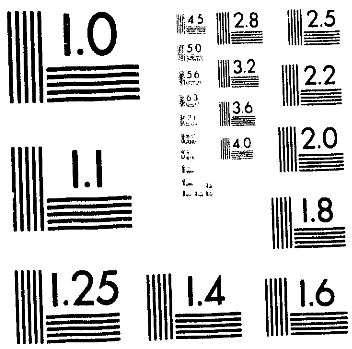
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RADIOLOGICAL RISK GUIDELINES FOR NONREACTOR NUCLEAR FACILITIES AT THE PACIFIC NORTHWEST LABORATORY

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SUMMARY

Radiological risk evaluation guidelines for the public and workers have been developed at the Pacific Northwest Laboratory (PNL) based upon the Nuclear Safety Policy of the U.S. Department of Energy (DOE) established in Secretary of Energy Notice SEN-35-91. The DOE nuclear safety policy states that the general public shall be protected such that no individual bears significant additional risk to health and safety from the operation of a DOE nuclear facility above the risks to which members of the general population are normally exposed.

The radiological risk evaluation guidelines developed at PNL are unique in that they are 1) based upon quantitative risk goals and 2) provide a consistent level of risk management. These guidelines are used to evaluate the risk from radiological accidents that may occur during research and development activities at PNL, and are not intended for evaluation of routine exposures. A safety analyst uses the frequency of the potential accident and the radiological dose to a given receptor to determine if the accident consequences meet the objectives of the Nuclear Safety Policy.

To achieve their purpose, risk evaluation guidelines should provide a consistent risk level for a range of accident frequencies and a range of dose consequences. The risk should be based upon comparison with other types of risk to which the public and worker are exposed. For the public, accidents at DOE nuclear facilities represent an involuntary risk. Therefore, the public guideline risk level should be small compared to other risks the public commonly encounters. For workers, the risk guideline should represent a level of risk comparable to the risk to workers in other, relatively safe industries.

DOE's Nuclear Safety Policy and published death rate statistics for the public and workers were used to develop risk evaluation guidelines. The methodology developed here was used to calculate and plot risk values (fatalities $\cdot$ yr^{-1}) based on various causes of death as a function of event frequency and dose. From this information four regions of risk were defined: unacceptable risk, normal risk, very low risk, and insignificant risk. These data and the resulting regions of risk provide perspective for comparing the radiological risk evaluation guidelines to actual risks the public and workers experience in normal day-to-day living. The risk guideline established by PNL for the public falls within the very low risk region. The risk guideline established by PNL for the worker falls within the lower portion of the normal risk region.

The radiological risk evaluation guidelines are an effective tool for assisting in the management of risk at DOE nonreactor nuclear facilities. These guidelines 1) meet the nuclear safety policy of DOE, 2) establish a tool for managing risk at a consistent level within the defined constraints, and 3) set risk at an appropriate level, as compared with other risks encountered by the public and worker. Table S.1 summarizes the guidelines developed in this report.

Table S.1. Summary of Radiological Risk Evaluation Guidelines

Nuclear Safety Goal	Risk Goal (fatalities yr^{-1})	Risk Evaluation Guideline[a] (rem)	Objective	Application
1	$R \leq 4 \times 10^{-7}$	$D_{event} \leq 100$ rem	prevent prompt fatalities	general public and DOE workers
2	$R \leq 2 \times 10^{-6}$	$D_{event} \leq \frac{0.004}{F}$ and $D_{event} \leq 100$ rem	limit latent cancer risk	general public
3	$R \leq 4 \times 10^{-5}$	$D_{event} \leq \frac{0.1}{F}$ and $D_{event} \leq 100$ rem	limit latent cancer risk	DOE workers

(a) Risk Evaluation Guideline 1 is defined in terms of dose equivalent.
Risk Evaluation Guidelines 2 and 3 are defined in terms of effective dose equivalent.
Applies only to credible events, i.e., $F \geq 10^{-6}$ yr^{-1}.

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LIST OF TERMS

Absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest in that material. Units: rad (Gy, where 1 rad = 0.01 Gy).

Cancer Induction Rate (I). The predicted number of fatal cancers produced as a function of dose received. Cancer induction rates are dependent upon several parameters including dose, dose rate, and age of the population. Expressed in units of cancer fatalities/rem or cancer fatalities/Sv.

Credible. An event with a frequency of 10^{-6} per year or greater.

Consequence (C). An undesirable effect that results from an event. Consequences used in this report include: absorbed dose, dose equivalent, fatalities (immediate and delayed).

Dose (D). A measure of consequence from exposure to radiation. In this report, both absorbed dose and dose equivalent are used to express radiation dose.

Dose equivalent. The product of absorbed dose in rad (or Gy) in tissue, and its quality factor. The dose equivalent to an organ, tissue, or whole body will be that received from the direct exposure plus the 50-year committed dose equivalent received from the radionuclides taken into the body during the year. Expressed in units of rem or Sv, where 1 rem = 0.01 Sv.

Effective dose equivalent (EDE). The summation of the products of the dose equivalent received by specified tissues of the body and a tissue-specific weighting factor. This sum is a risk-equivalent value and can be used to estimate the health-effects risk of the exposed individual. The tissue-specific weighting factor represents the fraction of the total health risk resulting from uniform whole-body irradiation that would be contributed by that particular tissue. The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides, and the effective dose equivalent due to penetrating radiation from sources external to the body. Expressed in units of rem or Sv.

Event. A hypothetical accident or natural phenomena occurrence.

Frequency (F). The predicted number of events per unit time. Expressed in units of events/yr or yr^{-1}.

Probability. The number of expected occurrences per possible number of occurrences, expressed as a unitless ratio.

Public Maximally Exposed Individual (Public MEI). The theoretical, maximally exposed individual at or beyond the site boundary.

Quality Factor (Q). The principal modifying factor that is employed to derive dose equivalent from absorbed dose.

Risk (R). A measure of potential undesirable effect due to the combination of the frequency and consequence of an event. Risk may be expressed in qualitative or quantitative terms. In strict usage, risk is the mathematical product of the frequency of an event and its potential consequences. Expressed in units of fatalities yr^{-1} (as used in this report).

Site Boundary. The boundary of the property over which the owner or operator can exercise strict control without the aid of outside authorities. The site boundary does not have to constitute a fence or other physical barrier.

Worker Maximally Exposed Individual (Worker MEI). The theoretical, maximally exposed individual inside the site boundary but not within the facility under evaluation. This individual is located at the nearest point of access (but no closer than 100 meters) where the maximum dose would be received unless access restrictions justify use of a greater distance.

1.0 INTRODUCTION

This report has been prepared to document the technical bases of the radiological risk evaluation guidelines used by Pacific Northwest Laboratory (PNL)[a] in the evaluation of prospective accidents and natural phenomena events. Pacific Northwest Laboratory's radiological risk guidelines are provided for the use of safety analysists and PNL management in the evaluation of the risk associated with performing operations that involve radioactive materials.

It is the policy of the U.S. Department of Energy (DOE), as stated in Secretary of Energy Notice SEN-35-91, that the general public be protected such that no individual bears significant additional risk to health and safety from the operation of a DOE nuclear facility above the risks to which members of the general population are normally exposed (DOE 1991). This report presents risk guidelines for the public that are based upon the nuclear safety risk goals of SEN-35-91. Additionally, the authors have developed a comparable risk goal for the work force not directly involved with the operation being evaluated and have developed corresponding risk guidelines. In this report, 1) the risk goals are presented and evaluated, 2) quantitative risk guidelines are derived, and 3) the derived risk guidelines are compared to risks encountered by the public and worker in day-to-day living.

Traditionally, the radiological risk criteria used in accident analyses of nonreactor nuclear facilities are dose-based and include little consideration of actual risk. Often, these criteria are based upon arbitrary assignments of event frequencies to various regulatory limits that were intended for purposes other than the control of health effects from low-frequency accidents. Many of these limits have been for the control of routine annual exposures, and were never intended to be used as the technical basis for accident risk guidelines. However, through repeated use, referencing, and tradition, some of these "risk" criteria have essentially become the standard. Policy notice SEN-35-91 provides the philosophy and quantitative criteria needed for breaking away from this tradition and developing risk guidelines that are based upon risk concepts and objectives rather than dose limits.

(a) Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

2.0 DEFINING RISK

There are many types of risks (i.e., monetary risks, environmental risks, and risks to the health and safety of individuals) and there are numerous ways of expressing risk. The radiological risk guidelines developed by PNL are concerned with the health and safety of individuals, which can be thought of in terms of lost workdays, injuries, illness, reduced life expectancy, fatality rates, genetic defects, etc. Although all of these consequences are important, it is not practical to address all health and safety factors. Death represents the ultimate area of concern and is used as the basis of these risk guidelines; therefore, risk is presented in terms of fatalities occurring per unit time.

