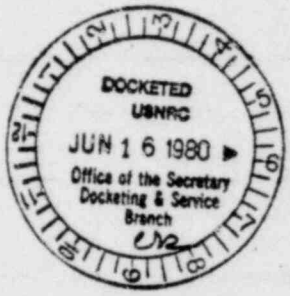
RADIATION EXPOSURE DUE TO VENTING TMI-2

REACTOR BUILDING ATMOSPHERE



A Study Prepared by the Institute for Energy and Environmental Research, Heidelberg,*) Federal Republic of Germany for the Three Mile Island Legal Fund, Washington, D.C.

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Summary

This study analyzes the radiological assessments made by the Metropolitan Edison Company and the U.S. Nuclear Regulatory Commission for the proposed venting of the atmosphere within the TMI-2 reactor building.

Our findings are:

1. Previous discussion of the venting of radioactive gases from TMI-2 has concerned only the noble gas krypton-85. Besides krypton-85, the afmosphere of the reactor building includes a great number of other radionuclides, some of which would be released into the environment during the blow off of the gases. This could lead to radiation exposures significantly higher than those caused by krypton-85. The most important radionuclides, which have not been sufficiently considered so far include:

   C 14, Co 60, Sr 89, Sr 90, Ru 106, Cs 134, Cs 137, Pu 239, Pu 241 and others. Even allowing for high filter efficiency, a model calculation for only three of these nuclides showed that population doses would be high enough to cause about three additional cancer cases and an equivalent amount of genetical damage.

2. Uncertainties inherent in the meteorological models and dose calculations mean that it is impossible to exclude that in the proposed purge program individual skin doses due to krypton-85 could exceed the 10 mrem limit.

3. Estimates of health damage should consider not only regional but also global population doses which are an indication of all health effects caused by the release of radioactivity. Both can be estimated only with great uncertainty. The dose effect relation is subject to wide

scientific discussion. We cannot exclude that venting krypton-85 alone could cause at least one additional cancer case (probably skin cancer) plus one case of genetic damage within the next century. However nothing is known about a potential synergism between krypton-85 beta and ultraviolet radiation.

4. The environmental monitoring program cannot ensure that all significant radiation doses to the community as a result of decontamination of the atmosphere of the TMI-2 reactor building atmosphere will be detected. Most measurements are not frequent enough and are not made at all in some important localities. Important pathways and radionuclides are neglected.

5. As considerable health damage could be caused by venting the atmosphere of the TMI-2 reactor building, we strongly advise against this procedure. The report of the Union of Concerned Scientists concludes that decontamination is not as urgent as stated by Met Ed and NRC. Therefore, we strongly recommend that the alternative methods for decontamination proposed by UCS and Prof. Morgan be used.

1. Introduction

On April 23, 1980, the Institute for Energy and Environmental Research was asked by the Three Miles Island Legal Fund to prepare a study on the community radiation exposure that could be expected if the atmosphere of the TMI-2 reactor was vented.
We did not receive detailed information on the plans of Met Ed and NRC's statements until May 23, and therefore had only limited time to prepare this report.

For this reason we can give only preliminary results and pose questions which should be analyzed in more detail. However, we believe that our study may indicate some aspects of the proposed venting which have not been considered by Met Ed, NRC, and UCS.

2. Radiological Impact of other radionuclides excluding krypton-85

2.1. General situation

Table 1 summarizes the result of the computer run with an ORIGEN program for the present radionuclide inventory at TMI-2. Only nuclides with more than one curie are listed. In their radioecological assessment, Met Ed, NRC, and UCS considered only one of these 71 nuclides to be relevant - krypton-85.

