RAS D-25

April 14, 2008

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE NUCLEAR REGULATORY COMMISSION

In the Matter of:	)	
	)	
Pacific Gas and Electric Co.	)	Docket No. 72-26-ISFSI
	)	
(Diablo Canyon Power Plant Independent Spent Fuel Storage Installation)	)	

SUMMARY OF FACTS, DATA, AND ARGUMENTS ON WHICH PACIFIC GAS AND ELECTRIC COMPANY WILL RELY AT THE SUBPART K ORAL ARGUMENT ON CONTENTION 2

Jennifer Post, Esq.
PACIFIC GAS AND ELECTRIC CO.
77 Beale Street, B30A
San Francisco, CA 94105

David A. Repka, Esq.
Tyson R. Smith, Esq.
WINSTON & STRAWN LLP
1700 K Street, N.W.
Washington, DC 20006-3817

COUNSEL FOR PACIFIC GAS AND
ELECTRIC COMPANY

Template Secy-055

US-03

TABLE OF CONTENTS

ATTACHMENTS

TAB	TITLE
1	Testimony of Mr. Jearl Strickland and Mr. Mark Mayer, PE
2	Figures and Tables Figure 1 – HISTORM Cask Figure 2 – 10 Mile Population Wheel Figure 3 – 50 Mile Population Wheel Figure 4 – 10 Mile Land Use Figure 5 – 50 Mile Land Use Table 1 – Summary of Nearby Populations and Land Use
3	Statement of Professional Qualifications – Mr. Jearl Strickland
4	Statement of Professional Qualifications – Mr. Mark Mayer
5	Environmental Report for Diablo Canyon ISFSI, Chapter 5
6	Safety Analysis Report for Diablo Canyon ISFSI, Excerpts from Chapters 3 and 8
7	Regulatory Guide 8.29, Rev. 1, "Instruction Concerning Risks From Occupational Exposure" (February 1996).
8	Excerpts from U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA-400-R-92-001 (May 1992).

April 14, 2008

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE COMMISSION

In the Matter of:	)	
	)	
Pacific Gas and Electric Co.	)	Docket No. 72-26-ISFSI
	)	
(Diablo Canyon Power Plant Independent Spent Fuel Storage Installation)	)	

SUMMARY OF FACTS, DATA, AND ARGUMENTS ON
WHICH PACIFIC GAS AND ELECTRIC COMPANY WILL
RELY AT THE SUBPART K ORAL ARGUMENT ON CONTENTION 2

I. Introduction

In accordance with the schedule established by the Commission in its Order, dated January 25, 2008, Pacific Gas and Electric Co. ("PG&E") hereby submits its "Summary of Facts, Data, and Arguments on Which Pacific Gas and Electric Company Will Rely at the Subpart K Oral Argument on Contention 2" ("PG&E's Summary"). As required by 10 C.F.R. § 2.1113(a), PG&E's Summary includes this written summary as well as attachments with supporting facts and data in the form of sworn written testimony and referenced documents. In this filing, PG&E demonstrates that there is no genuine dispute of fact to be resolved through an adjudicatory hearing. Consistent with 10 C.F.R. § 2.1115(a)(2), the single contention here at issue should be dismissed.

II. Procedural History for this Subpart K Proceeding

On December 21, 2001, PG&E submitted an application for a 10 C.F.R. Part 72 license to possess spent fuel and other radioactive materials associated with spent fuel in an independent spent fuel storage installation ("ISFSI") located at the Diablo Canyon Power Plant ("DCPP") site in San Luis Obispo County, California. That application included an Environmental Report ("ER") and a Safety Analysis Report ("SAR").

In accordance with the National Environmental Policy Act ("NEPA"), the NRC issued an Environmental Assessment ("EA") and Finding of No Significant Impact ("FONSI") for the ISFSI application on October 24, 2003. The NRC also issued its Safety Evaluation Report ("SER") on the application on March 22, 2004. On that same day, the NRC issued a site-specific license (SNM-2511) to PG&E for the ISFSI at the DCPP.

This present matter is before the Commission on remand from the Ninth Circuit Court of Appeals.[1] In accordance with the Commission's directions in CLI-07-11,[2] the NRC Staff prepared a supplemental Environmental Assessment ("EA Supplement") under the National Environmental Policy Act ("NEPA") — addressing the likelihood and consequences of terrorist attacks at the Diablo Canyon ISFSI site. The EA Supplement was served on the parties on May 29, 2007.[3] On June 28, 2007, the San Luis Obispo Mothers for Peace ("SLOMFP" or

---

1 *See San Luis Obispo Mothers for Peace v. NRC*, 449 F.3d 1016 (9th Cir. 2006).

2 Memorandum and Order, CLI-07-11, February 27, 2007.

3 "Supplement to Environmental Assessment and Draft Finding of No Significant Impact Related to Construction and Operation of the Diablo Canyon Independent Spent Fuel Storage Installation," May 29, 2007 ("Draft EA Supplement").

"Petitioner") filed proposed contentions addressing the NRC Staff's EA Supplement.[4] PG&E responded to those proposed contentions on the issue of admissibility on July 9, 2007.[5] Before the Commission acted on the contentions, the NRC Staff issued its final EA Supplement, which took into account public comments.[6] The Commission directed the parties to file pleadings addressing the effects, if any, of the NRC Staff's final EA Supplement on the pending contentions.[7] SLOMFP responded that its contentions remained valid.[8] PG&E and the NRC Staff again opposed SLOMFP's proposed contentions.[9]

The Commission ruled on admissibility of the contentions in CLI-08-01. The Commission admitted and established a process for resolution of Contention 1(b). That process

---

4 "San Luis Obispo Mothers for Peace's Contentions and Request for Hearing Regarding Diablo Canyon Environmental Assessment Supplement," dated June 28, 2007, as corrected June 29, 2007 ("Proposed Contentions").

5 "Pacific Gas and Electric Company's Response to Proposed Contentions," dated July 9, 2007. PG&E supplemented that response in a filing dated October 11, 2007, addressing the issue of the impact of the Staff's issuance of the final EA Supplement on August 31, 2007.

6 *Supplement to Environmental Assessment and Final Finding of No Significant Impact Related to Construction and Operation of the Diablo Canyon Independent Spent Fuel Storage Installation* (August 2007).

7 *Pacific Gas and Electric Co.* (Diablo Canyon Independent Spent Fuel Storage Installation), unpublished Order (Sept. 11, 2007).

8 "San Luis Obispo Mothers for Peace's Response to NRC Staff's Supplement to the Environmental Assessment and Finding of No Significant Impact for the Diablo Canyon Independent Spent Fuel Storage Installation" (Oct. 1, 2007).

9 "Pacific Gas and Electric Company's Response to Commission Order and San Luis Obispo Mothers for Peace Filing on the Final Environmental Assessment Supplement" (Oct. 11, 2007); "NRC Staff's Response to San Luis Obispo Mothers for Peace's Response to Commission Order and Supplement to Final Environmental Assessment" (Oct. 11, 2007).

remains ongoing and Contention 1(b) is beyond the scope of the present filing. The Commission also admitted only a portion of proposed Contention 2 related to whether the NRC Staff considered the environmental impacts of a terrorist attack on the surrounding land and whether the NRC Staff took into account the non-fatal health effects (*e.g.*, latent cancers) from a hypothetical terrorist attack. CLI-08-01, slip op. at 20. Contention 2 is the subject of this filing.

With respect to Contention 2, the Commission specifically noted that the NRC Staff may be able to explain how such issues were addressed by reference to source documents, including the 2003 EA, or otherwise explain how such issues are bounded by or implicitly considered by the very low dose estimates. *Id.*, slip op. at 21. The Commission denied the portion of Contention 2 alleging a lack of clarity about the role of emergency planning in mitigating harm from radiological releases, noted that there is no reason to convene an NRC hearing to debate the self-evident, and unexceptional, proposition that emergency planning and response actions may provide an additional measure of protection in the event of a terrorist attack. CLI-08-01, slip op. at 21.

Importantly, in ruling on the admissibility of proposed contentions, the Commission rejected proposed Contention 3. In that proposed contention, SLOMFP sought to litigate specific postulated terrorist attack scenarios that it claimed would result in consequences much larger than those calculated by the NRC Staff and reported in the EA Supplement as limiting doses for the scenarios that the NRC Staff determined to be plausible. In rejecting the proposed contention, the Commission stated that "[w]e do not understand the Ninth Circuit's remand decision — which expressly recognized NRC security concerns and suggested the possibility of a 'limited proceeding' — to require a contested adjudicatory inquiry into the credibility of various hypothetical terrorist attacks against the Diablo Canyon ISFSI." CLI-08-01,

slip op., at 23-24. The Commission held that the NRC Staff's approach to terrorist attack scenarios, which is "grounded in the NRC Staff's access to classified threat assessment information, is reasonable on its face." *Id.* (footnotes omitted).

III. Strict Threshold for an Adjudicatory Hearing in a Subpart K Proceeding

The procedures in 10 C.F.R. Part 2, Subpart K, were established in response to a congressional mandate found in the Nuclear Waste Policy Act of 1982, 42 U.S.C. § 10101, *et seq.* ("NWPA"). The NWPA was passed to establish a federal program for funding and development of a permanent disposal repository for spent nuclear fuel and other high-level nuclear waste. *See* H.R. Rep. No. 97-785, pt. 1, at 32 (1982). Congress determined that the operators of civilian nuclear power reactors have "primary responsibility" for interim storage of spent fuel, and that they should do so "by maximizing, to the extent practical, the effective use of existing storage facilities at the site of each civilian nuclear power reactor, and by adding new onsite storage capacity in a timely manner where practical." 42 U.S.C. § 10151(a)(1). Congress also declared that the purpose of the NWPA was to promote the "addition of new spent nuclear fuel storage capacity" at civilian reactor sites. *Id.* at § 10151(b)(1). The NWPA directed federal agencies to "encourage and expedite the effective use of available storage, and necessary storage" at reactor sites. *Id.* at § 10152.

The NWPA § 134(a)-(b), 42 U.S.C. § 10154(a)-(b), further states that for any application for the construction of dry fuel storage capacity, the Commission was to provide parties to any hearing on the expansion amendment with the opportunity to present facts, data, and arguments, by way of written summaries and sworn testimony, and an oral argument. Based on the summaries sworn testimony and the argument, the Commission then would designate "any disputed questions of fact, together with any remaining questions of law, for resolution in an

adjudicatory hearing" — but only if the Commission finds that "there is a genuine and substantial dispute of fact which can only be resolved with sufficient accuracy by the introduction of evidence at an adjudicatory hearing" and "the decision of the Commission is likely to depend in whole or in part on the resolution of such dispute."

The NRC implemented NWPA through a 1985 rulemaking that added Subpart K to 10 C.F.R. Part 2. 50 Fed. Reg. 41,662 (1985). The statutory requirements related to limiting adjudicatory hearings on spent fuel storage matters are incorporated in the Commission's regulations at 10 C.F.R. §§ 2.1113 and 2.1115. Section 2.1115(a)(1)-(2) provides that the presiding officer shall "[d]esignate any disputed issues of fact, together with any remaining issues of law, for resolution in an adjudicatory hearing," and "[d]ispose of any issues of law or fact not designated for resolution in an adjudicatory hearing." Under the Commission's regulations, 10 C.F.R. § 2.1115(b), an issue may be designated for an adjudicatory hearing only if:

a. There is a genuine and substantial dispute of fact; *and*

b. The dispute can be resolved with sufficient accuracy only through introduction of evidence at an adjudicatory hearing; *and*

c. The NRC's ultimate decision is likely to depend in whole or in part on the resolution of the dispute.

Any issues that do not meet all three of these criteria are to be disposed of by the Commission promptly after an oral argument. *Id.* at § 2.1115(a)(2).

The NRC made it clear in the 1985 rulemaking that the threshold for an adjudicatory hearing in Subpart K is quite high:

> The Commission continues to believe that the statutory criteria are sufficient. As the Commission pointed out in connection with the proposed rules, the statutory criteria are quite strict and are designed to

> ensure that the hearing is focused exclusively on real issues. They are similar to the standards under the Commission's existing rule for determining whether summary disposition is warranted. They go further, however, in requiring a finding that adjudication is necessary to resolution of the dispute and in placing the burden of demonstrating the existence of a genuine and substantial dispute of material fact on the party requesting adjudication.

50 Fed. Reg. at 41,667; *see also Carolina Power & Light Company* (Shearon Harris Nuclear Power Plant), LBP-00-12, 51 NRC 247, 255, at 2 (quoting 50 Fed. Reg. 41,662, 41,667 (1985)) (May 5, 2000). As a result, in the present case SLOMFP bears the heavy burden of demonstrating that they are entitled to an adjudicatory hearing.

First, SLOMFP must demonstrate that there is a factual dispute; the Commission can dispose of pure questions of law without the need for an adjudicatory hearing. As will be discussed below, Contention 2 can be disposed of on this basis.

Second, SLOMFP must demonstrate a genuine and substantial fact issue in dispute, and that the NRC's decision is likely to depend on the resolution of that dispute. With respect to Contention 2, SLOMFP has failed in this regard. Based on responses to discovery in this case, the Intervenors will not dispute any fact offered here by PG&E. Rather, their case revolves around postulated, hypothetical terrorist attacks. PG&E concludes, based on evidence presented here, that these matters do not present genuine and substantial disputes of fact. While the NRC's summary disposition regulation, 10 C.F.R. § 2.749, requires a factual issue that is "material" to justify an evidentiary hearing, the Subpart K requirement is that an adjudicatory hearing be held only if the NRC's decision "is likely to depend in whole or in part" on the resolution of the factual dispute. This Subpart K threshold is a much stricter threshold than "materiality." The factual dispute must play a central role in the ultimate disposition of the proceeding. Otherwise, no adjudicatory hearing is required. The Commission can dispose of the

SLOMFP's issue on the basis of the sworn testimony and written submissions because the issues are neither substantial nor central to the Commission's decision.

Third, even if the Commission were to find a factual dispute that is genuine and substantial, an adjudicatory hearing is not required unless it is shown that the dispute can only be resolved through traditional adjudicatory procedures, such as live testimony subject to cross-examination. With respect to Contention 2, this is not the case. PG&E (and the NRC Staff) have presented a substantial record on which the Commission can render a decision in PG&E's favor. There is no basis whatsoever to conclude that further hearings are warranted.

IV. Contention 2: Reliance on Hidden and Unjustified Assumptions

A. Restatement of Contention 2 and its Bases

SLOMFP asserts in Contention 2 that the EA Supplement is inadequate because it fails to adequately disclose the health impacts (*e.g.*, latent cancers) and land contamination associated with a terrorist attack on the Diablo Canyon ISFSI. The contention, as admitted by the Commission, is a narrow contention of omission asserting that the EA Supplement needs to consider the issues of latent health effects and land contamination. SLOMFP's discovery filings implicitly suggest an overly-broad scope to the contention. For example, SLOMFP states that the NRC Staff's answers to the question could help SLOMFP evaluate "the question of whether the NRC Staff did . . . judge that non-fatal health effects are too *improbable* to warrant consideration" and "the question of whether the [NRC] Staff used the presumed *low likelihood* of nonfatal radiological consequences to determine that the environmental impacts of an attack on the Diablo Canyon ISFSI would be insignificant."[10] As noted above, the Commission has

---

10 "San Luis Obispo Mothers for Peace's Motion to Compel Discovery Responses by NRC Staff," dated March 3, 2008, at 3 ("Motion to Compel") (emphasis added).

already decided that this limited proceeding does not extend to adjudicating the credibility or likelihood of hypothetical terrorist scenarios. CLI-08-01, slip op. at 24. Accordingly, the facts and arguments discussed below focus on the specific admitted issue of whether the NRC's EA Supplement must further discuss the environmental impacts of a terrorist attack on the Diablo Canyon ISFSI in terms of long-term health effects and/or land contamination. We conclude that the EA Supplement is adequate.

B. Summary of Facts and Arguments in Response to Contention 2

The relevant facts concerning Contention 2 are provided in the ISFSI license application, the original EA Supplement dated October 24, 2003, the final EA Supplement dated August 2007, and the attached technical declaration of Messrs. Jearl Strickland and Mark Mayer with supporting exhibits ("PG&E Testimony").

1. There is no "omission" in the EA Supplement.

As mentioned above, Contention 2 is a contention of omission that alleges that the NRC Staff failed to take into account the environmental impacts of a terrorist attack in two areas: latent health effects and land contamination. The EA Supplement, however, contains ample information to support the conclusion that the there are no significant environmental impacts associated with a terrorist attack. In the EA Supplement the NRC Staff bases its conclusion of no significant environmental impact on an assessment of dose — 5 rem or below to the nearest affected resident as a result of the most severe plausible threat scenarios. EA Supplement, at 7. This maximum credible dose coincides with the design basis accident limit specified in 10 C.F.R. § 72.106(b). This dose standard is not directly correlated to either early fatalities or latent fatalities. However, there is no regulatory basis (or basis in NEPA) for an assertion that such a correlation is necessary. *See Friends of Endangered Species, Inc. v. Jantzen,* 760 F.2d 976, 986

(9th Cir. 1985) ("NEPA does not require that we decide whether an [environmental assessment] is based on the best scientific methodology available, nor does NEPA require us to resolve disagreements among various scientists as to methodology.").[11] Early phase dose is a commonly-used and acceptable metric for off-site accident consequences (*see, e.g.*, 10 C.F.R. § 72.106(b), PG&E Testimony, at ¶¶21-32). Moreover, it is clear that the NRC Staff does not view a 5 rem dose as one that would involve significant environmental (*e.g.*, land contamination) or human health consequences (*e.g.*, latent cancers). Thus, there is no "omission" in the EA Supplement and, as a purely legal matter, the EA Supplement satisfies NEPA.

In any event, further detailed analysis of land contamination and non-fatal health effects is not necessary. Given the results reported in the EA Supplement — early dose to the nearest affected resident well below 5 rem — there is no need for further analysis. The environmental impacts of a terrorist attack at the Diablo Canyon ISFSI are expected to be small for the following reasons: (1) the HI-STORM 100 cask has a robust design; (2) prior analyses demonstrate that there are no significant environmental impacts associated with a 5 rem early dose; and (3) site-specific factors further reduce the environmental and human health impacts that would be associated with a terrorist attack on the Diablo Canyon ISFSI. These matters are discussed in detail in the PG&E Testimony and are summarized below.

2. The cask design is robust.

Each storage canister at DCPP stores fuel assemblies in a stainless steel multi-purpose canister ("MPC"), which is placed inside the HI-STORM steel/concrete overpack. The

---

[11] The NRC has not traditionally discussed the environmental impacts of severe accidents or radiological sabotage in quantitative terms. See NUREG-1437, "Generic Environmental Impact Statement for License Renewal" (December 1995), at 5-17; *id.*, at 5-18.

HI-STORM overpack is a rugged, heavy-walled, cylindrical, steel and concrete structure. It is made from concentric carbon-steel inner and outer shells, totaling 2 inches in thickness. The carbon-steel shells provide 30 inches of annular space that is filled with concrete. The overall system can weigh up to 170 tons when fully loaded. There is no direct line of sight through the upper or lower vents in the overpack to the MPC shell. By design, this effectively prevents access to the surface of the MPC (for example, for placing explosive charges) and prevents an airborne missile or projectile from directly impacting the MPC surface. PG&E Testimony, at ¶8.

In addition to the structural features of the cask, the spent fuel within the MPC is protected by the metallic zircaloy cladding surrounding the fuel pellets in each rod of a fuel assembly. The fuel itself is in the form of solid pellets. As recognized in any accident consequence analysis, even if the external barriers are breached, only a small fraction of the radioactive material could be released in a form (either fine particulates or radioactive gases) that could be transported offsite. The fuel rod array and the basket geometry would also act as a filter (by creating a tortuous release path) that would contain and limit the flow of particulates (including fines) to the environment. PG&E Testimony, at ¶11.

3. There are no significant environmental impacts associated with a 5 rem early dose.

The NRC has previously used a 5 rem dose as an indicator of environmental impacts in several contexts, uniformly concluding that the environmental impacts and human health effects associated with such a dose would be insignificant. In the most immediate example, in promulgating 10 C.F.R. § 72.106(b), the NRC set a dose limit of 5 rem at an ISFSI controlled area boundary for any design basis accident. The NRC further concluded in the accompanying environmental assessment that the rulemaking would not result in a significant

environmental impact. PG&E Testimony, at ¶22. The NRC has reached a similar conclusion with respect to occupational dose exposures. In a rulemaking on 10 C.F.R. Part 20, the NRC set a 5 rem total effective dose equivalent ("TEDE") for adult occupational exposures. At this level, the NRC concluded that the risk— that is, the potential for delayed biological effects (*e.g.*, latent cancers) — to an exposed individual of radiation induced health damage is 8E-4 over the individual's lifetime. The NRC considered this risk to be acceptable. PG&E Testimony, at ¶23.

The Commission and other Federal agencies have also considered radiation risks in the context of an emergency, such as a radiological release from an ISFSI. For example, the U.S. Environmental Protection Agency recommends limiting doses to all workers during emergencies to 5 rem. *See* U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA-400-R-92-001 (May 1992). Applying the EPA's protective action guidelines to the Diablo Canyon ISFSI, a projected early dose of "less than 5 rem" would not necessarily trigger an evacuation or even a directive to shelter in place. PG&E Testimony, at ¶27. Moreover, releases with an early phase dose of "less than 5 rem" would not be expected to require relocation of affected residents. PG&E Testimony, at ¶31. These conclusions implicitly reflect that such low early doses will not equate to significant long-term health effects or land contamination.

Nor would releases with an early phase dose of less than 5 rem be expected to lead to significant ingestion doses or significant costs associated with land contamination. The Food and Drug Administration ("FDA") recommends emergency action (*e.g.*, isolate food to prevent its introduction into commerce or condemnation) at projected radiation doses of 5 rem whole body. This dose is equivalent to the current occupational annual limit, which is permitted each year over a working lifetime, and is associated with the expectation of minimal increased

radiation risks. PG&E Testimony, at ¶29. Preventive actions (*e.g.*, transfer of dairy cows from fresh forage to uncontaminated stored feed and diversion of whole milk potentially contaminated with short-lived radionuclides) would also limit exposures. Further, given the relatively short time period during which the preventive measures would be in effect, the costs associated with a release from an ISFSI would be limited. And, in the case of Diablo Canyon, due to the large distance — approximately 12 miles —from the site to the nearest dairy, the cost of low-impact preventive actions would be expected to be particularly small. PG&E Testimony, at ¶¶30, 36.

At bottom, given past NRC regulatory determinations, it is clear that early phase doses well below 5 rem will not be associated with significant environmental impacts — either in the short term or the long term. Simply as a generic matter, it is clear that in an offsite consequences analysis, these doses will not be associated with significant health or economic consequences.

4. Factors at the Diablo Canyon ISFSI Further Reduce Environmental and Human Health Impacts.

In addition to the low environmental and human health effects that would be expected from a release as part of a generic evaluation, there are important site-specific factors at DCPP that would further limit the environmental and human health effects associated with a terrorist attack. Most importantly, the Diablo Canyon power plant site is large, and located in a sparsely-populated area. Only a few individuals reside within 5 miles of the ISFSI site. The nearest residential community is Los Osos, approximately 8 miles north of the ISFSI site. The township of Avila Beach is located down the coast at a distance of approximately 6 miles southeast of the ISFSI site. The city of Morro Bay is located up the coast approximately 10 miles northwest of the site. Due to the low population density and low total population, the number of

individuals that could be exposed in the event of a release from the site would be small. Similarly, any costs associated with evacuation or relocation would be minimal. PG&E Testimony, at ¶35.

Moreover, the DCPP site is very unusual with respect to the amount of land owned and controlled by PG&E, which has the effect of reducing potential public impacts. This is shown in Figures 4 and 5. PG&E has full authority to control all activities within the ISFSI site and the large PG&E-owned area surrounding the power plant and the ISFSI site. The only agricultural activities are cattle grazing in the area surrounding the site, and a small farm in the east-southeast sector, producing legumes and cereal grass. These activities are being conducted on land leased from PG&E. The only dairy activity is 12 miles northeast of the site at California Polytechnic State University. Overall, due to the relative lack of productive land and the large distance to the nearest dairy, any costs associated with protective actions for ingestion pathways would be minimal. PG&E Testimony, at ¶36. Thus, qualitatively, it is a simple matter to conclude that long-term health impacts and land contamination are not significant environmental impact issues for DCPP — particularly for releases with an early phase dose well below 5 rem.

Finally, as it did in the EA Supplement, the NRC has also long acknowledged that protective actions can be effective in reducing exposures during an emergency.[12] In the event of a terrorist attack on the ISFSI that causes a release, the DCPP emergency plan would be activated. This would further reduce the already-low doses projected in the EA Supplement.

---

12 *See, e.g.,* "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," 53 Fed. Reg. 31651, 31654 (Aug. 19, 1988) (noting that "in the unlikely event that there should be an accidental release of radioactivity by reason of an act of terrorism or act of sabotage, protective actions would be taken as prescribed in the emergency response plan, just as they would be taken in the case of an accidental release arriving from other causes").

PG&E Testimony, at ¶37. These actions further assure low long term impacts, both in the 10-mile emergency planning zone and in the 50-mile ingestion pathway zone.

C. Conclusion on Contention 2: No Basis for Legal Issue/No Substantial Issue of Fact

Based upon the above, there is no genuine or substantial dispute of fact as to Contention 2. Contention 2 is a contention of omission which, as a purely legal matter, has no support in the regulation, the regulatory history, or longstanding NRC practice. Neither NEPA nor NRC regulations require the NRC Staff to utilize a particular metric for assessing the consequences of beyond-design-basis accidents or terrorist attacks.[13] Moreover, the EA Supplement, as written, discloses the environmental impacts of a terrorist attack in a manner that satisfies NEPA. Put simply, there is no omission and thus, there need be no hearing.

Alternatively, as a factual matter, Contention 2 does not require the introduction of evidence in a formal adjudicatory proceeding. Contention 2 can be resolved in favor of PG&E based upon the sworn testimony and supporting references. As demonstrated herein and in the EA Supplement, the environmental impacts of plausible terrorist attack scenarios are expected to be small. There is simply no need for further analysis, evidence, or testimony on this subject.[14]

---

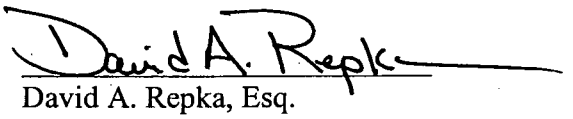
13 The Commission has held that the NRC hearing process does not serve to "fly speck" the agency's NEPA documents or to simply "add details or nuances" to the NEPA documents. *System Energy Resources, Inc.* (Early Site Permit for Grand Gulf ESP Site), CLI-05-4, 61 NRC 10, 13 (2005).

14 The EA Supplement, as written, complies with NEPA. Nevertheless, if the Commission believes that the EA Supplement would benefit from additional discussion of the bases for the NRC Staff's conclusion, the Commission could elucidate those bases in its decision by drawing on the record in this proceeding, which would then become part of the overall the Record of Decision. *See* 10 C.F.R. § 51.103.

V. Conclusion

For the reasons discussed in this written summary, and based upon the sworn testimony and the exhibits attached hereto, PG&E concludes that SLOMFP's Contention 2 does not raise a factual issue requiring resolution for the Commission to make a decision on the adequacy of the final EA Supplement. Nor does Contention 2 raise a genuine and substantial dispute of fact that can only be resolved with sufficient accuracy by the introduction of evidence in an adjudicatory hearing. Therefore, the admitted contention should not be designated for resolution in an adjudicatory hearing. Based on the record presented in PG&E's written summary and the attachments, Contention 2 should be resolved in PG&E's favor.

Respectfully submitted,



David A. Repka, Esq.
Tyson R. Smith, Esq.
WINSTON & STRAWN LLP
1700 K Street, N.W.
Washington, DC 20006-3817

COUNSEL FOR PACIFIC GAS AND ELECTRIC COMPANY

Jennifer Post, Esq.
PACIFIC GAS AND ELECTRIC CO.
77 Beale Street, B30A
San Francisco, CA 94105

Dated in Washington, District of Columbia
this 14th day of April 2008

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE COMMISSION

In the Matter of:	)	
	)	
Pacific Gas and Electric Co.	)	Docket No. 72-26-ISFSI
	)	
(Diablo Canyon Power Plant Independent Spent Fuel Storage Installation)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of "SUMMARY OF FACTS, DATA, AND ARGUMENTS ON WHICH PACIFIC GAS AND ELECTRIC COMPANY WILL RELY AT THE SUBPART K ORAL ARGUMENT ON CONTENTION 2" have been served as shown below by electronic mail, this 14th day of April 2008. Additional service has also been made this same day by deposit in the United States mail, first class, or for parties marked by an asterisk (*), by same-day hand delivery.

Office of the Secretary*
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
Attn: Rulemakings and Adjudications Staff
(original + two copies)
e-mail: HEARINGDOCKET@nrc.gov

Judge E. Roy Hawkens*
U.S. Nuclear Regulatory Commission
Atomic Safety and Licensing Board
Washington, DC 20555-0001
e-mail: erh@nrc.gov
Erica.LaPlante@nrc.gov

Atomic Safety and Licensing Board Panel
U.S. Nuclear Regulatory Commission
Mail Stop T-3F23
Washington, DC 20555-0001

Office of Commission Appellate Adjudication
U.S. Nuclear Regulatory Commission
Mail Stop O-16C1
Washington, DC 20555-0001

Diane Curran, Esq.*
Harmon, Curran, Spielberg & Eisenberg, LLP
1726 M Street N.W., Suite 600
Washington, DC 20036
e-mail: dcurran@harmoncurran.com

Lisa B. Clark, Esq.*
Molly Barkman, Esq.
Office of the General Counsel
U.S. Nuclear Regulatory Commission
Mail Stop O-15D21
Washington, DC 20555-0001
e-mail: OGCMailCenter@nrc.gov
lbc@nrc.gov
Molly.Barkman@nrc.gov

San Luis Obispo Mothers for Peace
P.O. Box 164
Pismo Beach, CA 93448
e-mail: beckers@thegrid.net
jzk@charter.net

Barbara Byron, Staff Counsel
California Energy Commission
Chief Counsel's Office
1516 Ninth Street, MS 14
Sacramento, CA 95814
e-mail: Bbyron@energy.state.ca.us

Timothy McNulty, Esq.
Office of County Counsel
County Government Center Room 386
San Luis Obispo, CA 93408
e-mail: tmcnulty@co.slo.ca.us

David A. Repka, Esq.
Counsel for Pacific Gas
and Electric Company

April 10, 2008

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE NUCLEAR REGULATORY COMMISSION

In the Matter of:	)	
	)	
Pacific Gas and Electric Co.	)	Docket No. 72-26-ISFSI
	)	
(Diablo Canyon Power Plant Independent Spent Fuel Storage Installation)	)	

TESIMONY OF JEARL STRICKLAND AND MARK MAYER ON BEHALF OF PACIFIC GAS AND ELECTRIC COMPANY REGARDING CONTENTION 2

I. INTRODUCTION

1. (JS) I am Jearl Strickland. I am employed by Pacific Gas and Electric Company ("PG&E") as Manager of the Used Fuel Project for the Diablo Canyon Power Plant ("DCPP"). As such, I am responsible for the design, licensing, and construction of the DCPP Independent Spent Fuel Storage Installation (ISFSI). A copy of my Statement of Professional Qualifications is attached.

2. (MM) I am Mark Mayer. I am currently employed by PG&E as a Reactor Engineering Supervisor at DCPP. From 1998 to 2007, I was employed by PG&E at DCPP as a Supervisor, Systems and Transient Analysis. In that capacity, my group was responsible for the preparation of thermal/hydraulic analyses, review of vendor safety analyses, and preparation and review of power plant accident analyses and offsite dose consequence analyses. With respect to the latter, we also specifically had responsibility for supporting the safety and accident analyses for the DCPP ISFSI. A copy of my Statement of Professional Qualifications is attached.

3. (JS, MM) Contention 2 concerns the NRC Staff's Environmental Assessment ("EA") Supplement related to the construction and operation of the DCPP ISFSI, dated August 2007. The EA Supplement specifically addresses the environmental consequences of a hypothetical terrorist attack on the ISFSI. The NRC Staff performed a dose calculation for the most severe plausible threat scenarios — including ground assault and aircraft impact scenarios — and concluded in the EA Supplement that the early dose to the nearest affected resident would be well below 5 rem. EA Supplement at 7. The specific issue in Contention 2, as we understand it, is whether given these results the EA Supplement needs to also address the potential that plausible terrorist scenarios would cause significant land contamination or non-fatal health effects (*e.g.*, latent cancers).

4. (JS, MM) We conclude that further detailed analysis of land contamination and non-fatal health effects is not necessary. We accept the NRC Staff's threat assessment and do not here address the plausibility of hypothetical attack scenarios. Also, we accept the NRC Staff's calculation of dose consequences for the scenarios that they have considered. Our testimony focuses on the issue of land contamination and non-fatal health effects, taking the NRC's EA Supplement analysis as a starting point. Given the results reported in the EA Supplement — there is no need for further analysis. With doses to the nearest resident well below 5 rem, we can conclude that the land contamination and non-lethal health consequences would be very low. This conclusion follows as a generic matter for any dose consequence analysis. In addition, there are a number of unusual or unique aspects of the DCPP site that further support a conclusion that land contamination and long-term health effects would be minimal in the event of a terrorist attack.

II. BACKGROUND

A. Dry Cask Design and Licensing Basis Analyses

5. (JS) To put this issue in some perspective, I will first give an overview of the HI-STORM 100SA dry cask storage system that will be employed at the DCPP ISFSI. We will also discuss the licensing basis analyses previously completed — and accepted by the NRC Staff — prior to the issuance of the site-specific license for the ISFSI.

6. (JS) The HI-STORM 100SA is designed and constructed by Holtec International ("Holtec"). It is specifically licensed by the NRC for DCPP, but is actually an anchored version (for seismic reasons) of the standard HI-STORM 100 that has been certified by the NRC for more general use.[1] Each storage canister at DCPP will store up to 32 fuel assemblies (or certain non-fuel hardware) in a stainless steel multi-purpose canister ("MPC"). The MPC contains an "egg-crate" fuel basket. After loading, the MPC is fully sealed. The MPC is then placed, and is well-protected, inside the HI-STORM steel/concrete overpack. The overall system can weigh up to 170 tons when fully loaded.

7. (JS) The HI-STORM overpack is a rugged, heavy-walled, cylindrical, steel and concrete structure. It is made from concentric carbon-steel inner and outer shells, totaling 2 inches in thickness. The carbon-steel shells provide 30 inches of annular space that is filled with concrete. Figure 1 shows a side-view cutaway of the HI-STORM 100. This illustrates the location of the MPC within the overpack and the very ample structural system.

8. (JS) The HI-STORM overpack is designed to allow natural circulation of air around the exterior shell of the MPC, providing passive cooling of the spent fuel in the MPC by a

---

[1] The HI-STORM 100SA has now been licensed for general use. *See* "List of Approved Spent Fuel Storage Casks: HI-STORM 100 Revision," 67 Fed. Reg. 14627 (March 27, 2002).

chimney effect. The only openings are 4 air inlet ducts located at 90-degree spacing in the base of the cask (10"H by 15" W) and 4 air outlet ducts located in the top lid of the overpack (4 3/4"H by 25 1/2" W). The cooling air enters the inlet ducts, absorbs heat from the MPC surface, flows upward in the annulus, and exits the MPC. As can be seen in Figure 1, the top and bottom air inlets are located, respectively, above the MPC steel lid and below the MPC baseplate. There is no direct line of sight through the upper or lower vents to the MPC shell. By design, this effectively prevents access to the surface of the MPC (for example, for placing explosive charges) and prevents an airborne missile or projectile from directly impacting the MPC surface.

9. (JS) The HI-STORM 100SA has been fully analyzed and found by the NRC to be qualified to meet all design basis operational and accident conditions. In connection with its application for a site-specific license (originally submitted on December 21, 2001), PG&E prepared a Safety Analysis Report ("SAR") and an Environmental Report ("ER"). The NRC Staff reviewed these analyses and prepared its own Safety Evaluation Report ("SER") and the original Environmental Assessment ("EA"). The Staff issued the SER along with the site-specific license on March 22, 2004. The Staff issued the EA with a Finding of No Significant Environmental Impact on October 23, 2003.

10. (JS) From a structural standpoint, the HI-STORM 100SA system has been demonstrated to be able to withstand the impacts of missiles generated by tornados and other natural phenomena. This is discussed in Sections 3.2.1 and 8.2.2 of PG&E's SAR and Section 15.1.2.10 of the NRC Staff's March 2004 SER for the ISFSI. These design basis events include the impacts of an automobile hurled into the cask at 203 km/hr (126 mph) as well as the impacts of other solid steel objects at high velocities. The analysis results are summarized in Table 15-1 of the NRC Staff's SER. For DCPP, as discussed in Section 8.2.16.2 of the SAR, the HI-

STORM 100SA has also been demonstrated to be able to withstand the impacts from the postulated collapse of two 500-kV transmission towers located in the vicinity of the ISFSI.

11. (MM) In addition to the structural features discussed already, the spent fuel within the MPC is protected by the metallic zircaloy cladding surrounding the fuel pellets in each rod of a fuel assembly. The fuel itself is in the form of solid pellets. As recognized in design-basis accident consequence analyses of dry casks, even if the external barriers are breached, only a small fraction of the radioactive material would be released in a form (either fine particulates or radioactive gases) that could be transported offsite. The fuel rod array and the basket geometry would also act as a filter (by creating a tortuous release path) that would contain and limit the flow of particulates (including fines) to the environment.

12. (MM) Relative to an operating power plant, any releases from the ISFSI would be expected to have smaller environmental and human health impacts. For example, the Commission has previously noted that the high temperature and high pressure driving forces behind dispersion of radioactive material in operating reactors is absent in dry storage. *See* NUREG-1092, "Environmental Assessment for 10 CFR Part 72 Licensing Requirements for the Independent Storage of Spent Fuel and High-Level Radioactive Waste," at II-25 (August 1984). This would reduce the dispersal of radionuclides in the event of a successful terrorist attack. In addition, the dry storage casks contain only a limited inventory of radionuclides — more than an order of magnitude less than in an operating plant. And, the radionuclides that are present have relatively low activity having been allowed to decay for a number of years prior to storage in the ISFSI. This reduces the risk of some typical latent health effects associated with radiation exposures (*e.g.*, the absence of iodine reduces the risk of thyroid cancer).

13. (MM) Environmental effects of postulated accidents were addressed in Chapter 5 of PG&E's ER for the ISFSI license application. In Section 5.1.3.2, PG&E noted that canister leakage under hypothetical accident conditions is not considered to be a credible event. Nonetheless, the licensing basis includes an analysis of hypothetical canister leakage to demonstrate compliance with 10 CFR 72.106(b) — whereby an individual located on the boundary of the controlled area may not receive a total effective dose equivalent ("TEDE") of 5 rem. PG&E performed the required dose consequence analysis utilizing conservative regulatory assumptions regarding fuel failures and radionuclide release fractions. No credit was taken in that analysis for any confinement function of the fuel cladding or the HI-STORM 100 overpack. The analysis was performed for the nearest distance to the DCPP site boundary — which was taken to be 1,400 feet. (As is discussed further below, this is very conservative for DCPP because the PG&E property surrounding the site is much larger than that.) The 30-day TEDE was 0.83 mrem (0.00083 rem), a very small fraction of the 5 rem regulatory limit.

14. (JS) PG&E is aware that the NRC has access to other structural evaluations of the HI-STORM system, including analyses of airplane impacts and large explosive blasts. At least some of these are referenced in the EA Supplement. PG&E is also aware that in the context of NRC licensing of the proposed Private Fuel Storage facility in Utah, Holtec analyzed HI-STORM casks with respect to thermal effects from fires. The NRC has also analyzed fire scenarios with respect to Holtec's HI-STAR transportation cask. While PG&E does not have access to these classified and safeguards studies, we qualitatively conclude that the ruggedness of the Holtec system provides assurance that credible fires will not cause cask failure (*i.e.,* rupture) by over-pressurization.

15. (JS, MM) In total, the HI-STORM cask design is extremely robust and the NRC licensing basis analyses are thorough and conservative. This provides a very sound basis for the conclusion that there will not be significant releases of radioactive material to the environment in the event of a postulated terrorist attack. In addition, any accident consequences in terms of dose at the site boundary would be very small.

B. NRC Staff's EA Supplement

16. (JS) As noted above, the NRC Staff prepared an EA Supplement on the issue of the environmental impacts of postulated terrorist attacks. The NRC determined "the probability of a successful terrorist attack (*i.e.*, one which results in a significant radiological event), to be very low." EA Supplement, at A-6. The NRC Staff credited the facts that: (a) storage canisters are robust structures, designed to "meet stringent requirements for structural, thermal, shielding, and criticality performance, and containment integrity, for normal and accident events;" (b) in addition to the storage overpack and sealed MPC, the spent fuel is further protected by the fuel cladding; and (c) the nuclear fuel is in ceramic pellet form that assures that a large amount of the radioactive material would not be transported beyond "the immediate vicinity" of the ISFSI. EA Supplement, at 6.

17. (JS) The NRC Staff also recognized that existing safety and security measures "are adequate and effective in countering and mitigating the effects of terrorist attacks against dry cask storage systems." *Id.* These measures include requirements for enhanced security and emergency response. *Id.* While the probability of a terrorist attack cannot be reliably quantified, the "protective strategy [in place] reduces the risk from a terrorist attack to an acceptable level." *Id.*

18. (MM) In the EA Supplement the NRC Staff also reports the results of what it characterizes as "conservative assessments" of dose consequences from plausible attack scenarios — "to assess the potential for early fatalities from radiological impacts from those plausible scenarios." *Id.* at 7. The NRC Staff performed a dose consequence assessment using source term (and presumably release fractions) and meteorology from generic dose consequence assessments for dry cask storage installations. This resulted in a projected dose "of less than 5 rem for the nearest resident." *Id.*

19. (MM) The EA Supplement further notes that there are considerable conservatisms in the result. It states that use of DCPP meteorology would reduce projected dose consequences "by a factor of 10 to 100." *Id.* Further, use of DCPP-specific source terms (including site-specific fuel characteristics such as low burnup) would reduce projected doses even further. *Id.* And, emergency response actions — which could involve sheltering or evacuation in cases where there is a release — would even further mitigate dose consequences. *Id.*

20. (MM) In responding to comments, the NRC Staff clarified that it used a dose estimate, and not early fatalities, in assessing environmental impacts. *Id.* at A-6. The Staff concluded that "a terrorist attack that would result in a significant release of radiation affecting the public is not reasonably expected to occur." The Staff concluded that "the storage of spent nuclear fuel at the Diablo Canyon ISFSI will not have a significant effect on the quality of the human environment, based on the facility design features and mitigative security measures incorporated as part of the licensing action and in response to NRC security orders." *Id.* at 8.

III. DISCUSSION

A. Prior Analyses Demonstrate That There Are No Significant Environmental Impacts Associated With a 5 rem Early Dose

21. (MM) The NRC has previously used a 5 rem dose as an indicator of environmental impacts in several contexts, uniformly concluding that the environmental impacts and human health effects associated with such a dose will be insignificant.

22. (MM) For example, in promulgating 10 C.F.R. § 72.106(b), the NRC set a dose limit of 5 rem at the ISFSI controlled area boundary from any design basis accident. *See* "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste," 53 Fed. Reg. 31651, 31672-31673 (Aug. 19, 1988). In the accompanying environmental assessment, the NRC concluded that "the proposed rulemaking to include the criteria of 10 CFR Part 72 for storing spent nuclear fuel and high-level radioactive waste does not significantly affect the environment." *See* 53 Fed. Reg. at 31658, *citing* NUREG-1092, at III-2. More specifically, the NRC stated in the Part 72 EA that the exposure limits in Part 72, which include those in Section 72.106(b), protect the public and therefore are assumed to protect the environment. NUREG-1092, at II-10.

23. (MM) The NRC reached a similar conclusion with respect to occupational dose exposures. In a rulemaking on 10 C.F.R. Part 20, the NRC set a 5 rem total effective dose equivalent ("TEDE") for adult occupational exposures. *See* 10 C.F.R. § 20.1201(a)(1)(i). At this level, the NRC concluded that the risk to an exposed individual of radiation induced health damage is 8E-4 over the individual's lifetime. "Standards for Protection Against Radiation; Republication," 51 Fed. Reg. 1092, 1102 (Jan. 9, 1986). According to the NRC, the 5 rem dose limit in 10 C.F.R. § 20.1201 is based on maintaining the potential for delayed biological effects (*e.g.*, latent cancers) at a level considered acceptable by the NRC. *See* Reg. Guide 8.29,

"Instruction Concerning Risks From Occupational Exposures," Revision 1, at 10 (February 1996). The Commission also determined that the dose limits in Part 20 will not have a significant impact on the environment. *Id.* at 1120.

24. (MM) The NRC further discussed its conclusions regarding the human health impacts of various exposures in Reg. Guide 8.29. There, the NRC noted that the normal incidence of effects from natural and manmade causes is significant — approximately 20% of people die from various forms of cancer whether or not they ever receive occupational exposure to radiation. With respect to the risk associated with various exposures, the NRC calculated the following:

- 1 rem exposure raises risk of developing fatal cancer from 20% to 20.04%.
- 10 rem exposure raises risk of developing fatal cancer from 20% to 20.40%.
- 25 rem exposure raises risk of developing fatal cancer from 20% to 21.0%.
- 100 rem exposure raises risk of developing fatal cancer from 20% to 24%.

Using the same relationship, a 5 rem exposure would increase the cancer risk by about 0.2%. As discussed above, the NRC, in promulgating 10 C.F.R. § 20.1201, concluded that a 5 rem dose and the small associated increase in cancer risk is not a significant environmental or human health effect.

25. (MM) The Commission and other Federal agencies have also considered radiation risks in the context of an emergency, such as a release from an ISFSI. Although 10 C.F.R. Part 20 does not set any dose limits for emergencies, the Commission has addressed those rare situations where a dose in excess of occupational limits would be unavoidable by referencing the Environmental Protection Agency ("EPA") emergency dose guidelines. *See* U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA-400-R-92-001 (May 1992) ("PAGs Manual"). The guidelines state that doses to all workers during emergencies should, to the extent practicable, be limited to 5 rem. The guidelines also suggest limiting exposures to 10 rem in order to protect valuable property and 25

rem for lifesaving activities and protection of large populations. *See* Reg. Guide 8.29, at 13. According to the EPA, an acute dose of 25 rem from an emergency might increase an individual's chances of developing cancer from about 20% to 21%.

26 (MM) The EPA's protective action guides ("PAGs") provide a useful perspective on the magnitude of environmental and human health impacts associated with emergencies.[2] The goals of the PAGs are to (1) avoid acute effects; (2) ensure that delayed effects do not exceed upper bounds of adequate protection under emergency conditions; (3) be no higher than justified based on optimization of costs and collective risks on human health; and (4) be set such that risk to health from protective action does not exceed risk to health from dose avoided.

27 (MM) The EPA defined the "early phase" of a nuclear incident as the period beginning at the initiation of a release and extending to a few days later, when deposition of airborne materials has ceased. PAGs Manual, at 2-3. According to the EPA, during the early phase of an incident doses may accrue from both airborne and deposited radioactive materials. *Id.* Since the dose to persons who are not evacuated will continue until relocation can be implemented (if it is necessary), the EPA includes in the early phase the total dose that will be received prior to such relocation. *Id.* For projected early phase doses in excess of 5 rem, the EPA recommends evacuation or sheltering in place. *Id.*, at Table 2-1 (defining the PAG for evacuation as 1 to 5 rem). By comparison, the EPA recommends administration of stable iodine only for projected early phase doses in excess of 25 rem. *Id.* As applied to the Diablo Canyon ISFSI, a projected dose of "less than 5 rem" would not necessarily trigger an evacuation or even a directive to

---

2 The PAGs encompass three different phases associated with a release: (1) the early phase, which begins at the start of the incident and involves immediate actions; (2) the intermediate phase, which encompasses the period of time after the source of release is brought under control and environmental monitoring can begin; and (3) the late phase (or recovery phase) during which recovery begins to reduce radiation to acceptable levels for unrestricted release.

shelter in place. This implicitly reflects that such low early doses will not equate to significant long-term health effects.

28. (MM) The EPA defines the "intermediate phase" of a nuclear incident as the period of time after the source of release is brought under control and environmental monitoring can begin. Prior to this period protective actions will have been taken based upon the PAGs for the early phase. There are separate PAGs for ingestion exposure pathways and external exposure/inhalation pathways during the intermediate phase.

29. (MM) For the *ingestion* exposure pathways during the intermediate phase, the Food and Drug Administration ("FDA") recommends action (the Emergency PAG) at projected radiation doses of 5 rem whole body. *See* "Accidental Radioactive Contamination of Human Food and Animal Feed; Recommendations for State and Local Agencies," 47 Fed. Reg. 47073, 47074 (Oct. 22, 1982). At the Emergency PAG level, responsible officials should isolate food to prevent its introduction into commerce and determine whether condemnation or other disposition is appropriate. The Emergency PAG of 5 rem for the whole body is equivalent to the current occupational annual limit. This limit, which is permitted each year over a working lifetime, is associated with the expectation of minimal increased radiation risks. *See* Food and Drug Administration, Bureau of Radiological Health, *Background for Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds*, at 7 (August 1982), *reprinted in* PAGs Manual, Chapter 6. As applied to Diablo Canyon, releases with an early phase dose of less than 5 rem would not be expected to lead to ingestion doses of greater than 5 rem. Thus, the Emergency PAG for ingestion would not be triggered for the doses projected by the NRC Staff for plausible scenarios.

30. (MM) The FDA recommends "low impact" preventive actions (the Preventive PAG) at projected radiation doses of 0.5 rem whole body. Preventive PAGs include the transfer of dairy cows from fresh forage (pasture) to uncontaminated stored feed and the diversion of whole milk potentially contaminated with short-lived radionuclides to products with a long shelf life to allow radioactive decay of the radioactive material. Even assuming that initial contamination of these radionuclides was at the Preventive PAG level, radioactive decay and weathering would reduce the levels so that protective actions could be ceased after 1 or 2 months. *Id.* The relatively short time period during which the Preventive PAGs would be in effect would limit both the exposures and the costs associated with a release from an ISFSI. And, as is discussed in greater detail below, due to site specific conditions at the Diablo Canyon ISFSI (*e.g.*, the large distance — approximately 12 miles — from the site to the nearest dairy), the cost of low-impact Preventive PAGs (if any) would be expected to be small.

31. (MM) For the external exposure/inhalation pathways used in the intermediate phase *relocation* PAGs, the projected doses include external exposure to radiation from deposited radioactivity and inhalation of re-suspended radioactive materials. The PAG for relocation is 2 rem. PAGs Manual, at Table 4-1. The PAGs for relocation refer only to estimates of doses due to exposure during the first year after the incident, but take into account the long term exposures that would be associated with a decision not to relocate. Specifically, the relocation PAGs assure that doses in any single year after the first will not exceed 0.5 rem, and that the cumulative dose over 50 years (including the first and second years) will not exceed 5 rem. PAGs Manual, at 4-4. As applied to Diablo Canyon, releases with an early phase dose of "less than 5 rem" would be expected to have intermediate phase doses of less than 2 rem to the public. Thus, relocation would likely not be warranted.

32. (MM) All of these examples make clear that the NRC and other Federal agencies have consistently viewed the 5 rem early phase dose limit as an effective surrogate or proxy for insignificant environmental impacts and low human health effects. In the Diablo Canyon EA Supplement, the NRC is simply continuing along the same path that it has tread in the past — reaffirming that doses of less than 5 rem do not result in significant environmental or human health effects.

B. Factors at the Diablo Canyon ISFSI Further Reduce Environmental and Human Health Impacts

33. (MM) There are several site-specific factors at DCPP that would limit the environmental and human health effects associated with a terrorist attack. Most importantly, the Diablo Canyon power plant site is large, and located in a sparsely-populated area. The San Luis Range, reaching a height of 1,800 ft, dominates the region between the site and US Highway 101. The terrain east of US Highway 101, lying in the mostly inaccessible Santa Lucia Mountains, is sparsely populated with little development and little agricultural activity. A large portion of this area is included within the Los Padres National Forest. As a result, long-term health effects would be limited, ingestion pathway exposures would be limited, and economic costs would be small.

34. (MM) The owner-controlled area at Diablo Canyon consists of approximately 760 acres of land located in San Luis Obispo County, California, adjacent to the Pacific Ocean. This area is located along the coast of California in San Luis Obispo County directly southeast of Montana de Oro State Park and is approximately 12 miles west-southwest of the city of San Luis Obispo, the county seat and the nearest significant population center. The nearest residential community is Los Osos, approximately 8 miles north of the ISFSI site. The township of Avila Beach is located down the coast at a distance of approximately 6 miles southeast of the ISFSI site. The city of Morro Bay is located up the coast approximately 10 miles northwest of the site. A

number of other communities, as well as some unincorporated residential areas, exist along the coast and inland. However, these are at distances greater than 8 miles from the ISFSI site. Figures 2 and 3 are a visual representation of the nearby population. Figures 4 and 5 are a visual representation of land use.

