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Journal of Hazardous Materials 75 (2000) 131–144

Journal of Hazardous Materials

www.elsevier.nl/locate/jhazmat

Selection of protective action guides for nuclear incidents ☆

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Abstract

In 1991 the Environmental Protection Agency (EPA) published its revised Manual of Protective Action Guides and Protective Actions for Nuclear Incidents. The protective action guides contained in the manual represent EPA's formal recommendations to Federal, State, and local emergency response officials for protecting public health and safety during a nuclear incident. These guides are expressed in terms of the projected dose at which action(s) should be taken to reduce or eliminate that dose. In determining the appropriate values for the protective action guides, the Agency considered the following four principles: (1) acute health effects should be avoided, (2) the risk of delayed health effects should be minimized, (3) the values should not be higher than justified by a cost–benefit analysis, and (4) the risk to health from implementing the protective action should not be greater than the risk from the dose avoided. This paper examines each of these principles and their application in the selection of the evacuation and sheltering protective action guides for the early, or immediate, phase of a nuclear incident. Published by Elsevier Science B.V.

Keywords: Protective action guides; Nuclear incidents; Evacuation; Sheltering in-place

☆ Throughout this paper reference will be made to numerous values contained in the existing manual of protective action guides. These values, although current at the time the manual was published in 1990, may have changed since then. Should the protective action guides be revised in the future these values would need to be reexamined.

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0304-3894/00/$ - see front matter. Published by Elsevier Science B.V.
PII: S0304-3894(00)00176-X

1. Introduction

When the Environmental Protection Agency (EPA) was established by President Richard Nixon through Reorganization Plan Number 3 in 1970, it was assigned all the functions of the Federal Radiation Council. These functions include the development of protective action guides (PAGs) that are used by Federal, State, and local emergency response officials to protect public health and safety during a nuclear incident. This responsibility has been defined further in the Federal Radiological Emergency Response Plan [1] and 44 Code of Federal Regulations Part 351, *Radiological Emergency Planning and Preparedness* [2] to include the preparation of implementation guidance, such as recommendations on protective actions and training programs for State and local officials on the PAGs and protective actions.

In 1991, the EPA revised the PAGs in order to expand their applicability to all types of peacetime nuclear incidents, and not just nuclear power plant accidents. The new PAG values and the principles upon which they are based were reviewed by the Protective Action Guides Subcommittee of the Federal Radiological Preparedness Coordinating Committee (FRPCC). The subcommittee was chaired by the EPA and included representatives from the Department of Energy, Department of Defense, Department of Agriculture, Department of Health and Human Services, and the Nuclear Regulatory Commission. It also included representative(s) from the Conference of Radiation Control Program Directors. The revised PAGs were endorsed by the FRPCC in 1991. The Nuclear Regulatory Commission placed them into effect for its licensees on January 1, 1994, simultaneously with its revised 10 CFR 20, *Standards for Protection Against Radiation.*

These 1991 PAGs should not be confused with the Federal Radiation Council (FRC) guidance issued in the 1960s for avoidance of exposure due to the ingestion of Sr-89, Sr-90, Cs-137, and I-131. That FRC guidance was developed for worldwide atmospheric fallout from nuclear weapons testing and only is appropriate for application to contamination from such atmospheric releases [3]. The FRC guidance was not developed for local protective actions relevant to prompt exposure to an airborne release from a fixed facility or specific accident site. Thus the 1991 PAGs do not supersede the previous FRC guidance, but instead provide new guidance for different exposure pathways and nuclear emergency situations.

As mentioned in the foreword to the PAG Manual, it is EPA's intent to reexamine and refine these recommendations as necessary when experience is gained in their application. As this process progresses, and new PAGs are developed for food and drinking water, EPA will consolidate this guidance and submit it to the President for approval as Federal Radiation Protection Guidance. Until that time, however, the 1991 PAGs represent EPA's formal recommendations and, as such, constitute the relevant Federal guidance. Because the PAG Manual is EPA's formal recommendation issued to meet all of the above mentioned responsibilities, an understanding of the principles utilized to develop these recommendations, and how EPA evaluated each principle, may be beneficial to Federal, State, and local emergency responders and decision makers. This paper presents a brief discussion on the selection of the value for the evacuation PAG.