However, because of different volatilities, only a small part of the inventory of most nuclides would be present in the containment atmosphere. Measurements of the containment inventory have been made only by the Met Ed. No independent control measurement was made. Furthermore, in their 1979 re-report Met Ed only listed measurements of 13 nuclides (i.e. Co 58, Co 60, Kr 85, Xe 131m, Xe 133m, Xe 133, Xe 135, Cs 134,

Table 1: Radionuclide Inventory of TMI-2 at July 31, 1980
(activity > 1 Ci)

Nuclide	Half-Life	Inventory (Ci)	Nuclide	Half-Life	Inventory (Ci)
H 3	12.3 a	3 800.	Te 127m	109. d	11 000.
Mn 54	312. d	29 000.	Te 129	1.2 h	62.
Fe 55	2.7 a	29 000.	Te 129m	34.1 d	96.
Co 58	70.8 d	26 000.	Cs 134	2.1 a	220 000.
Fe 59	45. d	4 300.	Cs 135	$2 \cdot 10^6$ a	4.3
Ni 59	75 000. a	70.	Cs 137	30. a	880 000.
Co 60	5.3 a	300 000.	Ba 137m	2.6 m	830 000.
Ni 63	100. a	10 000.	Ce 141	32.5 d	3 500.
Se 79	65 000. a	3.3	Ce 144	284. d	7 700 000.
Kr 85	10.8 a	95 000.	Pr 144	17.3 m	7 700 000.
Sr 89	50.5 d	90 000.	Pr 144m	7.2 m	92 000.
Sr 90	28.1 a	790 000.	Pm 147	2.6 a	2 300 000.
Y 90	2.8 d	790 000.	Pm 148	5.4 d	19.
Y 91	58.8 d	260 000.	Pm 148m	41.3 d	340.
Zr 93	$1.5 \cdot 10^6$ a	17.	Sm 151	87. a	6 700.
Nb 93m	13.6 a	1.2	Eu 152	12.4 a	35.
Nb 95	35. d	1 000 000.	Gd 153	242. d	19.
Nb 95m	3.8 d	3 400.	Eu 154	16. a	12 000.
Zr 95	65.5 d	460 000.	Eu 155	1.8 a	20 000.
Tc 99	210 000. a	120.	Tb 160	72.1 d	11.
Ru 103	39.5 d	13 000.	Th 231	25.6 h	3.3
Rh 103m	57. m	11 000.	Pa 233	27. d	1.
Rh 106	30. s	1 300 000.	Th 234	24.1 d	18.
Ru 106	1. a	1 300 000.	U 235	$7 \cdot 10^8$ a	3.3
Ag 110	25. s	14.	U 236	$2.3 \cdot 10^7$ a	4.1
Ag 110m	250. d	1 000.	Np 237	$2.1 \cdot 10^6$ a	1.
Cd 113m	13.6 a	110.	U 237	6.8 d	2.3
Cd 115m	43. d	12.	Pu 238	87.8 d	1 000.
Sn 119m	245. d	290.	U 238	$4.5 \cdot 10^9$ a	18.
Sn 123	129. d	3 300.	Pu 239	24 390. a	7 900.
Sb 124	60.3 d	10.	Pu 240	6 537. a	2 200.
Sb 125	2.7 a	42 000.	Am 241	433. a	220.
Te 125m	58. d	10 000.	Pu 241	14.9 d	95 000.
Sb 126m	19. m	3.	Cm 242	163. d	120.
Sn 126	100 000. a	3.	Cm 244	18.1 a	3.3
Te 127	9.4 h	11 000.			

Note: uncertainty of values ± 20 %, in some cases up to a factor of 10

Cs 136, Cs 137, Ba 140 and La 140). In the 1980 report (Met Ed, 1980) additional values for gross beta activity are given. A rough extrapolation is made for I 129. In addition, NRC gives a value for tritium concentration. Also, some measurements of strontium-89/90 activities exist. 63 of the 71 nuclides in table 1 are neglected by Met Ed and NRC, although they focused attention on other nuclides (e.g. I 131, Xe 133 and others) with such a low activity as to be indeed irrelevant.

Met Ed's measurements of radionuclide contentration in the reactor atmosphere vary by up to seven orders of magnitude. According to table 2-1 in (Met Ed, 1979), within 5 days (from June 21, 1979 to June 26, 1979) air concentrations

of cobalt 60 increased by a factor of ~46 000 000 and

of cesium 137 increased by a factor of ~ 1 500 000.