Risk (R) from an accident in a nuclear facility is defined as the product of the frequency (F) of an event and an associated consequence (C) to a hypothetical maximally exposed individual, who could be either a member of the public or of the DOE-contractor work force. This relationship of an event's risk to its frequency and consequence may be quantified as

$$R = F \cdot C \tag{1}$$

where R = the risk of the event, in fatalities per year

F = the estimated frequency of an event occurring during a given year (yr^{-1}); e.g., an event estimated to occur once every 10,000 years has a frequency of $1 \times 10^{-4}\ yr^{-1}$

C = the consequence of the event, defined as the number of fatalities caused by the event.

As the frequency or the consequence of an event increases, so does the risk associated with that event. Because of this relationship, it is possible to control events such that the combination of frequency and consequence does not exceed a specified risk level. Thus, risk can be managed to a constant, acceptable level over a range of frequencies and consequences.

The U.S. Department of Energy manages the risk associated with its nuclear operations, in part, through preparation of safety analyses. The safety analyst evaluates a spectrum of hypothetical credible events to determine if the risk presented by an operation is acceptable. The risk guidelines are used as a basis for decision-making. Generally, if the analyst can demonstrate that the risk guidelines are met, further action is not necessary. If the risk guidelines are not met, the consequence or frequency of the event, or both, may need to be reduced. In some cases, exceeding the risk guideline may be justified. This could be the case when the operation is judged to be especially important and/or the risk guideline is only slightly and/or temporarily exceeded.

3.0 NUCLEAR SAFETY GOALS

The U.S. Department of Energy has established two nuclear safety goals, set forth in SEN-35-91 (DOE 1991). Both goals address risks to the general population from accidents at DOE nuclear facilities. Risk Goal 1 addresses prompt fatalities (deterministic effects), while Risk Goal 2 addresses delayed cancer fatalities (stochastic effects).

Nuclear Safety Goal 1

The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatalities resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals are assumed to be located within one mile of the site boundary.

Nuclear Safety Goal 2

The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within ten miles of the site boundary.

Neither nuclear safety goal specifically addresses prompt fatalities or delayed cancer fatalities in the DOE work force as a result of accidents. The risk to workers as a result of DOE nuclear operations should also be maintained within a defined level of acceptability relative to delayed cancer fatalities. Therefore, this report establishes an additional nuclear safety goal, Nuclear Safety Goal 3, which addresses and limits the risk to workers from delayed cancer fatalities. The objectives of this goal are consistent with the philosophy of SEN-35-91.

Nuclear Safety Goal 3

The risk to a worker in the vicinity of a DOE nuclear facility for cancer fatalities that might result from accidents should not exceed the risk of fatality to which workers in other, relatively safe industries are exposed. For evaluation purposes, onsite individuals are assumed to be individuals not directly associated with the operation and to be located at the nearest point of access (but no closer than 100 meters) where the maximum dose would be received unless access restrictions justify use of a greater distance.

This report derives and evaluates risk evaluation guidelines for meeting these goals in evaluating potential accidental releases of radioactive material from DOE facilities and operations at the PNL.

4.0 DERIVATION OF THE RISK EVALUATION GUIDELINES

The three nuclear safety goals presented in Section 3.0 are the starting point in the derivation of the risk evaluation guidelines. These goals must be interpreted and converted into quantitative dose and accident frequency criteria (i.e., risk evaluation guidelines) that can be used by the safety analyst for accident analysis and risk management activities. The nuclear safety goals are first quantified and re-stated as risk goals. The risk goals are derived using 1) general population or worker death rate statistics and 2) specific requirements provided in the applicable nuclear safety goal. The risk evaluation guidelines are then developed from the risk goals using data on radiation health effects. This process is illustrated in Figure 4.1.

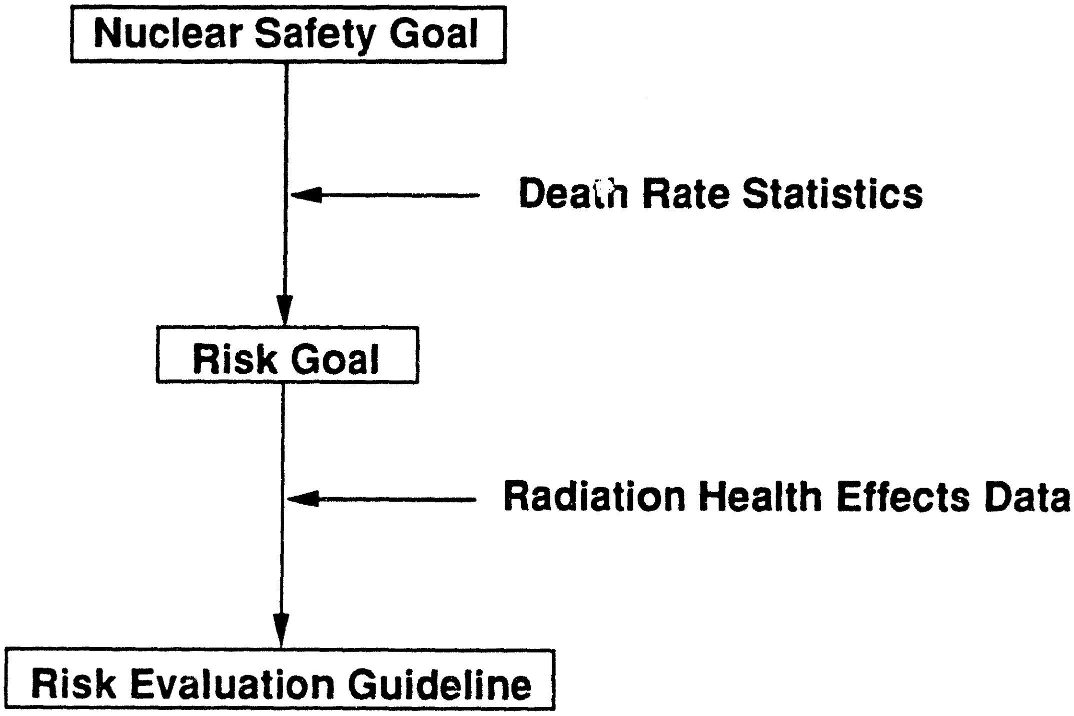

Figure 4.1. Process for Deriving Risk Evaluation Guidelines

Before the risk evaluation guidelines can be developed, the consequences (i.e., radiation health effects) and the hypothetical recipients of the dose (i.e., dose receptors) must be defined.

4.1 RADIATION HEALTH EFFECTS

The consequence of a particular accident is most often given in terms of the immediate effect, e.g., death. For the case of exposure to radiation, however, both prompt and latent fatalities are of concern.

Prompt fatalities are conservatively defined here as including all deterministic effects which may cause death out to 60 days post-exposure. The $LD_{50/60}$, which is the dose at which half of the exposed individuals would be expected to die in 60 days, provides a measure of thus-defined prompt fatalities expected as a function of absorbed dose for an average individual. SEN-35-91 uses the "average individual" as the basis for limiting prompt fatalities (DOE 1991). The $LD_{50/60}$ after acute exposure is estimated to be between 300 and 500 rad (ICRP 1991). Occasionally, fatalities from radiation may occur in some individuals with whole-body doses in the range of 200 rad. Generally, such people are more susceptible than the average person (probably because of concurrent illness, age, and so on). The upper limit that humans can tolerate is probably absorbed dose in the range of 700 rad; at this dose level, acute whole-body irradiation will essentially cause 100% of persons to die without medical intervention. With bone marrow transplantation and appropriate supportive therapy, individuals may survive whole-body doses as high as 1200 rad (Mettler and Moseley 1985).

The risk of prompt fatalities can be kept to essentially zero by limiting the maximum dose equivalent received by an individual to 100 rem, which is well below the $LD_{50/60}$. At acute, whole body exposure levels of 100 rad or less, no individuals would be expected to die from prompt effects (ICRP 1991).

Latent fatalities are fatal effects due to induction of cancer caused by the radiation exposure. The consequence (C) of latent cancer fatalities can be calculated for direct comparison to immediate fatalities using the following equation:

$$C = D \cdot I \qquad (2)$$

where C = the consequence, death caused by cancer

D = the effective dose equivalent received by an individual as a result of a given event (rem)

I = nominal coefficient for induction of fatal cancers, that is, the estimated fatal cancer incidence for a given exposure to radiation, in fatalities per unit of radiation received (rem^{-1}).

For the risk evaluation guidelines, the coefficients for fatal cancer induction are assumed to be 5×10^{-4} rem^{-1} for the general public and 4×10^{-4} rem^{-1} for workers (ICRP 1991). Since I is a constant in Equation 2, changes in the consequence (C) of an event are dependent only upon the dose (D) an individual is estimated to have received from that event. (This is an important point for a safety analyst's calculations, as will be shown in Section 5.0.)

