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At the outset, I want to make it clear that I speak as an individual who has been professionally trained and employed in radiation protection for the past twenty-five years. I am a member of Energy Education Exponents ($E^3$) in order to promote the availability of factually accurate information about energy to the public, which I believe is essential to the formation of sensible public policy in this area. Common sense suggests to me that on Long Island we should aim toward a mix of fuels for the generation of electricity, rather than being virtually 100% dependent on oil, and that nuclear power can and should play a central role in achieving this deversification. I start from this position in my advocacy of the granting of a license to LILCO to operate the Shoreham Nuclear Power Station.

My particular expertise has to do with the health risks of radiation, including that associated with nuclear power stations. In recent years, there have been a number of studies of the health risks of the alternative means of generating electricity (     ). Uniformly, they have concluded that the health risks of the nuclear fuel cycle are as low or lowest than those of the practicable alternatives. Whatever criteria are employed for deciding for or against any of the available choices, in my view, neither the overall health risks nor their relative risks are sufficient to warrant selecting or rejecting one solely on a basis of health and safety.

Following the accident three years ago in March 1979 at the Three Mile Island Nuclear Power Station, emergency planning seems to be an aspect which



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has greatly preoccuppied the NRC and which has greatly worried the public. As part of my duties, I am a team captain in the Department of Energy's Radiological Assistance Plan for Region I (covering the northeastern U.S.). I was at Harrisburg within a few hours of the accident and shortly thereafter became responsible for the interpretation of the extensive environmental monitoring data that was obtained during the following several weeks. From this experience I became curious as to why the environmental releases of radioactivity in addition to the noble gasses, were so much smaller that had been anticipated.

Subsequently, I have presented several technical papers on emergency planning at meetings of the American Public Health Association, the American Nuclear Society, the Health Physics Society and a symposium of the International Atomic Energy Agency. These have been based on my direct involvement at TMI and on a careful reading of many of the related authoritative analyses (such as the main report of the President's Commission and the technical background appendices). The most recent, "Emergency Planning for What?", was published in Nuclear News a year ago. I intend to submit it as a backup to the written version of this statement.

The essential argument of this article is that both NRC's current requirements for emergency planning and the public perception of the consequences of ~~the~~ a nuclear accident are excessive and lacking a technical basis ~~based on~~ from actual experience.

Prior to the TMI-2 accident, detailed emergency planning was essentially confined to the Low Population Zone (LPZ), typically a radius of three to so miles from a power reactor. Nothing happened at TMI to warrent the enlargement of this zone. On that occasion, only the radiogasses were released in large quantities. The maximum dose to the most nearby persons was about 100 milli~~curies~~rems (equivalent to the background radiation they might have received by moving to Denver for a year). The average to the population within 50 miles was about 1/100 of this and within the variability of local background throughout the U.S.

Even if all of the available radiogasses were released at one time from a large power reactor such as Shoreham (a most unlikely event, compared to the possibility of a gradual release), the anticipated radiation dose to persons downwind would be insufficient to warrant protective actions beyond the LPZ.

Since the accident at TMI, several scientists have made careful examinations of the release mechanisms at TMI and of a number of previous smaller intentional and unintentional incidents. All of the evidence from experience suggests that the probability of the release of radioiodines or solids is during a water-cooled power reactor accident is appreciably lower than had been assumed heretofor.

In the absence of such releases, there is simply no reason (aside from the current paranoia exposure to radiation, no matter how in[illegible] ) for an emergency response beyond the LPZ. There is even less warrant for evacuation, which in my view is being <u>over-emphasized</u>. If there is a serious malfunction at Shoreham or any other power reactor in the northerly [illegible] of the U.S. where almost all homes have cellars, the first response should be sheltering, which would avert a life-threatening dose from the largest imaginable release of radiogasses.

The current thinking about evacuation with regard to reactor malfunctions seems to me akin to contemplating it to escape from the projected path of a hurricane which it is still hundreds of miles at sea and many hours away, or to escape the possible path of a forest fire which is still many miles distant. In neither case does it seem wise or prudent to adapt a protective strategy which could result in large numbers of persons being on the road at the time the hurricane or fire actually arrives and possibly in its actual path with less protection than they would have had by staying put in their homes, places of business, or schools. The sad experience of persons killed while trying to drive out of the path of tornados should be a lesson in this regard.

In my judgment, there would be little if any technical justification for calling for evacuation until experts in making environmental measurements have made field surveys to ascertain if any deposition of radioiodines or solids have actually occurred. In this extremely unlikely possibility that they are present in sufficient amounts to result in large dose-rates, there would be time to accomplish an orderly removal of those at significant risk.

Immediate sheltering of those close in (within a few miles of a power reactor) on the sounding of an alarm and relocation only after radiation surveys (if at all) is the adopted protective strategy of almost every country, with light water power reactor programs, (such as France, Germany, Switzerland and Japan).

In this instance, our U.S. penchant for "bigger" is not better, but in fact could put large numbers of persons at unnecessary risk.