35. (MM) Table 1, which is taken from the DCPP Radiological Environmental Monitoring Plan, lists the nearest residences and associated uses in each sector. Most importantly, only a few individuals reside within 5 miles of the ISFSI site. The nearest residents are very few in number and are all located on land owned by PG&E. The nearest residents on land not owned by PG&E are located approximately 3 miles from the ISFSI site. In contrast, the "less than 5 rem" dose projected in the EA Supplement was calculated at a distance of about 1.5 miles from the ISFSI. Due to the low population density and low total population, the number of individuals exposed in the event of a release from the site is expected to be small. Similarly, any costs associated with evacuation or relocation are expected to be minimal.

36. (MM) PG&E has full authority to control all activities within the ISFSI site and owner-controlled area boundaries. The only agricultural activities are grazing in much of the area surrounding the site, and a small farm in the east-southeast sector, producing legumes and cereal grass such as grains. The farm is located along the site access road on the coastal plateau, starting approximately 3 miles from the plant and extending to 4.5 miles from the plant. There is also a household garden greater than 500 square ft in the east sector. These activities are being conducted on land leased from PG&E. The only dairy activity is approximately 12 miles northeast of the site at California Polytechnic State University, located in the city of San Luis Obispo, which produces 1,200 gallons of milk per day. Some replacement heifers and dry cows are intermittently pastured on property adjacent to the site. Overall, due to the relative lack of productive land and the

large distance to the nearest dairy, any costs associated with protective actions for ingestion pathways are expected to be minimal.

37. (MM) As it did in the EA Supplement, the NRC has long acknowledged that protective actions can be effective in reducing exposures during an emergency. *See* 53 Fed. Reg. at 31654 (noting that "in the unlikely event that there should be an accidental release of radioactivity by reason of an act of terrorism or act of sabotage, protective actions would be taken as prescribed in the emergency response plan, just as they would be taken in the case of an accidental release arriving from other causes"). In the event of a terrorist attack on the ISFSI that causes a release, the emergency plan would be activated. This would further reduce the already-low doses projected in the EA Supplement.

IV. CONCLUSIONS

38. (JS, MM) In our opinion, Contention 2 is without merit. Several facts lead to this conclusion. First, even assuming a hypothetical attack, the robust nature of the storage casks makes significant radiological releases unlikely. Second, assuming releases leading to early exposures as projected by the NRC Staff, there will be minimal potential for long term health effects and land contamination. Third, the nature of the area surrounding the DCPP ISFSI further reduces the potential for such impacts. And finally, any consequences that do result can be further mitigated by prudent emergency response — including actions to address ingestion pathways exposures. The NRC Staff is correct in concluding that with early doses well below 5 rem, further evaluation of non-lethal health effects, land contamination, and economic consequences is not warranted.

I certify that the statements and opinions in such response are true and correct to the best of personal knowledge and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on April 10, 2008.

Mark Mayer

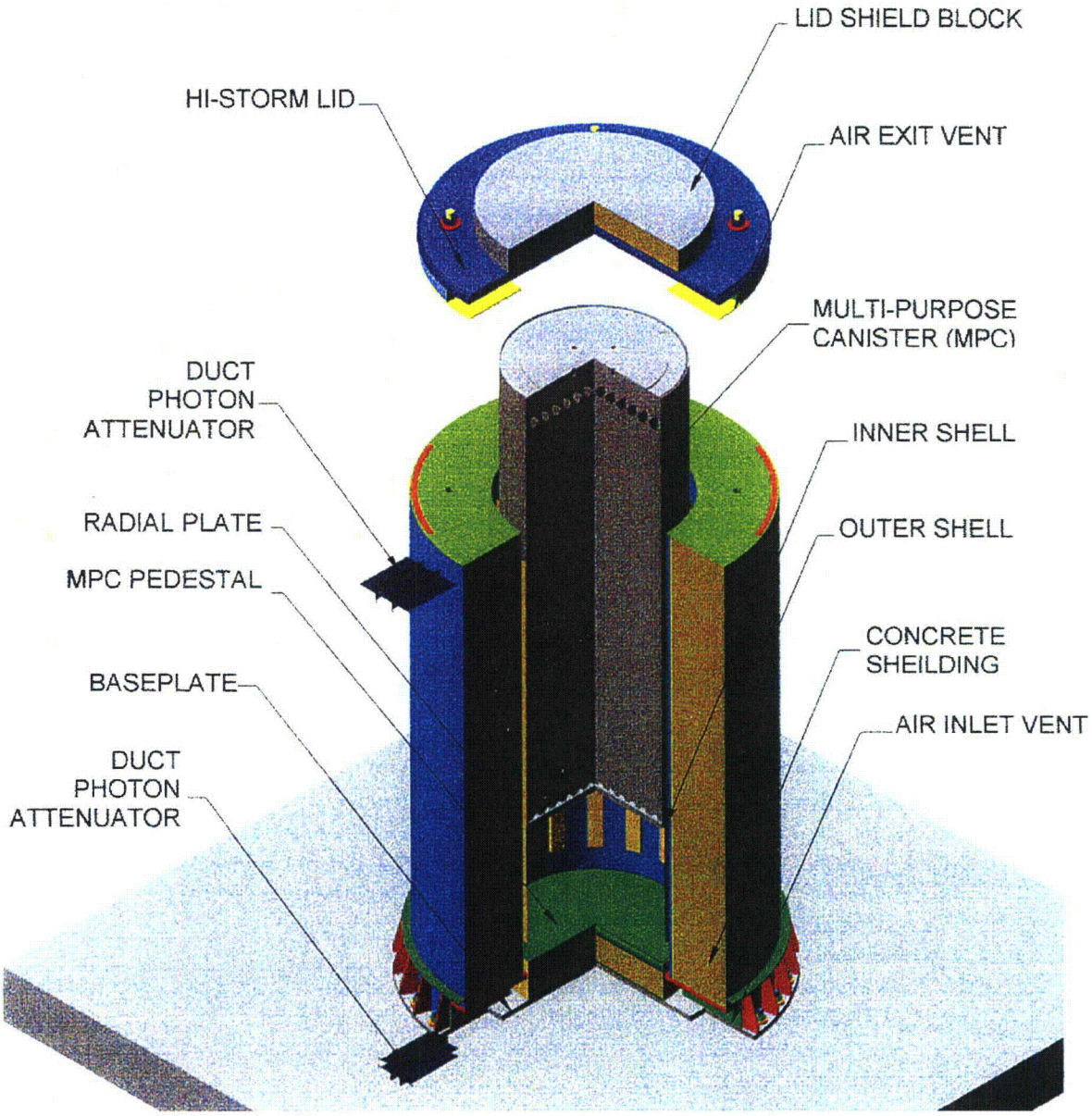
I certify that the statements and opinions in such response are true and correct to the best of personal knowledge and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on April 10, 2008.

L. Jearl Strickland

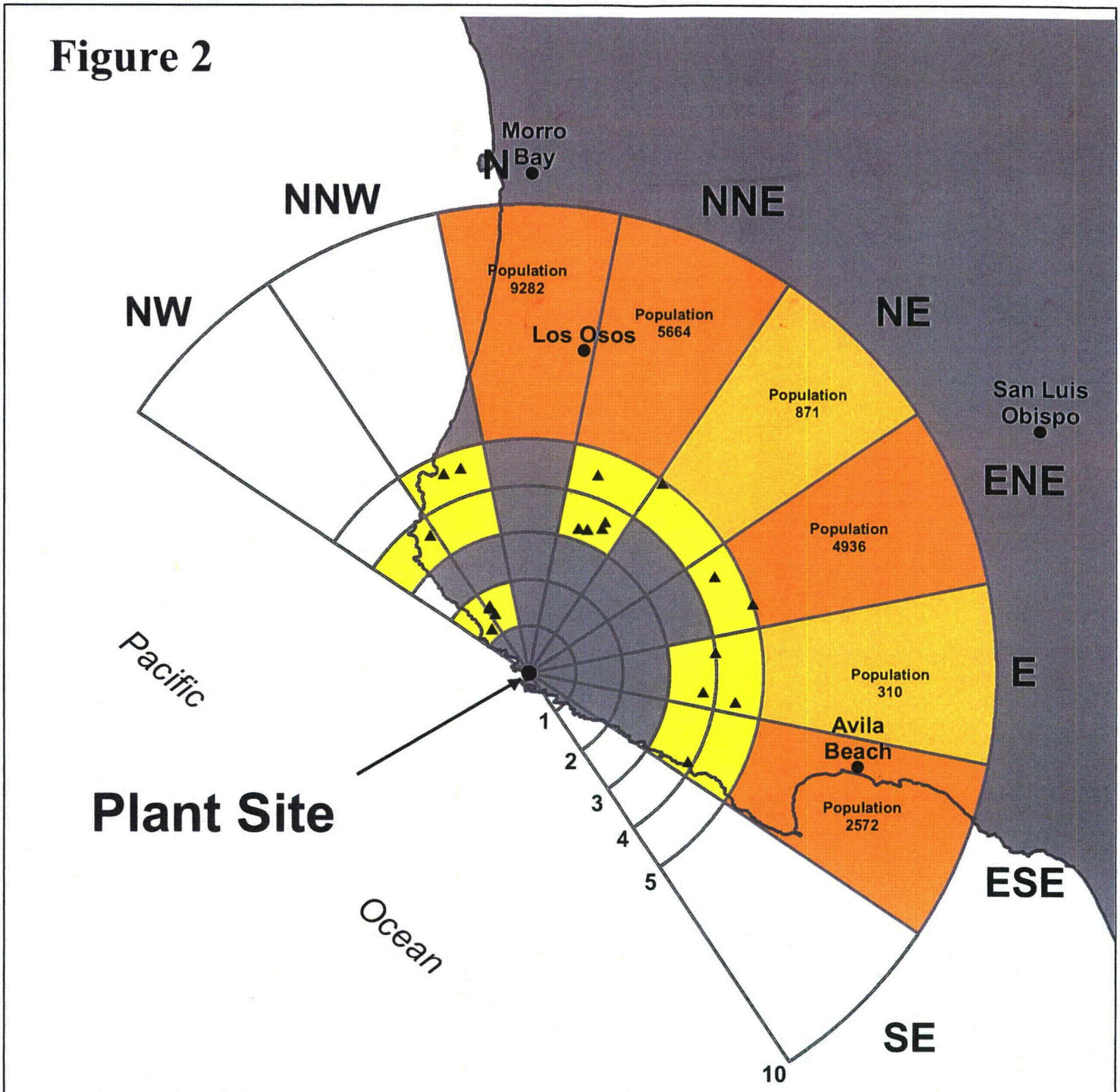
Figure 1



NOTE: For clarity, air exit vents are not shown rotated.

ENVIRONMENTAL REPORT
DIABLO CANYON ISFSI
FIGURE 3.3-1 HI-STORM 100SA OVERPACK WITH MPC PARTIALLY INSERTED

Figure 2



▲ Residence (0-5 Miles)

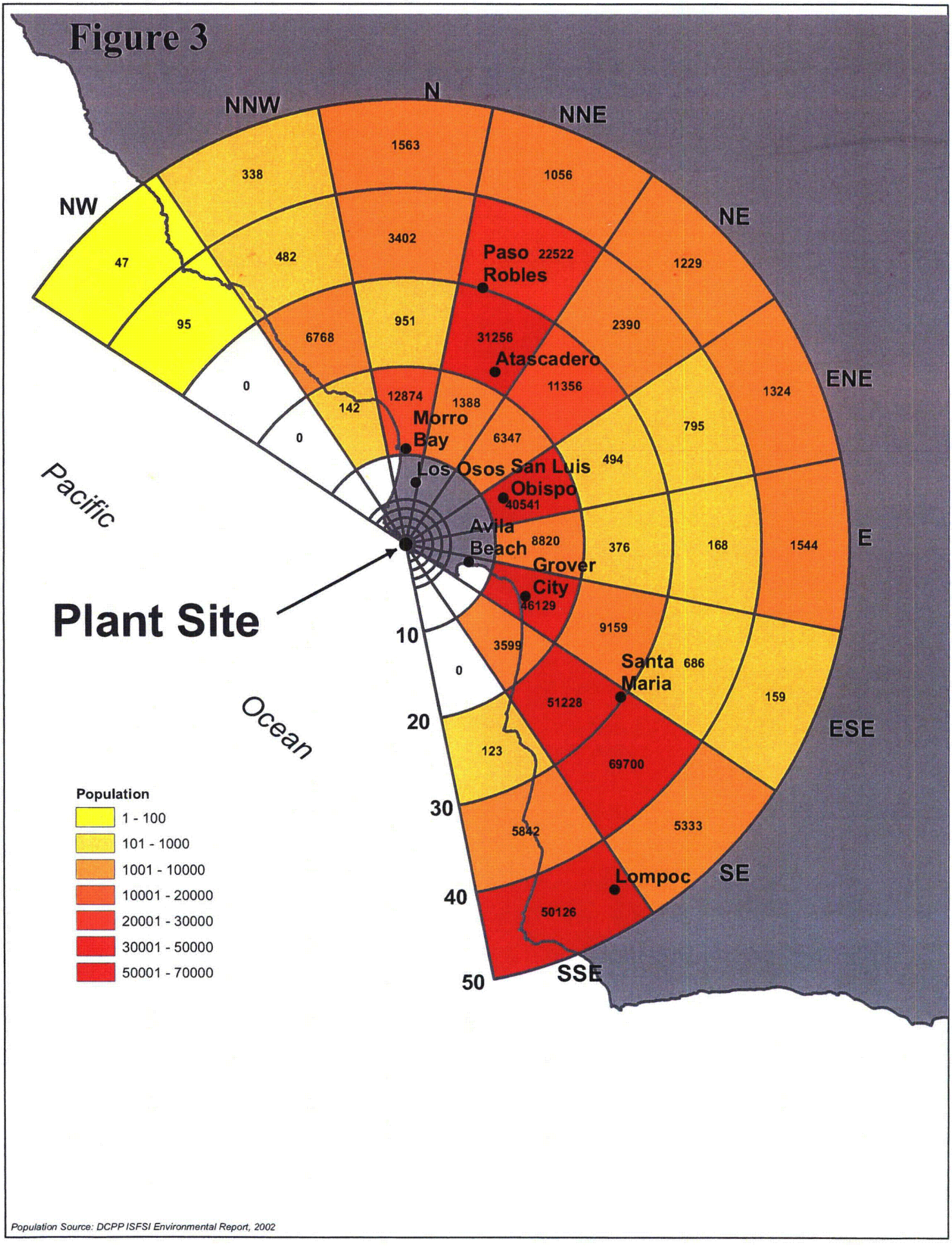
Population

- 1 - 100
- 101 - 1000
- 1001 - 10000
- 10001 - 20000
- 20001 - 30000
- 30001 - 50000
- 50001 - 70000

*No color indicates no data available

Population Source: DCPP ISFSI Environmental Report, 2002

Figure 3



Population Source: DCPP ISFSI Environmental Report, 2002

Figure 4

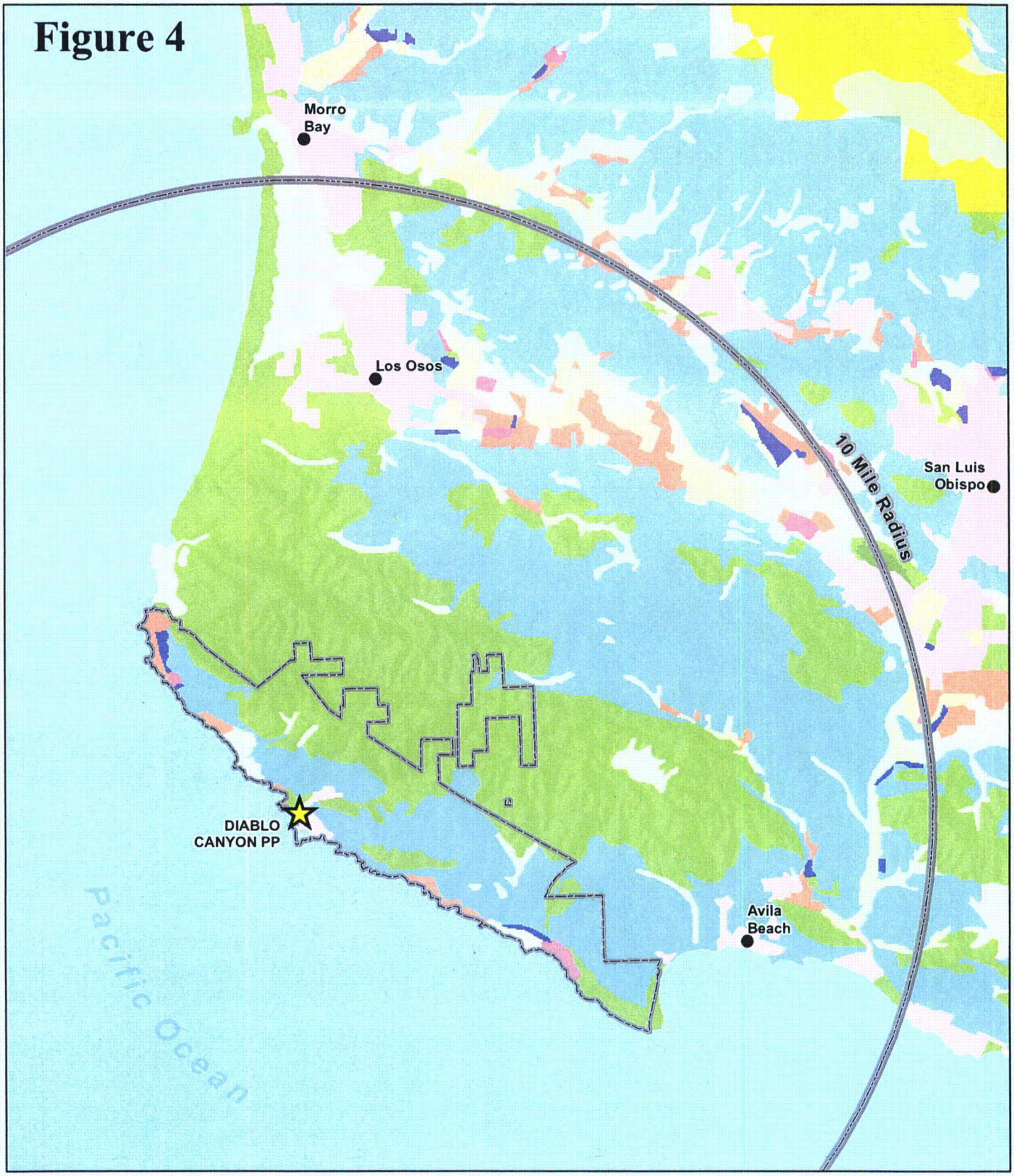

Morro Bay
Los Osos
San Luis Obispo
10 Mile Radius
DIABLO CANYON PP
Avila Beach
Pacific Ocean
PG&E Property
Landtype
Forest Land
Hervaceous Rangeland
Mixed Barren Land
Orchards, Groves, Vineyards
Shrub and Brush Rangeland
Landuse
Farmland of Local Importance
Farmland of Statewide Importance
Grazing Land
Irrigated Farmland (interim)
Non-irrigated Farmland (interim)
Other Land
Prime Farmland
Unique Farmland
Urban and Built-up Land
Water
0 1 2 3 4 Miles
DIABLO CANYON PP

Figure 5

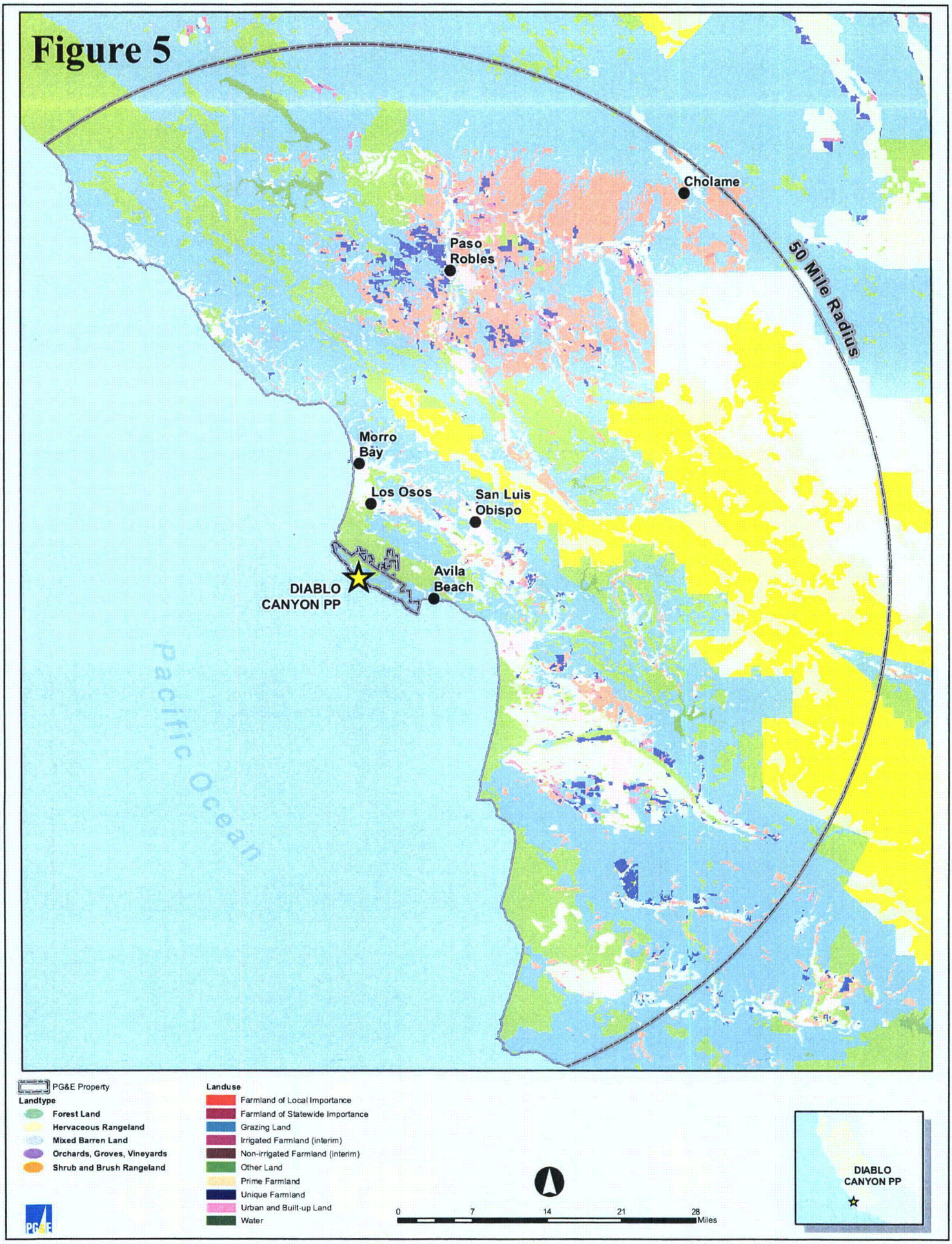

Cholame
Paso Robles
50 Mile Radius
Morro Bay
Los Osos
San Luis Obispo
Avila Beach
DIABLO CANYON PP
Pacific Ocean
PG&E Property
Landtype
Forest Land
Hervaceous Rangeland
Mixed Barren Land
Orchards, Groves, Vineyards
Shrub and Brush Rangeland
Landuse
Farmland of Local Importance
Farmland of Statewide Importance
Grazing Land
Irrigated Farmland (interim)
Non-irrigated Farmland (interim)
Other Land
Prime Farmland
Unique Farmland
Urban and Built-up Land
Water
0 7 14 21 28 Miles
DIABLO CANYON PP

Table 1: Summary of Nearby Populations (within 5 miles) and Land Uses

Residences	Azimuth[1]	Distance[2]	Gardens[3]	Milk Animals
1 trailer, limited use, approx 30 days/yr	319.5° NW	1.931 km (1.2 miles)	None	None
1 house, full-time use	324.5° NW	5.794 km (3.6 miles)	None	None
1 house, full time use, old conference center	331° NNW	2.414 km (1.5 miles)	None	None
1 abandoned house	328.7° NNW	2.607 km (1.62 miles)	None	None
1 abandoned guest house	330.0° NNW	2.672 km (1.66 miles)	None	None
1 Ranger Office occupied every day; 1000 - 1500	337.1° NNW	7.483 km (4.65 miles)	None	None
Public Campground	342.7° NNW	7.387 km (4.59 miles)	None	None
1 cabin, limited use, used approximately 100 days per year[5]	19.8° NNE	5.214 km (3.24 miles)	None	None
1 trailer, limited use, about 42 days per year	21.8° NNE	5.327 km (3.31 miles)	None	None
1 trailer, uninhabitable and abandoned	27.7° NNE	5.552 km (3.45 miles)	None	None
1 cabin, abandoned and uninhabitable	27.3° NNE	5.778 km (3.59 miles)	None	None
1 house, full time use (caretaker residence)	19.5° NNE	7.081 km (4.41 miles)	Yes- ¼ acre fruits and vegetables	None
1 house, full-time use	36° NE	7.886 km (4.9 miles)	None	None
1 house, full-time use; 1 trailer, full-time use	63.5° ENE	7.081 km (4.4 miles)	None	None
1 house, full-time use	74° ENE	8.047 km (5.0 miles)	None	None
3 cabins, part-time use; 1 trailer, part-time use	97.5° E	5.955 km (3.7 miles)	None	None
1 cabin, occasional use, Staff use	83.5° E	6.437 km (4.0 miles)	None	None
1 house, full-time use[4]	98° E	7.242 km (4.5 miles)	Yes - Very small quantity of vegetables, berries, and legumes	None
None (day use by field workers)	122.0° ESE	between 4.8 to 8.0 km (3 to 5 miles)	No personal use, (90% oat hay & 10% squash)	None

1 - Reference from True North
2 - From a point centered between U-1 & U-2 containment domes in kilometers and (miles).
3 - 500 ft^2 with broadleaf vegetation
4 - This property (168 acres) is leased. One garden used all summer (beans, tomatoes, lettuce, berries, onions, grapes, herbs). They also have 326 lemon trees.
5 - The cabin is used approximately 7 days per month, and then every weekend from March through October. Abandoned trailer is not used.

LUTHER JEARL STRICKLAND

5680 Pinehurst Way
San Luis Obispo, CA 93401
wk (805) 545-6080
hm (805) 594-1775

EDUCATION

- **California State University, Chico.** B. S. Degree in Civil Engineering.
- **Golden Gate University, San Francisco.** M.B.A. Degree in Project and Construction Management.
- **University of California, Berkeley**. Graduate course work in Structural Analysis, Dynamics and Soil Structure Interaction

EXPERIENCE

MANAGER - USED FUEL STORAGE PROGRAM, (July 2000 to January 2006, June 2006 to present) Diablo Canyon Nuclear Power Plant. Responsible for the development of an Independent Spent Fuel Storage Installation (ISFSI) including; site studies, site selection, conceptual design, detailed design, development of request for proposals (RFP) for cask vendor, and ISFSI construction. Development of part 72 and part 50 License applications including Environmental Report (NEPA) and the Safety Analysis Report. Development of State applications including Coastal Development Permit, land use permits and grading/building permits (CEQA).

Management of the Licensing, Engineering, Environmental, and Geotechnical project related efforts. Teamed with corporate and outside legal council to support licensing and litigation with the Department of Energy.

DIRECTOR – STRATEGIC PROJECTS (interim), (January 2006 through June 2006), Diablo Canyon Power Plant. Responsible for the leadership of major projects including; Turbine Replacement, Independent Spent Fuel Storage Installation, and Steam Generator Replacement. Established 2006 department goals, Human Performance plans, 2R13 ALARA plans, etc. Supported Outage Leadership in management of containment related projects during 2R13.

CHIEF CIVIL ENGINEER, (April 1993 to June 2000), Diablo Canyon Nuclear Power Plant Project. Managed a group of engineers, architects and designers. Responsible for leading the plant design efforts including fire protection, environmental, interface with government agencies and the development of new facilities. Major projects include: Chemical Waste Pond clean closure, Vital Area Boundary Reconfiguration, Intake Structure Concrete Degradation, ASW Buried Piping By-pass and Meteorological Tower replacement. Participation on numbers Task Force and Management teams including: Design Change Process, Chair of Civil Performance Recognition Team, ESC Labor Management Team, OCC Engineering Representative.

ASSISTANT TO THE VP, Engineering and Construction Business Unit- Generation, (July 1991 to April 1993) Responsible for managing the office including department budget, correspondence, strategic planning, preparation of Officer Presentations, interface with department Directors, special projects and participation on various Task Force including Competitive Assessment and Organizational Restructuring.

ENGINEERING MANAGER (Acting), Diablo Canyon Nuclear Power Plant Project, (April 1990 thru June 1991) Responsible for the management and direction of 56 engineers, architects and designers in support of plant maintenance, development of design for plant improvements, and resolution of operability issues.

ENGINEERING GROUP SUPERVISOR – CIVIL/ARCHITECTURAL; Diablo Canyon Nuclear Power Plant Project, (September 1987 to April 1990). Responsible for managing the civil and architectural design of plant improvements and capital improvements.

RESPONSIBLE ENGINEER/CONSTRUCTION COMPLETION MANAGER, Diablo Canyon Nuclear Power Plant Project, (January 1984 to September 1987) Facilities Developed: 30,000 sq. ft. Maintenance Shop Facility, 80,000 sq. ft. Warehouse, Reinforces Concrete Radioactive Waste Storage Facility and a 60,000 sq. ft. 6 story bldg. Responsibilities included development of design criteria, design concepts, performing cost/feasibility studies, supervising preparation of design documents, review bid packages and shop drawings. Coordinated construction activities for all disciplines, resolution of constructability problems, developed methods for controlling and maintaining construction budget and schedule. Interface with contractor, consultants and regulatory agencies.

GROUP LEADER, Diablo Canyon Project, (October 1982 to January 1984) Seconded to Bechtel Power Division, Independent Design Verification Program. Developed design criteria, project scope, analysis and design of modifications. Group Leader responsibilities for 26 engineers including assigning work, preparing schedules, reviewing/approving calculations and coordinating group activities with other disciplines and construction Organization.

DESIGN ENGINEER, Geysers 17 & 18 and Diablo Canyon Power Plants, (January 1980 to June 1982) Design and analysis of reinforced concrete and steel structures. Development of input data for seismic spectra development.

LICENSE and COMMITTEES

Registered Civil Engineer, State of California.

Mark L. Mayer
581 Belanger Drive
Nipomo, CA 93444

Education

SB, Nuclear Engineering, Massachusetts Institute of Technology, 1981

Experience

1981 to 1986 Bechtel Power Corporation, Los Angeles Power Division, Norwalk, CA

Nuclear Engineer on the Vogtle Electric Generating Plant, responsible for ALARA design reviews, plant shielding and radiological analyses, support for plant licensing hearings related to radiological aspects of environmental qualification. Provided support to the ASLB hearings including presentation of testimony on a licensing contention.

1986 to Date Pacific Gas and Electric Company

1986 to 1988 Licensing Engineer in the San Francisco General Office

Supported generic licensing activities for the Diablo Canyon Power Plant (DCPP). Duties included support of FSAR reviews and revisions and support for licensing hearings related to the reracking of the DCPP spent fuel pools.

1988 to 1998 Reactor Engineer, Diablo Canyon

Responsible for supporting reactor core surveillances, fuel handling support, special nuclear materials tracking and related activities. Acting supervisor for 18 months while the regular supervisor was in license class.

1998 to 2007 Supervisor, Systems and Transient Analysis, Diablo Canyon

Supervised the Systems and Transient Analysis group. Was responsible for the preparation of thermal/hydraulic analyses, review of vendor safety analyses, FSAR Chapter 15 analysis preparation and review, and offsite dose analysis. Key initiatives supported by this function have included revision of the DCPP safety analyses in support of the steam generator replacement project, support for the independent spent fuel storage facility licensing activities and resolution of technical issues associated with Generic Safety Issue 191.

2007 to Date Supervisor, Reactor Engineering, Diablo Canyon

Responsible for supporting reactor core surveillances, fuel handling support, special nuclear materials tracking and related activities.

Professional Certifications and Affiliations

Licensed Professional Engineer in the State of California
Member of the American Society of Mechanical Engineers
Member of the National Society of Professional Engineers

CHAPTER 5

ENVIRONMENTAL EFFECTS OF ACCIDENTS

CONTENTS

CHAPTER 5

ENVIRONMENTAL EFFECTS OF ACCIDENTS

TABLES

CHAPTER 5

ENVIRONMENTAL EFFECTS OF ACCIDENTS

5.1 ACCIDENTS INVOLVING RADIOACTIVITY

The Diablo Canyon ISFSI SAR addresses the four categories of design events as defined in ANSI/ANS-57.9, which include normal, off-normal, and accident events that are postulated to occur while a loaded storage cask is being moved to the ISFSI storage pad and after the storage cask has been placed on the pad. The four ANSI/ANS-57.9 categories considered in the ISFSI SAR are:

(1) Design Event I: an event associated with normal operations.

(2) Design Event II: an event associated with off-normal operations that can be expected to occur with moderate frequency, or on the order of once during a calendar year of operation of the ISFSI.

(3) Design Event III: an infrequent event that could be reasonably expected to occur over the lifetime of the ISFSI.

(4) Design Event IV: an event that is postulated to occur because it establishes a conservative design basis for systems, structures, and components important to safety.

5.1.1 DESIGN EVENT I

Doses from the Design Event I category are included in the normal routine radiological effects discussion in ER Section 4.2.9. The annual doses resulting from normal operations and anticipated occurrences at the ISFSI are well below the 10 CFR 72.104 criteria for radioactive materials in effluents and direct radiation. Table 5.1-1 presents the annual doses at the site boundary and nearest resident from direct radiation and nonmechanistic effluent release for normal ISFSI operations. The dose rates from other fuel cycle operations (i.e., DCPP) are also shown in this table to demonstrate compliance with 10 CFR 72.104. While Table 5.1-1 demonstrates that the Diablo Canyon ISFSI will meet 10 CFR 72.104 regulatory requirements, ultimate compliance will be demonstrated through the DCPP environmental monitoring program. The actual dose from the ISFSI will be considerably less than the conservatively estimated values in Table 5.1-1. The following are some of the conservative assumptions used in calculating the dose rates presented:

- The design basis fuel assembly and design basis burnup and cooling time were conservatively chosen.

- All fuel assemblies in the MPC are assumed to be identical with the design basis burnup and cooling time.

- Burnable poison and rod assemblies are assumed to be present in all fuel assemblies in all casks.

- The assumed ISFSI loading plan was conservatively chosen to result in the highest offsite dose rate.

- The dose rate was calculated at the most conservative location around the ISFSI.

Table 5.1-2 presents the occupational exposures associated with ISFSI activities.

5.1.2 DESIGN EVENT II

Off-normal operations and accidents could potentially result in members of the general public being exposed to additional levels of radiation or radiological effluents beyond those associated with routine operations. The analyses of potential radiological impacts of off-normal operations and hypothetical accidents are presented in this section only to identify and bound the types of environmental impacts that could accompany these events. A more detailed assessment is included in SAR Chapter 8. None of the credible off-normal operations and hypothetical accidents results in offsite radiological consequences except for the postulated off-normal confinement boundary leakage.

The events designated as Design Event II include a loss of external electrical power, off-normal ambient temperatures, off-normal pressures internal to the MPC, confinement boundary leakage, cask drop less than allowable heights, off-normal transporter operation, and MPC partial blockage of storage cask air ducts. Of these events, only partial blockage of the storage cask inlet ducts was found to result in worker exposures in association with the corrective actions to remove the debris or other foreign material blocking the duct(s).

5.1.2.1 Off-Normal Confinement Leakage

The HI-STORM 100 System MPC has a reliable seal-welded confinement boundary to contain radioactive fission products under all design basis normal, off-normal, and accident conditions. Notwithstanding these design features, a nonmechanistic leak in the MPC confinement boundary has been evaluated as both an off-normal and an accident condition. The difference between the two evaluations is in the radioactive source terms, where 10 percent and 100 percent of the fuel rods are assumed to rupture

under off-normal and accident conditions, respectively. This is consistent with Interim Staff Guidance (ISG) Document 5 (Reference 1).

The dose consequences of a non-mechanistic leak in the MPC confinement boundary have been analyzed on a site-specific basis for the Diablo Canyon ISFSI using appropriate source terms, release fraction, leak rate, meteorology, breathing rate, and occupancy times. The analysis of a confinement boundary leak as an off-normal event considers a rupture of 10 percent of the stored fuel rods. The evaluation of this event is discussed in SAR Section 7.5.2. Annual doses at the site boundary were calculated assuming leakage from 140 storage casks (MPC-24 or MPC-32) and 100 percent occupancy, and are provided in Table 5.1-3. The calculated doses are less than the regulatory limits in the 10 CFR 72.104(a).

5.1.2.1.1 Partial Duct Blockage

The corrective action for the partial blockage of air ducts is the removal of the cause of the blockage, and the cleaning, repair, or replacement, as necessary, of the affected mesh screens. After clearing of the blockage, the cask heat removal system is restored to its design condition and temperatures will return to the normal range. Partial blockage of the air ducts does not affect the HI-STORM 100 Systems ability to safely store spent fuel in the long term (SAR Section 8.1.4). The radiation dose received by the worker who removes a partial blockage of the inlet ducts on the storage cask is presented in Table 5.1-4. The radiation dose received by the worker would be well below the acceptance limits of 10 CFR 20, Subpart C for occupational dose. Exposures to members of the public are not affected by this event.

5.1.3 DESIGN EVENTS III AND IV

For the purpose of this evaluation, no distinction is made between Design Events III and IV. Design Events III and IV include events such as earthquakes; tornados and missiles generated by natural phenomena; floods; fire and explosions; canister leakage under hypothetical accident conditions; storage cask drop or tip-over; loss of shielding; 100 percent blockage of air inlet ducts; electrical accidents; and transmission tower collapse. Three of these events (that is, 100 percent duct blockage, canister leakage, and loss of neutron shielding) might create situations in which worker personnel could be exposed to higher levels of radiation than normal. For the purposes of demonstrating compliance with 10 CFR 72.106(b), a hypothetical accident that results in an offsite release is described in Section 5.1.3.2.

5.1.3.1 Complete Duct Blockage

Onsite workers might receive a dose during removal of debris or other foreign material that created a 100 percent blockage of the inlet ducts on a storage cask. A partial

blockage was discussed under Design Event II. The radiation worker who removes the 100 percent blockage is estimated to receive double the dose estimated for the partial blockage case. The radiation dose received by the worker who removes the 100 percent blockage of the inlet ducts on the storage cask is presented in Table 5.1-4. However, the radiation dose received by the worker would still be well below the acceptance limits of 10 CFR 20, Subpart C for occupational dose. Exposures to members of the public are not affected by this event.

5.1.3.2 Canister Boundary Leakage

Canister leakage under hypothetical accident conditions is not considered to be a credible event. Nevertheless, to demonstrate compliance with 10 CFR 72.106(b), a bounding calculation for exposures to personnel and the members of the public was performed to assess the consequences of the leakage. The radioactive source term assumes 100 percent of the fuel rods within the cask rupture. The breach could result in the release of gaseous fission products, fines, volatiles, and airborne crud particulates to the MPC cavity. Doses resulting from the canister leakage under hypothetical accident conditions were calculated in accordance with Interim Staff Guidance (ISG) Document 5, ISG- 11 (Reference 2) and NUREG/CR-6487 (Reference 3).

The assumption that 100 percent of the fuel rods have ruptured is incorporated into the postulated pressure increase within the MPC cavity to determine the maximum possible pressure of the MPC cavity. This pressure, combined with the maximum MPC cavity temperature under accident conditions, is used to determine a postulated leakage rate during an anticipated occurrence. This leakage rate is based on the Diablo Canyon ISFSI Technical Specification leakage rate limit for the helium leak rate test, and is adjusted for the higher temperature and pressure during the accident to result in a hypothetical accident leak rate of 1.28×10^{-5} cm^3/sec.

The radionuclide release fractions, which account for the radionuclides trapped in the fuel matrix and radionuclides that exist in a chemical or physical form that is not releasable to the MPC cavity from the fuel cladding, are based on ISG-5. Additionally, only 10 percent of the fines released to the MPC cavity are assumed to remain airborne long enough to be available for release through the confinement boundary (Reference 4). It is conservatively assumed that 100 percent of the volatiles, crud, and gases remain airborne and available for release. The release rate for each radionuclide was calculated by multiplying the quantity of radionuclides available for release in the MPC cavity by the leakage rate calculated above, divided by the MPC cavity volume. No credit is taken for any confinement function of the fuel cladding or the ventilated HI-STORM 100 overpack.

Doses at the Diablo Canyon ISFSI site boundary resulting from a postulated leaking MPC-32 were calculated. The nearest distance from the ISFSI to the DCPP site boundary was estimated to be 1,400 ft. A χ/Q value of 4.50×10^{-4} sec/m^3 was assumed based on 1,325 ft being the nearest distance from the ISFSI to the DCPP site boundary. This χ/Q value is conservative because the χ/Q value at 1,325 ft would bound the χ/Q value at 1,400 ft and it is based on a 1-hour release period, whereas the hypothetical accident duration is 30 days per ISG-5. The dose conversion factors for internal doses due to inhalation and submersion in a radioactive plume were taken from EPA Federal Guidance Report No. 11 (Reference 5) and EPA Federal Guidance Report No. 12 (Reference 6), respectively. An adult breathing rate of 3.3×10^{-4} m^3/s was assumed, as recommended by ISG-5.

The following 30-day doses to an individual being continuously present at the minimum controlled area boundary of 1,400 ft and the wind constantly blowing in the same direction for 30 days as a result of an assumed effluent release from a single cask under hypothetical accident conditions were determined:

- The committed dose equivalent from inhalation and the deep dose equivalent from submersion for critical organs and tissues (gonad, breast, lung, red marrow, bone surface, and thyroid).
- The committed effective dose equivalent from inhalation and the deep dose equivalent from submersion for the whole body.
- The lens dose equivalent for the lens of the eye.
- The shallow dose equivalent from submersion for the skin.
- The resulting total effective dose equivalent and total organ dose equivalent.

Table 5.1-5 summarizes the accident doses for a hypothetical confinement boundary leak. The estimated doses are a fraction of the limits specified in 10 CFR 72.106(b).

5.1.3.3 Loss of Neutron Shielding

This accident event postulates the loss of neutron shielding provided by the HI-TRAC transfer cask water jacket and the Holtite-A solid neutron shielding in the HI-TRAC transfer cask top lid and bottom shield. Throughout all design basis accident conditions, the axial location of the fuel will remain fixed within the MPC because of the upper and lower fuel spacers. ISFSI SAR Chapter 3 shows that the fuel spacers, transfer cask inner shell, lead, and outer shell remain intact throughout all design basis normal, off-normal, and accident loading conditions. Localized damage of the transfer

cask outer shell could be experienced during a drop event, but no loss of shielding results.

Three potential causes for the loss of neutron shielding provided by the transfer cask are:

(1) Elevated temperatures as a result of a fire accident could cause the temperature of the Holtite-A to exceed its design accident temperature and the pressure of the water jacket could increase to the point where overpressure relief valve on the water jacket would vent steam and water to the atmosphere. This would result in the loss of some amount of the water used for neutron shielding.

(2) Puncture of the transfer cask outer neutron shield jacket by a small object traveling at high speed, such as a tornado-borne missile, would cause the shield water to drain out at the point of puncture.

(3) A drop of the loaded transfer cask may cause local damage to the water jacket sufficient to drain the shield water.

Other shielding credited in the shielding analyses includes the steel transfer cask and overpack structures, concrete, and lead. There are no credible events that could cause a significant degradation or loss of these solid forms of shielding.

In the 125-ton HI-TRAC, which uses Holtite-A in the top lid and the bottom shield for neutron shielding, the elevated fire temperatures could cause the Holtite-A to exceed its design accident temperature limit. For the dose analysis, it is conservatively assumed that all the Holtite-A in the 125-ton HI-TRAC transfer cask top lid and the bottom shield is lost. The potential reduction in shielding effectiveness of the Holtite-A in the transfer cask top lid and the bottom shield is bounded by the normal dose rates in the area of the access hole in the top lid. Therefore, no additional analysis of this scenario is performed.

The bounding consequence that affects the shielding materials of the HI-TRAC transfer cask is the potential for damage to the water jacket shell and the loss of the neutron shield (water). In the accident consequence analysis, it is conservatively assumed that the neutron shield (water) is completely lost and replaced by a void.

The assumed loss of all the water in the water jacket results in an increase in the radiation dose rates at locations adjacent to the water jacket. The assumed loss of all of the Holtite-A in the HI-TRAC transfer cask top lid and the bottom shield results in an increase in the radiation dose rates at locations adjacent to the lids. The shielding

analysis results presented in Section 5.1.2 of the HI-STORM 100 FSAR, as amended by LAR 1014-1, demonstrate that the dose limits of 10 CFR 72.106 are not exceeded.

There is no degradation in confinement capabilities of the MPC due to the minimal increase in fuel cladding temperatures caused by the loss of water in the water jacket. There are increases in the local dose rates adjacent to the water jacket. The complete loss of the HI-TRAC transfer cask neutron shield along with the water jacket shell is assumed in the shielding analysis for the post-accident analysis of the loaded transfer cask in Section 5.1.2 of the HI-STORM 100 FSAR, as amended by LAR 1014-1. The complete loss of the HI-TRAC neutron shield significantly affects the dose rate at mid-height of the transfer cask. The accident dose rate (calculated using the burnups and cooling times that produce the highest dose rates) is 1.47 mrem/hr at the minimum allowed controlled area boundary distance of 100 meters from the ISFSI. For the 30-day duration of the event, the total dose at this location is 1.058 Rem, which is less than the accident dose limits in 10 CFR 72.106. The controlled area boundary at the Diablo Canyon ISFSI is approximately 1,400 ft (427 m). Therefore, the generically calculated doses for this accident from the HI-STORM 100 System FSAR bound the Diablo Canyon ISFSI site.

Doses to onsite personnel will be monitored after the loss of neutron shielding event and temporary shielding may be employed at the discretion of the DCPP radiation protection organization.

The consequences of the design basis accident conditions for the MPC-24E storing damaged fuel and the MPC-24EF storing damaged fuel and/or fuel debris differ slightly from those with intact fuel. It is conservatively assumed that during a drop accident (vertical, horizontal, or tip-over) the damaged fuel collapses and the fuel pellets rest in the bottom of the damaged fuel container. Analyses discussed in HI-STORM FSAR Section 5.4.2 demonstrate that the damaged fuel in the post-accident condition does not significantly affect the dose rates around the cask. Therefore, the damaged fuel post-accident doses are bounded by the intact fuel post-accident doses.

5.1.4 REFERENCES

1. Interim Staff Guidance Document 5, Revision 1, Normal, Off-normal and Hypothetical Dose Estimate Calculations, USNRC, June 1999.

2. Interim Staff Guidance Document 11, Revision 1, Transportation and Storage of Spent Fuel Having Burnups in Excess of 45GWD/MTU, USNRC, May 2000.

3. NUREG/CR-6487, Containment Analysis for Type B Packages Used to Transport Various Contents, UCRL-ID-124822, Anderson, B.L. et al, Lawrence Livermore National Laboratory, November 1996.

4. SAND88-2778C, An Estimate of the Contribution of Spent Fuel Products to the Releasable Source Term in Spent Fuel Transport Casks, Rashid, Y.R., et al, Sandia National Laboratories, 1988.

5. US EPA, Federal Guidance Report No.11, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion, DE89-011065, 1988.

6. US EPA, Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil, EPA 402-R-93-081, 1993.

5.2 TRANSPORTATION ACCIDENTS INVOLVING RADIOACTIVITY

Cask handling and transfer operations will be conducted totally within the DCPP site boundary. Potential accidents involving drops and tipovers during transport of a loaded transfer cask from the DCPP fuel handling building/auxiliary building (FHB/AB) to the ISFSI are considered in SAR Section 8.2.4. It is concluded that such accidents are not credible events outside the DCPP FHB/AB.

This section is considered to be non-applicable, as it is believed to apply to accidents associated with offsite transportation of spent fuel in accordance with 10 CFR 71, which is beyond the scope of this ER.

TABLE 5.1-1

TOTAL ANNUAL OFFSITE COLLECTIVE DOSE (MREM) AT THE SITE BOUNDARY AND NEAREST RESIDENT FROM THE DIABLO CANYON ISFSI CONTAINING 140 CASKS FOR NORMAL OPERATION[a]

Organ	Effluent Release	Direct Radiation	HI-STORM Loading Operations	Other Uranium Fuel Cycle Operations[b]	10 CFR 72.104 Regulatory Limit
Site Boundary (1,400 ft/427 m)					
Whole body ADE[c]	0.064	5.6	13.1E-02	4.357E-02	25
Thyroid ADE	0.010	5.6	13.1E-02	1.260E-01	75
Critical Organ ADE (Max)	0.33	5.6	13.1E-02	5.590E-02	25
Nearest Resident (1.5 miles/7,920 ft/2,414 m)					
Whole body ADE	0.27	3.5E-04	13.1E-02	4.357E-02	25
Thyroid ADE	0.043	3.5E-04	13.1E-02	1.260E-01	75
Critical Organ ADE (Max)	1.46	3.5E-04	13.1E-02	5.590E-02	25

[a] This table was taken from ISFSI SAR Table 7.5-4.

[b] Data for uranium fuel cycle operations were obtained from the DCPP FSAR Update, Rev. 11, Table 11.3-32. Table 11.3-32 was selected based on the highest dose values in the sectors at the site boundary (0.5 miles). These dose values for the site boundary were conservatively applied to the nearest resident. The critical organ dose listed was based on the total liver dose in Table 11.3-32. The values listed in Table 11.3-32 should bound the results calculated from effective dose equivalent (EDE) methodology.

[c] ADE is the annual dose equivalent.

TABLE 5.1-2

OCCUPATIONAL EXPOSURES ASSOCIATED WITH ISFSI ACTIVITIES[a]

Activity	Dose Rate (mrem/hr)	Duration (hours/year)	Number of Personnel	Total Dose (rem/year)
Completion of ISFSI (140 casks)				
ISFSI walk-downs	15.0	122	1	1.8
Overpack repairs	65.0	12	2	1.6
Construction of last storage pad	6.0	480	15	43.2

[a] This table was taken from ISFSI SAR Table 7.4-3.

TABLE 5.1-3

NORMAL OPERATION ANNUAL DOSES AT THE SITE BOUNDARY AND NEAREST RESIDENT FROM AN ASSUMED EFFLUENT RELEASE FROM THE 140 CASKS AT THE DIABLO CANYON ISFSI[a]

	Annual Dose[b] (mrem)
Site Boundary (1,400 ft/427 m)	
Whole body ADE	0.064
Thyroid ADE	0.010
Critical Organ ADE (Max)	0.35
Nearest Resident (1.5 miles/7,920 ft/2,414 m)	
Whole body ADE	0.27
Thyroid ADE	0.043
Critical Organ ADE (Max)	1.46

TABLE 5.1-4

OCCUPATIONAL EXPOSURES ASSOCIATED WITH REMOVING A CASK INLET VENT BLOCKAGE

Activity	Dose Rate (mrem/hr)	Duration (hours/year)	Number of Personnel	Total Dose (man-rem)
Completion of ISFSI (140 casks)				
Removal of Partial Inlet Blockage	58	1	2	0.116
Removal of 100% Inlet Blockage	58	2	2	0.232

TABLE 5.1-5

CONFINEMENT BOUNDARY LEAKAGE DOSES AT THE SITE BOUNDARY[a]

Dose Category	30-Day Dose (mrem)	10 CFR 72.106 Limit (mrem)
TEDE	0.83	5,000
TODE=DDE+CDE (Max)	6.36	50,000
LDE	0.022	15,000
SDE	0.026	50,000

[a] This table was taken from ISFSI SAR Table 8.2-12
TEDE: Total Effective Dose Equivalent
TODE: Total Organ Dose Equivalent
DDE: Deep Dose Equivalent
CDE: Committed Dose Equivalent
LDE: Lens Dose Equivalent
SDE: Shallow Dose Equivalent

3.2.1 TORNADO AND WIND LOADINGS

3.2.1.1 Applicable Design Parameters

As stated in Section 2.3.2, the highest recorded peak wind gust at the DCPP site was 84 mph. For storage system design purposes, a wind velocity of 80 mph is used (Section 3.3.1 of the DCPP FSAR Update) with a gust factor of 1.1, which envelopes the recorded, peak-gust value of 84 mph.

Tornado winds and outdoor tornado-borne missiles for the DCPP site are included in Section 3.3.2.1 of the DCPP FSAR Update. Specific wind speeds, pressure drops, and missile descriptions applicable to the operating configurations associated with the ISFSI site are presented in Tables 3.2-1 and 3.2-2. As shown in Table 3.2-1, the Diablo Canyon ISFSI tornado wind speeds are based on the DCPP FSAR Update and are bounded by those evaluated for licensing of the HI-STORM 100 System.

The HI-STORM 100 System, which includes all operating configurations applicable to the Diablo Canyon ISFSI, is generically designed to withstand pressures, wind loads, and missiles generated by a tornado as described in Section 2.2.3.5 of the HI-STORM 100 System FSAR. The design-basis tornado and wind loads for the HI-STORM 100 System are consistent with Regulatory Guide 1.76 (Reference 9), ANSI/ANS 57.9 (Reference 10), and ASCE 7-88 (Reference 11).

The tornado wind and missile evaluations for the DCPP ISFSI are based on the DCPP site licensing-basis wind speed of 200 mph shown in Table 3.2-1, and are considered representative of the ISFSI site. The tornado missiles evaluated for the Diablo Canyon ISFSI are listed in Table 3.2-2 and are a compilation of those from the DCPP FSAR Update; NUREG-0800, Section 3.5.1.4 (Reference 12) Spectrum II missiles; and three 500-kV tower missiles specific to the Diablo Canyon ISFSI site. Several of these missiles differ from those identified in the HI-STORM 100 System FSAR. The effects of these missiles are evaluated for Level D stress limits and cask penetration. The evaluation is consistent with the design criteria, as specified in NUREG-0800, Section 3.5.1.4, to withstand tornados in accordance with 10 CFR 72.120(a) and 72.122(b).

