APPENDIX A

GENERAL DESCRIPTION OF AN AIRBORNE RELEASE OF RADIOACTIVITY

In all of the accident sequences to be described, the final result is an airborne release of radioactivity in the form of invisible, "aerosol" particles which rise to some height above the reactor and "float" downwind. Figure A-1 and A-II show schematic views of the approximate wedge-shaped region in which the radioactivity would be initially contained. It is important for the reader to have a mental picture of this wedge in mind to avoid making the common mistake of thinking that people in all directions around the reactor would necessarily be exposed in a reactor accident.

We shall refer to the airborne radioactivity as a "cloud" even though it could not be seen after it had traveled any appreciable distance from the reactor.*

Only the simplest case of a constant wind direction has been shown. A shift in wind during or after the release could change the pattern, producing perhaps a "bent" wedge or a complex shape from the superposition of wedges. The exact pattern would depend upon the timing of the wind shift(s) and the duration of the radioactivity release.

People caught in the cloud would receive radiation doses in three ways:**

1) from inhaled radioactivity
2) from external radiation from the passing cloud ("cloudshine"), and
3) from external radiation from aerosols which stick to the ground and building surfaces ("groundshine").

Subsequent to the accident, the deposited radioactivity would continue to act as a source of radiation superimposed upon natural background radiation.

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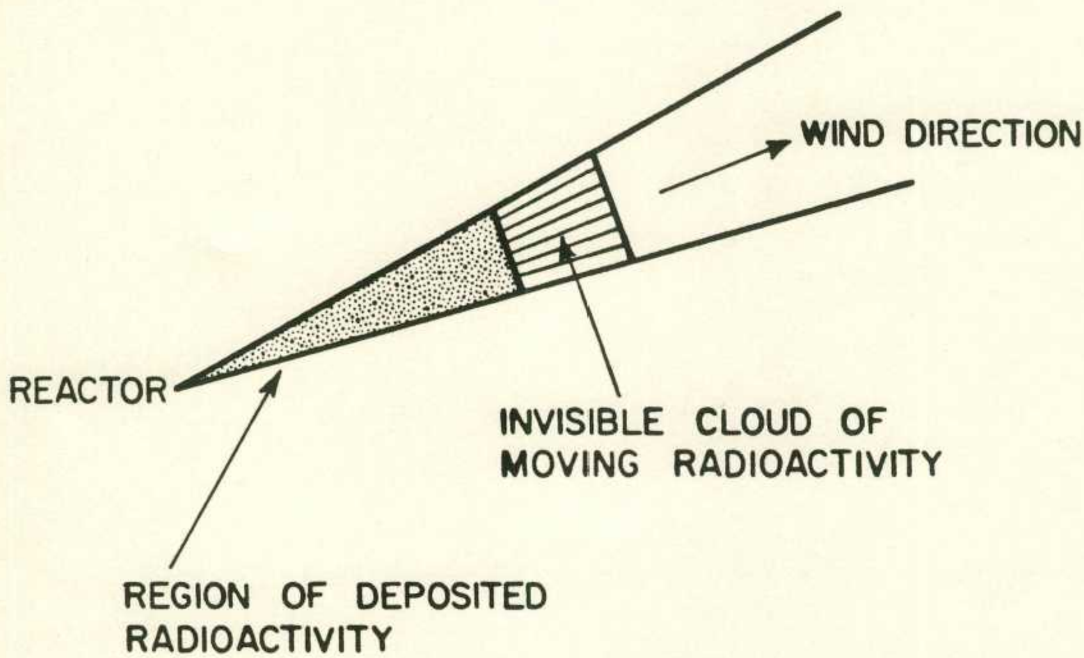
* The cloud would only be made visible by entrained water droplets which would evaporate relatively quickly.

** A radiation dose refers to the amount of disruptive energy which is deposited in the cells of the body.

Some radioactivity could make its way into the food chain. At high enough ground concentrations, restrictions would be put upon land use and, possibly, attempts would be made to decontaminate.

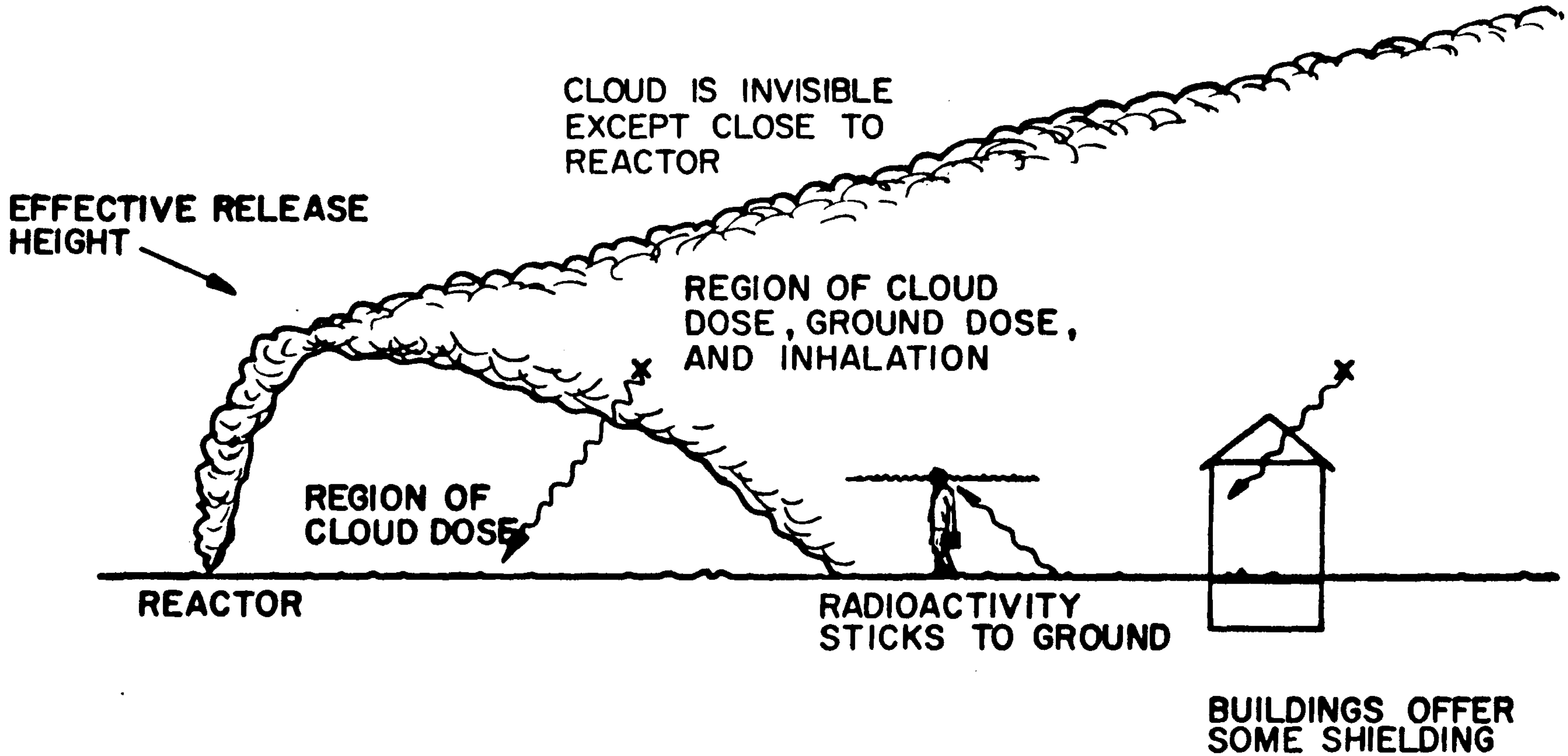
Over the years, some of the radioactivity on the ground would spread outside the initial wedge area as a result of wind action. Particles would be eroded, resuspended, and blown about by the wind. This spreading, although representing a relatively small fraction of the released radioactivity, could be a source of worry for residents of other areas.

Table A-I indicates the time-frame of doses received by the population and Table A-II indicates the time-frame of the resulting health effects.



TOP VIEW OF PLUME

FIGURE A-I



SIDE VIEW OF RADIOACTIVE PLUME

FIGURE A-II

Table A-I Time Frame of Received Doses

(Doses are in Addition to Natural Background Dose of about .1 rem/year.)

Short term (days)

1) From passing "cloudshine".
2) From inhaled radioactivity.
3) From "ground shine" received while remaining on contaminated ground.

Long term

1) From inhaled radioactivity stored in the body.
2) From ground contaminated to levels too low to justify evacuation.
3) From radioactivity in food at levels low enough to be considered acceptable.
4) From wind-blown, resuspended radioactivity.

Table A-II Time Frame of Health Effects

Short term (within several weeks)

Sickness and death from doses of the order of 100's of rems. (Close to the reactor.)

Long term (after years)

Cancer, diseases, developmental and genetic birth defects. (These effects will occur with some probability among all exposed populations with a ratio of incidence which decreases, however, with decreasing dose.)

Appendix B

RELEASES CONSIDERED

Appendix B
HYPOTHETICAL RELEASES CONSIDERED

TMI-0 A 10% release of the core noble gases. This release is meant to approximate the actual end result at TMI. The consequences are small, with 4 delayed cancer deaths representing the maximum number calculated here. Doses come from cloudshine and inhalation (see Appendix A). Since noble gases do not stick to the ground, there is no significant level of radioactive contamination left after the cloud passes.

TMI-1 60% Release of the core noble gases. This hypothetical accident represents a more serious containment failure than TMI-0, with essentially all of the noble gases assumed present in the containment being released (but at a time when negligible amounts of iodine and cesium were airborne within the containment) The number of calculated cancer deaths ranges from 1 to 25.

Note that a deliberate release of this magnitude might have been decided upon at TMI because of concern about the buildup of hydrogen in the containment and the threat of explosion or fire.

TMI-2 60% Noble gases plus 5% iodines. This hypothetical accident assumes containment failure or deliberate venting of the containment at a time when a significant fraction of the iodine it contains is airborne.* The release percentages are similar

*Due to special circumstance at Three Mile Island, it appears that most of the gases released from the core were "scrubbed" of soluble species prior to their escape from the reactor vessel through water-filled pathways. Thus, the amount of airborne radioiodine at TMI may never have reached this level. See Appendix H.

to those predicted in the Reactor Safety Study for a PWR5 accident.

Radioiodine represents a qualitatively different hazard than the noble gases since it is readily absorbed by the body and stored selectively in the thyroid. Damage to the thyroid represents the major threat from this accident, accounting for more than 50% of the 3 to 350 cancer deaths projected and virtually all of the 200 to 27,000 cases of thyroid nodules.

Radioiodine also differs from the noble gases in that it sticks to buildings and ground surfaces. Thus, there would be a groundshine dose (see Appendix A), most of which would be accumulated in a few weeks.

Iodine can enter the food chain through the milk/cow pathway. Grazing restrictions would therefore be necessary (over an area of 25,000 mi^2 for this release). However, because iodine isotopes which lead to large thyroid doses have short lifetimes, the land restrictions would not last very long. (See Table B-IV.)

