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OBJECTIVES OF EMERGENCY RESPONSE AND THE POTENTIAL BENEFITS OF EVACUATION AND SHELTER

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ABSTRACT

Basic radiation protection objectives for the controlled environment are transferrable verbatim for use in the uncontrolled or emergency situation. These objectives are: avoid near-term injury or fatality and reduce individual risks and total health effects to levels as low as reasonably achievable (ALARA). The potential benefits of sheltering and evacuation in meeting these objectives during a response to a severe LWR accident was investigated. It could be very difficult to reduce total health effects because collective dose (man-rem) increases monotonically for scores, perhaps hundreds of miles from a release point. In this regard, shelter and ad hoc respiratory protection appear to be the only rational and feasible near-term protective actions that would be available to most people. However, the first two objectives can be met by early, precautionary evacuation, within two to three miles immediately upon the declaration of a General Emergency (e.g., a core melt accident), and sheltering elsewhere. In the event of an actual major release, later relocation from highly contaminated areas would be an integral part of the emergency response. Analyses performed to investigate the various emergency response options and potential benefits are described. The perspectives obtained should be reflected in emergency plans.

INTRODUCTION

Radiological emergency plans for fixed nuclear facilities should be constructed to achieve specific radiation protection objectives in the event of a future radiological release. Basic radiation protection objectives for controlled environments, such as a work place, can be succinctly stated as follows:

- o AVOID serious non-stochastic radiation effects (i.e., near term, or early, injuries and fatalities), and
- o REDUCE individual stochastic risks and total latent health effects to levels as low as reasonably achievable.

These basic objectives are transferrable directly to the uncontrolled or accident environment, so long as it is recognized that there can be no guarantees proffered that all objectives can be met in all conceivable circumstances in an uncontrolled environment (US78; US80; In84). For this paper the potential benefits and practicality of combinations of evacuation and shelter to achieve these objectives in response to severe light water nuclear power plant (LWR) accidents was investigated.

The LWR accidents considered was the set SST1, SST2 and SST3, suggested by the U.S. Nuclear Regulatory Commission (NRC) as representative groupings of severe accident source terms (fractions of the core inventory of radionuclides released to the atmosphere) (US81; US82a). Although these "source terms" are being intensively investigated (Ba84) and may be revised in the future, the NRC set was used as the best current estimates of severe accident source terms. The important characteristics of this set are listed in Table 1.

These would all be core melt accidents. The estimated probabilities of these accidents occurring are very low, but the estimated release fractions (of the core inventory) to the atmosphere would be large, especially for SST1. In general terms, SST1 would correspond to a coincident early, massive failure of containment, with little or no scrubbing of the release by engineered safety features in a plant. SST2 would correspond to a coincident major containment failure with degraded performance of engineered safety features. SST3 could involve a late basemat melt-through accident, with efficient scrubbing of particulates and a smaller release of noble gases, as well.

BACKGROUND

Clearly, even without an emergency plan some off-site emergency response by the public would be expected in the event of these accidents. Examined here was the question: What would be a practical emergency protective action scheme involving evacuation and shelter, which would satisfy the basic radiation protection objectives? It was recognized that individual entrapment situations

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can be readily visualized; thus, the perspective was to investigate evacuation and sheltering benefits that could accure for most of the people most of the time given the postulated accidents.

Certain leading clues were available from previous studies. Three are especially noteworthy. In NUREG-0396 (US78), risk vs distance was displayed in a simple manner in a figure reproduced here as Figure 1. This figure merely indicates that dose (and risk) vs distance decreases monitonically from a source point for an atmospheric release. Theoretically, the decrease varies as $r^{-1.5}$, approximately, where r is the downwind distance. Because of obstructions, wind meander & wind shifts during a release period, dose might more realistically vary as r^{-2} (inverse squared). The r^{-1} (inverse distance) curve in Figure 1 was included as an aid to the reader. Without further elaboration or caveats, the information in Figure 1 can be taken to indicate that protective actions within a few miles of a release point would be most beneficial because the risk is clearly greatest within this distance.