3.2.1.2 Determination of Forces on Structures

Tornado wind loads include consideration of the following, as applicable: (a) tornado wind load, (b) tornado differential pressure load, and (c) tornado missile impact load. The method of combining the applicable effective tornado wind, differential pressure, and missile impact loads to determine the total tornado load is done in accordance with NUREG-0800, Section 3.3.2.

3.2.1.3 Tornado Missiles

The HI-STORM 100 System, including the overpack and the transfer cask, is generically designed to withstand three types of tornado-generated missiles in accordance with NUREG-0800, Section 3.5.1.4, as noted in Table 3.2-2. The design basis for these missiles is discussed in Section 2.2.3.5 of the HI-STORM 100 System FSAR. The mass and velocity of these missiles, along with the design-basis tornado missiles for the Diablo Canyon ISFSI site are presented in Table 3.2-2. Table 3.2-2 also lists the DCPP licensing-basis tornado missiles. Due to the proximity of a 500-kV transmission tower to the ISFSI site, other missiles were evaluated as shown in Table 3.2-2. Missile evaluations are described in detail in Section 8.2.2 for cask transport from the FHB/AB, activities at the CTF, and at the ISFSI storage pad.

3.2.2 WATER LEVEL (FLOOD) DESIGN

The Diablo Canyon ISFSI pad is located at elevation +310 ft mean sea level (MSL). The Diablo Canyon ISFSI site surface hydrology is described in Section 2.4. It is concluded in Section 2.4 that there is no potential for flooding in the vicinity of the ISFSI. Therefore, flooding is not a consideration for ISFSI operations or on the capability of the dry storage cask system to safely store the spent fuel. Likewise, due to the elevation of the ISFSI site, tsunami is not a threat to the HI-STORM 100 Systems that are stored on the pad. Since the CTF is located adjacent to the ISFSI, these conclusions are also applicable for the potential flooding and tsunami impact on the CTF. A design-basis flooding event occurring during movement of the cask to or from the CTF along the transport route is not considered credible. Flooding of the overpack while it is located in the underground vault at the CTF is precluded by the use of a sump designed to remove any significant accumulation of water in the vault.

Therefore, while the HI-STORM 100 System is designed to withstand pressure and water forces associated with floods, such design features are unnecessary for the Diablo Canyon ISFSI and do not need to be evaluated. In conclusion, the ISFSI design is consistent with the design criteria of NUREG-0800 and ASCE 7-88 and can withstand floods as required by 10 CFR 72.120(a) and 72.122(b).

3.2.3 SEISMIC DESIGN

In accordance with 10 CFR 72.102(f)(1), the seismic design of the important-to-safety ISFSI SSCs, which include the HI-TRAC transfer cask, the HI-STORM 100SA overpack, the MPC, the CTF, the onsite cask transporter, and ISFSI storage pads, is based on design-earthquake ground motions that have been established for the plant site. Site seismic characteristics and vibratory ground motion are discussed in Sections 2.6.1 and 2.6.2.

The ISFSI SSCs are designed to withstand seismic loads during: (a) onsite transport of the loaded transfer cask, (b) transfer operations at the CTF, (c) transport of loaded overpack to the storage pad, and (d) storage of the overpack on the ISFSI pad. The design bases for the ISFSI SSCs, including analyses and design procedures, are discussed in Sections 4.2, 4.3, 4.4.5, and 8.2.1. Seismic design for the loading and handling of the transfer cask while in the

below unity, as such the design shear of 515 kips (and associated moments) remains valid for design.

(5) The best estimate of maximum vertical tensile load after sliding remains unchanged. Thus the design axial bolt tensions of the analysis described in Section 8.2.1.2.3.1 remain valid.

(6) The response spectra comparison plots of the rock versus pad sliding indicate that the responses at the cask-to-pad interface generally do not vary up to about 16 Hz. However, above this frequency some differences in the responses are seen as a result of sliding. An evaluation by the cask supplier determined that there were no components inside the cask are sensitive to changes in input motion in this higher frequency range. The highest peak spectral ordinate associated with change in motion as a result of pad sliding is 4.1 g at approximately 26 Hz and 5 percent critical damping well below the cask qualifications.

(7) Given that the base shear (and therefore base moments) and axial tension do not change as a result of pad sliding, it is concluded that analyses described in Section 8.2.1.2.3.1 remain valid.

8.2.1.3 Earthquake Accident Dose Calculations

The HI-STORM 100SA overpack and the HI-TRAC transfer cask were explicitly analyzed for, and shown to withstand the seismic ground motion during transport to the CTF, during activities conducted at the CTF, during movement from the CTF to the storage pads, and during storage operations, as applicable. The seismic ground motion does not cause stresses above allowable limits in the MPC confinement boundary, the transfer cask, or the storage overpack during canister transport, transfer, or storage operations. The CTF and cask transporter structures are also designed to withstand the DCPP ground motion. No radioactivity would be released in the event of an earthquake and there would be no resultant dose.

8.2.2 TORNADO

A tornado is classified as a natural phenomenon Design Event IV, as defined in ANSI/ANS-57.9. This event involves the potential effects of tornado-induced wind, differential pressure, and missile impact loads on the ISFSI SSCs that are important to safety. The design basis wind and tornado evaluation is provided in Reference 27.

8.2.2.1 Cause of Accident

The cause of this event is the occurrence, at or near the ISFSI site, of meteorological conditions that are favorable to the generation of a tornado. The design-basis tornado wind speed for the ISFSI is based on a conservative estimate appropriate for DCPP (annual probability of 10^{-7}), which was developed by the NRC (SSER No. 7). The specific topography

associated with the plant site indicates that the postulated tornado event is unlikely. However, it has been included in the ISFSI design basis as a potential accident event.

8.2.2.2 Accident Analysis

The accident analysis for tornado effects involves evaluation of the loaded transfer cask during transport to the CTF, MPC transfer activities at the CTF, transport of a loaded HI-STORM 100SA overpack to the ISFSI pad, and long-term storage of the loaded overpack at the ISFSI pad. As discussed in Section 3.2.1 and 4.2.3.3.2.6, tornado-wind and missile design criteria are a combination of Diablo Canyon site-specific winds and missiles and the design-basis missiles described in the HI-STORM 100 System FSAR. In the evaluation of the Diablo Canyon ISFSI for tornado effects, the missiles were categorized as large, intermediate, or small missiles and were compared with those missiles for which the HI-STORM 100 System was generically designed to withstand. The description, mass, and velocity of all missiles considered for evaluation are listed in Table 3.2-2. As noted in Table 3.2-2, some of the additional Diablo Canyon ISFSI missiles were conservatively evaluated for the generic Region II missile velocities described in NUREG-0800, Section 3.5.1.4. The 1800 kg automobile and the 4 kg, 1-inch-diameter steel rod were determined to be the bounding large, and small missiles, respectively. For the intermediate missile category, the 500-kV insulator string was found to be bounding for penetration resistance and the 8-inch-diameter steel rod was determined to be bounding for the global stress evaluation.

The bounding large and intermediate (for penetration only) missiles were chosen by comparison of the kinetic energies of the missiles. The small missile was chosen based on the guidance of NUREG-0800, Section 3.5.1.4, for selecting a missile that can pass through an opening in a protective barrier. For the global stress evaluation of the intermediate category missile, the bounding missile was chosen based on a comparison of safety factors (SF), the missile producing the lower SF being bounding. If the generic analysis described in the HI-STORM 100 System FSAR was bounding, no additional evaluation was performed. If a DCPP site or Diablo Canyon ISFSI-specific missile was bounding, an analysis was performed for the applicable component (that is, the overpack and/or the transfer cask). The following is a summary of the evaluations performed for the four operating ISFSI configurations: transport to the CTF, MPC transfer activities at the CTF, transport to the ISFSI pad, and long-term storage at the ISFSI pad.

The missile impacts are analyzed using formulas from Bechtel Power Corporation Topical Report BC-TOP-9A (Reference 14), ORNL Report TM-1312 (Reference 33), and energy balance methods. In all cases, at all locations away from the impact locations, missile-induced stresses in the transfer cask and overpack are below ASME Level D stress intensity limits.

Another possible consequence of a tornado is to cause the collapse of a nearby 500-kV transmission tower. This event is discussed in Section 8.2.16.

8.2.2.2.1 Transport to the CTF

The transfer cask is transported between the DCPP FHB/AB and the CTF in a horizontal position. Section 3.4.8.2.2 of the HI-STORM 100 System FSAR discusses the side impact from a large missile and concludes loads are below ASME Level D stress intensity limits. The small missile is bounded by the intermediate missile. The evaluations for the side, top, and bottom impact from an intermediate missile (344.7 kg insulator string traveling at 157 mph) are as follows.

- For the side impact, conservatively neglecting the water jacket and the lead shielding, the intermediate missile will penetrate the outer steel shell, but will not penetrate the 3/4-inch inner shell of the transfer cask. Using this conservative model, the minimum inner shell thickness required to withstand the missile impact is 0.266 inch. The design inner shell thickness is 0.75 inch.
- A bottom shield is attached to the transfer cask while suspended horizontally in the cask transporter. On the bottom of the transfer cask, the missile impact occurs on the bottom shield, which covers the pool lid. The HI-STORM 100 System FSAR contains an evaluation for the impact of the intermediate missile on the HI-TRAC transfer lid door. The analysis shows that the intermediate missile would not penetrate the 2-1/4-inch, carbon-steel top plate of the transfer lid door. The minimum required steel thickness to withstand the missile impact is 0.619 inch. This evaluation is conservative for the configuration used at the Diablo Canyon ISFSI, which includes the pool lid (3 inches of steel) and the bottom shield (7-1/4 inches of steel).
- On the top of the transfer cask, the top lid has a hole for rigging, lowering, and raising the MPC during transfer of the canister between the transfer cask and the overpack. While suspended horizontally, this hole is shielded from tornado missiles by the cask transporter body. Conservatively neglecting credit for the missile protection provided by the transporter, an analysis was performed for the 500-kV insulator string intermediate missile entering the transfer cask through the hole in the top lid and impacting the MPC lid. If the insulator string missile directly impacts the MPC, it will not penetrate the 9-1/2-inch-thick, stainless-steel lid. The global stress analysis of the 8-inch steel cylinder missile impacting the MPC lid yielded a safety factor against failure of the peripheral MPC lid-to-shell (LTS) weld of 1.23 versus a safety factor of 7.1 for the insulator string.

8.2.2.2.2 Transfer Operations at the CTF

During MPC transfer operations at the CTF, the transfer cask and the overpack are oriented vertically with the transfer cask stacked on top of the overpack. All but approximately the top 3 ft of the overpack are below grade and not susceptible to tornado missile strikes. The top of the overpack is shielded by the transfer cask until the transfer cask is removed to allow installation of the HI-STORM lid. As discussed in Section 8.2.3.1, cask transport and transfer operations will not be conducted during severe weather. The top of the MPC will only be

exposed for a short duration (nominally less than 4 hours). Therefore, in the configuration with the lid removed, a tornado missile impact is not credible. With the top of the MPC exposed during this time, the evaluation of an intermediate missile impact on the MPC lid, described in Section 8.2.2.2.1 ensures the MPC integrity is maintained.

In the vertical orientation, the top of the transfer cask is not subject to direct impacts from these missile strikes and the bottom of the transfer cask is not exposed to tornado-missile strikes. The evaluation of the missile strike on the side of the transfer cask described in Section 8.2.2.2.1 is applicable for this configuration.

8.2.2.2.3 Overpack Transport to the ISFSI Pad

The effect of tornado missiles impacting the transporter while carrying an overpack during transport to the ISFSI pad was evaluated for a horizontal large tornado missile. The transporter with overpack will not turnover from the impact.

Tornado wind effects are enveloped by the HI-STORM 100 System FSAR analysis of a freestanding HI-STORM on a pad. The overpack is lifted only to those heights necessary to travel from the CTF to the ISFSI storage pad. Typically, this is only several inches. This small lift height eliminates tornado missiles striking the bottom of the cask as a credible event.

8.2.2.2.4 Long-Term Storage at the ISFSI Pad

The HI-STORM 100 and 100S free-standing overpack designs have been analyzed for steady state tornado wind loads with a concurrent, large-missile impact, as well as intermediate and small-sized missiles for penetration, as described in Appendices 3.C and 3.G of the HI-STORM 100 System FSAR. The anchored version of the HI-STORM 100S overpack (HI-STORM 100SA) to be deployed at the Diablo Canyon ISFSI is bounded by the free-standing analysis because the anchorage provides additional protection against overturning. The wind loading evaluated in the HI-STORM 100 System FSAR bounds the maximum wind loading at the Diablo Canyon ISFSI site (Table 3.2-1). The loads on the MPC confinement boundary due to the design-basis, 3.0-psi pressure differential are bounded by the 100-psi normal design internal pressure for the MPC described in Section 3.4.4.3.1.2 of the HI-STORM 100 System FSAR, as amended by LAR 1014-1. The HI-STORM 100SA overpack is a ventilated design that includes four air inlet ducts and four air outlet ducts at the bottom and top, respectively. Therefore, no tornado-induced pressure differential analysis was performed for the overpack.

The HI-STORM 100SA overpack is generically designed to withstand three types of tornado missiles in accordance with Section 3.5.1.4 of NUREG-0800.

Sections 3.4.8 and 3.4.8.1, as well as Appendices 3.C and Appendix 3.G of the HI-STORM 100 System FSAR, provide discussions of the generic design criteria and the effects of the large (automobile), intermediate (rigid cylinder) and small (sphere) tornado

missiles on the overpack. The Diablo Canyon ISFSI-specific intermediate missile (344.7-kg insulator string) is a more limiting design-basis missile for penetration and was evaluated for penetration after impacting the outer shell and the top lid of the overpack at design-basis velocity. The 8-inch-diameter steel cylinder was evaluated generically for global stresses induced after a strike on the top lid of the overpack. The Diablo Canyon ISFSI-specific small missile (1-inch-diameter steel rod) was evaluated for puncture and whether it will enter the overpack air ducts and impact the MPC at design-basis velocity.

The small missile, while less energetic than the intermediate missile, was analyzed specifically due to its unique ability to travel through one of the overpack air inlet ducts and directly impact the MPC pedestal. The evaluations of the effects of the large, intermediate, and small categories of missiles impacting the overpack are described below.

- The free-standing overpack is capable of withstanding the combination of tornado wind (or instantaneous pressure drop) and a large-missile-load impact with a conservative safety factor against overturning of greater than two. The anchored cask system, which provides additional resistance to overturning, is bounded by the free-standing overpack analysis. Local damage to the cask surface by a large-missile impact is bounded by the small and intermediate category missiles.

- Conservatively neglecting the concrete in the overpack, the 500-kV insulator string intermediate missile will penetrate the outer shell of the overpack, but will not penetrate the 1-1/4-inch inner shell of the overpack or result in loss of MPC retrievability. Using this conservative model, the minimum inner shell thickness required to withstand the missile impact is 0.619 inches.

- The 500-kV insulator string intermediate missile will not penetrate the 2-inch top lid of the overpack. The minimum required thickness to withstand the missile impact is 1.089 inches.

- The 8-inch steel cylinder intermediate missile will not cause an over-stress condition on the overpack lid. The factor of safety is 1.4 for this event. The factor of safety for the 500-kV insulator string for this event is 1.6.

- The 1-inch diameter steel rod (that is, small missile) is postulated to enter an overpack inlet duct and impact the pedestal shell. The analysis shows that the rod will pierce the shell and penetrate the concrete to a depth of 6.179 inches, which is significantly less than the radius of the pedestal shield. The damage to the concrete pedestal shield does not affect the confinement boundary or the ability of the MPC to remain standing on the pedestal, nor does it affect the retrievability of the MPC.

The effects of large and small missiles on the free-standing HI-STORM 100 overpack, which were determined in the generic evaluations, are applicable to and bounding for the anchored HI-STORM 100SA overpack to be deployed at the Diablo Canyon ISFSI. The Diablo Canyon ISFSI-specific intermediate missile has been evaluated for penetration and found to have

acceptable consequences. The effect of the intermediate missile impact on the overpack lid has been evaluated and found to have acceptable consequences.

8.2.2.3 Conclusions

The above discussion demonstrates that the HI-STORM 100SA overpack and the HI-TRAC transfer cask provide effective missile barriers for the MPC. No missile strike will cause instability of the overpack, compromise the integrity of the confinement boundary or jeopardize retrievability of the MPC. In addition, global stress intensities arising from the missile strikes satisfy ASME Code Level D limits for an ASME Section III Subsection NF structure. For the case where the transfer cask is being transported to the CTF in the horizontal position, the MPC top lid has been evaluated for an intermediate missile strike. The stress intensities from this missile strike satisfy the ASME Section III Subsection NB Level D limits. Therefore the requirements of 10 CFR 72.122(b) are met with regard to tornadoes.

The cask transporter has redundant drop protection by design (Section 3.3.3). Therefore, a loss of load due to a direct missile strike on the transporter is not credible. Since the CTF structure at DCPP is underground, it is not exposed to missile impacts (Section 3.3.4).

8.2.2.4 Accident Dose Calculations

Extreme winds in combination with tornado missiles are not capable of overturning a storage cask or of damaging an MPC within a storage cask resulting in a loss of shielding. Therefore, no radioactivity would be released due to tornado effects on the overpack in the event of a tornado. Dose rates at the controlled area boundary and onsite would not be affected by the minor damage to the transfer or storage cask from tornado-driven missile strikes.

8.2.3 FLOOD

A flood is classified as a natural phenomenon Design Event IV in accordance with ANSI/ANS 57.9.

8.2.3.1 Cause of Accident

The probable maximum flood is classified as a severe natural phenomenon. In general, floods are caused by extended periods of rainfall, tsunamis, storm surges, or structural failures, such as a dam break.

The Diablo Canyon ISFSI storage pads are located at an elevation of over 300 ft mean sea level (MSL). The Diablo Canyon ISFSI site surface hydrology is described in Section 2.4. It is concluded in Section 2.4 that there is no potential for flooding in the vicinity of the ISFSI storage pads. Therefore, flooding is not a consideration for ISFSI operations or on the capability of the dry storage cask system to safely store the spent fuel. Likewise, due to the

radiation doses to workers who remove debris blocking the inlet ducts are estimated to be double those conservatively estimated for the analysis of the partial inlet blockage in Section 8.1.4. The dose rate at this location is estimated to be 58 mrem/hour. The total exposure for two people taking 2 hours to perform these corrective actions is 0.232 man-rem.

8.2.16 TRANSMISSION TOWER COLLAPSE

Two 500-kV transmission towers are located in the vicinity of the ISFSI storage pads and CTF. This section addresses the impact of a fallen transmission tower on a loaded overpack. During transportation to the CTF and all handling and lifting activities at the CTF, a loaded transfer cask is protected from the impact of a falling transmission tower at all times by the structure of the cask transporter. Therefore, an analysis of the transfer cask for tower collapse impact loads is not required and has not been performed. A postulated transmission tower collapse at both the ISFSI storage site and CTF was analyzed to demonstrate that there is no loss of confinement from damage to an MPC during both transfer operations or while stored at the ISFSI pad in an overpack. The collapse of a transmission tower is classified as Design Event IV, as defined by ANSI/ANS-57.9.

8.2.16.1 Cause of Transmission Tower Collapse

The transmission tower collapse is postulated as a consequence of extreme wind speeds (above 84 mph) creating greater than design loads on the tower structure.

8.2.16.2 Analysis of the Transmission Tower Collapse

The location of the transmission towers with respect to the CTF and ISFSI storage pads is shown in Figure 2.1-2. A transmission tower is postulated to collapse by hinging of the legs and failure of braces without incident of leg or pile foundation pullout or lateral failure due to wind- or tornado-wind-generated loads. The transmission tower is a four-legged structure with a "T" shape at the top. Based on the location of the transmission corridor with respect to the CTF and the ISFSI storage pad and the conduct of loading operations, in the unlikely event of a collapse, a tower could impact the loaded overpack in different orientations at the CTF and the storage pad. At the CTF, the tower collapse is modeled with the pointed section of the "T" cross-bar impacting the MPC lid directly because the overpack may not have its top lid installed at the time of the event. At the ISFSI, the flat side of the "T" cross-bar impacts the overpack top lid.

A commercial computer code developed by the Livermore Software Technology Corporation and QA validated by Holtec International, LS-DYNA (Reference 26), was used to numerically model the problem and develop the impact forces of the tower structure on the target. LS-DYNA is a general purpose, explicit finite element program used to analyze the nonlinear dynamic response of two- and three-dimensional inelastic structures.

There are two towers that are close enough in proximity to the CTF and ISFSI storage site to impact a cask if a tower collapse were to occur. The applicable physical characteristics for the two transmission towers are:

(1) One tower has a height of approximately 125 ft, measured from the ground to the highest point. It is located, at its nearest foundation, approximately 100 ft west of the ISFSI pads and 60 ft south of the CTF. It has a total structural weight of approximately 25 kips.

(2) The other tower has a height of approximately 135 ft, measured from the ground to the highest point. It is located, at its nearest foundation, approximately 60 ft east of the ISFSI pads. It has a total structural weight of approximately 31 kips.

The analysis evaluates the impact forces generated by collapse of the second tower as the governing case since it is a taller and heavier tower.

8.2.16.2.1 Tower Collapse at the CTF

The LS-DYNA computer simulation of the tower collapse at the CTF models the pointed portion of the "T" bar impacting the MPC lid. The force of the tower impact on the MPC lid is 427 kips. This force is much smaller than the allowable impact force for the weld (2,789 kips) determined in the tornado-missile analysis, and thus will not cause a breach of the MPC confinement boundary. The maximum local stress of the MPC lid due to the impact is 14.6 ksi, which is smaller than the yield stress of the lid material (18.8 ksi). The potential for MPC-lid puncture due to this event is bounded by the intermediate-missile evaluation described in Section 8.2.2. The design-basis intermediate missile (a 760-lb insulator string traveling at 157 mph) is shown not to penetrate the 9-1/2-inch-thick MPC lid.

8.2.16.2.2 Tower Collapse at the ISFSI Storage Pad

The LS-DYNA computer simulation of the tower collapse at the ISFSI storage pad models the flat side of the "T" bar impacting the overpack top lid. The unfiltered impact force was computed to be 534 kips. To convert this to an equivalent g-load on the overpack, the 534 kips is divided by the weight of the loaded overpack:

$$534 / 360 = 1.48 \text{ g}$$

The overpack structure is designed to withstand a 45-g deceleration. Therefore, the impact of the force due to the transmission tower collapse is bounded with margin. The horizontal component of the impact force is less than 93 kips, which is bounded by the large tornado missile load of 122 kips described in Section 8.2.2. The overturning moments are also bounded for the effects on the anchorage to the ISFSI pad. MPC confinement boundary integrity related to tower impact discussed in Section 8.2.16.2.1 is applicable at the pad.

8.2.16.3 Dose Calculation for Transmission Tower Collapse

There are no offsite dose consequences as a result of this accident because the MPC confinement boundary remains intact. Potential damage to the overpack structure as a result of this event will vary based on the actual location and severity of the impact on the overpack. Based on the loads described above, no significant damage to the shielding effectiveness of the overpack is expected. If necessary, corrective actions will be implemented based on the nature of the damage in a time frame commensurate with safety significance.

8.2.17 NONSTRUCTURAL FAILURE OF A CTF LIFT JACK

This section addresses the nonstructural failure of one CTF lift jack on a loaded overpack requiring convective cooling. Three lift jacks are used simultaneously to raise and lower the CTF lifting platform on which the overpack rests. A postulated failure of one lift jack at the CTF was evaluated as a hypothetical accident. The nonstructural failure of a lift jack at the CTF is classified as Design Event IV, as defined by ANSI/ANS-57.9.

The lift jacks and platform are designed using the applicable guidelines of NUREG-0612 and seismically analyzed to ensure that structural failure is not a credible event. The CTF design criteria, facility description, and operations and maintenance activities are presented in Sections 3.3.4, 4.4.5, and 5.1, respectively.

8.2.17.1 Cause of Nonstructural Failure of a CTF Lift Jack

The nonstructural failure of a lift jack is postulated as a consequence of an electrical or mechanical malfunction of a lift jack component causing all lift jacks to stop.

8.2.17.2 Analysis of the Nonstructural Failure of a CTF Lift Jack

The CTF is designed to position an overpack sufficiently below grade where the transfer cask can be mated to the overpack using the cask transporter. In this position, the top approximately 3 ft of the overpack remains above grade while the base of the overpack is in a confined air space. The CTF lift platform, suspended by each jack screw, raises and lowers the overpack. Three lift jacks provide the lifting force for the lifting platform. The jacks are located on the circumference of the main shell in the extensions, 120 degrees apart. The jacks are supported at the top end and use a traveling-nut design. The captured nut travels along the rotating threaded jack screw shaft to provide the lifting and lowering motion for the lifting platform. All jacks operate in unison to keep the platform level through the entire travel range (approximately 150 inches).

The CTF lifting platform provides the support of the overpack and transmits the lifting jack force to the overpack. The platform provides a level base on which the overpack rests. To interface with the lifting jacks, the platform has extensions that enter into each main shell

U.S. NUCLEAR REGULATORY COMMISSION

Revision 1
February 1996

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 8.29

(Draft was issued as DG-8012)

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

A. INTRODUCTION

Section 19.12 of 10 CFR Part 19, "Notices, Instructions and Reports to Workers: Inspection and Investigations," requires that all individuals who in the course of their employment are likely to receive in a year an occupational dose in excess of 100 mrem (1 mSv) be instructed in the health protection issues associated with exposure to radioactive materials or radiation. Section 20.1206 of 10 CFR Part 20, "Standards for Protection Against Radiation," requires that before a planned special exposure occurs the individuals involved are, among other things, to be informed of the estimated doses and associated risks.

This regulatory guide describes the information that should be provided to workers by licensees about health risks from occupational exposure. This revision conforms to the revision of 10 CFR Part 20 that became effective on June 20, 1991, to be implemented by licensees no later than January 1, 1994. The revision of 10 CFR Part 20 establishes new dose limits based on the effective dose equivalent (EDE), requires the summing of internal and external dose, establishes a requirement that licensees use procedures and engineering controls to the extent practicable to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA), provides for planned special exposures, establishes a dose limit for the embryo/fetus of an occupationally exposed declared pregnant woman, and explicitly states that Part 20 is not to be construed as limiting action that may be necessary to protect health and safety during emergencies.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 19 or 10 CFR Part 20. These regulations provide the regulatory bases for this guide. The information collection requirements in 10 CFR Parts 19 and 20 have been cleared under OMB Clearance Nos. 3150-0044 and 3150-0014, respectively.

B. DISCUSSION

It is important to qualify the material presented in this guide with the following considerations.

The coefficient used in this guide for occupational radiation risk estimates, 4×10^{-4} health effects per rem, is based on data obtained at much higher doses and dose rates than those encountered by workers. The risk coefficient obtained at high doses and dose rates was reduced to account for the reduced effectiveness of lower doses and dose rates in producing the stochastic effects observed in studies of exposed humans.

The assumption of a linear extrapolation from the lowest doses at which effects are observable down to

the occupational range has considerable uncertainty. The report of the Committee on the Biological Effects of Ionizing Radiation (Ref. 1) states that

> "... departure from linearity cannot be excluded at low doses below the range of observation. Such departures could be in the direction of either an increased or decreased risk. Moreover, epidemiologic data cannot rigorously exclude the existence of a threshold in the 100 mrem dose range. Thus, the possibility that there may be no risk from exposures comparable to external natural background radiation cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero."

The issue of beneficial effects from low doses, or hormesis, in cellular systems is addressed by the United Nations Scientific Committee on the Effects of Atomic Radiation (Ref. 2). UNSCEAR states that "... it would be premature to conclude that cellular adaptive responses could convey possible beneficial effects to the organism that would outweigh the detrimental effects of exposures to low doses of low-LET radiation."

In the absence of scientific certainty regarding the relationship between low doses and health effects, and as a conservative assumption for radiation protection purposes, the scientific community generally assumes that any exposure to ionizing radiation can cause biological effects that may be harmful to the exposed person and that the magnitude or probability of these effects is directly proportional to the dose. These effects may be classified into three categories:

Somatic Effects: Physical effects occurring in the exposed person. These effects may be observable after a large or acute dose (e.g., 100 rems[1] (1 Sv) or more to the whole body in a few hours); or they may be effects such as cancer that may occur years after exposure to radiation.

Genetic Effects: Abnormalities that may occur in the future children of exposed individuals and in subsequent generations (genetic effects exceeding normal incidence have not been observed in any of the studies of human populations).

Teratogenic Effects: Effects such as cancer or congenital malformation that may be observed in children who were exposed during the fetal and embryonic stages of development (these effects have been observed from high, i.e., above 20 rems (0.2 Sv), acute exposures).

The normal incidence of effects from natural and manmade causes is significant. For example, approximately 20% of people die from various forms of cancer whether or not they ever receive occupational exposure to radiation. To avoid increasing the incidence of such biological effects, regulatory controls are imposed on occupational doses to adults and minors and on doses to the embryo/fetus from occupational exposures of declared pregnant women.

Radiation protection training for workers who are occupationally exposed to ionizing radiation is an essential component of any program designed to ensure compliance with NRC regulations. A clear understanding of what is presently known about the biological risks associated with exposure to radiation will result in more effective radiation protection training and should generate more interest on the part of the workers in complying with radiation protection standards. In addition, pregnant women and other occupationally exposed workers should have available to them relevant information on radiation risks to enable them to make informed decisions regarding the acceptance of these risks. It is intended that workers who receive this instruction will develop respect for the risks involved, rather than excessive fear or indifference.

C. REGULATORY POSITION

Instruction to workers performed in compliance with 10 CFR 19.12 should be given prior to occupational exposure and periodically thereafter. The frequency of retraining might range from annually for licensees with complex operations such as nuclear power plants, to every three years for licensees who possess, for example, only low-activity sealed sources. If a worker is to participate in a planned special exposure, the worker should be informed of the associated risks in compliance with 10 CFR 20.1206.

In providing instruction concerning health protection problems associated with exposure to radiation, all occupationally exposed workers and their supervisors should be given specific instruction on the risk of biological effects resulting from exposure to radiation. The extent of these instructions should be commensurate with the radiological risks present in the workplace.

The instruction should be presented orally, in printed form, or in any other effective communication media to workers and supervisors. The appendix to this guide provides useful information for demonstrating compliance with the training requirements in 10 CFR Parts 19 and 20. Individuals should be given an opportunity to discuss the information and to ask questions. Testing is recommended, and each trainee should be asked to acknowledge in writing that the instruction has been received and understood.

[1] In the International System of Units (SI), the rem is replaced by the sievert; 100 rems is equal to 1 sievert (Sv).

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes acceptable alternative methods for complying with specified portions of the Commission's regulations, the guidance and instructional materials in this guide will be used in the evaluation of applications for new licenses, license renewals, and license amendments and for evaluating compliance with 10 CFR 19.12 and 10 CFR Part 20.

REFERENCES

1. National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR V), National Academy Press, Washington, DC, 1990.

2. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation*, United Nations, New York, 1993.

APPENDIX

INSTRUCTION CONCERNING RISKS FROM OCCUPATIONAL RADIATION EXPOSURE

This instructional material is intended to provide the user with the best available information about the health risks from occupational exposure to ionizing radiation. Ionizing radiation consists of energy or small particles, such as gamma rays and beta and alpha particles, emitted from radioactive materials, which can cause chemical or physical damage when they deposit energy in living tissue. A question and answer format is used. Many of the questions or subjects were developed by the NRC staff in consultation with workers, union representatives, and licensee representatives experienced in radiation protection training.

This Revision 1 to Regulatory Guide 8.29 updates the material in the original guide on biological effects and risks and on typical occupational exposure. Additionally, it conforms to the revised 10 CFR Part 20, "Standards for Protection Against Radiation," which was required to be implemented by licensees no later than January 1, 1994. The information in this appendix is intended to help develop respect by workers for the risks associated with radiation, rather than unjustified fear or lack of concern. Additional guidance concerning other topics in radiation protection training is provided in other NRC regulatory guides.

1. What is meant by health risk?

A health risk is generally thought of as something that may endanger health. Scientists consider health risk to be the statistical probability or mathematical chance that personal injury, illness, or death may result from some action. Most people do not think about health risks in terms of mathematics. Instead, most of us consider the health risk of a particular action in terms of whether we believe that particular action will, or will not, cause us some harm. The intent of this appendix is to provide estimates of, and explain the bases for, the risk of injury, illness, or death from occupational radiation exposure. Risk can be quantified in terms of the probability of a health effect per unit of dose received.

When x-rays, gamma rays, and ionizing particles interact with living materials such as our bodies, they may deposit enough energy to cause biological damage. Radiation can cause several different types of events such as the very small physical displacement of molecules, changing a molecule to a different form, or ionization, which is the removal of electrons from atoms and molecules. When the quantity of radiation energy deposited in living tissue is high enough, biological damage can occur as a result of chemical bonds being broken and cells being damaged or killed. These effects can result in observable clinical symptoms.

The basic unit for measuring absorbed radiation is the rad. One rad (0.01 gray in the International System of units) equals the absorption of 100 ergs (a small but measurable amount of energy) in a gram of material such as tissue exposed to radiation. To reflect biological risk, rads must be converted to rems. The new international unit is the sievert (100 rems = 1 Sv). This conversion accounts for the differences in the effectiveness of different types of radiation in causing damage. The rem is used to estimate biological risk. For beta and gamma radiation, a rem is considered equal to a rad.

2. What are the possible health effects of exposure to radiation?

Health effects from exposure to radiation range from no effect at all to death, including diseases such as leukemia or bone, breast, and lung cancer. Very high (100s of rads), short-term doses of radiation have been known to cause prompt (or early) effects, such as vomiting and diarrhea,[1] skin burns, cataracts, and even death. It is suspected that radiation exposure may be linked to the potential for genetic effects in the children of exposed parents. Also, children who were exposed to high doses (20 or more rads) of radiation prior to birth (as an embryo/fetus) have shown an increased risk of mental retardation and other congenital malformations. These effects (with the exception of genetic effects) have been observed in various studies of medical radiologists, uranium miners, radium workers, radiotherapy patients, and the people exposed to radiation from atomic bombs dropped on Japan. In addition, radiation effects studies with laboratory animals, in which the animals were given relatively high doses, have provided extensive data on radiation-induced health effects, including genetic effects.

It is important to note that these kinds of health effects result from high doses, compared to occupational levels, delivered over a relatively short period of time.

Although studies have not shown a consistent cause-and-effect relationship between current levels of occupational radiation exposure and biological effects, it is prudent from a worker protection perspective to assume that some effects may occur.

[1]These symptoms are early indicators of what is referred to as the acute radiation syndrome, caused by high doses delivered over a short time period, which includes damage to the blood-forming organs such as bone marrow, damage to the gastrointestinal system, and, at very high doses, can include damage to the central nervous system.

3. What is meant by early effects and delayed or late effects?

EARLY EFFECTS

Early effects, which are also called immediate or prompt effects, are those that occur shortly after a large exposure that is delivered within hours to a few days. They are observable after receiving a very large dose in a short period of time, for example, 300 rads (3 Gy) received within a few minutes to a few days. Early effects are not caused at the levels of radiation exposure allowed under the NRC's occupational limits.

Early effects occur when the radiation dose is large enough to cause extensive biological damage to cells so that large numbers of cells are killed. For early effects to occur, this radiation dose must be received within a short time period. This type of dose is called an acute dose or acute exposure. The same dose received over a long time period would not cause the same effect. Our body's natural biological processes are constantly repairing damaged cells and replacing dead cells; if the cell damage is spread over time, our body is capable of repairing or replacing some of the damaged cells, reducing the observable adverse conditions.

For example, a dose to the whole body of about 300–500 rads (3–5 Gy), more than 60 times the annual occupational dose limit, if received within a short time period (e.g., a few hours) will cause vomiting and diarrhea within a few hours; loss of hair, fever, and weight loss within a few weeks; and about a 50 percent chance of death if medical treatment is not provided. These effects would not occur if the same dose were accumulated gradually over many weeks or months (Refs. 1 and 2). Thus, one of the justifications for establishing annual dose limits is to ensure that occupational dose is spread out in time.

It is important to distinguish between whole body and partial body exposure. A localized dose to a small volume of the body would not produce the same effect as a whole body dose of the same magnitude. For example, if only the hand were exposed, the effect would mainly be limited to the skin and underlying tissue of the hand. An acute dose of 400 to 600 rads (4–6 Gy) to the hand would cause skin reddening; recovery would occur over the following months and no long-term damage would be expected. An acute dose of this magnitude to the whole body could cause death within a short time without medical treatment. Medical treatment would lessen the magnitude of the effects and the chance of death; however, it would not totally eliminate the effects or the chance of death.

DELAYED EFFECTS

Delayed effects may occur years after exposure. These effects are caused indirectly when the radiation changes parts of the cells in the body, which causes the normal function of the cell to change, for example, normal healthy cells turn into cancer cells. The potential for these delayed health effects is one of the main concerns addressed when setting limits on occupational doses.

A delayed effect of special interest is genetic effects. Genetic effects may occur if there is radiation damage to the cells of the gonads (sperm or eggs). These effects may show up as genetic defects in the children of the exposed individual and succeeding generations. However, if any genetic effects (i.e., effects in addition to the normal expected number) have been caused by radiation, the numbers are too small to have been observed in human populations exposed to radiation. For example, the atomic bomb survivors (from Hiroshima and Nagasaki) have not shown any significant radiation-related increases in genetic defects (Ref. 3). Effects have been observed in animal studies conducted at very high levels of exposure and it is known that radiation can cause changes in the genes in cells of the human body. However, it is believed that by maintaining worker exposures below the NRC limits and consistent with ALARA, a margin of safety is provided such that the risk of genetic effects is almost eliminated.

4. What is the difference between acute and chronic radiation dose?

Acute radiation dose usually refers to a large dose of radiation received in a short period of time. Chronic dose refers to the sum of small doses received repeatedly over long time periods, for example, 20 mrem (or millirem, which is 1-thousandth of a rem) (0.2 mSv) per week every week for several years. It is assumed for radiation protection purposes that any radiation dose, either acute or chronic, may cause delayed effects. However, only large acute doses cause early effects; chronic doses within the occupational dose limits do not cause early effects. Since the NRC limits do not permit large acute doses, concern with occupational radiation risk is primarily focused on controlling chronic exposure for which possible delayed effects, such as cancer, are of concern.

The difference between acute and chronic radiation exposure can be shown by using exposure to the sun's rays as an example. An intense exposure to the sun can result in painful burning, peeling, and growing of new skin. However, repeated short exposures provide time for the skin to be repaired between exposures. Whether exposure to the sun's rays is long term or spread over short periods, some of the injury may not be repaired and may eventually result in skin cancer.

Cataracts are an interesting case because they can be caused by both acute and chronic radiation. A certain threshold level of dose to the lens of the eye is required before there is any observable visual impairment, and the impairment remains after the exposure is stopped. The threshold for cataract development

from acute exposure is an acute dose on the order of 100 rads (1 Gy). Further, a cumulative dose of 800 rads (8 Gy) from protracted exposures over many years to the lens of the eye has been linked to some level of visual impairment (Refs. 1 and 4). These doses exceed the amount that may be accumulated by the lens from normal occupational exposure under the current regulations.

5. What is meant by external and internal exposure?

A worker's occupational dose may be caused by exposure to radiation that originates outside the body, called "external exposure," or by exposure to radiation from radioactive material that has been taken into the body, called "internal exposure." Most NRC-licensed activities involve little, if any, internal exposure. It is the current scientific consensus that a rem of radiation dose has the same biological risk regardless of whether it is from an external or an internal source. The NRC requires that dose from external exposure and dose from internal exposure be added together, if each exceeds 10% of the annual limit, and that the total be within occupational limits. The sum of external and internal dose is called the total effective dose equivalent (TEDE) and is expressed in units of rems (Sv).

Although unlikely, radioactive materials may enter the body through breathing, eating, drinking, or open wounds, or they may be absorbed through the skin. The intake of radioactive materials by workers is generally due to breathing contaminated air. Radioactive materials may be present as fine dust or gases in the workplace atmosphere. The surfaces of equipment and workbenches may be contaminated, and these materials can be resuspended in air during work activities.

If any radioactive material enters the body, the material goes to various organs or is excreted, depending on the biochemistry of the material. Most radioisotopes are excreted from the body in a few days. For example, a fraction of any uranium taken into the body will deposit in the bones, where it remains for a longer time. Uranium is slowly eliminated from the body, mostly by way of the kidneys. Most workers are not exposed to uranium. Radioactive iodine is preferentially deposited in the thyroid gland, which is located in the neck.

To limit risk to specific organs and the total body, an annual limit on intake (ALI) has been established for each radionuclide. When more than one radionuclide is involved, the intake amount of each radionuclide is reduced proportionally. NRC regulations specify the concentrations of radioactive material in the air to which a worker may be exposed for 2,000 working hours in a year. These concentrations are termed the derived air concentrations (DACs). These limits are the total amounts allowed if no external radiation is received. The resulting dose from the internal radiation sources (from breathing air at 1 DAC) is the maximum allowed to an organ or to the worker's whole body.

6. How does radiation cause cancer?

The mechanisms of radiation-induced cancer are not completely understood. When radiation interacts with the cells of our bodies, a number of events can occur. The damaged cells can repair themselves and permanent damage is not caused. The cells can die, much like the large numbers of cells that die every day in our bodies, and be replaced through the normal biological processes. Or a change can occur in the cell's reproductive structure, the cells can mutate and subsequently be repaired without effect, or they can form precancerous cells, which may become cancerous. Radiation is only one of many agents with the potential for causing cancer, and cancer caused by radiation cannot be distinguished from cancer attributable to any other cause.

Radiobiologists have studied the relationship between large doses of radiation and cancer (Refs. 5 and 6). These studies indicate that damage or change to genes in the cell nucleus is the main cause of radiation-induced cancer. This damage may occur directly through the interaction of the ionizing radiation in the cell or indirectly through the actions of chemical products produced by radiation interactions within cells. Cells are able to repair most damage within hours; however, some cells may not be repaired properly. Such misrepaired damage is thought to be the origin of cancer, but misrepair does not always cause cancer. Some cell changes are benign or the cell may die; these changes do not lead to cancer.

Many factors such as age, general health, inherited traits, sex, as well as exposure to other cancer-causing agents such as cigarette smoke can affect susceptibility to the cancer-causing effects of radiation. Many diseases are caused by the interaction of several factors, and these interactions appear to increase the susceptibility to cancer.

7. Who developed radiation risk estimates?

Radiation risk estimates were developed by several national and international scientific organizations over the last 40 years. These organizations include the National Academy of Sciences (which has issued several reports from the Committee on the Biological Effects of Ionizing Radiations, BEIR), the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Each of these organizations continues to review new research findings on radiation health risks.

Several reports from these organizations present new findings on radiation risks based upon revised estimates of radiation dose to survivors of the atomic bombing at Hiroshima and Nagasaki. For example, UNSCEAR published risk estimates in 1988 and 1993 (Refs. 5 and 6). The NCRP also published a report in 1988, "New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates" (Ref. 7). In January 1990, the National Academy of Sciences released the fifth report of the BEIR Committee, "Health Effects of Exposure to Low Levels of Ionizing Radiation" (Ref. 4). Each of these publications also provides extensive bibliographies on other published studies concerning radiation health effects for those who may wish to read further on this subject.

8. What are the estimates of the risk of fatal cancer from radiation exposure?

We don't know exactly what the chances are of getting cancer from a low-level radiation dose, primarily because the few effects that may occur cannot be distinguished from normally occurring cancers. However, we can make estimates based on extrapolation from extensive knowledge from scientific research on high dose effects. The estimates of radiation effects at high doses are better known than are those of most chemical carcinogens (Ref. 8).

From currently available data, the NRC has adopted a risk value for an occupational dose of 1 rem (0.01 Sv) Total Effective Dose Equivalent (TEDE) of 4 in 10,000 of developing a fatal cancer, or approximately 1 chance in 2,500 of fatal cancer per rem of TEDE received. The uncertainty associated with this risk estimate does not rule out the possibility of higher risk, or the possibility that the risk may even be zero at low occupational doses and dose rates.

The radiation risk incurred by a worker depends on the amount of dose received. Under the linear model explained above, a worker who receives 5 rems (0.05 Sv) in a year incurs 10 times as much risk as another worker who receives only 0.5 rem (0.005 Sv). Only a very few workers receive doses near 5 rems (0.05 Sv) per year (Ref. 9).

According to the BEIR V report (Ref. 4), approximately one in five adults normally will die from cancer from all possible causes such as smoking, food, alcohol, drugs, air pollutants, natural background radiation, and inherited traits. Thus, in any group of 10,000 workers, we can estimate that about 2,000 (20%) will die from cancer without any occupational radiation exposure.

To explain the significance of these estimates, we will use as an example a group of 10,000 people, each exposed to 1 rem (0.01 Sv) of ionizing radiation. Using the risk factor of 4 effects per 10,000 rem of dose, we estimate that 4 of the 10,000 people might die from delayed cancer because of that 1-rem dose (although the actual number could be more or less than 4) in addition to the 2,000 normal cancer fatalities expected to occur in that group from all other causes. This means that a 1-rem (0.01 Sv) dose may increase an individual worker's chances of dying from cancer from 20 percent to 20.04 percent. If one's lifetime occupational dose is 10 rems, we could raise the estimate to 20.4 percent. A lifetime dose of 100 rems may increase chances of dying from cancer from 20 to 24 percent. The average measurable dose for radiation workers reported to the NRC was 0.31 rem (0.0031 Sv) for 1993 (Ref. 9). Today, very few workers ever accumulate 100 rems (1 Sv) in a working lifetime, and the average career dose of workers at NRC-licensed facilities is 1.5 rems (0.015 Sv), which represents an estimated increase from 20 to about 20.06 percent in the risk of dying from cancer.

It is important to understand the probability factors here. A similar question would be, "If you select one card from a full deck of cards, will you get the ace of spades?" This question cannot be answered with a simple yes or no. The best answer is that your chance is 1 in 52. However, if 1000 people each select one card from full decks, we can predict that about 20 of them will get an ace of spades. Each person will have 1 chance in 52 of drawing the ace of spades, but there is no way we can predict which persons will get that card. The issue is further complicated by the fact that in a drawing by 1000 people, we might get only 15 successes, and in another, perhaps 25 correct cards in 1000 draws. We can say that if you receive a radiation dose, you will have increased your chances of eventually developing cancer. It is assumed that the more radiation exposure you get, the more you increase your chances of cancer.

The normal chance of dying from cancer is about one in five for persons who have not received any occupational radiation dose. The additional chance of developing fatal cancer from an occupational exposure of 1 rem (0.01 Sv) is about the same as the chance of drawing any ace from a full deck of cards three times in a row. The additional chance of dying from cancer from an occupational exposure of 10 rem (0.1 Sv) is about equal to your chance of drawing two aces successively on the first two draws from a full deck of cards.

It is important to realize that these risk numbers are only estimates based on data for people and research animals exposed to high levels of radiation in short periods of time. There is still uncertainty with regard to estimates of radiation risk from low levels of exposure. Many difficulties are involved in designing research studies that can accurately measure the projected small increases in cancer cases that might be caused by low exposures to radiation as compared to the normal rate of cancer.

These estimates are considered by the NRC staff to be the best available for the worker to use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should try to keep exposure to radiation as low as is reasonably achievable (ALARA) to avoid unnecessary risk.

9. If I receive a radiation dose that is within occupational limits, will it cause me to get cancer?

Probably not. Based on the risk estimates previously discussed, the risk of cancer from doses below the occupational limits is believed to be small. Assessment of the cancer risks that may be associated with low doses of radiation are projected from data available at doses larger than 10 rems (0.1 Sv) (Ref. 3). For radiation protection purposes, these estimates are made using the straight line portion of the linear quadratic model (Curve 2 in Figure 1). We have data on cancer probabilities only for high doses, as shown by the solid line in Figure 1. Only in studies involving radiation doses above occupational limits are there dependable determinations of the risk of cancer, primarily because below the limits the effect is small compared to differences in the normal cancer incidence from year to year and place to place. The ICRP, NCRP, and other standards-setting organizations assume for radiation protection purposes that there is some risk, no matter how small the dose (Curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (Curve 3), the threshold effect. The ICRP and NCRP endorse the linear quadratic model as a conservative means of assuring safety (Curve 2).

For regulatory purposes, the NRC uses the straight line portion of Curve 2, which shows the number of effects decreasing linearly as the dose decreases. Because the scientific evidence does not conclusively demonstrate whether there is or is not an effect at low doses, the NRC assumes for radiation protection purposes, that even small doses have some chance of causing cancer. Thus, a principle of radiation protection is to do more than merely meet the allowed regulatory limits; doses should be kept as low as is reasonably achievable (ALARA). This is as true for natural carcinogens such as sunlight and natural radiation as it is for those that are manmade, such as cigarette smoke, smog, and x-rays.

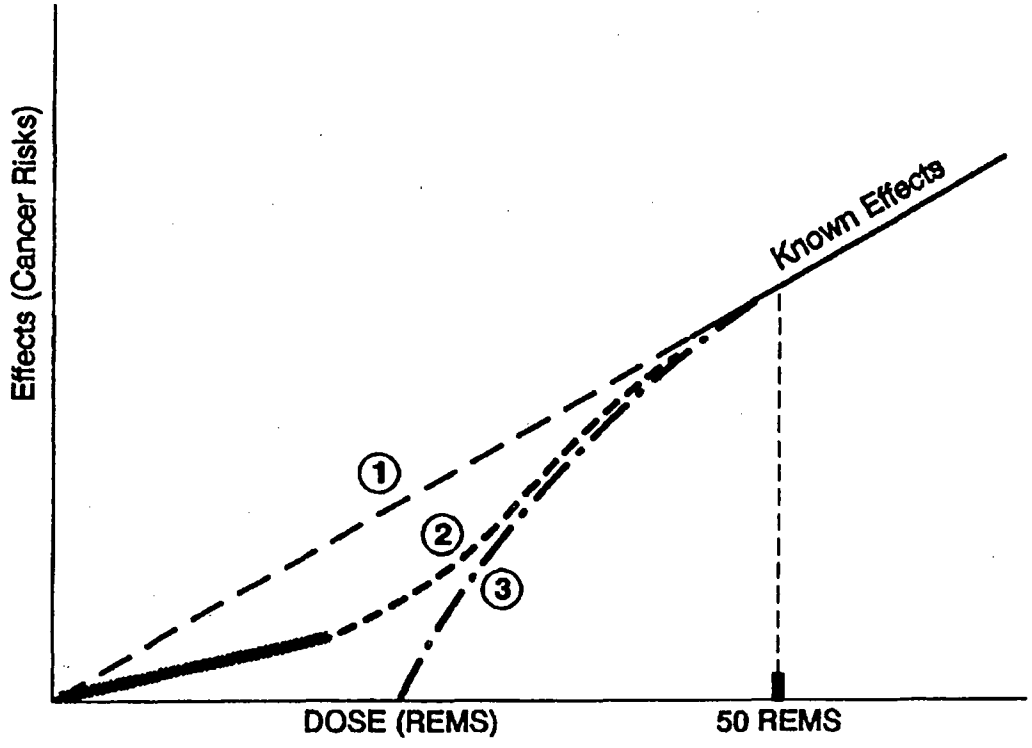


Figure 1. Some Proposed Models for How the Effects of Radiation Vary With Doses at Low Levels

10. How can we compare the risk of cancer from radiation to other kinds of health risks?

One way to make these comparisons is to compare the average number of days of life expectancy lost because of the effects associated with each particular health risk. Estimates are calculated by looking at a large number of persons, recording the age when death occurs from specific causes, and estimating the average number of days of life lost as a result of these early deaths. The total number of days of life lost is then averaged over the total observed group.

Several studies have compared the average days of life lost from exposure to radiation with the number of days lost as a result of being exposed to other health risks. The word "average" is important because an individual who gets cancer loses about 15 years of life expectancy, while his or her coworkers do not suffer any loss.

Some representative numbers are presented in Table 1. For categories of NRC-regulated industries with larger doses, the average measurable occupational dose in 1993 was 0.31 rem (0.0031 Sv). A simple calculation based on the article by Cohen and Lee (Ref. 10) shows that 0.3 rem (0.003 Sv) per year from age 18 to 65 results in an average loss of 15 days. These estimates indicate that the health risks from occupational radiation exposure are smaller than the risks associated with many other events or activities we encounter and accept in normal day-to-day activities.

It is also useful to compare the estimated average number of days of life lost from occupational exposure to radiation with the number of days lost as a result of working in several types of industries. Table 2 shows average days of life expectancy lost as a result of fatal work-related accidents. Table 2 does not include non-accident types of occupational risks such as occupational disease and stress because the data are not available.

These comparisons are not ideal because we are comparing the possible effects of chronic exposure to radiation to different kinds of risk such as accidental death, in which death is inevitable if the event occurs. This is the best we can do because good data are not available on chronic exposure to other workplace carcinogens. Also, the estimates of loss of life expectancy for workers from radiation-induced cancer do not take into consideration the competing effect on the life expectancy of the workers from industrial accidents.