2. What are protective action guides?

Protective action guides are defined as, ''The projected dose to reference man, or other defined individual, from an accidental release of radioactive material at which a specific protective action to reduce or avoid that dose is warranted'' [4]. It is a decision level, or more specifically, a projected radiation dose, at which public officials should implement measures to protect the health and safety of the general public.

The PAGs apply to all radiological incidents except nuclear war. Some examples of applicable accident sites and situations include: nuclear power plants, nuclear weapons, transportation accidents, satellite incidents, foreign nuclear accidents that impact the United States, terrorist deployed or unknown radioactive sources, and other nuclear facilities (e.g., Department of Energy facilities, hospitals, etc.) However, guidance for implementing the PAGs is aimed primarily at nuclear power facilities due to their number, size of radionuclide inventory for release (or potential source term), and energy available to drive a release; they most likely provide an ''upper bound'' on the magnitude of a nuclear incident affecting the general public. And since the other varieties of nuclear incidents with more limited consequence will probably have affected populations, and cost/benefits of protective actions, scaled to the magnitude of the smaller emergency in roughly the same proportion, the conclusions developed for nuclear power plant incidents are taken to be valid for the broader spectrum of nuclear incidents.

It is important to acknowledge that in the development of the PAGs, it is impossible for EPA to anticipate the detailed local conditions that will be present in an actual nuclear emergency. Therefore the PAGs do not provide a ready-made plan; their use only is considered mandatory for local officials in developing emergency response plans. Professional judgment will be required to implement the PAGs when an actual emergency arises.

3. What are the PAGs for the early phase of an accident?

The EPA identifies three phases to a radiological emergency response: early or emergency phase, intermediate phase, and the late or recovery phase. Separate PAGs have been developed for the early and intermediate phases of an accident. It must be remembered that the PAGs for each phase are independent of those in the other phases. Therefore, when applying them, it is not necessary to consider any dose that may be received during the other phases.

The early phase of an accident generally includes the time period at the beginning of an incident when immediate protective action decisions must be made by responding officials and may last for several hours to several days. Decisions made during the early phase are based primarily on *predictions* about the radiological conditions that may be encountered in the environment if the accident progresses as anticipated. For purposes of

dose projection, the duration of the early phase is assumed to last 4 days (approximately 100 h).

There are several important definitions of dose considered in the development of the PAGs.

- *Dose equivalent*: the product of the absorbed dose in rad, a quality factor related to the biological effectiveness of the radiation involved, and any other modifying factors.
- *Effective dose equivalent:* the sum of the products of the dose equivalent to each organ and a weighting factor, where the weighting factor is the ratio of the risk of mortality from delayed health effects arising from irradiation of a particular organ or tissue to the total risk of mortality from delayed health effects when the whole body is irradiated uniformly to the same dose.
- *Committed dose*: the radiation dose due to radionuclides in the body over a 50-year period following their inhalation or ingestion.

Within these definitions, EPA defines the projected dose calculated in the early phase of an emergency to be the sum of the projected effective dose equivalent from external gamma radiation from the plume and from 4 days exposure to materials deposited from the plume, and the projected committed effective dose equivalent from inhalation of the plume. This definition of projected dose does not give credit for shielding from structures and use of dose reduction techniques. That is, it assumes that those in the affected area are outdoors for the entire duration of the 4-day exposure period. Obviously, this provides a very conservative (i.e., upwardly biased) estimate of projected dose.

