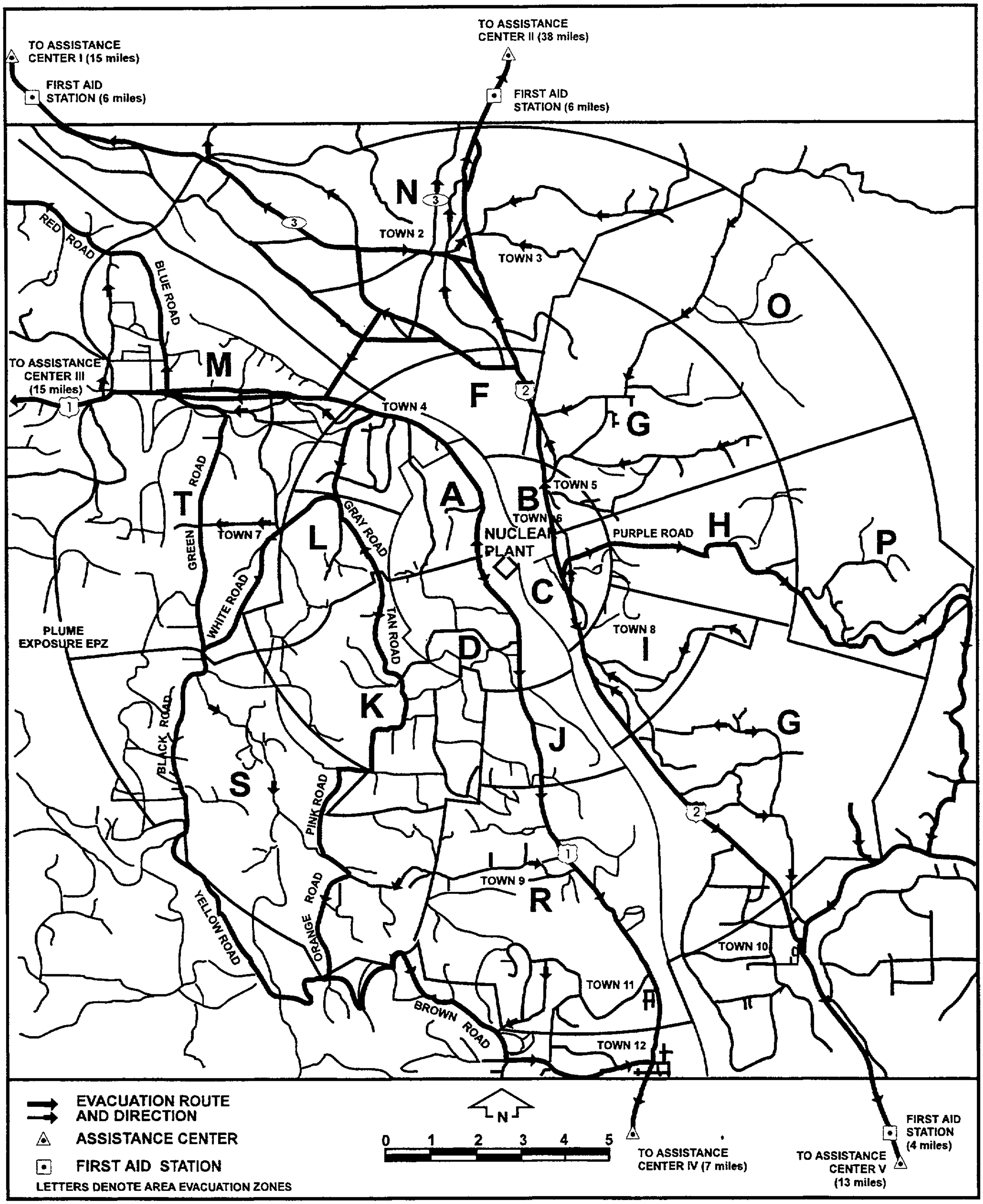