11. What are the health risks from radiation exposure to the embryo/fetus?

During certain stages of development, the embryo/fetus is believed to be more sensitive to radiation damage than adults. Studies of atomic bomb survivors exposed to acute radiation doses exceeding 20 rads (0.2 Gy) during pregnancy show that children born after receiving these doses have a higher risk of mental retardation. Other studies suggest that an association exists between exposure to diagnostic x-rays before birth and carcinogenic effects in childhood and in adult life. Scientists are uncertain about the magnitude of the risk. Some studies show the embryo/fetus to be more sensitive to radiation-induced cancer than adults, but other studies do not. In recognition of the possibility of increased radiation sensitivity, and because dose to the

Table 1 Estimated Loss of Life Expectancy from Health Risks[a]

Health Risk	*Estimate of Life Expectancy Lost (average)*	
Smoking 20 cigarettes a day		6 years
Overweight (by 15%)		2 years
Alcohol consumption (U.S. average)		1 year
All accidents combined		1 year
Motor vehicle accidents	207 days	
Home accidents	74 days	
Drowning	24 days	
All natural hazards (earthquake, lightning, flood, etc.)		7 days
Medical radiation		6 days
Occupational Exposure		
0.3 rem/y from age 18 to 65	15 days	
1 rem/y from age 18 to 65	51 days	

[a]Adapted from Reference 10.

Table 2 Estimated Loss of Life Expectancy from Industrial Accidents[a]

Industry Type	*Estimated Days of Life Expectancy Lost (Average)*
All industries	60
Agriculture	320
Construction	227
Mining and Quarrying	167
Transportation and Public Utilities	160
Government	60
Manufacturing	40
Trade	27
Services	27

[a]Adapted from Reference 10.

embryo/fetus is involuntary on the part of the embryo/fetus, a more restrictive dose limit has been established for the embryo/fetus of a declared pregnant radiation worker. See Regulatory Guide 8.13, "Instruction Concerning Prenatal Radiation Exposure."

If an occupationally exposed woman declares her pregnancy in writing, she is subject to the more restrictive dose limits for the embryo/fetus during the remainder of the pregnancy. The dose limit of 500 mrems (5 mSv) for the total gestation period applies to the embryo/fetus and is controlled by restricting the exposure to the declared pregnant woman. Restricting the woman's occupational exposure, if she declares her pregnancy, raises questions about individual privacy rights, equal employment opportunities, and the possible loss of income. Because of these concerns, the declaration of pregnancy by a female radiation worker is voluntary. Also, the declaration of pregnancy can be withdrawn for any reason, for example, if the woman believes that her benefits from receiving the occupational exposure would outweigh the risk to her embryo/fetus from the radiation exposure.

12. Can a worker become sterile or impotent from normal occupational radiation exposure?

No. Temporary or permanent sterility cannot be caused by radiation at the levels allowed under NRC's occupational limits. There is a threshold below which these effects do not occur. Acute doses on the order of 10 rems (0.1 Sv) to the testes can result in a measurable but temporary reduction in sperm count. Temporary sterility (suppression of ovulation) has been observed in women who have received acute doses of 150 rads (1.5 Gy). The estimated threshold (acute) radiation dose for induction of permanent sterility is about 200 rads (2 Gy) for men and about 350 rads (3.5 Gy) for women (Refs. 1 and 4). These doses are far greater than the NRC s occupational dose limits for workers.

Although acute doses can affect fertility by reducing sperm count or suppressing ovulation, they do not have any direct effect on one's ability to function sexually. No evidence exists to suggest that exposures within the NRC's occupational limits have any effect on the ability to function sexually.

13. What are the NRC occupational dose limits?

For adults, an annual limit that does not exceed:

- 5 rems (0.05 Sv) for the total effective dose equivalent (TEDE), which is the sum of the deep dose equivalent (DDE) from external exposure to the whole body and the committed effective dose equivalent (CEDE) from intakes of radioactive material.
- 50 rems (0.5 Sv) for the total organ dose equivalent (TODE), which is the sum of the DDE from external exposure to the whole body and the committed dose equivalent (CDE) from intakes of radioactive material to any individual organ or tissue, other than the lens of the eye.
- 15 rems (0.15 Sv) for the lens dose equivalent (LDE), which is the external dose to the lens of the eye.
- 50 rems (0.5 Sv) for the shallow dose equivalent (SDE), which is the external dose to the skin or to any extremity.

For minor workers, the annual occupational dose limits are 10 percent of the dose limits for adult workers.

For protection of the embryo/fetus of a declared pregnant woman, the dose limit is 0.5 rem (5 mSv) during the entire pregnancy.

The occupational dose limit for adult workers of 5 rems (0.05 Sv) TEDE is based on consideration of the potential for delayed biological effects. The 5-rem (0.05 Sv) limit, together with application of the concept of keeping occupational doses ALARA, provides a level of risk of delayed effects considered acceptable by the NRC. The limits for individual organs are below the dose levels at which early biological effects are observed in the individual organs.

The dose limit for the embryo/fetus of a declared pregnant woman is based on a consideration of the possibility of greater sensitivity to radiation of the embryo/fetus and the involuntary nature of the exposure.

14. What is meant by ALARA?

ALARA means "as low as is reasonably achievable." In addition to providing an upper limit on an individual's permissible radiation dose, the NRC requires that its licensees establish radiation protection

programs and use procedures and engineering controls to achieve occupational doses, and doses to the public, as far below the limits as is reasonably achievable. "Reasonably achievable" also means "to the extent practicable." What is practicable depends on the purpose of the job, the state of technology, the costs for averting doses, and the benefits. Although implementation of the ALARA principle is a required integral part of each licensee's radiation protection program, it does not mean that each radiation exposure must be kept to an absolute minimum, but rather that "reasonable" efforts must be made to avert dose. In practice, ALARA includes planning tasks involving radiation exposure so as to reduce dose to individual workers and the work group.

There are several ways to control radiation doses, e.g., limiting the time in radiation areas, maintaining distance from sources of radiation, and providing shielding of radiation sources to reduce dose. The use of engineering controls, from the design of facilities and equipment to the actual set-up and conduct of work activities, is also an important element of the ALARA concept.

An ALARA analysis should be used in determining whether the use of respiratory protection is advisable. In evaluating whether or not to use respirators, the goal should be to achieve the optimal sum of external and internal doses. For example, the use of respirators can lead to increased work time within radiation areas, which increases external dose. The advantage of using respirators to reduce internal exposure must be evaluated against the increased external exposure and related stresses caused by the use of respirators. Heat stress, reduced visibility, and reduced communication associated with the use of respirators could expose a worker to far greater risks than are associated with the internal dose avoided by use of the respirator. To the extent practical, engineering controls, such as containments and ventilation systems, should be used to reduce workplace airborne radioactive materials.

15. What are background radiation exposures?

The average person is constantly exposed to ionizing radiation from several sources. Our environment and even the human body contain naturally occurring radioactive materials (e.g., potassium-40) that contribute to the radiation dose that we receive. The largest source of natural background radiation exposure is terrestrial radon, a colorless, odorless, chemically inert gas, which causes about 55 percent of our average, nonoccupational exposure. Cosmic radiation originating in space contributes additional exposure. The use of x-rays and radioactive materials in medicine and dentistry adds to our population exposure. As shown below in Table 3, the average person receives an annual radiation dose of about 0.36 rem (3.6 mSv). By age 20, the average person will accumulate over 7 rems (70 mSv) of dose. By age 50, the total dose is up to 18 rems (180 mSv). After 70 years of exposure this dose is up to 25 rems (250 mSv).

Table 3 Average Annual Effective Dose Equivalent to Individuals in the U.S.[a]

Source	*Effective Dose Equivalent (mrems)*	
Natural		
Radon	200	
Other than Radon	100	
Total		300
Nuclear Fuel Cycle		0.05
Consumer Products[b]		9
Medical		
Diagnostic X-rays	39	
Nuclear Medicine	14	
Total		53
Total		about 360 mrems/year

[a]Adapted from Table 8.1, NCRP 93 (Ref. 11).

[b]Includes building material, television receivers, luminous watches, smoke detectors, etc. (from Table 5.1, NCRP 93, Ref. 11).

16. What are the typical radiation doses received by workers?

For 1993, the NRC received reports on about a quarter of a million people who were monitored for occupational exposure to radiation. Almost half of those monitored had no measurable doses. The other half had an average dose of about 310 mrem (3.1 mSv) for the year. Of these, 93 percent received an annual dose of less than 1 rem (10 mSv); 98.7 percent received less than 2 rems (20 mSv); and the highest reported dose was for two individuals who each received between 5 and 6 rems (50 and 60 mSv).

Table 4 lists average occupational doses for workers (persons who had measurable doses) in various occupations based on 1993 data. It is important to note that beginning in 1994, licensees have been required to sum external and internal doses and certain licensees are required to submit annual reports. Certain types of licensees such as nuclear fuel fabricators may report a significant increase in worker doses because of the exposure to long-lived airborne radionuclides and the requirement to add the resultant internal dose to the calculation of occupational doses.

Table 4 Reported Occupational Doses for 1993[a]

Occupational Subgroup	Average Measurable Dose per Worker (millirems)
Industrial Radiography	540
Commercial Nuclear Power Reactors	310
Manufacturing and Distribution of Radioactive Materials	300
Low-Level Radioactive Waste Disposal	270
Independent Spent Nuclear Fuel Storage	260
Nuclear Fuel Fabrication	130

[a]From Table 3.1 in NUREG–0713 (Ref. 9).

17. How do I know how much my occupational dose (exposure) is?

If you are likely to receive more than 10 percent of the annual dose limits, the NRC requires your employer, the NRC licensee, to monitor your dose, to maintain records of your dose, and, at least on an annual basis for the types of licensees listed in 10 CFR 20.2206, "Reports of Individual Monitoring," to inform both you and the NRC of your dose. The purpose of this monitoring and reporting is so that the NRC can be sure that licensees are complying with the occupational dose limits and the ALARA principle.

External exposures are monitored by using individual monitoring devices. These devices are required to be used if it appears likely that external exposure will exceed 10 percent of the allowed annual dose, i.e., 0.5 rem (5 mSv). The most commonly used monitoring devices are film badges, thermoluminescence dosimeters (TLDs), electronic dosimeters, and direct reading pocket dosimeters.

With respect to internal exposure, your employer is required to monitor your occupational intake of radioactive material and assess the resulting dose if it appears likely that you will receive greater than 10 percent of the annual limit on intake (ALI) from intakes in 1 year. Internal exposure can be estimated by measuring the radiation emitted from the body (for example, with a "whole body counter") or by measuring the radioactive materials contained in biological samples such as urine or feces. Dose estimates can also be made if one knows how much radioactive material was in the air and the length of time during which the air was breathed.

18. What happens if a worker exceeds the annual dose limit?

If a worker receives a dose in excess of any of the annual dose limits, the regulations prohibit any occupational exposure during the remainder of the year in which the limit is exceeded. The licensee is also required to file an overexposure report with the NRC and provide a copy to the individual who received the dose. The licensee may be subject to NRC enforcement action such as a fine (civil penalty), just as individuals are subject to a traffic fine for exceeding a speed limit. The fines and, in some serious or repetitive cases, suspension of a license are intended to encourage licensees to comply with the regulations.

Radiation protection limits do not define safe or unsafe levels of radiation exposure. Exceeding a limit does not mean that you will get cancer. For radiation protection purposes, it is assumed that risks are related to the size of the radiation dose. Therefore, when your dose is higher your risk is also considered to be higher. These limits are similar to highway speed limits. If you drive at 70 mph, your risk is higher than at 55 mph, even though you may not actually have an accident. Those who set speed limits have determined that the risks of driving in excess of the speed limit are not acceptable. In the same way, the revised 10 CFR Part 20 establishes a limit for normal occupational exposure of 5 rems (0.05 Sv) a year. Although you will not necessarily get cancer or some other radiation effect at doses above the limit, it does mean that the licensee's safety program has failed in some way. Investigation is warranted to determine the cause and correct the conditions leading to the dose in excess of the limit.

19. What is meant by a "planned special exposure"?

A "planned special exposure" (PSE) is an infrequent exposure to radiation, separate from and in addition to the radiation received under the annual occupational limits. The licensee can authorize additional dose in any one year that is equal to the annual occupational dose limit as long as the individual's total dose from PSEs does not exceed five times the annual dose limit during the individual's lifetime. For example, licensees may authorize PSEs for an adult radiation worker to receive doses up to an additional 5 rems (0.05 Sv) in a year above the 5-rem (0.05–Sv) annual TEDE occupational dose limit. Each worker is limited to no more than 25 rems (0.25 Sv) from planned special exposures in his or her lifetime. Such exposures are only allowed in exceptional situations when alternatives for avoiding the additional exposure are not available or are impractical.

Before the licensee authorizes a PSE, the licensee must ensure that the worker is informed of the purpose and circumstances of the planned operation, the estimated doses expected, and the procedures to keep the doses ALARA while considering other risks that may

be present. (See Regulatory Guide 8.35, "Planned Special Exposures.")

20. Why do some facilities establish administrative control levels that are below the NRC limits?

There are two reasons. First, the NRC regulations state that licensees must take steps to keep exposures to radiation ALARA. Specific approval from the licensee for workers to receive doses in excess of administrative limits usually results in more critical risk-benefit analyses as each additional increment of dose is approved for a worker. Secondly, an administrative control level that is set lower than the NRC limit provides a safety margin designed to help the licensee avoid doses to workers in excess of the limit.

21. Why aren't medical exposures considered as part of a worker's allowed dose?

NRC rules exempt medical exposure, but equal doses of medical and occupational radiation have equal risks. Medical exposure to radiation is justified for reasons that are quite different from the reasons for occupational exposure. A physician prescribing an x-ray, for example, makes a medical judgment that the benefit to the patient from the resulting medical information justifies the risk associated with the radiation. This judgment may or may not be accepted by the patient. Similarly, each worker must decide on the benefits and acceptability of occupational radiation risk, just as each worker must decide on the acceptability of any other occupational hazard.

Consider a worker who receives a dose of 3 rems (0.03 Sv) from a series of x-rays in connection with an injury or illness. This dose and any associated risk must be justified on medical grounds. If the worker had also received 2 rems (0.02 Sv) on the job, the combined dose of 5 rems (0.05 Sv) would in no way incapacitate the worker. Restricting the worker from additional job exposure during the remainder of the year would not have any effect on the risk from the 3 rems (0.03 Sv) already received from the medical exposure. If the individual worker accepts the risks associated with the x-rays on the basis of the medical benefits and accepts the risks associated with job-related exposure on the basis of employment benefits, it would be unreasonable to restrict the worker from employment involving exposure to radiation for the remainder of the year.

22. How should radiation risks be considered in an emergency?

Emergencies are "unplanned" events in which actions to save lives or property may warrant additional doses for which no particular limit applies. The revised 10 CFR Part 20 does not set any dose limits for emergency or lifesaving activities and states that nothing in Part 20 "shall be construed as limiting actions that may be necessary to protect health and safety."

Rare situations may occur in which a dose in excess of occupational limits would be unavoidable in order to carry out a lifesaving operation or to avoid a large dose to large populations. However, persons called upon to undertake any emergency operation should do so only on a voluntary basis and with full awareness of the risks involved.

For perspective, the Environmental Protection Agency (EPA) has published emergency dose guidelines (Ref. 2). These guidelines state that doses to all workers during emergencies should, to the extent practicable, be limited to 5 rems (0.05 Sv). The EPA further states that there are some emergency situations for which higher limits may be justified. The dose resulting from such emergency exposures should be limited to 10 rems (0.1 Sv) for protecting valuable property, and to 25 rems (0.25 Sv) for lifesaving activities and the protection of large populations. In the context of this guidance, the dose to workers that is incurred for the protection of large populations might be considered justified for situations in which the collective dose to others that is avoided as a result of the emergency operation is significantly larger than that incurred by the workers involved.

Table 5 presents the estimates of the fatal cancer risk for a group of 1,000 workers of various ages, assuming that each worker received an acute dose of 25 rems (0.25 Sv) in the course of assisting in an emergency. The estimates show that a 25-rem emergency dose might increase an individual's chances of developing fatal cancer from about 20% to about 21%.

Table 5
Risk of Premature Death from Exposure to 25-Rems (0.25-Sv) Acute Dose

Age at Exposure (years)	*Estimated Risk of Premature Death (Deaths per 1,000 Persons Exposed)*
20–30	9.1
30–40	7.2
40–50	5.3
50–60	3.5

Source: EPA-400-R-92-001 (Ref. 2).

23. How were radiation dose limits established?

The NRC radiation dose limits in 10 CFR Part 20 were established by the NRC based on the recommendations of the ICRP and NCRP as endorsed in Federal radiation protection guidance developed by the EPA

(Ref. 12). The limits were recommended by the ICRP and NCRP with the objective of ensuring that working in a radiation-related industry was as safe as working in other comparable industries. The dose limits and the principle of ALARA should ensure that risks to workers are maintained indistinguishable from risks from background radiation.

24. Several scientific reports have recommended that the NRC establish lower dose limits. Does the NRC plan to reduce the regulatory limits?

Since publication of the NRC's proposed rule in 1986, the ICRP in 1990 revised its recommendations for radiation protection based on newer studies of radiation risks (Ref. 13), and the NCRP followed with a revision to its recommendations in 1993. The ICRP recommended a limit of 10 rems (0.1 Sv) effective dose equivalent (from internal and external sources), over a 5-year period with no more than 5 rems (0.05 Sv) in 1 year (Ref. 13). The NCRP recommended a cumulative limit in rems, not to exceed the individual's age in years, with no more than 5 rems (0.05 Sv) in any year (Ref. 14).

The NRC does not believe that additional reductions in the dose limits are required at this time. Because of the practice of maintaining radiation exposures ALARA (as low as is reasonably achievable), the average radiation dose to occupationally exposed persons is well below the limits in the current Part 20 that became mandatory January 1, 1994, and the average doses to radiation workers are below the new limits recommended by the ICRP and the NCRP.

25. What are the options if a worker decides that the risks associated with occupational radiation exposure are too high?

If the risks from exposure to occupational radiation are unacceptable to a worker, he or she can request a transfer to a job that does not involve exposure to radiation. However, the risks associated with the exposure to radiation that workers, on the average, actually receive are comparable to risks in other industries and are considered acceptable by the scientific groups that have studied them. An employer is not obligated to guarantee a transfer if a worker decides not to accept an assignment that requires exposure to radiation.

Any worker has the option of seeking other employment in a nonradiation occupation. However, the studies that have compared occupational risks in the nuclear industry to those in other job areas indicate that nuclear work is relatively safe. Thus, a worker may find different kinds of risk but will not necessarily find significantly lower risks in another job.

26. Where can one get additional information on radiation risk?

The following list suggests sources of useful information on radiation risk:

- The employer—the radiation protection or health physics office where a worker is employed.
- Nuclear Regulatory Commission Regional Offices:

King of Prussia, Pennsylvania	(610) 337-5000
Atlanta, Georgia	(404) 331-4503
Lisle, Illinois	(708) 829-9500
Arlington, Texas	(817) 860-8100

- U.S. Nuclear Regulatory Commission
  Headquarters
  Radiation Protection & Health Effects Branch
  Office of Nuclear Regulatory Research
  Washington, DC 20555
  Telephone: (301) 415-6187
- Department of Health and Human Services
  Center for Devices and Radiological Health
  1390 Piccard Drive, MS HFZ-1
  Rockville, MD 20850
  Telephone: (301) 443-4690
- U.S. Environmental Protection Agency
  Office of Radiation and Indoor Air
  Criteria and Standards Division
  401 M Street NW.
  Washington, DC 20460
  Telephone: (202) 233-9290

REFERENCES

1. B.R. Scott et al., "Health Effects Model for Nuclear Power Plant Accident Consequence Analysis," Part I: *Introduction, Integration, and Summary*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Revision 2, Part I, October 1993.*

2. U.S. Environmental Protection Agency, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA-400-R-92-001, May 1992.

3. International Commission on Radiological Protection, *Annals of the ICRP, Risks Associated with Ionising Radiation*, Volume 22, No.1, Pergamon Press, Oxford, UK, 1991.

4. National Research Council, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, Report of the Committee on the Biological Effects of Ionizing Radiation (BEIR V), National Academy Press, Washington, DC, 1990.

5. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources, Effects and Risks of Ionizing Radiation*, Report E.88.IX.7, United Nations, New York, 1988.

6. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation*, United Nations, New York, 1993.

7. National Council on Radiation Protection and Measurements, *New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates*, Proceedings of the Twenty-third Annual Meeting of the National Council on Radiation Protection and Measurements Held on April 8-9, 1987 (1988).

8. National Council on Radiation Protection and Measurements, *Comparative Carcinogenicity of Ionizing Radiation and Chemicals*, NCRP Report No. 96, March 1989.

9. C.T. Raddatz and D. Hagemeyer, "Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 1993," U.S. Nuclear Regulatory Commission, NUREG-0713, Volume 15, January 1995.*

10. B.L. Cohen and I.S. Lee, "Catalog of Risks Extended and Updated," *Health Physics*, Vol. 61, September 1991.

11. National Council on Radiation Protection and Measurements, *Ionizing Radiation Exposure of the Population of the United States*, NCRP Report No. 93, September 1987.

12. U.S. Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register*, Vol. 52, No. 17, January 27, 1987.

13. International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 60, Pergamon Press, Oxford, UK, 1991.

14. National Council on Radiation Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, NCRP Report No. 116, March 1993.

*Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202) 634-3273; fax (202) 634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202) 512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

BIBLIOGRAPHY

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev. 1, Part II, May 1989.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Recent Reports on Health Effects of Ionizing Radiation, Low LET Radiation," Part II: *Scientific Basis for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 1, August 1991.[1]

Abrahamson, S., *et al.*, "Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Modifications of Models Resulting From Addition of Effects of Exposure to Alpha-Emitting Radionuclides," Part II: *Scientific Bases for Health Effects Models*, U.S. Nuclear Regulatory Commission, NUREG/CR-4214, Rev.1, Part II, Addendum 2, May 1993.[1]

International Commission on Radiological Protection, *Radiation Protection*, Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Pergamon Press, Oxford, UK, January 1977.

National Council on Radiation Protection and Measurements, *Public Radiation Exposure From Nuclear Power Generation in the United States*, NCRP Report No. 92, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the Population in the United States and Canada from Natural Background Radiation*, NCRP Report No. 94, December 1987.

National Council on Radiation Protection and Measurements, *Exposure of the U.S. Population From Occupational Radiation*, NCRP Report No. 101, June 1989.

National Council on Radiation Protection and Measurements, *Risk Estimates for Radiation Protection*, NCRP Report No. 115, December 1993.

National Council on Radiation Protection and Measurements, *Limitation of Exposure to Ionizing Radiation*, NCRP Report No. 116, March 1993.

National Safety Council, *Accident Facts, 1993 Edition*, Itasca, Illinois, 1993.

U.S. Environmental Protection Agency, "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register*, Vol. 52, No. 17, January 27, 1987.

U.S. Nuclear Regulatory Commission, "Instruction Concerning Prenatal Radiation Exposure," Regulatory Guide 8.13, Revision 2, December 1987.[2]

U.S. Nuclear Regulatory Commission, "Monitoring Criteria and Methods To Calculate Occupational Radiation Doses," Regulatory Guide 8.34, July 1992.[2]

U.S. Nuclear Regulatory Commission, "Planned Special Exposures," Regulatory Guide 8.35, June 1992.[2]

U.S. Nuclear Regulatory Commission, "Radiation Dose to the Embryo/Fetus," Regulatory Guide 8.36, July 1992.[2]

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202) 512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

[2]Single copies of regulatory guides may be obtained free of charge by writing the Office of Administration, Attn: Distribution and Services Section, USNRC, Washington, DC 20555, or by fax at (301) 415-2260. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555-0001; telephone (202) 634-3273; fax (202) 634-3343.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this Revision 1 to Regulatory Guide 8.29. A value/impact statement, which evaluated essentially the same subjects as are discussed in a regulatory analysis, accompanied Regulatory Guide 8.29 when it was issued in July 1981.

This Revision 1 to Regulatory Guide 8.29 is needed to conform with the Revised 10 CFR Part 20, "Standards for Protection Against Radiation," as published May 21, 1991 (56 FR 23360). The regulatory analysis prepared for 10 CFR Part 20 provides the regulatory basis for this Revision 1 of Regulatory Guide 8.29, and it examines the costs and benefits of the rule as implemented by the guide. A copy of the "Regulatory Analysis for the Revision of 10 CFR Part 20" (PNL-6712, November 1988), is available for inspection and copying for a fee in the NRC's Public Document Room at 2120 L Street NW., Washington, DC 20555-0001.

400R92001

MANUAL OF PROTECTIVE ACTION GUIDES

AND

PROTECTIVE ACTIONS

FOR NUCLEAR INCIDENTS

Office of Radiation Programs
United States Environmental Protection Agency
Washington, DC 20460

Revised 1991

Second printing, May 1992

FOREWORD

Public officials are charged with the responsibility to protect the health of the public during hazardous incidents. The purpose of this manual is to assist these officials in establishing emergency response plans and in making decisions during a nuclear incident. It provides radiological protection guidance that may be used for responding to any type of nuclear incident or radiological emergency, except nuclear war.

Under regulations governing radiological emergency planning and preparedness issued by the Federal Emergency Management Agency (47 FR 10758, March 11, 1982), the Environmental Protection Agency's responsibilities include, among others, (1) establishing Protective Action Guides (PAGs), (2) preparing guidance on implementing PAGs, including recommendations on protective actions, (3) developing and promulgating guidance to State and local governments on the preparation of emergency response plans, and (4) developing, implementing, and presenting training programs for State and local officials on PAGs and protective actions, radiation dose assessment, and decision making. This document is intended to respond to the first two responsibilities.

The manual begins with a general discussion of Protective Action Guides (PAGs) and their use in planning for protective actions to safeguard public health. It then presents PAGs for specific exposure pathways and associated time periods. These PAGs apply to all types of nuclear incidents. This is followed by guidance for the implementation of PAGs. Finally, appendices provide definitions, background information on health risks, and other information supporting the choice of the numerical values of the PAGs.

PAGs for protection from an airborne plume during the early phase of an incident at a nuclear power plant were published in the 1980 edition of this manual. These have now been revised to apply to a much broader range of situations and replace the PAGs formerly published in Chapters 2 and 5. Recommendations and background information for protection from ingestion of contaminated food were published by the Food and Drug Administration in 1982. These are reprinted here as Chapter 3 and Appendix D. Recommendations for PAGs for relocation are presented in Chapters 4 and 7. Additional radiation protection guidance for recovery will be developed at a later date. We are continuing work to develop PAGs for drinking water and, in cooperation with FDA, revised PAGs for food. When experience has been gained in the application of these PAGs, they will be reexamined and refined as necessary, proposed for review, and then recommended to the President as Federal radiation protection guidance.

This manual is being re-published to consolidate existing recommendations in a single volume. As revised and additional recommendations are developed, they will be issued as revisions to this manual. These revised PAGs are appropriate for incorporation into emergency response plans when they are revised or when new plans are developed. However, it is important to recognize that regulatory requirements for emergency response are not provided by this manual; they are established by the cognizant agency (e.g., the Nuclear Regulatory Commission in the case of commercial nuclear reactors, or the Department of Energy in the case of their contractor-operated nuclear facilities).

Users of this manual are encouraged to provide comments and suggestions for improving its contents. Comments should be sent to Allan C. B. Richardson, Criteria and Standards Division (ANR-460), Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC 20460.

Margo T. Oge
Director, Office of
Radiation Programs

Washington, D.C.

CONTENTS

Page

TABLES

FIGURES

APPENDICES

CHAPTER 1

Overview

1.0 Introduction

Public officials, in discharging their responsibility to protect the health of the public during hazardous situations, will usually be faced with decisions that must be made in a short period of time. A number of factors influencing the choice of protective actions will exist, so that the decisions may be complex. Further, all of the information needed to make the optimum choice will usually not be immediately available. In such situations, it will therefore be helpful if the complexity of the information upon which needed decisions are based can be reduced by careful planning during the formulation of emergency response plans.

The U.S. Environmental Protection Agency has developed this manual to assist public officials in planning for emergency response to nuclear incidents. In the context of this manual, a nuclear incident is defined as an event or a series of events, either deliberate or accidental, leading to the release, or potential release, into the environment of radioactive materials in sufficient quantity to warrant consideration of protective actions. (The term "incident" includes accidents, in the context of this manual.) A radiological emergency may result from an incident at a variety of types of facilities, including, but not limited to, those that are part of the nuclear fuel cycle, defense and research facilities, and facilities that produce or use radioisotopes, or from an incident connected with the transportation or use of radioactive materials at locations not classified as "facilities". This manual provides radiological protection criteria intended for application to all nuclear incidents requiring consideration of protective actions, other than nuclear war. It is designed for the use of those in Federal, State, and local government with responsibility for emergency response planning. The manual also provides guidance for implementation of the criteria. This has been developed primarily for incidents at nuclear power facilities. Although this implementation guidance is intended to be useful for application at other facilities or uses of radioactivity, emergency response plans will require the development of additional implementation procedures when physical characteristics of the radionuclides involved are different from those considered here.

The decision to advise members of the public to take an action to protect themselves from radiation from a nuclear incident involves a complex judgment in which the risk avoided by the protective action must be weighed in the context of the risks involved in taking the action. Furthermore, the

decision may have to be made under emergency conditions, with little or no detailed information available. Therefore, considerable planning is necessary to reduce to a manageable level the complexity of decisions required to effectively protect the public at the time of an incident.

An objective of emergency planning is to simplify the choice of possible responses so that judgments are required only for viable and useful alternatives when an emergency occurs. During the planning process it is possible to make some value judgments and to determine which responses are not required, which decisions can be made on the basis of prior judgments, and which judgments must be made during an actual emergency. From this exercise, it is then possible to devise operational plans which can be used to respond to the spectrum of hazardous situations which may develop.

The main contribution to the protection of the public from abnormal releases of radioactive material is provided by site selection, design, quality assurance in construction, engineered safety systems, and the competence of staff in safe operation and maintenance. These measures can reduce both the probability and the magnitude of potential consequences of an accident. Despite these measures, the occurrence of nuclear incidents cannot be excluded. Accordingly, emergency response planning to mitigate the consequences of an incident is a necessary supplementary level of protection.

During a nuclear incident, when the source of exposure of the public is not under control, the public usually can be protected only by some form of intervention which will disrupt normal living. Such intervention is termed protective action. 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 objective of this manual is to provide such PAGs for the principal protective actions available to public officials during a nuclear incident, and to provide guidance for their use.

1.1 Nuclear Incident Phases and Protective Actions

It is convenient to identify three time phases which are generally accepted as being common to all nuclear incident sequences; within each, different considerations apply to most protective actions. These are termed the early, intermediate, and late phases. Although these phases cannot be represented by precise periods and may overlap, they provide a useful framework for the considerations involved in emergency response planning.

The early phase (also referred to as the emergency phase) is the period at the beginning of a nuclear incident when immediate decisions for effective use of protective actions are required and must therefore usually be based primarily on the status of the nuclear

facility (or other incident site) and the prognosis for worsening conditions. When available, predictions of radiological conditions in the environment based on the condition of the source or actual environmental measurements may also be used. Protective actions based on the PAGs may be preceded by precautionary actions during this period. This phase may last from hours to days.

The intermediate phase is the period beginning after the source and releases have been brought under control and reliable environmental measurements are available for use as 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 phase and may last from weeks to many months.

The late phase (also referred to as the recovery phase) is the period beginning when recovery action designed to reduce radiation levels in the environment to acceptable levels for unrestricted use are commenced, and ending 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 1-1. Evacuation and sheltering (supplemented by bathing and changes of clothing), are the principal protective actions for use during the early phase to protect the public from exposure to direct radiation and inhalation from an airborne plume. It may also be appropriate to initiate protective action for the milk supply during this period, and, in cases where emergency response plans include procedures for issuing stable iodine to reduce thyroid dose (FE-85), this may be an appropriate protective action for the early phase.

Some protective actions are not addressed by assignment of a PAG. For example, the control of access to areas is a protective action whose introduction is coupled to a decision to implement one of the other early or intermediate phase protective actions and does not have a separate PAG. And, although the use of simple, ad hoc respiratory protection may be applicable for supplementary protection in some circumstances, this protective action is primarily for use by emergency workers.

There are two types of protective actions during the intermediate phase. First, relocation and decontamination are the principal protective actions for protection of the public from whole body external exposure due to deposited material and from inhalation of any resuspended radioactive particulate materials during the intermediate and late phases. It is assumed that decisions will be made during the intermediate phase concerning whether areas from which the public has been relocated will be decontaminated and reoccupied, or condemned and the occupants permanently relocated. The second major type of protective action during the intermediate phase encompasses

TABLE 1-1. EXPOSURE PATHWAYS, INCIDENT PHASES, AND PROTECTIVE ACTIONS.

POTENTIAL EXPOSURE PATHWAYS AND INCIDENT PHASES		PROTECTIVE ACTIONS
1. External radiation from facility	*Early*	Sheltering Evacuation Control of access
2. External radiation from plume		Sheltering Evacuation Control of access
3. Inhalation of activity in plume		Sheltering Administration of stable iodine Evacuation Control of access
4. Contamination of skin and clothes	*Intermediate*	Sheltering Evacuation Decontamination of persons
5. External radiation from ground deposition of activity		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.

restrictions on the use of contaminated food and water. This protective action, in particular, may overlap the early and late phases.

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 based on the relocation PAGs, while others may be converted to relocation status.

1.2 Basis for Selecting Protective Action Guides

The PAGs in this manual incorporate the concepts and guidance contained in Federal Radiation Council (FRC) Reports 5 and 7 (FR-64 and FR-65). One of these is that the decision to implement protective actions should be based on the projected dose that would be received if the protective actions were not implemented. However, since these reports were issued, considerable additional guidance has been developed on the subject of emergency response (IC-84, IA-89). EPA considered the following four principles in establishing values for the PAGs:

1. Acute effects on health (those that would be observable within a short period of time and which have a dose threshold below which such effects are not likely to occur) should be avoided.

2. The risk of delayed effects on health (primarily cancer and genetic effects for which linear nonthreshold relationships to dose are assumed) should not exceed upper bounds that are judged to be adequately protective of public health under emergency conditions, and are reasonably achievable.

3. PAGs should not be higher than justified on the basis of optimization of cost and the collective risk of effects on health. That is, any reduction of risk to public health achievable at acceptable cost should be carried out.

4. Regardless of the above principles, the risk to health from a protective action should not itself exceed the risk to health from the dose that would be avoided.

The above principles apply to the selection of any PAG. Principles 1, 3, and 4 have been proposed for use by the international community as essential bases for decisions to intervene during an incident and Principle 2 has been recognized as an appropriate additional consideration (IA-89). Appendices C and E apply these principles to the choice of PAGs for evacuation and relocation. Although in establishing the PAGs it is prudent to consider a range of source terms to assess the costs associated with their implementation, the PAGs

are chosen so as to be independent of the magnitude or type of release.

1.3 Planning

The planning elements for developing radiological emergency response plans for nuclear incidents at commercial nuclear power facilities are provided in a separate document, NUREG-0654 (NR-80), which references the PAGs in this Manual as the basis for emergency response. Planning elements for other types of nuclear incidents should be developed using similar types of considerations.

Similarly, guidance for nuclear power facilities on time frames for response, the types of releases to be considered, emergency planning zones (EPZ), and the potential effectiveness of various protective actions is provided in NUREG-0396 (NR-78). The size and shape of the recommended EPZs were only partially based on consideration of the numerical values of the PAGs. A principle additional basis was that the planning zone for evacuation and sheltering should be large enough to accommodate any urban and rural areas affected and involve the various organizations needed for emergency response. This consideration is appropriate for any facility requiring an emergency response plan involving offsite areas. Experience gained through emergency response exercises is then expected to provide an adequate basis for expanding the response to an actual incident to larger areas, if needed. It is also noted that the 10-mile radius EPZ for the early phase is large enough to avoid exceeding the PAGs for the early phase at its boundary for low-consequence, nuclear reactor, core-melt accidents and to avoid early fatalities for high-consequence, nuclear reactor core-melt accidents. The 50-mile EPZ for ingestion pathways was selected to account for the proportionately higher doses via ingestion compared to inhalation and whole body external exposure pathways.

1.4 Implementation of Protective Actions

The sequence of events during the early phase includes evaluation of conditions at the location of the incident, notification of responsible authorities, prediction or evaluation of potential consequences to the general public, recommendations for action, and implementing protection of the public. In the early phase of response, the time available to implement the most effective protective actions may be limited.

Immediately upon becoming aware that an incident has occurred that may result in exposure of the population, responsible authorities should make a preliminary evaluation to determine the nature and potential magnitude of the incident. This evaluation should determine whether conditions indicate a significant possibility of a major release and, to the extent feasible, determine potential exposure pathways, populations at risk, and projected doses. The incident evaluation and recommendations should

then be presented to emergency response authorities for action. In the absence of recommendations for protective actions in specific areas from the official responsible for the source, the emergency plan should, where practicable, provide for protective action in predesignated areas.

Contrary to the usual situation during the early phase, dose projections used to support protective action decisions during the intermediate and late phases will be based on measurements of environmental radioactivity and dose models. Following relocation of the public from affected areas to protect them from exposure to deposited materials, it will also be necessary to compile radiological and cost of decontamination data to form the basis for radiation protection decisions for recovery.

The PAGs do not imply an acceptable level of risk for normal (nonemergency conditions). They also do not represent the boundary between safe and unsafe conditions, rather, they are the approximate levels at which the associated protective actions are justified. Furthermore, under emergency conditions, in addition to the protective actions specifically identified for application of PAGs, any other reasonable measures available should be taken to minimize radiation exposure of the general public and of emergency workers.

References

FE-85 Federal Emergency Management Agency. Federal Policy on Distribution of Potassium Iodide around Nuclear Power Sites for Use as a Thyroidal Blocking Agent. Federal Register, 50, 30256; July 24, 1985.

FR-64 Federal Radiation Council. Radiation Protection Guidance for Federal Agencies. Federal Register, 29, 12056-7; August 22, 1965.

FR-65 Federal Radiation Council. Radiation Protection Guidance for Federal Agencies. Federal Register, 30, 6953-5; May 22, 1965.

IA-89 International Atomic Energy Agency. Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency. Safety Series No. 72, revision 1, International Atomic Energy Agency, Vienna (1991).

IC-84 International Commission on Radiological Protection. Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning, ICRP Publication 40, Pergamon Press, Oxford (1984).

NR-78 Nuclear Regulatory Commission. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Washington (1978).

NR-80 Nuclear Regulatory Commission. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. U.S. Nuclear Regulatory Commission, Washington (1980).

CHAPTER 2

Protective Action Guides for the Early Phase of an Atmospheric Release

2.1 Introduction

Rapid action may be needed to protect members of the public during an incident involving a large release of radioactive materials to the atmosphere. This chapter identifies the levels of exposure to radiation at which such prompt protective action should be initiated. These are set forth as Protective Action Guides (PAGs) for the general population. Guidance for limiting exposure of workers during such an incident is also provided. This guidance applies to any type of nuclear accident or other incident (except nuclear war) that can result in exposure of the public to an airborne release of radioactive materials.

In the case of an airborne release the principal relevant protective actions are evacuation or sheltering. These may be supplemented by additional actions such as washing and changing clothing or by using stable iodine to partially block uptake of radioiodine by the thyroid.

The former Federal Radiation Council (FRC), in a series of recommendations issued in the 1960's, introduced the concept of PAGs and issued guides for avoidance of exposure due to ingestion of strontium-89, strontium-90, cesium-137, and iodine-131. Those guides were developed for the case of worldwide atmospheric fallout from weapons testing, and are appropriate for application to intake due to long term contamination from such atmospheric releases. That is, they were not developed for protective actions relevant to prompt exposure to an airborne release from a fixed facility. The guidance in this chapter thus does not supersede this previous FRC guidance, but provides new guidance for different exposure pathways and situations.

2.1.1 Applicability

These PAGs are expected to be used for planning purposes: for example, to develop radiological emergency response plans and to exercise those plans. They provide guidance for response decisions and should not be regarded as dose limits. During a real incident, because of characteristics of the incident and local conditions that cannot be anticipated, professional judgment will be required in their application. Situations could occur, for example, in which a nuclear incident happens when environmental conditions or other constraints make evacuation impracticable. In these situations, sheltering may be the

protective action of choice, even at projected doses above the PAG for evacuation. Conversely, in some cases evacuation may be useful at projected doses below the PAGs. Each case will require judgments by those responsible for decisions on protective actions at the time of an incident.

The PAGs are intended for general use to protect all of the individuals in an exposed population. To avoid social and family disruption and the complexity of implementing different PAGs for different groups under emergency conditions, the PAGs should be applied equally to most members of the population. However, there are some population groups that are at markedly different levels of risk from some protective actions -- particularly evacuation. Evacuation at higher values is appropriate for a few groups for whom the risk associated with evacuation is exceptionally high (e.g., the infirm who are not readily mobile), and the PAGs provide for this.

Some incidents may occur under circumstances in which protective actions cannot be implemented prior to a release (e.g., transportation incidents). Other incidents may involve only slow, small releases over an extended period, so that the urgency is reduced and protective action may be more appropriately treated as relocation (see Chapter 4) than as evacuation. Careful judgment will be needed to decide whether or not to apply these PAGs for the early phase under such circumstances.

The PAGs do not imply an acceptable level of risk for normal (nonemergency) conditions. PAGs also do not represent the boundary between safe and unsafe conditions; rather, they are the approximate levels at which the associated protective actions are justified. Furthermore, under emergency conditions, in addition to the protective actions specifically identified, any other reasonable measures available should be taken to reduce radiation exposure of the general public and of emergency workers. These PAGs are not intended for use as criteria for the ingestion of contaminated food or water, for relocation, or for return to an area contaminated by radioactivity. Separate guidance is provided for these situations in Chapters 3 and 4.

2.1.2 Emergency Planning Zones and the PAGs

For the purpose of identifying the size of the planning area needed to establish and test radiological emergency response plans, emergency planning zones (EPZs) are typically specified around nuclear facilities. There has been some confusion among emergency planners between these EPZs and the areas potentially affected by protective actions. It is not appropriate to use the maximum distance where a PAG might be exceeded as the basis for establishing the boundary of the EPZ for a facility. For example, the choice of EPZs for commercial nuclear power facilities has been based, primarily, on consideration of the area needed to assure an

adequate planning basis for local response functions and the area in which acute health effects could occur.[1] These considerations will also be appropriate for use in selecting EPZs for most other nuclear facilities. However, since it will usually not be necessary to have offsite planning if PAGs cannot be exceeded offsite, EPZs need not be established for such cases.

2.1.3 Incident Phase

The period addressed by this chapter is denoted the "early phase." This is somewhat arbitrarily defined as the period beginning at the projected (or actual) initiation of a release and extending to a few days later, when deposition of airborne materials has ceased and enough information has become available to permit reliable decisions about the need for longer term protection. During the early phase of an incident doses may accrue both from airborne and from deposited radioactive materials. Since the dose to persons who are not evacuated will continue until relocation can be implemented (if it is necessary), it is appropriate to include in the early phase the total dose that will be received prior to such relocation. For the purpose of planning, it will usually be convenient to assume that the early phase will last for four days -- that is, that the duration of the primary release is less than four days, and that exposure to deposited materials after four days can be addressed through other protective actions, such as relocation, if this is warranted. (Because of the unique characteristics of some facilities or situations, different time periods may be more appropriate for planning purposes, with corresponding modification of the dose conversion factors cited in Chapter 5.)

2.2 Exposure Pathways

The PAGs for members of the public specified in this chapter refer only to doses incurred during the early phase. These may include external gamma dose and beta dose to the skin from direct exposure to airborne materials and from deposited materials, and the committed dose to internal organs from inhalation of radioactive material. Exposure pathways that make only a small contribution (e.g., less than about 10 percent) to the dose incurred in the early phase need not be considered. Inhalation of resuspended particulate materials will, for example, generally fall into this category.

Individuals exposed to a plume may also be exposed to deposited material over longer periods of time via ingestion, direct external exposure, and inhalation pathways. Because it is

---

[1]The development of EPZs for nuclear power facilities is discussed in the 1978 NRC/EPA document "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" NUREG-0396. EPZs for these facilities have typically been chosen to have a radius of approximately 10 miles for planning evacuation and sheltering and a radius of approximately 50 miles for planning protection from ingestion of contaminated foods.

usually not practicable, at the time of an incident, to project these long-term doses and because different protective actions may be appropriate, these doses are not included in the dose specified in the PAGs for the early phase. Such doses are addressed by the PAGs for the intermediate phase (see Chapters 3 and 4).

The first exposure pathway from an accidental airborne release of radioactive material will often be direct exposure to an overhead plume of radioactive material carried by winds. The detailed content of such a plume will depend on the source involved and conditions of the incident. For example, in the case of an incident at a nuclear power reactor, it would most commonly contain radioactive noble gases, but may also contain radioiodines and radioactive particulate materials. Many of the these materials emit gamma radiation which can expose people nearby, as the plume passes. In the case of some other types of incidents, particularly those involving releases of alpha emitting particulate materials, direct exposure to gamma radiation is not likely to be the most important pathway.

A second exposure pathway occurs when people are directly immersed in a radioactive plume, in which case radioactive material is inhaled (and the skin and clothes may also become contaminated), e.g., when particulate materials or radioiodines are present. When this occurs, internal body organs as well as the skin may be exposed. Although exposure from materials deposited on the skin and clothing could be significant, generally it will be less important than that from radioactive material taken into the body through inhalation. This is especially true if early protective actions include washing exposed skin and changing clothing. Inhaled radioactive particulate materials, depending on their solubility in body fluids, may remain in the lungs or move via the bloodstream to other organs, prior to elimination from the body. Some radionuclides, once in the bloodstream, are concentrated in a single body organ, with only small amounts going to other organs. For example, if radioiodines are inhaled, a significant fraction moves rapidly through the bloodstream to the thyroid gland.

As the passage of a radioactive plume containing particulate material and/or radioiodine progresses, some of these materials will deposit onto the ground and other surfaces and create a third exposure pathway. People present after the plume has passed will receive exposure from gamma and beta radiation emitted from these deposited materials. If large quantities of radioiodines or gamma-emitting particulate materials are contained in a release, this exposure pathway, over a long period, can be more significant than direct exposure to gamma radiation from the passing plume.

2.3 The Protective Action Guides

The PAGs for response during the early phase of an incident are summarized in Table 2-1. The PAG for

evacuation (or, as an alternative in certain cases, sheltering) is expressed in terms of the projected sum of the effective dose equivalent from external radiation and the committed effective dose equivalent incurred from inhalation of radioactive materials from exposure and intake during the early phase. (Further references to dose to members of the public in this Chapter refer to this definition, unless otherwise specified.) Supplementary guides are specified in terms of committed dose equivalent to the thyroid and dose equivalent to the skin. The PAG for the administration of stable iodine is specified in terms of the committed dose equivalent to the thyroid from radioiodine. This more complete guidance updates and replaces previous values, expressed in terms of whole-body dose equivalent from external gamma exposure and thyroid dose equivalent from inhalation of radioactive iodines, that were recommended in the 1980 edition of this document.

2.3.1 Evacuation and Sheltering

The basis for the PAGs is given in Appendix C. In summary, this analysis indicates that evacuation of the public will usually be justified when the projected dose to an individual is one rem. This conclusion is based primarily on EPA's judgment concerning acceptable levels of risk of effects on public health from radiation exposure in an emergency situation. The analysis also shows that, at this radiation dose, the risk avoided is usually much greater than the risk from evacuation itself. However, EPA recognizes the uncertainties associated with quantifying risks associated with these levels of radiation exposure, as well as the variability of risks associated with evacuation under differing conditions.

Some judgment will be necessary when considering the types of protective actions to be implemented and at what levels in an emergency situation. Although the PAG is expressed as a range of 1-5 rem, it is emphasized that, under normal conditions, evacuation of members of the general population should be initiated for most incidents at a projected dose of 1 rem. (It should be recognized that doses to some individuals may exceed 1 rem, even if protective actions are initiated within this guidance.) It is also possible that conditions may exist at specific facilities which warrant consideration of values other than those recommended for general use here.[3]

Sheltering may be preferable to evacuation as a protective action in some situations. Because of the higher risk associated with evacuation of some special groups in the population (e.g. those who are not readily mobile), sheltering may be the preferred alternative for such groups as a

---

[3]EPA, in accordance with its responsibilities under the regulations governing radiological emergency planning (47FR10758; March 11, 1982) and under the Federal Radiological Emergency Response Plan, will consult with Federal agencies and the States, as requested, in such cases.

Table 2-1 PAGs for the Early Phase of a Nuclear Incident

Protective Action	PAG (projected dose)	Comments
Evacuation (or sheltering[a])	1-5 rem[b]	Evacuation (or, for some situations, sheltering[a]) should normally be initiated at 1 rem. Further guidance is provided in Section 2.3.1
Administration of stable iodine	25 rem[c]	Requires approval of State medical officials.

[a]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 (see Section 2.3.1).

[b]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.

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

protective action at projected doses up to 5 rem. In addition, under unusually hazardous environmental conditions use of sheltering at projected doses up to 5 rem to the general population (and up to 10 rem to special groups) may become justified. Sheltering may also provide protection equal to or greater than evacuation due to the nature of the source term and/or in the presence of temporal or other site-specific conditions. Illustrative examples of situations or groups for which evacuation may not be appropriate at 1 rem include: a) the presence of severe weather, b) competing disasters, c) institutionalized persons who are not readily mobile, and d) local physical factors which impede evacuation. Examples of situations or groups for which evacuation at 1 rem normally would be appropriate include: a) an

incident which occurs at night, b) an incident which occurs when children are in school, and c) institutionalized persons who are readily mobile. Evacuation seldom will be justified at less than 1 rem. The examples described above regarding selection of the most appropriate protective action are intended to be illustrative and not exhaustive. In general, sheltering should be preferred to evacuation whenever it provides equal or greater protection.

No specific minimum level is established for initiation of sheltering. Sheltering in place is a low-cost, low-risk protective action that can provide protection with an efficiency ranging from zero to almost 100 percent, depending on the circumstances. It can also be particularly useful to assure that a population is positioned so that, if the need arises, communication with the population can be carried out expeditiously. For the above reasons, planners and decision makers should consider implementing sheltering at projected doses below 1 rem; however, implementing protective actions for projected doses at very low levels would not be reasonable (e.g. below 0.1 rem). (This guidance should not be construed as establishing an additional lower level PAG for sheltering.) Sheltering should always be implemented in cases when evacuation is not carried out at projected doses of 1 rem or more.

Analyses for some hypothesized accidents, such as short-term releases of transuranic materials, show that sheltering in residences and other buildings can be highly effective at reducing dose, may provide adequate protection, and may be more effective than evacuation when evacuation cannot be completed before plume arrival (DO-90). However, reliance on large dose reduction factors for sheltering should be accompanied by cautious examination of possible failure mechanisms, and, except in very unusual circumstances, should never be relied upon at projected doses greater than 10 rem. Such analyses should be based on realistic or "best estimate" dose models and include unavoidable dose during evacuation. Sheltering and evacuation are discussed in more detail in Section 5.5.

2.3.2 Thyroid and Skin Protection

Since the thyroid is at disproportionately high risk for induction of nonfatal cancer and nodules, compared to other internal organs, additional guidance is provided to limit the risk of these effects (see footnote to Table 2-1). In addition, effective dose, the quantity used to express the PAG, encompasses only the risk of fatal cancer from irradiation of organs within the body, and does not include dose to skin. Guidance is also provided, therefore, to protect against the risk of skin cancer (see Table 2-1, footnote b).

The use of stable iodine to protect against uptake of inhaled radioiodine by the thyroid is recognized as an effective alternative to evacuation for situations involving radioiodine releases when evacuation cannot be

implemented or exposure occurs during evacuation. Stable iodine is most effective when administered immediately prior to exposure to radioiodine. However, significant blockage of the thyroid dose can be provided by administration within one or two hours after uptake of radioiodine. If the administration of stable iodine is included in an emergency response plan, its use may be considered for exposure situations in which the committed dose equivalent to the thyroid can be 25 rem or greater (see 47 FR 28158; June 29, 1982).

Washing and changing of clothing is recommended primarily to provide protection from beta radiation from radioiodines and particulate materials deposited on the skin or clothing. Calculations indicate that dose to skin should seldom, if ever, be a controlling pathway. However, it is good radiation protection practice to recommend these actions, even for alpha-emitting radioactive materials, as soon as practical for persons significantly exposed to a contaminating plume (i.e., when the projected dose from inhalation would have justified evacuation of the public under normal conditions).

2.4 Dose Projection

The PAGs are expressed in terms of projected dose. However, in the early phase of an incident (either at a nuclear facility or other accident site), parameters other than projected dose may frequently provide a more appropriate basis for decisions to implement protective actions. When a facility is operating outside its design basis, or an incident is imminent but has not yet occurred, data adequate to directly estimate the projected dose may not be available. For such cases, provision should be made during the planning stage for decisions to be made based on specific conditions at the source of a possible release that are relatable to ranges of anticipated offsite consequences. Emergency response plans for facilities should make use of Emergency Action Levels (EALs)[4], based on in-plant conditions, to trigger notification of and recommendations to offsite officials to implement prompt evacuation or sheltering in specified areas in the absence of information on actual releases or environmental measurements. Later, when these data become available, dose projections based on measurements may be used, in addition to plant conditions, as the basis for implementing further protective actions. (Exceptions may occur at sites with large exclusion areas where some field and source data may be available in sufficient time for protective action decisions to be based on environmental measurements.) In the case of transportation accidents or other incidents that are not related to a facility, it will often not be practicable to establish EALs.