The coefficients for fatal cancer induction are the estimated probability of a fatal cancer per unit effective dose, which the ICRP calls the "nominal fatality probability coefficient." This applies to low doses at all dose rates and to high doses at low dose rates. Because the ICRP has included a "dose and dose rate effectiveness factor" of 2 in probability coefficients for all equivalent doses resulting from absorbed doses below 20 rad and from higher absorbed doses when the dose rate is less than 10 rad $\cdot$ hr^{-1}, the consequences calculated for estimated effective doses between 20 and 100 rem may not have the same basis as doses below 20 rad. However, the possible uncertainty (a factor of 2) introduced by use of the published ICRP values is considered to be comparable to or smaller than uncertainties in calculations and estimating event frequencies. This uncertainty is also hedged by typically conservative calculational assumptions. Therefore, the effects of dose and dose rate factors are not used in the derivation of the risk evaluation guidelines.

4.2 DOSE RECEPTORS

Before the nuclear safety goals can be quantified, specific hypothetical dose receptors must be defined. Thus, the risk evaluation guidelines developed in the rest of this chapter are intended for use with two maximally exposed dose receptors, one for a hypothetical member of the public and the other for a hypothetical worker:

Public Maximally Exposed Individual (Public MEI) -- The Public MEI is the theoretical, maximally exposed individual at or beyond the site boundary.

Worker Maximally Exposed Individual (Worker MEI) -- The Worker MEI is the theoretical, maximally exposed individual inside the site boundary but not within the facility under evaluation. This individual is located at the nearest point of access (but no closer than 100 meters) where the maximum dose would be received unless access restrictions justify use of a greater distance.

4.3 DERIVATION OF RISK EVALUATION GUIDELINE 1

The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatalities resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals are assumed to be located within one mile of the site boundary.

This goal is concerned with prompt fatalities among the public from accidents at DOE nuclear facilities, assuming an individual (as receptor of the dose) within 1 mile of the site boundary. Also, the goal is stated in terms of risk to an "average" individual. However, the risk to any individual from prompt, radiation-induced fatality should be low. Therefore, the application of this goal is extended 1) to the Public MEI (rather than limiting it to an average individual) and 2) to the Worker MEI (rather than limiting it to the public). Limiting the risk to this extent ensures that the goal will be met for all individuals.

4.3.1 Quantifying Risk Goal 1

Death rate statistics from the National Safety Council (NSC 1991) were used to quantify this goal. Annually, there are approximately 40 fatalities per 100,000 individuals in the general population due to accidents. This death rate and the objective of 0.1% provided in Nuclear Safety Goal 1 were used to quantify Risk Goal 1 for prompt fatalities (R):

$$R \leq F \cdot C \tag{3}$$

$$R \leq (40 \text{ fatalities} / 100{,}000 \text{ yr}^{-1})\ 0.001 \tag{4}$$

$$R \leq 4 \times 10^{-7} \text{ prompt fatalities} \cdot \text{yr}^{-1} \tag{5}$$

This is a very low risk of prompt fatalities.

The consequence (C) in this goal is any prompt fatality, so the limiting case is one prompt fatality per event. Solving for event frequency (F), this goal becomes:

$$F = \frac{R}{C} = \frac{4 \times 10^{-7}\,[\text{fatalities}] \cdot yr^{-1}}{1\,[\text{fatality}] \cdot event^{-1}} \tag{6}$$

$$F = 4 \times 10^{-7}\,yr^{-1} \tag{7}$$

which is just into the incredible region (defined as $F < 10^{-6}\,yr^{-1}$) for event frequencies. Therefore, a quantitative interpretation of this goal is that prompt, radiation-induced fatalities are unacceptable for credible events ($F \geq 10^{-6}\,yr^{-1}$). To reflect this quantitative result, the goal may be restated as:

The risk of deterministic, fatal effects to a member of the public or worker, should be limited to a level considered to be very low. Specifically, a prompt, radiation-induced fatality in the Public MEI or the Worker MEI as a result of credible accidents at a DOE nuclear operation is unacceptable.

4.3.2 Risk Evaluation Guideline 1

The condition of no prompt fatalities for credible events requires that a strict maximum acceptable dose equivalent be established. This condition is met by limiting the maximum dose allowed to 100 rem dose equivalent for both MEIs. That is, no prompt fatalities are expected at doses of 100 rem (see Section 4.1). Thus, Nuclear Safety Goal 1 is met by the following criterion (where D is dose equivalent and F is event frequency):

Risk Evaluation Guideline 1

$D_{event} \leq 100$ rem dose equivalent for $F_{event} \geq 10^{-6}\,yr^{-1}$

Application: Public MEI and Worker MEI

4.4 DERIVATION OF RISK EVALUATION GUIDELINE 2

The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within ten miles of the site boundary.

This goal is concerned with latent cancer fatalities in the general population as a result of releases from DOE operations. The goal is stated in terms of the population out to 10 miles and in terms of operations, not accidents specifically. However, for the purpose of managing risk from accidents, the assumption is made that the goal of a 0.1% cancer fatality rate must be met for all members of the public. This assumption is consistent with the philosophy that the general public should be protected such that no individual bears significant additional risk from DOE operations. Therefore, the Public MEI must be used in demonstrating compliance with this goal to ensure that the goal is met for all possible individuals.

4.4.1 Quantifying Risk Goal 2

The concern of Nuclear Safety Goal 2 is latent cancer fatalities. Death rate statistics from the National Safety Council were used to quantify this goal. There are approximately 200 deaths per 100,000 individuals in the general population annually due to cancer (NSC 1991). Using this death rate, determining the quantitative risk to the Public MEI from cancer fatalities that meets Nuclear Safety Goal 2 begins with Equation 3:

$$R \leq F \cdot C \tag{3}$$

$$R \leq (200 \text{ fatalities} / 100{,}000 \text{ yr}^{-1})\ 0.001 \tag{8}$$

$$R \leq 2 \times 10^{-6} \text{ fatalities} \cdot \text{yr}^{-1} \tag{9}$$

Once quantified in this way, this goal may be restated as follows:

The risk of stochastic, latent fatal cancers to a member of the general public should be limited to a level considered to be very low. Specifically, the risk to the Public MEI should not exceed 2×10^{-6} fatalities per year as a result of an accident at a DOE nuclear operation.

4.4.2 Risk Evaluation Guideline 2

The ICRP Publication 60 (ICRP 1991) states that the fatal cancer induction rate (I) for the general population (all ages) is 5×10^{-4} fatalities $\cdot$ rem^{-1}. Risk Goal 2 indicates that the risk to the Public MEI from cancer fatalities should not exceed 2×10^{-6} cancer fatalities yr^{-1} as a result of an accident at a DOE nuclear operation. Using these values, a quantitative risk evaluation guideline for Risk Goal 2 can be derived as shown below.

The starting point is combining Equations 1 and 2, which state fatal latent cancer risk in terms of frequency, dose, and cancer induction rates:

$$R = F \cdot (D \cdot I) \tag{10}$$

The risk guideline can then be expressed in terms of dose for a given event frequency:

$$D = \frac{R}{F \cdot I} \tag{11}$$

Using Equation 11, a quantitative risk evaluation guideline can be determined using the R value for Risk Goal 2, and the value of I for the general population from ICRP 60 (1991):

$$D_{event} \leq \frac{2 \times 10^{-6} \text{ fatalities} \cdot \text{yr}^{-1}}{F \cdot 5 \times 10^{-4} \text{ fatalities} \cdot \text{rem}^{-1}} \tag{12}$$

Simplifying this equation, Risk Evaluation Guideline 2 can be stated as follows:

Risk Evaluation Guideline 2

$$D_{event} \leq \frac{0.004}{F}$$

where D is rem EDE
and F is yr^{-1}

Application: Public MEI

The limitations established in Risk Evaluation Guideline 1 also apply to the Public MEI.

4.5 DERIVATION OF RISK EVALUATION GUIDELINE 3

The risk to a worker in the vicinity of a DOE nuclear facility for cancer fatalities that might result from accidents should not exceed the risk of fatality to which workers in other, relatively safe industries are exposed. For evaluation purposes, onsite individuals are assumed to be individuals not directly associated with the operation and to be located at the nearest point of access (but no closer than 100 meters) where the maximum dose would be received unless access restrictions justify use of a greater distance.

This goal limits the risk to workers from delayed cancer fatalities. Only delayed cancer fatalities are addressed in this goal because Nuclear Safety Goal 1 was expanded to protect workers from prompt radiation-induced fatalities. The goal is stated in terms of the Worker MEI.