The distributions of cancer deaths and thyroid nodule cases with distance are shown in Table II in the main text and in Table B- I. For the NYC/Boston wind direction the health effects peak at 100-150 miles. The risk to exposed individuals is also shown in the tables.

TMI-3a <u>60% Noble gases, 5% iodines, and 10% cesiums</u>. This hypothetical accident assumes containment failure or deliberate venting of the containment at a time when both iodine and cesium are airborne. The release percentages are similar to those predicted in the Reactor Safety Study for a PWR4 accident.

Radioactive cesium, like radioiodine, also sticks to buildings and ground. It would cause both agricultural restrictions and long-term land occupation restrictions. The addition of cesium-137 to the release, with a 30 year half-life, adds a long-term component to the radiation hazard. For this release 15 to 2000 cancer deaths and about 75 mi^2 of long-term land contamination are estimated, in addition to the 200 to 27,000 cases of thyroid nodules from the radioiodine.

TMI-3b <u>A TMI-3a release with a mature core (rather than a three month old core)</u>. The inventory of cesium-137 in a reactor core increases approximately linearly with the equivalent length of time that the core has operated at full power. Typical nuclear reactor fuel has been in a reactor core for about 18 months, whereas the fuel at TMI had been in full power operation for only about 3 months. Thus, for the same release percentages, approximately six times as much cesium-137 would be released as in a TMI-3a accident. As a result the consequences predictions increase: 65 to 8,500 delayed cancer deaths and about 550 mi^2 of long-term land contamination.

TMI-4a A 50% cesium release. For this hypothetical accident it is assumed, for illustrative purposes, that only cesium is released. Consequences for such a hypothetical release have been calculated to demonstrate that it is the cesiums which dominate the long-term consequences expected from a full core meltdown. (Compare the results with TMI-5a.)

An estimated 100 to 12,000 delayed cancer deaths, about 3,700 mi^2 of temporary agricultural restrictions and about 650 mi^2 of long-term land contamination result.

TMI-4b A TMI-4a release with a mature core. An estimated 440/48,000 cancer deaths, about 18,000 mi^2 of temporary agricultural restrictions and about 4,300 mi^2 of long-term land contamination.result. (Compare with TMI-5b.)

TMI-5a PWR2 release. This hypothetical accident is meant to simulate a release following a full core meltdown with breach of containment by overpressurization.* The same release fractions are used as were used in the Reactor Safety Study for a "PWR2" reference accident. This is not the worst accident considered in that study, but close to it.** In the Reactor Safety Study, the PWR2 release was assigned the highest probability among the large release accidents for the pressurized water reactor accidents.

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*An important question to answer is whether or not a hydrogen explosion or fire in the TMI containment could have damaged cooling and safety systems sufficiently to trigger such an accident.

**A PWR1 accident would only cause about 40% more cancer deaths by our calculations. For completeness, we note that release of 50% of the core in aerosol form--an unrealistic possibility considered in an older government study (WASH-740[B1]) often quoted by the anti-nuclear movement--would produce six times as many cancer deaths (not including bone cancer).

For the T.M.I. core inventory an estimated 200 to 23,000 delayed cancer deaths and about 1,400 mi^2 of land contamination would result following a PWR2 accident. (This does not differ very much from TMI-4a, demonstrating the importance of the volatile cesium isotopes for reactor accidents.)

In addition to a 50% cesium release, a 70% radioiodine release is also assumed in a PWR2 release. About 25% of the cancer deaths are caused by thyroid cancer resulting from inhalation of iodine. The iodine release also leads to 175,000 mi^2 of temporary restrictions on milk production and 3,500 to 450,000 cases of thyroid nodules.

Distributions of the cancer deaths and thyroid nodule cases with distance are given in Tables B-II and B-III. The risk to exposed individuals is also shown.

TMI-5b A TMI-5a accident with mature core. The range of predicted delayed cancer deaths increases to 550/60,000 with 10% of the deaths caused by thyroid cancer. The long-term land contamination area increases to about 5,300 mi^2.

It might be possible to reduce the number of cancer deaths by decontaminating land or relocating populations even further downwind than 50 miles to avoid low-level doses. However, the affected area would be very large. Should crowded urban areas be involved, it is unlikely that permanent relocation would be the chosen policy. The Reactor Safety Study estimated that in urban areas, such as lie in the NYC/Boston direction, a 25 rem dose in 30 years would be the triggering level for protective action.* This level would be reached out to 100 miles. Relocation of the 365,000 people living in contaminated ground out to 100 miles would reduce the 60,000 upper range number to 45,000 cancer deaths.

(Note that the 60,000 upper range cancer death number was calculated assuming population relocation out to 50 miles.)

Decontamination to prevent doses lower than 25 rem in 30 years is a possibility, but there exists little experience with the difficult process of removing aerosol-sized particles from urban areas. The success of urban decontamination must be considered an open question at the present time. It might very well be decided to simply tolerate the small increased individual risk of cancer should valuable urban land be involved.

Clearly, research on this problem should be given high priority. Demonstration of an effective way to remove reactor-accident-generated cesium aerosols from pavement and buildings would be an important contribution to consequence mitigation strategies.

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* A radiation dose, as measured in rem, measures the cumulative amount of disruptive energy which is deposited in cells of the body. Over 30 years natural radiation background itself would cause about a 3 rem dose. Thus, the 25 rem dose triggering level would be about 8 times background.

Reference for Appendix B

B1 U.S. Atomic Energy Commission, Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants (Washington, D.C., WASH-740, 1957).

Table B-I Thyroid Nodule Cases at Different Distances Caused by TMI-2,3 Accidents[a] 5% Iodines Released

Distance Range	Initial Population In Plume Path	Total Delayed Thyroid Nodule Cases Due to the Accident[b]	Percentage of Exposed People Who Eventually Develop Nodules[b] From the Accident
	Wind towards N.Y. City area		
0-50	95,000	(870-6600[c])	.9-7[c]
50-100	270,000	570-4200	.2-2
100-150	1,800,000	1400-11,000	.07-.6
150-200	2.700.000	1300-9,400	.05-.4
200-250	850,000	210-1,600	.03-.2
250-300	590,000	100-750	.02-.1
300-400	1,300,000	42-320	.003-.02
400 -	0		
TOTAL	7,600,000	4500-34,000[d]	
	Wind towards Eastern Maryland		
0-50	48,000	(1600-12,000[c])	3-25[c]
50-100	66,000	140-1000	.2-2
100-150	72,000	55-420	.07-.5
150-200	26,000	10-75	.04-.3
200-250	0		
250-300	0		
300-400	0		
400 -	0		
TOTAL	210,000	1800-13,000[e]	

Notes:

a) For typical meteorological conditions.

b) Variation in numbers is due to uncertainties in computing doses to the thyroid and in relating doses to the number of resulting nodules. ~~Lowest numbers correspond to WASH-1400 assumptions.~~

c) Would be zero if people were evacuated before arrival of the plume.

d) Would be 3600-27,000 if people were evacuated out to 50 miles before arrival of the plume.

e) Would be 200-1500 if people were evacuated out to 50 miles before arrival of the plume.

X

Table B-II Thyroid Nodule Cases at Different Distances Caused by TMI-5a,b Accidents[a)]

(PWR2 Accident with either 3 month or mature core)

Distance Range	Initial Population In Plume Path	Total Delayed Thyroid Nodule Cases Due to the Accident[b)]	Percentage of Exposed People Who Eventually Develop Nodules From the Accident[b)]
		Wind towards N.Y. City area	
0-50	95,000	(13,000-95,000[c)])	10-100[c)]
50-100	270,000	10,000-74,000	3-30
100-150	1,800,000	25,000-190,000	1-10
150-200	2,700,000	19,000-140,000	.7-5
200-250	850,000	3,800-21,000	.5-3
250-300	590,000	1,800-14,000.	.3-2
300-400	1,300,000	760-5,700	.06-.4
400 -	0		
TOTAL	7,600,000	73,000-540,000[d)]	
		Wind towards Eastern Maryland	
0-50	48,000	(21,000-48,000[c)])	40-100[c)]
50-100	66,000	2,300-18,000	3-30
100-150	72,000	1,000-7,400	1-10
150-200	26,000	170-1300	.7-5
200-250	0		
250-300	0		
300-400	0		
400 -	0		
TOTAL	270,000	24,000-75,000[e)]	

Notes:

a) For typical meteorological conditions.

b) Variation in numbers is due to uncertainties in computing doses to the thyroid and in relating doses to the number of resulting nodules. Lowest numbers correspond to WASH-1400 assumptions.

c) Assumes relocation after 1 week. The numbers would be zero if people were evacuated before arrival of plume.

d) Would be 60,000-450,000 if people were evacuated out to 50 miles before arrival of the plume.

e) Would be 3500-27,000 if people were evacuated out to 50 miles before arrival of the plume.

Table B-III Cancer Deaths at Different Distances Caused by TMI-5a Accident[a)]

(PWR2 Accident with 3 month old core)

Distance Range	Initial Population In Plume Path	Total Delayed Cancer Deaths From the Accident[b)]	Percentage of Exposed People Who Eventually Die From the Accident[b)]
		Wind towards N.Y. City area	
0-50	95,000	(300-2400[c)])	.3-3[c)]
50-100	270,000	390-3500	.1-1
100-150	1,800,000	1000-9200	.05-.5
150-200	2,700,000	770-7000	.03-.3
200-250	850,000	160-1500	.02-.2
250-300	590,000	89-830[d)]?	.02-.1[d)]?
300-400	1,300,000	58-560[d)]?	.004-.04[d)]?
400 -	0	0	
TOTAL	7,600,000	2800-25,000[e)]	
		Wind towards Eastern Maryland	
0-50	48,000	(430-3500[c)])	1-7[c)]
50-100	66,000	140-1300	.2-2
100-150	72,000	60-560	.08-.8
150-200	26,000	12-110	.05-.4
200-250	0		
250-300	0		
300-400	0		
400 -	0		
TOTAL	210,000	640-5500[f)]	

Notes:

a) For typical meteorological conditions.

b) Variation in numbers is due to uncertainties in relating doses to cancer deaths. The individual risk is overestimated here, perhaps by a factor of two, because some of the deaths are associated with people not yet born who receive a dose sometime in the future from contaminated ground.

c) Relocation is assumed after one week. These numbers can be up to 5 times higher for the wind blowing in other directions or zero if people are evacuated before arrival of the plume.

d) Doses byond 250 miles for this accident are small, falling in a dose region where little is known about health effects. These numbers must be considered speculative.

e) Would be 2,500-23,000 if people were evacuated out to 50 miles before arrival of the plume.

f) Would be 200-2,000 if people were evacuated out to 50 miles before arrival of the plume.