The calculation of projected doses should be based on realistic dose

[4]Emergency Action Levels related to plant conditions at commercial nuclear power plants are discussed in Appendix 1 to NUREG-0654 (NR-80).

models, to the extent practicable. Doses incurred prior to initiation of a protective action should not normally be included. Similarly, doses that might be received following the early phase should not be included for decisions on whether or not to evacuate or shelter. Such doses, which may occur from food and water, long-term radiation exposure to deposited radioactive materials, or long-term inhalation of resuspended materials, are chronic exposures for which neither emergency evacuation nor sheltering are appropriate protective actions. Separate PAGs relate the appropriate protective action decisions to those exposure pathways (Chapter 4). As noted earlier, the projection of doses in the early phase need include only those exposure pathways that contribute a significant fraction (e.g., more than about 10 percent) of the dose to an individual.

In practical applications, dose projection will usually begin at the time of the anticipated (or actual) initiation of a release. For those situations where significant dose has already occurred prior to implementing protective action, the projected dose for comparison to a PAG should not include this prior dose.

2.5 Guidance for Controlling Doses to Workers Under Emergency Conditions

The PAGs for protection of the general population and dose limits for workers performing emergency services are derived under different assumptions. PAGs consider the risks to individuals, themselves, from exposure to radiation, and the risks and costs associated with a specific protective action. On the other hand, workers may receive exposure under a variety of circumstances in order to assure protection of others and of valuable property. These exposures will be justified if the maximum risks permitted to workers are acceptably low, and the risks or costs to others that are avoided by their actions outweigh the risks to which workers are subjected.

Workers who may incur increased levels of exposure under emergency conditions may include those employed in law enforcement, fire fighting, radiation protection, civil defense, traffic control, health services, environmental monitoring, transportation services, and animal care. In addition, selected workers at institutional, utility, and industrial facilities, and at farms and other agribusiness may be required to protect others, or to protect valuable property during an emergency. The above are examples - not designations - of workers that may be exposed to radiation under emergency conditions.

Guidance on dose limits for workers performing emergency services is summarized in Table 2-2. These limits apply to doses incurred over the duration of an emergency. That is, in contrast to the PAGs, where only the future dose that can be avoided by a specific protective action is considered, all doses received during an emergency are included in the limit. Further, the dose to workers performing emergency

Table 2-2 Guidance on Dose Limits for Workers Performing Emergency Services

Dose limit[a] (rem)	Activity	Condition
5	all	
10	protecting valuable property	lower dose not practicable
25	life saving or protection of large populations	lower dose not practicable
>25	lifesaving or protection of large populations	only on a voluntary basis to persons fully aware of the risks involved (See Tables 2-3 and 2-4)

[a]Sum of external effective dose equivalent and committed effective dose equivalent to nonpregnant adults from exposure and intake during an emergency situation. Workers performing services during emergencies should limit dose to the lens of the eye to three times the listed value and doses to any other organ (including skin and body extremities) to ten times the listed value. These limits apply to all doses from an incident, except those received in unrestricted areas as members of the public during the intermediate phase of the incident (see Chapters 3 and 4).

services may be treated as a once-in-a-lifetime exposure, and not added to occupational exposure accumulated under nonemergency conditions for the purpose of ascertaining conformance to normal occupational limits, if this is necessary. However, any radiation exposure of workers that is associated with an incident, but accrued during nonemergency operations, should be limited in accordance with relevant occupational limits for normal situations. Federal Radiation Protection Guidance for occupational exposure recommends an upper bound of five rem per year for adults and one tenth this value for minors and the unborn (EP-87). We recommend use of this same value here for the case of exposures during an emergency. To assure adequate protection of minors and the unborn during emergencies, the performance of emergency services should be limited to nonpregnant adults. As in the case of normal occupational exposure, doses received under emergency conditions should also be maintained as low as reasonably achievable (e.g., use of stable iodine, where appropriate, as a prophylaxis to

reduce thyroid dose from inhalation of radioiodines and use of rotation of workers).

Doses to all workers during emergencies should, to the extent practicable, be limited to 5 rem. There are some emergency situations, however, for which higher exposure limits may be justified. Justification of any such exposure must include the presence of conditions that prevent the rotation of workers or other commonly-used dose reduction methods. Except as noted below, the dose resulting from such emergency exposure should be limited to 10 rem for protecting valuable property, and to 25 rem for life saving activities and the protection of large populations. In the context of this guidance, exposure of workers that is incurred for the protection of large populations may be considered justified for situations in which the collective dose avoided by the emergency operation is significantly larger than that incurred by the workers involved.

Situations may also rarely occur in which a dose in excess of 25 rem for emergency exposure would be unavoidable in order to carry out a lifesaving operation or to avoid extensive exposure of large populations. It is not possible to prejudge the risk that one should be allowed to take to save the lives of others. However, persons undertaking any emergency operation in which the dose will exceed 25 rem to the whole body should do so only on a voluntary basis and with full awareness of the risks involved, including the numerical levels of dose at which acute effects of radiation will be incurred and numerical estimates of the risk of delayed effects.

Tables 2-3 and 2-4 provide some general information that may be useful in advising emergency workers of risks of acute and delayed health effects associated with large doses of radiation. Table 2-3 presents estimated risks of early fatalities and moderately severe prodromal (forewarning) effects that are likely to occur shortly after exposure to a wide range of whole body radiation doses. Estimated average cancer mortality risks for emergency workers corresponding to a whole-body dose equivalent of 25 rem are given in Table 2-4, as a function of age at the time of exposure. To estimate average cancer mortality for moderately higher doses the results in Table 2-4 may be increased linearly. These values were calculated using a life table analysis that assumes the period of risk continues for the duration of the worker's lifetime. Somewhat smaller risks of serious genetic effects (if gonadal tissue is exposed) and of nonfatal cancer would also be incurred. An expanded discussion of health effects from radiation dose is provided in Appendix B.

Some workers performing emergency services will have little or no health physics training, so dose minimization through use of protective equipment cannot always be assumed. However, the use of respiratory protective equipment can reduce dose from inhalation, and clothing can reduce beta dose. Stable iodine is also recommended for blocking thyroid

Table 2-3 Health Effects Associated with Whole-Body Absorbed Doses Received Within a Few Hours[a] (see Appendix B)

Whole Body Absorbed dose (rad)	Early Fatalities[b] (percent)	Whole Body Absorbed dose (rad)	Prodromal Effects[c] (percent affected)
140	5	50	2
200	15	100	15
300	50	150	50
400	85	200	85
460	95	250	98

[a]Risks will be lower for protracted exposure periods.

[b]Supportive medical treatment may increase the dose at which these frequencies occur by approximately 50 percent.

[c]Forewarning symptoms of more serious health effects associated with large doses of radiation.

Table 2-4 Approximate Cancer Risk to Average Individuals from 25 Rem Effective Dose Equivalent Delivered Promptly (see Appendix C)

Age at exposure (years)	Appropriate risk of premature death (deaths per 1,000 persons exposed)	Average years of life lost if premature death occurs (years)
20 to 30	9.1	24
30 to 40	7.2	19
40 to 50	5.3	15
50 to 60	3.5	11

uptake of radioiodine in personnel involved in emergency actions where atmospheric releases include radioiodine. The decision to issue stable iodine should include consideration of established State medical procedures, and planning is required to ensure its availability and proper use.

References

DO-90 U.S. Department of Energy. Effectiveness of Sheltering in Buildings and Vehicles for Plutonium, DOE/EH-0159, U.S. Department of Energy, Washington (1990).

EP-87 U.S. Environmental Protection Agency. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822; January 27, 1987.

NR-80 U.S. Nuclear Regulatory Commission. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. NUREG-0654, U.S. Nuclear Regulatory Commission, Washington, (1980).

CHAPTER 3

Protective Action Guides for the Intermediate Phase (Food and Water)

a) Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies*

b) Drinking Water**

---

* These recommendations were published by FDA in 1982.

**Protective action recommendations for drinking water are under development by EPA.

DEPARTMENT OF HEALTH AND HUMAN SERVICES

Food and Drug Administration

[Docket No. 76N-0050]

Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies

AGENCY: Food and Drug Administration.

ACTION: Notice.

SUMMARY: The Food and Drug Administration (FDA) is publishing this notice to provide to State and local agencies responsible for emergency response planning for radiological incidents recommendations for taking protective actions in the event that an incident causes the contamination of human food or animal feeds. These recommendations can be used to determine whether levels of radiation encountered in food after a radiological incident warrant protective action and to suggest appropriate actions that may be taken if action is warranted. FDA has a responsibility to issue guidance on

appropriate planning actions necessary for evaluating and preventing contamination of human food and animal feeds and on the control and use of these products should they become contaminated.

FOR FURTHER INFORMATION CONTACT: Gail D. Schmidt, Bureau of Radiological Health (HFX-1), Food and Drug Administration, 5600 Fishers Lane, Rockville, MD 20857, 301-443-2850.

SUPPLEMENTARY INFORMATION:

Background

This guidance on accidental radioactive contamination of food from fixed nuclear facilities, transportation accidents, and fallout is part of a Federal interagency effort coordinated by the Federal Emergency Management Agency (FEMA). FEMA issued a final regulation in the Federal Register of March 11, 1982 (47 FR 10758), which reflected governmental reorganizations and reassigned agency responsibilities for radiological incident emergency response planning. A responsibility assigned to the Department of Health and Human Services (HHS) (and in turn delegated to FDA) is the responsibility to develop and specify to State and local governments protective actions and associated guidance for human food and animal feed.

In the Federal Register of December 15, 1978 (43 FR 58790), FDA published proposed recommendations for State and local agencies regarding accidental radioactive contamination of human food and animal feeds. Interested persons were given until February 13, 1979 to comment on the proposal. Twenty-one comments were received from State agencies, Federal agencies, nuclear utilities, and others. Two of the comments from environmentally concerned organizations were received after the March 28, 1979 accident at Three Mile Island, which increased public awareness of protective action guidance. Although these comments were received after the close of the comment period, they were considered by the agency in developing these final recommendations.

The Office of Radiation Programs, Environmental Protection Agency (EPA), submitted a detailed and exhaustive critique of the proposed recommendations. EPA addressed the dosimetry data, the agricultural models used in calculating the derived response levels, and the philosophical basis for establishing the numerical value of the protective action guides. FDA advises that, to be responsive to the EPA comments, FDA staff met with staff of the Office of Radiation Programs, EPA, during the development of these final recommendations. Although EPA's formal comments are responded to in this notice, EPA staff reviewed a draft of the final recommendations, and FDA has considered their additional informal comments. These contacts were considered appropriate because EPA has indicated that it intends to use the recommendations as the basis for revising its guidance to Federal agencies on protective action guides for radioactivity in food.

Protective Action Guidance

Although not raised in the comments received, FDA has reconsidered its proposal to codify these recommendations in 21 CFR Part 1090. Because these recommendations are voluntary guidance to State and local agencies (not regulations), FDA has decided not to codify the recommendations; rather, it is issuing them in this notice. Elsewhere in this issue of the Federal Register, FDA is withdrawing the December 15, 1978 proposal.

The recommendations contain basic criteria, defined as protective action guides (PAG's), for establishing the level of radioactive contamination of human food or animal feeds at which action should be taken to protect the public health and assure the safety of food. The recommendations also contain specific guidance on what emergency protective actions should be taken to prevent further contamination of food or feeds or to restrict the use of food, as well as more general guidance on the development and implementation of emergency action. The PAG's have been developed on the basis of considerations of acceptable risk to identify that level of contamination at which action is necessary to protect the public health.

In preparing these recommendations, FDA has reviewed and utilized the Federal guidance on protective actions contained in Federal Radiation Council (FRC) Reports No. 5, July 1964 (Ref. 1) and No. 7, May 1965 (Ref. 2). The Federal guidance provides that each Federal agency, by virtue of its immediate knowledge or its operating problems, would use the applicable FRC guides as a basis for developing detailed standards to meet the particular needs of the agency. FDA's recommendations incorporate the FRC concepts and the FRC guidance that protective actions, in the event of a contaminating accident, should be based on estimates of the projected radiation dose that would be received in the absence of taking protective actions. Similarly, protective actions should be implemented for a sufficient time to avoid most of the projected radiation dose. Thus, the PAG's define the numerical value of projected radiation doses for which protective actions are recommended.

FDA has reviewed the recent report of the National Academy of Sciences/National Research Council (Ref. 3) on radiation risks and biological effects data that became available after publication of the FRC guidance and has reviewed the impact of taking action in the pasture/cow/milk/person pathway in light of the current concerns in radiation protection. Based on these considerations and the comments received on the proposed recommendations, FDA has concluded that protective actions of low impact should be undertaken at projected radiation doses lower than those recommended by FRC (Refs. 1 and 2). Accordingly, FDA is recommending low-impact protective actions (termed the Preventive PAG) at projected radiation doses of 0.5 rem whole body and 1.5 rem thyroid. FDA intends that such protective actions be implemented to prevent the appearance of radioactivity in food at levels that would require its condemnation. Preventive PAG's include the transfer of dairy cows from fresh forage (pasture) to uncontaminated stored feed and the diversion of whole milk potentially contaminated with short-lived radionuclides to products with a long shelf life to allow radioactive decay of the radioactive material.

In those situations where the only protective actions that are feasible present high dietary and social costs or impacts (termed the Emergency PAG) action is recommended at projected radiation doses of 5 rem whole body and 15 rem thyroid. At the Emergency PAG level responsible officials should isolate food to prevent its introduction into commerce and determine whether condemnation or other disposition is appropriate. Action at the Emergency PAG level is most likely for the population that is near to the source of radioactive contamination and that consumes home-grown produce and milk.

The PAG's represent FDA's judgment as to that level of food contamination resulting from radiation incidents at which action should be taken to protect the public health. This is based on the agency's recognition that safety involves the degree to which risks are judged acceptable. The risk from natural disasters (approximately a one in a million annual individual risk of death) and the risk from variations in natural background radiation have provided

perspective in selecting the PAG values. This issue is further discussed in the responses to specific comments later in this notice, especially in paragraph 9. A more detailed treatment of the rationale, risk factors, dosimetric and agricultural models, and methods of calculation is contained in the "Background for Protective Action Recommendations; Accidental Radioactive Contamination of Food and Animal Feeds" (Ref. 22).

Organ PAG Values

Current scientific evidence, as reflected by BEIR–I (Ref. 18), UNSCEAR–1977 (Ref. 8), and BEIR–III (Ref. 3), indicates that the relative importance of risk due to specific organ exposure is quite different from the earlier assumptions. The International Commission on Radiological Protection (ICRP) clearly recognized this in its 1977 recommendations (ICRP–26 (Ref. 6)), which changed the methodology for treating external and internal radiation doses and the relative importance of specific organ doses. ICRP–26 assigned weighting factors to specific organs based on considerations of the incidence and severity (mortality) of radiation cancer induction. For the radionuclides of concern for food PAG's, ICRP–26 assigned weighting factors of 0.03 for the thyroid and 0.12 for red bone marrow. Thus, the organ doses equal in risk to 1 rem whole body radiation dose are 33 rem to the thyroid and 8 rem to Red bone marrow. (The additional ICRP–26, nonstochastic limit, however, restricts the thyroid dose to 50 rem or 10 times the whole body occupational limit of 5 rem.)

In the Federal Register of January 23, 1981 (46 FR 7836), EPA proposed to revise the Federal Radiation Protection Guidance for Occupational Exposures using the ICRP approach for internal organ radiation doses, modified to reflect specific EPA concerns. The EPA proposal has been subject to considerable controversy. Also, the National Council on Radiation Protection and Measurements (NCRP) curently is evaluating the need to revise its recommendations. FDA does not, however, expect the protection model for internal organ radiation doses to be resolved rapidly in the United States and has based the relative PAG dose assignments in these recommendations on current U.S. standards and the 1971 recommendations in NCRP–39 (Ref. 19). Thus, the red bone marrow is assigned the same PAG dose as the whole body (0.5 rem Preventive PAG), and the thyroid PAG is greater by a factor of three (1.5 rem Preventive PAG). This results in PAG assignments for the thyroid and red bone marrow that are lower by factors of 3.3 and 8, respectively, than values based on ICRP–26 (Ref. 6). FDA advises that it will make appropriate changes in recommendations for internal organ doses when a consensus in the United States emerges.

Analysis of Comments

The following is a summary of the comments received on the December 15, 1978 proposal and the agency's response to them:

1. Several comments requested clarification of the applicability and compatibility of FDA's recommendations with other Federal actions, specifically the PAG guidance of EPA (Ref. 7), the FRC Reports No. 5 (Ref. 1) and No. 7 (Ref. 2), and the Nuclear Regulatory Commission (NRC) definition of "Extraordinary Nuclear Occurrence" in 10 CFR Part 140. A comment recommended that the term, "Protective Action Guide (PAG)", not be used because that term traditionally has been associated with the FRC, and the general public would confuse FDA's recommendations with Federal guidance.

The FRC Report No. 5 specifically recommended that the term, "protective action guide," be adopted for Federal use. The report defines the term as the "projected absorbed dose to the individuals in the general population which warrants protective action following a contaminating event," a concept that is addressed by FDA's recommendations. To use the concept with a different description would, in FDA's opinion, be unnecessarily confusing to State and local agencies as well as Federal agencies.

These recommendations are being issued to fulfill the HHS responsibilities under FEMA's March 11, 1982 regulation. FDA fully considered FRC Reports No. 5 and No. 7 and the basic concepts and philosophy of the FRC guidance form the basis for these recommendations. The specific PAG values are derived response levels included in these recommendations are based on current agricultural pathway and radiation dose models and current estimates of risk. The FRC guidance provided that protective actions may be justified at lower (or higher) projected radiation doses depending on the total impact of the protective action. Thus, FDA's recommendation that protective actions be implemented at projected radiation doses lower than those recommended by FRC doses is consistent with the FRC guidance. The FRC guidance is applicable to Federal agencies in their radiation protection activities. FDA's recommendations are for use by State and local agencies in response planning and implementation of protective actions in the event of a contaminating incident. Further, FDA's recommendations would also be used by FDA in implementing its authority for food in interstate commerce under the Federal Food, Drug, and Cosmetic Act.

FDA's recommendations are being forwarded to EPA as the basis for revising Federal guidance on food accidentally contaminated by radionuclides. EPA has advised FDA that it intends to forward the FDA recommendations to the President under its authority to "advise the President with respect to radiation matters directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards * * *". (This authority was transferred to EPA in 1970 when FRC was abolished.)

The recommendations established in this document apply only to human food and animal feeds accidentally contaminated by radionuclides. They should not be applied to any other source of radiation exposure. EPA already has issued protective action guidance for the short-term accidental exposure to airborne releases of radioactive materials and intends also to forward the EPA guides to the President as Federal guidance. EPA also is considering the development of guidance for acidentally contaminated water and for long-term exposures due to contaminated land, property, and materials. Guidance for each of these exposure pathways is mutually exclusive. Different guidance for each exposure pathway is appropriate because different criteria of risk, cost, and benefit are involved. Also, each exposure pathway may involve different sets of protective or restorative actions and would relate to different periods of time when such actions would be taken.

2. Several comments expressed concern about radiation exposure from multiple radionuclides and from multiple pathways, e.g., via inhalation, ingestion, and external radiation from the cloud (plume exposure) and questioned why particular pathways or radionuclides and the does received before assessment were not addressed in the recommendations. Several comments recommended that the PAG's include specific guidance for tap water (and potable water). Other comments noted that particular biological forms of specific radionuclides (i.e., cyanocobalamin Co 60), would lead to significantly different derived response levels.

FDA advises that the PAG's and the protective action concepts of FRC apply to actions taken to avoid or prevent projected radiation dose (or future dose). Thus, by definition, the PAG's for food do not consider the radiation doses already incurred from the plume pathway or from other sources. The population potentially exposed by ingestion of contaminated food can be divided into that population near the source of contamination and a generally much larger population at distances where the doses from the cloud are not significant. The NRC regulations provide that State and local planning regarding plume exposure should extend for 10 miles and the ingestion pathway should extend for 50 miles (see 45 FR 55402; August 19, 1980). The total population exposed by ingestion, however, is a function of the animal feed and human food production of any given area and is not limited by distance from the source of contamination. Exposure from multiple pathways would not be a concern for the more distant population group. Further, individuals in this larger population would most likely receive doses smaller than that projected for continuous intake because the contaminated food present in the retail distribution system would be replaced by uncontaminated food.

FRC Report No. 5 states that, for repetitive occurrences, the total projected radiation dose and the total impact of protective actions should be considered. Similar considerations on a case-by-case basis would then appear to be appropriate in the case of multiple exposures from the plume and the ingestion pathway. Accordingly, the final recommendations are modified to note that, specifically in the case of the population near the site that consumes locally grown produce, limitations of the total dose should be considered (see paragraph (a)(2)). The agency concludes, however, that a single unified PAG covering multiple pathways, e.g., external radiation, inhalation, and ingestion is not practical because different actions and impacts are involved. Further, FDA's responsibility in radiological incident emergency response planning extends only to human food and animal feeds.

The agency's primary charge is to set recommended PAG dose commitment limits for the food pathway. Thus, deriving response levels for only the radionuclides most likely to enter the food chain and deliver the highest dose to the population permits FDA to establish recommendations that are practical for use in an emergency. In discussing with EPA the list of definitive models, FDA and EPA staffs agreed that further pathway studies would be useful. Elsewhere in this notice, FDA references models for other radionuclides, providing a resource for those requiring more details.

The chemical form of radionuclides in the environment may be important when considering the derivation of an appropriate "response level" in specific situations, but would not change the PAG's, which are in terms of projected dose commitments. Cyanocobalamin Co 60 has not been identified as a likely constituent of health importance to be released from a nuclear reactor accident and, therefore, the agency rejects the recommendation that it provide derived response levels for this radionuclide. However, after reviewing current agricultural and dose models, the agency concludes that cesium-134 would likely be released and has added it to the tables in paragraph (d) of the recommendations identifying radionuclide concentrations equivalent to the PAG response levels.

FDA rejects the comment recommending that the PAG's include guidance for water. A memorandum of understanding between EPA and FDA provides that FDA will have primary responsibility over direct and indirect additives and other substances in drinking water (see 44 FR 42775; July 20, 1979). Thus, FDA defers to EPA for developing guides specifically for drinking water.

3. Three comments requested clarification of the proposed recommendations, including the time over which the guides apply, the time of ingestion required to reach the PAG, and the time that protective actions should be implemented.

FDA advises that the recommendations are intended to provide guidance for actions to be implemented in an emergency, and the duration of protective action should not exceed 1 or 2 months. The agency believes that the actions identified in paragraphs (a) and (h) of the recommendations should be continued for a sufficient time to avoid most of the emergency radiation dose and to assure that the remaining dose is less than the Preventive PAG. This period of time can be estimated by considering the effective half-life of the radioactive material taking into account both radioactive decay and weathering. Each case must be examined separately considering the actual levels of contamination and the effective half-life of the radioactive material present. For the pasture/cow/milk pathway, the effective half-lives are 5 days for iodine-131 and 14 days for cesium or strontium. Assuming that initial contamination by these radionuclides was at the Preventive PAG level, radioactive decay and weathering would reduce the levels so that protective actions could be ceased after 1 or 2 months.

The model used to compute the derived response levels specified in paragraph (d) of the recommendations assumes a continous or infinite ingestion period, i.e., intake that is limited only by radioactive decay and weathering. This is the approach recommended in estimating the projected radiation dose (in the absence of protective actions.). Further revisions have been made in the recommendations to clarify these aspects.

4. A comment stated that action should be initiated by notification received from the facility itself. Another comment noted the importance of timely announcements to the public of the necessity for protective actions.

These recommendations on protective action guides for food and feed are not intended to cover other aspects of emergency planning for radiological incidents. The general responsibilities of NRC licensees in radiation emergencies have been further defined in a rule issued by NRC (45 FR 55402; August 19, 1980). FDA recognizes, however, that notification and public announcements are vital to effective protective actions and, in paragraph (e)(5) of the recommendations, urges that State and local emergency plans should provide for such notice.

5. A comment offered clarification of proposed § 1000.400(g) regarding verification of sample measurements, while another comment suggested that Preventive PAG's should be based on projected levels and that Emergency PAG.s require verification.

The FRC concepts and philosophy, which FDA fully endorses, use estimates of projected radiation dose as the criteria for taking protective action. FDA believes that projected radiation dose estimates should be based on verified measurements of radioactivity in the food pathway. Such verification might include the analysis of replicate samples, laboratory measurements, sample analysis by other agencies, samples of various environmental media, and descriptive data of the radioactive release and has so provided in paragraph (g) of the recommendations.

6. A comment suggested that some States do not have the resources to evaluate projected radiation doses. The comment asked what regulatory agency would have control over interstate

shipment of contaminated foods from States without sufficient resources and what would be the applicable PAG.

FEMA, as the lead agency for the Federal effort, is providing to States guidance and assistance on emergency response planning including evaluation of projected doses. Also, NRC requires nuclear power plant licensees to have the capability to assess the off-site consequences of radioactivity releases and to provide notification to State and local agencies (45 FR 55402; August 19, 1980). FDA has authority under the Federal Food, Drug, and Cosmetic Act to remove radioactively contaminated food from the channels of interstate commerce. In this circumstance, FDA would use these PAG recommendations as the basis for implementing regulatory action.

Risk Estimates

7. *Many comments questioned the risk* estimates on which FDA based the proposed PAG's. The comments especially suggested that risk estimates from WASH-1400 (Ref. 4) were of questionable validity. Other comments argued that the proposed recommendations used an analysis of only lethal effects; that they used an absolute risk model; and that genetic effects were not adequately considered. The risk estimates themselves were alleged to be erroneous because recent studies show that doubling doses are lower than are those suggested by WASH=1400. The tinea capitis study by Ron and Modan, which indicates an increased probability of thyroid cancer at an estimated radiation dose of 9 rem to the thyroid (Ref. 5), was cited as evidence that the PAG limits for the thyroid were too high. The comments requested further identification and support for using the critical population selected.

Most of these issues were addressed in the preamble to the FDA proposal. The final recommendations issued in this notice employ the most recent risk estimates (somatic and genetic) of the National Academy of Sciences Committee on Biological Effects of Ionizing Radiation (Ref. 3).

The thyroid PAG limits are based on the relative radiation protection guide for thyroid compared to whole body contained in NRC's current regulations (10 CFR Part 20). The derived response levels for thyroid are based on risk factors for external x-ray irradiation. Therefore, the criticism of the PAG limits for the thyroid is not applicable, no "credit" having been taken for an apparent lower radiation risk due to iodine-131 irradiation of the thyroid gland. Further, as discussed above under "ORGAN PAG VALUES", the use of BEIR-III risk estimates or the ICRP-26 recommendations would result in an increase of the thyroid PAG relative to the whole body PAG. For these reasons, FDA believes the PAG limits for projected dose commitment to the thyroid are conservative when considered in light of current knowledge of radiation to produce equal health risks from whole body and specific organ doses.

Although it may be desirable to consider total health effects, not just lethal effects, there is a lack of data for total health effects to use in such comparisons. In the case of the variability of natural background, as an estimate of acceptable risk, consideration of lethal effects or total health effects is not involved because the comparison is the total dose over a lifetime.

Rational

8. Several comments questioned the rational FDA used in setting the specific PAG values included in the December 1978 proposal. A comment from EPA stated that the guidance levels should be justified on the grounds that it is not practical or reasonable to take protective actions at lower risk levels. Further, EPA argued that the protective action concept for emergency planning and response should incorporate the principle of keeping radiation exposures as low as reasonably achievable (ALARA). EPA noted that the principle of acceptable risk involves a perception of risk that may vary from person to person and that the implication that an acceptable genetic risk has been established should be avoided.

FDA accepts and endorses the ALARA concept, but the extent to which a concept, which is used in occupational settings, should be applied to emergency protective actions is not clear. To use the ALARA concept as the basis for specific PAG values and also require ALARA during the implementation of emergency protective actions appears to be redundant and may not be practical under emergency conditions.

FDA advises that these guides do not constitute acceptable occupational radiation dose limits nor do they constitute acceptable limits for other applications (e.g., acceptable genetic risk). The guides are not intended to be used to limit the radiation dose that people may receive but instead are to be compared to the calculated projected dose, i.e., the future dose that the people would receive if no protective action were taken in a radiation emergency. In this respect, the PAG's represent trigger levels calling for the initiation of recommended protective actions. Once the protective action is initiated, it should be executed so as to prevent as much of the calculated projected dose from being received as is reasonably achievable. This does not mean, however, that all doses above guidance levels can be prevented.

Further, the guides are not intended to prohibit taking actions at projected exposures lower than the PAG values. They have been derived for general cases and are just what their name implies, guides. As provided in FRC Reports No. 5 and No. 7 and as discussed in paragraph 1 of this notice, in the absence of significant constraints, responsible authority may find it appropriate to implement low-impact protective actions at projected radiation doses less than those specified in the guides. Similarly, high impact actions may be justified at higher projected doses. These judgments must be made according to the facts of each situation. Paragraphs (a) (2) and (3) have been added to the final recommendations to incorporate this concept.

9. Several comments questioned the adequacy of the level of risk judged acceptable in deriving the proposed PAG values. A comment stated that the estimated one in a million annual individual risk of death from natural disasters is extremely conservative. EPA suggested that comparative risk is appropriate for perspective but not for establishing the limits. EPA further suggested that the population-weighted average of the variability in natural background dose or the variation in dose due to the natural radioactivity in food should be the basis for judging acceptable risk.

FDA concludes that the differences between EPA's suggested approach and that employed by FDA largely involve the semantics of the rationale descriptions. As discussed in the preamble to the proposal, FDA believes that safety (or a safe level of risk) needs to be defined as the degree to which the risks are judged acceptable, because it is not possible to achieve zero risk from human endeavors. Further, ICRP (Ref. 6) recommends that, for a given application involving radiation, the net benefit to society should be positive, considering the total costs and impacts and the total benefit (this is termed "justification"). FDA believes that, to establish a PAG, the primary concern is to provide adequate protection (or safe level of risk) for members of the public. To decide on safety or levels of acceptable risk to the public from a contaminating event, FDA introduced the estimates of acceptable risk from

natural disasters and background radiation. These values provided background or perspective for FDA's judgment that the proposed PAG's represent that level of food or feed radiation contamination at which protective actions should be taken to protect the public health; judgment which, consistent with FRC Report No. 5, also involves consideration of the impacts of the action and the possibility of future events. The recommendations are based on the assumption that the occurrences of environmental contamination requiring protective actions in a particular area is an unlikely event, that most individuals will never be so exposed, and that any individual is not likely to be exposed to projected doses at the PAG level more than once in his or her lifetime.

FDA continues to believe that the average risks from natural disasters and variation of background radiation provide appropriate bases for judging the acceptability of risk represented by the Preventive PAG. These recommendations incorporate the philosophy that action should be taken at the Preventive PAG level of contamination to avoid a potential public health problem. Should this action not be wholly successful, the Emergency PAG provides guidance for taking action where contaminated food is encountered. FDA expects that action at the Emergency PAG level of contamination would most likely involve food produced for consumption by the population near the source of contamination. As discussed in paragraph 2, this is also the population which might receive radiation doses from multiple pathways. Thus, the Emergency PAG might be considered to be an upper bound for limiting the total radiation dose to individuals. FDA emphasizes, however, that the Emergency PAG is not a boundary between safe levels and hazardous or injury levels of radiation. Individuals may receive an occupational dose of 5 rem each year over their working lifetime with the expectation of minimal increased risks to the individual. Persons in high elevation areas such as Colorado receive about 0.04 rem per year (or 2.8 rem in a lifetime) above the average background radiation dose for the United States population as a whole. The Emergency PAG is also consistent with the upper range of PAG's proposed by EPA for the cloud (plume) pathway (Ref. 7).

FDA agrees that a population-weighted variable is as applicable to the evaluation of comparative risks as is a geographic variable. Arguments can be made for using either variable. Because persons rather than geographic areas are the important parameter in the evaluation of risk associated with these guides, FDA has used population-weighting in estimating the variability of the annual external dose from natural radiation. A recent EPA study (Ref. 20) indicates that the average population dose from external background radiation dose is 53 millirem (mrem) per year, and the variability in lifetime dose taken as two standard deviations is about 2,000 mrem. The proposal, which indicated that the variation in external background was about 600 mrem, utilized a geographic weighting of State averages.

Radioactivity in food contributes about 20 mrem per year to average population doses and about 17 mrem per year of this dose results from potassium-40 (Ref. 8). Measurements of potassium-40 (and stable potassium) indicate that variability (two standard deviations) of the potassium-40 dose is about 28 percent or a lifetime dose of 350 mrem. It should be noted that body levels of potassium are regulated by metabolic processes and not dietary selection or residence. The variation of the internal dose is about one-fifth of the variation from external background radiation. FDA has retained the proposed preventive PAG of 500 mrem whole body even though the newer data indicate a greater variation in external background radiation.

FDA did not consider perceived risks in deriving the proposed PAG values because perceived risk presents numerous problems in its appropriateness and application. If the factor of perception is added to the equation, scientific analysis is impossible.

10. Two comments questioned the assumptions that the Emergency PAG might apply to 15 million people and that the Preventive PAG might apply to the entire United States. One comment noted that 15 million persons are more than that population currently within 25 miles of any United States reactor sites; thus, using this figure results in guides more restrictive than necessary. The other comment noted that, by reducing the population involved, and unacceptably high value could result.

The ratio of total United States population to the maximum number of people in the vicinity of an operating reactor could be erroneously interpreted so that progressively smaller populations would be subject to progressively larger individual risks. This is not the intent of the recommendations. Hence, the risk from natural disasters, the variation in the population-weighted natural background radiation dose to the total population, and the variation in dose due to ingestion of food, have been used to provide the basis for the Preventive PAG. The basis for the Emergency PAG involves considerations of (1) The ratio between average and maximum individual radiation doses (taken as 1 to 10), (2) the cost of low and high impact protective actions, (3) the relative risks from natural disasters, (4) health impact, (5) the upper range of the PAG's proposed by EPA (5 rem projected radiation dose to the whole body and 25 rem projected dose to the thyroid), and (6) radiation doses from multiple pathways.

11. A comment, citing experience with other contaminants, suggested that further consideration should be given to the problem of marketability of foods containing low levels of radioactivity.

Marketability is not a concern for PAG development. However, the publication of the PAG's should enhance marketability of foods because it will enhance public confidence in food safety. Also, FEMA has been specifically directed to undertake a public information program related to radiation emergencies to allay public fears and perceptions.

12. A comment noted the difficulty in assessing the impacts of and the benefits to be gained from protective actions. Another comment suggested that there were lower impact actions which could be implemented to keep food off the market until radiation levels in the food approach normal background.

The recommendation that planning officials consider the impacts of protective actions in implementing action does not imply that a mathematical analysis is required. Rather, FDA intends that the local situation, resources, and impacts that are important in assuring effective protective actions be considered in selecting any actions to be implemented. As discussed in paragraph 8, if the local constraints permit a low impact action, this can be appropriate at lower projected doses. Because it is not possible in general guidance to consider fully all local constraints, the PAG's represent FDA's judgment as to when protective actions are appropriate.

Agricultural and Dose Models

13. Several comments noted errors either in approach or calculations regarding the proposed agricultural and dose models, while others specifically noted that there are newer and better

models for use in computation of the derived response levels.

FDA appreciates the careful review and the suggestions as to better data and models. The references suggested, as well as other current reports, have been carefully reviewed and appropriate ones are being used as the basis for computation of the derived response levels for the final PAG's. The specific models and data being used are as follows:

Agricultural Model—UCRL-51939, 1977 (Ref. 9).

Intake per unit deposition—Table B-1, UCRL-51939 (Ref. 9).

Peak milk activity—Equation 8, UCRL-51939 (Ref. 9).

Area grazed by cow—45 square meters/day. UCRL-51939 (Ref. 9).

Initial retention on forage—0.5 fraction. UCRL-51939 (Ref. 9).

Forage yield—0.25 kilogram/square meter (dry weight). UCRL-51939 (Ref. 9).

Milk consumption—0.7 liter/day infant, ICRP-23, 1974 (Ref. 10);—0.55 liter/day adult, USDA, 1965 (Ref. 11).

Dose conversion factors (rem per microcurie ingested).

	Infant	Adult	
Iodine-131	16	1.5	Welman and Anger, 1971 (Ref. 12).
Cesium-134	0.118	0.068	Adult—ORNL/NUREG/TM-190, 1978 (Ref. 13). Infant—Extrapolated from adult based on relative body weight 70 kilograms (kg) and 7.7 kg and effective retention, 102 days and 19.5 days, adult and infant respectively.
Cesium-137	0.071	0.061	NCRP No. 52, 1977 (Ref. 14).
Strontium-89	0.194	0.012	Adult, ICRP-30, 1979 (Ref. 15).
Strontium-90	2.49	0.70	Infant, Papworth and Vennart, 1973 (Ref. 16).

The use of the newer agricultural model (Ref. 9) has resulted in a 20 percent increase in the iodine-131 derived response levels identified in paragraph (d)(1) and (d)(2) of the recommendations. Generally, similar magnitude changes are reflected in the derived response levels for the other radionuclides. Newer data on iodine-131 dose conversion factors (Ref. 17) would have further increased the derived response levels for that radionuclide by about 40 percent, but these data have not been used pending their acceptance by United States recommending authorities. In addition, the proposal contained a systematic error in that the pasture derived response levels were stated to be based on fresh weight but were in fact based on dry weight. Fresh weight values (¼ of dry weight values) are identified in the final recommendations and are listed under "Forage Concentration".

Other Comments

14. A comment addressed the definition of the critical or sensitive population for the tables in proposed § 1090.400(d) and observed that there is a greater risk per rem to the younger age groups than to adults. Another comment requested further explanation of the relative ability to protect children and adults.

FDA agrees that, ideally, the critical segment of the population should be defined in terms of the greatest risk per unit intake. However, this would introduce greater complexity into the recommendations than is justified, because the risk estimates are uncertain. The final recommendations provide derived response levels for infants at the Preventive PAG and infants and adults for the Emergency PAG.

FDA has reexamined the available data and concludes that taking action at the Preventive PAG (based on the infant as the critical or sensitive population) will also provide protection of the fetus from the mother's ingestion of milk. The definition of newborn infant in the tables in paragraph (d) of the PAG's has been revised to reflect this conclusion.

15. EPA commented that its regulations governing drinking water (40 CFR Subchapter D) permit blending of water to meet maximum contaminant levels. EPA suggested that FDA's short-term recommendations should be compatible with the long-term EPA regulations.

As stated in paragraphs 1 and 2 of this notice, FDA's recommendations apply to human food and animal feed, whereas EPA is responsible for providing guidance on contaminated water. Also, as discussed in paragraph 3 of the proposal, there is a long-standing FDA policy that blending of food is unlawful under the Federal Food, Drug, and Cosmetic Act. Further, these guides are intended for protective actions under emergency situations and are not for continuous exposure applications. For these reasons, FDA concludes that the differences between its recommendations and EPA's regulations are appropriate.

16. Two comments were received on the adequacy or availability of resources for sampling and analysis of State, local, and Federal agencies and the adequacy of guidance on sampling procedures.

These recommendations are not designed to provide a compendium of sampling techniques, methods, or resources. The Department of Energy through its Interagency Radiological Assistance Plan (IRAP) coordinates the provision of Federal assistance and an Offsite Instrumentation Task Force of the Federal Radiological Preparedness Coordinating Committee administered by FEMA is developing specific guidance on instrumentation and methods for sampling food (Ref. 21).

Cost Analysis

17. Several comments argued that FDA's cost/benefit analysis used to establish the PAG levels was inadequate. Comments stated that it is not appropriate to assign a unique fixed dollar value to the adverse health effects associated with one person-rem of dose.

FDA advises that its cost/benefit analysis was not conducted to establish the PAG levels. FDA considers such use inappropriate in part because of the inability to assess definitively the total societal impacts (positive and negative) of such actions. Rather, the cost/benefit analysis was used to determine whether protective actions at the recommended PAG's would provide a net societal benefit. To make such an assessment, it is necessary to place a dollar value on a person-rem of dose.

18. Several comments also questioned the appropriateness of the assumption in the cost/benefit analysis of 23 days of protective action, the need to address radionuclides other than iodine-131, and the need to consider the impact of other protective actions.

The cost assessments have been extensively revised to consider all the radionuclides for which derived response levels are provided in the recommendations and to incorporate updated cost data and risk estimates (Ref. 22). The cost/benefit analysis is limited to the condemnation of milk and the use of stored feed because accident analyses indicate that the milk pathway is the most likely to require protective action. Further, these two actions are the most likely protective actions that will be implemented.

FDA approached the cost/benefit analysis by calculating the concentration of radioactivity in milk at which the cost of taking action equals the risk avoided by the action taken on a daily milk intake basis. The assessment was done on a population basis and considered only the direct costs of the protective actions. The analysis indicates that, for restricting feed to stored feed, the cost-equals-benefit concentrations are about one-fiftieth to one-eightieth of the Preventive PAG level (derived peak milk concentration) for iodine-131, cesium-134, and cesium-137 and about one-third

of the level for strontium-89 and strontium-90. For condemnation of milk, based on value at the farm, the cost-equals-benefit concentrations are similar fractions of the Emergency PAG levels (derived peak milk concentration). If condemnation of milk is based on retail market value, the cost-equals-benefit concentrations are greater by a factor of two. Thus, it appears that protective actions at the Preventive or Emergency PAG levels will yield a net societal benefit. However, in the case of strontium-89 and strontium-90, protective action will yield a benefit only for concentrations greater than about one-third the derived peak values. In the case of iodine-131, cesium-134, and cesium-137, protective actions could be continued to avoid 95 percent of the projected radiation dose for initial peak concentrations at the PAG level.

References

The following information has been placed on display in the Dockets Management Branch (HFA-305), Food and Drug Administration, Rm. 4-62, 5600 Fishers Lane, Rockville, MD 20857, and may be seen between 9 a.m. and 4 p.m., Monday through Friday.

1. Federal Radiation Council, Memorandum for the President, "Radiation Protection Guidance for Federal Agencies," Federal Register, August 22, 1964 (29 FR 12056), and Report No. 5 (July 1964).

2. Federal Radiation Council, Memorandum for the President, "Radiation Protection Guidance for Federal Agencies," Federal Register," May 22, 1965 (30 FR 6953), and Report No. 7 (May 1965).

3. National Academy of Sciences/National Research Council, "The Effects on Population of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on Biological Effects of Ionizing Radiation (BEIR-III) (1980).

4. United States Nuclear Regulatory Commission, Reactor Safety Study, WASH-1400, Appendix VI (October 1975).

5. Ron, E. and B. Modan, "Benign and Malignant Thyroid Neoplasms After Childhood Irradiation for Tinea Capitis," *Journal of the National Cancer Institute*, Vol. 65, No. 1 (July 1980).

6. International Commission on Radiological Protection (ICRP), Recommendations of the International Commission on Radiological Protection, ICRP Publication 26, Annals of the ICRP, Pergamon Press (1977).

7. Environmental Protection Agency, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 520/1-75-001, revised June 1980.

8. United Nations Scientific Committee on the Effects of Atomic Radiation, 1977 Report, United Nations, New York (1977).

9. Ng, Y. C., C. S. Colsher, D. J. Quinn, and S. E. Thompson, "Transfer Coefficients for the Prediction of the Dose to Man Via the Forage-Cow-Milk Pathway from Radionuclides Released to the Biosphere," UCRL-51939, Lawrence Livermore Laboratory (July 15, 1977).

10. International Commission on Radiological Protection, Report of a Task Group of Committee 2 on Reference Man, Publication 23, p. 360, Pergamon Press, Oxford (1974).

11. U.S. Department of Agriculture, "Household Food Consumption Survey 1965-1966."

12. Wellman, H. N. and R. T. Anger, "Radioiodine Dosimetry and the Use of Radioiodines Other Than ^{131}I in Thyroid Diagnosis," *Seminars in Nuclear Medicine*, 3:356 (1971).

13. Killough, G. G., D. E. Dunning, S. R. Bernard, and J. C. Pleasant, "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities, Vol. 1," ORNL/NUREG/TM-190, Oak Ridge National Laboratory (June 1978).

14. National Council on Radiation Protection and Measurements, "Cesium-137 From the Environment to Man: Metabolism and Dose," NCRP Report No. 52, Washington (January 15, 1977).

15. International Commission on Radiological Protection, Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Part 1, Annals of the ICRP, Pergamon Press (1979).

16. Papworth, D. G., and J. Vennart, "Retention of ^{90}Sr in Human Bone at Different Ages and Resulting Radiation Doses," *Physics in Medicine and Biology*, 18:169-186 (1973).

17. Kereiakes, J. G., P. A. Feller, F. A. Ascoli, S. R. Thomas, M. J. Gelfand, and E. L. Saenger, "Pediatric Radiopharmaceutical Dosimetry" *in* "Radiopharmaceutical Dosimetry Symposium," April 26-29, 1976, HEW Publication (FDA) 76-8044 (June 1976).

18. National Academy of Sciences/National Research Council, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on Biological Effects of Ionizing Radiation (BEIR-I) (1972).

19. National Council on Radiation Protection and Measurements (NCRP), "Basic Radiation Protection Criteria," NCRP Report No. 39, Washington (1971).

20. Bogen, K. T., and A. S. Goldin, "Population Exposure to External Natural Radiation Background in the United States," ORP/SEPD-80-12, Environmental Protection Agency, Washington, DC (April 1981).

21. Federal Interagency Task Force on Offsite Emergency Instrumentation for Nuclear Accidents, "Guidance on Offsite Emergency Radiation Measurement Systems: Phase 2, Monitoring and Measurement of Radionuclides to Determine Dose Commitment in the Milk Pathway," developed by Exxon Nuclear Idaho Co. Inc., Idaho Falls, ID, Draft, July 1981 (to be published by FEMA).

22. Shleien, B., G. D. Schmidt, and R. P. Chiacchierini, "Background for Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds," September 1981, Department of Health and Human Services, Food and Drug Administration, Bureau of Radiological Health, Rockville, MD.

Pertinent background data and information on the recommendations are on file in the Dockets Management Branch, and copies are available from that office (address above).

Based upon review of the comments received on the proposal of December 15, 1978 (43 FR 58790), and FDA's further consideration of the need to provide guidance to State and local agencies for use in emergency response planning in the event that an incident results in the radioactive contamination of human food or animal feed, the agency offers the following recommendations regarding protective action planning for human food and animal feeds:

Accidental Radioactive Contamination of Human Food and Animal Feeds; Recommendations for State and Local Agencies

(a) *Applicability.* (1) These recommendations are for use by appropriate State or local agencies in response planning and the conduct of radiation protection activities involving the production, processing, distribution, and use of human food and animal feeds in the event of an incident resulting in the lease of radioactivity to the environment. The Food and Drug Administration (FDA) recommends that this guidance be used on a case-by-case basis to determine the need for taking appropriate protective action in the event of a diversity of contaminating events, such as nuclear facility accidents, transportation accidents, and fallout from nuclear devices.

(2) Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The Protective Action Guides (PAG's) in paragraph (c) of these recommendations represent FDA's judgment as to the level of food contamination resulting from radiation incidents at which protective action should be taken to protect the public health. Further, as provided by Federal guidance issued by the Federal Radiation Council, if, in a particular situation, and effective action with low total impact is available, initiation of such action at a projected dose lower than the PAG may be justifiable. If only very high-impact action would be effective, initiation of such action at a projected dose higher than the PAG may be justifiable. (See 29 FR 12056; August 22, 1964.) A basic assumption in the development of protective action guidance is that a condition requiring protective action is unusual and should not be expected to occur frequently.

Circumstances that involve repetitive occurrence, a substantial probability of recurrence within a period of 1 or 2 years, or exposure from multiple sources (such as airborne cloud and food pathway) would require special consideration. In such a case, the total projected dose from the several events and the total impact of the protective actions that might be taken to avoid the future dose from one or more of these events may need to be considered. In any event, the numerical values selected for the PAG's are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes.

(3) A protective action is an action or measure taken to avoid most of the radiation dose that would occur from future ingestion of foods contaminated with radioactive materials. These recommendations are intended for implementation within hours or days from the time an emergency is recognized. The action recommended to be taken should be continued for a sufficient time to avoid most of the projected dose. Evaluation of when to cease a protective action should be made on a case-by-case basis considering the specific incident and the food supply contaminated. In the case of the pasture/cow/milk/person pathway, for which derived "response levels" are provided in paragraph (d) of these recommendations, it is expected that actions would not need to extend beyond 1 or 2 months due to the reduction of forage concentrations by weathering (14-day half-life assumed). In the case of fresh produce directly contaminated by deposition from the cloud, actions would be necessary at the time of harvest. This guidance is not intended to apply to the problems of long-term food pathway contamination where adequate time after the incident is available to evaluate the public health consequences of food contamination using current recommendations and the guidance in Federal Radiation Council (FRC) Report No. 5, July 1964 and Report No. 7, May 1965.

(b) *Definitions.* (1) "Dose" is a general term denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. In these recommendations it refers specifically to the term "dose equivalent."

(2) "Dose commitment" means the radiation dose equivalent received by an exposed individual to the organ cited over a lifetime from a single event.

(3) "Dose equivalent" is a quantity that expresses all radiation on a common scale for calculating the effective absorbed dose. It is defined as the product of the absorbed dose in rads and certain modifying factors. The unit of dose equivalent is the rem.

(4) "Projected dose commitment" means the dose commitment that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken.

(5) "Protective action" means an action taken to avoid most of the exposure to radiation that would occur from future ingestion of foods contaminated with radioactive materials.

(6) "Protective action guide (PAG)" means the projected dose commitment values to individuals in the general population that warrant protective action following a release of radioactive material. Protective action would be warranted if the expected individual dose reduction is not offset by negative social, economic, or health effects. The PAG does not include the dose that has unavoidably occurred before the assessment.

(7) "Preventive PAG" is the projected dose commitment value at which responsible officials should take protective actions having minimal ipact to prevent or reduce the radioactive contamination of human food or animal feeds.

(8) "Emergency PAG" is the projected dose commitment value at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce and at which the responsible officials should determine whether condemnation or another disposition is appropriate. At the Emergency PAG, higher impact actions are justified because of the projected health hazards.

(9) "Rad" means the unit of absorbed dose equal to 0.01 joule per kilogram in any medium.

(10) "Rem" is a special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors.

(11) "Response level" means the activity of a specific radionuclide (i) initially deposited on pasture; or (ii) per unit weight or volume of food or animal feed; or (iii) in the total dietary intake which corresponds to a particular PAG.

(c) *Protective action guides (PAG's).* To permit flexibility of action for the reduction of radiation exposure to the public via the food pathway due to the occurrence of a contaminating event, the following Preventive and Emergency PAG's for an exposed individual in the population are adopted:

(1) *Preventive PAG* which is (i) 1.5 rem projected dose commitment to the thyroid, or (ii) 0.5 rem projected dose commitment to the whole body, bone marrow, or any other organ.

(2) *Emergency PAG* which is (i) 15 rem projected dose commitment to the thyroid, or (ii) 5 rem projected dose commitment to the whole body, bone marrow, or any other organ.

(d) *Response levels equivalent to PAG.* Although the basic PAG recommendations are given in terms of projected dose equivalent, it is often more convenient to utilize specific radionuclide concentrations upon which to initiate protective action. Derived response levels equivalent to the PAG's for radionuclides of interest are:

(1) *Response level for Preventive PAG.* Infant [1] as critical segment of population.

[1] Newborn infant includes fetus (pregnant women) as critical segment of population for iodine-131. For other radionuclides, "infant" refers to child less than 1 year of age.

Response levels for preventive PAG	^{131}I,[2]	^{134}Cs,[4]	^{137}Cs,[4]	^{90}Sr	^{89}Sr
Initial Activity Area Deposition (microcuries/square meter)	0.13	2	3	0.5	8
Forage Concentration [3] (microcuries/kilogram)	0.05	0.8	1.3	0.18	3
Peak Milk Activity (microcuries/liter)	0.015	0.15	0.24	0.009	0.14
Total intake (microcuries)	0.09	4	7	0.2	2.6

[2] From fallout, iodine-131 is the only radioiodine of significance with respect to milk contamination beyond the first day. In case of a reactor accident, the cumulative intake of iodine-133 via milk is about 2 percent of iodine-131 assuming equivalent deposition.

[3] Fresh weight.

[4] Intake of cesium via the meat/person pathway for adults may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat as appropriate. If both cesium-134 and cesium-137 are equally present as might be expected for reactor accidents, the response levels should be reduced by a factor of two.

(2) *Response level for Emergency PAG.* The response levels equivalent to the Emergency PAG are presented for both infants and adults to permit use of either level and thus assure a flexible approach to taking action in cases where exposure of the most critical portion of the population (infants and pregnant women) can be prevented:

Response levels for emergency PAG	^{131}I[2]		^{134}Cs[3]		^{137}Cs[3]		^{90}Sr		^{89}Sr	
	Infant[1]	Adult	Infant[1]	Adult	Infant[1]	Adult	Infant[1]	Adult	Infant[1]	Adult
Initial Activity Area Deposition (microcuries/square meter)	1.3	18	20	40	30	50	5	20	80	1600
Forage Concentration [4] (microcuries/kilogram)	0.5	7	8	17	13	19	1.8	8	30	700
Peak Milk Activity (microcuries/liter)	0.15	2	1.5	3	2.4	4	0.09	0.4	1.4	30
Total Intake (microcuries)	0.9	10	40	70	70	80	2	7	26	400

[1] Newborn infant includes fetus (pregnant women) as critical segment of population for iodine-131.
[2] "Infant" refers to child less than 1 year of age.
[3] From fallout, iodine-131 is the only radioiodine of significance with respect to milk contamination beyond the first day. In case of a reactor accident the cumulative intake of iodine-133 via milk is about 2 percent of iodine-131 assuming equivalent deposition.
[4] Fresh weight.
[5] Intake of cesium via the meat/person pathway for adults may exceed that of the milk pathway; therefore, such levels in milk should cause surveillance and protective actions for meat as appropriate. If both cesium-134 and cesium-137 are equally present, as might be expected for reactor accidents, the response levels should be reduced by a factor of 2.