Therefore, the exposure pathways that must be protected during the early phase are external whole-body gamma dose and beta skin dose from direct exposure to airborne and deposited materials, and the committed dose to internal organs from inhalation or ingestion of radioactive material. Protective actions that can be implemented to reduce the projected doses from these pathways include evacuation, sheltering in-place, administration of stable iodine (KI), control of access to the affected or potentially affected area, and decontamination efforts such as washing and changing of clothes and showering.

The EPA's PAG for evacuation (or sheltering in-place) for the general population is a projected effective dose equivalent range of 1–5 rem. However, the established policy has been that evacuation normally should be initiated at 1 rem. There are special situations or population groups that may warrant sheltering in-place rather than evacuation, even up to projected doses of 10 rem. These include: (a) the presence of severe weather, (b) concurrent disasters (e.g., earthquakes, hazardous material accidents, etc.), (c) institutionalized persons who are not readily mobile, and (d) local physical factors which impede evacuation. There is no minimum projected dose established at which sheltering in-place should be implemented (although it is unlikely that protective actions would be needed unless the projected dose exceeded 100 mrem).

The thyroid PAG is 25 rem committed dose equivalent to the thyroid from radioiodine. The decision to administer stable iodine to block the uptake of radioiodine is made by State medical officials.

4. How were the early PAGs selected?

The EPA considered the following four principles when establishing the dose values for the PAGs:

1. Acute health effects (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 health effects (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. The PAG value 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.

5. Principle 1 — avoid acute health effects

Principle 1 deals with the avoidance of acute effects in the affected public in the vicinity of a radiological incident. Acute effects are clinically observable and manifest themselves about 2–3 months after exposure. There generally is a dose threshold below which acute effects are not expected to occur and the severity of the acute effects that do occur depends on the magnitude of the dose received. Acute effects do not occur unless the dose is relatively large, and are generally classified as having severe or non-severe pathophysiological effects. Severe effects are those which have clinically observable symptoms and can lead to serious disease and death. Table 1 provides an understanding of the relationship between increasing dose and the percentage of early deaths that are expected to be observed in an exposed population. Non-severe effects may be detrimental in varying degrees (hematologic deficiencies, temporary infertility, chromosome changes). Some acute effects can also be classified as prodromal, or forewarning of more serious pathophysiological effects, including death. Examples of prodromal effects

Table 1
Early fatality dose–response function

Whole body absorbed dose (rad)	Early fatalities (%)
<140	none[a]
140	5
200	15
300	50
400	85
460	95

[a] The risk of death below 140 rad is not necessarily zero; rather it is indeterminate and likely to remain so.

Table 2
Prodromal dose–response function

Whole body absorbed dose (rad)	Prodromal effects (% affected)
50	< 2[a]
100	15
150	50
200	85
250	98

[a]Although some incidence of prodromal effects has been observed at doses in the range of 15–20 rad in patients [LU-68] and in the 0–10 rad range in Japanese atomic bomb survivors [SU-80a, GI-84], there is great uncertainty in interpreting the data. The prodromal dose–response function described above is more likely to overestimate the percentage of persons affected than to underestimate it.

include erythema (abnormal skin redness), loss of appetite, nausea, fatigue, diarrhea, and nonmalignant skin damage. Table 2 provides an understanding of the relationship between the percentage of prodromal effects expected to be observed in an acutely exposed population and increasing radiation dose [5–10].

Based on the review of numerous clinical studies and reports since World War II on the acute effects of large radiation doses and the information contained in Tables 1 and 2, EPA utilizes the following whole-body doses as guidelines for avoiding acute and other biological effects from large doses delivered over a short period of time. These levels are intended to be useful reference levels for decision making on PAGs.

50 rad — The dose level below which less than 2% of the exposed population would be expected to exhibit prodromal (forewarning) symptoms.

25 rad — The dose level below which prodromal symptoms have been observed.

10 rad — The dose level below which a fetus would not be expected to suffer teratogenesis.

5 rad — The approximate minimum level of detectability for acute cellular effects using the most sensitive methods. Although these are not severe pathophysiological effects, they may be detrimental.