# Emergency preparedness for what? (Implications of the TMI-2 accident)

**by Andrew P. Hull**

The possibility of a major accident at a large nuclear power plant was recognized at the outset of the commercial implementation of nuclear power in the United States in 1957. A study of the theoretical possibilities of such an accident and of the consequences of various accident cases, with or without large uncontrolled releases of fission products to the environment, was initiated by the U.S. Atomic Energy Commission at that time.[1] For the worst postulated case—the release to the atmosphere, under the most adverse meteorological conditions, of 50 percent of the core inventory of fission products—the study envisaged the necessity of the evacuation of as many as 460 000 persons from an area of 760 square miles.

Prior to the accident at Unit 2 of the Three Mile Island station on March 28, 1979, however, formal planning for protective actions (including evacuation) was generally not required beyond the low-population zone (LPZ). The LPZ is the area beyond the site boundary within which, during the first 2 hours following the onset of a design-basis accident, an individual would not receive a whole-body radiation dose of more than 25 rem or not more than 300 rem to the thyroid due to exposure to or inhalation of constituents of the radioactive plume.[2] Some potential offsite doses due to several postulated incidents, including the maximum design-basis accident, are shown in Table I. They are based on leakage from the containment at the peak pressure.[3] The LPZ is further defined as an area containing "residents, the total number and density of which are such that there is a reasonable probability that appropriate protective measures can be taken on their behalf in the event of a serious accident."[4] Prior to the TMI accident, the NRC staff had adopted a position that a distance of 3 miles to the outer boundary of the LPZ was usually adequate.[5]

A more sophisticated assessment of power reactor accident risks than that contained in the 1957 study was published by the U.S. Nuclear Regulatory Commission in 1975.[6] This assessment adopted an evacuation model for a series of postulated reactor malfunctions, the area of which included a 360-degree circle out to a radius of 5 miles, and a 45-degree sector out to 25 miles in the downwind direction. As shown in Fig. 1, even a very slow effective evacuation speed of 1.2 mph was expected to materially reduce the probability of early fatalities for the most severe postulated releases from a pressurized water reactor (PWR). As also indicated, more rapid effective speeds were expected to reduce this probability to near zero.

As a result, at least in part, of concerns raised by this assessment, an ad hoc task force of the Conference of Radiation Control Program Directors passed a resolution in 1976 asking the NRC to make a determination of the most severe accident basis for which radiological response plans should be developed by offsite agencies.[7] A task force consisting of NRC and Environmental Protection Agency representatives was convened to address this request and related issues. It prepared a report, published in 1978,[8] on the planning basis for the development of state and local

TABLE I

POTENTIAL OFFSITE DOSES DUE TO DESIGN-BASIS ACCIDENTS (CONSERVATIVE CASE)[2]

| | Two-Hour Exclusion Boundary (3200 feet) | | Duration of Accident Low Population Zone (4 Miles) | |
|---|---|---|---|---|
| Accident | Thyroid (Rem) | Whole Body (Rem) | Thyroid (Rem) | Whole Body (Rem) |
| Loss of Coolant | 155 | 3 | 81 | 3 |
| Control Rod Ejection | <1 | <1 | <1 | <1 |
| Fuel Handling | 2 | 2 | <1 | <1 |
| Steam Line Break | 16 | 1 | 3 | 1 |
| 10CFR100 Dose Guideline | 300 | 25 | 300 | 25 |

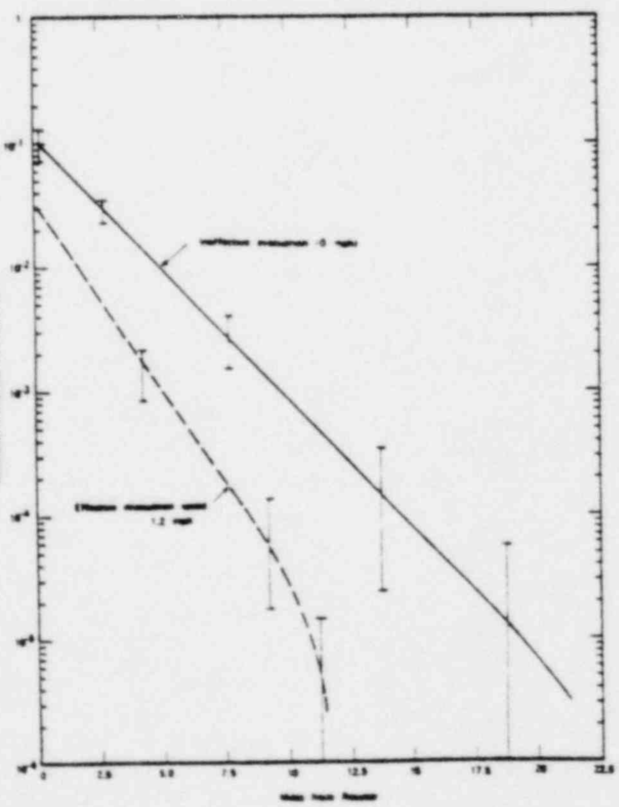

Fig. 1: Conditional probability of early death as a function of distance from reactor