Table B-IV

Areas in Which Cattle Grazing Might be Restricted
to Prevent Milk Contamination by Radioactive Iodine
Following Hypothetical Accidents at T.M.I.[a]

Accident Type	Area[b]				
	Initial Contamination	After 1 month	After 2 months	After 3 months	After 4 months
TMI-2,3 (5% iodines)	25,000 mi^2 [c]	2500	130	5	----
TMI-5a,b (PWR2, 70% iodines)[d]	175,000[c]	50,000[c]	3400	170	5

Notes:

a) The affected areas decrease in time because the radioiodines are decaying. The half life for the principal isotope, iodine 131 is 8 days. The areas were calculated using a threshold of 4 $\mu Ci/m^2$ of Iodine 131 deposition, a value which lies between those recommended by the Food and Drug Administration for consideration of ~~productive~~ action for infants and adults. These calculations have been carried out for typical meteorological conditions. See Appendix E for technical details.

X protective

b) Approximately the area of a 7.5° wedge extending from the plant. The length of the wedge is given below for the various cases shown in the table.

maximum distance of wedge	wedge area
1600 mi	175,000 mi^2
880 mi	50,000
620	25,000
230	3,400
200	2,500
50	170
45	130
9	5

c) Much of this area could lie over water.

d) For either a 3 month or mature core.

Table B-V

Areas in Which Initial Agricultural Use and Long-Term Human Occupation might be Restricted in the Absence of Successful Decontamination[a)]

Accident Type	Initial Area[b)] limited occupation[c)]	Initial Area[b)] limited agriculture[d)]	Area[b)] Still Contaminated After 10 Years limited occupation[c, e)]	Area[b)] Still Contaminated After 40 Years limited occupation[c, e)]
TMI-3 (10% cesiums)				
a) 3 month old core	75 mi^2	420 mi^2	6-75 mi^2	<3-55 mi^2
b) mature core	550	2600	60-550	25-300
TMI-4 (50% cesiums)				
a) 3 month old core	650	3700	65-650[a)]	20-450
b) mature core	4300[f)]	18,000[g)]	550-4300	240-3300
TMI-5 (PWR2)				
a) 3 month old core	1400	3700	65-650	20-450
b) mature core	5300[f)]	18,000[g)]	550-4300	240-3300

Notes:

a) For typical meteorological conditions. (See Appendix E for technical details.) Ground Shielding factor = .33.

b) Approximate area of 7.5° wedge extending from the plant. No decontamination is assumed. The length of the wedge for various areas is given below:

Maximum distance of wedge	Area of wedge
525 mi	18,000 mi^2
260	4,300
240	3,700
100	650
30	65

c) We assume that occupation would be restricted if the resident population would otherwise receive more than a 10 rem whole body radiation dose over 30 years. This corresponds to about a three-fold increase over the natural background dose in the same period. A ten rem whole body dose has associated with it a risk of a .05 to .5% chance of cancer death.

d) Using criterion for cesium 134 as specified in Appendix E with the infant as the critical individual. Food grown in this area would not be allowed to be fed to infants. Restrictions apply to crops growing at the time of the accident; we do not attempt to calculate the more difficult problem of determining agricultural contamination after the first year.

e) The land contamination threshold used to calculate the lower number in the table is 10 rem in 30 years. In some sense, the threshold is set to balance the (small) individual risk of cancer against the hardships involved in uprooting people. Criteria which would be used to allow re-entry might be stricter. The higher number assumes that a 10-fold stricter criterion (corresponding to a one third increase over natural background) is applied in deciding whether vacant land can be re-used.

f) For comparison purposes, we note that the maximum corresponding figure in WASH-1400 was 3300 mi^2 [App. VI, Fig. 13-35].

g) Some of this area might be water should the wind be blowing towards the east.

Appendix C

CONSEQUENCE MITIGATING MEASURES

1) Filtered Venting of Containment Buildings

There are technical improvements which can help to make up for the absence of adequate design features to contain the airbourne radioactivity from meltdowns. One option, "filtered venting of the containment," is very promising and can be backfitted into existing reactor containment buildings.[C1-9]

Filtered venting would allow the option of rapidly releasing gases in the containment through huge filters to prevent an uncontrolled escape through a leak in the containment, to prevent containment failure due to overpressure, or to prevent the buildup of hydrogen concentrations to dangerous levels. Detailed designs already exist.[C7] The cost is estimated to range between 1 and 10 million dollars per plant[C6,7] -- a small fraction of the total cost of a reactor.

While filtered venting would not solve all safety problems and would not protect against all imaginable meltdown scenarios or prevent the release of noble gases, it would add another level of defense to current safety approaches and it would reduce the consequences of a large class of failure modes by 10 to 100 times. It could turn a TMI-5 accident into a TMI-1 accident as far as consequences were concerned.

2) Post-Accident Mitigating Strategies

Evacuation before the radioactive cloud arrives is the most obvious defense against a release of radioactivity. (However, before ordering the evacuation of populations far from the reactor, it would be necessary to weigh the potential benefits to be gained against the potential risk of accidents which could occur during a stress-filled, mass evacuation.)

The fact that large numbers of people have been evacuated without panic following accidents involving toxic chemicals, flammable materials and poisonous gases suggests that evacuation is a practical way to protect at least some of the population at risk at most reactor sites. However, no one knows whether or not special fears about radiation might make this experience with evacuation invalid in the nuclear case. Panic over the possibility of a dreaded "nuclear meltdown" could trigger disorderly evacuation attempts even far from the reactor, preventing orderly traffic movement. Therefore, emergency planning strategies for reactor accidents should be designed keeping in mind the psychology of evacuation under highly stressful conditions. The development of public confidence <u>prior to the accident</u> in the adequacy of the protective strategies available should help to prevent panic.

Practice drills for all emergency personnel and a system capable of rapid notification of the population appear to be critical for making evacuation successful. A 15-minute warning capability for persons within 10 miles of reactors--probably through the use of sirens--is being promoted by Federal authorities.[C10-11] Since an accident might occur in the middle of the night, it would be prudent to use sirens capable of waking the population in the evacuation zone. Such sirens should have their own emergency power, since a reactor accident might lead to disruption of normal electricity service.

Although it would be possible, given enough warning time, to evacuate people beyond the present 10 mile planning limit, evacuation is probably only a viable strategy out to 30 miles from a reactor. It would be difficult, to say the least, to move the millions of people who might risk low-level exposure at greater distances. Furthermore, attempts to evacuate people beyond 30 miles might lead to a backup of traffic on roads planned for the escape of persons residing or working nearer to the accident site.

Three other strategies offer some important possibilities for protecting people beyond 30 miles (and those closer for whom evacuation is not attempted or is not successful): 1) The taking of thyroid-blocking medicine; 2) sheltering in buildings; and 3) breathing through make-shift cloth filters or distributed respirators. Complete logistical details for these strategies need to be carefully worked out. Hopefully, none will be rejected prematurely because satisfactory implementation may appear, at first sight, to have some difficulties. A combination of all three strategies would be most effective and most likely to prevent panic among those not included in evacuation plans. Successful use of these mitigating measures has three prerequisites:

- monitoring and forecasting of the position of the radioactive cloud,
- communication of detailed instructions to the public,
- and, in the case of thyroid-blocking medicine and respirators, a satisfactory distribution system.

Pre-distribution of sheltering instructions (to radio and television stations) and pre-distribution of medicine (fastened perhaps to all electric utility meters) may be necessary to insure timely availability and to prevent distribution centers from being overrun by a panicked public. However, the necessity of pre-distribution is controversial.[C12]

In considering these strategies, it should be noted that they do not represent absolute protection against reactor accident consequences. It is unlikely that the necessary instructions and/or equipment would reach the entire targeted population and, in any case, these methods only reduce (do not eliminate) radiation doses.

Nevertheless, with careful planning these measures could significantly reduce the risk of illness and cancer. Each would add a separate level of defense to the reactor safety "arsenal."

A) Thyroid-Blocking

Potassium iodide pills taken before inhalation or ingestion of radioactive iodine would reduce thyroid doses by ten to one-hundred times, due to the blocking of radioactive iodide uptake by the already saturated thyroid.[C13] Since, as shown in Table I of the main text, thyroid damage could affect more people in an accident (in the absence of thyroid-blocking) than any other radiation effect, this strategy is extremely important. As discussed in the main text, thyroid-blocking would provide a net benefit at least out to 100 miles in a worst case release of radioiodine.

Potassium iodide is cheap and quite safe at the recommended doses (it is the form of iodine added to iodized salt), and could significantly reduce the number of people affected by an accident. It certainly would not cost more than 10 cents per year per person to keep a fresh supply available.[C14] Even should the medicine never be used, the expense can be justified as the premium on an accident "insurance policy."

This medicine, in our opinion, should be made available to any population which is likely to be exposed to radioiodine in quantities sufficient to produce a 10 rem or larger thyroid dose.[C15]

At the time of the Three Mile Island accident, potassium iodide was not yet available for mass distribution in the proper dosages. The U. S. Food and and Drug Administration therefore ordered large-scale production on an emergency basis and within a few days had flown enough into the area in liquid form for more than a half-a-million people. But this would have been too late if the containment building at Three Mile Island had failed early in the course of the accident. In addition, problems with packaging would have made mass distribution of the medicine difficult: the two-and-a-half-inch droppers didn't fit the two-inch-tall bottles, and the dropper outlet produced too small a dosage.[C16] According to the Secretary of Health for the State of Pennsylvania, "The most important public-health lesson that we learned is that you just have to be prepared."[C17]

The drug is now being manufactured in tablet form by the Carter-Wallace Company, Cranbury, New Jersey, under the name "Thyro-Block". The company has indicated that about half of the states in the U. S. have expressed an interest in the product. Although distribution of the drug in a radiation emergency is widely supported by radiation specialists, there is considerable disagreement about the wisdom of making it accessible to the general population before an accident rather than stockpiling it for distribution after an emergency has been declared.[C12, 18] What is peculiar about the present official status of the drug is that the Nuclear Regulatory Commission appears to be resisting any use at all of potassium iodide as an emergency measure for the general population--a posture for which it has been criticized by the Federal Emergency Management Agency.[C11, 18]

B) Sheltering

Sheltering in buildings is another strategy which could be employed to reduce radiation doses in case of a release of radioactivity.[C19] Some filtering occurs as air penetrates into structures.[C20] Also, masonry buildings offer some shielding from external doses from the cloud and from radioactivity deposited outside. With proper instructions, people could position themselves in optimal locations (similar to those recommended for protection against fallout from nuclear weapons).

In addition, there would be a delay before outside radioactive air would seep inside buildings -- a delay which under certain circumstances could be used to advantage. If residents could be informed by radio or television approximately when the cloud would reach them and when it would leave, the delay period could be used to reduce the inhalation dose. By closing windows and doors during cloud passage, when the indoor concentration was low, and opening them afterwards, when the outdoor concentration was low, some reduction in inhalation doses would be possible. This strategy might reduce inhalation doses by a factor of two or three in summertime under low wind conditions, when natural infiltration rates in residences can be made quite small by shutting windows, doors, and sealing other openings. Such a strategy would be less effective in wintertime when infiltration rates are often unavoidably high even when doors and windows are closed.