Two other clues were provided in NUREG/CR-2239 (US82b), especially in two figures reproduced here as Figures 2 and 3. Figure 2 displays the probability of exceeding various numbers of early fatalities given an SST1 accidental release and various emergency response assumptions. The bottom curve in the figure clearly illustrates the potential benefits of a minimal delay before evacuation. For the summary evacuation curve; delays of 1, 3 and 5 hours were assumed to occur 0.3, 0.4 and 0.3 of the time, respectively. Unfortunately, for the bottom curve in this figure an evacuation within twenty-five miles was assumed, at a speed of 10 miles per hour. This implies that a large area could be cleared in 2.5 hours - hardly a practical assumption for most people most of the time.

Figure 3 contains two important clues. Shown here is the conditional probability of incurring an early fatality beyond various distances assuming the SST1 accidental release and various emergency responses. Again, the importance of a minimal delay before evacuation is clear from the bottom curve which indicates that with a short delay time the early fatality distance should not exceed two miles. Again, the impractical twenty-five mile evacuation distance is noted. Further, as indicated in this figure, all shelterees were assumed to stay on contaminated ground for a full day before relocation to uncontaminated areas. This is hardly a realistic assumption considering that dose rates in many areas could exceed 10 rem per hour in the wake of the puff (US84). Relocation from shelter would be expected to occur soon after radiological monitoring teams identified such "hot spots".

CALCULATIONS

Following these clues, consequence estimates were performed using the following protective action assumptions:

- o Early, precautionary evacuation within 1, 2 or 3 miles and immediate shelter elsewhere, in the event of a core melt accident (General Emergency),
- o In the further event of an actual major atmospheric release from containment, people in shelters would relocate from highly contaminated areas left in the wake of the release.

It is noted that most core melt accidents would not involve early containment failure (US75, US82, Ba84). Rather, it is estimated currently that only about one out of ten core melt accidents might lead to an SST1 type of release, on the average. For this reason, the phrase "early, precautionary evacuation...in the event of a core melt" was used above.

A version of the CRAC2 code which provides for three emergency response zones was used for the calculations (US83a; US83b). People in shelters were provided protection factors of 0.33 for each of the three major pathways-external gammas from the plume, inhalation, and ground contamination. These protection factors are typical for residences with basements (US75).

Evacuation was modeled in the first, or near, zone by assuming a one hour delay after an initial warning (e.g. declaration of a General Emergency by the plant), and a 10 mph evacuation speed radially away from the plant. Under this assumption, people begin to leave one-half hour after the SST1 release begins. The assumption that people leave one half hour after a major release begins is a generally pessimistic one. This certainly should not be the planned sequence. This has been noted previously (Ma77, Ma80, Ma82, Bu84).

The second, or mid, zone extended from the inner zone to 10 miles. People in this area were assumed to relocate after four hours exposure to ground contamination left in the wake of the puff. The third, or far, zone extended from 10 miles. Here, people were assumed to relocate after eight hours exposure to ground contamination. These relocation times were estimates of the time it would take to locate hot spots, provide notifications, and for people to move a short distance (Ma77, US84) away from the hot spots.

The New York City meteorological set in the CRAC2 data files was used for the calculations. This set contains rainfall about eight percent of the time. Rain can cause heavier than normal ground contamination. Also, the population distributions in the CRAC2 data sets were used.

RESULTS

Individual Risks

Principal results of the calculations are displayed in Figure 4 and Table 2. As shown in Figure 4, for an 800 megawatt - electrical LWR at a coastal site in the U.S. zero early fatalities was calculated for the most severe SST1 accident postulated, for an early evacuation distance of three miles. The uppermost curve in this figure shows that the predominantly sheltering protective action strategy clearly suffers by comparison to the early, short range evacuation strategy. These results bear out the intuitive, qualitative perspective illustrated in Figure 1.

Identical calculations were performed for four other LWR sites in the U.S. Principal results for these five sites are shown in Table 2. Although the CRAC2 population distributions of these sites were used for the calculations, the results were normalized to 500 persons per square mile within 10 miles. The power levels of these LWRs ranges over a factor of two. The results for the lowest power level are indicative of what results for the highest power level would be with a factor of two reduction in the SST1 source term.