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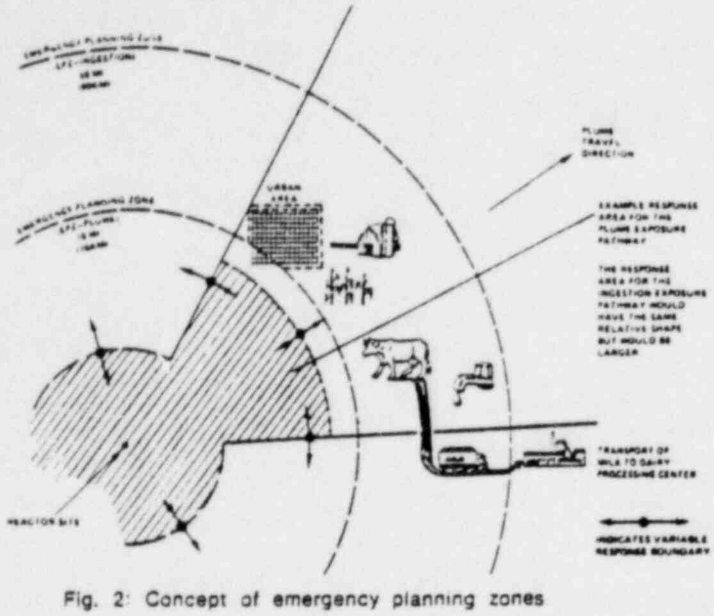

Fig. 2: Concept of emergency planning zones

government emergency response plans. In it the task force concluded that "[t]he objective of emergency response plans should be to provide dose savings for a spectrum of accidents that could produce off-site doses in excess of the Protective Action Guides." These guides were 5 rem whole-body dose and 10 rem thyroid.[9]

The NRC-EPA task force recommended that emergency planning zones (EPZs) be defined around each nuclear reactor, both for the short-term "plume exposure pathway" and for the longer term "ingestion exposure pathway." As shown in Fig. 2, these had, respectively, radii of 10 and 50 miles. The task force suggested that within the plume exposure EPZ, "shelter and/or evacuation would likely be the immediate protective actions recommended for the general public."

Reference was made to studies[10] that indicated that if such actions were taken within about 10 miles of a nuclear power reactor, there could be significant savings of early injuries and deaths following even the most severe atmospheric releases. From these studies, the task force concluded that evacuation appeared to be more effective than sheltering in reducing the number of early health effects within 5 miles of a reactor, as long as the delay time and the nonparticipating segment of the population were kept sufficiently small. Between 5 and 10 miles, this distinction was not so apparent, especially for an "atmospheric" (core melt followed by catastrophic failure of containment) incident. For areas beyond 10 miles, there was little apparent distinction between the benefits of sheltering and evacuation in terms of projected early fatalities or injuries.

It is interesting to note, in the current post-TMI emergency planning climate, that in its report the NRC-EPA task force also stated: "The EPZ guidance does not change the requirements for emergency planning, it only sets bounds on the planning problem. The Task Force does not recommend that massive emergency preparedness programs be established around all nuclear power stations."

The task force noted in this connection that some capabilities already existed under the general emergency plans of federal and state agencies.

A notice of the availability of the report of the task force and a request for public comment was published in the *Federal Register* on December 15, 1978 (42 FR 58658). The indicated deadline for such comments was March 30, 1979—two days after the TMI-2 accident.

## Evacuation: was it technically justified?

The sequence of events during the first hours, days, and even weeks after the initiating event at TMI-2 at 4 a.m. March 28, 1979, has been set forth in detail in several in-depth reviews.[11-13] From their accounts, as well as from the author's first-hand involvement,[14] it is evident that the directly concerned radiation protection agency, the Bureau of Radiation Protection of the Commonwealth of Pennsylvania's Department of Environmental Resources (BRP), did not initiate any recommendations for evacuation at any time during the incident.

The legal authority for the proclamation of a state of emergency and for ordering an evacuation belonged to the governor of Pennsylvania. Supposedly, his decision to exercise this authority would have been based on information about the extent of a nuclear accident as supplied by the involved facility, an assessment of its offsite potential by the BRP, and the recommendation of the Pennsylvania secretary of health.[15] As is well known, however, the situation of the reactor was not clearly established for several days, and communications were difficult. The BRP, however, was in continuous contact with the reactor emergency operations center, as well as with the U.S. Department of Energy's offsite environmental surveillance center. At no time did the information supplied *directly* to the BRP by these two centers support the implementation of emergency protective actions.[16]

Starting on Thursday afternoon (March 29), however, remotely located federal agencies began making such recommendations, either directly to Gov. Richard Thornburgh, or through his secretary of health. The first call to the secretary came from the director of the National Institute of Occupational Safety and Health, who suggested that a precautionary evacuation was advisable since it was "not known how to shut down the reactor."[17]

On the basis of a misinterpretation of the location of a helicopter, when a measurement of a radiation level of 1200 mR/h was made in the plume during intentional venting, the NRC Operations Center recommended in mid-morning on Friday, March 30, an evacuation out to 10 miles. This recommendation was headed off at the Governor's office by the BRP, which had more accurate and more current information.[16] Later on in the day, the NRC became concerned about the explosive potential of the "hydrogen bubble" and recommended an evacuation out to 10 miles, which the Governor reduced to an advisory that pregnant women and young children leave the area. According to a study, 21 000 persons within a 5-mile radius and 144 000 persons within 25 miles did evacuate, many prior to the Governor's advisory. The costs of this evacuation have been estimated at $9.8 million.[15] In the months that followed the accident, a review by the Emergency Preparedness and Response Task Force to the President's Commission on the Accident at Three Mile Island indicated that federal officials in several key bureaus and at the White House remained preoccupied for the next few days with evacuation and particularly with the appropriate radius, with proponents arguing variously for 5, 10, and even 20 miles.[17]