This information led EPA to determine that in selecting PAG values, 50 rem for adults and 10 rem for fetuses appear to be the upper bound limit in the application of Principle 1, avoiding acute health effects.

6. Principle 2 — minimize delayed health effects

In addressing Principle 2, minimizing the occurrence of delayed health effects, the EPA estimated the risks from the two types of delayed effects caused by exposure to radiation, cancer and genetic effects. EPA has examined numerous studies related to the estimation of the risk of cancer due to (1) whole-body exposure (mainly low linear energy transfer (LET) radiation, or beta/gamma), (2) thyroid exposure, (3) skin exposure, and (4) exposure of the fetus. The EPA has also examined several studies concerning the risk of genetic damage associated with exposure to radiation.

Table 3
Average risk of delayed health effects[a]

	Effects per person-rem		
	Whole body	Thyroid[b]	Skin
Fatal cancers	2.8E−4[c]	3.6E−5	3.0E−6
Nonfatal cancers	2.4E−4[c]	3.2E−4	3.0E−4
Genetic disorders	1.0E−4		

[a]We assume a population with same age distribution as that of the US population in 1970.
[b]Risk to fetus is estimated to be 5–10 times higher.
[c]Risk to young children is estimated to be about two to three times higher.

Table 3 displays the average numerical risk per person-rem estimates derived by the EPA from these studies [4]. It is important to note that based on the linear, nonthreshold dose–effect relationships assumed for delayed health effects, there is no dose value below which the risk can be assumed to be zero. In evaluating the risk of delayed health effects, the EPA also examined some of the risk associated with radiation standards and guidance. Federal Radiation Protection Guidance for nonemergency situations recommends that the dose from all sources combined (except from exposure to medical and natural radiation) to individuals in the population not exceed 0.5 rem in a single year [11], and that dose to the fetus of occupationally exposed mothers not exceed 0.5 rem during the 9-month gestation period [12]. This represents an annual incremental risk of fatal cancer of 1.4E − 4. The EPA also considered the International Commission on Radiation Protection's (ICRP) recommendation on limiting the dose to members of the public to 0.5 rem/year for nonrecurring exposure to all sources of radiation combined, other than natural sources or beneficial medical uses of radiation [13]. The ICRP also recommended a limiting dose to members of the public of 0.1 rem/year from all sources combined for chronic (i.e., planned) exposure [14]. These data support a dose of 0.5 rem as an appropriate value that will limit the risk of delayed health effects incurred by exposures during an emergency.

7. Mental retardation

Brain damage to the unborn is a class of injury reported in Japanese atomic bomb survivors which does not fall into either the acute or delayed health effect category, but which exhibits characteristics of both. A significant, dose-related increase in the incidence and severity of mental retardation, microencephaly (small head size) and microcephaly (small brain size) when exposed in utero during the 8th to 15th week after conception has been observed [15,16]. While the actual injury may be an acute health effect, it is not identified until sometime after birth. Mole [17] suggested that, although radiation may not be the sole cause of these effects, it is prudent to treat them as radiation-related.

Otake and Schull [18] have concluded: (1) there is no risk to live-born associated with doses delivered up to 8 weeks after conception, (2) most damage occurs at 8–15 weeks

of gestational age when the rapid proliferation of neuronal elements occurs, (3) the dose–response relationship appears to fit a linear model, (4) the risk during the 8th to 15th week time period is about five times higher than in subsequent weeks, and (5) after the 15th week, a threshold for damage may exist. Based on their analysis, they estimated that the risk was 3–4E − 3 cases per rad during the 8th to 15th week of gestation and 5–7E − 4 cases per rad for 16 or more weeks after gestation.

As a result of this information, Federal Radiation Protection Guidance, adopted in 1987, recommends that dose to occupationally exposed pregnant women be controlled to keep the fetal dose below 0.5 rem over the term of the pregnancy, and that no dose be delivered at more than the uniform monthly rate that would satisfy this limit [12]. The National Council on Radiation Protection and Measurements (NCRP) recommends a limit of 0.5 rem [5], while the ICRP recommends controlling the exposure of the fetus to less than 0.5 rem in the first 2 months to provide protection during the critical period of organogenesis [13].