4.5.1 Quantifying Risk Goal 3

Accident statistics provided by the National Safety Council are used to quantify the risk objective of this goal. Trades and services was the safest industry, with approximately 4 accidental deaths annually per 100,000 workers (NSC 1991). Although these deaths were not due to cancer, this statistic provides a measure of a low fatality rate in the workplace. Using this annual death rate as the basis for meeting the risk objective for cancer fatalities, Risk Goal 3 becomes:

$$R \leq (4 \text{ fatalities} / 100{,}000 \text{ yr}) \quad (13)$$

$$\therefore \; R \leq 4 \times 10^{-5} \text{ fatalities} \cdot yr^{-1} \quad (14)$$

Thus, this goal may be restated as follows:

The risk of stochastic, latent fatal cancers to a worker at a DOE facility should be low relative to the risk of fatality to which workers in other industries are exposed. Specifically, the risk to the Worker MEI should not exceed 4×10^{-5} cancer fatalities yr^{-1} as a result of an accident at a DOE nuclear operation."

4.5.2 Risk Evaluation Guideline 3

The ICRP Publication 60 (ICRP 1991) states that the latent fatal cancer induction rates for the work force (20 to 64 years of age) is $I = 4 \times 10^{-4}$ fatalities $\cdot rem^{-1}$. Risk Goal 3 indicates that the risk to the Worker MEI from cancer fatalities should not exceed 4×10^{-5} cancer fatalities yr^{-1} as a result of an accident at a DOE nuclear operation. Using these values, the quantitative risk guidelines for Risk Goal 3 can be derived in a manner similar to that used for the general public under Risk Evaluation Guideline 2. As for the general public, the worker risk guideline is determined using Equation 11:

$$D = \frac{R}{F \cdot I} \tag{11}$$

The risk guideline can be expressed in terms of dose for a given event frequency using the risk value from Risk Goal 3 and cancer induction rate for the work force from ICRP 60 (1991):

$$D_{event} \leq \frac{4 \times 10^{-5} \text{ fatalities} \cdot yr^{-1}}{F \cdot 4 \times 10^{-4} \text{ fatalities} \cdot rem^{-1}} \tag{15}$$

Simplifying this equation, Risk Evaluation Guideline 3 can be stated as follows:

<u>**Risk Evaluation Guideline 3**</u>
$D_{event} \leq \frac{0.1}{F}$
where D is rem EDE and F is yr^{-1}
Application: Worker MEI

The limitations established in Risk Evaluation Guideline 1 also apply to the Worker MEI.

4.6 FINAL RISK EVALUATION GUIDELINES

In presenting the final risk evaluation guidelines, one additional limitation is placed on Risk Evaluation Guidelines 2 and 3. The maximum effective dose equivalent that may be received by either the public or worker MEI from any credible event cannot exceed 100 rem. This serves to limit the stochastic risk of fatal cancer induction that could potentially be received if an extremely low-frequency event ($F < 4 \times 10^{-5}$ yr^{-1}) should occur.

The decision to place a 100-rem EDE limit on Risk Evaluation Guidelines 2 and 3 is a deviation from a strictly consistent risk-based approach to safety analysis. However, the authors feel there is still a reluctance to address nuclear safety and accident analysis using a strictly risk-based approach, which considers potential dose <u>and</u> event frequency in tandem. Too often, only the potential dose received is considered, while the equally important aspect of event frequency is essentially neglected.

The imposition of a 100-rem EDE limit does have some practical benefits. It provides an added margin of safety for the admittedly difficult task of determining the frequencies for those events with incredible, extremely unlikely, and perhaps even unlikely, frequencies of occurrence. This is of value when using methods 2 and 3 presented in Section 5.0. It is also the same numeric value as Risk Evaluation Guideline 1 (although the dose terminology and concept is different), and will make the safety analysis process somewhat easier. In most cases dealt with by safety analysts today, the 100-rem EDE limit of Guidelines 2 and 3 will be more limiting than the 100-rem dose equivalent limit of Guideline 1. Concomitantly, most computer software used for safety analysis today calculates impacts to dose receptors in terms of EDE. Preventing prompt fatalities and making dose equivalent calculations are no longer the primary emphases of safety analysis; now, limiting stochastic risk of cancer induction and calculating effective dose equivalent are.

The final risk evaluation guidelines, incorporating the 100-rem EDE limit for stochastic risk, are shown in Table 4.1.

Table 4.1. Summary of Radiological Risk Evaluation Guidelines

Nuclear Safety Goal	Risk Goal (fatalities yr^{-1})	Risk Evaluation Guideline[a] (rem)	Objective	Application
1	$R \leq 4 \times 10^{-7}$	$D_{event} \leq 100$ rem	prevent prompt fatalities	general public and DOE workers
2	$R \leq 2 \times 10^{-6}$	$D_{event} \leq \frac{0.004}{F}$ and $D_{event} \leq 100$ rem	limit latent cancer risk	general public
3	$R \leq 4 \times 10^{-5}$	$D_{event} \leq \frac{0.1}{F}$ and $D_{event} \leq 100$ rem	limit latent cancer risk	DOE workers

(a) Risk Evaluation Guideline 1 is defined in terms of dose equivalent.
Risk Evaluation Guidelines 2 and 3 are defined in terms of effective dose equivalent.
Applies only to credible events, i.e., $F \geq 10^{-6}\ yr^{-1}$.

5.0 RISK EVALUATION METHODS

Three methods have been developed to evaluate radiological risk to the public and the work force, providing flexibility to the safety analyst and encouraging the use of cost-effective techniques in the performance of accident analyses. Each method provides the analyst with the dose to the MEI for a given event, allowing comparison to the appropriate risk evaluation guideline. The method selected depends upon the level-of-confidence in the estimate of event frequency. In going from method 1 (which uses specific frequency values) to method 2 (using order of magnitude frequency estimates) to method 3 (using qualitative descriptions of large event frequency ranges), the level-of-confidence in the event frequency is lower and the required level of analysis gets progressively easier. Concomitantly, the dose determined using the method becomes more conservative, providing a greater margin-of-error for lower level-of-confidence estimates.

The analyst may choose the method most appropriate for his needs and limitations, allowing the best use of resources. For example, if the risk evaluation guidelines can be met using the most conservative method (method 3), then no additional effort is needed to refine the estimate of the event frequency. Conversely, if the risk of an event is determined to be unacceptable using the qualitative frequency description and method 3, the analyst may need to further refine the estimate of the event frequency so that methods 1 or 2 can be used. The three methods of evaluating risk are described in greater detail in the following sections.

When using the radiological risk evaluation guidelines, it must be remembered that they are intended to assist safety analysts, contractor management, and the DOE in making judgments. These guidelines should not be treated as rigid criteria. The risk guidelines represents judgements as to acceptable levels of risk to workers and the public. Acceptability is an imprecise concept subject to the beliefs of each individual. Also, there is significant uncertainty in estimating and evaluating the risk associated with hypothetical accidents. Therefore, it does not necessarily constitute an unacceptable situation for the consequence or frequency of a postulated event to exceed the risk guidelines. Conversely, being within the risk guidelines does not automatically preclude the need for additional controls.

Each event must be evaluated on a case-by-case basis to determine how far to go in limiting risk. In some cases, although the risk guidelines are met, a small increase in controls (engineered safety features and/or administrative controls) may produce a large reduction in risk. In such cases, the additional expense may be justified based upon the ALARA (as low as reasonably achievable) principle. In other cases, exceeding the risk guidelines may be justified. This could be the case when the operation is judged to be especially important and/or the risk guideline is only slightly and/or temporarily exceeded.

5.1 METHOD 1: RISK EVALUATION USING A SPECIFIC EVENT FREQUENCY VALUE

Method 1 can be used only when a relatively precise event frequency has been calculated, which in many cases is not cost-effective or even possible.

When the frequency of the event is technically supportable and calculated to one or more significant figures, the analyst should use the dose guideline equations in Table 5.1 to determine if the calculated dose for the event will meet the risk evaluation guidelines. The dose from an event with a given frequency can be plotted in Figure 5.1 to show graphically where the dose is in relation to the risk evaluation guideline.