(e) *Implementation.* When using the PAG's and associated response levels for response planning or protective actions, the following conditions should be followed:

(1) *Specific food items.* To obtain the response level (microcurie/kilogram) equivalent to the PAG for other specific foods, it is necessary to weigh the contribution of the individual food to the total dietary intake; thus,

$$\text{Response Level} = \frac{\text{Total intake (microcuries)}}{\text{Consumption (kilograms)}}$$

Where: Total intake (microcuries) for the appropriate PAG and radionuclide is given in paragraph (d) of these recommendations
and
Consumption is the product of the average daily consumption specified in paragraph (e)(1)(i) of these recommendations and the days of intake of the contaminated food as specified in paragraph (e)(1)(ii) of these recommendations.

(i) The daily consumption of specific foods in kilograms per day for the general population is given in the following table:

Food	Average consumption for the general population (kilogram/day)
Milk, cream, cheese, ice cream [1]	.570
Fats, oils	.055
Flour, cereal	.091
Bakery products	.150
Meat	.220
Poultry	.055
Fish and shellfish	.023
Eggs	.055
Sugar, sirups, honey, molasses, etc.	.073
Potatoes, sweet potatoes	.105
Vegetables, fresh (excluding potatoes)	.145
Vegetables, canned, frozen, dried	.077
Vegetables, juice (single strength)	.009
Fruit, fresh	.165
Fruit, canned, frozen, dried	.036
Fruit, juice (single strength)	.045
Other beverages (soft drinks, coffee, alcoholic)	.180
Soup and gravies (mostly condensed)	.036
Nuts and peanut butter	.009
Total	2.099

[1] Expressed as calcium equivalent; that is, the quantity of whole fluid milk to which dairy products are equivalent in calcium content.

(ii) Assessment of the effective days of intake should consider the specific food, the population involved, the food distribution system, and the radionuclide. Whether the food is distributed to the retail market or produced for home use will significantly affect the intake in most instances. Thus, while assessment of intake should be on a case-by-case basis, some general comments may be useful in specific circumstances.

(*a*) For short half-life radionuclides, radioactive decay will limit the ingestion of radioactive materials and the effective "days of intake". The effective "days of intake" in this case is 1.44 times the radiological half-life. For iodine–131 (half-life—8.05 days), the effective "days of intake" is, thus, 11 days.

(*b*) Where the food product is being harvested on a daily basis, it may be reasonable to assume reduction of contamination due to weathering. As an initial assessment, it may be appropriate to assume a 14-day weathering half-life (used for forage in pasture/cow/milk pathway) pending further evaluation. In this case, the effective "days of intake" is 20 days. A combination of radioactive decay and weathering would result in an effective half-life for iodine–131 of 5 days and reduce the "days of intake" to 7 days.

(*c*) In the case of a food which is sold in the retail market, the effective "days of intake" would probably be limited by the quantity purchased at a given time. For most food, especially fresh produce, this would probably be about a 1 week supply. In some cases, however, larger quantities would be purchased for home canning or freezing. For most foods and members of the public, an effective "days of intake" 30 days is probably conservative.

(iii) For population groups having significantly different dietary intakes, an appropriate adjustment of dietary factors should be made.

(2) *Radionuclide mixtures.* If a mixture of radionuclides is present, the sum of all the ratios of the concentration of each specific radionulide to its specific response level equivalent to the PAG should be less than one.

(3) *Other radionuclides.* The response level for the Preventive and Emergency PAG for other radionuclides should be calculated from dose commitment factors available in the literature (Killough, G. G., et al., ORNL/NUREG/TM–190 (1978) (adult only), and U.S. Nuclear Regulatory Commission Reg. Guide 1.109 (1977)).

(4) *Other critical organs.* Dose commitment factors in U.S. Nuclear Regulatory Commission Reg. Guide 1.109 (1977) refer to bone rather than bone marrow dose commitments. For the purpose of these recommendations, dose commitment to the bone marrow is considered to be 0.3 of the bone dose commitment. This is based on the ratio of dose rate per unit activity in the bone marrow to dose rate per unit activity in a small tissue-filled cavity in bone and assumes that strontium–90 is distributed only in the mineral bone (Spiers, F. W., et al., *in* "Biomedical Implications of Radiostrontium Exposure," AEC Symposium 25 (1972). The ratio for strontium–89 is the same because the mean particle energies are similar (0.56 MeV (megaelectronvolts)). Situations could arise in which an organ other than those discussed in this paragraph could

be considered to be the organ receiving the highest dose per unit intake. In the case of exposure via the food chain, depending on the radionuclide under consideration, the gastrointestinal tract could be the primary organ exposed. The references cited in paragraph (e)(3) of these recommendations contain dose commitment factors for the following organs: bone, kidneys, liver, ovaries, spleen, whole body, and gastrointestinal tract.

(5) Prompt notification of State and local agencies regarding the occurrence of an incident having potential public health consequences is of significant value in the implementation of effective protective actions. Such notification is particularly important for protective actions to prevent exposures from the airborne cloud but is also of value for food pathway contamination. Accordingly, this protective action guidance should be incorporated in State/local emergency plans which provide for coordination with nuclear facility operators including prompt notification of accidents and technical communication regarding public health consequences and protective action.

(f) *Sampling parameter.* Generally, sites for sample collection should be the retail market, the processing plant, and the farm. Sample collection at the milk processing plant may be more effcient in determining the extent of the food pathway contamination. The geographic area where protective actions are implemented should be based on considerations of the wind direction and atmospheric transport, measurements by airborne and ground survey teams of the radioactive cloud and surface deposition, and measurements in the food pathway.

(g) *Recommended methods of analysis.* Techniques for measurement of radionuclide concentrations should have detection limits equal to or less than the response levels equivalent to specific PAG. Some useful methods of radionuclide analysis can be found in:

(1) *Laboratory Methods*—"HASL Procedure Manual," edited by John H. Harley, HASL 300 ERDA, Health and Safety Laboratory, New York, NY, 1973; "Rapid Methods for Estimating Fission Product Concentrations in Milk," U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999–R–2, May 1963; "Evaluation of Ion Exchange Cartridges for Field Sampling of Iodine–131 in Milk," Johnson, R. H. and T. C. Reavy, *Nature*, 208, (5012): 750–752, November 20, 1965; and

(2) *Field Methods*—Kearny, C. H., ORNL 4900, November 1973; Distenfeld, C. and J. Klemish, Brookhaven National Laboratory, NUREG/CR–0315, December 1978; and International Atomic Energy Agency, "Environmental Monitoring in Emergency Situations," 1966. Analysis need not be limited to these methodologies but should provide comparable results. Action should not be taken without verification of the analysis. Such verification might include the analysis of duplicate samples, laboratory measurements, sample analysis by other agencies, sample analysis of various environmental media, and descriptive data on radioactive release.

(h) *Protective actions.* Actions are appropriate when the health benefit associated with the reduction in dose that can be achieved is considered to offset the undesirable health, economic, and social factors. It is the intent of these recommendations that, not only the protective actions cited for the Emergency PAG be initiated when the equivalent response levels are reached, but also that actions appropriate at the Preventive PAG be considered. This has the effect of reducing the period of time required during which the protective action with the greater economic and social impact needs to be taken. FDA recommends that once one or more protective actions are initiated, the action or actions continue for a sufficient time to avoid most of the projected dose. There is a longstanding FDA policy that the purposeful blending of adulterated food with unadulterated food is a violation of the Federal Food, Drug, and Cosmetic Act. The following protective actions should be considered for implementation when the projected dose equals or exceeds the appropriate PAG:

(1) *Preventive PAG.* (i) For pasture: (*a*) Removal of lactating dairy cows from contaminated pasturage and substitution of uncontaminated stored feed.

(*b*) Substitute source of uncontaminated water.

(ii) For milk: (*a*) Withholding of contaminated milk from the market to allow radioactive decay of short-lived radionuclides. This may be achieved by storage of frozen fresh milk, frozen concentrated milk, or frozen concentrated milk products.

(*b*) Storage for prolonged times at reduced temperatures also is feasible provided ultrahigh temperature pasteurization techniques are employed for processing (Finley, R. D., H. B. Warren, and R. E. Hargrove, "Storage Stability of Commercial Milk," *Journal of Milk and Food Technology*, 31(12):382–387, December 1968).

(*c*) Diversion of fluid milk for production of dry whole milk, nonfat dry milk, butter, cheese, or evaporated milk.

(iii) For fruits and vegetables: (*a*) Washing, brushing, scrubbing, or peeling to remove surface contamination.

(*b*) Preservation by canning, freezing, and dehydration or storage to permit radioactive decay of short-lived radionuclides.

(iv) For grains: (*a* Milling and (*b*) polishing.

(v) For other food products, processing to remove surface contamination.

(vi) For meat and meat products, intake of cesium-134 and cesium-137 by an adult via the meat pathway may exceed that of the milk pathway; therefore, levels of cesium in milk approaching the "response level" should cause surveillance and protective actions for meat as appropriate.

(vii) For animal feeds other than pasture, action should be on a case-by-case basis taking into consideration the relationship between the radionuclide concentration in the animal feed and the concentration of the radionuclide in human food. For hay and silage fed to lactating cows, the concentration should not exceed that equivalent to the recommendations for pasture.

(2) *Emergency PAG.* Responsible officials should isolate food containing radioactivity to prevent its introduction into commerce and determine whether condemnation or another disposition is appropriate. Before taking this action, the following factors should be considered:

(i) The availability of other possible protective actions discussed in paragraph (h)(1) of these recommendations.

(ii) Relative proportion of the total diet by weight represented by the item in question.

(iii) The importance of the particular food in nutrition and the availability of uncontaminated food or substitutes having the same nutritional properties.

(iv) The relative contribution of other foods and other radionuclides to the total projected dose.

(v) The time and effort required to effect corrective action.

This notice is issued under the Public Health Service Act (secs. 301, 310, 311, 58 Stat. 691–693 as amended, 88 Stat. 371 (42 U.S.C. 241, 242*o*, 243)) and under authority delegated to the Commissioner of Food and Drugs (21 CFR 5.10).

Dated: October 11, 1982.

Arthur Hull Hayes, Jr.,

Commissioner of Food and Drugs.

[FR Doc. 82–28595 Filed 10–21–82; 8:45 am]

BILLING CODE 4160–01–M

CHAPTER 4

Protective Action Guides for the Intermediate Phase (Deposited Radioactive Materials)

4.1 Introduction

Following a nuclear incident it may be necessary to temporarily relocate the public from areas where extensive deposition of radioactive materials has occurred until decontamination has taken place. This chapter identifies the levels of radiation exposure which indicate when relocation from contaminated property is warranted.

The period addressed by this chapter is denoted the "intermediate phase." This is arbitrarily defined as the period beginning after the source and releases have been brought under control and environmental measurements are available for use as a basis for decisions on protective actions and extending until these protective actions are terminated. This phase may overlap the early and late phases and may last from weeks to many months. For the purpose of dose projection, it is assumed to last for one year. Prior to this period protective actions will have been taken based upon the PAGs for the early phase. It is assumed that decisions will be made during the intermediate phase concerning whether particular areas or properties from which persons have been relocated will be decontaminated and reoccupied, or condemned and the occupants permanently relocated. These actions will be carried out during the late or "recovery" phase.

Although these Protective Action Guides (PAGs) were developed based on expected releases of radioactive materials characteristic of reactor incidents, they may be applied to any type of incident that can result in long-term exposure of the public to deposited radioactivity.

PAGs are expressed in terms of the projected doses above which specified protective actions are warranted. In the case of deposited radioactivity, the major relevant protective action is relocation. Persons not relocated (i.e., those in less contaminated areas) may reduce their dose through the application of simple decontamination techniques and by spending more time than usual in low exposure rate areas (e.g., indoors).

The PAGs should be considered mandatory only for use in planning, e.g., in developing radiological emergency response plans. During an incident, because of unanticipated local conditions and constraints, professional judgment by responsible officials will be required in their application. Situations can be envisaged, where contamination from a nuclear incident

occurs at a site or time in which relocation of the public, based on the recommended PAGs, would be impracticable. Conversely, under some conditions, relocation may be quite practicable at projected doses below the PAGs. These situations require judgments by those responsible for protective action decisions at the time of the incident. A discussion of the implementation of these PAGs is provided in Chapter 7.

The PAGs for relocation specified in this chapter refer only to estimates of doses due to exposure during the first year after the incident. Exposure pathways include external exposure to radiation from deposited radioactivity and inhalation of resuspended radioactive materials. Protective Action Guides for ingestion exposure pathways, which also apply during the intermediate phase, are discussed separately in Chapter 3.

Individuals who live in areas contaminated by long-lived radionuclides may be exposed to radiation from these materials, at a decreasing rate, over the entire time that they live in the area. This would be the case for those who are not relocated as well as for persons who return following relocation. Because it is usually not practicable, at the time of a decision to relocate, to calculate the doses that might be incurred from exposure beyond one year, and because different protective actions may be appropriate over such longer periods of time, these doses are not included in the dose specified in the PAGs for relocation.

4.1.1 Exposure Pathways

The principal pathways for exposure of the public occupying locations contaminated by deposited radioactivity are expected to be exposure of the whole body to external gamma radiation from deposited radioactive materials (groundshine) and internal exposure from the inhalation of resuspended materials. For reactor incidents, external gamma radiation is expected to be the dominant source.

Almost invariably relocation decisions will be based on doses from the above pathways. (However, in rare cases where food or drinking water is contaminated to levels above the PAG for ingestion, and its withdrawal from use will create a risk from starvation greater than that from the radiation dose, the dose from ingestion should be added to the dose from the above pathways.) PAGs related specifically to the withdrawal of contaminated food and water from use are discussed in Chapter 3.

Other potentially significant exposure pathways include exposure to beta radiation from surface contamination and direct ingestion of contaminated soil. These pathways are not expected to be controlling for reactor incidents (AR-89).

4.1.2 The Population Affected

The PAGs for relocation are intended for use in establishing the boundary of a restricted zone within an

area that has been subjected to deposition of radioactive materials. During their development, consideration was given to the higher risk of effects on health to children and fetuses from radiation dose and the higher risk to some other population groups from relocation. To avoid the complexity of implementing separate PAGs for individual members of the population, the relocation PAG is established at a level that will provide adequate protection for the general population.

Persons residing in contaminated areas outside the restricted zone will be at some risk from radiation dose. Therefore, guidance on the reduction of dose during the first year to residents outside this zone is also provided. Due to the high cost of relocation, it is more practical to reduce dose in this population group by the early application of simple, low-impact, protective actions other than by relocation.

4.2 The Protective Action Guides for Deposited Radioactivity

PAGs for protection from deposited radioactivity during the intermediate phase are summarized in Table 4-1. The basis for these values is presented in detail in Appendix E. In summary, relocation is warranted when the projected sum of the dose equivalent from external gamma radiation and the committed effective dose equivalent from inhalation of resuspended radionuclides exceeds 2 rem in the first year. Relocation to avoid exposure of the skin to beta radiation is warranted at 50 times the numerical value of the relocation PAG for effective dose equivalent.

Persons who are not relocated, i.e., those in areas that receive relatively small amounts of deposited radioactive material, should reduce their exposure by the application of other measures. Possible dose reduction techniques range from the simple processes of scrubbing and/or flushing surfaces, soaking or plowing of soil, removal and disposal of small spots of soil found to be highly contaminated (e.g., from settlement of water), and spending more time than usual in lower exposure rate areas (e.g., indoors), to the difficult and time-consuming processes of removal, disposal, and replacement of contaminated surfaces. It is anticipated that simple processes will be most appropriate for early application. Many can be carried out by residents themselves with support from response officials for assessment of the levels of contamination, guidance on appropriate actions, and disposal of contaminated materials. Due to the relatively low cost and risk associated with these protective actions, they may be justified as ALARA measures at low dose levels. It is, however, recommended that response officials concentrate their initial efforts in areas where the projected dose from the first year of exposure exceeds 0.5 rem. In addition, first priority should be given to cleanup of residences of pregnant women who may exceed this criterion.

Table 4-1 Protective Action Guides for Exposure to Deposited Radioactivity During the Intermediate Phase of a Nuclear Incident

Protective Action	PAG (projected dose)[a]	Comments
Relocate the general population.[b]	≥2 rem	Beta dose to skin may be up to 50 times higher
Apply simple dose reduction techniques.[c]	<2 rem	These protective actions should be taken to reduce doses to as low as practicable levels.

[a]The projected sum of effective dose equivalent from external gamma radiation and committed effective dose equivalent from inhalation of resuspended materials, from exposure or intake during the first year. Projected dose refers to the dose that would be received in the absence of shielding from structures or the application of dose reduction techniques. These PAGs may not provide adequate protection from some long-lived radionuclides (see Section 4.2.1).

[b]Persons previously evacuated from areas outside the relocation zone defined by this PAG may return to occupy their residences. Cases involving relocation of persons at high risk from such action (e.g., patients under intensive care) should be evaluated individually.

[c]Simple dose reduction techniques include scrubbing and/or flushing hard surfaces, soaking or plowing soil, minor removal of soil from spots where radioactive materials have concentrated, and spending more time than usual indoors or in other low exposure rate areas.

4.2.1 Longer Term Objectives of the Protective Action Guides

It is an objective of these PAGs to assure that 1) doses in any single year after the first will not exceed 0.5 rem, and 2) the cumulative dose over 50 years (including the first and second years) will not exceed 5 rem. For source terms from reactor incidents, the above PAG of 2 rem projected dose in the first year is expected to meet both of those objectives through radioactive decay, weathering, and normal part time occupancy in structures. Decontamination of areas outside the restricted area may be required during the first year to meet these objectives for releases consisting primarily of long-lived radionuclides. For situations where it is impractical to meet these objectives though decontamination, consideration should be given to relocation at a lower projected first year dose than that specified by the relocation PAG.

After the population has been protected in accordance with the PAGs for relocation, return for occupancy of previously restricted areas should be governed on the basis of Recovery Criteria as presented in Chapter 8.

Projected dose considers exposure rate reduction from radioactive decay and, generally, weathering. When one also considers the anticipated effects of shielding from partial occupancy in homes and other structures, persons who are not relocated should receive a dose substantially less than the projected dose. For commonly assumed reactor source terms, we estimate that 2 rem projected dose in the first year will be reduced to about 1.2 rem by this factor. The application of simple decontamination techniques shortly after the incident can be assumed to provide a further 30 percent or more reduction, so that the maximum first year dose to persons who are not relocated is expected to be less than one rem. Taking account of decay rates assumed to be associated with releases from nuclear power plant incidents (SN-82) and shielding from partial occupancy and weathering, a projected dose of 2 rem in the first year is likely to amount to an actual dose of 0.5 rem or less in the second year and 5 rem or less in 50 years. The application of simple dose reduction techniques would reduce these doses further. Results of calculations supporting these projections are summarized in Table E-6 of Appendix E.

4.2.2 Applying the Protective Action Guides for Relocation

Establishing the boundary of a restricted zone may result in three different types of actions:

1. Persons who, based on the PAGs for the early phase of a nuclear incident (Chapter 2), have already been evacuated from an area which is now designated as a restricted zone must be converted to relocation status.

2. Persons not previously evacuated who reside inside the restricted zone should relocate.

3. Persons who normally reside outside the restricted zone, but were previously evacuated, may return. A gradual return is recommended, as discussed in Chapter 7.

Small adjustments to the boundary of the restricted zone from that given by the PAG may be justified on the basis of difficulty or ease of implementation. For example, the use of a convenient natural boundary could be cause for adjustment of the restricted zone. However, such decisions should be supported by demonstration that exposure rates to persons not relocated can be promptly reduced by methods other than relocation to meet the PAG, as well as the longer term dose objectives addressed in Section 4.2.1.

Reactor incidents involving releases of major portions of the core inventory under adverse atmospheric conditions can be postulated for which

large areas would have to be restricted under these PAGs. As the affected land area increases, they will become more difficult and costly to implement, especially in densely populated areas. For situations where implementation becomes impracticable or impossible (e.g., a large city), informed judgment must be exercised to assure priority of protection for individuals in areas having the highest exposure rates. In such situations, the first priority for any area should be to reduce dose to pregnant women.

4.3 Exposure Limits for Persons Reentering the Restricted Zone

Individuals who are permitted to reenter a restricted zone to work, or for other justified reasons, will require protection from radiation. Such individuals should enter the restricted zone under controlled conditions in accordance with dose limitations and other procedures for control of occupationally-exposed workers (EP-87). Ongoing doses received by these individuals from living in a contaminated area outside the restricted zone need not be included as part of this dose limitation applicable to workers. In addition, dose received previously from the plume and associated groundshine, during the early phase of the nuclear incident, need not be considered.

References

AR-89 Aaberg, Rosanne, Evaluation of Skin and Ingestion Exposure Pathways. EPA 520/1-89-016. U.S. Environmental Protection Agency, Washington, (1989).

EP-87 U.S. Environmental Protection Agency. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822; January 27, 1987.

SN-82 Sandia National Laboratory. Technical Guidance for Siting Criteria Development. NUREG/CR-2239. U.S. Nuclear Regulatory Commission, Washington, (1982).

CHAPTER 5

Implementing the Protective Action Guides for the Early Phase

5.1 Introduction

This chapter provides general guidance for implementing the Protective Action Guides (PAGs) set forth in Chapter 2. In particular, the objective is to provide guidance for estimating projected doses from exposure to an airborne plume of radioactive material, and for choosing and implementing protective actions.

Following an incident which has the potential for an atmospheric release of radioactive material, the responsible State and/or local authorities will need to decide whether offsite protective actions are needed and, if so, where and when they should be implemented. These decisions will be based primarily on (a) the potential for releases, (b) projected doses as a function of time at various locations in the environment, and (c) dose savings and risks associated with various protective actions.

Due to the wide variety of nuclear facilities, incidents, and releases that could occur, it is not practical to provide specific implementing guidance for all situations. Examples of the types of sources leading to airborne releases that this guidance may be applied to are nuclear power reactors, uranium fuel cycle facilities, nuclear weapons facilities, radiopharmaceutical manufacturers and users, space vehicle launch and reentry, and research reactors. For many specific applications, however, it will be appropriate to develop and use implementing procedures that are designed for use on a case-by-case basis.

Dose conversion factors (DCF) and derived response levels (DRL) are provided for radionuclides that are most likely to be important in an incident involving an airborne release of radioactive materials. DCFs and DRLs for radionuclides not listed may be developed from the sources referenced in the tables. The values provided here are the best currently available. However, as new information is developed these values may change. This chapter will be revised from time to time to reflect such changes.

5.2 Initial Response and Sequence of Subsequent Actions

In the case of an atmospheric release, the protective actions which may be required are those which protect the population from inhalation of radioactive materials in the plume, from exposure to gamma radiation

from the plume, and from short-term exposure to radioactive materials deposited on the ground. For releases which contain a large amount of pure beta emitters, it may also be necessary to consider protective action to avoid doses to the skin from radioactive material deposited on the skin and clothing.

The early phase can be divided into two periods: (a) the period immediately following the start of an incident (possibly before a release has occurred), when little or no environmental data are available to confirm the magnitude of releases, and (b) the subsequent period, when environmental or source term measurements permit a more accurate assessment of projected doses.

During the first period, speed in completing such actions as evacuating, sheltering, and controlling access may be critical to minimizing exposure. Environmental measurements made during this period may have limited use because of the lack of availability of significant data and uncertainty about changes in environmental releases of radioactive material from their sources. In the case of a facility, for example, the uncertainty might be due to changes in pressure and radionuclide concentrations within the structures from which the plume is being released. Therefore, it is advisable to initiate early protective actions in a predetermined manner that is related to facility conditions. This will normally be carried out through recommendations provided by the facility operator. During the second period, when environmental levels are known, these actions can be adjusted as necessary.

For an incident at a facility involving significant potential for an atmospheric release with offsite consequences, the following sequence of actions is appropriate:

1. Notification of State and/or local authorities by the facility operator that conditions are such that a release is occurring, or could occur with offsite consequences. For severe incidents (e.g., general emergencies) the operator should provide protective action recommendations to State and local authorities.[1]

2. For emergencies with the potential for offsite consequences, immediate evacuation (and/or sheltering) of populations in predesignated areas without waiting for release rate information or environmental measurements.

3. Monitoring of facility conditions, release rates, environmental concentrations, and exposure rates.

---

[1]In the case of commercial nuclear power plants, fuel facilities and certain material facilities licensed by the NRC, regulations (NR-89) require that the facility operator have the capability to notify predesignated State and/or local authorities within 15 minutes of any emergency declaration. The initial notification message to State and/or local officials for any General Emergency declaration must include a protective action recommendation.

4. Estimation of offsite consequences (e.g., calculation of the plume centerline dose rates and projected doses at various distances downwind from the release point).

5. Implementation of protective actions in additional areas if needed.

6. Decisions to terminate existing protective actions should include, as a minimum, consideration of the status of the plant and the PAGs for relocation (Chapter 4). (Withdrawal of protective actions from areas where they have already been implemented is usually not advisable during the early phase because of the potential for changing conditions and confusion.)

For other types of incidents the sequence of actions may vary in details, depending on the specific emergency response plan, but in general the sequence and general reporting requirements will be the same.

5.2.1 Notification

The nuclear facility operator or other designated individual should provide the first notification to State and/or local authorities that a nuclear incident has occurred. In the case of an incident with the potential for offsite consequences, notification of State and local response organizations by a facility operator should include recommendations, based on plant conditions, for early evacuation and/or sheltering in predesignated areas. Early estimates of the various components of projected doses to the population at the site boundary, as well as at more distant locations, along with estimated time frames, should be made as soon as the relevant source or release data become available. Emergency response planners should make arrangements with the facility operator to assure that this information will be made available on a timely basis and that dose projections will be provided in units that can be directly compared to the PAGs. Planners should note that the toxic chemical hazard is greater than the radiation hazard for some nuclear incidents, e.g. a uranium hexafluoride release.

For some incidents, such as re-entry of satellites or an incident in a foreign country, notification is most likely to occur through the responsible Federal agency, most commonly the Environmental Protection Agency or the National Aeronautics and Space Administration. In such cases projections of dose and recommendations to State and local officials for protective actions will be made at the Federal level, under the Federal Radiological Emergency Response Plan (FE-85).

5.2.2 Immediate Protective Action

Guidance for developing emergency response plans for implementation of immediate protective actions for incidents at commercial nuclear power plants is contained in NUREG-0654 (NR-80). Planning elements for

incidents at other types of nuclear facilities should be developed using similar considerations. Information on the offsite consequences of accidents that can occur at commercial fuel cycle and material facilities licensed by the NRC can be found in NUREG-1140 (NR-88). The "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" (NR-78) recommends that States designate an emergency planning zone (EPZ) for protective action for plume exposure (see Chapter 2). Within this zone, an area should be predesignated for immediate response based on specified plant conditions prior to a release, or, given a release, prior to the availability of information on quantities of radioactive materials released. The shape of this area will depend on local topography and political and other boundaries. Additional areas in the balance of the EPZ, particularly in the downwind direction, may also require evacuation or sheltering, as determined by dose projections. The size of these areas will be based on the potential magnitude of the release, and of an angular spread determined by meteorological conditions and any other relevant factors.

The predesignated areas for immediate protective action may be reserved for use only for the most severe incidents and where the facility operator cannot provide a quick estimate of projected dose based on actual releases. For lesser incidents, or if the facility operator is able to provide prompt offsite dose projections, the area for immediate protective action may be specified at the time of the incident, in lieu of using a predesignated area.

Such prompt offsite dose projections may be possible when the facility operator can estimate the potential offsite dose, based on information at the facility, using relationships developed during planning that relate abnormal plant conditions and meteorological conditions to potential offsite doses. After the release starts and the release rate is measurable and/or when plant conditions or measurements can be used to estimate the characteristics of the release and the release rate as a function of time, then these factors, along with atmospheric stability, windspeed, and wind direction, can be used to estimate integrated concentrations of radioactive contamination as a function of location downwind. Although such projections are useful for initiating protective action, the accuracy of these methods for estimating projected dose will be uncertain prior to confirmatory field measurements because of unknown or uncertain factors affecting environmental pathways, inadequacies of computer modeling, and uncertainty in the data for release terms.

5.3 The Establishment of Exposure Patterns

During and immediately following the early response to a nuclear incident, sufficient environmental

measurements are unlikely to be available to project doses accurately. Doses must be projected using initial environmental measurements or estimates of the source term, and using atmospheric transport previously observed under similar meteorological conditions. These projections are needed to determine whether protective actions should be implemented in additional areas during the early phase.

Source term measurements, or exposure rates or concentrations measured in the plume at a few selected locations, may be used to estimate the extent of the exposed area in a variety of ways, depending on the types of data and computation methods available. The most accurate method of projecting doses is through the use of an atmospheric diffusion and transport model that has been verified for use at the site in question. A variety of computer software can be used to estimate exposures in real time, or to extrapolate a series of previously-prepared isopleths for unit releases under various meteorological conditions. The latter can be adjusted for the estimated source magnitude or environmental measurements at a few locations during the incident. If the model projections have some semblance of consistency with environmental measurements, extrapolation to other distances and areas can be made with greater confidence. If projections using a sophisticated site-specific model are not available, a simple, but crude, method is to measure the plume centerline exposure rate[2] at ground level (approximately one meter height) at a known distance downwind of the release point and then to calculate exposure rates at other downwind locations by assuming that the plume centerline exposure rate is a known function of the distance from the release point.

The following relationship can be used for this calculation:

$$D_2 = D_1 (R_1/R_2)^y \ ,$$

where D_1 and D_2 are measurements of exposure rates at the centerline of the plume at distances R_1 and R_2, respectively, and y is a constant that depends on atmospheric stability. For stability classes A and B, y = 2; for stability classes C and D, y = 1.5; and for stability classes E and F, y = 1. Classes A and B (unstable) occur with light winds and strong sunlight, and classes E and F (stable) with light winds at night. Classes C and D generally occur with winds stronger than about 10 mph. This method of extrapolation is risky because the measurements available at the reference distance may be unrepresentative, especially if the plume is aloft and has a looping

---

[2]The centerline exposure rate can be determined by traversing the plume at a point sufficiently far downwind that it has stabilized (usually more than one mile from the release point) while taking continuous exposure rate measurements.

behavior. In the case of an elevated plume, the ground level concentration increases with distance from the source, and then decreases, whereas any high energy gamma radiation from the overhead cloud continuously decreases with distance. For these reasons, this method of extrapolation will perform best for surface releases or if the point of measurement for an elevated release is sufficiently distant from the point of release for the plume to have expanded to ground level (usually more than one mile). The accuracy of this method will be improved by the use of measurements from many locations averaged over time.

5.4 Dose Projection

The PAGs set forth in Chapter 2 are specified in terms of the effective dose equivalent. This dose includes that due to external gamma exposure of the whole body, as well as the committed effective dose equivalent from inhaled radionuclides. Guidance is also provided on protective action levels for the thyroid and skin, in terms of the committed dose equivalent to these organs. Further references to effective or organ dose equivalent refer to these two quantities, respectively. Methods for estimating projected doses for each of these forms of exposure are discussed below. These require knowledge of, or assumptions for, the intensity and duration of exposure and make use of standard assumptions on the relation, for each radioisotope, between exposure and dose. Exposure and dose projections should be based on the best estimates available. The methods and models used here may be modified as necessary for specific sites to achieve improved accuracy.

5.4.1 Duration of Exposure

The projected dose for comparison to the early phase PAGs is normally calculated for exposure during the first four days following the projected (or actual) start of a release. The objective is to encompass the entire period of exposure to the plume and to deposited material prior to implementation of any further, longer-term protective action, such as relocation. Four days is chosen here as the duration of exposure to deposited materials during the early phase because, for planning purposes; it is a reasonable estimate of the time needed to make measurements, reach decisions, and prepare to implement relocation. However, officials at the site at the time of the emergency may decide that a different time is more appropriate. Corresponding changes to the dose conversion factors found in tables in Section 5.4.2 will be needed if another exposure period is selected.

Protective actions are taken to avoid or reduce projected doses. Doses incurred before the start of the protective action being considered should not normally be included in evaluating the need for protective action. Likewise, doses that may be incurred at later times than those affected by the specific protective action should not be included. For

example, doses which may be incurred through ingestion pathways or long-term exposure to deposited radioactive materials take place over a different, longer time period. Protective actions for such exposures should be based on guidance addressed in other chapters.

The projected dose from each radionuclide in a plume is proportional to the time-integrated concentration of the radionuclide in the plume at each location. This concentration will depend on the rate and the duration of the release and meteorological conditions. Release rates will vary with time, and this time-dependence cannot usually be predicted accurately. In the absence of more specific information, the release rate may be assumed to be constant.

Another factor affecting the estimation of projected dose is the duration of the plume at a particular location. For purposes of calculating projected dose from most pathways, exposure will start at a particular location when the plume arrives and end when the plume is no longer present, due either to an end to the release, or a change in wind direction. Exposure from one pathway (whole body exposure to deposited materials) will continue for an extended period. Other factors such as the aerodynamic diameter and solubility of particles, shape of the plume, and terrain may also affect estimated dose, and may be considered on a site- and/or source-specific basis.

Prediction of time frames for releases is difficult because of the wide range associated with the spectrum of potential incidents. Therefore, planners should consider the possible time periods between an initiating event and arrival of a plume, and the duration of releases in relation to the time needed to implement competing protective actions (i.e., evacuation and sheltering). Analyses of nuclear power reactors (NR-75) have shown that some incidents may take several days to develop to the point of a release, while others may begin as early as one-half hour after an initiating event. Furthermore, the duration of a release may range from less than one hour to several days, with the major portion of the release usually occurring within the first day.

Radiological exposure rates are quite sensitive to the wind speed. The air concentration is inversely related to the wind speed at the point of release. Concentrations are also affected by the turbulence of the air, which tends to increase with wind speed and sunlight, and by meandering of the plume, which is greater at the lower wind speeds. This results in higher concentrations generally being associated with low winds near the source, and with moderate winds at larger distances. Higher windspeed also shortens the travel time. Planning information on time frames for releases from nuclear power facilities may be found in Reference NR-78. Time frames for releases from other facilities will depend on the characteristics of the facility.

Since a change in wind direction will also affect the duration of exposure, it is very important that arrangements be made for a public, private, or military professional weather service to provide information on current meteorological and wind conditions and predicted wind direction persistence during an incident, in addition to information received from the facility operator.

5.4.2 Dose Conversion Factors

This section provides dose conversion factors (DCFs) and derived response levels (DRLs) for those radionuclides important for responding to most types of incidents. These are supplemented by an example to demonstrate their application. The DCFs are useful where multiple radionuclides are involved, because the total dose from a single exposure pathway will be the sum of the doses calculated for each radionuclide. The DRLs are surrogates for the PAG and are directly usable for releases consisting primarily of a single nuclide, in which case the DRL can be compared directly to the measured or calculated concentration. (DRLs also can be used for multiple radionuclides by summing the ratios of the environmental concentration of each nuclide to its respective DRL. To meet the PAG, this sum must be equal to or less than unity.)

DCFs and DRLs for each of the three major exposure pathways for the early phase (external exposure to plume, plume inhalation, and external exposure from deposited materials) are provided separately in Section 5.6. They are all expressed in terms of the time-integrated air concentration at the receptor so they can be conveniently summed over the three exposure pathways to obtain composite DRLs and DCFs for each radionuclide. These composite values are tabulated in Table 5-1 for effective dose and in Table 5-2 for thyroid dose from inhalation of radioiodines.

The tabulated DCFs and DRLs include assumptions on particle size, deposition velocity, the presence of short-lived daughters, and exposure duration as noted. The existence of more accurate data for individual radionuclides may justify modification of the DCFs and DRLs. The procedures described in Section 5.6 for developing the DCFs and DRLs for individual exposure pathways may be referred to, to assist such modifications.

To apply Tables 5-1 and 5-2 to decisions on implementing PAGs, one may use either the DCFs or DRLs. DCFs are used to calculate the projected composite dose for each radionuclide; these doses are then summed and compared to the PAG. The DRLs may be used by summing the ratios of the concentration of each radionuclide to its corresponding DRL. If the sum of the ratios exceeds unity, the corresponding protective action should be initiated.

Table 5-1, Continued

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[c] $\mu Ci \cdot cm^{-3} \cdot h$
Cm-243	3.7E+08	2.7E-09
Cm-244	3.0E+08	3.4E-09
Cm-245	5.5E+08	1.8E-09
Cm-246	5.4E+08	1.9E-09
Cf-252	1.9E+08	5.3E-09

[a]Sum of doses from external exposure and inhalation from the plume, and external exposure from deposition. "Dose" means the sum of effective dose equivalent from external radiation and committed effective dose equivalent from intake.

[b]See footnote a to Table 5-4 for assumptions on inhalation and footnote b to Table 5-5 for assumptions on deposition velocity. The quantity $\mu Ci \cdot cm^{-3} \cdot h$ refers to the time-integrated air concentration at one meter height.

[c]For 1 rem committed effective dose equivalent.

[d]The contribution from the short-lived daughter is included in the factors for the parent radionuclide.

[e]These factors should only be used in situations where I-132 appears without the parent radionuclide.

Persons exposed to an airborne particulate plume will receive dose to skin from beta emitters in the plume as well as from those deposited on skin and clothing. Although it is possible to detect beta radiation, it is not practical, for purposes of decisions on evacuation and sheltering, to determine dose to skin by field measurement of the beta dose equivalent rate near the skin surface. Such doses are determined more practically through calculations based on time-integrated air concentration, an assumed deposition velocity, and an assumed time period between deposition and skin decontamination. For the purpose of evaluating the relative importance of skin dose compared to the dose from external gamma exposure and inhalation, dose conversion factors were evaluated using a deposition velocity of 1 cm/sec and an exposure time before decontamination of 12 hours. Using these conservative assumptions, it was determined that skin beta dose should seldom, if ever, be a controlling pathway during the early phase. Therefore, no DCFs or DRLs are listed for skin beta dose.

Table 5-2 Dose Conversion Factors (DCF) and Derived Response Levels (DRL) Corresponding to a 5 rem Dose Equivalent to the Thyroid from Inhalation of Radioiodine

Radionuclide	DCF rem per $\mu Ci \cdot cm^{-3} \cdot h$	DRL[a] $\mu Ci \cdot cm^{-3} \cdot h$
Te/I-132[b]	2.9E+05	1.8E-05
I-125	9.6E+05	5.2E-06
I-129	6.9E+06	7.2E-07
I-131	1.3E+06	3.9E-06
I-132	7.7E+03	6.5E-04
I-133	2.2E+05	2.3E-05
I-134	1.3E+03	3.9E-03
I-135	3.8E+04	1.3E-04

[a]For a 5 rem committed dose equivalent to the thyroid.

[b]The contribution from the short-lived daughter is included in the factors for the parent radionuclide.

Because of large uncertainties in the assumptions for deposition, air concentrations are an inadequate basis for decisions on the need to decontaminate individuals. Field measurements should be used for this (See Chapter 7, Section 7.6.3.). It should be noted that, even in situations where the skin beta dose might exceed 50 rem, evacuation would not usually be the appropriate protective action, because skin decontamination and clothing changes are easily available and effective. However, evacuation would usually already be justified in these situations due to dose from inhalation during plume passage.

The following example demonstrates the use of the data in Tables 5-1 and 5-2 for a simple analysis involving three radionuclides.

Based on source term and meteorological considerations, it is assumed that the worst probable nuclear incident at an industrial facility is a fire that could disperse radioactive material into the atmosphere, yielding a time-integrated concentration of radionuclides at a nearby populated area, as follows:

Radionuclide	$\mu Ci \cdot cm^{-3} \cdot h$
Zr-95	2E-6
Cs-134	4E-8
I-131	1.2E-5

We examine whether evacuation is warranted at these levels, based on PAGs of 1 rem for effective dose and 5 rem for dose to the thyroid. We use the DCFs in Table 5-1 for effective dose and Table 5-2 for thyroid dose from inhalation of radioiodines to calculate the relevant doses, H, as follows:

$$H = \sum_{1}^{n} DCF_i \times C_i$$

where DCF_i = dose conversion factor for radionuclide i,
C_i = time-integrated concentration of radionuclide i,
and n = the number of radionuclides present.

For the committed effective dose equivalent (see Table 5-1):

(2 E-6 x 3.2E+4)+(4E-8 x 6.3 E+4)
+(1.2E-5 x 5.3E+4) = 0.71 rem.

For the committed dose equivalent to the thyroid (see Table 5-2):

1.2E-5 x 1.3E+6 = 16 rem.

The results of these calculations show that, at the location for which these time-integrated concentrations are specified, the committed dose equivalent to the thyroid from inhalation would be over three times the PAG for dose to thyroid, thus justifying evacuation. Using meteorological dilution factors, one could calculate the additional distance to which evacuation would be justified to avoid exceeding the PAG for thyroid dose.

To use the DRLs from Table 5-1 and 5-2, find the sum,

$$\sum_{1}^{n} \frac{C_i}{DRL_i}$$

for both effective dose and thyroid dose, where DRL_i is the derived response level for radionuclide i, and C_i is defined above. If the sum in either case is equal to or greater than unity, evacuation of the general population is warranted.

For effective dose (see Table 5-1):

$$\frac{2E-6}{3.2E-5} + \frac{4E-8}{1.6E-5} + \frac{1.2E-5}{1.9E-5} = 0.7$$

For dose to the thyroid (see Table 5-2):

$$\frac{1.2E-5}{3.9E-6} = 3$$

It is apparent that these calculations yield the same conclusions as those using the DCFs.

5.4.3 Comparison with Previously-Recommended PAGs

Many emergency response plans have already been developed using previously-recommended PAGs that apply to the dose equivalent to the whole body from direct (gamma) radiation from the plume and to the thyroid from inhalation of radioiodines. For nuclear power plant incidents, the

former PAG for whole body exposure provides public health protection comparable to that provided by the new PAG expressed in terms of effective dose equivalent. This is demonstrated in Table C-9 (Appendix C), which shows comparative doses for nuclear power plant fuel-melt accident sequences having a wide range of magnitudes. The PAG for the thyroid is unchanged. On the other hand, application of these PAGs to alpha emitting radionuclides leads to quite different derived response levels from those based on earlier health physics considerations, because of new dose conversion factors and the weighting factors assigned to the exposed organs (EP-88).

5.5 Protective Actions

This section provides guidance for implementing the principal protective actions (evacuation and sheltering) for protection against the various exposure pathways resulting from an airborne plume. Sheltering means the use of the closest available structure which will provide protection from exposure to an airborne plume, and evacuation means the movement of individuals away from the path of the plume.

Evacuation and sheltering provide different levels of dose reduction for the principal exposure pathways (inhalation of radioactive material, and direct gamma exposure from the plume or from material deposited on surfaces). The effectiveness of evacuation will depend on many factors, such as how rapidly it can be implemented and the nature of the accident. For accidents where the principal source of dose is inhalation, evacuation could increase exposure if it is implemented during the passage of a short-term plume, since moving vehicles provide little protection against exposure (DO-90). However, studies (NR-89a) continue to show that, for virtually all severe reactor accident scenarios, evacuation during plume passage does not increase the risk of acute health effects above the risk while sheltering. Sheltering, which in most cases can be almost immediately implemented, varies in usefulness depending upon the type of release, the shelter available, the duration of the plume passage, and climatic conditions.

Studies have been conducted to evaluate shelter (EP-78a) and evacuation (HA-75) as protective actions for incidents at nuclear power facilities. Reference EP-78b suggests one method for evaluating and comparing the benefits of these two actions. This requires collecting planning information before and data following an incident, and using calculations and graphical means to evaluate whether evacuation, sheltering, or a combination of sheltering followed by evacuation should be recommended at different locations. Because of the many interacting variables, the user is forced to choose between making decisions during the planning phase, based on assumed data that may be grossly inaccurate, or using a time-consuming more comprehensive process after the

incident when data may be available. In the former situation, the decision may not have a sound basis, whereas in the latter, the decision may come too late to be useful.

The recommended approach is to use planning information for making early decisions. The planned response should then be modified following the incident only if timely detailed information is available to support such modifications.

The planner should first compile the necessary information about the emergency planning zone (EPZ) around the facility. For the case of power reactors, some of this information is described in NUREG-0654 (NR-80). It should include identifying the population distribution, the sheltering effectiveness of residences and other structures, institutions containing population groups that require special consideration, evacuation routes, logical boundaries for evacuation zones, transportation systems, communications systems, and special problem areas. In addition, the planner should identify the information that may be available following an incident, such as environmental monitoring data, meteorological conditions, and plant conditions. The planner should identify key data or information that would justify specific protective actions. The evaluation and planning should also include the selection of institutions where persons should be provided with stable iodine for thyroid protection in situations where radioiodine inhalation is projected.

The following sections discuss key factors which affect the choice between evacuation and sheltering.

5.5.1 Evacuation

The primary objective of evacuation is to avoid exposure to airborne or deposited radioactive material by moving individuals away from the path of the plume. Evacuation, if completed before plume arrival, can be 100 percent effective in avoiding future exposure. Even if evacuation coincides with or follows plume passage, a large reduction of exposure may be possible. In any case, the maximum dose avoided by evacuation will be the dose not avoidable by sheltering.

Some general conclusions regarding evacuation (HA-75) which may be useful for planning purposes are summarized below:

1. Advanced planning is essential to identify potential problems that may occur in an evacuation.

2. Most evacuees use their own personal transportation.

3. Most evacuees assume the responsibility of acquiring food and shelter for themselves.

4. Evacuation costs are highly location-dependent and usually will not

be a deterrent to carrying out an evacuation.

5. Neither panic nor hysteria has been observed when evacuation of large areas is managed by public officials.

6. Large or small population groups can be evacuated effectively with minimal risk of injury or death.

7. The risk of injury or death to individual evacuees from transportation does not change as a function of the number of persons evacuated, and can be conservatively estimated using National Highway Safety Council statistics for motor vehicle accidents (subjective information suggests that the risks will be lower).

Evacuation of the elderly, the handicapped, and inhabitants of medical and other institutions may present special problems. When sheltering can provide adequate protection, this will often be the protective action of choice. However, if the general public is evacuated and those in institutions are sheltered, there is a risk that attendants at these institutions may leave and make later evacuation of institutionalized persons difficult because of a lack of attendants. Conversely, if evacuation of institutions is attempted during evacuation of the public, traffic conditions may cause unacceptable delays. If evacuation of institutions is attempted before evacuating the public, increased risk to the public from a delayed evacuation could occur, unless the incident is very slow in developing to the point of an atmospheric release. Because of the above difficulties, medical and other institutions located within the EPZ should be evaluated to determine whether there are any logical categories of persons that should be evacuated after the public (or, when time permits, before).

5.5.2 Sheltering

Sheltering refers here to the use of readily available nearby structures for protection against exposure to an airborne plume.

Sheltering may be an appropriate protective action because:

1. It positions the public to receive additional instructions when the possibility of high enough doses to justify evacuation exists, but is small.

2. It may provide protection equal to or greater than evacuation.

3. It is less expensive and disruptive than evacuation.

4. Since it may be implemented rapidly, sheltering may be the protective action of choice if rapid evacuation is impeded by, a) severe environmental conditions--e.g. severe weather or floods; b) health constraints--e.g. patients and workers in hospitals and nursing homes; or c) long mobilization times--certain industrial and farm workers, or prisoners and guards; d) physical

constraints to evacuation--e.g. inadequate roads.

5. Sheltering may be more effective against inhalation of radioactive particulates than against external gamma exposure, especially for short-term plumes.

The use of large structures, such as shopping centers, schools, churches, and commercial buildings, as collection points during evacuation mobilization will generally provide greater protection against gamma radiation than use of small structures.

As with evacuation, delay in taking shelter during plume passage will reduce the protection from exposure to radiation. The degree of protection provided by structures is governed by attenuation of gamma radiation by structural components (the mass of walls, ceilings, etc.) and by outside/inside air-exchange rates.

If external dose from the plume or from deposited materials is the controlling criterion, shelter construction and shelter size are the most important considerations; ventilation control and filtering are less important. Although sheltering will reduce the gamma exposure rate from deposited materials, it is not a suitable protective action for this pathway for long duration exposure. The main factors which reduce whole body exposure are:

1. Wall materials and thickness and size of structure,

2. Number of stories overhead, and

3. Use of a central location within the structure.

If a major release of radioiodine or respirable particulate materials occurs, inhalation dose will be the controlling pathway. For releases consisting primarily of noble gases, external gamma exposure will be most important. However, when inhalation is the primary exposure pathway, consideration should be given to the following:

1. Ventilation control is essential for effective sheltering.

2. Dose reduction factors for sheltering can be improved in several ways for the inhalation pathway, including reducing air exchange rates by sealing cracks and openings with cloth or weather stripping, tape, etc. Although the risk to health from the action could be a constraint (particularly for infants and the infirm), using wet towels or handkerchiefs as a mask to filter the inhaled air will reduce dose from inhalation.

3. Following plume passage, people should open shelters to reduce airborne activity trapped inside, and they should leave high exposure areas as soon as possible after cloud passage to avoid exposure to deposited radioactive material.

4. Consideration should be given to the prophylactic administration of potassium iodide (KI) as a

thyroid-blocking agent to workers performing emergency services and other groups in accordance with the PAGs in Table 2-1 and the provisions in reference FD-82.[3]

5.5.3 General Guidance for Evacuation and Sheltering

The process of evaluating, recommending, and implementing evacuation or shelter for the public is far from an exact science, particularly in view of time constraints that prevent thorough analysis at the time of an incident. Their effectiveness, however, can be improved considerably by planning and testing. Early decisions should be based on information collected from the emergency planning zone during the planning phase and on information regarding conditions at the nuclear facility at the time of the incident. Best estimates of dose projections should be used for decisions between evacuation and sheltering.

The following is a summary of planning guidance for evacuation and sheltering, based on the information in Sections 5.5.1 and 5.5.2.

1. For severe incidents, where PAGs may be significantly exceeded, evacuation may be the only effective protective action close to the facility.

2. Evacuation will provide total protection from any airborne release if it is completed before arrival of the plume.

3. Evacuation may increase exposure if carried out during the plume passage, for accidents involving inhalation dose as a major contributor.

4. Evacuation is also appropriate for protection from groundshine in areas with high exposure rates from deposited materials.

5. Sheltering may be appropriate (when available) for areas not designated for immediate evacuation because:

a. It positions the public to receive additional instructions; and

b. It may provide protection equal to or greater than evacuation.

6. Sheltering is usually not appropriate where high doses are projected or for exposure lasting longer than two complete air exchanges of the shelter.

7. Because sheltering may be implemented in less time than evacuation, it may be the temporary protective action of choice if rapid evacuation is impeded by a) certain environmental conditions--e.g. severe weather or floods; b) health constraints--e.g. patients and workers

[3]Each State has the responsibility for formulating guidance to define when (and if) the public should be given potassium iodide. Planning for its use is discussed in "Potassium Iodide as a Thyroid-blocking Agent in a Radiation Emergency: Final Recommendations on Use" (FD-82).

in hospitals and nursing homes; or c) long mobilization times--e.g. certain industrial and farm workers, or prisoners and guards; d) physical constraints to evacuation--e.g. inadequate roads.

8. If a major release of radioiodine or particulate materials occurs, inhalation dose may be the controlling criterion for protective actions. In this case:

a. Breathing air filtered through common household items (e.g., folded wet handkerchiefs or towels) may be of significant help, if appropriate precautions are taken to avoid possible suffocation.

b. After confirmation that the plume has passed, shelters should be opened to avoid airborne activity trapped inside, and persons should leave high exposure areas as soon as possible after cloud passage to avoid exposure to deposited radioactive material.

c. Consideration should be given to the prophylactic administration of potassium iodide (KI) as a thyroid-blocking agent to emergency workers, workers in critical industries, or others in accordance with the PAGs in Table 2-1 and reference FD-82.

9. If dose from external gamma radiation is the controlling criterion, shelter construction and size are the most important considerations; ventilation control and filtering are less important. The main factors which reduce whole body external dose are; a) wall thickness and size of structure, b) number of stories overhead, c) central location within the structure, and d) the height of the cloud with respect to the building.

5.6 Procedures for Calculating Dose Conversion Factors

This section provides information used in the development of the DCFs in Tables 5-1 and 5-2. Three exposure pathways are included: whole body exposure to gamma radiation from the plume, inhalation from the plume, and whole body exposure to gamma radiation from deposited materials. Although exposure of the skin from beta radiation could be significant, evaluations show that other exposure pathways will be controlling for evacuation and sheltering decisions. Therefore, DCFs for skin are not provided. Individual DCFs for the three exposure pathways are provided in the following sections. They are each expressed in terms of the time-integrated air concentration so that they may be combined to yield a composite DCF for each radionuclide that reflects all three pathways. These data may be used to facilitate revising the DCFs in Tables 5-1 and 5-2 when more specific or technically improved assumptions are available, as well as to evaluate the relative importance of the individual pathways for specific radionuclide mixes.