Again, the application of this information to Principle 2 suggests that a value of 0.5 rem could be used for emergencies.

8. Principle 3 — cost–benefit optimization

The costs to reduce the radiation risk from nuclear accidents can be placed into one of three categories. The first category includes design, construction, and operation of nuclear facilities in such a way as to minimize the consequences of radiological accidents. The second category includes the development of emergency response plans that invoke actions to reduce the exposure of potentially exposed populations, and consequently their risks, if a major accident should occur. The third category includes the actual expenses incurred by taking protective actions as the result of an accident. In general, the choice of levels for PAGs will affect only the third category of costs.

These analyses are based on an evaluation of the evacuation costs and the doses that would be received in the absence of protective actions for nuclear reactor accidents. They are calculated as a function of offsite location, meteorological condition, and accident type. The cost and dose data are based on the following assumptions.

1. All of the nuclear power plant accidents result in airborne releases due to fuel melt followed by containment failure:

- SST-1: Severe Core Damage with loss of all installed safety features and a severe direct breach of containment,
- SST-2: Severe Core Damage, containment fails to isolate with fission product mitigating systems reducing the release, and
- SST-3: Severe Core Damage with containment failure by base-mat melt-through, release mitigation systems function as designed.

2. Meteorological conditions range from unstable (Stability Class A) to unstable (Stability Class F) and windspeeds are typical of the associated stability class.

3. The plume is assumed to follow a Gaussian distribution, with a 0.01 m/s dry deposition velocity for iodine and particulate materials.

4. The doses incurred result from whole-body gamma radiation from the plume, inhalation of radioactive material in plume, and 4 days exposure to deposited radioactive material.

5. Population distributions are the average values observed around 111 commercial nuclear power plants based on 1970 data.

6. The cost, in 1982 dollars, of a 100-mile round trip evacuation for a family of three for 4 days is $185 per person. This cost includes the salaries of personnel directing the evacuation, the transportation costs of the evacuees to and from the staging location, food and shelter costs for the evacuees during the evacuation, and the loss of personal and corporate income during the evacuation period.

7. The estimated costs and doses avoided are based on an idealized evacuation model in which all people within a 2-mile radius of the accident are evacuated. Also, the population is evacuated in the downwind area bounded by equivalent rays on either side of the centerline of the plume which define the angular spread (70°, 90°, or 180°) of the area evacuated by an arc at the distance beyond which the evacuation dose would not be exceeded on the plume centerline. Fig. 1 illustrates the relationship between the area in which the evacuation dose would be exceeded and the larger area that might be evacuated.

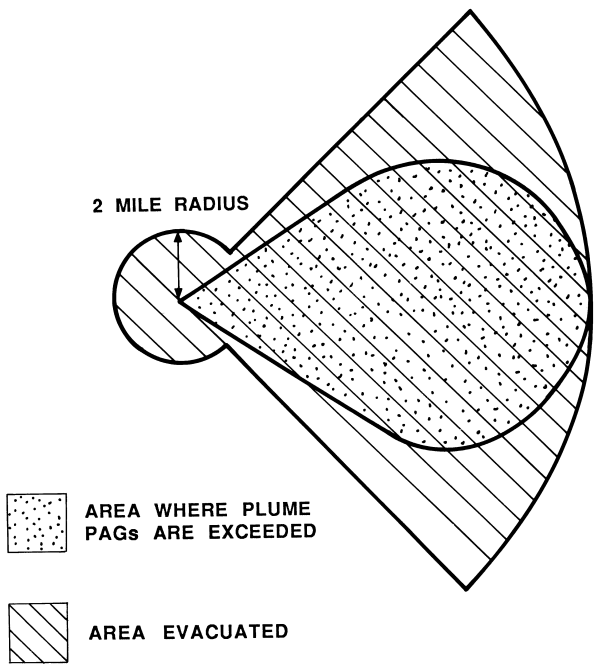

Fig. 1. Evacuation model.