Several interesting aspects of the results are shown in, or may be inferred from, the information in Table 2. There were no residents within three miles of site number one, and zero early fatalities was calculated. This illustrates the potential benefit of a very early evacuation of nearby areas, i.e. before a release given a core melt. For the highest power levels, a few early fatalities were calculated for SST1 for site number two even with a three mile early evacuation assumption. These people were caught by the front of the plume, in most cases. This was a high population density site. In all cases, several tens of persons suffered early injuries (e.g. prodromal vomiting). These calculated injuries occurred at various azimuths and to distances to 12.5 miles, but mostly well within 10 miles. The total number of early injuries calculated is an artifact of the CRAC code, which adds up calculated injuries wherever they are located. At any particular azimuth, no more than a few early injuries was calculated, which would be the case for a single puff. Further, these injuries occurred at low conditional probabilities.

In all cases, peak early fatalities and injuries were associated with rainfall, a sudden calm after transport, or stable meteorological conditions (low wind speed, narrow plumes, nightime conditions). Emergency planners should be especially aware of the import of these particularly adverse, low probability weather conditions, which lead to heavy ground contamination by particulates. Separate calculations, not shown, indicate that for the SST1 release, calculated early injuries could be eliminated by slightly smaller particulate source terms (lower ground contamination), better shielding, faster relocation or combinations thereof.

No early fatalities or injuries were calculated for the SST2 and SST3 accident scenarios, for the noted emergency response assumptions, at all power levels. It should be clear from Figure 1 that early, precautionary evacuation of nearby areas in the event of a core melt accident would significantly reduce individual latent cancer risks in the event of a core melt accident.

Collective Dose

In contrast with individual risks of nonstochastic effects, which would be relatively near-field or close range effects, estimated total latent cancers would increase monitonically with distance. Further, for releases which include a substantial abundance of long half-lived particulates, the collective risk would be associated with long term (years) exposure to ground contamination. Thus, protective actions during the emergency phase would provide little benefit in reducing total latent health effects.

These perspectives are illustrated in Table 3 and Figure 5. Table 3 is a summary of pertinent information in NUREG-0340 (US77), which illustrates the pathway and temporal contributions to total calculated latent cancer fatalities for the PWR-1 and PWR-2 accident categories of the Reactor Safety Study (US75). These accidents would be of the ilk of SST1, and would include substantial releases of long half-lived cesium radionuclides. It is readily apparent from this table that long term exposure pathways would dominate the total number of latent cancers. Only extensive and expensive decontamination and condemnation processes over the long term would be efficacious in reducing total latent cancers.

Figure 5 illustrates how collective dose and total latent cancer estimates increase with distance. This figure was taken from NUREG/CR-2239 (US82b). Calculated total latent cancers accrue to large distances, regardless of the composition and magnitude of the release. Indeed, for the average site fully half the latent cancers could accrue outside of fifty miles from a release point. This phenomenon has been noted previously for routine atmospheric emissions of purely noble gases (Ma74). A corollary is that near field emergency protective measures would provide little benefit as regards the objective of reducing collective dose and total latent health effects. However, for a purely noble gas release the cloud (external) gamma dose pathway would dominate. In this case immediate sheltering to large distances would be an effective protective action to achieve the objective of reducing total latent cancers ALARA, especially where sheltering would not be inconvenient anyway. This would be little different from an air pollution alert.

The interlay between estimates of stochastic-latent cancer fatalities and costs of condemnation of contaminated property is illustrated in Figure 6 for the SST1 accident at the Indian Point site. The data points for this figure were obtained from NUREG/CR-2239 (US82b). These are for various dose projection criteria for land interdiction (condemnation). Normally in CRAC2, people are allowed to remain in contaminated areas where the projected whole body dose is less than 0.25 Sv (25 rem) in 30 years. As illustrated in Figure 6, for SST1 a very large increment in costs would be incurred in reducing total latent cancer fatalities by interdicting property at a lower dose projection.