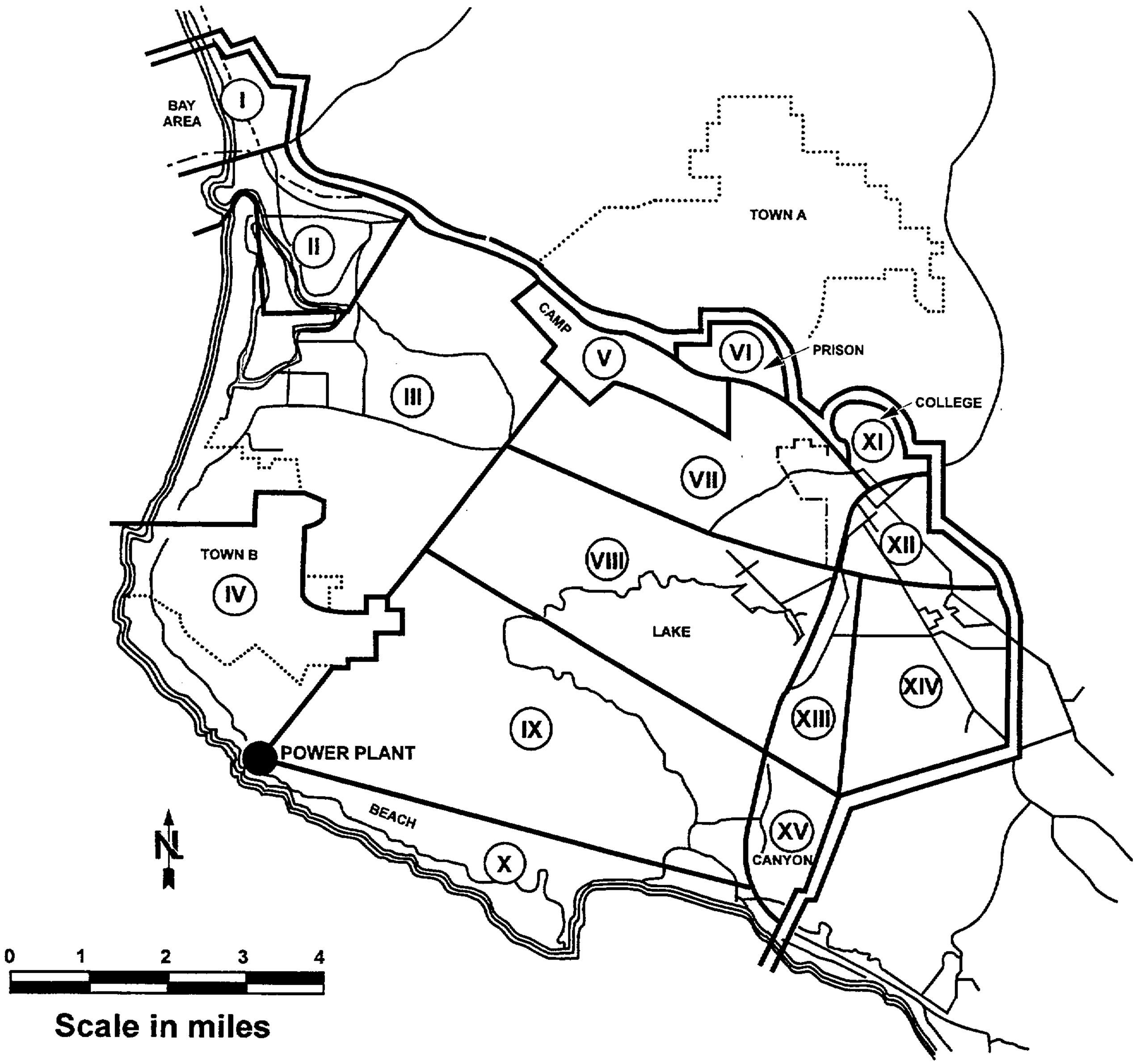