5.6.1 External Exposure to Gamma Radiation from the Plume

Table 5-3 provides DCFs and DRLs for external exposure to gamma radiation due to immersion in contaminated air. The values for gamma radiation will provide conservative estimates for exposure to an overhead plume. They are derived under the assumption that the plume is correctly approximated by a semi-infinite source.

The DCFs given in Table 5-3 are used to calculate the effective dose equivalent from external exposure to gamma radiation from the plume. They are based on dose-rate conversion factors for effective dose in Table A.1 of reference DO-88. The units given in Table A.1 are converted to those in Table 5-3 as follows:

$$\frac{mrem \cdot y^{-1}}{\mu Ci \cdot m^{-3}} \times 0.1142 = \frac{rem}{\mu Ci \cdot cm^{-3} \cdot h}$$

Only the short-lived daughters of Ru-106 and Cs-137 emit gamma radiation and, therefore, the DCFs from Table A.1 for these entries are attributable to their daughters. The DCF for Ce-144 is combined with that for its short-lived daughter; it is assumed they are in equilibrium. Since the DRLs apply to a PAG of 1 rem, they are simply the reciprocals of the DCFs.

5.6.2 Inhalation from the Plume

Table 5-4 provides DCFs and DRLs for committed effective dose equivalent due to inhalation of an airborne plume of radioactive particulate materials and for committed dose equivalent to the thyroid due to inhalation of radioiodines. It is assumed that the radionuclides are in the chemical and physical form that yields the highest dose, and that the particle size is one micrometer mean aerodynamic diameter. For other chemical and physical forms of practical interest the doses may differ, but in general only by a small factor. If the chemical and/or physical form (e.g. solubility class or particle size) is known or can be predicted, the DCFs for inhalation should be adjusted as appropriate.

The dose factors and breathing rate used to develop the DCFs in Table 5-4 are those given in Table 2.1 of Federal Guidance Report No.11 and were derived for "standard man" (EP-88). Although the DCFs for some radionuclides would be slightly higher for children, the conservatism in the PAGs and procedures for their application provide an adequate margin for safety. The advantage of using a single source of current data for the development and timely revision of DCFs for these and any other relevant radionuclides is also a consideration in the selection of this data base for use in emergency response applications.

The units given in Table 2-1 of EP-88 are converted to the units in Table 5-4, using a breathing rate of 1.2E+6 $cm^3 \cdot h^{-1}$, by the factor

$$Sv \cdot Bq^{-1} \cdot 4.4E+12 = rem \text{ per } \mu Ci \cdot cm^{-3} \cdot h.$$

The DRLs are simply the reciprocal of the DCF.

5.6.3 External Dose from Deposited Materials

Table 5-5 provides DCFs and DRLs for 4-day exposure to gamma radiation from selected radionuclides following deposition of particulate materials on the ground from a plume. The deposition velocity (assumed to be 1 cm/s for iodines and 0.1 cm/s for other particulate materials) could vary widely depending on the physical and chemical characteristics of the deposited material and the surface, and meteorological conditions. In the case of precipitation, the amount of deposition (and thus the dose conversion factors for this exposure pathway) will be much higher. To account for the ingrowth of short-lived daughters in deposited materials after measurements are made, the tabulated values include their contribution to dose over the assumed 4-day period of exposure. Because the deposition velocity can be much lower or higher than assumed in developing the dose conversion factors for deposited materials, decision makers are cautioned to pay particular attention to actual measurements of gamma exposure from deposited materials for evacuation decisions after plume passage.

The objective is to calculate DCFs for single radionuclides in terms of effective dose equivalent from 4 days exposure to gamma radiation from deposited radioactive materials. In order to be able to sum the dose conversion factors with those for other exposure pathways, the DCF is expressed in terms of dose per unit time-integrated air concentration, where the deposition from the plume is assumed to occur at approximately the beginning of the incident. The following equation was used to generate Table 5-5:

$$DCF = V_g \cdot DCRF \cdot 1.14E\text{-}3\left[\frac{1-e^{-\lambda t}}{\lambda}\right]$$

Where:

DCF = the dose per unit air concentration ($\mu Ci \cdot cm^{-3} \cdot h$)

V_g = the deposition velocity, assumed to be 3600 $cm \cdot h^{-1}$ for iodines and 360 $cm \cdot h^{-1}$ for other particulate materials

$DRCF$ = the dose rate conversion factor ($mrem \cdot y^{-1}$ per $\mu Ci \cdot m^{-2}$) (DO-88)

1.14E-3 = a factor converting $mrem \cdot y^{-1}$ per m^2 to $rem \cdot h^{-1}$ per cm^2

λ = the decay constant for the radionuclide (h^{-1})

t = duration of exposure (hours),assumed to be 96 hours (4 days)

References

DO-88 U.S. Department of Energy. External Dose-Rate Conversion Factors for Calculation of Dose to the Public, DOE/EH- 0070, U.S. Department of Energy, Washington (1988).

DO-90 U.S. Department of Energy. Effectiveness of Sheltering in Buildings and Vehicles for Plutonium. DOE/EH-0159, U.S. Department of Energy, Washington (1990).

EP-78a U.S. Environmental Protection Agency. Protective Action Evaluation Part I - The Effectiveness of Sheltering as a Protective Action Against Nuclear Accidents Involving Gaseous Releases. EPA 520/1-78-001A, U.S. Environmental Protection Agency, Washington (1978).

EP-78b U.S. Environmental Protection Agency. Protective Action Evaluation Part II - Evacuation and Sheltering as Protective Actions Against Nuclear Accidents Involving Gaseous Releases. EPA 520/1-78-001B, U.S. Environmental Protection Agency, Washington (1978).

EP-88 U.S. Environmental Protection Agency. Federal Guidance Report No. 11. Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. EPA 520/1-88-020. U.S. Environmental Protection Agency, Washington (1988).

FD-82 U. S. Department of Health and Human Services, Food and Drug Administration. Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency: Final Recommendations on Use. Federal Register, 47, 28158; June 29, 1982.

FE-85 Federal Emergency Management Agency. Federal Radiological Emergency Response Plan. Federal Register, 50, 46542; November 8, 1985.

HA-75 Hans, J.M. Jr., and Sell, T.C. Evacuation Risks - An Evaluation. EPA-520/6-74-002, U.S. Environmental Protection Agency, Washington, (1975).

IC-75 International Commission On Radiological Protection. Report of the Task Group on Reference Man. ICRP Publication 23, Pergamon Press, New York, (1975).

NR-75 U.S. Nuclear Regulatory Commission. An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400, U.S. Nuclear Regulatory Commission, Washington, (1975).

NR-78 U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency. Task Force Report. Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants. NUREG-0396 or EPA-520/1-78-016, U.S. Environmental Protection Agency, Washington, (1978).

NR-80 U.S. Nuclear Regulatory Commission. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants. NUREG-0654, FEMA-REP-1, Rev.1., Washington, (1980).

NR-88 U.S. Nuclear Regulatory Commission. A Regulatory Analysis on Emergency Preparedness for Fuel Cycle and Other Radioactive Material Licensees. NUREG-1140, U.S. Nuclear Regulatory Commission, Washington, (1988).

NR-89 U.S. Nuclear Regulatioy Commission. Appendix E - Emergency Planning and Preparedness for Production and Utilization Facilities. Title 10, CFR Part 50, U.S. Nuclear Regulatory Commission, Washington, (1975).

NR-89a U.S. Nuclear Regulatory Commission. Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants. NUREG-1150, U.S. Nuclear Regulatory Commission, Washington, (1990).

CHAPTER 6

Implementing the PAGs for the Intermediate Phase (Food and Water)

See Chapter 3 and Appendix D for Current Implementation Recommendations for Food. Also refer to the following documents:

Federal Emergency Management Agency
Guidance Memorandum IN-1, The Ingestion Exposure Pathway. February 26, 1988 Federal Emergency Management Agency. Washington, DC 20472

Guidance on Offsite Emergency Radiation Measurement Systems Phase 2, The Milk Pathway, FEMA REP-12, September 1987.

Guidance on Offsite Emergency Radiation Measurement Systems. Phase 3, Water and Non-Dairy Food Pathway, September 1989.

HHS Publication FDA 82-8196

Background for Protective Action Recommendations: Accidental Radioactive Contamination of Food and Animal Feeds

B. Shleien, Pharm.D.
G.D. Schmidt
Office of the Bureau Director

and

R. P. Chiacchierini, Ph.D.
Division of Biological Effects

BRH
bureau of radiological health

WHO Collaborating Centers for:
- Standardization of Protection Against Nonionizing Radiations
- Training and General Tasks in Radiation Medicine
- Nuclear Medicine

August 1982

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Food and Drug Administration
Bureau of Radiological Health
Rockville, Maryland 20857

PREFACE

By FEDERAL REGISTER action of March 11, 1982 (47 FR 10758), the Federal Emergency Management Agency (FEMA) outlined the responsibilities of several Federal agencies concerning emergency response planning guidance that the agencies should provide to State and local authorities. This updated a prior notice published in the FEDERAL REGISTER by the General Services Administration (GSA) on December 24, 1975 (40 FR 59494), on the same subject. GSA responsibility for emergency management was transferred by Executive Order to FEMA. The Department of Health and Human Services (HHS) is responsible for assisting State and local authorities in developing plans for preventing adverse effects from exposure to radiation in the event that radioactivity is released into the environment. This includes developing and specifying protective actions and associated guidance to State and local governments for human food and animal feeds.

Proposed recommendations were published in the FEDERAL REGISTER on December 15, 1978 (43 FR 58790) and a background document accompanied their publication. Twenty-one comment letters were received in response to the proposal in addition to comments from various Federal agencies. Review of these comments led to changes in the recommendations and supporting rationale, dosimetric and agricultural models, and cost/benefit analysis. These changes have been incorporated into this background document, which is intended to accompany and support FDA's final recommendations on Accidental Radioactive Contamination of Human Foods and Animal Feeds: Recommendations for State and Local Agencies. The final recommendations will appear in the FEDERAL REGISTER.

This background report discusses the rationale for the Protective Action Guides; the dosimetric and agricultural models used in their calculation; some methods of analysis for radionuclide determination; appropriate protective actions; and cost considerations.

Bernard Shleien

Bernard Shleien, Pharm. D.
Assistant Director for
Scientific Affairs
Bureau of Radiological Health

CONTENTS

CHAPTER 1. RATIONALE FOR DETERMINATION OF THE PROTECTIVE ACTION GUIDES

1.1 INTRODUCTION

The process of determining numerical limits for radiation standards is one of risk assessment. This process, in which risk considerations are an important factor in decision-making, consists of two elements: determination of the probability that an event will occur, and determination of "acceptable risk." A recent discussion of acceptable risk defines risk as a measure of the probability and severity of adverse effects. Safety is the degree to which risks are judged acceptable (1).

Since initiation of protective action assumes that an accident has occurred, no attention will be given to the estimation of probabilities for accident occurrence in the present analysis.

One process of determining "acceptable risk" is to compare estimates of risk associated with an action with already prevalent or "natural" risks that are accepted by society. This method of evaluation is employed in the present discussion by comparing the risk from natural disasters and from the variation in "natural radiation background" to the radiation risk associated with the numerical limits for the Protective Action Guides (PAG).

"Protective action guide" (PAG) means the projected dose commitment values to individuals in the general population that warrant protective action following a release of radioactive material. Protective action would be warranted if the expected individual dose reduction is not offset by negative social, economic, or health effects. The PAG does not include the dose that has unavoidably occurred prior to the assessment. "Projected dose commitment" means the dose commitment that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken. The projected dose commitment is expressed in the unit of dose equivalent or the rem.

The "natural radiation background" consists of contributions from external radiation and internal deposited radioactivity from ingestion and inhalation. For the most part, the variation in the internal natural radiation dose is due to the variability of whole-body potassium-40. Since these PAG's are limited to ingestion, a parameter that describes the variability of the internal natural radiation dose might appear more appropriate than using the variability of the external or total natural radiation dose in evaluating the acceptability of a given level of risk. However, the potassium level in the body (and hence internal dose) is controlled by metabolic processes and dietary intake has little effect. Hence the risk of natural disasters, which is dependent on geographical location of residence, is in this agency's opinion a better measure of acceptable risk.

1.2 MODELS FOR EVALUATION OF RISK

Models for the somatic and genetic effects of radiation are required for comparisons of radiation risks from the PAG's relative to other naturally occurring risks.

1.2.1 Somatic Risk Evaluation

A review of the current literature indicates that the risk estimates developed in the National Academy of Science Committee on the Biological Effects of Ionizing Radiation or the BEIR-I report (2) and the BEIR-III report (3) are appropriate for use in analysis of

somatic risk. Mortality rather than incidence estimates are employed in the comparisons. In the case of comparisons to natural background radiation, use of mortality data or incidence estimates would yield the same numerical PAG limits, because these limits are based on a comparison between risks rather than an evaluation of absolute risk.

The radiation doses in the event of a contaminating accident will most likely result from ingestion of the fission products cesium-134 and -137; strontium-89 and -90; and iodine-131. For the purpose of this analysis it is assumed that all projected extra cancers can be attributed to internal radiation via the food pathway (i.e., the risks from ingested radioactive material is the same as that from external radiation).

The BEIR-III (3) best estimate of lifetime cancer risk (linear quadratic model) for a single exposure to low-dose, low LET radiation is from 0.77 to 2.26 x 10^{-4} deaths per person-rem, depending on whether the absolute or relative-risk projection model is used (calculated from Table 1). The equivalent risk estimate from BEIR-I (2) is 1.17 to 6.21 x 10^{-4} deaths per person-rem.

Table 1. Risk estimates for single dose

	Deaths per million persons per 10 rads single dose whole-body BEIR-III	
Dose response model	Absolute risk	Relative risk
Linear quadratic	766	2255
Linear	1671	5014
Quadratic	95	276

These risk estimates are for a single dose of 10 rem, because limitations of the scientific information do not justify estimates at lower doses according to the BEIR Committee. Because of the uncertainty of risk estimates at low doses, BEIR-III provided risk estimates based on a linear model and a pure quadratic dose response model as well as estimates based on the preferred linear quadratic model. The risk estimates for the linear model are about a factor of 2 higher and those of the quadratic model and about a factor of 8 lower than those of the linear quadratic model. It should further be noted, that BEIR-III does not recommend that their risk estimates be extrapolated to lower doses because of the inadequacies of the scientific basis. BEIR-III does recognize however that Federal agencies have a need to estimate impacts at lower doses. While BEIR-III prefers the linear-quadratic dose response model as the best estimate, regulatory agencies have continued to favor the linear model as the basis for making risk estimates. While the BEIR-III estimates will be used here to estimate the impact (health effects) at lower doses, it is fully recognized that current scientific opinion leaves alternatives as to which dose response and risk model to use.

As previously stated, for the purpose of setting PAG's, comparison of radiation risks to those from natural disasters is considered the approach of choice in this document.

1.2.2 Genetic Risk Evaluation

The model for genetic risks from radiation exposure is described in the BEIR-III report (3). In the first generation, it is estimated that 1 rem of parental exposure throughout the general population will result in an increase of 5 to 75 additional serious genetic disorders per million liveborn offspring. The precision for estimating genetic risks is less precise than those for somatic risks. Given the broad range, genetic risks are evaluated, but are not precise enough to be a basis for setting the PAG's.

1.3 ASSESSMENT OF COMMON SOCIETAL AND NATURAL BACKGROUND RADIATION RISKS

1.3.1 Common Societal Risks

As previously stated, one method of determining the acceptability of a risk is by comparing prevalent or normal risks from hazards common to society. A list of the annual risks from common societal hazards is given in Table 2. Comparision of radiation risks to commonly accepted societal risks assumes that the age dependencies are similar and that all individuals are equally exposed to the hazard. This latter assumption is, of course, not entirely valid in that persons nearer a nuclear power plant or a dam, or in an earthquake or tornado area might be expected to be at greater risk than persons living at a distance from the particular hazard.

Table 2. Annual risk of death from hazards common to society

Category	Reference	Risk of death (per person per year)
All disease	(4)	8×10^{-3}
Leukemia and all other cancer	(5)	1.5×10^{-3}
Motor vehicle accidents	(6)	3×10^{-4}
Accidental poisoning	(6)	1×10^{-5}
Air travel	(7)	9×10^{-6}
Tornadoes (Midwest)	(8)	2×10^{-6}
Earthquakes (Calif.)	(8)	2×10^{-6}
Floods (46 million at risk)	(9)	2.2×10^{-6}
Catastrophic accidents (tornadoes, floods, hurricanes, etc.)	(10)	1.2×10^{-6}
Natural disasters	(11)	9×10^{-7}
	(6)	8×1^{-7}
Tornadoes	(7)	0.4×10^{-6}
	(9)	0.6×10^{-6}
Hurricanes	(7)	0.4×10^{-6}
	(9)	0.3×10^{-6}
Floods	(8)	2×10^{-6}
	(9)	0.5×10^{-6}
Lightning	(7)	0.5×10^{-6}
Winter storms	(9)	0.4×10^{-6}
Natural disasters (sum of above)		2.1 to 3.9×10^{-6}

Table 2 indicates that the annual individual risk from natural disasters is approximately 1 to 4×10^{-6}. This risk represents a common risk level, which is generally not considered in selecting place of residence. At this level of risk, some action to prevent further loss of life could be expected by society following the occurrence of a natural disaster. It thus appears prudent to evaluate the somatic risks from radiation in relation to the risk of death from a natural disaster. For comparison purposes, a value of 1 in a million (1×10^{-6}) annual risk of death, which is often quoted as an acceptable risk, will be used as the risk of natural disasters. Actual data indicate that the risk of natural disasters may be a 2 or 3 times greater risk than this value. For a risk of death of 1×10^{-6} per year, the lifetime accepted societal risk would be about 70×10^{-6}. This is equivalent to a single radiation dose of 140 to 420 mrem, using the linear model, or 310 to 910 mrem using the BEIR-III linear quadratic model (see Table 1). The upper and lower ranges are those obtained from employment of relative and absolute risk models and the dose response extrapolations mentioned above (from calculations based on data in Table 1). Genetic effects are not considered in evaluating common societal hazards because of the difficulty in assessing

deaths occurring from genetic consequences, either natural or radiation induced. If spontaneous abortions are deleted from this category, then fatal genetic effects are a small portion of the overall genetic impact on health. However, it is difficult to accurately evaluate genetic effects, and even more difficult to compare its impact to the impact of somatic effects in an effective manner.

1.3.2 Risks From Natural Radiation

Further perspective on acceptable risk can be obtained by examining the risks of natural background radiation. In risk assessments where a radiation risk is compared to that from the natural radiation background, the question is which variable associated with natural background should be used to determine "acceptable risk?" Since background radiation has always been a part of the natural environment, a plausible argument might be to assume that the risks associated with the average natural radiation dose represent an "acceptable risk."

It has also been argued that because of the ever present risk from natural radiation, a level of manmade radiation ought to be acceptable if it is "small" compared to natural background (12). It has been suggested that "small" be taken as the standard deviation of the population-weighted natural background (13). In previous evaluations that led to the FDA's proposed PAG recommendations (14) the geographic variable (two standard deviations) in the natural radiation dose was used as a point of comparison for judging acceptable radiation risk (15). This value, calculated on a State-by-State basis assuming a log-normal distribution and not weighted for population, is 8.5 mrem per year. The cumulative lifetime dose equivalent would thus be about 500 mrem, which was the basis for the proposed PAG recommendation for the whole body at the Preventive PAG level. The Environmental Protection Agency (EPA), in a further analysis of previously published data (16), has calculated the cumulative distribution of dose equivalent in the U.S. population. These data show that 95 percent of the population receives between 28 and 84 mrem/year from cosmic and terrestrial background radiation (17). The actual distribution is asymmetric and not log-normal. Thus, one-half of this 95-percent increment range, or 28 mrem/year, will be taken as the value for judging acceptable risk. Adler (13) notes that one standard deviation of the natural external and internal radiation background derived from earlier sources (18) is 20 mrem. Personal conversations with Adler revealed that this estimate is based on air exposures rather than dose equivalent (mean whole body) and involved a broad rounding off of values. At the 95-percent increment value (latest EPA data) of 28 mrem/year (19), the additional lifetime dose over 70 years is about 2000 mrem. About 6 million persons (2-1/2 percent of the population) receive lifetime doses that exceed the mean background radiation dose by this amount or more.

Another possibility, especially applicable to setting limits for internal emitters, is using the variation in internal natural radiation dose as a reference for establishing an acceptable standard for PAG's. For PAG limits for radionuclides via the ingestion pathway, doses to organs other than the lungs are most pertinent. Using this suggestion still requires a judgmental decision as to whether the variation in internal natural radiation dose is "small." A summary of internal natural radiation doses is given in Table 3. It is apparent that natural radiation doses to human tissues and organs is determined mainly by potassium-40 concentration. The average annual internal whole-body radiation dose per person from ingested natural radioactivity is 19.6 mrem, of which 17 mrem is due to potassium-40.

In potassium-40 whole-body measurements of 10,000 persons, a standard deviation of about 12 percent (95-percent confidence level of 23.52 percent) was observed (20). The study further concluded that the standard deviation is also the same for different groups of age and sex, and therefore, it may be concluded that the same biological variation exists for all the different age-sex groups. In another study based on the chemical determinations of total body potassium the average amount in a 70-kg man was estimated to be 136 g with a standard deviation of ± 28 g or ± 20 percent (95-percent confidence increment of ± 40 percent) (21).

Table 3. Annual internal radiation dose per person for non-inhaled natural radioactivity[a]

	Annual dose (mrads/year) whole-body average (unless otherwise noted)
H-3	0.001
Be-7	0.008
C-14	1.3
Na-22	0.02
K-40	17
Rb-87	0.4
U-238-U-234 series	0.043[b]
Ra-222	0.064[b]
Po-210	0.7
Ra-226	0.031[b]
Th-230	0.04[b]
Th-232	0.04[b]
Total	19.65

[a]UNSCEAR (1977).
[b]Based on soft tissue dose (lung, testes, and ovaries)

An indirect means of determining the variability of whole-body potassium values is based on the constant ratio of mean potassium values to total body water up to age 50 (20). The 95-percent confidence increment for the variability of total body water in males, ages 16 to 90 is 16 percent, while for females it is 13 percent for ages 16 to 30 and 21 percent for ages 31 to 90 (22).

From the above data, it appears that the increment for the 95-percent confidence level for whole-body potassium, and hence potassium-40, is between ± 15 percent and ± 40 percent. Note that this variability may be due to differences in body water or body weight. Only in the case of one study (21) is it clear the total body weight is considered a constant. It is apparent that a range of values between approximately 3 to 7 mrad per year may be used to describe the variability in natural potassium-40 dose to the population on a whole-body dosimetric basis. The mid-point of this range is 5 mrad per year or a lifetime dose commitment (70 years) of 350 mrem.

Thus, the lifetime radiation dose associated with the variability in natural radiation is about 350 mrem (internal) and 2000 mrem (external).

1.4 PREVENTIVE AND EMERGENCY PAG'S

PAG's have been proposed for two levels of response:

1. Preventive PAG - applicable to situations where protective actions causing minimal impact on the food supply are appropriate. A preventive PAG establishes a level at which responsible officials should take protective action to prevent or reduce the concentration of radioactivity in food or animal feed.

2. Emergency PAG - applicable to incidents where protective actions of great impact on the food supply are justified because of the projected health hazards. An Emergency PAG establishes a level at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce, and at which the responsible officials must determine whether condemnation or another disposition is appropriate.

1.4.1 Preventive PAG

During recent years numerous reports on risks and risk/benefit assessments for the evaluation of technological insults have been published. A number of these have concluded that an annual risk of death of 1 in a million is acceptable to the public (8). The total average annual risk to the U.S. population from natural disasters appears to be about 2 or 3 times greater than the 1 in a million annual risk. Those individuals living in certain flood plains, tornado, or earthquake areas accept risks that may be greater than the average by a factor of 2 or more (See data for tornadoes and earthquakes in Table 2).

As previously mentioned, based on BEIR-III (3) upper risk estimates, a 1 in a million annual risk of death corresponds to a single radiation dose of 140 to 910 mrem.

It is our conclusion that an annual risk of 1 in a million provides a proper perspective for setting food protective actions guides (PAG's) for radiation contamination accidents of low probability. It appears that most individuals in the United States will never be exposed to such a radiation contamination accident and that any one individual is not likely to be potentially exposed more than once in his lifetime.

Based on the above considerations, the uncertainty in radiation risk estimates and the uncertainty in the average natural disaster risks, a value of 0.5 rem whole body is selected for the Preventive PAG. Thus, at projected doses of 0.5 rem from contaminated food, it is recommended that protective actions having low impacts be taken for protection of the public. The specific value of 0.5 rem represents a judgment decision rather than a specifically derived value from specific models and assumptions.

Further perspective on acceptable risks for setting the PAG's is the risks associated with natural background radiation. The discussion above indicates that lifetime dose associated with the 95-percent increment of the variability in natural radiation is about 350 mrem internal and 2000 mrem external (that is, 2-1/2 percent of the population receives doses greater than the average by this amount or more).

This Preventive PAG is applicable to whole-body radiation exposure and to major portions of the body including active marrow (ingestion of strontium) in conformity with current U.S. radiation protection practice. Coincidently, 0.5 rem is the Federal Radiation Council's (FRC) annual limit for individuals of the general population (23).

Present convention, recommended by the Federal Radiation Council (23) based on prior estimates of relative radiation risks for various organs indicates that radiation limits for the thyroid gland be set at 3 times those for the whole body. More recent scientific information indicates that the risks from organ doses relative to whole body differ from those assumed when the current U.S. regulations and FRC guidance were established. The International Commission on Radiological Protection (ICRP) in revising its recommendations on internal exposure derived weighting factors that represent the ratio of risk from irradiation to a given tissue (organ) to the total cancer risk due to uniform irradiation to the whole body. The ICRP weighting factors are 0.12 for red bone marrow and 0.03 for thyroid, indicating that the cancer risk is 8 times less for red bone marrow and 33 times less for thyroid than for whole body exposure (24). Further considerations of effects other than cancer resulted in the limitation of organ doses to 50 rems per year for occupational workers. Thus the ICRP recommendations in effect provide for or allow single organ doses that are 8 times greater for red bone marrow and 10 times greater for thyroid than for whole body. The EPA has recently proposed Federal guidance for occupational radiation protection that incorporates the basic ICRP recommendations (46 FR 7836, Jan. 23, 1980). Setting the Preventive PAG at 0.5 rem for whole body and red bone marrow and 1.5 rem for thyroid provides significantly more protection from the actual risks of organ doses than from whole-body risks. To the extent that the whole-body risk is considered acceptable, the red bone marrow and thyroid limits are conservative by factors of 8 and 3.3, respectively.

1.4.2 Emergency PAG

The philosophy of the protective action guidance of FDA is that low impact protective actions should be initiated when contamination of food exceeds the Preventive PAG. The intent is that such protective actions be implemented to prevent the appearance of radioactivity in food at levels that would require the condemnation of food. If such actions are ineffective, or high levels appear in food, then the Emergency PAG is that level at which higher impact (cost) protective actions are warranted. At the Emergency PAG radiation level, action should be taken to isolate and prevent the introduction of such food into commerce and to determine whether condemnation or other disposition is appropriate.

With regard to the numerical relationship between the Preventive PAG level and the Emergency PAG level, prior conventions may be considered. For example, the Federal Radiation Council (23) assumed that the dose to the most highly exposed individual does not vary from the average dose to the whole population by a factor greater than three; Hence, a factor of 3 was used to define the difference between maximum and average population limits. Traditionally, it has been more common to use a factor of 10 as a safety factor, such as between occupational and general public limits. A factor of 10 difference between the Emergency and Preventive PAG levels, based on these traditional radiation protection approaches has in the past been thought to introduce a sufficient level of conservatism. The proposed PAG's (14) adopted this rationale in setting the Emergency PAG's. The analyses of costs, to follow, also indicate that a factor of 10 between the Preventive PAG and Emergency PAG is appropriate. As calculated in the last chapter of this report the cost of condemnation of milk (high impact protective action) is about a factor of 10 greater than the cost of using uncontaminated stored feed (low impact protective action). Since contamination of the milk pathway is considered to be the most probable and significant food problem, this is the only pathway that is cost analyzed.

The use of a factor of 10 adopted here results in an Emergency PAG of 5 rem for the whole body which numerically is equivalent to the current occupational annual limit. This limit permitted each year over a working lifetime is associated with the expectation of minimal increased radiation risks.

1.5 EVALUATION OF PAG RISKS

The risks associated with a radiation dose equal to the PAG's can be readily calculated from the BEIR-III risk estimates in Table 1. For the Preventive PAG of 0.5 rem, the deaths per million persons exposed are one-twentieth of those given for the 10-rad single dose (or about 38 to 250 deaths for the linear quadratic and linear models respectively). On an individual basis, this is a risk of death of 0.38 to 2.50 x 10^{-4} (0.0038 to 0.025 percent) over a lifetime. BEIR-III gives the expectation of cancer deaths in the U.S. population as 167,000 per million or an individual expectation of cancer death of 16.7 percent.

As noted above, the BEIR-III estimate of serious first generation genetic disorders is 5 to 75 per million live offspring per rem of parental exposure. Thus, for a dose of 0.5 rem, the expectation is 2.5 to 38 disorders per million live offspring. BEIR-III notes the current estimate of the incidence of serious human disorders of genetic origin as roughly 10 percent of liveborn offspring.

CHAPTER 4. PROTECTIVE ACTIONS

The National Advisory Committee on Radiation (56) (NACOR) made the following recommendation that applies to action taken to reduce potential exposure following the accidental release of radioactivity:

"A countermeasure, useful to public health, must fulfill a number of requirements. First, it must be effective; that is, it must substantially reduce population exposures below those which would prevail if the counter measure were not used. Second, it must be safe; i.e., the health risks associated with its use must be considerably less than those of the contaminant at the level at which the countermeasure is applied. Third, it must be practical. The logistics of its application must be well worked out; its costs must be reasonable; and all legal problems associated with its use must be resolved. Next, responsibility and authority for its application must be well identified. There must be no indecision due to jurisdictional and misunderstandings between health and other agencies concerned with radiation control. Finally, careful attention must be given to such additional considerations as its impact on the public, industry, agriculture, and government."

An action, in order to be useful must be effective, safe, and practical. An action may be applied at the source in an attempt to control the release of radioactivity from the source; or, the action may be applied at the beginning of the food chain (soil, vegetation, or cattle), to the immediate vector prior to ingestion by man (milk or food), or to the population itself. For the most part these recommendations suggest protective actions to milk, human and animal foods, or soil and this chapter is limited to actions concerning these media. Further recommendations by NACOR (56) extend the discussion of protective measures to public health actions directly affecting the exposed population. For details of agriculture actions, several Department of Agriculture reports are available that deal with specific actions for crops and soil (57,58,59).

Potential actions relative to the pasture-milk-man pathway are summarized in Table 17. For this pathway, only four countermeasures are rated as effective, safe, and practical (a somewhat arbitrary scale of judgment was used). Of the four, one has distinctive disadvantages. Although removal of radionuclides from milk has been shown to be practical no facilities for doing this exist. Another, diverting fresh milk to processed milk products, freezing and/or storage, is effective only for short-lived radionuclides. Thus, changing dairy cattle to an alternate source of uncontaminated feed and condemnation of milk are the only two protective actions rated good for effectiveness, safety, and practicality.

Of course the other countermeasures should also be considered, but they appear less promising.

Actions for fruits and vegetables are presented in Table 18 (60,61,62). Note that studies in which these products were contaminated under actual conditions with fallout (Studies 2 and 3) yielded a lower reduction in the radioactivity removed during preparation than was the case in an investigation (Study 1) in which radionuclides were sprayed on the food. Depending on the food, reductions between 20 and 60 percent in strontium-90 contaminations are possible by ordinary home preparation or by food canning processes (60).

Milled grains contain only a small portion of the total radioactive contamination of the whole grain; removal of bran from wheat and polishing of rice are effective methods of reducing contaminating fallout (58). Todd indicated average concentration of Sr-90 (pCi/kg)

in wheat of wheat berry (22%), wheat bran (68%), and only 4.4% in flour. In rice the corresponding values are: whole grain (4.9%), and milled rice (0.7%) (58).

Although these recommendations are intended for implementation within hours or days after an emergency, long-term actions applicable to soil are shown for information purposes only in Table 19. Alternatives to decontamination and soil management should be considered, especially if the radioactive material is widespread, because great effort is required for effective treatment of contaminated land.

The concept of Protective Action assumes that the actions implemented will continue for a sufficient period of time to avoid most of the projected dose. The concentration of radioactivity in a given food will decrease because of radioactive decay and weathering as a function of time after the incident. Thus, as discussed in Chapter 5 of this report, actions that have a positive cost-benefit ratio at the time of initial contamination or maximum concentration may not have a positive cost-benefit ratio at later times. Therefore, dependent on the particular food and food pathway, it may be appropriate to implement a series of protective actions until the concentrations in the food have essentially reached background levels.

As an example of the implementation of protective actions, consider the case where an incident contaminates the pasture-cow-milk-man pathway with a projected dose of 2-3 times the Emergency PAG due to iodine-131. In such a situation these protective actions may be considered appropriate:

1. Immediately remove cows from pasture and place them on stored feed in order to prevent as much iodine-131 as is possible from entering the milk;

2. Condemn any milk that exceeds the Emergency PAG response at the farm or milk plant receiving station;

3. Divert milk contaminated at levels below the Emergency PAG to milk products; and

4. Since the supply of stored feed may be limited and the costs of this protective action greater than diversion to milk products, the use of stored feed may be the first action to cease; this should not be done, however, until the concentration of I-131 has dropped below the Emergency PAG and preferably is approaching the Preventive PAG.

5. The diversion of fresh milk to milk products must continue until most of the projected dose has been avoided; this action might be ceased when the cost-effectiveness point is reached or the concentration of iodine-131 approaches the background levels.

This discussion assumes that there is an adequate supply of whole milk from noncontaminated sources, that there is an available manufacturing capacity to handle the diverted milk, and that the iodine-131 is the only radionuclide involved. In an actual situation these conditions may not be present and other factors may affect the practicality of proposed protective actions. The agency responsible for emergency action must identify and evaluate those factors that affect the practicality of protective action, and thus develop a response plan (with tentative protective action) that is responsive to local conditions and capabilities.

CHAPTER 5. COST CONSIDERATIONS

5.1 COST/BENEFIT ANALYSIS

5.1.1 Introduction

The general expectation is that protective action taken in the event of a nuclear incident will result in a net societal benefit considering the cost of the action and the corresponding avoided dose. These cost assessments, including cost/benefit analysis, have not been used to set the numerical value of the PAG's but rather to evaluate the feasibility of specific protective actions.

At least two basically different approaches can be used to assess the cost/benefit ratio of protective actions for the milk pathway. One approach would be to assume a protective action scenario (maximum milk concentration and length of time of protective action) and to calculate the total cost of the action and the benefit because of the avoided dose. The ratio of the cost/benefit can then be used to scale the maximum milk concentration to that concentration that yields equal costs and benefits. The problem with this approach is that positive net benefits when milk concentration of radioactivity is high are used to offset the negative net benefits during the later times of action.

This deficiency leads to the second approach of calculating the milk concentration on a per liter basis where the cost of the protective action equals the benefit because of the dose avoided. This approach will be used here since it gives a clearer picture of the identified costs and benefits. The specific concentration at which costs equals benefits should not however be viewed as the appropriate level for taking protective action. The philosophy of protective action is to take action to avoid most of the projected doses. Further, the simple analysis considered here treats only the direct cost of protective actions and ignores the administrative costs of starting, monitoring, and ceasing action, and other related social and economic impacts.

Although the PAG recommendations provide that protective actions be taken on the basis of projected dose to the infant, cost/benefit analysis must consider the cost impact on the milk supply and the benefit on a whole population basis. Accordingly the benefit realized from avoiding the dose associated with a given level of milk contamination C (μCi/l) must be summed over the age groups having different Intakes (I) and Dose Factors (DF) and is:

$$\text{Benefit} = C\ (\mu Ci/l) \times \text{Value}\ (\$/\text{rem})\ \Sigma Ii(l/d).DFi(\text{rem}/\mu Ci).$$

The total cost of the protective actions, which must also be summed over all the age intake groups is:

$$\text{Cost} = \text{PA COST} \times \Sigma Ii$$

Costs are in 1980 - 1981 dollars. These equations can then be solved for the concentration (C) at which cost = benefit giving:

$$C\ (C=B) = \frac{\text{PA COST}\ \Sigma Ii}{\text{Value}\ (\$/\text{rem})\ \Sigma(Ii \cdot DF_i)}$$

5.1.2 Benefit of Avoided Dose

In situations in which there has been an uncontrolled release of radioactivity to the environment, both the health savings and cost of a protective action can be expressed in terms of dollar values. This does not exclude the probability that undesirable features will result from an action that is difficult to evaluate in economic terms.

A previous cost-benefit analysis described the radioactive concentration of iodine-131 in milk at which it would be justifiable to initiate condemnation of milk (63). Following is a summary of the monetary benefit of radiation dose avoided using the approach suggested, with changes because of increased costs over time and new data on the relative incidence of various tumors.

The International Commission on Radiological Protection, (64) has endorsed the principle of expressing the detriment from radiation in monetary terms in order to facilitate simplified analysis of costs and benefits. This permits a direct comparison between the societal advantage gained in a reduction of the radiation dose and the cost of achieving this reduction. Cost-benefit analysis is the evaluation process by which one can determine the level at which, or above which, it would be justifiable to initiate the protective action because the health savings equaled or exceeded, the economic costs of the protective action. Certain factors, such as loss of public confidence in a food supply, are not considered; nor are economic factors because of hoarding and a shortage of supply considered. A similar treatment of the problem with almost the same result has been published (65). This type of exercise is useful prior to taking an action as one, and only one, of a series of inputs into decisionmaking.

The costs, and hence health savings to society, of 1 person-rem of whole-body dose (the product of a dose of 1 rem to the whole body and 1 person) has been estimated by various authors to be between $10 and $250 (66). The Nuclear Regulatory Commission (NRC) value for a cost-benefit analysis for augmented equipment for light-water reactors to reduce population dose, sets radiation costs at $1000 per person-rem (67).

Based on medical expenses in 1970, the total future cost of the consequences of all genetic damage of 1 person-rem (whole-body) was estimated by the BEIR Committee (2) to be between $12 and $120. These costs are in good agreement with estimates made by Arthur D. Little, Inc., for the Environmental Protection Agency, which calculated that in terms of 1973 dollars, 1 person-rem of radiation yielded a tangible cost of between $5 and $181 due to excess genetic disorders. A tangible cost of between $7 and $24 per person-rem was estimated to be the result of excess cancer in the same report. Therefore, the total health cost of a person-rem from these studies is between $12 and $205 (68).

Assuming that $200 is a reasonable estimate for the overall somatic health cost to society per person-rem whole body, the proportionate cost for individual organ doses must then be derived. For the purposes of assessing health cost, it is appropriate to use the relative incidence of cancer estimated to result from organ doses vs. whole body doses. From BEIR-III (3) (Table V-14 and V-17, and using an average of the male and female incidence) the thyroid contributes 20 percent of cancer and leukemia (red bone marrow doses) 11 percent of the total cancer incidence. Hence, the monetary costs per rem of radiation dose avoided are: to thyroid $40; and to red bone marrow $22.

5.1.3 Protective Action Costs

The direct cost of protective action will be assessed for (1) cost of stored feed, (2) condemnation at the farm (farm value), and (3) condemnation at the processing plant (retail value).

1. Cost of stored feed. For the participating herds (May 1, 1978 - April 30, 1979) the Dairy Herd Improvement Letter (69) reports a consumption of 12,600 lbs. of succulent

forage and 3,000 lbs. of dry forage, with a corresponding annual milk production of 14,129 lbs. (6200 liters). (The cows also consumed 5,800 lbs. of concentrates, which are not of concern here.) Taking 3 lbs. of succulent forage (silage) as equivalent to 1 lb. of hay, the annual hay equivalent consumption is 7,200 lbs (70). Thus, 1.16 lbs. of hay equivalent is consumed per liter of milk production. The 1980 average price received by farmers for all baled hay was $67.10 per ton or $0.0335 per lb. (71). The Protective Action (PA) cost of buying baled hay to replace pasture as the sole forage source is then $0.039 per liter.

2. Milk-farm value. The average price received by farmers for fluid-eligible milk, sold to plants and dealers in 1980, was $13.71 per hundred weight (monthly range $12.70 to $14.20) (71). The lower prices are received during the pasture season of April through August. For 44 liters per hundred weight, the farmer value of milk is $0.30 per liter.

3. Milk-retail value. Since it may be necessary to take protective action at some stage in the milk processing and distribution system it is appropriate to consider the retail value of milk. If condemnation of milk is taken at the receiving station or processing plant there will be additional costs above farm value associated with disposal. It is felt that retail price should represent an appropriate value. The average city retail price of fortified fresh whole milk sold in stores, January through October 1980 was $1.037 per 1/2 gallon (72). The monthly price increased from $1.015 in January to $1.067 in October, apparently because of inflation. Based on the average price the value of $0.56 per liter will be used.

5.1.4 Population Milk Intake and Dose

Table 20 summarizes the milk intake by population age groups and gives values of the age group intake factor Ii(l/d). The total intake by a population of 1000 is 281 l/d or an average individual daily intake of 0.28 l. The intake factor (Ii) is used with the dose factor DFi listed in Table 21 to calculate the dose factor summed over the whole population weighted by age per μCi/l of milk contamination.

5.1.5 Milk Concentration For Cost = Benefit

The above results are then used to calcultate the milk concentration at which the Protective Action (PA) costs equals the benefit from the dose avoided. The results are presented in Table 22. The cost = benefit concentration for use of stored feed in place of contaminated pasture is about 0.2 to 0.3 of the Preventive PAG for strontium and 0.01 to 0.02 for iodine and cesium. For condemnation, the cost = benefit concentrations based on farm value of milk have ratios of the Emergency PAG similar to those above. The cost = benefit concentrations based on retail value of milk are about a factor of 2 greater than those based on the milk's farm value. The fact that the cost = benefit concentrations are a significant percent of the PAG for strontium results largely because the value of the person-rem dose to red bone marrow is one-ninth that of whole-body doses while the PAG's are set at equal doses consistent with current regulations. Further the controlling PAG's are for the infant, while the cost/benefit reflects population averaged benefits.

Table 20. Population milk intake (Σ Ii)

Age group	Persons per 1000 population	Milk intake[a] (l/d)	Intake (Ii) by age group (l/d)
In utero	11	.4	4.4
0 < 1	14	.775	10.9
1 - 10	146	.470	68.6
11 - 20	196	.360	70.6
>20	633	.200	126.7
		ΣIi	281.2

[a]ICRP, 1974

Table 21. Population dose factors

Age group	Sr-89 DFi rem/μCi	Sr-89 Ii x DFi rem/μCi • 1/d	Sr-90 DFi rem/μCi	Sr-90 Ii x DFi rem/μCi • 1/d	Reference for DFi values[a]
In utero	.414	1.82	4.03	17.7	0 yr old
0 < 1	.194	2.12	2.49	27.2	0.5 yr-old
1 - 10	.0565	3.88	.929	63.8	Average
11 - 20	.0175	1.24	.82	57.9	Av 11 yr & adult
> 20	.012	1.52	.70	88.7	Adult
	ΣIiDFi	10.58		255.3	

[a]See Chapter 2.

Age group	Cs-134 DFi rem/μCi	Cs-134 Ii x DFi rem/μCi • 1/d	Cs-137 DFi rem/μCi	Cs-137 Ii x DFi rem/μCi • 1/d	Reference for DFi values[a]
In utero	.068	.3	.061	.27	Adult[b]
0 < 1	.118	1.29	.071	.77	Infant
1 - 10	.093	6.39	.066	4.53	Av. infant & adult
11 - 20	.093	6.57	.066	4.66	"
> 20	.068	8.51	.061	7.73	Adult
	ΣIiDFi	23.06		17.966	

[a]See Chapter 2.
[b]No credit taken for reduced biological half-life in pregnant women.

Age group	I-131 DFi rem/μCi	I-131 Ii x DFi rem/μCi • 1/d	Reference for DFi values[a]
In utero	.8	35	Max. estimate
0 < 1	16	174	Newborn
1 - 10	5.7	391	Average from smooth curve
11 - 20	2.1	148	15 yr old
> 20	1.5	190	Adult
	ΣIi DFi	938	

[a]See Chapter 2.

Table 22. Milk concentration at which cost = benefit
(Population basis - value of ΣIixDFi for 1000 persons)

	Sr-89	Sr-90	I-131	Cs-134	Cs-137
$\Sigma Ii \times DFi$ $\frac{rem}{\mu Ci} \cdot \frac{1}{d}$	10.58	255	938	23.1	17.96
Value ($/rem)	22	22	40	200	200
	PA cost	CONC. (Cost = Benefit) (μCi/l)			
Stored Feed	$0.039	.047	.002	.0003	.0025	.003
Farm Milk	0.30	.36	.015	.0023	.018	.025
Retail Milk	0.56	.68	.028	.0042	.034	.044
		Peak CONC. (μCi/l)				
Preventive PAG		.14	.009	.015	.15	.24
Emergency PAG infant		1.4	.09	.15	1.5	2.4
Emergency PAG adult		30	.4	2.0	3.0	4.0

5.2 ECONOMIC IMPACT

The Emergency Planning Zone (EPZ) for the ingestion pathway has been set at 50 miles (73). The area impacted that requires protective action is the major factor influencing cost. Assessment of the economic impact will be considered for the case of contamination of the milk pathway in one 22.5° Sector out to a distance of 50 miles. Table 23 gives data on the annual sales of whole milk and total area of leading dairy States and selected States. The annual milk sales in Wisconsin of 3.52×10^5 lbs. per sq. mile exceeds that of any other State and will be used to assess the economic impact. There may, of course, be individual counties and areas surrounding nuclear power plants where milk production exceeds the Wisconsin State average. The Wisconsin average should, however, represent a maximum for most areas of the United States.

Table 23. Milk production of selected States
(Statistical Abstract of the U.S., 1978)

State	Whole milk sold (10^9 lbs/year)	Total area (mi^2)	Milk per unit area 10^5 lbs/mi^2
WI	20.5	56,154	3.52
VT	2.06	9,609	2.14
NY	9.92	49,576	2.00
PA	7.37	45,333	1.64
IA	4.07	56,290	1.38
CT	.595	5,009	1.19
MN	9.27	84,068	1.10
OH	4.43	41,222	1.08
MI	4.63	58,216	0.80
CA	11.53	158,693	0.73
MA	0.55	8,257	0.67
NJ	0.52	7,836	0.66

Another important factor in assessing the economic impact of protective actions in the milk pathway is the length of time that such actions will be necessary. During most of the year in northern parts of the U.S., cattle will already be on stored feed and there will be no

additional costs for the stored feed protective action. For other situations and the Emergency PAG, the time over which protective actions will be necessary is a function of a number of parameters unique to each site and the causative accident. Thus, what are intended as conservative assumptions will be selected. The time behavior of I-131 on pasture grass is controlled by the 8-day radioactive half-life and the 14-day weathering half-life (yielding an effective half-life of about 5 days). Milk which contains I-131 at the Emergency PAG of 0.15 μCi/l will be reduced to the cost = benefit concentration (farm value) of 0.0023 μCi/l about 30 days later. Obviously in most cases of an atmospheric release, those areas closer to the release point will have higher levels of contamination and longer times of protective action. The NRC and EPA in the Planning Basis Report NUREG-0396 (NRC, 1978) assume that radiation doses from the airborne plume decrease according to the $r^{-1.5}$ factor. Use of this factor for contamination of pasture results in milk concentrations at 2 miles that are about 100 times that at 50 miles. For an effective half-life of 5 days this would require an additional 30-35 days of protective action at 2 miles over that at 50 miles to yield the same milk levels upon ceasing action. Although these models cannot be assumed to be rigorously accurate in a specific accident situation, they do indicate that action might be required for 1 or 2 months.

NUREG-0396 notes that the dose from milk pathway is of the order of 300 times the thyroid dose from inhalation (74). Under this assumption (and above models), the food PAG's would be exceeded at hundreds of miles if protective action because of inhalation were required at 10 miles. It should be noted that the meteorological models that are empirically derived are not likely to be valid for such long distances. Further changes in wind direction and meteorological dispersion conditions may reduce the levels of pasture contamination and the downwind distance. For assessing ecomomic impact, contamination of a 22.5° Sector out to a distance of 50 miles will be arbitrarily assumed, even though actual contamination patterns are not likely to be similar.

Under these assumptions we then have:

Area (Circle - 50 mile radius) - 7850 mi^2

Area (22.5° Sector - 50 mile) - 491 mi^2

Milk Production - 3.52×10^5 lbs/mi^2 per year - 2.93×10^4 lbs/mi^2 per month

Production (22.5°/50 mi Sector) - 1.44×10^7 lbs./month

Cost of Stored Feed - $0.017 per lb. milk

Cost Impact (22.5°/50 mile Sector) - $\$2.46 \times 10^5$ per month

Thus, the direct cost of placing cows on stored feed within a 22.5° Sector out to 50 miles based on farm value, would be about $0.25 million per month. The cost would be zero during that portion of the year and in geographical areas where cattle are already on stored feed. While such protective actions might be required for periods up to 2 months at areas near the accident site, such would not be the case at the greater distances which involve the major portion of the area. Condemnation of milk is the protective action of last resort for areas of very high contamination. As noted above, the farm value of milk is $0.30 per liter. Thus, the condemnation of milk at the Emergency PAG for a 22.5°/50 mile sector would have a cost of about $2 million for a month of protective action. Where I-131 is the only significant contaminant, whole milk can be diverted to manufactured products, such as powdered milk, which can be stored to allow disappearance of the radioactivity. We do not have cost figures for this action.

It is of interest to compare the arbitrary assumptions on land area used above to the contamination resulting from the Windscale accident. (NB: This was not a power reactor of the type presently used in the United States). According to Booker, the Windscale accident resulted in milk values exceeding 0.015 μCi/l at about 200 kilometers or 125 miles

downwind (75). Milk contamination was estimated as exceeding 0.01 μCi/l over 16,700 km^2 or 6400 mi^2. Thus, the Windscale accident resulted in contamination exceeding the Preventive PAG over an area about 10 times greater than that assumed above. Protective actions were taken at Windscale at milk concentrations of 0.1 μCi/l (approximately the Emergency PAG) and involved an area of about 520 km^2 or 200 mi^2 for periods of 3-6 weeks.

5.3 COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is defined as the economy with which a particular task may be carried out.

The data available for this analysis was obtained with the cooperation of the Nuclear Regulatory Commission. Briefly, the NRC employed the models cited in the Reactor Safety Study (7) to evaluate the agricultural costs and cumulative dose commitment that could occur under two accident conditions - a design basis for siting purposes and a PWR 7 accident (7). A typical reactor site in the northeastern United States was envisioned. Unfortunately, the parameters employed are not directly comparable with the pathways and dosimetric parameters associated with the PAG's. Nevertheless, a good indication of the effects of taking a protective action (in this case the condemnation of milk) at specific interdiction levels can be ascertained.

Figure 5 presents the agricultural costs at specific interdiction criteria. The costs are, for the most part, associated with the market value of milk. The interdiction criteria are in terms of rem to an infant thyroid. From Figure 3, it can be seen that costs drop rapidly between 0.5 and 10 rem and more gradually after 20 rem. The ratio of costs for a design basis accident (siting) to a PWR 7 remains constant.

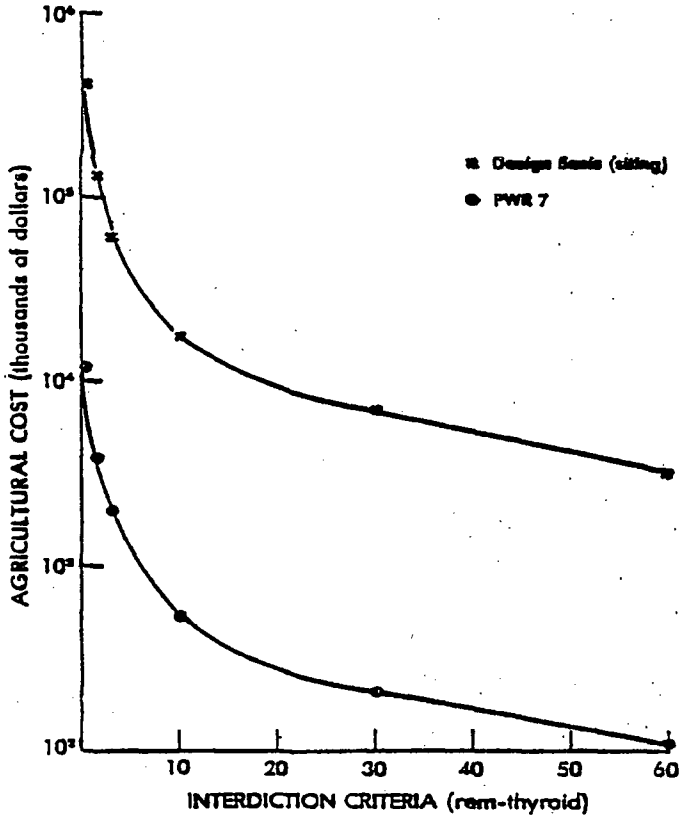


Figure 3. Agricultural cost model accident.