Almost from the onset, it was established that the radioactivity that was being released to the atmosphere as a result of the accident did not come directly from the containment building, but rather indirectly from leakage from the coolant letdown system and gaseous waste treatment systems in the auxiliary building.[11-13] From the results of the first post-accident sampling of the primary coolant water on March 29 and of the containment atmosphere on March 31, it appeared that $5.0 \times 10^7$ Ci of xenon-133 (5.3 days half-life), or 41 percent of the core inventory, was present in the containment atmosphere. The total release of Xe-133 from the auxiliary building was estimated by the President's Commission as between $2.4 \times 10^6$ Ci and $13 \times 10^6$ Ci, or 2–10 percent of the core inventory. Other evidence, however, suggests that the actual amount released was closer to the lower estimate.[18,19] The early sampling indicated that $4.4 \times 10^6$ Ci of iodine-131, or 7 percent of the core inventory, was contained in the primary system. A more complete inventory of I-131, as of April 1, was indicated in the report of the President's Commission as follows: primary loop, $7.5 \times 10^6$ Ci; containment building water, $10.6 \times 10^6$ Ci; auxiliary building tanks, $4.0 \times 10^6$ Ci. The total, $22 \times 10^6$ Ci, was 34 percent of the equilibrium core inventory.

The early sampling also indicated that $4.3 \times 10^3$ Ci, or 0.007 percent of the core inventory of I-131 was airborne in the containment atmosphere. The President's Commission indicated that $3.6 \times 10^4$ Ci, or 0.06 percent of the core inventory, was airborne, but this appears to have been a typographical error.[20] The early estimates of the amount of I-131 indirectly released to the atmosphere ranged from 8 to 13 Ci. The President's Commission indicated that 13–17 Ci were released to the atmosphere through the next month.

The integrated external dose from the released radiogases to the population within 50 miles has been estimated variously from 50 to 5000 person-rem, with a most probable value of about 2000 person-rem.[18,19] Ground-level isodose contours, which were derived from DOE helicopter-based measurements of dose rates in the plume centerline, are shown in Fig. 3. For purposes of comparison, the total doses for the same period, as measured by the utility's thermoluminescent dosimeters (TLD) at several locations established long before the accident, are also shown. The maximum estimated dose to the most nearby individuals, located about 0.5 miles east of TMI-2, was less than 100 mrem. A child located close to the TMI boundary would have received an estimated inhalation dose to the thyroid of 2–3 mrem resulting from the releases of the 8–13 Ci of I-131.

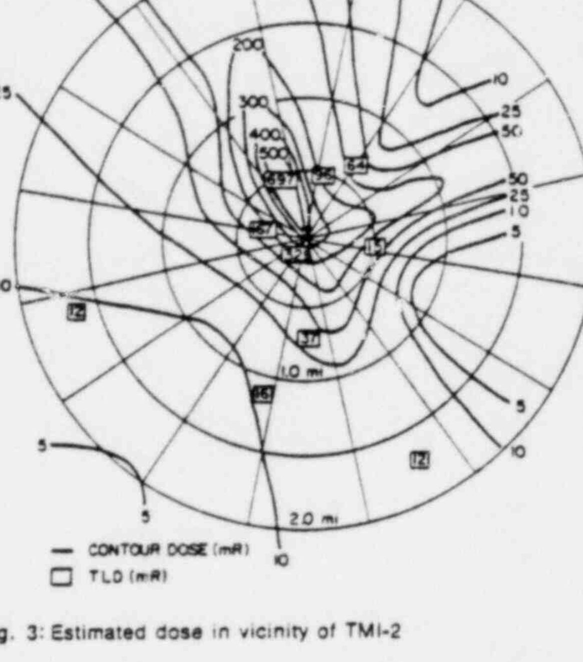


Fig. 3: Estimated dose in vicinity of TMI-2

## What if?

The initial sampling showed that a large fraction of the core inventory of radiogases had been released from the fuel and had become airborne in the containment, and that a somewhat smaller fraction of the radioiodines appeared to have been released into the primary coolant, and only a small amount of this release was airborne in the containment. A tabulation showing the amounts of some of the principal nuclides of radiological concern that escaped from the fuel to the primary coolant and that subsequently migrated to the containment and to the auxiliary building is shown in Table II. The estimated amounts released to the atmosphere during the incident, normalized to March 29,