C) Personal Air Filters

In addition to thyroid-blocking and sheltering, it would be helpful, during cloud passage (and for a few hours thereafter), to breathe through several layers of cloth. Some of the larger radioactive aerosols would stick to the cloth material instead of entering the body. However, because the physical size of the aerosols governs the efficiency of filtration--a parameter which cannot be predicted with confidence in a reactor accident--it is difficult to make any quantitative estimates of the effectiveness of this technique. Possibly, more efficient filters could be designed and fabricated for predistribution or distribution with potassium iodide.

D) Relocation

After the cloud passed by, it would be desirable to relocate certain residents to uncontaminated ground. Since there may be an optimal time to begin traveling out of the contaminated regions (so that the total groundshine dose would be minimized), public authorities should be prepared to survey and monitor the ground deposition pattern, as well as keep track of traffic flow rates, in order to properly advise residents when to leave their homes or workplaces.

References for Appendix C

C1. J. Beyea, F. von Hippel, Nuclear Reactor Accidents: The Value of Improved Containment, (Princeton University, Center for Energy and Environmental Studies, Princeton, N.J., PU/CEES #94, 1980).

C2. A detailed review of the issues involved in this concept can be found in Allan S. Benjamin, Program Plan for the Investigation of Vent-filtered Containment Conceptual Designs for Light Water Reactors, (Washington, D.C., Nuclear Regulatory Commission, NUREG/CR-1029, 1979).

C3. Recently a U.S. Nuclear Regulatory Commission task force recommended that the agency make a decision within approximately a year on whether or not to require a filtered release system on reactor containments. [NRC, TMI-2 Lesson Learned Task Force Final Report, (Washington, D.C., NUREG-0585, 1979), p. 3-5.]

C4. Aerospace Corporation, Evaluation of the Feasibility, Economic Impact, and Effectiveness of Underground Nuclear Power Plants, Report to the California Energy Commission, [Los Angeles, ATR-78 (7652-14)-1].

C5. P. Cybulskis, R.O. Wooton, R.S. Denning, Effect of Containment Venting on the Risk from LWR Meltdown Accidents, (Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-0138, BMI-2002, 1978).

C6. D. Carlson, J. Hickman, A Value-Impact Assessment of Alternate Containment Concepts, (Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-0165, 1978).

C7. B. Gossett, M. Simpson, L. Cave, C.K. Chan, D. Okrent, I. Catton, Post-Accident Filtration as a Means of Improving Containment Effectiveness, (Los Angeles, University of California, UCLA-ENG-7775, 1977).

C8. J.L. Kovach, "Gas Clean-up System for Vented Containment," 14th ERDA Air Cleaning Conference, Nuclear Consulting Services, Inc., Columbus, Ohio, undated.

C9. "Report to the American Physical Society by the Study Group on Light Water Reactor Safety," Reviews of Modern Physics, 47, 1975, p. S110.

C10. Nuclear Regulatory Commission, NRC Action Plan Developed as a Result of the TMI-2 Accident, (Washington, D.C., NUREG-0660, May 1980).

C11. Federal Emergency Management Agency, Report to the President: State Radiological Emergency Planning and Preparedness in Support of Commercial Nuclear Power Plants, (Washington, D.C., June 1980).

C12. Luther Carter, "Nationwide Protection of Iodine-131 Urged," Science, 206, Pages 201-206.

C13. Potassium iodide was approved for this purpose by the U.S. Food and Drug Administration (FDA) in December of 1978:

"The Commissioner concludes that potassium iodide is safe and effective for use as a thyroid-blocking agent in a radiation emergency under certain specified conditions of use because it has been widely used for many years, in large doses, and on a long-term basis with an incidence of side effects and toxicities, in general, proportional directly to dose and duration of therapy. The risks from short-term use of relatively low doses of potassium iodide in a radiation emergency are outweighed by the risks involved from exposure to radioiodine.

Almost complete (greater than 90 percent) blocking of peak radioactive iodine uptake by the thyroid gland can be obtained by the oral administration of 100 milligrams (mg) of iodide (130 mg of potassium iodide) just before or at the time of exposure. A smaller dose (64 mg of potassium iodide) can be used in infants under 1 year of age. A daily dose is required to maintain the blocked state. The use of a blocking agent is not expected to exceed about 10 days."[7]

-Food and Drug Administration, ["Potassium Iodide as Thyroid-Blocking Agent in a Radiation Emergency", Department of H.E.W., Fed. Reg., 43, pps. 58798-58800, December 15, 1978.]

On February 22, 1980 FDA published a notice in the Federal Register officially notifying the public, States, local governments and the nuclear industry of the availability of the approved drug for use in the event of radiological accidents at nuclear power plants, that it requires no prescription, and is available over the counter. ["Potassium Iodide for Thyroid Blocking in Radiation Emergency Only; Approval and Availability," Fed. Reg., 45, 11912 February 22, 1980).]

C14. Main text, Note 25.

C15. Main text, Notes 19-23.

C16. M. Rogovin, G.T. Frampton, Jr., et. al, Nuclear Regulatory Commission Special Inquiry Group, Three Mile Island, A Report to the Commissioners and to the Public (Washington, D.C. 1980, Volume II, Page 1029).

C17. New York Times, October 7, 1979, Page 49.

C18. Main text., Note 26.

C19. For some numerical calculations of the impact of this type of strategy, see D.C. Aldrich and D.M. Ericson, Jr., Public Protection Strategies in the Event of a Nuclear Reactor Accident: Multicompartment Ventilation Model for Shelter, (Sandia Laboratories, Albuquerque, New Mèxico, Sand 77-1555 1978). The U.S. Department of Environmental Protection has also studied sheltering strategies: Protective Action Evaluation as Protective Actions Against Nuclear Accidents Involving Gaseous Releases, Washington, D.C., Parts I and II, EPA 520/1-78-001, A and B).

C20. A.F. Cohen, B.L. Cohen, Infiltration of Particulate Matter into Buildings, (Albuquerque, New Mexico, Sandia Laboratories, Report SAND 74-2079 NUREG/CR-1151, November 1979).

Appendix D

EARLY FATALITIES

The fact that early fatalities (death within sixty days) could have occurred out to 20 miles from Three Mile Island following a catastrophic release is really not in doubt, although the probability at such distances is very low based on meterological factors alone. (The probability of large numbers of early fatalities appears to be much lower than the probability of large numbers of cancer deaths.)

There is a threshold for the occurrence of early fatalities (approximately 150 rem to the whole body), which means it is possible to have a large release without any early fatalities at all. If meteorological conditions are favorable (high winds, rapid dispersion, and low deposition), enormous quantities of radioactivity can be released without doses reaching threshold even if evacuation is very slow. On the other hand, if meterological conditions are unfavorable (low winds, slow dispersion, and high deposition*), threshold doses can extend out beyond 20 miles. This is shown, for example, in two figures reproduced from the NRC's Reactor Safety Study.

The first, Figure D-1, shows mortality probabilities in the cloud path following a near maximal release** for two sets of weather conditions. The maximum distance predicted for early fatalities is about 9 miles. Other weather and accident conditions can extend the range further, as can be seen in Figure D-2. In this figure, mortality probability has been averaged over all weather conditions and over all wind directions, and as a result, the probability of early death drops off very quickly with distance compared to Figure D-1. Nevertheless, the curve does show a non-zero value out to 20 miles for the "ineffective evacuation" case.

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*Due to 1) rain, 2) sudden reduction in wind speed, 3) sudden increase in turbulence, or 4) terrain with a high affinity for aerosols.

**For a ground level release and ineffective evacuation time of 24 hours.

FIG. D-I. REPRODUCED FROM WASH-1400

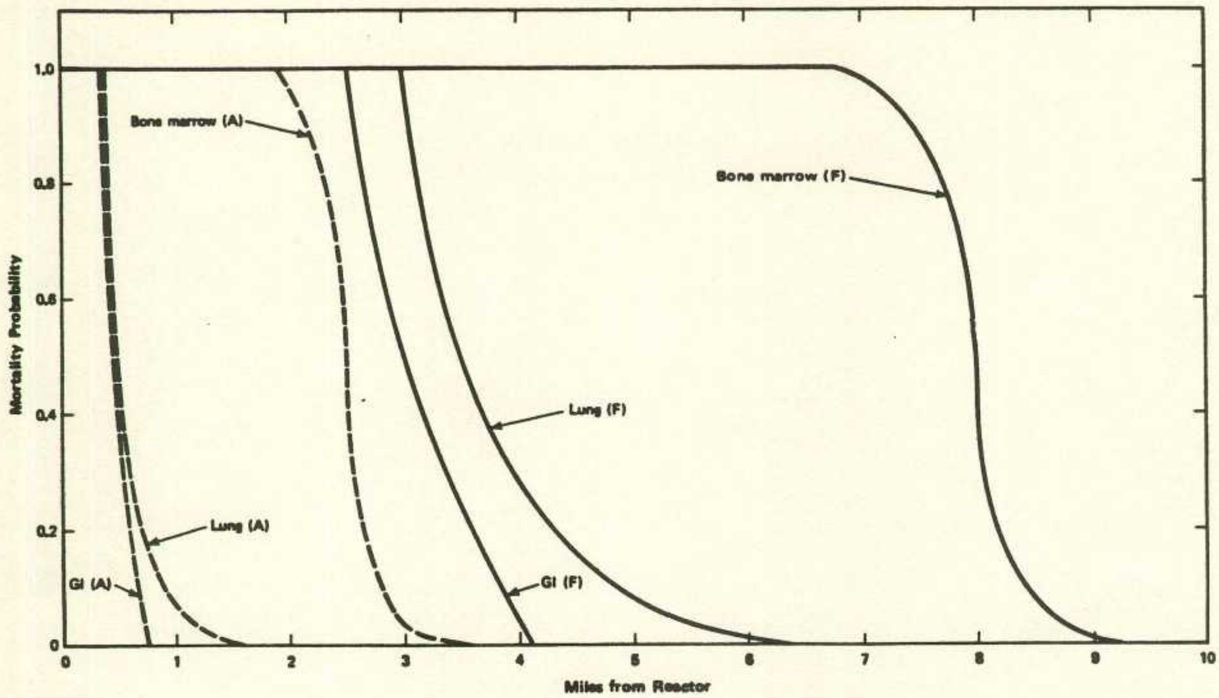

FIGURE VI 13-7 Mortality probability for an affected population versus distance from reactor for two hypothetical weathers: stability category A, wind speed = 0.5 m/sec; stability category F, wind speed = 2.0 m/sec.