The last reported measurements of september 26, 1979 showed smaller values than those from June 26, 1979, but as can be seen from the data of gross beta analysis (Met Ed, 1980) during the month of November and December, a considerable rise of airborne concentrations was reported. Either the atmospheric concentrations are constantly changing or the results are not reproducable for other reasons. In any event the worst possible case should be considered. We have doubts that the "best estimate" provided by Met Ed describes the actual state and can be relied on as representing conditions during venting. There is a risk that during the venting particulates from the walls and floors could volatilize and thus lead to a rise in reactor air concentrations.
If, for example, maximum values for airborne activity as shown in table 2-1 (Met Ed, 1979) existed during venting, the total inventory of airborne Cs 137 and Co 60 could be about 790 Ci and 45 Ci respectively. Even with the assumed filter efficiency of 99 % (instead of Met Ed's 90 % estimate) 7.9 Ci of Cs 137 and 0.45 Ci of Co 60 would be released.

Potential radiation exposures of radionuclides excluding krypton-85 are discussed in section 2.2. We conclude here that it is essential to measure the amount of each radionuclide present in the reactor atmosphere and to estimate the potential release rate during venting the range of associated uncertainty.

2.2. Potential radiation exposures

The relevance of the above considerations is clear from our estimate of the potential health effects of a release of selected radionuclides. We present our results in table 2. Individual radiation doses (50 year commitment) were calculated for three nuclides (Cs 134, Cs 137, and Co 60), assuming moderate atmospheric dispersion ($\chi = 1 \times 10^{-6}$ sec/m³) and a deposition velocity of 1.3×10^{-2} m/sec. We assumed that persons would take only half of their food from the area of maximum concentration. Calculations were made according to default values in the German Federal Regulation Guide (BMI, 1979) except the dose conversion factors which are taken from BRULAND et al. (1978 and 1979).
Radiation exposures from other radionuclides and by other exposure pathways (such as inhalation, ground exposure etc.) were not considered. The calculated ingestion dose to whole body of 530 mrem and to kidney of 7 500 mrem is considerably higher than NRC's limits for public radiation exposures.

In our considerations of all health effects, we estimated population doses which would be of the order of 2 800 man-rem, about 30 times the whole body population dose by krypton-85. Assuming the incidence of one cancer case per 1 000 man-rem (SCHMITZ-FEUERHAKE et al., 1979), three additional cancer cases could result from the release of the three radionuclides considered. In addition, an equivalent amount of genetic damage is estimated.

A further problem is represented by the radionuclide carbon-14, presumably present in TMI-2 to the order of a few curies in gas form. Because of its very long half-life

Table 2: Potential Radiation Exposure by Radionuclides other than krypton-85

Nuclide	Total Inventory at July 31, 1980	Maximum Inventory in Reactor Atmosphere[a]	Release[b]	50 Year Individual Dose Commitment[c] (mrem) whole body	critical organ	Collective Dose[d] to Whole Body (man-rem)
Co 60	300 000 Ci	45 Ci	0.45 Ci	8	34 (liver)	160
Cs 134	220 000 Ci	200 Ci	2. Ci	130	1 400 (kidney)	420
Cs 137	880 000 Ci	790 Ci	7.9 Ci	390	6 100 (kidney)	2 200
			Total	530	—	2 800

a) calculated from table 2-1 in (Met Ed, 1979); maximum values for Co 60 and Cs 137; concentration for Cs 134 corrected, as Met Ed values are inconsistent

b) filter efficiency of 99% assumed

c) see text

d) estimated from UNSCEAR (1977) assuming a region with population density of 200 km^{-2} (e.g. sector ENE at TMI) correction factor of 2 for varying of radioecological parameters from the mean value of UNSCEAR

(5 730 years), it will cause considerable population doses although individual doses in the vicinity of the release will be small. One Ci of carbon-14 would lead to population doses of 400 to 590 man-rem, when integrated over the whole decay period (KILLOUGH and ROHWER, 1978). Compared with the whole body population dose due to krypton-85, release of only one Ci of carbon-14 would lead to doses and hence to health effects five times greater. The radionuclides considered by us to be most relevant for individual and collective doses include C 14, Co 60, Sr 89, Sr 90, Ru 106, Cs 134, Cs 137, Pu 239, Pu 241 and others. Detailed investigations are necessary.