One additional perspective is important in this regard. For a core melt accident with failure of containment, the constituents of a release may not be known for some time (Ma80; Ma82). Thus, the shelter to large distance (where convenient) option should be predetermined, as well as the evacuation to short distance option, as an immediate response to the declaration of a General Emergency (core melt). Indeed, it was in this light that the protective action assumptions listed under CALCULATIONS, above, were made.

One caveat is important here. These collective dose perspectives derive from the assumption of a proportional relationship between risk and dose.

DISCUSSION

The calculations discussed above show that in the event of a core melt accident early evacuation of relatively small areas near a LWR and sheltering elsewhere would provide significant reductions in individual risks of stochastic and non-stochastic health effects. The simple emergency response scheme suggested can be predetermined for specific in-plant emergency action levels appropriate for the General Emergency class. Because the actions are so simple and easily understood, there is an excellent chance the plan would work, if need be.

The early, immediate evacuation area suggested by these calculations is the size of many low population zones around LWRs in the United States, and the early evacuation radius (2-3 miles) is less than the distance to the nearest population center of 25,000 persons, or more, at most LWR sites in the U.S.(US79). Thus, there should be few impediments to evacuation in these areas most of the time.

A further conclusion is that reduction in collective dose and latent cancers would be very difficult to achieve in the early (emergency) response phase. Sheltering during the passage of a predominantly noble gas release would be efficacious, but only if sheltering to long distances were undertaken.

A few caveats to these conclusions are noteworthy: There are large uncertainties in the absolute values of the results of the calculations. Nevertheless, the relative potential benefits of various evacuation/sheltering/relocation protective action strategies should be clear, especially where large differences in results are obtained.

At a few LWR sites in the U.S., and at many foreign sites, heavily populated areas exist in the near vicinity, which could make early, immediate evacuation difficult, impractical, or impossible. For these sites, better shielding protection factors may pertain and smaller early evacuation distances may be justified. On the other hand, some low population zones persist for many miles, and early, immediate evacuation of such areas may be a reasonable objective for a core melt accident.

It is acknowledged that entrapment situations can exist for some people or many people at some time. Early, immediate evacuation may be physically impossible or extremely hazardous during a snow or ice storm, for example. Special arrangements should be made in emergency plans for identified persons in early evacuation zones who suffer from significant impediments to mobility. In the event of a core melt during a highly immobile situation, e.g., the ice storm, remaining in shelter and relocation from hot spots (if a release occurs) as quickly as possible would be the only reasonable and practical alternatives. These are highly unlikely combinations of unlikely situations and the suggested protective action scheme should satisfy the basic radiation protection objectives for most people, most of the time.

Finally, as compared to the suggested predetermined protective action plans, protective action decisions can be made on an ad hoc basis at any time. The distinction between predetermined actions and ad hoc actions is very important for emergency planners.

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Table 1: Characteristics of Postulated Severe Accident Scenarios

Release Characteristics	Accident Type SST 1	SST 2	SST 3
Warning Time Before Release (hr)	0.5	1.0	0.5
Release Duration (hr)	2	2	4

Radionuclide Group[a]	Inventory[b] (EBq)[c]	Fraction Released to the Atmosphere		
Xe-Kr	13.	1.0	0.9	0.006
I	27.	0.45	0.003	2(-4)[d]
Cs-Rb	0.6	0.67	0.009	1(-5)
Te-Sb	8.	0.64	0.03	2(-5)
Ba-Sr	14.	0.07	0.001	1(-6)
Ru	21.	0.05	0.002	2(-6)
La	110.	0.009	0.0003	1(-6)

a. As defined in the Reactor Safety Study (US75).
b. For a 1000 MW(e) LWR one-half hour after shutdown at end of core life (3 years) (US75).
c. 1 EBq = 1 ExaBq = 10^{18} disintegrations/sec. Noble gas plus I activity equals 1.06 billion curies.
d. 1(-5) = 1 x 10^{-5}

Table 2: Results assuming SST1 and five population distributions.

Site Number	Power Level (MW-e)	Early Evacuation Radius (miles)	Mean Number of Early Fatalities[a]	Mean Number of Early Injuries[a]
1	1100	1,2, & 3	0[b]	60
2	1100	1	50	200
		2	20	100
		3	4	50
3	800	1	40	200
		2	4	90
		3	0	20
4	650	1	20	130
		2	0	70
		3	0	60
5	550	1	0	60

a. Normalized to 500 persons/sq mile within 10 miles.
b. No residents with three miles - equivalent to evacuation <u>before</u> a release.