FIG. D-II. REPRODUCED FROM WASH-1400

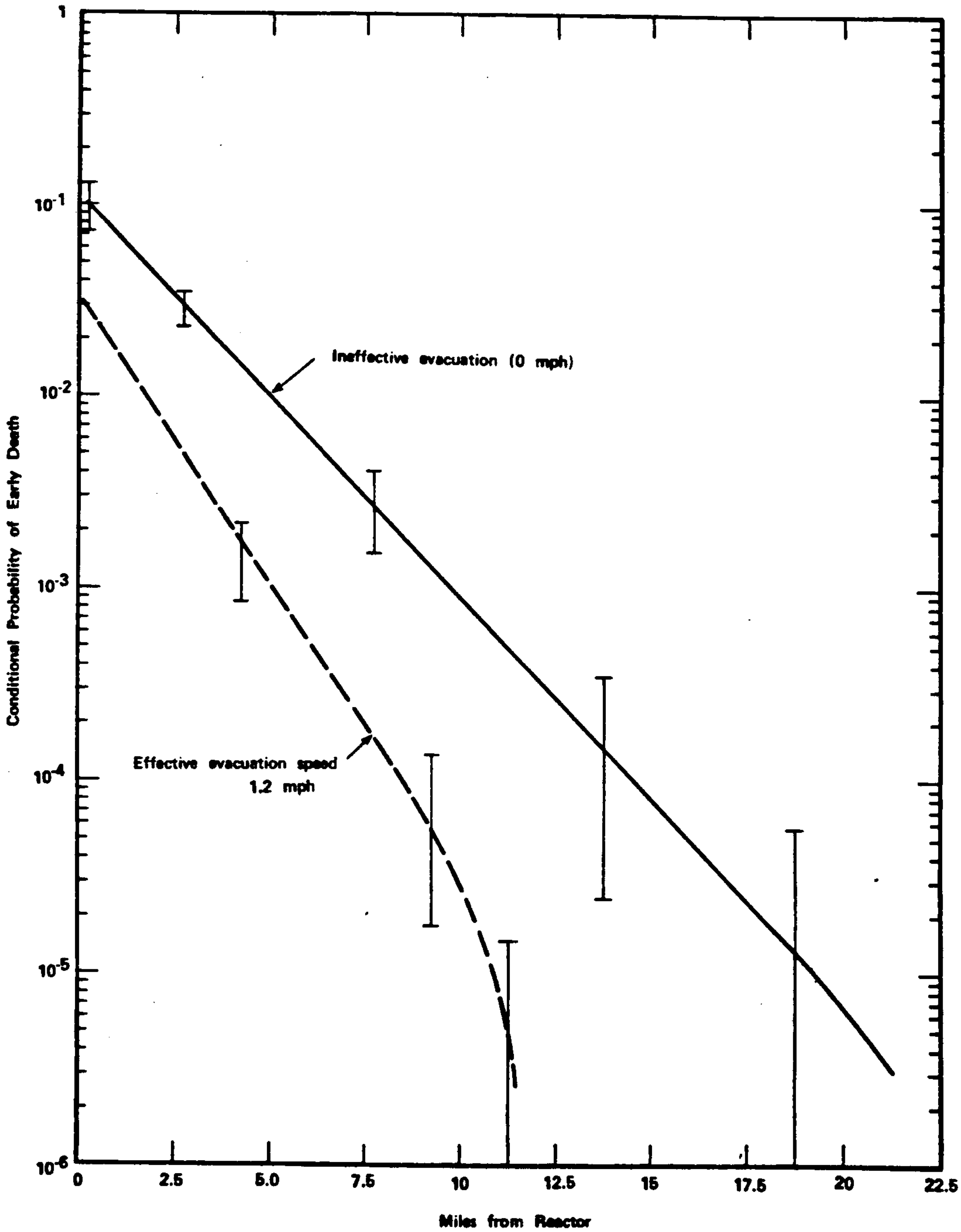

FIGURE VI 13-23 Conditional probability of early death as a function of distance from reactor for three effective evacuation speeds given a PWR-1A release.

(a) Approximately, absolute mortality probabilities are 10^{-6} per reactor year times quoted values.
(b) The error bars denote the variation in the mean values for the six meteorological data sets.
(c) For effective evacuation speeds of 4.7 and 7 mph, the conditional probability of early death is effectively zero within 25 miles.

One can easily argue about the exact slope of this curve*, and we doubt there can be any wide technical agreement on the matter at this time. The qualitative shape is not controversial however. Our own independent calculations for the Barsebäck Reactor site carried out for the Swedish Energy Commission also showed a similar rapid probability decline with distance for early effects.[D1] This decreasing probability had nothing to do with reactor technology, only with meteorology.

Thus, early deaths could have occurred in a crowded area like Harrisburg had the Three Mile Island accident led to a very large release, but the probability of large numbers was low -- although it cannot reliably be said exactly how low. Meterological conditions were unfavorable, for instance, during the evening of March 29th. The winds were blowing up the river towards Harrisburg under inversion conditions.[D2] The seriousness of a major release of radioactivity at that time would also have depended, however, upon the rate at which aerosols stuck to the ground and buildings as well as on the rapidity of evacuation.

The probability of a large number of early deaths even in the worst accident considered is certainly much much lower than the 1 in 4 chance that the wind would have blown towards distant crowded urban areas with subsequent large numbers of cancer deaths.

This does not mean that we should rely on probabilities for protection against early effects. A reliable evacuation plan adds an additional level of defense. In any case, it is desirable to move people out rapidly to prevent

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*Some observers feel that the <u>Reactor Safety Study</u> assumed rather optimistic post-exposure health treatment and a rather optimistic definition of "ineffective" evacuation (4 hours spent in contaminated ground), but there does not seem to be much doubt about the fact that the probability of early death does decrease relatively rapidly with distance.

even doses which are too low to cause early fatalities (e.g., tens of rems) -- because these doses do carry significant probability of cancer. Emergency planning out to 20 miles to deal with the possibility of early fatalities can be considered a contingency plan to deal with a low probability event, whereas emergency planning out to 20 miles to decrease the population radiation dose in this area should be considered a necessity in light of the Three Mile Island incident.

References for Appendix D

D1. Figure I-6 in Jan Beyea's, A Study of the Consequences of Hypothetical Reactor Accidents at Barsebäck, (Stockholm, Swedish Energy Commission, 1978, Report DsI 1978:5).

D2. March 29th, 1979, 10:30 pm, Ariel (Sic) Survey from N.R.C. "Preliminary Notification of Event".

Appendix E

TECHNICAL DETAILS OF CALCULATIONS

This appendix has been written for readers who are familiar with accident consequence calculations--particularly Appendix VI of WASH-1400 (the Reactor Safety Study). Any modeling parameters used in this report which are not listed in this appendix have been taken from WASH-1400.

1) Dose Calculations

Dose calculations were made using a Gaussian plume computer model, PLUMEDOSE, developed at Princeton. This program is capable of reproducing the WASH-1400 time-independent dose calculations [including: 1) groundshine dose from deposited radioactivity, 2) cloudshine dose from the finite radioactive cloud, and 3) dose commitment from inhaled radioactivity]. Comparison of the doses calculated by the Princeton program with those calculated by the WASH-1400 program, for the same input parameters, has generally shown good agreement.[E1,2] Equations for the calculated doses can be found in WASH-1400 or Reference E-1.

Although in other reports[E1] we have explored the sensitivity of the WASH-1400 model to variation in uncertain parameters, it was not necessary to do so here, since the long-term effects presented in this report are not overly sensitive to uncertainties in modeling the dispersion of radioactivity. For this report, the Princeton program was run using parameters consistent with those used in WASH-1400 for typical weather conditions:

A. Meteorological Parameters

5 m/sec wind speed; Pasquill stability Class, D; .01 m/sec deposition velocity. A time-independent Gaussian plume model was used with "top hat" approximation.*

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*See Appendix VI of WASH-1400. Note that full Gaussian calculations were made when calculating contaminated areas.

Dispersion parameters were taken identical to those used in WASH-1400 (for a 30 minute release duration). Although experimental data used to determine the dispersion parameters are scarce beyond 20 miles, the model is satisfactory for calculating health effects when a linear relationship is used between dose and response. In such a case, the total number of health effects depends only upon the summed population dose, which is insensitive, (unlike the dose distribution) to the choice of dispersion parameters and other modelling details -- at least when the population distribution is uniform.[E1]

Because the population density at the TMI site is not uniform, the calculated number of health effects does show some sensitivity to the choice of dispersion parameters. However, the resulting variations are not significant when compared with the variation in calculated health effects for different wind directions.

In a uniform population distribution model, the inhalation dose component of the population dose tends to vary inversely with the deposition velocity[E3]. To investigate the significance of deposition velocity in the T.M.I. non-uniform population calculation, the deposition velocity was decreased to .003 m/sec and the cancer death calculations repeated. The results for all wind directions changed by less than a factor of two. The (TMI5a) results changed by less than 25% for the N.Y.C./Boston wind direction. (Higher deposition velocities might tend to decrease the totals somewhat and the direction corresponding to maximum deaths might shift to a direction with population concentrated closer to the reactor than the N.Y.C./Boston direction.)

The prediction of areas above a threshold, which is necessary for land contamination calculations, also tends to be model independent -- at least for large releases.[E4]

It should be noted that, although the meteorological model used here is satisfactory for predicting contaminated areas and total health effects (for a linear dose-effects model), it is less satisfactory in predicting actual doses -- especially beyond 20 miles. Since the dose is (inversely) proportional to the horizontal dispersion coefficient, σ_y, uncertainties in σ_y are directly transferred to the dose predictions.

The dose values shown in Table E-1 are not presented as accurate predictions of the expected dose but are presented to show the values used in our calculations.

B. Other Parameters

Effective plume height:

TMI 0-3   25 meters

TMI 4,5   125 meters

Restriction on vertical dispersion coefficient due to atmospheric inversion layer:

800 meters

Ground Shielding Factor:

.2 for urban areas* (most of population in N.Y.C./Boston direction)

.33 for rural areas (most of population in Eastern Maryland direction)

Cloud Shielding Factor:

.6

C. Isotope Inventory and Release Fractions

The isotope inventory for an equilibrium core (18 month average burnup) was taken from WASH-1400. For a 3 month old core, the inventory of long-lived isotopes such as cesium 137 and strontium 90 was reduced, since their concentrations is approximately proportional to burnup. Short-lived isotopes with lifetimes less than a month were left unchanged. This procedure accounts for the isotopes which have a significant impact on the consequence results.

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*Urban area being defined as a population sector with population density greater than 300 people per square mile.

For completeness, reduction factors for isotopes with intermediate lifetimes also were used -- determined from a simple production and decay model. (The numbers are consistent, in general, with inventories given in Ref. E-5.)

Inventory of isotopes of major interest (in millions of curies):

	TMI Core	Mature Core
Cesium 134	1.7	7.5
Cesium 137	0.77	4.6
Iodine 131	85	85
Iodine 133	170	170
Xenon 133	170	170
Xenon 135	34	34
Krypton 87	47	47
Krypton 88	68	68

Release percentages for a TMI-5 accident (WASH-1400, PWR2):

CS, Rb	50%
I	70%
Xe-Kr	90%
Te, Sb	30%
Ba, Sr	6%
Ru, Rh, Co, Mo, Tc,	2%
La, Y, Zr, Nb, Ce/Pr, Nd, Np, Pu, Am, Cm,	.4%

D. Dose Conversion Factors, and their Use

Dose conversion factors were taken from WASH-1400, Appendix VI, Tables VI C1, C2, D2. The important conversion factors for the isotopes of major interest are reproduced here.