Table 5.1. Method 1 Risk Guidelines for Use with Explicit Event Frequencies

For all credible events ($F \geq 10^{-6}\ yr^{-1}$):

1. D_{event} shall not exceed 100 rem dose equivalent

AND

2. D_{event} is limited as a function of event frequency per year, not to exceed 100 rem EDE:

   a. For Worker MEI

$$D_{event} \leq \frac{0.1}{F}$$

   b. For Public MEI

$$D_{event} \leq \frac{0.004}{F}$$

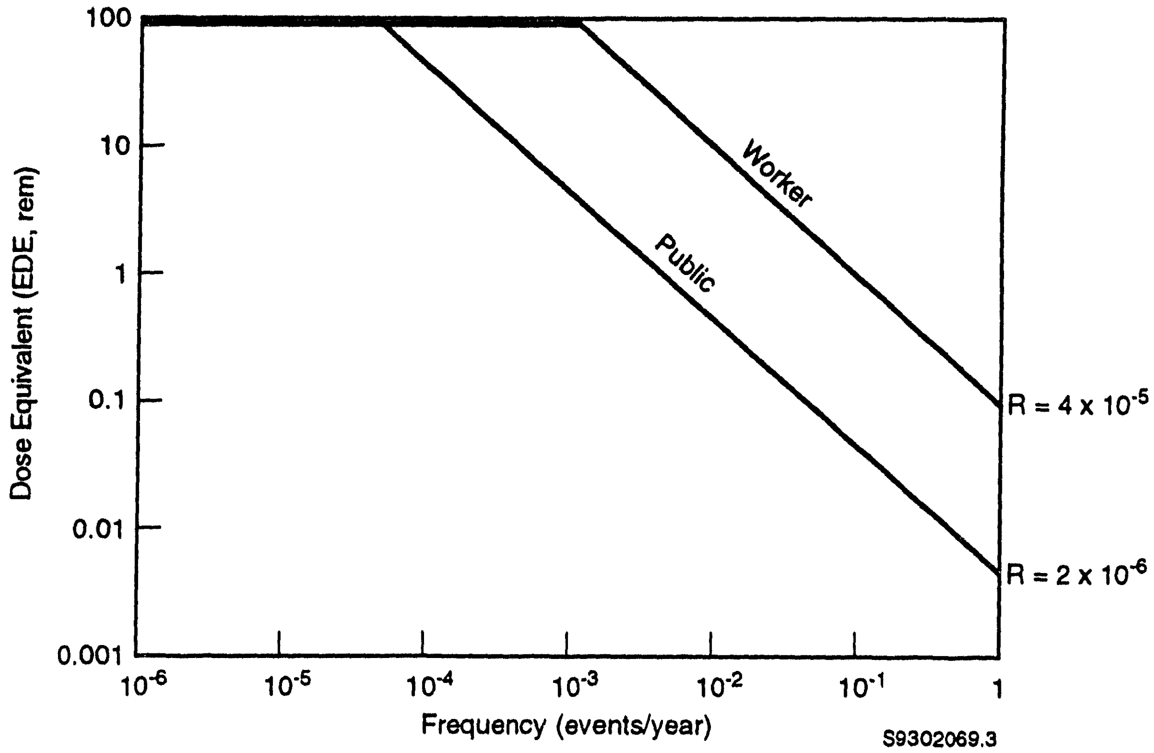

Figure 5.1. Risk Guidelines for the Public and Workers

5.2 METHOD 2: RISK EVALUATION USING ORDER OF MAGNITUDE FREQUENCY ESTIMATES

Method 2 provides an intermediate means of risk evaluation. To use this method, the event frequency must be estimated to within an order of magnitude. Acceptable dose guidelines determined with this method are more conservative than those derived with method 1.

When the frequency of the event is justified to an order of magnitude, the analyst should use Table 5.2 to select the maximum acceptable consequence for the event, noting that Table 5.2 sets risk acceptance guidelines that tend to be more conservative than those of method 1. For example, using Table 5.2 values, all events in the frequency range of 1.0×10^{-3} yr^{-1} through 9.9×10^{-3} yr^{-1} have risk guidelines of 0.4 rem (0.004 Sv) for the public and 10 rem (0.1 Sv) for the worker. These are the risk guidelines that correspond to an event frequency of 1.0×10^{-2} yr^{-1} when the maximum acceptable dose is calculated according to method 1. Therefore, if the risk of an event is determined to be unacceptable using method 2, the analyst should consider further refinement of the estimate of the event frequency so that method 1 can be used.

The dose guidelines for the order of magnitude estimates of event frequency in Table 5.2 are shown in Figure 5.2 to graphically show where the maximum allowable dose is in relation to the line corresponding to the risk evaluation guideline.

Table 5.2. Method 2 Risk Guidelines When Event Frequency is Estimated to Within an Order of Magnitude

Event Frequency (yr^{-1})	Maximum Allowed Dose to the Public MEI (EDE, rem)	Maximum Allowed Dose to the Worker MEI (EDE, rem)
$\geq 10^{-1}$	0.004	0.1
10^{-2}	0.04	1
10^{-3}	0.4	10
10^{-4}	4	100[a]
10^{-5}	40	100[a]
10^{-6}	100[a]	100[a]

(a) And dose equivalent.

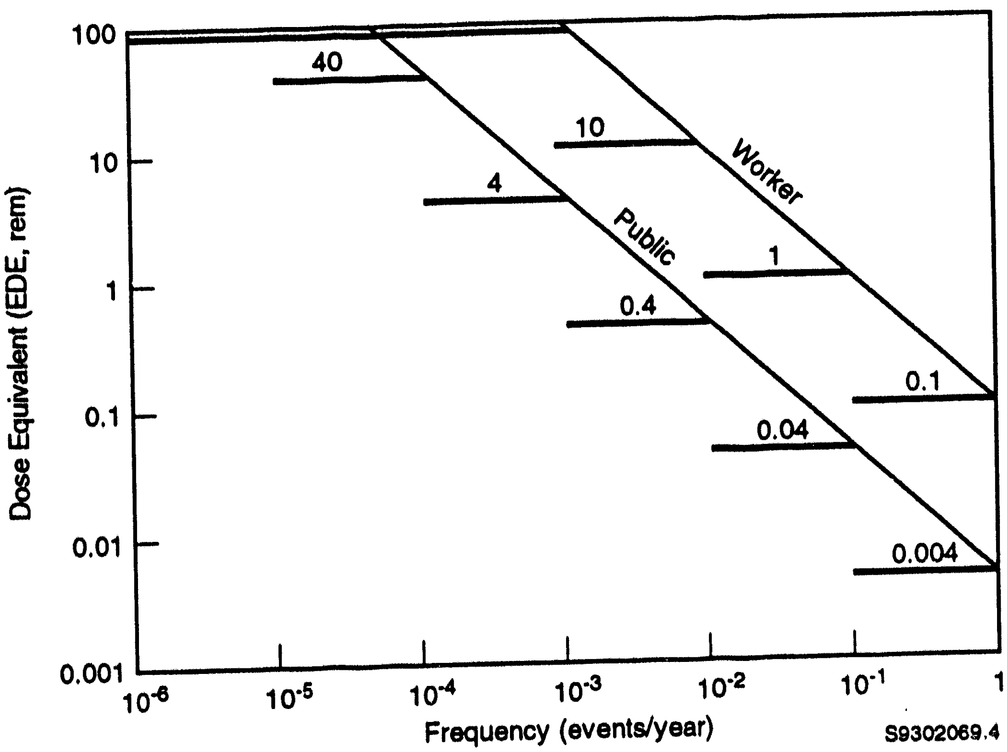

Figure 5.2. Risk Guidelines for Order of Magnitude Event Frequency

5.3 METHOD 3: RISK EVALUATION USING QUALITATIVE FREQUENCY DESCRIPTIONS

Method 3 provides the easiest, but most conservative means of risk evaluation. This method is used when the frequency of the event is set qualitatively. This method uses three broad descriptions of event frequency and therefore is extremely conservative. The analyst should use this method only when event consequences are so low that a refined frequency estimate is not justified or when it is not possible to justify a better estimate of event frequency.

When the frequency of the event is set qualitatively, the analyst must use Table 5.3 to select the maximum allowable dose for the event. The qualitative descriptions of event frequency are:

Anticipated - Off-normal conditions that may occur once or more during the lifetime of the facility. Nominal event frequency: $>10^{-2}\ yr^{-1}$

Unlikely - Events that, individually, are not expected to occur. Collectively, events within this category may occur once or more during the lifetime of the facility. Nominal event frequency: 10^{-4} to $10^{-2}\ yr^{-1}$

Extremely Unlikely - Events that are of such exceedingly small frequency that even collectively none are expected to occur during the lifetime of the facility. Nominal event frequency: 10^{-6} to $10^{-4}\ yr^{-1}$

The dose guidelines for qualitative event frequency descriptions in Table 5.3 are shown in Figure 5.3 to graphically show where the maximum allowable dose is in relation to the line corresponding to the risk evaluation guideline.

Table 5.3. Method 3 Risk Guidelines for Use with Qualitative Event Frequency Descriptions

Qualitative Frequency Description	Maximum Allowed Dose to the Public MEI (EDE, rem)	Maximum Allowed Dose to the Worker MEI (EDE, rem)
Anticipated	0.004	0.1
Unlikely	0.4	10
Extremely Unlikely	40	100[(a)]

(a) And dose equivalent.