Table 3: Temporal and pathway contributions to latent cancer fatalities for severe source terms[a]

Exposure Pathway and Time Frame	Percent Contribution[b] PWR-1	PWR-2
External Cloud	1	1
Inhalation from Cloud	24	3
External Ground (< 7 days)	13	16
External Ground (> 7 days)	43	68
Inhalation of Resuspended Contamination	14	2
Ingestion of Contaminated Foods	5	10
	100	100

a. From NUREG-0340 (US77).
b. PWR-1 and PWR-2 are severe accident release categories from the Reactor Safety Study (US75). The releases are of the order of SST 1.

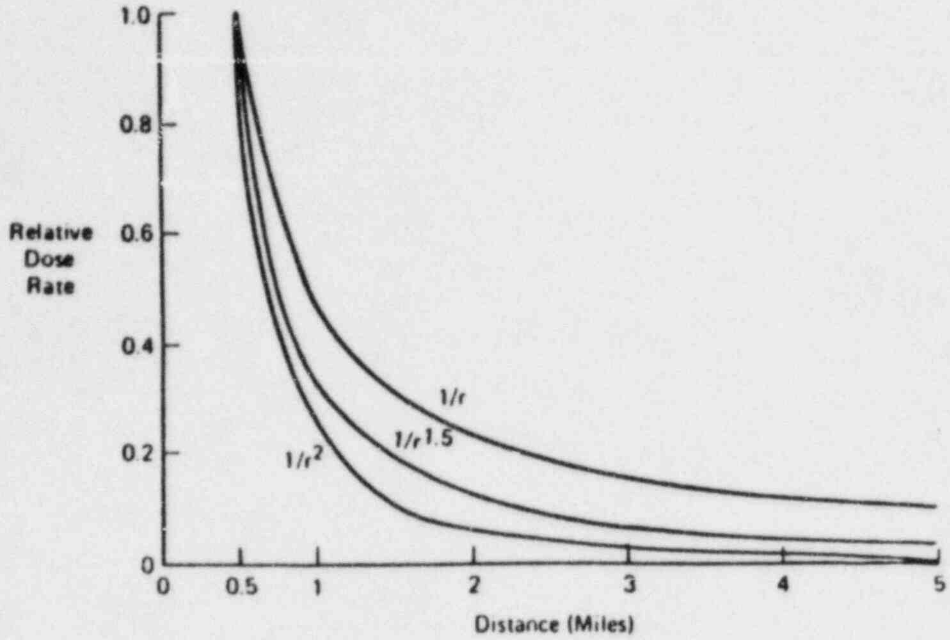

Figure 1. Relationship of dose rate and distance for a low level atmospheric release.