Isotopes	Halflives	Initial 1-day Groundshine dose to Whole Body (Rem per Ci/m^2)	Dose Commitment to Adult Thyroid per Curie Inhaled
Cesium 137	30 years	186	--
Cesium 134	2 years	530	--
Iodine 131	8 days	128	1.0×10^6
Iodine 133	21 hours	163	$.18 \times 10^6$

In the case of thyroid health effects, a separate calculation has been made for children and for adults since children are about five times more sensitive to exposure to airborne radioiodine than are adults. (See Footnote f in Table E-II for a discussion of the calculation for children.)

In calculating cumulative groundshine doses, the initial ground concentration was corrected for radioactive decay and, in the case of cesium, for weathering effects.[E6] The three components of the total dose to a particular organ from a particular isotope can be written as

groundshine: $(g_s v D_g C_g)\chi$,

inhalation dose commitment: $(bD_I)\chi$,

cloudshine: $g_c D_c F_c \chi$,

where:

χ = Integrated airborne concentration of radioactivity near ground level (in curie-seconds per cubic meter).

g_s = Ground shielding factor (dimensionless).

v = Deposition velocity (meters/second).

D_g = Groundshine conversion factor (in Rem per curie/m^2) as given for certain isotopes above.

C_g = A dimensionless correction factor which accounts for the dose accumulated beyond one day and takes into account subsequent radioactive decay and weathering. C_g equals the ratio of total groundshine dose (accumulated during the time period of interest) divided by the one day groundshine dose. For long-lived isotopes, in the absence of weathering, C_g would equal the exponential life (1.4 times the half-life) in days.

and long exposure times

b = Breathing rate (taken for adults as $2.7 \times 10^{-4} m^3$/second.)

D_i = Inhalation dose commitment conversion factor (in Rem/inhaled curie).

g_c = Cloud shielding factor (dimensionless).

D_c = Cloud dose conversion factor for an infinite cloud (in Rem/curie-seconds/m^3). (Values can be found in Table VI C-1 of WASH-1400).

F_c = Correction factor for the finite size of the cloud (dimensionless).

E. Numerical Dose Values

Table E-I shows sample doses to various organs as a function of distance for TMI 2 and TMI 5 accidents.

Table E-1 - DOSES (IN REM) USED FOR THIS STUDY
(Dose values, as opposed to population doses, are highly model dependent)[a)]

TMI-5b (PWR2)

Distance (miles)	Plume Width[b)] (m)	Whole Body Dose 1 wk groundshine[c)]	Whole Body Dose 50 yr groundshine[d)]	Adult Thyroid Dose	30 yr Inhalation Lung Dose
5	1.55E 03	2.53E 02	2.83E 03	9.41E 03	7.13E 02
15	4.07E 03	6.74E 01	7.79E 02	2.53E 03	1.93E 02
25	6.41E 03	3.11E 01	3.66E 02	1.18E 03	9.00E 01
75	1.72E 04	4.70E 00	6.00E 01	1.82E 02	1.42E 01
125	2.72E 04	1.74E 00	2.36E 01	6.82E 01	5.44E 00
275	5.55E 04	3.92E-01	6.05E 00	1.53E 01	1.31E 00
550	1.04E 05	7.53E-02	1.35E 00	2.89E 00	2.74E-01
1050	1.86E 05	7.33E-03	1.54E-01	2.64E-01	2.92E-02

TMI-2 (5% iodine and 60% noble gases)

5	1.55E 03	1.39E 01	1.80E 01	9.49E 02
15	4.07E 03	2.64E 00	3.39E 00	1.71E 02
25	6.41E 03	1.11E 00	1.42E 00	7.36E 01
75	1.72E 04	1.32E-01	1.81E-01	1.04E 01
125	2.72E 04	4.28E-02	6.15E-02	3.84E 00
275	5.55E 04	8.51E-03	1.30E-02	8.51E-01
550	1.04E 05	1.94E-03	2.86E-03	1.60E-01
1050	1.86E 05	4.80E-04	5.67E-04	1.46E-02

a) See text for a discussion. Note that "dose" multiplied times "plume width" is a quantity less model-dependent.

b) Doses are assumed constant over this width, zero outside.

c) Cloudshine . dose plus total internal dose commitment plus groundshine dose. Ground shielding factor = .2, appropriate for urban areas.

d) Approximately 3 times smaller for a TMI-5a accident (3 month old core).

2) Dose/Effects Coefficients

A. Values Used in This Study.

Considerable controversy and uncertainty exists about the effects of low-level radiation. At the present time, there is little alternative to stating a range of health effects. For this report we have used a coefficient range of 50 to 500 cancer deaths per million person-rem to the whole body--a range which the Environmental Protection Agency, in its comments on the draft report, agreed was reasonable.[E7] Table E-II compares our numbers with other studies and also shows the coefficient ranges we have used for thyroid and lung effects. (Thyroid cancer and lung cancer deaths were determined from inhalation doses calculated on an organ-by-organ basis. All other cancers were derived from the whole-body dose calculation alone.)

B. Some Other Assumptions which Might be Used.

Although the cancer coefficients used in WASH-1400 for most cancers fall at the bottom of the range used in this study, the upper range of cancer deaths for TMI 2-5 accidents would only drop by a factor of three to four, not a factor of eight, if WASH-1400 assumptions were used. This is because the WASH-1400 thyroid cancer death coefficient falls in the middle of our range, and the ground shielding coefficient used here for the N.Y.C./Boston direction is 0.6 times that assumed in WASH-1400 (i.e., we assume more shielding).

We have also estimated how our results would change if radiation-dose/cancer-death coefficients were used based on the work of Mancuso, Stewart and Kneale. Assuming one out of three cancers is fatal and that cancer represents 20% of the current death rate and using a linear fit to the 30 rad doubling dose for cancer proposed by Alice Stewart,[E8] we obtain a death coefficient of about $2{,}000 \times 10^{-6}$ per rem. This is four times the highest number used in this study, yet not so high that it would appear to change any of our conclusions or make reactor accidents seem dramatically more serious.

TABLE E-II- DOSE/EFFECTS COEFFICIENTS PER MILLION PERSON REM

FATAL CANCER INCIDENCE

	This Study	N.A.S. Draft Report (1979)[a]	WASH-1400 (1975)	APS Study (1975)[b]
Whole-body	50-500	68-353	65[c]	130
Lung	10-100		11[d]	13-35
Thyroid child	.5-3		5[e]	.5-3
adult	1.8-11		5[e]	1.8-11
Population weighted[f] thyroid	1.9-12[f]			
THYROID NODULE INCIDENCE				
Child	130[g]-1300[h]		330[e,i]	275-1300
Adult	130[g]-650[i]		330[e,i]	
Weighted[f]	200-1500[f]			

a) National Academy of Sciences, BEIR Report, 1979 (Draft). The upper number has been lowered by about a factor of two for the final report (1980) as a result of internal criticism of the use of a pure linear dose effects model.

b) Revs. Mod. Phys. 47, S1.

c) WASH-1400 mid-range values. (The so-called, "upper bound" numbers in WASH-1400 were calculated to be about two times higher.) To obtain its mid-range dose/effects coefficients, WASH-1400 used a linear model weighted by dose reduction factors depending on the dose magnitude. The number shown represents a weighted average of coefficients ranging from a low 24 to an "upper bound" of 122.

d) WASH-1400 mid-range value. The number shown is a dose weighted average of coefficients ranging from 4 to 22.

e) The Environmental Protection Agency uses coefficients for thyroid effects which would give a similar number (Reference E7). The number shown is a weighted average of the effects of Iodine 131 and other iodine isotopes. For example, in the case of fatal cancer incidence, the number 5 in the table is a weighted average of 1.3 deaths per million rem for I^{131} and 13 deaths per million rem for other iodine isotopes. See WASH-1400 App. VI, pp. 9-26, 27. Note, because of the shorter lifetime of I^{133}, the weighted average would drop by a factor of four if the hypothetical release occurred many days after fission stopped.

(Continuation of footnotes for Table E-II)

f) The weighted numbers are defined so that the entire population can be treated as adults. They are weighted according to the percentage of children and adults in the population and renormalized to the adult dose. The numbers are based on 1) the APS coefficients for children and adults, 2) a 5 times higher dose for children than adults for the same exposure, and 3) an assumed 15% fraction of children in the populations. [For example, 1.9 = .85 x 1.8 + .15 x 5 x .5, 12 = .85 x 11 + .15 x 5 x 3.]

g) The WASH-1400 value reduced by a factor of 2.5 to account for decay of short-lived Iodine isotopes should the accident occur a day or so after shutdown.

h) The APS value.

i) This number was incorrectly stated in the draft version of this report.

j) New data on the Marshallese victims suggests that the adult rate is 1/2 that of children, rem-for-rem [E9]. Insufficient data was available in 1975 for the APS study group to determine a range for adult nodule incidence.

Note that we use the linear hypothesis for relating dose to health effects as a mathematical convenience, assuming that possible non-linear effects are effectively contained in the range of coefficients assigned.

However, if the dose-effects relationship should be strongly quadratic, more so than assumed in WASH-1400, then the appropriate whole-body "effective" linear dose-effect coefficient could drop significantly below the lowest value we have used (50×10^{-6}) -- at least for TMI 0-3 accidents. For instance, should there be a threshold dose for cancer induction, the contribution from the whole-body dose would, no doubt, disappear for a TMI-2 Release. However, the contribution from thyroid cancer fatalities would still remain. These fatalities, alone, account for 50% of the total, so that the net change in fatalities would not necessarily be significant, unless even the relatively high thyroid doses were considered to fall below a threshold. (At 75 miles the child thyroid dose for a TMI-2 release is calculated to be 50 rem; the adult dose is calculated to be 10 rem. For 125 miles, the corresponding numbers are 20 and 4 rem respectively.* These internal doses are delivered within a few weeks.) In any case, the lowest numbers given in the summary table are already very small for TMI 0-3. Reducing them further would not change any of our conclusions.

3) Population Calculations

Average population densities were calculated as a function of distance within sixteen 22.5° angular sectors. For distances less than 50 miles, information provided in NRC-required documents for Three Mile Island was used.[E10] For distances greater than 50 miles but less than 300 miles, population of counties was used as the basic population input data. Beyond 300 miles, population of states and Canadian provinces was used.

*Note that these doses would be 14 times higher for a TMI 5a or 5b release. Thyroid cancers contribute 25% of the fatalities in case of a TMI 5a release and 10% of the fatalities in case of a TMI 5b release.

4) Interdiction Criteria for Agricultural and Human Use

A. Milk.

We have used 4 microcuries per square meter of I^{131} deposition during the grazing season as the threshold for milk interdiction. This value lies between the 1.4 $\mu Ci/m^2$ and 18 $\mu Ci/m^2$ recommended for infants and adults, respectively, by the Food and Drug Administration as criteria for considering milk interdiction.[E11] Thus, the areas given in Table B-IV underestimate the area which would produce milk with levels of iodine too high for infants and overestimate the areas involved which would produce milk with levels of iodine too high for adults.