Figure 5.4-2 Example of a plume emergency planning zone with boundaries and evacuation routes determined by roads



Evacuation boundary
Zone boundary
Roman numerals denote area evacuation zones

Figure 5.4-3 Example of a plume emergency planning zone (boundaries are determined by natural features)

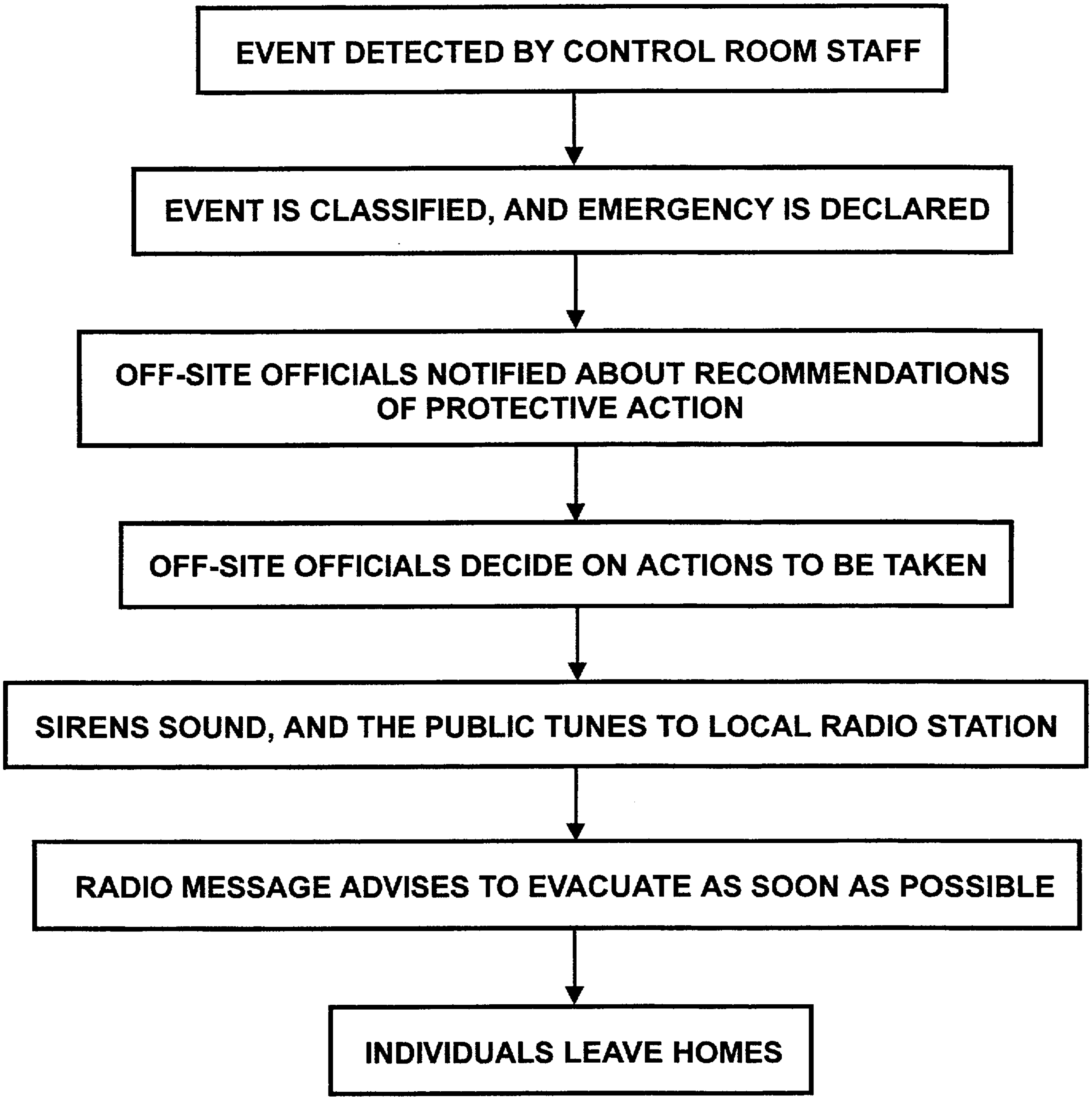


Figure 5.4-4 Flowchart showing steps from detection of a general emergency event in the control room to public evacuation

References for Section 5.4

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5. U.S. Nuclear Regulatory Commission, "Clarification of TMI Action Plan Requirements: Requirements for Emergency Response Capability," NUREG-0737, Supp. 1, No. 1, Washington, D.C., January 1983.

6. T. J. McKenna, et al., "Pilot Program: NRC Severe Reactor Accident Incident Response Training Manual," NUREG-1210, Volumes 1-5, December, 1990.

7. U.S. Nuclear Regulatory Commission, "RTM-96, Response Technical Manual," NUREG/BR-0150, Revision 4, March 1996.

Appendix 5A Protective Action Guides

A Protective Action Guide (PAG) is the projected dose to reference man, or other defined individual, from an unplanned release of radioactive material at which a specific protective action to reduce or avoid that dose is recommended. The Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) have established PAGs that are applicable to severe reactor accidents. These PAGs must be considered in licensees emergency plans and decisions as discussed in Sections 5.3 and 5.4.

Protective actions whose implementation early in an accident (before or shortly after an accidental release of radionuclides to the environment) would be crucial to their effectiveness include evacuation, sheltering, improvised respiratory protection, and the use of potassium iodide to block iodine uptake by the thyroid. These protective actions are discussed in Section 5.3. The Environmental Protection Agency has established PAGs for early protective actions. The EPA PAG levels are low enough to meet the secondary radiation protection objective of reducing doses. At the PAG levels, no health effects would be detectable, even for sensitive populations such as pregnant women.

There are currently two different sets of Environmental Protection Agency PAGs in use for early protective actions. The older PAGs, which were promulgated in 1980, are summarized in Table 5A-1. The newer PAGs were published in 1991 and are summarized in Table 5A-2. Reactor licensees continue to use the older PAGs until they revise their Emergency Plans to adopt new PAGs.

As indicated in Table 5A-1, the 1980 PAGs are based on the external gamma dose from plume exposure and the committed dose to the thyroid from inhalation. The 1991 PAGs replace projected whole body dose with the sum of the effective dose equivalent resulting from external exposure to the plume and the effective dose equivalent from inhalation. For reactor accidents, the change from the 1980 PAGs to the 1991 PAGs should not have any impact on protective action decisions because the thyroid dose is the controlling factor and the PAG levels for projected thyroid dose does not change.