TABLE II

DISTRIBUTION OF XE-131, XE-137, I-131, CS-137, AND SR-90 AT TMI-2

(NORMALIZED TO 0400 HOURS, MARCH 29, 1979, EXCEPT FOR I-131 TO APRIL 4, 1979)

| | Core Inventory (Ci) | Primary System (Ci) | Contaminated Water (Ci) | Contaminated Air (Ci) | Auxiliary Building (Ci) | | Ref |
|---|---|---|---|---|---|---|---|
| | | | | | Water | Air | |
| Xe-131 | $4.1 \times 10^5$ | ? | ? | $2.5 \times 10^5$ | ? | $3.4 \times 10^4$ | 21 |
| Xe-133 | $1.45 \times 10^8$ | ? | ? | $8.73 \times 10^7$ | ? | $1.19 \times 10^7$* | 21 |
| I-131 | $6.38 \times 10^7$ | $0.75 \times 10^7$ | $1.06 \times 10^7$ | $4.3 \times 10^3$ | $0.4 \times 10^7$ | 140** | 12 |
| Cs-137 | $8.45 \times 10^5$ | $1.31 \times 10^5$ | $3.65 \times 10^5$ | – | $0.11 \times 10^5$ | – | 21 |
| Sr-90 | $7.8 \times 10^5$ | $<1.4 \times 10^4$ | $<4.2 \times 10^2$ | – | $<0.1 \times 10^2$ | – | 21 |

*Eventually released as $8.3 \times 10^6$ Ci (Ref. 21). Lower estimates of Xe-133 released include $2.4 \times 10^6$ Ci (Ref. 18) and $2.9 \times 10^6$ Ci (Ref. 19).

**Includes estimated 125 Ci retained on filter and 15 Ci released from stack.

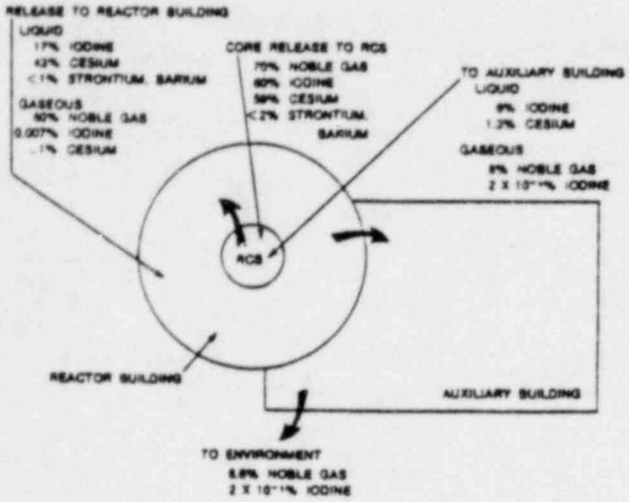


Fig. 4: Release fractions at TMI-2

1979, are also indicated. The principal source of these data is Bishop *et al*,[21] except for I-131, which is from the report of the President's Commission.[12] By comparison of the relative amounts of I-131 and cesium-137 in the primary coolant and the fraction of the latter that was released from the fuel, Bishop *et al* estimated that about 60 percent of the radioiodines were also released from the fuel. Much of the remainder, above that accounted for in the primary coolant and leakage, is believed to have settled into the containment building sump.[22] The fractions of the core inventory of these nuclides that were released to the reactor coolant system, to the reactor building, to the auxiliary building, and to the environment are depicted in Fig. 4.

As is apparent, in terms of the amounts and kinds of radioactivity actually released to the atmosphere and the resultant radiation dose to the nearby population, the TMI-2 accident was a relatively inconsequential event. However, there was a widespread concern about public safety especially in connection with the "hydrogen bubble" scare, which was based not so much on the actual amounts of activity released as on the perceived potential for much larger airborne releases in the event of a breach of the containment.

An elementary evaluation of the potential dose from the release of airborne activity due to the failure of the containment may be made simply by scaling from what did take place. If the release of 9 percent of the core inventory of Xe-133 produced a dose of approximately 100 mrem at the nearest occupied location offsite (about 0.5 mile east of TMI-2—see Fig. 3), then the release of the 60 percent that was airborne in the containment (see Fig. 4) would have resulted in a dose of about 700 mrem. This projection is based on the estimates by Bishop *et al* that the equivalent of $11.9 \times 10^6$ Ci of Xe-133 (adjusted for decay) was actually released. If a lower release estimate of $2.5 \times 10^6$ Ci is used, then the projected boundary dose would be about five times greater.

The above estimate implicitly assumes that the average meteorological dispersion during a week or so after the accident would have been applicable to a shorter time period. A more conservative estimate may be made by taking into account that about 70 percent of the total, or about $1.75 \times 10^6$ Ci of Xe-133 (using the lower estimate), was released during the first 36 hours after the accident,[23] and that a potential boundary dose of some 500 mrem, as measured on an essentially unoccupied island 0.6 mile to the northwest of TMI-2 (see Fig. 3), was delivered during this same period. With the use of these data, a boundary dose at that location of about 25 rem can be projected if the entire $8.7 \times 10^7$ Ci of Xe-133 that was airborne in the containment had been released during this same period. This estimate may neglect some portion of the shorter-lived noble gases, such as Xe-135 (9.1 hr) and Kr-88 (2.8 hr), which could have been significant contributors to environmental dose within the first day after the accident. Considering these and supposing that the containment failed during the afternoon of March 28, one could arrive at a projected boundary dose as much as five times greater than that projected solely on the basis of Xe-133.