B. Crops.

The FDA has also recommended threshold levels at which emergency protective action should be considered for crops, but only for Cesium-137 and Strontium-90, not Cesium-134. To obtain a threshold for Cesium-134, we have simply divided the 18 $\mu Ci/m^2$ guideline threshold for Cs^{137} by two, since Cesium-134 delivers approximatel twice as much energy per decay as does Cs^{137}. Each of the three isotopes has been considered separately and the largest resulting area (Cs^{134}) has been taken as indication of the amount of crop restrictions which would be imposed. This procedure underestimates the total area somewhat.

C. Occupation.

We have used a 10-rem-in-30-year threshold for rural land contamination -- about three times the average natural background dose over 30 years. This is the same criterion used in WASH-1400 for rural land. Residents at the edge of the contaminated region, in the absence of decontamination, might face an additional risk of death of .05 to .5% due to the radiation from the land and property contamination. Residents closer to the plant, where 30 year doses would be higher, would face a proportionately higher risk.

5. Additional Health Effects Tables

Table E-III shows the relative number of hypothetical cancer deaths for 16 wind directions around the TMI site. The distance at which the deaths peak (binned in 50 mi. intervals) is also shown for each direction.

Table E-III

Hypothetical Cancer Deaths for 16 Wind Directions Around TMI Site

		TMI-2			TMI-5a		
Angle from North[a)]	Sector	Max. Delayed Deaths Past 50 Miles	As Percentage of Sector 4[b)]	Distances at which Deaths Peak (miles)	Max. Delayed Deaths Past 50 Miles	As Percentage of Sector 4[b)]	Distances at which Deaths Peak (miles)
-11.25 to 11.25	1	39	11%	50-100	3,200	14%	50-100
11.25 to 33.75	2	59	17%	50-100	4,700	21%	50-100
33.75 to 56.25	3	69	20%	50-100	5,200	23%	50-100
56.25 to 78.75	4	340	100%	100-150	23,000	100%	100-150
78.75 to 101.25	5	170	51%	50-100	11,000	48%	50-100
101.25 to 123.75	6	200	61%	50-100	13,000	56%	50-100
123.75 to 146.25	7	43	13%	50-100	2,700	12%	50-100
146.25 to 168.75	8	26	8%	50-100	2,000	9%	50-100
168.75 to 191.25	9	190	55%	50-100	12,000	52%	50-100
191.25 to 213.75	10	140	42%	50-100	9,500	42%	50-100
213.75 to 236.25	11	44	13%	50-100	3,700	17%	50-100
236.25 to 258.75	12	42	13%	50-100	3,600	16%	300-800
258.75 to 281.25	13	79	23%	300-800	6,500	29%	300-800
281.25 to 303.75	14	90	27%	50-100	7,500	33%	300-800
303.75 to 326.25	15	42	12%	50-100	3,600	16%	50-100
326.25 to 348.75	16	56	17%	250-300	4,300	19%	250-300

a) Direction towards which wind is blowing.

b) Sector 4 (wind towards N.Y. City area) produced the largest maximum number of deaths past 50 miles.

E1. Jan Beyea, A Study of Some of the Consequences of Hypothetical Reactor Accidents at Barsebäck, (Stockholm, Swedish Energy Commission, 1978 Report DsI 1978:5).

E2. Private Communication, David C. Aldrich.

E3. Appendix H of Reference E1.

E4. Jan Beyea and Frank von Hippel, "Calculation of Land Areas in which Radiation Doses Exceed Given Thresholds Following an Airborne Release of Radioactivity," Section II of Nuclear Reactor Accidents: The Value of Improved Containment, (Princeton, N.J., Princeton University, Center for Energy and Environmental Studies Report CEES/#94).

E5. K.A. Varteressian, L. Burris, Fission Product Spectra from Fast and Thermal Fission of U-235 and Pu-239, (Argonne National Labs., 1970, ANL-7678).

E6. We assume that the gamma dose rate to the whole body (measured in Rem/day) one meter above the ground per Ci/m^2 of Cs^{137} is given on average by:

$D^{137}(t) = 186$ [$0.63 \exp(-1.15t) + 0.37 \exp(-0.030t)$], where t is measured in years.

The dose time dependence is based on measurements of the radiation above undisturbed soil from Cs^{137} deposited by fallout [UN, Ionizing Radiation: Levels and Effects, New York (United Nations, 1972), pp. 55-57]. The initial dose rate coefficient is based on calculations performed for WASH-1400 and includes self-shielding effects in the human body. (WASH-1400 Table VI C-2).

The initial rapid rate of decline (with a seven month half-life) is apparently associated with increased shielding of the gamma radiation resulting from movement of the Cs^{137} into the top 10 centimeters of soil. After a few years, however, the vertical distribution of Cs^{137} in the soil stabilizes and the continued slow decline in the dose rate is due primarily to the radioactive decay of the Cs^{137} (30 year half-life).

The time dependence for the Cs^{134} dose (in rads/day per Ci/m^2 contamination) has been obtained by factoring out the radioactive decay term associated with Cs^{137} [186 exp (-0.023t)] and replacing it with the corresponding radioactive decay term [530 exp (-0.34t)] associated with Cs^{134} (2 year half life).

The initial dose rate is higher for Cs^{134} because two gammas are emitted per decay (vs. 0.9 gammas per Cs^{137} decay). /_C.M. Lederer, et al., Table of Isotopes, 6th ed. (New York, John Wiley, 1968)_/, and because the average energy per gamma is also higher.

The final expression for the Cs^{134} dose rate therefore becomes, per Ci/m^2 of Cs^{134},

$D_{134}(t) = 530[0.63 \exp(-1.46t) + 0.37 \exp(-.34t)]$. Once again, the initial dose rate includes self-shielding effects -- as calculated in WASH-1400.

In urban areas, penetration into soil would not be a factor in reducing cumulative doses. However, runoff of precipitation over the years would act to remove cesium from urban surfaces. In the absence of experimental data on the long term effects of runoff on cesium deposited in urban areas, the same time dependence used for soil has been assumed.

E7. Letter to Dr. James Mackenzie of the Council on Environmental Quality, from Dr. William A. Mills, Acting Deputy Assistant Administrator for Radiation Probrams (ANR-458), October 2, 1979.

E8. Alice Stewart, Personal Communication, November 1978.

E9. Robert Conard, "Thyroid Lesions in Marshallese, July 1978," Brookhaven National Laboratory, Upton, Long Island (Mimeo).

E10. Preliminary Safety Analysis Report for Three Mile Island, Unit #1, Vol. 4, Docket 50289-9. Figures for 1967 and 1987 were averaged to obtain an estimate for the current population within 50 miles.

E11. Food and Drug Administration, "Accidental Radioactive Contamination of Human and Animal Feeds and Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency," Department of Health, Education and Welfare, Federal Register, Friday, December 15, 1978, Part VII, p. 58790.

Appendix F

Background of Participants

Jan Beyea is a nuclear physicist. His research interests at Princeton have been in two areas: a) nuclear safety, and b) energy conservation. He has served as a consultant on nuclear issues to Sweden, Germany and the state of New Jersey. Dr. Beyea's studies of nuclear accidents include the following:

Nuclear Reactor Accidents: The Value of Improved Containment, Princeton University, Center for Energy and Environmental Studies, Report PU/CEES 94, 1980 (with Frank von Hippel).

"Neuorientierung der Katastrophenschutz-Planung nach den Erfahrungen von Three Mile Island," Chapter 3 in Im Ernstfall Hilflos? (E.R. Koch, Fritz Vahrenholt, editors, Kiepenheuer & Witsch, Cologne, 1980).

The Effects of Releases to the Atmosphere of Radioactivity from Hypothetical Large-Scale Accidents at the Proposed Gorleben Waste Treatment Facility, report to the Government of Lower Saxony, Federal Republic of Germany, as part of the "Gorleben International Review," Feb. 1979.

A Study of Some of the Consequences of Hypothetical Reactor Accidents at Barseback, report to the Swedish Energy Commission, DSI 1978:5, Industridepartmentet Energikommissionen, Stockholm, 1978. (Also printed as Princeton University Center for Environmental Studies Report #61.)

Program BADAC, Short-term Doses Following a Hypothetical Core Melt-down; computer code written for the New Jersey Department of Environmental Protection, 1978.

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Frank von Hippel is a theoretical nuclear physicist. His research interests are in the area of energy policy. He was a member of: the American Physical Society Reactor Safety Study (1974-75), the outside steering committee of the Energy Research and Development Administration's review of the U.S. breeder reactor development program (1977), the Nuclear Regulatory Commission's Risk Assessment Review Group (1977-78), the Radiation Advisory Committee to the New York City Commissioner of Health (1978-), and the editorial advisory board of the Bulletin of the Atomic Scientists (1975-). Dr. von Hippel is also interested in improving the effectiveness of the use of technical advice in governmental policy-making. He is a member of the Committee on Scientific Freedom and Responsibility of the American Association for the Advancement of Science (1976-) and currently is the elected Chairman of the Federation of American Scientists. In 1977 he shared with Joel Primack the American Physical Society's Forum Award for Promoting the Understanding of the Relationship of physics and Society. Some selected publications are listed below:

Fission Power: An Evolutionary Strategy, Science, January 26, 1979, p. 330 (with H. A. Feiveson and R. H. Williams).

Looking Back on the Rasmussen Report, Bulletin of the Atomic Scientists, February 1977, p. 42.

"Report to the American Physical Society by the Study Group on Light-Water Reactor Safety," Review of Modern Physics, 47, 1975, p. S1 (with others).

"A Roadmap to the Major Issues Relating to Nuclear Energy," Oversight Hearings on Nuclear Energy-Overview of the Major Issues, U.S. House of Representatives, Committee on Interior and Insular Affairs, 1975, p. 5.

"Limited Nuclear Warfare," Scientific American, November 1976, p. 27 (with S. D. Drell).

Advice and Dissent: Scientists in the Political Arena, Basic Books, New York, 1974 (with J. Primack).

"Public Interest Science," Science 177, 1972, p. 1166 (with J. Primack).

Appendix G

Reviews of the Draft Report

Written comments were received from the organizations and individuals listed below. (Copies are included in a separate attachment to this report which can be obtained from The Council on Environmental Quality or from the author.) Most of the specific criticisms received were accepted in some form and the text modified accordingly.

1. Office of Radiation Programs, U. S. Environmental Protection Agency. Numerous specific technical comments and suggestions for clarifications of material in the text were contained in a letter dated October 2, 1979, from William A. Mills, Acting Deputy Assistant Administrator, to James Mackenzie of the Council on Environmental Quality. Almost all of these comments were accepted and appropriate changes made in the text.