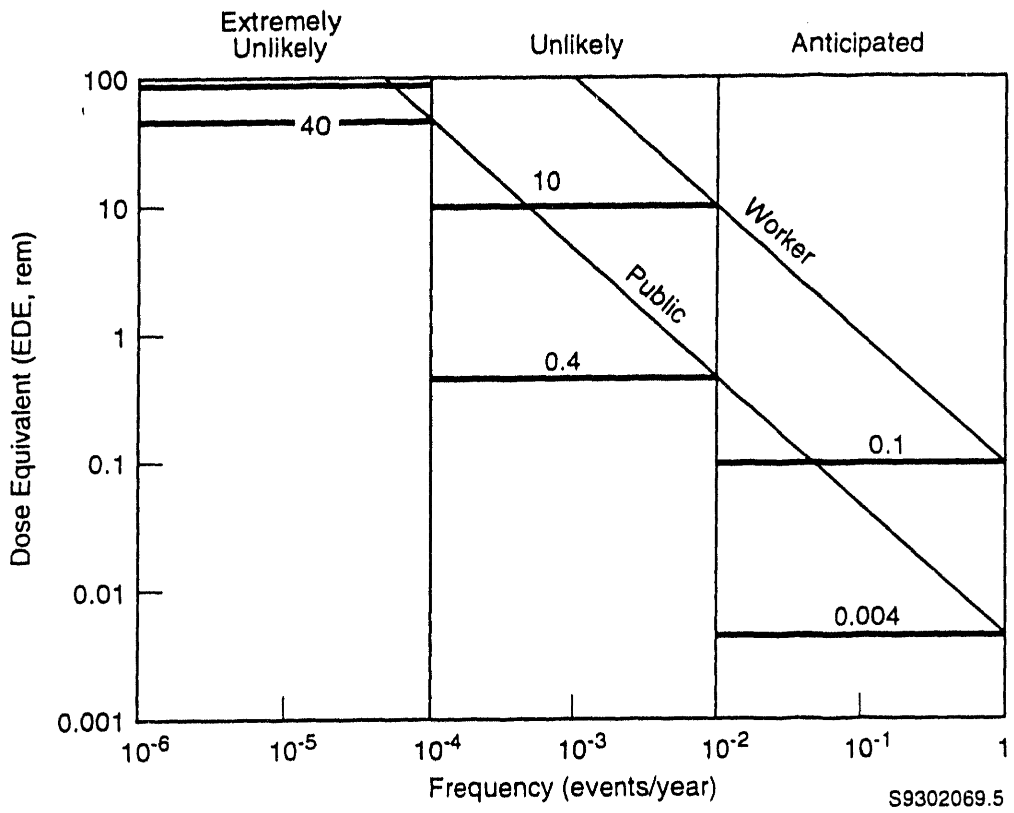

Figure 5.3. Risk Guidelines for Qualitative Event Frequency Categories

6.0 RADIOLOGICAL RISK IN PERSPECTIVE

To achieve their purpose satisfactorily, the radiological risk evaluation guidelines for the public and the worker must provide a consistent level of protection that is appropriate relative to the risk these individuals encounter from other sources. Actual death-rate statistics were used to determine where, within the credible frequency range, acceptable risk evaluation guidelines for the public and worker should be set. These statistics provide a valuable tool for keeping risk goals in perspective. Presentation of these statistics on a risk graph (consequence versus frequency) helps in visualizing the entire spectrum of risks to which all individuals are exposed every day.

Risk evaluation guidelines are set appropriately if they represent 1) a consistent level of risk through the frequency range of interest and 2) an appropriate level of risk relative to other risks.

6.1 RELATING RADIOLOGICAL RISK TO GENERAL RISK: DOSES OF COMPARABLE RISK

The statistics in Table 6.1 are annual death rates in the general population and in various industries. These statistics vary from year to year. However, typical fluctuations in annual death rate statistics are inconsequential relative to the magnitude of risk levels under consideration and thus would have no impact on the risk concepts presented. The numbers represent actual deaths from all causes, accidents as well as diseases.

These statistics differ somewhat from the concept of predicted delayed fatalities that is used in the risk guidelines. These statistics are the number of people that died of a cause during one year and thus represent a mixture of immediate and delayed fatalities. In cases such as accidents and homicides, many of the deaths were likely an immediate result of the cause. Conversely, deaths due to illnesses could have resulted from events that occurred in previous years. By comparison, fatalities from radiation exposure concern deaths due to fatal cancer induction which may not be expected to occur for 20 years or more following the exposure.

Although immediate and delayed fatalities have the same endpoint, the perception of risk associated with these may not be the same. Immediate fatalities from such causes as industrial accidents, heart attacks, motor vehicle accidents, etc., may be viewed as less acceptable than delayed fatalities from causes such as cancer or black lung disease. However, for the purpose of relating the risk guidelines to more familiar risks in people's lives, it is necessary to treat immediate and delayed fatalities as equivalent. This allows comparison of risks from various sources and gives perspective to the risk guidelines. Thus, the risk from delayed cancer fatalities due to hypothetical radiological events can be related to the risks from other causes of death that occur in our society and work places. This helps to ensure that the risk guidelines are set at an appropriate level. It also makes it possible for individuals in the public and work force to understand the risk guidelines relative to risks they experience on a day-to-day basis and thus make their own conclusions as to the acceptability of the guideline.

To help in comparing radiological risks to general risks, annual death rate statistics provided by the National Safety Council are adjusted to a dose equivalent (rem received per event where $F_{event} = 1\ yr^{-1}$), predicted to result in equivalent cancer fatality rates. This adjusted dose equivalent, presented in the final column of Table 6.1, is predicted to be capable of causing the same number of deaths from radiation-induced fatal cancers as occurred for the listed cause of death. This adjusted dose permits the risk of death from various actual causes to be compared to the risk from acute radiation exposures. It is assumed that dose response is linear and rate-independent in the dose range of interest.

Table 6.1. Statistics on Common Sources of Risk

Public Exposure to Risk			
Leading Causes of Death	Annual Death Rate/100,000 Population	Annual Death Rate per Person (fatalities yr^{-1})	Adjusted Dose (rem)[a]
All causes	882.1	8.8×10^{-3}	17.6
Heart disease	311.3	3.1×10^{-3}	6.2
Cancer	197.3	2.0×10^{-3}	4.0
Stroke	61.2	6.1×10^{-4}	1.2
Accidents	39.5	4.0×10^{-4}	0.8
Motor vehicle	20.0	2.0×10^{-4}	0.4
Homicide	9.0	9.0×10^{-5}	0.2
Fire & burns	2.0	2.0×10^{-5}	0.04
Poisoning	2.2	2.2×10^{-5}	0.04
Worker Exposure to Risk			
Industry	Annual Death Rate/100,000 Workers	Annual Death Rate per Worker (fatalities yr^{-1})	Adjusted Dose (rem)[a]
All industries	9	9.0×10^{-5}	0.18
Agriculture	42	4.2×10^{-4}	0.84
Mining, quarrying	43	4.3×10^{-4}	0.86
Construction	33	3.3×10^{-4}	0.66
Manufacturing	6	6.0×10^{-5}	0.12
Transport. & public utility	22	2.2×10^{-4}	0.44
Trade	4	4.0×10^{-5}	0.08
Services	4	4.0×10^{-5}	0.08
Government	9	9.0×10^{-5}	0.18

(a) EDE, with annual frequency = 1.
Source: NSC (1991)

The adjustment of general risk to radiological risk is shown in the following example. The annual death rate per 100,000 population due to motor vehicle accidents was reported by the National Safety Council to be 20.0 in 1991. Following Equation 1, the risk (R) to a hypothetical average individual from motor vehicle accidents is therefore 20.0 deaths per year per 100,000 people, or

$$R = F \cdot C \tag{1}$$

$$R_{\text{motor vehicle}} = 2.0 \cdot 10^{-4} \text{ fatalities yr}^{-1} \tag{16}$$

Following Equation 11, the radiation dose equivalent (D) predicted to produce a comparable risk from fatal cancer induction (i.e., the adjusted dose equivalent) as the result of an acute exposure with an annual frequency ($F = 1 \text{ yr}^{-1}$) is:

$$D_{\text{comparable motor vehicle}} = \frac{R_{\text{motor vehicle}}}{F \cdot I} \tag{17}$$

$$D_{\text{comparable motor vehicle}} = \frac{2.0 \cdot 10^{-4} \text{ fatalities yr}^{-1}}{(1 \text{ yr}^{-1})(5 \cdot 10^{-4} \text{ cancer fatalities rem}^{-1})} \tag{18}$$

$$D_{\text{comparable motor vehicle}} = 0.4 \text{ rem} \tag{19}$$

Thus, an individual's risk of dying in a motor vehicle accident in 1 year is predicted to be equivalent to his risk of contracting fatal cancer from an acute radiation dose of 0.4 rem.

This process is used to predict doses of comparable risk for the credible frequency range ($F > 10^{-6} \text{ yr}^{-1}$) and dose equivalents of less than 100 rem (1 Sv). For example, an individual's risk of dying in a motor vehicle accident over a period of 100 years ($F = 10^{-2} \text{ yr}^{-1}$) is predicted by this process to be equivalent to his risk of contracting fatal cancer from an acute radiation dose of 40 rem.