Figure 4 is a graph of the dose commitment for a design basis accident and a PWR 7 assuming protective action is initiated at specific interdiction levels. The dose commitments are accrued via external as well as internal exposure (inhalation and ingestion). Therefore, they do not exactly fit the situation described in the PAG's under consideration. The dose commitment rises rapidly when the interdiction criteria are between 0.5 and 20 rem. The increase in dose commitment for a design basis accident is less rapid than for a PWR 7. Hence, at or above an interdiction criteria of 20 rem, savings in radiation dose are minimal compared to the savings accrued below 10 rem.

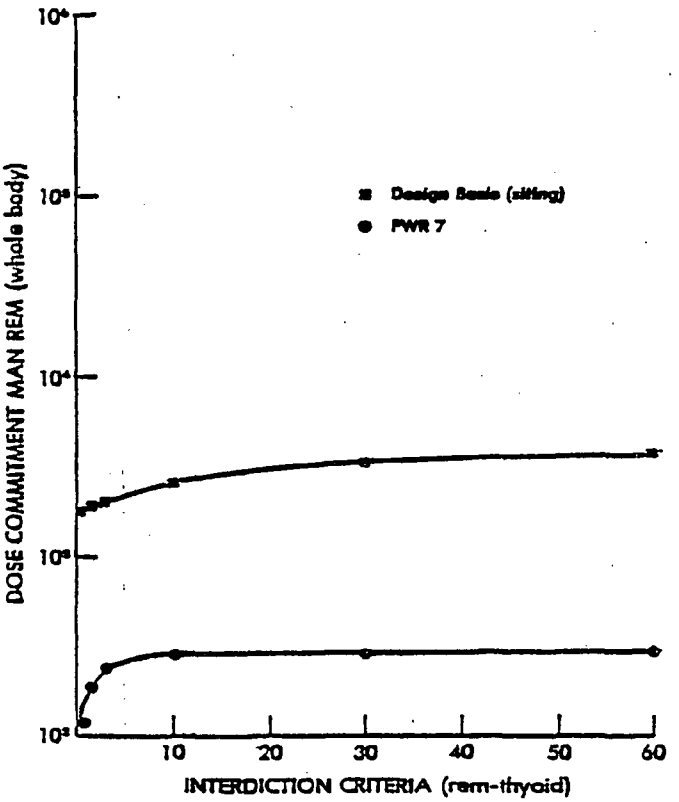


Figure 4. Dose commitment model accident.

5.4 SUMMARY AND CONCLUSION

The milk concentration at which the population benefits (from dose avoided) equals the direct costs of stored feed is equivalent to about one-third of the Preventive PAG for strontium and to one-fiftieth or less for iodine-131 and cesium. If condemnation is based on retail milk value, then the respective concentrations are about one-half and one-fiftieth of the Emergency PAG. Unless the indirect costs of implementing protective actions are significantly greater than the direct costs, it appears feasible to take protective actions at the respective PAG level and to continue such action to avoid about 90 percent of the projected dose for iodine and cesium. In the case of strontium contamination of milk, such action is only cost beneficial until the concentration is about 30 percent of the PAG response level.

Estimated costs of taking protective action within the Emergency Planning Zone (EPZ) for a 22.5° Sector to 50 miles (about 500 mi^2) is $2 million per month for condemnation (farm milk value) and $0.26 million per month for use of stored feed. In the case of

atmospheric dispersed contamination, protective action may have to continue for 2 months near the site.

The recommended approach is to place all cows on stored feed to prevent the contamination of milk at significant levels, to divert iodine contaminated milk to manufactured products that have a long shelf life to allow radioactive decay, and only consider condemnation of milk exceeding the Emergency PAG. It appears that doses to the public can be limited to less than 10 percent of the Preventive PAG (or less then 0.15 rem thyroid) by actions having direct costs of a few milion dollars for a significant accident.

REFERENCES

1. Lowrance, W.W. Of Acceptable Risk. William Kaufmann, Inc., Los Altos, CA, p. 8-11 (1976).

2. National Academy of Sciences, National Research Council. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation. Report of the Advisory Committee on the Biological Effects of Ionizing Radiation (1972).

3. National Academy of Sciences, National Research Council. The Effects on Population of Exposure to Low Levels of Ionizing Radiation. Report of the Advisory Committee on Biological Effects on Ionizing Radiation (1980).

4. U.S. Department of Commerce. Statistical Abstract. Washington, D.C. (1979).

5. National Cancer Institute. End Results in Cancer. Report No. 4, National Institutes of Health, DHEW, Washington, DC, pp. 161-164 (1972).

6. Otway, H.J., R.K. Lohrding, and M.E. Battat. Nucl Tech 72:173 (1971).

7. United States Nuclear Regulatory Commission. Reactor Safety Study. WASH-1400 Appendix VI. Washington, DC (1975).

8. Dinman, B.R. The reality and acceptance of risk. JAMA 244:1226 (September 1980).

9. National Oceanic and Atmospheric Administration (NOAA). A Federal Plan for National Disaster Warning and Preparedness. U.S. Department of Commerce, Washington, DC (June 1973).

10. Metropolitan Life Insurance Company. Catastrophic Accidents - A 35-year Review. Statistical Bulletin Vol. 58, New York, NY (March 1977).

11. Starr, C., M.A. Greenfield, and D.F. Hausknecht. Nucl News 15:37 (1972). United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1977 Report. United Nations, New York (1977).

12. Weinberg, A.W. On Dose-Response and Standard Setting. Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tenn. ORAU/IEA 78-21(0). (December 1978).

13. Adler, H. An Approach to Setting Radiation Standards. Health Phys 34:719-720 (June 1978).

14. Food and Drug Administration. Proposed Recommendations on Accidental Radioactive Contamination of Human Foods and Annual Feeds. Federal Register (43 FR 58790) (December 15, 1978).

CHAPTER 7

Implementing the Protective Action Guides for the Intermediate Phase: Exposure to Deposited Materials

7.1 Introduction

This chapter provides guidance for implementing the PAGs set forth in Chapter 4. It is for use by State and local officials in developing their radiological emergency response plans to protect the public from exposure to radiation from deposited radioactive materials. Due to the wide variety in types of nuclear incidents and radionuclide releases that could occur, it is not practical to provide implementing guidance for all situations. The guidance in this chapter applies primarily to radionuclides that would be involved in incidents at nuclear power plants. It may be useful for radionuclides from incidents at other types of nuclear facilities or from incidents not involving fixed facilities (e.g., transportation accidents).However, specific implementation procedures for incidents other than those at nuclear power plants should be developed by planners on a case-by-case basis.

Contrary to the situation during the early phase of a nuclear incident, when decisions usually must be made and implemented quickly by State and local officials before Federal assistance is available, many decisions and actions during the intermediate phase can be delayed until Federal resources are present, as described in the Federal Radiological Monitoring and Assessment Plan (FE-85). Because of the reduced level of urgency for immediate implementation of these protective actions, somewhat less detail may be needed in State radiological emergency response plans than is required for the early phase.

At the time of decisions on relocation and early decontamination, sheltering and evacuation should have already been completed to protect the public from exposure to the airborne plume and from high exposure rates from deposited materials. These protective actions may have been implemented prior to verification of the path of the plume and therefore some persons may have been unnecessarily evacuated from areas where actual doses are much lower than were projected. Others who were in the path of the plume may have been sheltered or not protected at all. During the intermediate phase of the response, persons must be relocated from areas where the projected dose exceeds the PAG for relocation, and other actions taken to reduce doses to persons who are not relocated from contaminated areas. Persons

evacuated from areas outside the relocation zone may return.

7.1.1 Protective Actions

The main protective actions for reducing exposure of the public to deposited radioactivity are relocation, decontami- nation, shielding, time limits on exposure, and control of the spread of surface contamination. Relocation is the most effective, and, usually, the most costly and disruptive. It is therefore only applied when the dose is sufficiently high to warrant it. The others are generally applied to reduce exposure of persons who are not relocated, or who return from evacuation status to areas that received lower levels of deposited radioactivity. This chapter provides guidance for translating radiological conditions in the environment to projected dose, to provide the basis for decisions on the appropriate protective actions.

7.1.2 Areas Involved

Figure 7-1 provides a generalized example of the different areas and population groups to be dealt with. The path of the plume is assumed to be represented by area 1. In reality, variations in meteorological conditions would almost certainly produce a more complicated shape, but the same principles would apply.

Because of plant conditions and other considerations prior to or after the release, persons will already have been evacuated from area 2 and sheltered in area 3. Persons who have been evacuated from or sheltered in areas 2 and 3, respectively, as precautionary actions for protection from the plume, but whose homes are outside the plume deposition area (area 1), may return to their homes as soon as environmental monitoring verifies the boundary of the area that received deposition (area 1).

Area 4 is designated a restricted zone and is defined as the area where projected doses are equal to or greater than the relocation PAG. Persons residing just outside the boundary of the restricted zone may receive a dose near the PAG for relocation if decontamination or other dose reduction efforts are not implemented.

Area 1, with the exception of the restricted zone, represents the area of contamination that may continue to be occupied by the general public. Nevertheless, there will be contamination levels in this area that will require continued monitoring and dose reduction efforts other than relocation.

The relative positions of the boundaries shown in Figure 7-1 depend on areas evacuated and sheltered, and the radiological characteristics of the release. For example, area 4 (the restricted zone) could fall entirely inside area 2 (area evacuated), so that the only persons to be relocated would be those residing in area 4 who were either missed in the evacuation process or who, because of the high risk for their evacuation, had remained sheltered during plume passage.

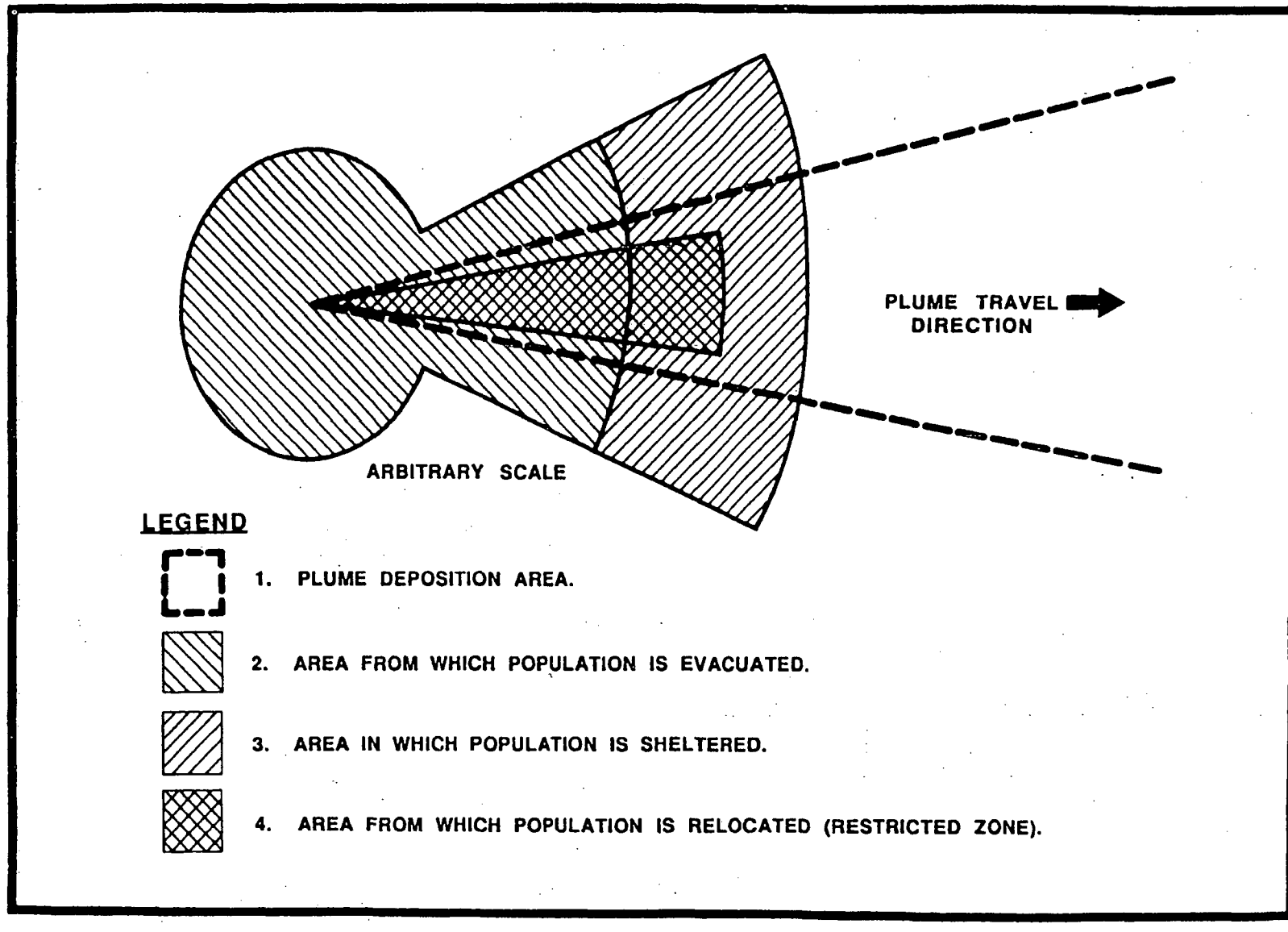


FIGURE 7-1. RESPONSE AREAS.

At the time the restricted zone is established, a temporary buffer zone (not shown in Figure 7-1) may be needed outside portions of the restricted zone in which occupants will not be allowed to return until monitoring confirms the stability of deposited contamination. Such zones would be near highly contaminated areas in the restricted zone where deposited radionuclides might be resuspended and then redeposited outside the restricted zone. This could be especially important at locations close to the incident site where the radioactivity levels are high and the restricted zone may be narrow. The extent of the buffer zone will depend on local conditions. Similarly, a buffer zone encompassing the most highly contaminated areas in which persons are allowed to reside may be needed. This area should be monitored routinely to assure acceptability for continued occupancy.

7.1.3 Sequence of Events

Following passage of the airborne plume, several tasks, as shown in Figure 7-2, must be accomplished simultaneously to provide for timely protection of the public. The decisions on the early task of relocating persons from high exposure rate areas must be based on exposure rate measurements and dose analyses. It is expected that monitoring and dose assessment will be an on-going process, with priority given to the areas with the highest exposure rate. The general sequence of events is itemized below, but the time frames will overlap, as demonstrated in Figure 7-2.

1. Based on environmental data, determine the areas where the projected one-year dose will exceed 2 rem and relocate persons from those areas, with priority given persons in the highest exposure rate areas.

2. Allow persons who were evacuated to return immediately to their residences if they are in areas where field gamma measurements indicate that exposure rates are near normal background levels (not in excess of twice the normal background in the area before the incident). If, however, areas of high deposition are found to be near areas with low deposition such that resuspended activity could drift into the occupied areas, a buffer zone should be established to restrict occupancy until the situation is analyzed and dose projections are confirmed.

3. Determine the location of the isodose line corresponding to the relocation PAG, establish the boundary of the restricted zone, and relocate any persons who still reside within the zone. Also, convert any evacuees who reside within the restricted zone to relocation status. Evacuated persons whose residence is in the area between the boundary of the plume deposition and the boundary to the restricted zone may return gradually as confidence is gained regarding the projected dose in the area.

4. Evaluate the dose reduction effectiveness of simple decontamination

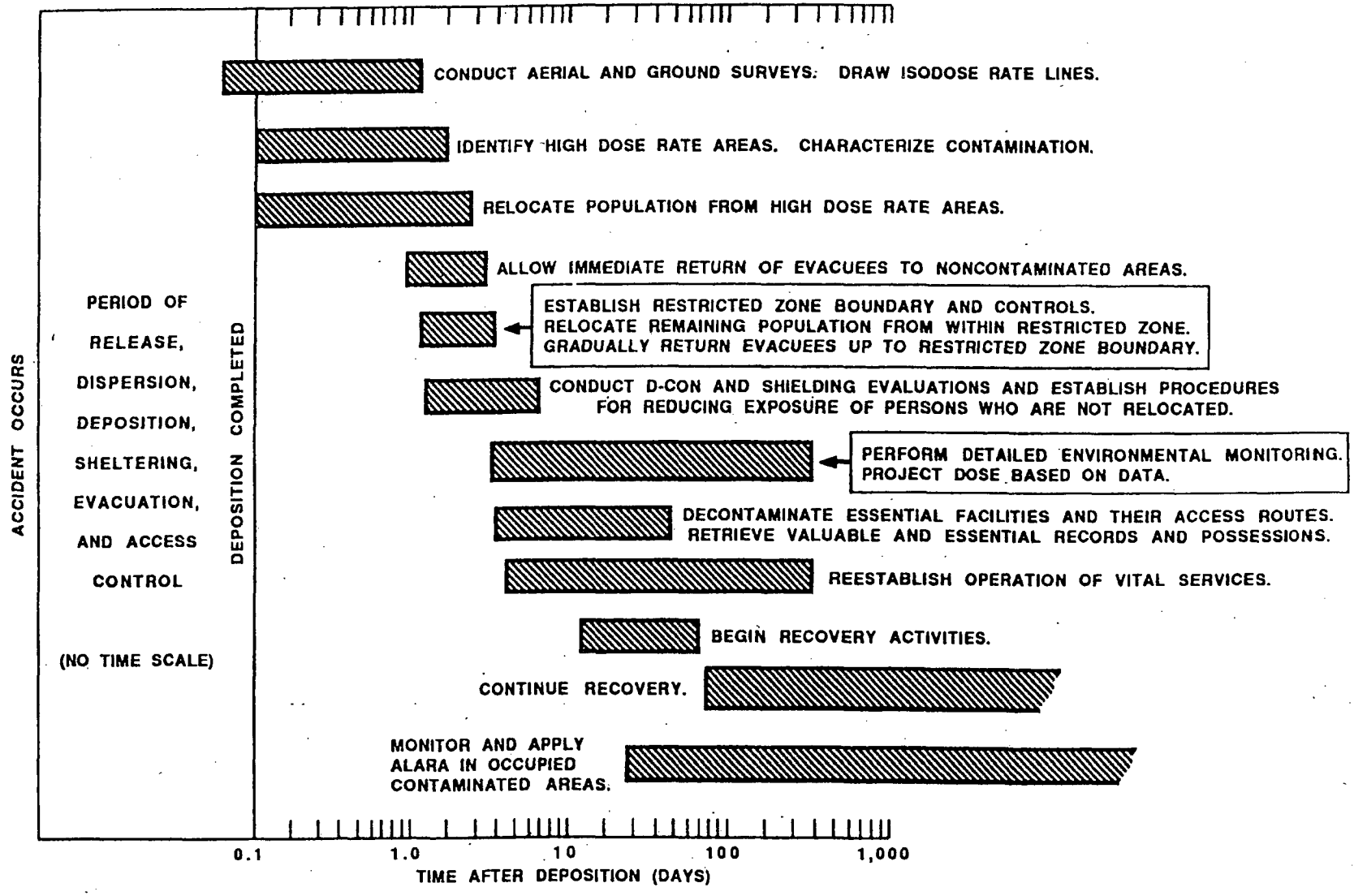


FIGURE 7-2. POTENTIAL TIME FRAME OF RESPONSE TO A NUCLEAR INCIDENT.

techniques and of sheltering due to partial occupancy of residences and workplaces. Results of these evaluations may influence recommendations for reducing exposure rates for persons who are not relocated from areas near, but outside, the restricted zone.

5. Establish a mechanism for controlling access to and egress from the restricted zone. Typically this would be accomplished through control points at roadway accesses to the restricted zone.

6. Establish monitoring and decontamination stations to support control of the restricted zone.

7. Implement simple decontamination techniques in contaminated areas outside the restricted zone, with priorities for areas with higher exposure rates and for residences of pregnant women.

8. Collect data needed to establish long-term radiation protection criteria for recovery and data to determine the effectiveness of various decontamination or other recovery techniques.

9. Begin operations to recover contaminated property in the restricted zone.

7.2 Establishment of Isodose-rate Lines

As soon as Federal or other assistance is available for aerial and ground monitoring, a concentrated effort should begin to establish isodose-rate lines on maps and the identification of boundaries to the restricted zone. Planning for this effort should include the development of standard maps that can be used by all of the involved monitoring and dose assessment organizations to record monitoring data.

Aerial monitoring (e.g., the Department of Energy Aerial Monitoring Service) can be used to collect data for establishing general patterns of radiation exposure rates from deposited radioactive material. These data, after translation to readings at 1 meter above ground, may form the primary basis for the development of isodose lines out to a distance where aerial monitoring shows no radiation above twice natural background levels. Air sample measurements will also be needed to verify the contribution to dose from inhalation of resuspended materials.

Gamma exposure rates measured at 1 meter will no doubt vary as a function of the location of the measurement within a very small area. This could be caused by different deposition rates for different types of surfaces (e.g., smooth surfaces versus heavy vegetation). Rinsing or precipitation could also reduce levels in some areas and raise levels in others where runoff settles. In general, where exposure rates vary within designated areas, the higher values should be used for dose projection for persons within these areas unless judgment can be

used to estimate an appropriate average exposure rate.

Measurements made at 1 meter to project whole body dose from gamma radiation should be made with instruments of the "closed window" type so as to avoid the detection of beta radiation. Although beta exposure will contribute to skin dose, its contribution to the overall risk of health effects from the radionuclides expected to be associated with reactor incidents should not be controlling in comparison to the whole body gamma dose (AR-89). Special beta dose analyses may be appropriate when time permits to determine its contribution to skin dose. Since beta dose rate measurements require sophisticated equipment that is generally not available for field use, beta dose to the skin should be limited based on measured concentrations of radionuclides per unit area.

7.3 Dose Projection

The primary dose of interest for reactor incidents is the sum of the effective gamma dose equivalent from external exposure and the committed effective dose equivalent from inhalation. The exposure periods of interest are first year, second year, and up to 50 years after the incident.

Calculation of the projected gamma dose from measurements will require knowledge of the principal radionuclides contributing to exposure and their relative abundances. Information on these radiological characteristics can be compiled either through the use of portable gamma spectrometers or by radionuclide analysis of environmental samples. Several measurement locations may be required to determine whether any selective radionuclide deposition occurred as a function of weather, surface type, distance from the point of release, or other factors. As part of the Federal Radio- logical Monitoring and Assessment Plan (FE-85), the U. S. Department of Energy and the U. S. Environmental Protection Agency have equipment and procedures to assist State officials in performing environmental measurements, including determination of the radiological characteristics of deposited materials.

The gamma exposure rate may decrease rapidly if deposited material includes a significant fraction of short-lived radionuclides. Therefore, the relationship between instantaneous exposure rate and projected first- and second-year annual or the 50-year doses will change as a function of time, and these relationships must be established for the particular mix of deposited radioactive materials present at the time of the gamma exposure rate measurement.

For incidents involving releases from nuclear power plants, gamma radiation from deposited radioactive materials is expected to be the principal exposure pathway, as noted above. Other pathways should also be evaluated, and their contributions considered, if significant. These may include inhalation of resuspended material and beta dose to the skin.

Exposure from ingestion of food and water is normally limited independently of decisions for relocation and decontamination (see Chapters 3 and 6). In rare instances, however, where withdrawal of food and/or water from use would, in itself, create a health risk, relocation may be an appropriate protective action for protection from exposure via ingestion. In this case, the committed effective dose equivalent from ingestion should be added to the projected dose from other exposure pathways for decisions on relocation.

The following sections provide methods for evaluating the projected dose from whole body external exposure and from inhalation of resuspended particulate material, based on environmental information.

7.3.1 Projected External Gamma Dose

Projected whole body external gamma doses at 1 meter height at particular locations during the first year, second year, and over the 50-year period after the incident are the parameters of interest. The environmental information available for calculating these doses is expected to be the current gamma exposure rate at 1 meter height and the relative abundance of each radionuclide contributing significantly to that exposure rate. Calculational models are available for predicting future exposure rates as a function of time due to radioactive decay and weathering. Weathering is discussed in WASH-1400, Appendix VI (NR-75), and information on the relationship between surface concentrations and gamma exposure rate at 1 meter is addressed in reference (DO-88).

Following the incident, experiments should be conducted to determine the dose reduction factors associated with part-time occupancy of dwellings and workplaces, and with simple, rapid, decontamination techniques, so that these factors can also be applied to the calculation of dose to persons who are not relocated. However, these factors should not be included in the calculation of projected dose for decisions on relocation.

Relocation decisions can generally be made on the basis of the first year projected dose. However, projected doses during the second year and over 50 years are needed for decisions on the need for other protective actions for persons who are not relocated. Dose conversion factors are therefore needed for converting environmental measurements to projected dose during the first year, second year, and over 50 years following the incident. Of the two types of environmental measurements that can be made to project whole body external gamma dose, gamma exposure rate in air is the easiest to make and is the most directly linked to gamma dose rate. However, a few measurements of the second type (radionuclide concentrations on surfaces) will also be needed to properly project decreasing dose rates.

Tables 7-1 and 7-2 provide information to simplify development

Table 7-1 Gamma Exposure Rate and Effective Dose Equivalent (Corrected for Radioactive Decay and Weathering) due to an Initial Uniform Concentration of 1 pCi/m^2 on Ground Surface

Radionuclide	Half-life (hours)	Initial exposure[a] rate at 1 m (mR/h per pCi/m^2)	Integrated dose (weathering factor included)[b] year one (mrem per pCi/m^2)	year two (mrem per pCi/m^2)	0-50 years (mrem per pCi/m^2)
Zr-95	1.54E+03	1.2E-08	3.3E-05	4.0E-07	3.4E-05
Nb-95	8.41E+02	1.3E-08	(b)	(b)	(b)
Ru-103	9.44E+02	8.2E-09	7.1E-06	0	7.1E-06
Ru-106	8.84E+03	3.4E-09	1.2E-05	3.7E-06	1.8E-05
Te-132	7.82E+01	4.0E-09	3.2E-06	0	3.2E-06
I-131	1.93E+02	6.6E-09	1.3E-06	0	1.3E-06
I-132	2.30E+00	3.7E-08	(b)	(b)	(b)
I-133	2.08E+01	1.0E-08	2.1E-07	0	2.1E-07
I-135	6.61E+00	2.4E-08	1.6E-07	0	1.6E-07
Cs-134	1.81E+04	2.6E-08	1.0E-04	4.7E-05	2.4E-04
Cs-137	2.65E+05	1.0E-08	4.5E-05	2.9E-05	6.1E-04
Ba-140	3.07E+02	3.2E-09	1.1E-05	0	1.1E-05
La-140	4.02E+01	3.5E-08	(b)	(b)	(b)

[a]Estimated exposure rate at 1 meter above contaminated ground surface. Based on data from reference (DO-88).

[b]Radionuclides that have short-lived daughters (Zr/Nb-95, Te/I-132, Ru/Rh-106, Cs-137/Ba-137m, Ba/La-140) are assumed to quickly reach equilibrium. The integrated dose factors listed are the effective gamma dose due to the parent and the daughter. Based on data from reference (DO-88).

Table 7-2 Exposure Rate and Effective Dose Equivalent (Corrected for Radioactive Decay) due to an Initial Concentration of 1 pCi/m^2 on Ground Surface

Radionuclide	Half-life (hours)	Initial exposure[a] rate at 1 m (mR/h per pCi/m^2)	Integrated dose (weathering factor not included)[b] year one (mrem per pCi/m^2)	year two (mrem per pCi/m^2)	0-50 years (mrem per pCi/m^2)
Zr-95	1.54E+03	1.2E-08	3.8E-05	8.0E-07	3.9E-05
Nb-95	8.41E+02	1.3E-08	(b)	(b)	(b)
Ru-103	9.44E+02	8.2E-09	7.8E-06	0	7.8E-06
Ru-106	8.84E+03	3.4E-09	1.5E-05	7.6E-06	3.0E-05
Te-132	7.82E+01	4.0E-09	3.3E-06	0	3.3E-06
I-131	1.93E+02	6.6E-09	1.3E-06	0	1.3E-06
I-132	2.30E+00	3.7E-08	(b)	(b)	(b)
I-133	2.08E+01	1.0E-08	2.1E-07	0	2.1E-07
I-135	6.61E+00	2.4E-08	1.6E-07	0	1.6E-07
Cs-134	1.81E+04	2.6E-08	1.3E-04	9.6E-05	4.7E-04
Cs-137	2.65E+05	1.0E-08	6.0E-05	5.9E-05	1.8E-03
Ba-140	3.07E+02	3.2E-09	1.2E-05	0	1.2E-05
La-140	4.02E+01	3.5E-08	(b)	(b)	(b)

[a]Estimated exposure rate at 1 meter above contaminated ground surface. Based on data from reference (DO-88).

[b]Radionuclides that have short-lived daughters (Zr/Nb-95, Ru/Rh-106, Te/I-132, Cs-137/Ba-137m, Ba/La-140) are assumed to quickly reach equilibrium. The integrated dose factors listed are the effective gamma dose due to the parent and the daughter. Based on data from reference (DO-88).

of dose conversion factors through the use of data on the radionuclide mix, as determined from environmental measurements. These tables list the deposited radionuclides most likely to be the major contributors to dose from incidents at nuclear power facilities. In addition to providing integrated, effective doses per unit of surface concentration, they provide, in column three, the exposure rate (mR/h) in air per unit of surface contamination. All exposure rate values are based on those given in reference (DO-88). They were estimated from the total body photon dose rate conversion factors for exposure at 1 m above the ground surface. Since the ratio of effective dose to air exposure is about 0.7, dividing the effective dose rate by 0.7 results in an estimate of the exposure rate in air. The integrated effective doses are based on dose conversion factors also listed in reference (DO-88). Table 7-1 takes into account both radioactive decay and weathering, whereas the values in Table 7-2 include only radioactive decay. The effect of weathering is uncertain and will vary depending on the type of weather, type of surface, and the chemical form of the radionuclides. The user may choose either table depending on the confidence accorded the assumed weathering factors.

The following steps can be used to develop dose conversion factors to calculate projected future doses from gamma exposure rate measurements for specific mixes of radionuclides:

1. Using spectral analysis of gamma emissions from an environmental sample of deposited radioactivity, determine the relative abundance of the principal gamma emitting radionuclides. Analyses of uniform samples from several different locations may be necessary to determine whether the relative concentrations of radionuclides are constant. The results may be expressed as the activity (pCi) of each radionuclide in the sample.

2. Multiply each activity from step 1 by the corresponding values in column 3 of Table 7-1 or Table 7-2 (depending on whether or not weathering is to be considered) to determine the relative contribution to the gamma exposure rate (mR/h) at 1-meter height for each radionuclide. Sum the results for each sample.

3. Similarly, multiply each activity from step 1 by the corresponding values in columns 4, 5, and 6 to determine the 1st-year, 2nd-year, and 50-year relative integrated doses contributed by each radionuclide. Sum these results for each sample. Radionuclides listed in Tables 7-1 and 7-2 that have short-lived daughters (Zr/Nb-95, Te/I-132, Ru/Rh-106, Cs-137/Ba-137m, Ba/La-140) were assumed to be in equilibrium with their daughters when the tabulated values for integrated dose were calculated. Since the values for the parents include the total dose from the parent and the daughter, do not double count these daughters in the sum. (In the cases of Cs-137/Ba-137m, and Ru-106/Rh-106, the parents are not gamma emitters, so the listed exposure rates and doses are actually those from the daughters alone.)

4. Using the results from steps 2 and 3, the relevant dose conversion factors, *DCF*, for each sample are then given by:

$$DCF = \frac{\sum_{1}^{n} H_i}{\sum_{1}^{n} X_i}$$

where H_i = effective dose equivalent for radionuclide i (mrem),
X_i = gamma exposure rate for radionuclide i (mR/h)
n = the number of radionuclides in the sample.

Since the samples represented in the numerator and denominator are identical, the effect of the size of the sample cancels.

These dose conversion factors may be applied to any measured gamma exposure rate for which the relative concentrations of radionuclides are the same as those in the sample that was analyzed.

The following example demonstrates the use of the above procedures for calculating a DCF. For purposes of the example it is assumed that environmental measurements revealed a mix of radionuclides as shown in column 3 of Table 7-3. The (relative) exposure rate conversion factors in column 4 of Table 7-3 are taken from column 3 of Table 7-1. The (relative) exposure rates in column 5 are the products of columns 3 and 4. The (relative) doses for individual radionuclides in columns 6, 7, and 8 were calculated by multiplying the concentrations in column 3 by the dose conversion factors in columns 4, 5, and 6 of Table 7-1, respectively. (Columns 4, 5, and 6 of Table 7-2, which do not include weathering, could have been used instead of those in Table 7-1.)

For this example, the conversion factor for dose in the first year was obtained for the assumed radionuclide mix from the totals of columns 5 and 6 of Table 7-3, which indicate that a calculated dose of 0.023 mrem in the first year corresponds to an initial exposure rate of 1.5E-4 mR/h. Therefore, the first year dose conversion factor (DCF_1) for this example is 150 mrem for each mR/h measured at the beginning of the period.

This DCF may be multiplied by any gamma exposure rate measurement to estimate the dose in the first year for locations where the exposure rate is produced by a radionuclide mix the same as assumed for calculating the DCF, and where weathering affects the exposure rate in the same manner as assumed. For example, if a gamma exposure rate measurement were taken at the location where the contamination sample in Table 7-3 was taken, this exposure rate could be multiplied by the DCF calculated in the above example to obtain the projected first year dose at that point. Based on the example analysis and a relocation PAG of 2 rem, for this case the exposure rate at the boundary of the restricted zone should be no greater than

Table 7-3 Example[a] Calculation of Dose Conversion Factors for Gamma Exposure Rate Measurements Based on Measured Isotopic Concentrations[b]

Radionuclide	Half-life (hours)	Measured concentration (pCi/sample[d])	$\frac{mR/h^2}{pCi/m^2}$	Calculated Exposure rate at 1 m (mR/hr)	Calculated effective dose at 1 meter		
					year one (mrem)	year two (mrem)	50 years (mrem)
I-131	1.93E+2	2.6E+2	6.6E-9	1.7E-6	3.3E-4	0	3.3E-4
Te-132	7.8E+1	3.6E+3	4.0E-9	1.4E-5	1.2E-2	0	1.2E-2
I-132	2.3	3.6E+3	3.7E-8	1.3E-4	(e)	(e)	(e)
Ru-103	9.44E+2	2.2E+2	8.2E-9	1.8E-6	1.6E-3	0	1.6E-3
Rh-106[f]	8.84E+3	5.0E+1	3.4E-9	1.7E-7	5.8E-4	1.9E-4	9.2E-4
Cs-134	1.81E+4	6.8E+1	2.6E-8	1.8E-6	6.9E-3	3.2E-3	1.6E-2
Ba-137m[f]	2.65E+5	4.2E+1	1.0E-8	4.2E-7	1.9E-3	1.2E-3	2.6E-2
Totals				1.5E-4	2.3E-2	4.6E-3	5.6E-2

[a]The data in this table are only examples to demonstrate a calculational process. The results should not be used in the prediction of relationships that would exist following a nuclear incident.

[b]Calculations are based on data in Table 7-1, which includes consideration of both radioactive decay and weathering.

[c]External exposure rate factors at 1 meter above ground for a person standing on contaminated ground, based on data in Table 7-1.

[d]The size of the sample is not important for this analysis because only the relative concentrations are needed to calculate the ratio of integrated dose to exposure rate.

[e]The integrated dose from I-132 is not calculated separately because it is the short-lived daughter of Te-132, and is assumed to be in equilibrium with it. The assumed quantity present is that for a daughter in equilibrium with the parent.

[f]This is a short lived daughter of a parent that has no gamma emissions and the halflife given is that of the parent.

$$\frac{2000\ mrem}{150\ mrem/mR/h} = 13\ mR/h,$$

if the contribution to effective dose from inhalation of resuspended radioactive materials is zero (See Section 7.3.2). The example DCF for the second year and 50 years are obtained by a similar process, yielding DCFs of 31 and 370 mrem per mR/h, respectively.

The ratio of the second year to first year dose is 31/150 = 0.21. If this is the case, persons not relocated on the basis of a 2 rem PAG should, for this example, receive no more than 0.21 x 2 = 0.4 rem in year 2. Similarly, the dose in fifty years should be no more than 4.9 rem. Actual doses should be less than these values to the extent that exposure rates are reduced by shielding from structures and by decontamination.

Prior to reaching conclusions regarding the gamma exposure rate that would correspond to the relocation PAG, one would need to verify by multiple sampling the consistency of the relative abundance of specific radionuclides as well as the relative importance of the inhalation pathway.

Dose conversion factors will change as a function of the radiological makeup of the deposited material. Therefore, dose conversion factors must be calculated based on the best current information following the incident. Since the relative concentrations will change as a function of time due to different decay rates, dose conversion factors must be calculated for specific measurement times of interest. By calculating the decay of the original sample(s), a plot of dose conversion factors (mrem per mR/h) as a function of time after the incident can be developed. As weathering changes the radionuclide mix, and as more is learned about other dose reduction mechanisms, such predictions of dose conversion factors may require adjustment.

7.3.2 Inhalation Dose Projection

It can be shown, for the mixture of radionuclides assumed to be deposited from postulated reactor incidents, and an assumed average resuspension factor of 10^{-6} m^{-1}, that the effective dose from inhalation is small compared to the corresponding effective dose from external exposure to gamma radiation. However, air sample analyses should be performed for specific situations (e.g., areas of average and high dynamic activity) to determine the magnitude of possible inhalation exposure. The 50-year committed effective dose equivalent (H_{50}) resulting from the inhalation of resuspended airborne radioactive materials is calculated as follows:

$$H_{50} = I \times DCF \qquad (1)$$

where

I = total intake (μCi), and
DCF = committed effective dose equivalent per unit intake (rem/μCi).

It is assumed that the intake rate will decrease with time due to

radioactive decay and weathering. No model is available to calculate the effect of weathering on resuspension of deposited materials, so the model developed for calculating its effect on gamma exposure rate (NR-75) is assumed to be valid. This should provide conservative results. The total intake (I) from inhalation over time t may be calculated for each radionuclide, using the following equation:

$$I = BC_0 \left[\frac{0.63}{\lambda_1+\lambda_2} \left(1-e^{-(\lambda_1+\lambda_2)\,t}\right) + \frac{0.37}{\lambda_1+\lambda_3} \left(1-e^{-(\lambda_1+\lambda_3)\,t}\right) \right] \quad (2)$$

where

B = average breathing rate for adults
= 1.05E+4 m^3/a (EP-88),

C_o = initial measured concentration of the resuspended radionuclide in air (pCi/m^3),

t = time during which radionuclides are inhaled (a),

λ_1 = radioactive decay constant (a^{-1}),

λ_2 = assumed weathering decay constant for 63 percent of the deposited activity, taken as 1.13 a^{-1} (NR-75), and

λ_3 = assumed weathering decay constant for 37 percent of the deposited activity, taken as 7.48 E-3 a^{-1} (NR-75).

Table 7-4 tabulates results calculated using the above assumptions for weathering. The table contains factors relating the committed effective dose from exposure during the first and second years after the incident to an initial air concentration of 1 pCi/m^3 for each of the principal radionuclides expected to be of concern from reactor incidents. The dose conversion factors are taken from FGR-11 (EP-88). Parent radionuclides and their short lived daughters are grouped together because these dose conversion factors are based on the assumption that both parents and daughters will occur in equal concentrations and will decay with the half life of the parent. Therefore, measured concentrations of the short lived daughters should be ignored and only the parent concentrations should be used in calculating long term projected doses.

Table 7-4 lists factors which include the effects of both weathering and radioactive decay, as well as those that include only the effects of radioactive decay. Users of these data should decide which factors to use based on their confidence on the applicability of the weathering models used (NR-75) to their environment.

The committed effective dose equivalent is calculated by multiplying the measured initial air concentration (pCi/m^3) for each radionuclide of concern by the appropriate factor from the table and summing the results. This sum may then be added to the corresponding external whole body gamma dose to yield the total com-

Table 7-4 Dose Conversion Factors for Inhalation of Resuspended Material[a]

Radionuclide[b]	Lung class[c]	Committed effective dose equivalent per unit air concentration at the beginning of year one (mrem per pCi/m^3)			
		Considering radioactive decay and weathering		Considering radioactive decay only	
		Year one	Year two	Year one	Year two
Sr-90/Y-90	Y/Y	1.0E+1	5.5E 0	1.4E+1	1.3E+1
Zr-95/Nb-95	Y/Y	6.5E-2	-	7.9E-2	-
Ru-103	Y	1.3E-2	-	1.5E-2	-
Ru-106/Rh-106	Y/D	2.8E 0	1.0E 0	3.7E 0	1.9E 0
Te-132/I-132	W/D	1.3E-3	-	1.3E-3	-
I-131	D	1.1E-2	-	1.1E-2	-
Cs-134	D	3.1E-1	1.5E-1	4.1E-1	3.0E-1
Cs-137/Ba-137^m	D/D	2.5E-1	1.4E-1	3.3E-1	3.2E-1
Ba-140/La-140	D/W	4.4E-3	-	4.7E-3	-
Ce-144/Pr-144	Y/Y	2.0E 0	4.2E-1	2.7E 0	9.8E-1

[a]Calculated using the dose factors in EP-88, Table 2.1.

[b]Short lived daughters are not listed separately because the entries include the dose from both the daughter and the parent. These factors are based on the concentration of the parent only, at the beginning of the exposure period.

[c]The lung clearance class chosen is that which results in the highest dose conversion factor.

mitted effective dose equivalent from these two pathways.

The PAGs include a guide for dose to skin which is 50 times the magnitude of the PAG for effective dose. Analysis (AR-89) indicates that this guide is not likely to be controlling for radionuclide mixes expected to be associated with nuclear power plant incidents. Dose conversion factors are provided in Table 7-5 for use in case of incidents where the source term consists primarily of pure beta emitters. The skin dose from each radionuclide may be calculated by multiplying the measured concentration (pCi/m^2) by the corresponding dose conversion factor in the table. This will yield the first year beta dose to the skin at one meter height from exposure to deposited materials plus the estimated dose to the skin from materials deposited on the skin as a result of being in the contaminated area. These factors are calculated based on information in Reference AR-89, which used weathering factors that apply for gamma radiation and would, therefore, be conservative for application to beta radiation. Calculated doses based on these factors should be higher than the doses that would be received.

7.4 Priorities

In most cases protective actions during the intermediate phase will be carried out over a period of many days. It is therefore useful to consider what priorities are appropriate. Further, for situations where the affected area is so large that it is impractical to relocate all of the public, especially from areas exceeding the PAGs by only a small amount, priorities are needed for protective actions. The following priorities are appropriate:

1. As a first priority, assure that all persons are protected from doses that could cause acute health effects from all exposure pathways, including previous exposure to the plume.

2. Recommend the application of simple decontamination techniques and that persons remain indoors as much as possible to reduce exposure rates.

3. Establish priorities for relocation with emphasis on high exposure rate areas and pregnant women (especially those in the 8th to 15th week of pregnancy).

7.5 Reentry

After the restricted zone is established, persons will need to reenter for a variety of reasons, including recovery activities, retrieval of property, security patrol, operation of vital services, and, in some cases, care and feeding of farm and other animals. It may be possible to quickly decontaminate access ways to vital institutions and businesses in certain areas so that they can be occupied by adults either for living (e.g., institutions such as nursing homes, and hospitals) or for employment. Clearance of these areas for such occupancy will require dose reduction to comply with occupational exposure

Table 7-5, Continued

Radionuclide	Dose conversion factors[b] (mrem per pCi/m^2)	
	Radioactive decay plus weathering	Radioactive decay only
Ce-143	2.3E-6	2.3E-6
Ce-144[c]	8.7E-7	1.1E-6
Pr-143	1.3E-5	1.4E-5
Nd-147	4.3E-6	4.5E-6
Np-239	3.4E-8	3.4E-8
Am-241	4.6E-8	6.4E-8

[a]Based on data from reference AR-89.

[b]Dose equivalent integrated for a one-year exposure at one meter height plus the estimated dose to the skin from materials deposited on the skin as a result of being in the contaminated area.

[c]Contributions from short-lived (one hour or less) decay products are included in dose factors for the parent radionuclides (i.e., Rh-106, Ba-136, Ba-137, and Pr-144).

limits (EP-87). Dose projections for individuals should take into account the maximum expected duration of exposure.

Persons working in areas inside the restricted zone should operate under the controlled conditions normally established for occupational exposure (EP-87).

7.6 Surface Contamination Control

Areas under the plume can be expected to contain deposited radioactive materials if aerosols or particulate materials were released during the incident. In extreme cases, individuals and equipment may be highly contaminated, and screening stations will be required for emergency monitoring and decontamination of individuals and to evaluate the need for medical evaluation. Equipment should be checked at this point and decontaminated as necessary to avoid the spread of contamination to other locations. This screening service would be required for only a few days following plume passage until all such

persons have been evacuated or relocated.

After the restricted zone is established, based on the PAGs for relocation, adults may reenter the restricted zone under controlled conditions in accordance with occupational exposure standards. Monitoring stations will be required along roadways to control surface contamination at exits from the restricted zone. Because of the possibly high background radiation levels at control points near exits, significant levels of surface contamination on persons and equipment may be undetectable at these locations. Therefore, additional monitoring and decontamination stations may be needed at nearby low background locations. Decontamination and other measures should be implemented to maintain low exposure rates at monitoring stations.

7.6.1 Considerations and Constraints

Surface contamination limits to control routine operations at nuclear facilities and to transport radioactive material are generally set at levels lower than are practical for situations involving high-level, widespread contamination of the environment.

The principal exposure pathways for loose surface contamination on persons, clothing, and equipment are (a) internal doses from ingestion by direct transfer, (b) internal doses from inhalation of resuspended materials, (c) beta dose to skin from contaminated skin or clothing or from nearby surfaces, and (d) dose to the whole body from external gamma radiation.

Because of the difficulties in predicting the destiny of uncontrolled surface contamination, a contaminated individual or item should not be released to an unrestricted area unless contamination levels are low enough that they produce only a small increment of risk to health (e.g., less than 20 percent), compared to the risk to health from the principle exposure pathway (e.g., whole body gamma dose) in areas immediately outside the restricted zone. On the other hand, a level of contamination comparable to that existing on surfaces immediately outside the restricted zone may be acceptable on materials leaving the restricted zone. Otherwise, persons and equipment occupying areas immediately outside the restricted zone would not meet the surface contamination limits. These two constraints are used to set permissible surface contamination limits.

The contamination limit should also be influenced by the potential for the contamination to be ingested, inhaled, or transferred to other locations. Therefore, it is reasonable to establish lower limits for surfaces where contamination is loose than for surfaces where the contamination is fixed except for skin. The expected period of fixed contamination on skin would be longer so a lower limit would be justified.

For routine (nonincident) situations, measurement of gross

beta-gamma surface contamination levels is commonly performed with a thin-window geiger counter (such as a CDV-700). Since beta-gamma measurements made with such field instruments cannot be interpreted in terms of dose or exposure rate, the guidance set forth below is related to the background radiation level in the area where the measurement is being made. Supplementary levels are provided for gamma exposure rates measured with the beta shield closed. Guidance levels expressed in this form should be easily detectable and should satisfy the above considerations. Corresponding or lower levels expressed in units related to instrument designations may be adopted for convenience or for ALARA determinations. Smears may also be used to detect loose surface contamination at very low levels. However, they are not considered necessary for emergency response and, therefore, such guidance is not provided.

7.6.2 Numerical Relationships

As discussed in Section 7.3.1, a relationship can be established between projected first year doses and instantaneous gamma exposure rates from properly characterized surface contamination. Based on assumed radiological characteristics of releases from fuel melt accidents, gamma exposure rates in areas where the projected dose is equal to the relocation PAG of 2 rem in the first year may be in the range of 2 to 5 mR/h during the first few days following the deposition from a type SST-2 accident (See Section E.1.2). (This relationship must be determined for each specific release mixture.) Based on relationships in reference (DO-88) and a mixture of radionuclides expected to be typical of an SST-2 type accident, surface contamination levels of 2×10^8 pCi/m^2 would correspond approximately to a gamma exposure rate of 1 mR/h at 1 meter height.

7.6.3 Recommended Surface Contamination Limits

Surface contamination must be controlled both before and after relocation PAGs are implemented. Therefore, this section deals with the control of surface contamination on persons and equipment being protected during both the early and intermediate phases of a nuclear incident.

For emergency situations, the following general guidance regarding surface contamination is recommended:

1. Do not delay urgent medical care for decontamination efforts or for time-consuming protection of attendants.

2. Do not waste effort trying to contain contaminated wash water.

3. Do not allow monitoring and decontamination to delay evacuation from high or potentially high exposure rate areas.

4. (Optional provision, for use only if a major contaminating event occurs, and rapid early screening is needed.)

After plume passage, it may be necessary to establish emergency contamination screening stations in areas not qualifying as low background areas. Such areas should be less than 5 mR/h gamma exposure rate. These screening stations should be used only during the early phase and for major releases of particulate materials to the atmosphere to monitor persons emerging from possible high exposure areas, provide simple (rapid) decontamination if needed, and make decisions on whether to send them for special care or to a monitoring and decontamination station in a lower background area. Table 7-6 provides guidance on surface contamination levels for use if such centers are needed.

5. Establish monitoring and personnel decontamination (bathing) facilities at evacuation centers or other locations in low background areas (less than 0.1 mR/h). Encourage evacuated persons who were exposed in areas where inhalation of particulate materials would have warranted evacuation to bathe, change clothes, wash clothes, and wash other exposed surfaces such as cars and trucks and their contents and then report to these centers for monitoring. Table 7-7 provides surface contamination guidance for use at these centers. These screening levels are examples derived primarily on the basis of easily measurable concentrations using portable instruments.

6. After the restricted zone is established, set up monitoring and decontamination stations at exits from the restricted zone. Because of the probably high background radiation levels at these locations, low levels of contamination may be undetectable. If contamination levels are undetectable, then they probably do not exceed those in some unrestricted areas occupied by the exposed population and no decontamination is required. Nevertheless, these individuals should be advised to bathe and change clothes at their first opportunity and certainly within the next 24 hours. If, after decontamination at the boundary of the restricted zone station, persons still exceed the limits for this station, they should be sent for further decontamination or for medical or other special attention. As an alternative to decontamination, contaminated items other than persons or animals may be retained in the restricted zone for radioactive decay.

7. Establish auxiliary monitoring and decontamination stations in low background areas (background less than 0.1 mR/h). These stations should be used to achieve ALARA surface contamination levels. Table 7-7 provides surface contamination screening levels for use at those stations.

Table 7-6 Recommended Surface Contamination Screening Levels for Emergency Screening of Persons and Other Surfaces at Screening or Monitoring Stations in High Background Radiation Areas (0.1 mR/h to 5 mR/h Gamma Exposure)[a]

Condition	Geiger-counter shielded-window reading	Recommended action
Before decontamination	<2X bkgd and <0.5 mR/h above background	Unconditional release
	>2X bkgd or >0.5 mR/h above background	Decontaminate Equipment may be stored or disposed of as appropriate.
After decontamination	<2X bkgd and <0.5 mR/h above background	Unconditional release
	>2X bkgd or >0.5 mR/h above background	Continue to decontaminate or refer to low background monitoring and d-con station. Equipment may also be stored for decay or disposed of as appropriate.

[a]Monitoring stations in such high exposure rate areas are for use only during the early phase of an incident involving major atmospheric releases of particulates. Otherwise use Table 7-7.

Table 7-7 Recommended Surface Contamination Screening Levels for Persons and Other Surfaces at Monitoring Stations in Low Background Radiation Areas (<0.1 mR/h Gamma Exposure Rate)

Condition	Geiger-counter thin window[a] reading	Recommended action
Before decontamination	<2X bkgd	Unconditional release
	>2X bkgd	Decontaminate
After simple[b] decontamination effort	<2X bkgd	Unconditional release
	>2X bkgd	Full decontamination
After full[c] decontamination effort	<2X bkgd	Unconditional release
	>2X bkgd	Continue to decontaminate persons
	<0.5 mR/h[d]	Release animals and equipment
After additional full decontamination effort	<2X bkgd	Unconditional full release
	>2X bkgd	Send persons for special evaluation
	<0.5 mR/h[d]	Release animals and equipment
	>0.5 mR/h[d]	Refer, or use informed judgment on further control of animals and equipment

[a]Window thickness of approximately 30 mg/cm^2 is acceptable. Recommended limits for open window readings are expressed as twice the existing background (including background) in the area where measurements are being made. Corresponding levels, expressed in units related to instrument designations, may be adopted for convenience. Levels higher than twice background

References

AR-89 Aaberg, Rosanne. Evaluation of Skin and Ingestion Exposure Pathways. EPA 520/1-89-016, U.S. Environmental Protection Agency, Washington (1989).

DO-88 U.S. Department of Energy. External Dose-Rate Conversion Factors for Calculation of Dose to the Public. DOE/EH-0070, U.S. Department of Energy, Washington (1988).

EP-87 U.S. Environmental Protection Agency. Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Federal Register, 52, 2822; January, 1987.

EP-88 U.S. Environmental Protection Agency. Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. EPA 520/1-88-020, U.S. Environmental Protection Agency, Washington (1988).

FE-85 Federal Emergency Management Agency. Federal Radiological Emergency Response Plan (FRERP). Federal Register, 50, 46542; November 8, 1985.

NR-75 U. S. Nuclear Regulatory Commission. Reactor Safety Study. An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants. WASH-1400, NUREG-75/014, U.S. Nuclear Regulatory Commission, Washington, (1975).

(footnote continued)

(not to exceed the meter reading corresponding to 0.1 mR/h) may be used to speed the monitoring of evacuees in very low background areas.

[b] Flushing with water and wiping is an example of a simple decontamination effort.

[c] Washing or scrubbing with soap or solvent followed by flushing is an example of a full decontamination effort.

[d] Closed shield reading including background.