In any event, this suggests that *only* for an accident that resulted in a prompt release of a large fraction of the core inventory of radiogases into the containment, followed very shortly thereafter by its catastrophic failure, would evacuation have been warranted in terms of the potential for exceeding the LPZ external dose limit of 25 rem at the site boundary or close to it. Furthermore, if one assumes that the dose decreased with distance as $(r/ro)^{-1.5}$, the warrant for evacuation under this external dose criterion would probably have been confined to the LPZ. Even for this most extreme case, it does not appear that the upper limit of 5 rem gamma dose for whole-body exposure, as set forth in the currently applicable Protective Action Guide (PAG),[24] could have been exceeded beyond 10 miles from the point of release.

If the previously indicated inhalation dose to the thyroid of a child from the elevated release of 15 Ci of I-131 is scaled up to the total 4300 Ci that was apparently airborne in the containment on March 28, its release would have produced a boundary inhalation dose of approximately 1 rem to this child's thyroid. This does not call for evacuation under the LPZ design limit of 300 rem or even the current upper PAG level of 25 rem. A ground-level release of this amount of I-131, (with the conservative assumption of an $X/Q$ of $10^{-4}$ sec/m$^3$), could have produced an inhalation dose of about 100 rem to the thyroid of a nearby child and could have exceeded the PAG out to about 3 miles.

These simple considerations suggest that the extreme "what if" scenarios that were imagined by the public, by the media, and even by many of the "absentee" TMI crisis managers were based more on imagination than on realism. If there were *a priori* grounds for considering evacuation, they were more on the anticipation of the possibility of a large release of radioiodines than on the potential exposure due to radiogases. Once the small amount of iodine that was actually airborne in the containment had been established and the absence of an explosive potential of the hydrogen bubble was realized—which appears to have come about on Saturday, March 31, or on Sunday, April 1, at the latest—it seems reasonable to have expected that consideration of evacuation would have terminated. The NRC however, never did straightforwardly disavow the threat from the hydrogen bubble, and so the "emergency" psychology it created was slow to dissipate. The Governor's advisory to pregnant women and preschool children was not formally lifted until April 9, two weeks after the incident.[13]

## The current situation: good news and bad news

*Good News.* The President's Commission found that the NRC had erred with regard to the explosive potential of the hydrogen bubble.[12] It also found that had a meltdown occurred, there was "a high probability that the containment building and the hard rock on which it is built would have been able to prevent the escape of a large amount of radioactivity." This finding appears to have been based on the report of the President's Commission's Technical Staff on Alternative Event Sequences.[22]

The technical staff also stated that the high retention of iodine in the primary water was attributable to "the chemical reducing conditions existing in the water near the fuel at the time of the releases of the iodine, to the high pH of the water, to the high chemical activity of iodine and possibly to the presence of silver in the reactor vessel." They also indicated that if all of the zirconium cladding of the fuel had reacted with water and the hydrogen gas so generated had burned or detonated, the containment building would have remained intact. They also concluded that a steam explosion leading to a failure of the containment would have been unlikely. A recent study in Sweden has come to the same conclusion with regard to steam explosions in LWRs.[25] This is the type of accident that was postulated in the *Reactor Safety Study* to lead to the largest atmospheric releases of radioactivity of short duration with minimal warning time.

*Bad News.* The bad news is that these findings of the President's Commission and its technical staff seem to have gone almost entirely unnoticed by the public, by the media, and even by the regulators. Judging by their extent, the requirements being called for by the NRC on the basis of "lessons learned" from the TMI-2 accident seem to call for the erection of a stout fence against the escape of a horse that might slip its tether, but has little likelihood of getting out of its stall and much less than previously surmised of escaping from the barn.

An example is to be found in the NRC's rule on emergency planning,[26] which calls for its considerable augmentation both on- and offsite. Although the rule is intended to assure that "adequate protective measures" can and will be taken in the event of a radiological emergency, evacuation is the only measure that is specifically mentioned. Not only is it thus given prominence, but much of the other required offsite planning appears to be closely related to evacuation—i.e., notification, dissemination of instructions, communications systems, etc.

In the supplementary information to the rule, both as initially proposed and in the final version, the NRC stated that, in the aftermath of the accident at Three Mile Island, "[s]afe siting and engineered features alone do not optimize protection of the public health and safety." It further stated that "[t]he accident showed clearly that the protection provided by siting and engineered safety features must be bolstered by the protective measures during the course of an accident" and also that it "showed clearly that on-site conditions, even if they do not cause significant off-site radiological consequences, will affect the way the various state and local entities react to protect the public from dangers, real or imagined, associated with the accident." In the light of this, the Commission concluded that "the public can be protected within the framework of the Atomic Energy Act only if additional attention is given to emergency response planning."

While the confusion following the accident at Three Mile Island supports the NRC's judgment of the need for additional attention to emergency response planning, it is open to question that the incident "clearly" demonstrated the need for the degree and extent of the protective measures being called for by the Commission. Also, while it clearly demonstrated that the perception of on-site conditions by various state and local entities affected the way they reacted, this is of questionable relevance for a future similar occasion. Should one occur, it is to be hoped that the concerned utility, the NRC, the state radiological and health bureaus, and the Federal Emergency Management Agency have a better coordinated response, in which case the confusion that reigned during the incident should not be replicated. This confusion was a significant contributory factor to the reaction of the state and local agencies to what were largely imagined dangers. Had these agencies responded to the situation in a more coordinated way, the public perception of the seriousness of the TMI accident would very likely have been much diminished. In the author's judgment, this should be one of the most important conclusions from the incident, but it does not yet seem to have been given appropriate emphasis in the "lessons learned."