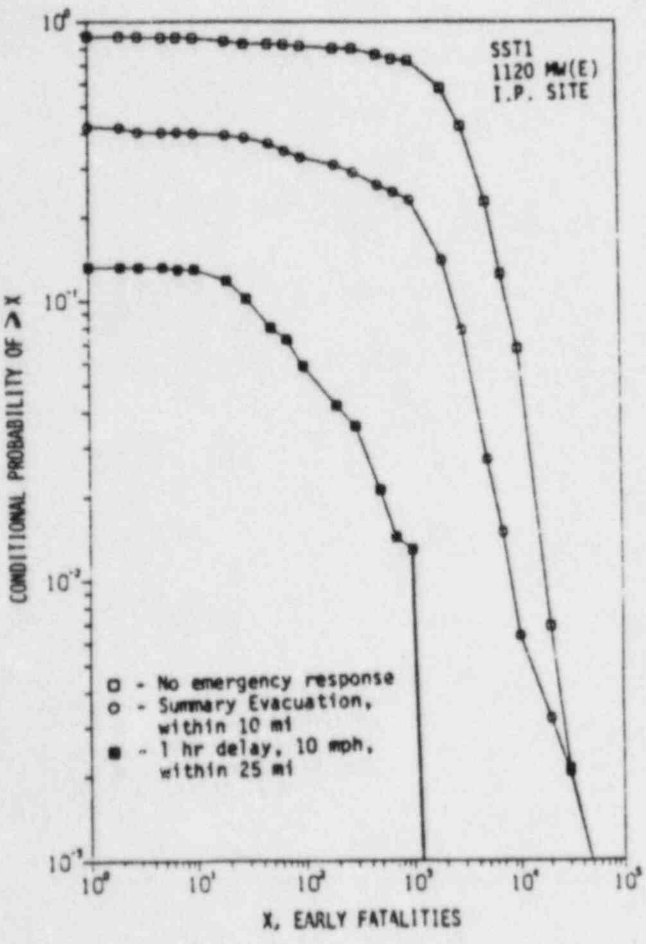

Figure 2. Impact of a range of emergency response assumptions on calculated early fatality probabilities.

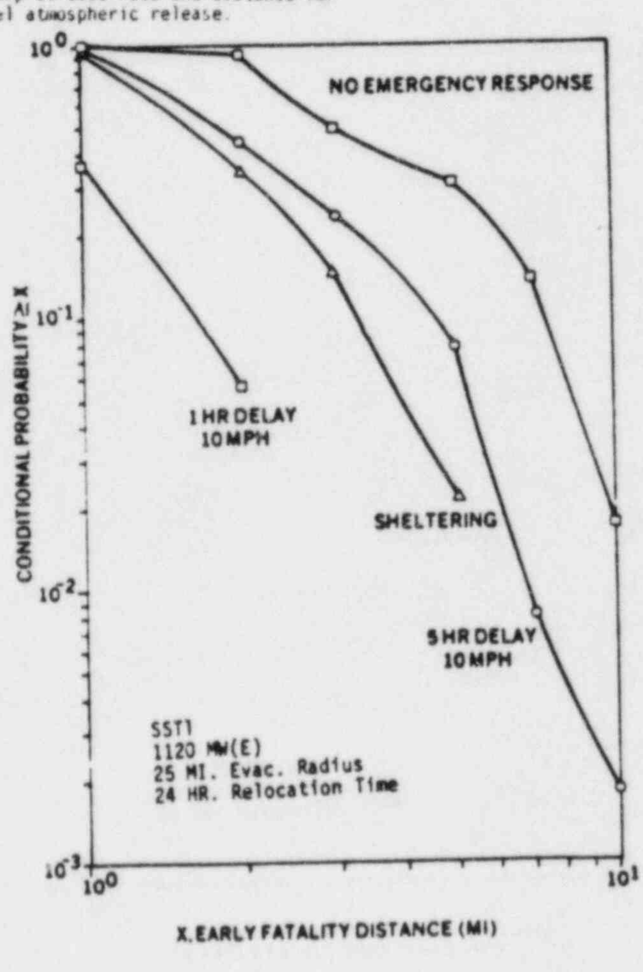

Figure 3. Sensitivity of early fatality distances to emergency response assumptions.