Table 4 presents the cost per person-rem avoided for the total area evacuated and the marginal area evacuated for an SST-2 type accident. This is the smallest category of fuel melt accident which would yield effective dose equivalents during the first 4 days of exposure that are greater than 0.5 rem outside the assumed 2-mile evacuation for all stability classes. When evaluating the cost per person-rem avoided it is appropriate to estimate the ratio of the total cost to the total dose avoided in order to calculate the average cost per person-rem avoided. However, when trying to choose among a variety of different PAG values, it is appropriate to compare the dose savings and costs at the margin, since the cost of evacuating the additional area is incurred to avoid the additional dose. Therefore, the appropriate quantities are the risk and cost for the additional area evacuated.

As shown in Table 5 for an SST-2 type reactor accident, the cost per unit dose avoided is greatest for wide angle evacuations and for the most stable weather conditions. Although a few emergency plans call for evacuation over wider angles (up to 360°), the model illustrated in Fig. 1 with a 90° angle is most common.

Table 4
Costs for implementing various PAGs for an SST-2 type accident

Stability class	Evacuation angle (degrees)	PAG value (rem)	Total dollars/total person-rem avoided	Marginal cost/marginal person-rem avoided
A	70	0.5	315	440
		1	164	223
		2	88	98
	90	0.5	391	550
		1	201	276
		2	102	120
	180	0.5	767	1080
		1	391	543
		2	190	235
C	70	0.5	439	750
		1	195	382
		2	66	165
	90	0.5	564	964
		1	250	491
		2	83	212
	180	0.5	1110	1910
		1	491	971
		2	159	419
F	70	0.5	194	2020
		1	112	977
		2	67	436
	90	0.5	250	2600
		1	144	1260
		2	87	560
	180	0.5	493	5120
		1	285	2480
		2	171	1110

Table 5
Upper bounds on dose for evacuation based on the cost of avoiding fatalities

Accident category	Stability class	Dose upper bounds	
		Maximum (rem)	Minimum (rem)
SST-1	A	5	0.4
	C	5	0.4
	F	10	0.8
SST-2	A	1	0.15
	C	3.5	0.25
	F	10	0.7
SST-3	A	([a])	([a])
	C	([a])	([a])
	F	5	0.45

[a] For stability classes A and C, the dose from an SST-3 accident is not predicted to exceed 0.5 rem outside a 2-mile radius.

In previous risk management decisions, EPA has used a range of $400,000 to $7,000,000 as an acceptable range of costs for avoiding a statistical death for pollutants other than radiation. Applying a risk of $3E-4$ cancer deaths per person-rem, this cost range is equivalent to $120 to $2000 per person-rem avoided. This cost range can then be compared to the marginal cost-effectiveness of evacuation over an angle of 90° for the three nuclear power plant scenarios. The results are shown in Table 5. From the table, the maximum upper bounds (based on minimum costs for avoiding risk) range from 1 to 10 rem, with 5 rem representing most cases. The minimum upper bounds (based on maximum costs for avoiding risk) range from 0.15 to 0.8 rem, with 0.5 rem valid for most situations. These values demonstrate that, based on cost of evacuation, a PAG larger than the range of 0.5 to 5.0 rem would be inconsistent with Principle 3.

9. Principle 4 — evacuation risk does not exceed risk from dose avoided

Principle 4 states that the risk from the protective action should not exceed the risk from the dose avoided, so the risk from evacuation itself had to be evaluated. Based on data gathered from actual evacuations, EPA estimates that the risk from evacuation in deaths per mile traveled is about the same as for ordinary auto transportation, that is $9E-8$ or $9E-6$ per 100-mile round trip [19]. Using the fatality risk of $3E-4$ cancer deaths per person-rem, the risk due to evacuation is equivalent to a radiation dose of 0.03 rem. Risk of injury or death to an individual during an evacuation does not appear to change as a function of the size of population evacuated.