3. Radiological impacts by krypton venting

Met Ed is planning to release about 57 000 curies of radioactive krypton-85 into the atmosphere to decontaminate TMI-2 reactor building. Met Ed proposes to vent and flush the reactor building through a 160-foot vent pipe over a period of five to 50 days.

3.1. Individual doses

To stay within NRC's regulatory limits of 10 CFR 50, Appendix I, noble gas skin doses should not exceed 15 mrem. Since NRC anticipates additional radiation exposures in the course of this year they propose a limit of 10 mrem.
We agree with Met Ed and NRC that the skin dose due to krypton-85 is the most relevant dose contribution to the individual.

Met Ed plans to release radioactivity from the plant stack under favourable meteorological donditions. Since these conditions are calculated by a computer, attention must be payed to the input data.
The calculated radiation dose depends linearely on the meteorological dispersion factor used.
Met Ed did not indicate the source of their data from which

the meteorological dispersion factor χ is computed in dependence of stability classes, wind speed and release height. However, it is clear that the data set used by Met Ed is not the only one available. Figure 1 shows the variation of meteorological dispersion as a function of the distance for a special weather situation and for certain distance from the emission source. When comparing the data sets from five different authors, we find a factor higher than 100 for χ at 1 000 m downwind. For other meteorological situations, a smaller variation is found. Since each data set presents mean values originally derived from several measurements, there is an additional uncertainty of up to one order of magnitude. Therefore, the question of data sets is in fact highly relevant to whether or not Met Ed only releases under favourable weather conditions. We found that under all weather conditions Met Ed calculations may underestimate actual doses up to more than one order of magnitude.

The meteorological program proposed by Met Ed should ensure that environmental doses do not exceed the 10 mrem-limit skin dose. They do not , however, take the uncertainties described into account.

Secondly, variations in dose factor calculations are ignored by NRC and Met Ed. The skin dose immersion factor is given by NRC and Met Ed as 4.3×10^{-2} (rem x m^3 x Ci^{-1} x sec^{-1}).

NCRP report no. 44 (NCRP, 1975) gives a summary of dose factor calculations by different authors. The results depend on the assumed skin layer thickness. The report's estimate is a value of 5.7×10^{-2} (rem x m^3 x Ci^{-1} x sec^{-1}), about one third higher than NRC's value.

Whole body dose factors also vary by more than 100 %, but since the gamma radiation of krypton-85 is low, whole body dose is less important than skin dose.