One of the principal features of the emergency planning rule is the adoption of the NRC-EPA task force recommendation that enlarges the zone for which detailed emergency planning is to be provided. As already indicated, its radius is about 10 miles for the plume-exposed pathway and about 50 miles for the ingestion pathway. In light of the improbability of immediate life-threatening exposures beyond the existing LPZ, the extent of this plume exposure EPZ appears excessive. In effect, it applies the same rigor to the *desirable* objective of the minimization of population dose and the possibility of hypothetical late effects as it applies to an obviously *urgent* objective, the prevention of early fatal effects or illness to nearby persons.

With regard to most other planning for natural or technological catastrophes, the emphasis appears to be on the prevention of imminent fatal effects or injuries. Subtle and/or long-term hypothetical effects (similar to those associated with up to a few rems exposure to radiation) do not appear to warrant emergency "protective" responses. The NRC's emergency planning rule appears to make dose minimization mandatory in all cases, without allowing for consideration of the cost-benefit trade-offs generally applied to low-dose radiation in other situations. In a recent study in which the costs of remedial actions were compared to the monetary value of health effects averted, it was found that even for a release of $10^7$ Ci of I-131 and associated fission products, evacuation would not be cost-effective if extended to include persons exposed to $<10$ rem.[27] Based on the TMI-2 release experience, the use of this criterion would have restricted remedial actions to within the previously accepted LPZ.

## Evacuation: the wrong emphasis?

Of the several modes of potential dose minimization, the new rule appears to give undue emphasis to evacuation. Both the report of the NRC-EPA task force on emergency planning and a related IAEA report[28] suggest that, whereas evacuation may be in many circumstances the most effective close-in mode of protection action, at greater distances from a reactor site it may be less effective than sheltering. The minimization of dose by alternative measures such as the control of ventilation, respiratory protection, or iodine prophylaxis is also considered in these two reports. As both observe, a malfunction could occur during weather conditions when evacuation might be difficult or even impossible. Thus, it seems unwise to condition emergency authorities and the public to think almost exclusively in terms of evacuation as the only available effective or most desirable protective measure in the event of a large airborne release from a power reactor.

In the author's view, reasonable emergency action plans should include a set of preestablished responses, graded according to the probability of the risk, as well as to the severity of the effects that might be incurred. The rule does not do so; rather, it seems to call for the same degree of protective planning for severe events with anticipated likelihoods of 1/20 000–1/100 000 per year[2] as it does for smaller ones that might be expected to happen much more frequently. In the case of flood plains, earthquake severity zones, prospective tornado impact areas, and the like, likelihood of recurrence generally seems to be considered in such planning. In order to achieve a sensible allocation of effort and resources, this factor ought to be considered in the case of emergency planning for nuclear reactor malfunctions.

It is almost self-evident that events with small consequences are more likely than are those with large ones. This raises a serious question about the desirability and/or need for providing the detailed information called for in the rule to the public throughout a 10-mile EPZ on a yearly frequency. The net result may well be to exacerbate the prevailing excessive fear of radiation,[29] and thus to be conducive to precipitate action if and when these minor events do occur. The author believes a more prudent approach would be to assure the public that in the event of an accident they will have information and instruction from an authoritative and informed source, as is the practice with regard to most other potential hazard situations. In this same vein, it may be observed that it is not deemed necessary to provide the public with detailed advance information about meteorology, hydrology, seismology, etc., to lead them to feel that they are being adequately protected against possible natural disasters, let alone with comparable information about the toxicity of specific chemicals that might get abroad in large quantities because of technological failures.

In comparison with emergency planning requirements of other countries, some with larger populations close to power reactors than are found in the United States, the new rule seems excessive and unduly preoccupied with evacuation. In West Germany, Switzerland, and Japan, for example, the recommended initial protective action is sheltering.[30-32] As shown in Fig. 5, in West Germany evacuation is contemplated only after some hours subsequent to the passage of the cloud of radioactive material released during an accident, and then only for persons who might be exposed to more than 25 rem if they remain sheltered. Emergency response, prior to actual measurements of radiation levels, is contemplated only within a radius of 5–8 km (3–5 miles). Beyond this radius, their plans call for a graded response *based on actual measurements* and only if, without countermeasures, the projected dose would exceed the 25-rem "emergency reference levels." The Swiss and Japanese emergency plans are similar in principle.

As is the case in the United States, these plans are based on release estimates that correspond closely to those in the *Reactor Safety Study* (WASH-1400). That these estimates are unduly conservative is suggested not only by the TMI-2 experience, but by recent reviews of past evidence from experiments and incidents by Levenson and Rahn[33] and by Morowitz.[34] A study of the solution chemistry of iodine in containment structures, which also supports this contention, has recently been provided by R. Lemire et al.[35].