6.2 LEVELS OF RISK

The relationship between consequence (which is expressed as effective dose equivalent, D), frequency (F), and risk (R) is illustrated in the risk graph shown in Figure 6.1. Risk levels appear as diagonal lines on the risk graph. Each diagonal line represents a consistent level of risk, or number of predicted fatalities per year, over the range of consequences and frequencies that is of interest in the development of risk acceptance guidelines. To illustrate this concept, consider the risk level of $R = 10^{-5}$ fatalities yr^{-1}. For events predicted to occur once per year ($F = 1$), the dose predicted to correspond to this level of risk is 0.02 rem. For events predicted to occur only once every 100 years ($F = 10^{-2}$), the dose predicted to cause the same level of risk is 2 rem. Therefore, an event that occurs annually and results in a dose of 0.02 rem presents the same level of risk as an event that occurs once every 100 years and results in a dose of 2 rem.

Four regions of risk are shown on the risk graph in Figure 6.1. These regions are 1) unacceptable risk (the region in solid black), 2) normal risk, 3) very low risk, and 4) insignificant risk. The public and worker risk guidelines which were derived from the nuclear safety risk goals are also shown in this figure.

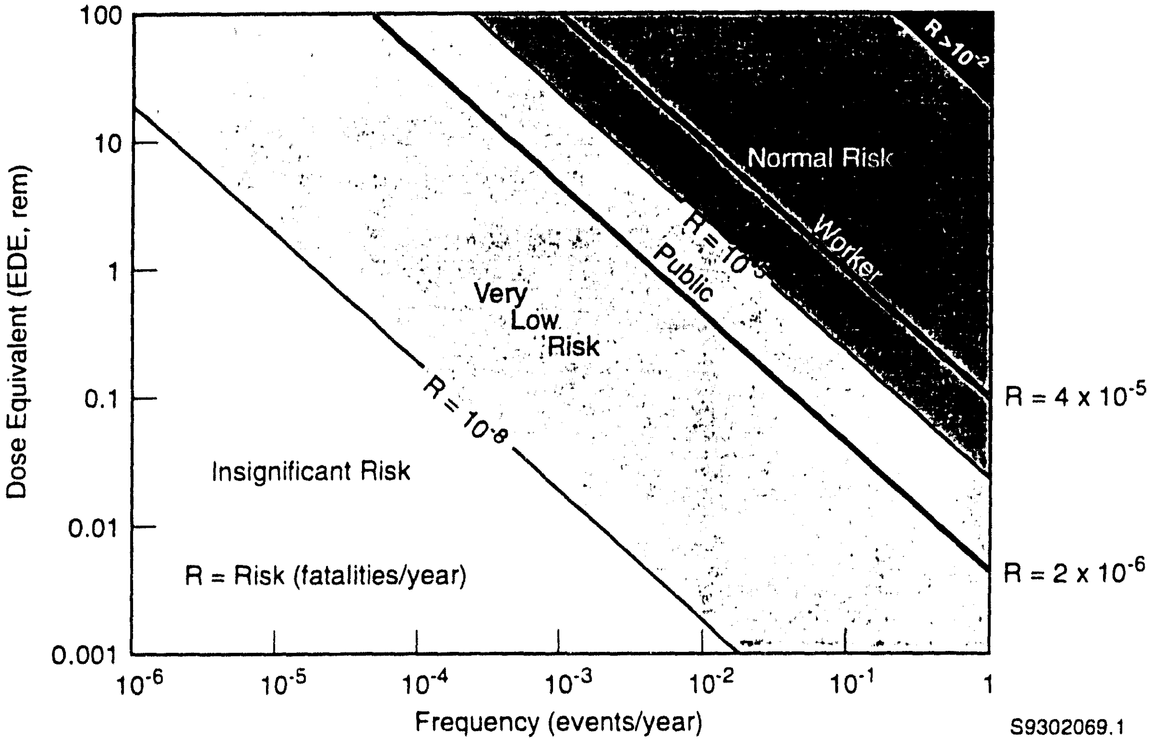

Figure 6.1. Risk Levels and Major Regions of Risk

The region of unacceptable risk is set at R ≥ 10^{-2} fatalities yr^{-1}. Most individuals would consider this level of risk unacceptable based upon the leading causes of death and work accident statistics. Risk levels commonly encountered by the worker and the public are well below this value (see Table 6.1). Setting this region at ≥ 10^{-2} fatalities/yr also is consistent with information provided in ICRP Publication 60 (1991), regarding a report of a Study Group of the British Royal Society (1983), which concluded that imposing a continuing annual occupational probability of death of 1 in 100 would be unacceptable.

The region of normal risk is the set of R values between 10^{-2} and 10^{-5} fatalities yr^{-1}. This is the region of risk most encountered in the work place and by the public. This region ranges from relatively high-risk causes of death (e.g., mining and agricultural accidents, heart disease and cancer) to low-risk causes of death (e.g., accidents in trade and service occupations and death due to homicide, fires, and burns).

The region of very low risk is the set of R values between 10^{-5} and 10^{-8} fatalities yr^{-1}. This range is below the lowest risk levels encountered in the work place and by the public (Table 6.1) and above the region of insignificant risk.

The region of insignificant risk is set at R ≤ 10^{-8} fatalities yr^{-1}. The U.S. Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) have established a *de minimis* level of cancer risk (EPA 1985; FDA 1985a, 1985b) that is used to define this region. In the risk-based guidelines used by the EPA and FDA, a 10^{-6} lifetime risk of cancer has been used as a quantitative criterion of insignificance. This value corresponds to R = 10^{-6} fatalities per 70 years, or 1.4 x 10^{-8} fatalities yr^{-1}. The risk line of R = 10^{-8} fatalities yr^{-1} is thus used to define the upper bound of the region of insignificant risk.

Figures 6.2 and 6.3 illustrate the risk levels that correspond to causes of death listed in Table 6.1. Figure 6.2 shows risk levels for causes of death in the general population. The risk evaluation guideline for the public that was derived from Risk Goal 2 is also shown in this figure. Figure 6.3 shows risk levels for workers in various industries and includes the risk evaluation guideline for the worker that was derived from Risk Goal 3.

6.3 RISK EVALUATION GUIDELINES IN PERSPECTIVE

The risk guidelines derived from Risk Goals 2 and 3 are set appropriately. The risk guidelines ensure 1) a consistent level of risk through the frequency and dose ranges of interest and 2) an appropriate level of risk relative to other risks.

6.3.1 Public Exposure to Risk

For the public, exposure to releases from an event at a DOE nonreactor nuclear facility is an involuntary risk. Therefore, the risk level associated with the public guidelines should be small compared with other risks commonly encountered by the public. The public risk guideline derived from Risk Goal 2 is within the very low risk region. This ensures that the incremental risk to the public as a result of events at DOE nuclear operations is kept very small compared to other risks already encountered by the public in day-to-day living in a relatively safe society. For comparison, the public risk guideline represents a level of risk below that corresponding to the EPA's annual airborne emissions limit of 10 mrem for DOE facilities (40 CFR 61), thus providing reasonable assurance that exposures to individual members of the public as a result of accidental releases will not add significantly to the risk level associated with the routine environmental release limit.