Compared to the uncertainty due to the meteorological cal-

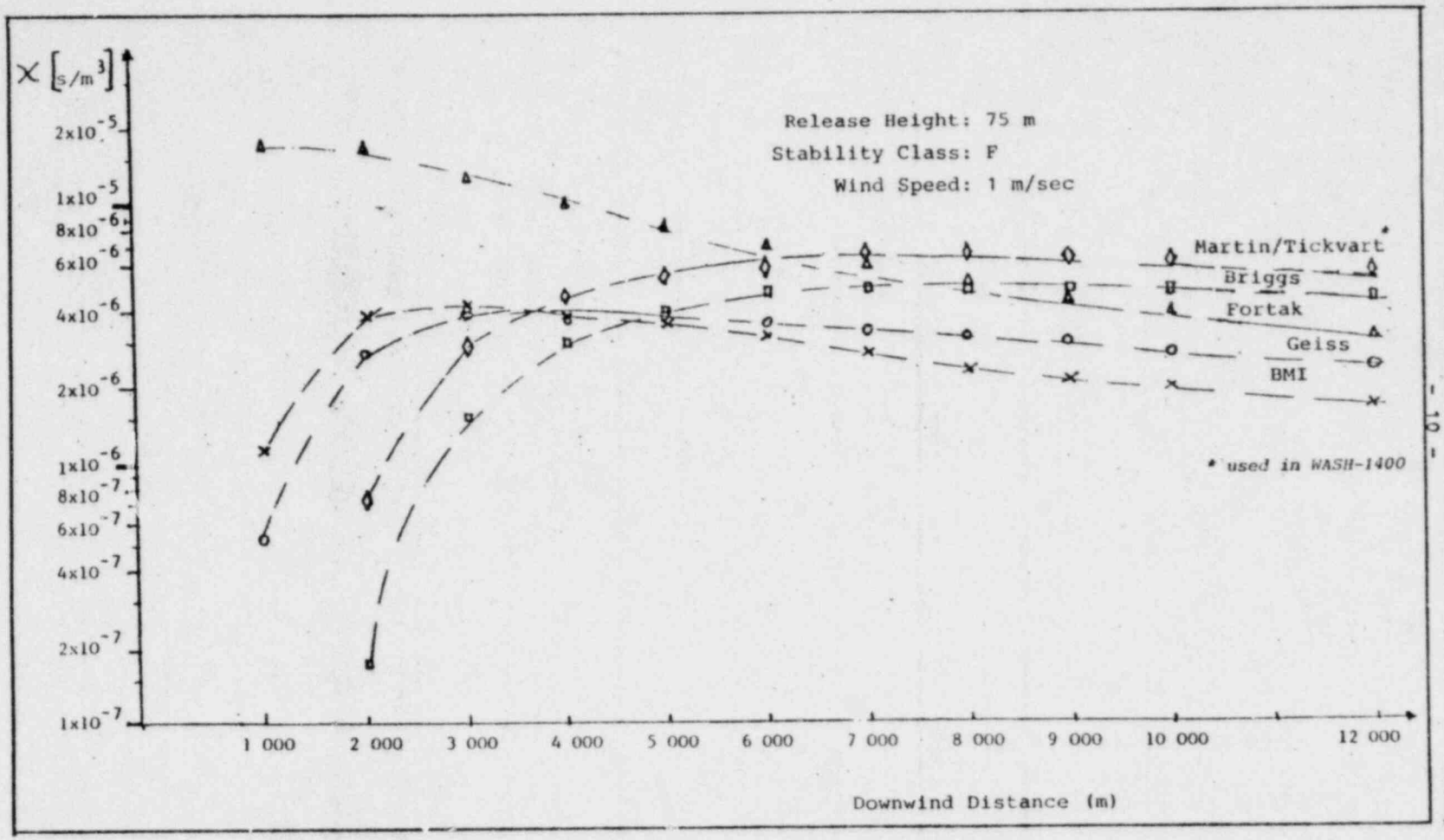

Figure 1: Comparison of Atmospheric Dispersion Factor Calculated with Data Sets from Different Authors

(from: Bussian et al., 1980)

culations, the uncertainty due to the dose conversion factor is of minor importance.

Assuming a release of all Kr 85 during unfavourable meteorological conditions (wind speed of 0.5 m/sec, stability class D), maximum skin doses could reach 320 mrem at a distance of 0.5 miles from the stack. In fact, these doses are too low to cause direct health effects such as radiation erythema. As we will point out in section 3.3., the risk of skin cancer induction will rise statistically.

A more extensive investigation is necessary to eliminate these uncertainties and to give precise information about combination of meteorological parameters, under which beta skin doses of more than 10 mrem could be eliminated with low probability of error. With the present meteorological models and dose calculations, there are considerable doubts that the proposed venting program can exclude the possibility of individual skin doses due to Kr 85 exceeding the 10 mrem limit.

A solution of the problem of reducing the individual doses could be venting by a tethered balloon as suggested by UCS. Or, secondly, all persons could be evacuated from the vicinity of the plant during the release. A third solution would be not to release krypton into the atmosphere at all, but to use alternative methods of decontamination.

3.2. Collective doses

For health effects estimates, the most relevant parameter is not the individual, but the collective dose, which is the sum of all individual doses (unit: man-rem). Whereas individual doses can be reduced by elevation of the stack, the collective dose will remain the same. Assuming a linear dose-response relation, collective doses are proportional to the total health effects caused by the emission.