## Conclusion

It appears to be generally recognized that almost all of the radioactivity that was released from the fuel during the TMI-2 accident was successfully retained within the con-

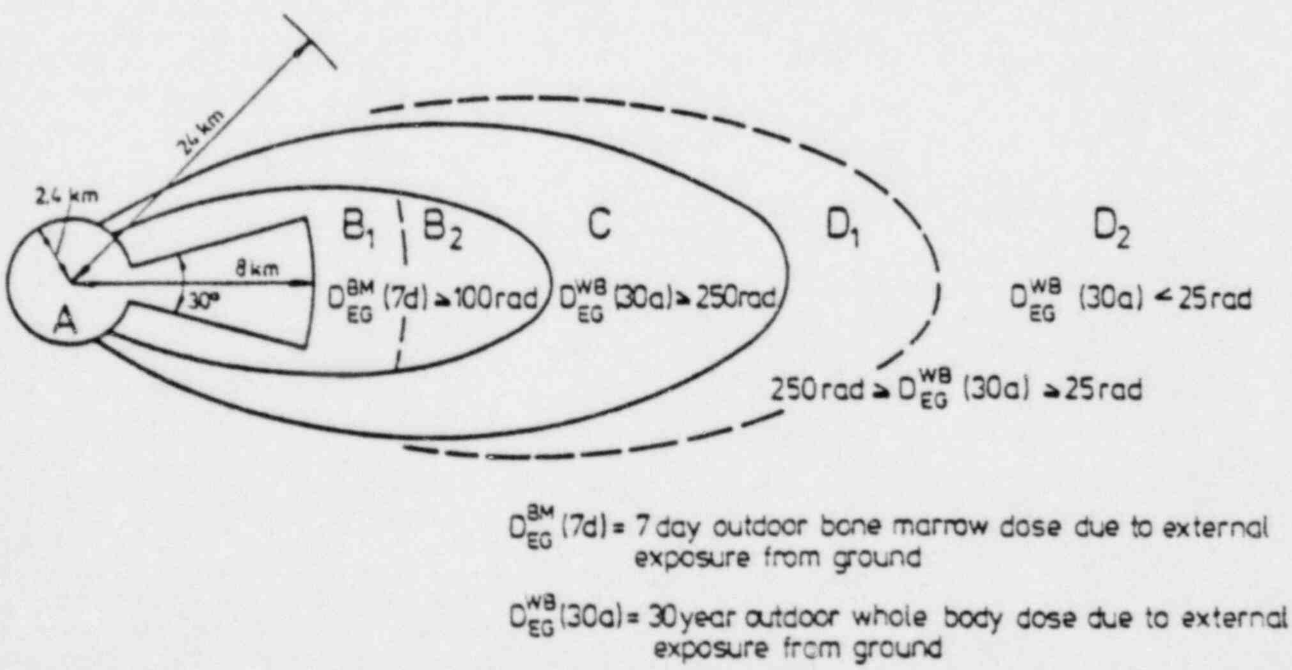


Fig. 5: Schematic of protective actions model. A: Sheltering two hours after operator knows release will occur (t=2h); evacuation at t=8h; travel time, 1.5h. $B_1$: Sheltering at t=2h; fast relocation takes place either two hours after cloud passage or t=14h, whichever is larger; travel time dependent on population. $B_2$: Normal activities; fast relocation as in Area $B_1$. C: Normal activities; relocation begins t=30d. $D_1$: Normal activities; decontamination to reduce $D_{EG}^{WB}$ (30a) to 25 rad. $D_2$: Normal activities.

tainment building and that no more than 10 percent of the fission gases escaped, via the auxiliary building.

It seems to be insufficiently recognized that, except for the fission gases, almost all of the other radioactivity that escaped from the fuel was retained in the coolant system or in the water that leaked from it by essentially *passive* mechanisms. Some of these were suggested by the Technical Staff on Alternative Event Sequences. Additional passive retention mechanisms for the retention of radioiodines and aerosols have recently been indicated in the recent reviews of release data from a number of fuel melt experiments, deliberate tests, and unplanned incidents at operating reactors, with and without containment. These data indicate that except for the radioactive noble gases, the current estimates by the NRC of potential releases of fission products to the environment from power reactor malfunctions are unrealistically conservative, possibly by several orders of magnitude.

This is not to suggest that the TMI-2 accident does not support the desirability of some improvements in emergency response, especially in its planning and organization. But neither TMI nor any other relevant experience appears to support the notion that the potential for airborne releases from a power reactor malfunction is sufficient to warrant the kind and extent of emergency planning that is currently being called for. Rather, it seems an example of regulatory caution that does not necessarily constitute wisdom and that could be potentially counterproductive to the optimum protection of the public as well as of questionable cost-effectiveness in most realistically imaginable situations.

In its review of the TMI-2 accident, the Congressional Subcommittee on Energy Research and Development concluded that the NRC had devoted too much attention to pipe break accidents leading to sudden large loss of coolant and that safety research had focused on the ability of the emergency coolant system to replace these losses.[36] The subcommittee concluded that there is a need for the study of scenarios that develop much more slowly. It also called for additional research in more important areas of small pipe breaks, combinations of circumstances, and human factors. By analogy, the TMI-2 experience strongly suggests the desirability of graded planning for emergencies, with the emphasis on the *more probable* rather than the most extreme cases.

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