Of course, to carry out an effective evacuation in the event of an emergency, advance planning is crucial so that potential problems can be identified early. Most evacuees use their own personal transportation and assume responsibility for acquiring food and shelter. Evacuation costs are highly location-dependent and usually are not a deterrent to carrying out an evacuation. Previous experience with actual evacuations demonstrates

that neither panic nor hysteria has been observed if the evacuation is properly managed by public officials.

It is important to note when evaluating the risk avoided by an evacuation that the protective action must be implemented over a larger population than will actually be exposed at the level of the PAG. Because of uncertainty or unpredictable changes in wind direction, the exact location, or ''footprint,'' of the plume will not always be known. Although dose projections are made for the maximum exposed individuals located on the plume centerline, it is necessary to implement the protective actions for individuals that are located on either side of the centerline in order to protect the maximum exposed individual. Such caution results in some members of the public being evacuated when the exposures are less than at the plume centerline, and maybe even zero. Although it is impossible to ensure that no individuals incur evacuation risks that are greater than the risk from the dose avoided, we can assure that this does not occur, on average, at the outer margin of the evacuation area. For this reason, EPA examined the average dose avoided per evacuated individual for incremental dose levels by stability class and found that even at the outer margin of the evacuation area, the average dose avoided is always significantly greater than 0.03 rem. Table 6 presents the results of this analysis. Therefore, EPA concluded the choice of PAG will not be influenced by Principle 4 for persons in the general population whose only risk from evacuation is the normal risk of transportation and the centerline dose avoided is greater than or equal to 0.5 rem. Of course, harsh weather and hazardous driving conditions may dictate that a higher projected dose be required before recommending evacuation.

In brief, EPA has selected 0.5 rem as the minimum dose that justifies an evacuation because: (1) it limits the risk of delayed health effects to levels adequately protective of public health under emergency situations, (2) the cost of implementing a lower value is not justified, and (3) it satisfies the two bounding requirements to avoid acute health effects and to avoid increasing risk by implementing the protective action itself.

Given this determination of 0.5 rem or greater as the dose to be avoided by an evacuation, how did EPA come up with a *projected dose* of 1 rem as the evacuation PAG? The benefits of the protective action of sheltering in-place must be accounted for. EPA assumes that the dose normally avoided by evacuation (i.e., the dose that is *not* avoided by the assumed alternative of sheltering in-place) is one half of the projected dose. Therefore the PAG value for evacuation of the general public under normal circumstances is 1 rem.

Table 6
Average dose avoided per evacuated individual

Centerline dose (rem)	Average dose avoided by stability class (rem/individual)		
	A	C	F
0.5 to 1	0.34	0.19	0.07
1 to 2	0.67	0.38	0.15
2 to 5	0.87	0.33	
5 to 10			0.75

10. Conclusions

As mentioned earlier, state and local officials always have the ultimate responsibility for decisions on protective actions to safeguard the public. EPA appreciates this tremendous responsibility and aims to provide the soundest, safest, and practicable advice to these officials in accordance with our legal and mutually understood organizational responsibilities. In the development of EPA's *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents*, EPA has utilized the application of four key principles to achieve this goal. They are summarized as follows: (1) avoid acute effects on health, (2) keep the risk of delayed effects on health within upper bounds that are adequately protective of public health (under emergency conditions) and reasonably achievable, (3) reduce any risk to public health that is achievable at acceptable cost, and (4) regardless of the above principles, the health risk from protective action should not exceed health risk from the dose that would be avoided.

It is EPA's belief that in understanding the principles upon which our PAGs have been developed, state and local officials responding to an actual nuclear emergency will be more able to judiciously determine the appropriate level of projected dose at which protective action is prudent given the circumstances of the event.

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