NRC made no man-rem calculation. Met Ed has calculated population dose within 50 miles from the reactor site, leading to whole body doses of about 1 man-rem. As this value corresponds to whole body dose, the value for collective skin dose will be about 100 man-rem within that distance. After meteorological dispersion, krypton-85 will be found beyond a 50-mile radius, since it has a half-life of 10.7 years. It will distribute globally and will cause a radiation dose over several decades. The integrated collective dose will reach its maximum after about 70 years when most Kr 85 will have decayed. This means that when in 1980, Kr 85 is released, it will still contribute to radiation doses up to the year 2050.

The global collective doses caused by the release of 57,000 curies of Kr 85 can only be roughly estimated. Using a simplified model of global dispersion, the collective dose commitment would be in the order of *)

100 man-rem whole body dose and
10 000 man-rem skin dose.

3.3 Potential health effects

Little is known about the dose-response relation of krypton radiation, especially about radiation induced skin cancers. According to the epidemiological studies summarized in the UNSCEAR report, there is strong evidence that even low radiation doses can induce skin cancers (UNSCEAR, 1977). Numerical risk values are very uncertain, as UNSCEAR states:

"No good estimate is available for skin cancer induction, but the induction of fatal cancers of skin appears also to be low."

The UNSCEAR risk values derived from three different references do not seem to describe the situation of skin exposure by Kr 85 adequately, since body areas exposed and other circumstances vary widely.

*) see e.g. NCRP (1975) and UNSCEAR (1977)

According to BEIR report, the absence of further data limits the accurancy of the estimates (BEIR, 1972).

The NCRP report on krypton gives no numerical estimates but points out possible interactions between ionizing and ultraviolet radiation. UV causes skin cancers. This may be a synergistic effect, meaning that small exposures to Kr 85 radiation in combination with UV would have the same effect as a high increase in UV exposure. The NCRP report concludes:

"It is impossible to predict the impact of low-level krypton 85 exposures on the induction of skin cancer by ultraviolet radiation in the absence of direct evidence." (NCRP, 1972)

These uncertainties mean that the possibility that the 10 000 man-rem collective dose to the skin may lead to one additional skin cancer case cannot be excluded.

Many estimates have been made of the relation of whole body radiation exposures and they have been the subject of intense scientific discussion. ICRP estimates one fatal cancer per 10 000 man-rem, or that 100 man-rem whole body radiation would lead to 0.01 fatal cancers. Evidently, ICRP's estimates are at the lower range of values. According to SCHMITZ-FEUERHAKE et al. (1979), incidence for all cancers and leukemia is of the order of 0.3 - 1.5 per 1 000 man-rem. MORGAN's conservative interpretation of the results of the Hanford study leads to a maximum value of one additional cancer case per 140 man-rem (MORGAN, 1978).

We therefore conclude, that for the radiation exposure caused by the release of Kr 85, the induction of one additional cancer case (probably skin cancer) cannot be excluded. Genetic effects are also expected and are normally assumed to be as frequent as somatic effects.

In a summary we conclude that

- population dose estimates of krypton 85 release should be made for a wider area than the 50 miles radius around TMI

- the global population dose estimates lead only to approximate figures about which there is a considerable uncertainty
- numerical values of dose-effect relation for skin cancer induction by krypton-85 beta radiation are very uncertain
- no information is available on synergism between krypton 85 beta radiation and UV radiation in induction of skin cancer
- estimates lead to maximum values of one additional cancer case (probably skin cancer) and one case of genetic damage as a result of the planned krypton-85 release at TMI-2.

4. Sensitivity of Radiological Environmental Program

In NUREG-0662, the NRC summarizes the projected radiological measurements. We analyzed the program which will be performed by Met Ed, the Commonwealth of Pennsylvania, the U.S. EPA, the U.S. NRC, and the U.S. DOE and found that important information is lacking in NRC's description of the program. Our critical analysis centers on:

1. the number of locations where measurements are performed
2. the frequency of measurements
3. the detection limits of measurements
4. the importance of "zero-dose" evaluations
5. the completeness of exposure pathways
6. the lack of comprehensiveness in the types of radionuclides considered in the program

Generally speaking, it must be stated that

1. no sensivity analysis is made of whether the location and frequencies of measurements are such that all radiation exposures will be detected. It cannot be concluded that TLD's or dose rate recorders cover the whole area inclu-

ding the maximum exposed place. Measurements on "projected plume touch-down area during the control purge" (NRC) will not ensure that the real touch-down area is measured because of the uncertainties inherent in the meteorological models stated in section 3.1. Although together at least 719 TLD's will be fixed at different locations a considerably smaller number of other types of measurements is projected: e.g. Sr 89/90 analysis of air sampling filters are only planned at 3 locations on a quarterly basis by the "Commonwealth of Pennsylvania" program.