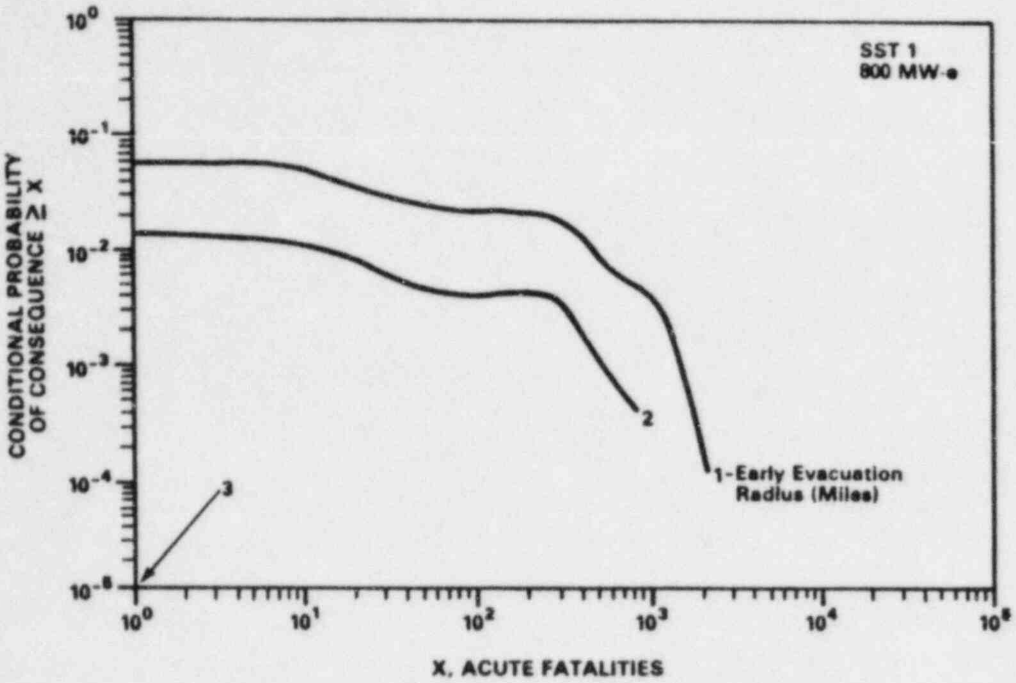

Figure 4. Conditional probabilities of various numbers of acute fatalities, assuming SST1 accident, early evacuation of small areas, and a slow relocation from highly contaminated areas.

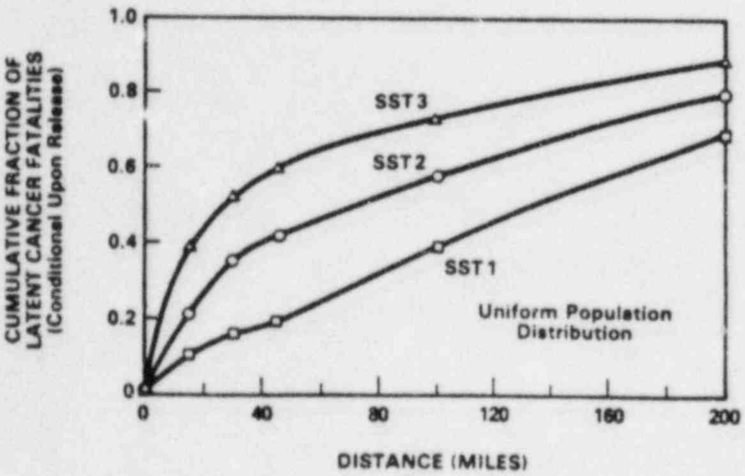

Figure 5. Increase in calculated latent cancer fatalities with distance for three source terms.

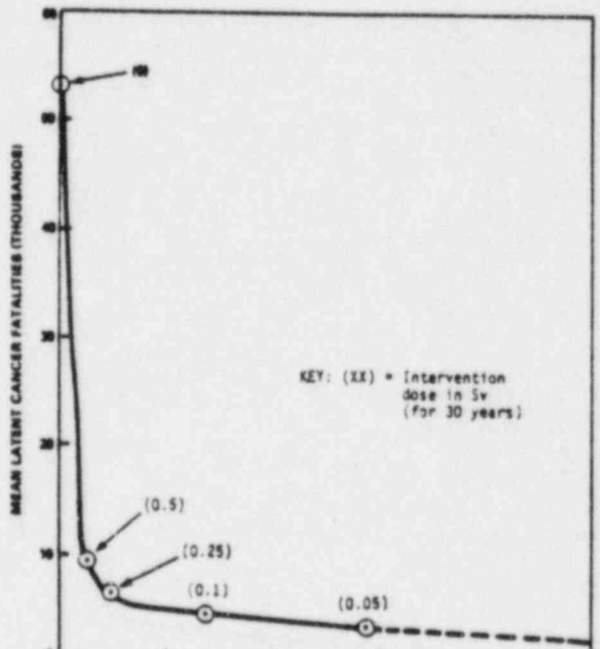

Figure 6. Calculated mean latent cancer fatalities and cost tradeoffs for several interdiction dose levels (SST1 accident at Indian Point site).