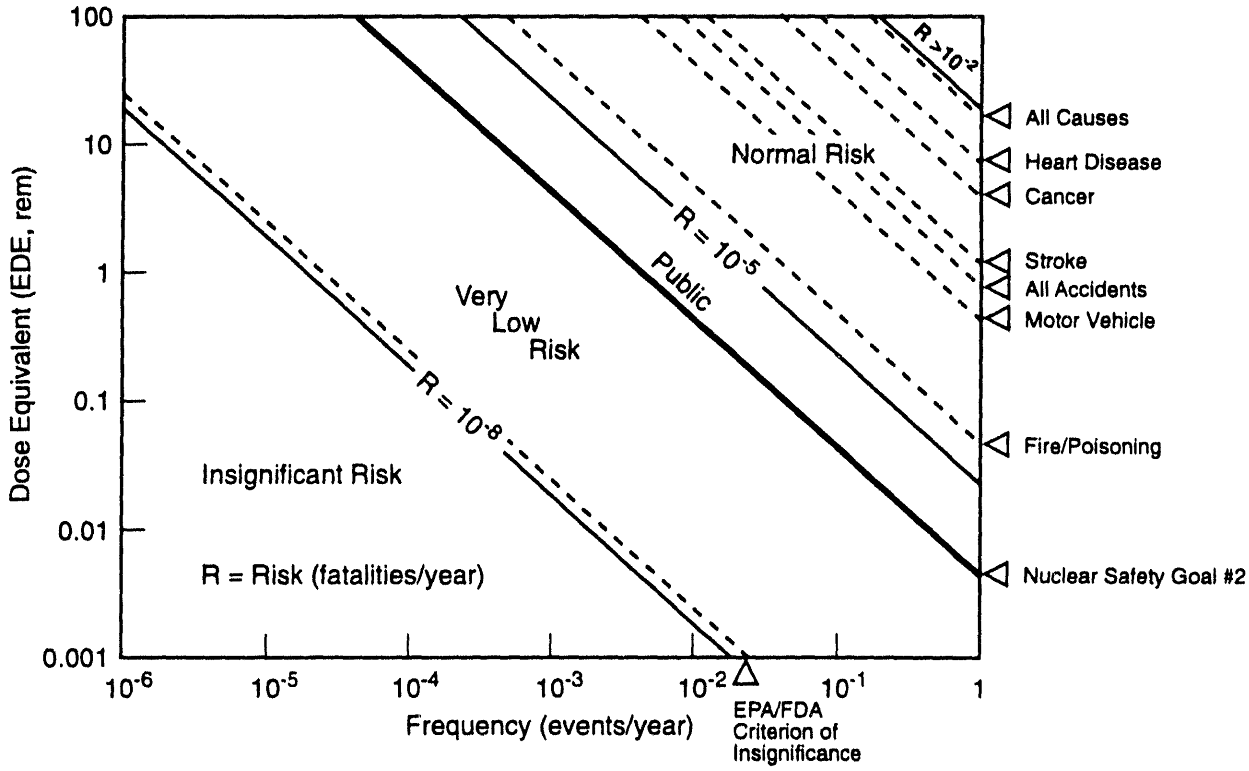

Figure 6.2. Levels of Risk Commonly Encountered by the Public

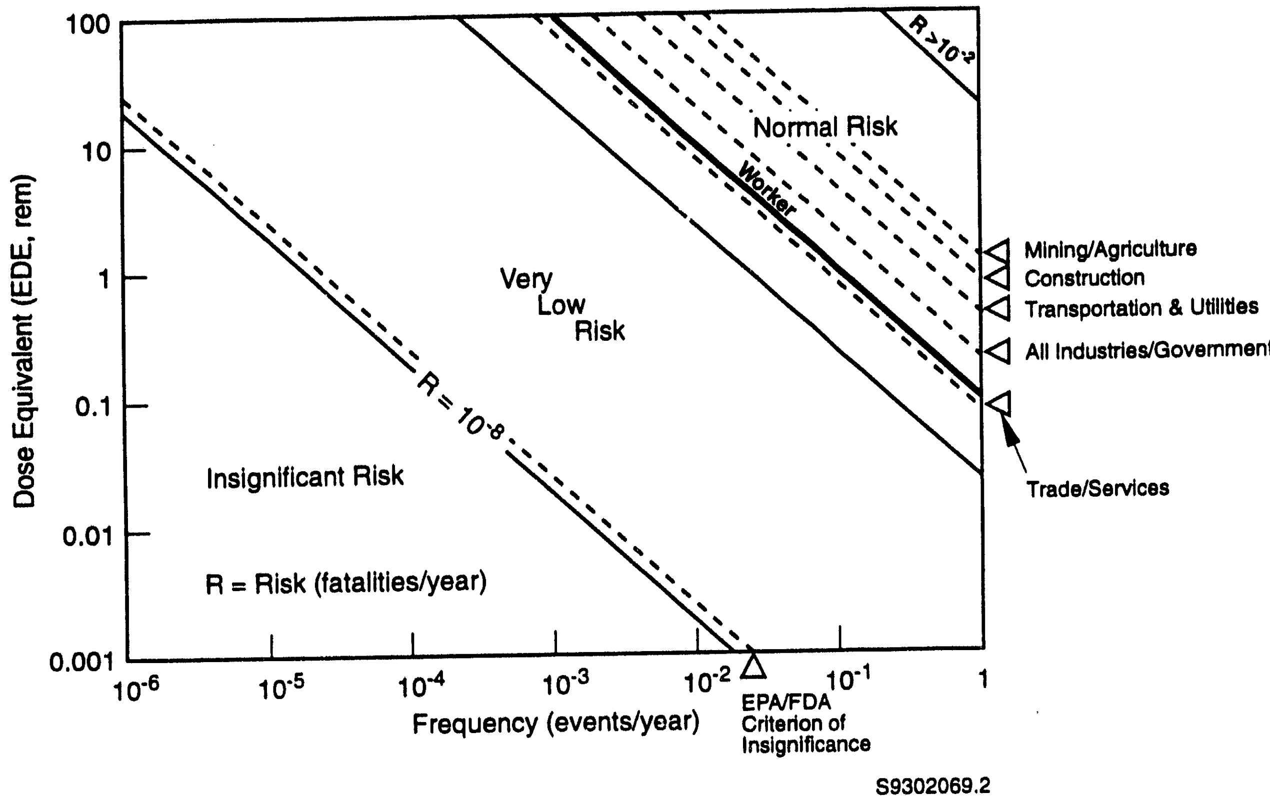

Figure 6.3. Levels of Risk for Various Industry Groups

6.3.2 Worker Exposure to Risk

For the worker, exposure to releases from an event at a DOE nonreactor nuclear facility is a work-place risk. Therefore, the risk level associated with the worker guidelines should be comparable to other work-related risks. The worker risk guideline derived from Risk Goal 3 is in the low-risk portion of the normal risk region. This ensures that the incremental risk to the worker as a result of unplanned releases from nearby DOE operations does not significantly increase the risk to which this worker is normally exposed. Thus, the risk to workers as a result of potential accidents in DOE nonreactor nuclear facilities is managed at a level that is comparable to other low-risk occupations.

Additionally, the selected worker risk guideline for Nuclear Safety Goal 3 ($R \leq 4 \times 10^{-5}$ fatalities yr^{-1}) approximates OSHA guidelines for occupational exposure. The Office of Safety and Health Administration has used an acceptable working lifetime risk of 1 in 1000 as a guide in determining permissible exposure levels for carcinogens (OSHA 1985):

$$R_{OSHA}(\text{worker}) = (1 \cdot 10^{-3}\ \text{fatalities})(70\ yr^{-1}) \tag{20}$$

$$R_{OSHA}(\text{worker}) = 1.4 \cdot 10^{-5}\ \text{fatalities}\ yr^{-1} \tag{21}$$

This is very close to Risk Goal 3.

7.0 CONCLUSIONS

Radiological risk evaluation guidelines are used by DOE contractors to make judgements as to the acceptability of the risk associated with prospective accidents at DOE nuclear facilities. It has been a long-standing practice within the DOE community to use such guidelines to establish maximum acceptable doses relative to event frequencies as part of the analysis of the safety of an operation. These risk evaluations are commonly documented in nuclear facility safety analysis reports (SARs). Administrative controls and engineered safety features are utilized as appropriate to limit risk (i.e., dose and/or consequence) based upon these guidelines.

Historically, the DOE contractors have taken a dose-based approach to defining risk guidelines. That is, dose limits developed for other purposes (e.g., annual exposure limits for routine operations) have been assigned to an event frequency or frequency range, with lower event frequencies receiving the higher dose limits. Until the development of the guidelines presented in this report, PNL was using this approach.

The radiological risk guidelines presented in this report represent a new and more technically supportable risk-based approach. These guidelines are based upon quantitative risk goals derived from DOE's nuclear safety policy and actual death rate statistics. The appropriateness of the numeric values of guidelines has been verified through comparison to other risks encountered by the public and the worker.

8.0 REFERENCES

International Commission on Radiological Protection (ICRP). 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Pergamon Press, Oxford, United Kingdom.

Mettler, C. A. Jr. and Moseley, R. D. Jr. 1985. Medical Effects of Ionizing Radiation. Grune & Stratton, Orlando.

National Safety Council (NSC). 1991. Accident Facts - 1991 Edition. Chicago, Illinois.

Occupational Safety and Health Administration (OSHA). 1985. "Occupational Exposure to Benzene." Federal Register 50:50512-50586.

Study Group of British Royal Society. 1983. Risk Assessment. The Royal Society, London.

U.S. Department of Energy (DOE). 1991. "Nuclear Safety Policy." DOE Notice SEN-35-91.

U.S. Environmental Protection Agency (EPA). 1985. Federal Register. "National Primary Drinking Water Regulations; Volatile Synthetic Organic Chemicals; Final Rule and Proposed Rule." (50:46830-46901, 1985). "National Primary Drinking Water Regulations, Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms; Proposed Rule." (50;46936-47025, 1985).

U.S. Environmental Protection Agency (EPA). 1991. "National Emission Standards for Hazardous Air Pollutants." 40 CFR 61.

U.S. Food and Drug Administration. 1985a. "Cosmetics: Proposed Ban on the Use of Methylene Chloride as an Ingredient of Aerosol Cosmetic Products." Federal Register 50:51551-51559.

U.S. Food and Drug Administration. 1985b. "Sponsored Chemicals in Food-Producing Animals; Criteria and Procedures for Evaluating the Safety of Carcinogenic Residues." Federal Register 50:45530-45553.

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