2. The frequency of measurements is inadequate. Many TLD's are measured only monthly or quarterly, gas samples are taken only weekly. Thus, higher dose rates that could occur over small time periods will not be detected.

3. In the description of the monitoring program, NRC indicates the detection limit only in one case. Such information is essential for independent assessment of whether or not the proposed program will ensure all radiation doses. In a study for a Committee of the parliament of the Federal Republic of Germany, the authors analyzed the sensitivity of the official radiation monitoring program in the vicinity of West German nuclear plants. Its results are summarized in table 3. It can be seen, that the unsufficient frequency of measurements and high detection limits allow radiation doses, namely those considerably higher than the stated value of one mrem per year or even higher than the dose limit of 30 mrem per year whole body dose in the F.R.G., to go undetected. A similar study could be made for the TMI monitoring program if more information were available.

4. No indication is given of whether pre-release measurements are taken for a sufficient time to allow "zero"-dose assessment. Variation of daily background external

Table 3: Sensivity of Environmental Monitoring of Radioactivity in the Vicinity of Nuclear Plants (according to standards in West Germany)
from: TEUFEL et al., 1980

Exposure pathway	Detection limit set by Federal Ministry of Interior	Location and Freqency of samples	Potential maximum radiation dose not detected
γ- dose (e.g. ground exposure)	50 mrem/yr	10 TLD's at site boundary; yearly measurement	250 mrem/yr
γ- aerosoles (air)	10 fCi/m³	from the samples taken by the licensee the "independent" institution takes a mix-sample quarterly	26 mrem/yr (whole body) 400 mrem/yr (kidney)
cow's milk (Strontium 90)	0.5 pCi/l	2 samples per year at farm at area max conc., 2 samples at dairy	40 mrem/yr (bone)
cow's milk (γ-nuclides)	0.5 pCi/l	ibid.	12 mrem/yr (liver) by Co 60/Vit B 12) 7 mrem/yr (kidney) by Cs 137
cow's milk (I 131)	0.5 pCi/l	one sample per month at point of max.concentration and dairy	110 mrem/yr (thyroid, infant)
vegetables (Sr 90)	1pCi/kg fresh weight	several samples preferably at area of max.concentration	130 mrem/yr (bone)
vegetables (γ- nuclides)	10 pCi/kg fresh weight	ibid.	20 mrem/yr (kidney) Cs 137

radiation , e.g. due to Rn 222 emanation in soil should be considered to detect additional radiation.

5. Important exposure pathways are not considered. At least samples of soil, plants, dairy products, etc., should be made. Because of the presence of fallout nuclides in these samples, zero measurements are necessary to detect a potential increase. As can be seen from table 3, especially for these pathways, detection limits and the frequency of measurements are very important as considerable doses can remain undetected with the official recommended monitoring program set in the F.R.G. Whole body measurements and urine samples from exposed persons could give additional security.

6. Important radionuclides are difficult to detect, particularly carbon-14, technetium-99 and other α- and β-nuclides. As stated above, β-nuclides will not be sufficiently detected by the proposed program, especially Sr 90, C 14 and Tc 99. Analysis of α-nuclides is also completely lacking.

To sum up, the proposed monitoring program is not satisfactory. Most measurements are not frequent enough and are not made at all in some important localities. Important pathways and nuclides are neglected. No indication is given whether and how frequently zero measurements are made. No analysis is made of the range of uncertainty of the program including detection limits.
Thus, the program cannot ensure that all significant radiation doses to the community as a result of decontamination of the atmosphere of the TMI-2 reactor building will be detected. It seems possible that radiation doses that go beyond official limits can occur without being detected.

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