It is important to emphasize that protective action guides are based on projected doses--future doses that can be avoided by the specific protective action being considered. Doses incurred prior to initiation of the protective action should not normally be included. Similarly, in considering early protective actions such as evacuation or sheltering, doses that could be avoided by a intermediate or long term protective actions such as control of contaminated food and water are excluded.

The Food and Drug Administration has established protective action guides for intermediate and late phase food and agricultural exposure pathways. These are summarized in Table 5A-3.

Table 5A-1 Environmental Protection Agency recommended protective actions[a] to reduce whole-body and thyroid dose from exposure to a gaseous plume

Projected Dose (rem) to the Population		Recommended actions[b]	Comments
Whole Body[c] Thyroid	< 1 < 5	No planned protective actions[d] State may issue an advisory to seek shelter and await further instructions. Monitor environmental radiation levels.	Previously recommended protective actions may be considered or terminated.
Whole Body Thyroid	1 to < 5 5 to < 25	Seek shelter as a minimum. Consider evacuation. Evacuate unless constraints make it impractical. Monitor environmental radiation levels. Control access.	If constraints exist, special consideration should be given for evacuation of children and pregnant women.
Whole Body Thyroid	5 and above 25 and above	Conduct mandatory evacuation. Monitor environmental radiation levels and adjust area for mandatory evacuation based on these levels. Control access.	Seeking shelter would be an alternative if evacuation were not immediately possible.

[a]EPA Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, 1980.
[b]These actions are recommended for planning purposes. Protective action decisions at the time of the incident must take existing conditions into consideration.
[c]Effective dose from external sources (cloud and ground) is approximately equal to whole body dose.
[d]At the time of the incident, officials may implement low-impact protective actions in keeping with the principle of maintaining radiation exposures as low as reasonably achievable.

Table 5A-2 Environmental Protection Agency recommended protective actions[a] to reduce external gamma dose from plume exposure and committed dose to the thyroid from inhalation

Projected Dose to the Population	Recommended actions[b]	Comments
1-5 rem[c]	Evacuation[d] (or sheltering)	Evacuation (or for some situations, sheltering[b]) should normally be initiated at one rem.
25 rem[d]	Administration of stable iodine	Requires approval of state medical officials.

[a] U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA 400-R-92-001, October 1991.

[b] Sheltering may be the preferred protective action when it will provide protection equal to or greater than evacuation, based on consideration of factors such as source term characteristics, and temporal or other site-specific conditions.

[c] The sum of the effective dose equivalent resulting from exposure to external sources and the committed effective dose equivalent incurred from all significant inhalation pathways during the early phase. Committed dose equivalents to the thyroid and to the skin may be 5 and 50 times larger, respectively.

[d] Committed dose equivalent to the thyroid from radioiodine.

Table 5A-3 Food and Drug Administration protective action guides

Organ	FDA PAG dose (rem)	Protective Action
Whole body (bone)	0.5-5	At lower projected dose, use of grazing land should be restricted. At higher projected dose, contaminated milk should be impounded.
Thyroid	1.5-15	
Other body organs	0.5-5	

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NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, If any.)

NUREG/CR-6042, Rev. 2
SAND93-0971

2. TITLE AND SUBTITLE

Perspectives on Reactor Safety

3. DATE REPORT PUBLISHED

MONTH	YEAR
March	2002

4. FIN OR GRANT NUMBER

Y6594

5. AUTHOR(S)

F. E. Haskin/ERI
A. L. Camp/SNL
S. A. Hodge/ORNL
D. A. Powers/ORNL

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

ERI Consulting
901 Brazos Place, SE
Albuquerque, NM 87123-4209

Sandia National Laboratories, Principal Contractor
Albuquerque, NM 87185-0747

Engineering Technology Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831-8057

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

U.S. NRC Technical Training Center
5746 Marlin Rd., Suite 200
U.S. Nuclear Regulatory Commission
Chattanooga, TN 37411-5677

10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The U.S. Nuclear Regulatory Commission (NRC) maintains a technical training center at Chattanooga, Tennessee to provide appropriate training to both new and experienced NRC employees. This document describes a one-week course in nuclear safety concepts. The course consists of five modules: (1) the development of safety concepts; (2) severe accident perspectives; (3) accident progression in the reactor vessel; (4) containment characteristics and design bases; and (5) source terms and offsite consequences. The course text is accompanied by slides and videos during the actual presentation of the course.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Browns Ferry Fire, Chernobyl, Containment Performance, Defense in Depth, NRC History, Light Water Reactor Safety, Offsite Radiation Doses, Protective Actions, Risk-Informed Regulation, Severe Accidents, Radiological Source Terms, Three Mile Island Unit 2 Accident

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page) unclassified

(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300