2. Office of Nuclear Regulation, Nuclear Regulatory Commission. Two brief comments were made in a letter dated October 9, 1979, from Director Howard Denton to James Mackenzie, Council on Environmental Quality. We do not agree with Denton's first comment that the calculated deaths given in the text should be classified as "risk estimators." We feel that the uncertainty in our calculations has been adequately treated by giving a range of health effects and by the discussion in the text. The second of Denton's comments, however, led to changes in our text acknowledging the success, in this instance, of the "defense in depth" philosophy. The multiple physical barriers at TMI did contain most of the harmful radioactivity. (It should be noted that Denton stated that the N.R.C. was not able "to conduct an exhaustive technical review." Therefore, the N.R.C. was "unable to confirm the accuracy or validity of quantitative results of the calculations of the Princeton group.")

3. Bernard Shleien, Bureau of Radiological Health, U.S. Food and Drug Administration. In a letter to Jan Beyea dated October 5, 1979, Bernard Shleien made some general criticisms about unstated assumptions in the report and asked that more calculational details be included. He also clarified certain positions of the F.D.A. For instance, he stated that the F.D.A. does not endorse the "unqualified" use of Potassium Iodide as a blocking agent. (Neither do we. We only endorse its use for people whose projected thyroid dose is greater than 10 rem.) The F.D.A.'s position on when Potassium Iodide should be distributed has been made vague--perhaps appropriately so-- given the overlapping responsibilities of various U.S. governmental agencies.

4. Institut De Protection Et de Surete Nucleaire, Rep. France, Commissariat A L'Energie Atomique. Both general and specific criticisms were contained in a letter to Jan Beyea dated November 12, 1979, from the director, P. Tanguy. Specifically, the upper range of dose/cancer coefficients was criticized as being too high. However, in light of the fact that the U.S. E.P.A. held that the range used in the draft report was reasonable (Reference 7 in Appendix E), no change has been made for the final report.

More generally, Director Tanguy stated that probability considerations were not given proper weight in the draft report, although he agreed that it is necessary to look carefully at consequence mitigation. In response, we repeat what is stated in the report, namely that we believe there has been an imbalance between attention paid to accident prevention and consequence mitigation. It is our hope that our report has helped to redress the balance.

5. F. R. Farmer, United Kingdom Atomic Energy Authority. In a letter to Jan Beyea dated October 9, 1979, F. R. Farmer commented that the land areas considered contaminated in the report might still be used for special purposes.

6. Samuel C. Morris, Biomedical and Environmental Assessment Division, U.S. Brookhaven National Laboratory. In a letter to Jan Beyea, dated November 15, 1979, Samuel Morris criticized the significance which was attached in the report to consequences occurring far from the hypothetical releases. Although agreeing with the consequence numbers, he criticized their significance as far as motivating action beyond 50 miles. Although we do not agree with his philosophy, we reprint a section of his letter because it articulately reflects a view held by many.

"In Table II, page 16, and in the text you do a good job of explaining how, although the absolute magnitude of the effects beyond 50 miles are large, the individual risk to any exposed person is small. You do not follow through, however, in examining the difference in action which would result from pursuing these two ways of looking at the problem. When one looks at total effects it's clear those beyond 50 miles are bigger and this would lead one to emphasize these effects in any mitigation strategy, the conclusion you draw. In looking at individual risk levels, however, one might ask how much would you, living in Princeton, be willing to pay to avoid an increase in the probability of an early death of 1/1,000 of 1%? How much less than that would you be willing to pay if that risk were not a certainty but would be imposed on you only in the event of a very unlikely accident. I suspect that if they were not told the cause was nuclear power most people would be willing to pay little or nothing. Certainly anyone willing to pay a substantial amount to avoid such a small risk would have long since gone broke at the expense of avoiding thousands of similar things posing risks of this magnitude. I suspect that this approach would lead one to put much less emphasis on the effects beyond 50 miles. I don't claim that the latter approach is the proper one but I do believe that as a criteria for decision, it deserves consideration.

In response to this criticism we have added for the final report material on the cost of stockpiling thyroid-blocking medicine (the major mitigating strategy we recommend) which we calculate to be 10 cents per year per person. With this economic information, the reader can make his or her own judgement on the wisdom of attending to consequences beyond 50 miles from a reactor accident.

7. Bent Sørenson, Niels Bohr Institute, Denmark (now at Roskilde University). In a letter to Jan Beyea, dated October 6, 1979, Bent Sørenson criticized the lack of attention given in the draft report to alternatives less risky than coal, oil and nuclear power, e.g., improved energy efficiency and renewable energy sources. Although we do not feel it is appropriate in this report to go into a detailed discussion of non-traditional energy alternatives and their merits, we have added a statement to the effect that problems with coal, nuclear and oil should serve as motivation towards development of such alternatives.

8. Oddvar Nygaard, U.S. National Cancer Institute, National Institute of Health. A number of helpful requests for clarification were made in a phone conversation with Jan Beyea in the Spring of 1980. Oddvar Nygaard also suggested that the report include a statement that most experts considered the linear hypothesis to be an overestimate of the risk. We do not consider such a statement appropriate in light of the fact that the majority of expert views are effectively contained in the range of cancer/dose risk coefficients used in the report.

APPENDIX H

A Preliminary Investigation of Some Alternative Event Sequences which Could Have Led, without a Meltdown, to Intermediate Scale Releases of Radioiodine and Radiocesium at TMI Unit No. 2

In this appendix event sequences are analyzed which might have led at T.M.I. to a significant release of radioiodine and radiocesium without the accident proceeding to a full core meltdown. (Discussions with Gregory Minor of MHB Associates, Palo Alto, California, have been helpful in developing these accident sequences.)

It appears that any releases from the accident sequences we have been able to devise would be considerably lower than postulated in the PWR 2 meltdown accident described in the Reactor Safety Study--i.e., the release used in this report to illustrate the long-term consequences of hypothetical "worst case" releases. Thus, at most, the accident sequences described in this appendix are expected to lead to intermediate scale releases.

Mechanisms for releasing radioactivity into the air.

The TMI Unit No. 2 accident led to the escape into the containment of approximately 25 percent of the core inventory of radioiodines and between 36 and 51 percent of the core inventory of radiocesium.[H1] Since most direct pathways of the containment appear to have been blocked by liquid,* most of the escaping radioactivity (except for the noble gases) probably entered into solution before leaving the reactor vessel or associated plumbing.

The possibility that alternative event sequences could have resulted in the creation of a direct pathway to the containment for the radioactive gases released from the core is discussed below. First, however we consider the mechanisms by which radioactivity could become airborne after having entered into solution.

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*For example, the liquid in the Pressurizer or in the Reactor Coolant Drain Tank.

Spray Release

Vaporization of radioactive water would not by itself be sufficient to drive radioiodine and radiocesium into the air. Were radioactive water allowed to boil slowly, under controlled conditions, the dissolved radioactivity would probably remain in solution, leaving the outgoing steam relatively uncontaminated.

However, should a direct leakage path develop in the primary coolant plumbing--one which would allow hot, pressurized coolant to escape into air -- droplets of radioactive water would become airborne. These droplets could remain suspended or they might evaporate leaving their radioactive contents in the air. In either case, radioactivity would be airborne in the containment atmosphere. Failure of the containment building (as discussed in the main text) would lead to an atmospheric release of radioiodine and radiocesium.

For all of the radioactivity in the coolant to have entered the atmosphere, it would be necessary for all of the leaking fluid to have vaporized after ejection from the leak site or be emitted in the form of aerosol-size droplets. This appears to be highly unlikely.

Consequently, only some fraction of the escaping coolant would be available for the droplet-forming process. 20% is the fractional figure used for the intermediate scale accidents discussed in the main text. (Thus, 20 percent of the escaping coolant is assumed to become airborne under the hypothetical conditions considered.)

As has been stated previously, considerable quantities of radioactivity did enter the containment building during the TMI accident, but not necessarily in airborne form. However, a leak in the primary coolant system, such as at the seals of the main reactor cooling pumps, would have directly vented highly radioactive steam and water droplets into the containment. (A leak in such seals has occurred in the past at the Arkansas Unit 1 reactor.) Subsequent failure of the containment could then lead to release of radioactivity into the atmosphere.

Severe vibrations in the cooling pumps did occur during the TMI accident --vibrations capable of damaging the seals and attached piping.[H2] These vibrations were severe enough to cause the operators to shut down all of the main coolant pumps at about two hours into the accident.[H3] (The pumps were actually ineffective in cooling the core at this time.) Had the operators felt it was necessary to leave the reactor cooling pumps on, it is possible that a seal leak would have developed. The fact that the operators tried to restart some of the coolant pumps on a number of subsequent occasions suggests that the initial decision to shut them down was not an inevitable decision.

Direct Paths to the Atmosphere

It appears that a substantial fraction of the radioactivity which escaped from the fuel rods could have escaped directly into the atmosphere as a result of leaks between the primary/secondary cooling system accompanied by a leak between the secondary cooling system and the atmosphere.

The most plausible pathway for such an escape during the actual accident appears to be by way of a leak in one of the steam generators. (The steam generators serve as heat exchangers between the primary and secondary cooling water.)

For such a pathway to develop, two leaks must occur. First, a leak must develop in one or both of the steam generators at the interface between the "primary" system containing the radioactivity and the secondary side. This did not occur at TMI. However, steam generator leaks have occurred at other reactors and the general problem remains an unresolved safety issue.[H4]

Second, in order to provide a path to the atmosphere, a leak must develop in the secondary side of the system--an event which actually did occur at TMI. One steam generator did release steam to the atmosphere from the secondary side. Furthermore, the steam escaping from the top of the reactor was not checked for radioactivity for two hours, so that had a leak actually occurred between the primary and secondary system there definitely would have been, according to the Rogovin Commission, a release to the atmosphere[H5] -- although not necessarily of the magnitude hypothesized for the examples given in the main text. The hypothesized release could occur 1) through a direct gaseous path from the core, 2) as a result of a spray release to the atmosphere of contaminated secondary coolant, or 3) as a combination of both phenomena. The fact that a complex path would be required for the escape of radioactivity suggests that any release would likely be smaller than a full scale release i.e. would constitute an intermediate release.

We have not made estimates of the probability of a leak in the steam generator developing under the actual accident conditions or during alternative sequences of events which might have stressed the steam generators to such a point that large leaks occurred. Any such estimates would be highly uncertain.

Notes and References for Appendix H

H1. Nuclear Regulatory Commission Special Inquiry Group, M. Rogovin, G.T. Frampton, Jr., et al., Three Mile Island, A Report to the Commissioners and to the Public,(Washington, D.C., 1980 Volume II, Table II-57, p. 527.

H2. Ibid, Vol. II, P. 319.

H3. Ibid, Vol. II, P. 323.

H4. Nuclear Regulatory Commission, NRC Program for the Resolution of Generic Issues Related to Nuclear Power, (Washington, D.C., NUREG-0410, 1978, Task A3); also Task Action Plans ~~from~~ for Unresolved Safety Issues Related to Nuclear Power Plants, (Washington, D.C., NUREG-0649, 1980, Tasks A3, A4, A5).

H5. Reference H1, Vol. II, P. 328.