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Dose to man from a hypothetical loss-of- coolant accident at the Rancho Seco nuclear power plant

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February 1981

Lawrence
Livermore
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Laboratory

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Dose to man from a hypothetical loss-of-coolant accident at the Rancho Seco nuclear power plant

ABSTRACT

At the request of the Sacramento Municipal Utilities District, we used our computer codes, MATHEW and ADPIC, to assess the environmental impact of a loss-of-coolant accident at the Rancho Seco Nuclear Power Plant, about 40 kilometres southeast of Sacramento, California. Meteorological input was selected so that the effluent released by the accident would be transported over the Sacramento metropolitan area.

With the release rates provided by the Sacramento Municipal Utilities District, we calculated the largest total dose for a 24-hour release as 70 rem about one kilometre northwest of the reactor. The largest total dose* in the Sacramento metropolitan area is 780 millirem. Both doses are from iodine-131, via the forage-cow-milk pathway to an infant's thyroid. The largest dose near the nuclear plant can be minimized by replacing contaminated milk and by giving the cows dry feed. To our knowledge, there are no milk cows within the Sacramento metropolitan area.

INTRODUCTION

The Rancho Seco Nuclear Power Plant, located about 40 km southeast of Sacramento, California, was first put on line in 1974 at a power rating of 913 MWe. The reactor is of the pressurized water (PWR) type and provides electric power to the Central Valley grid.

The Rancho Seco plant is operated by the Sacramento Municipal Utilities District (SMUD) in Sacramento. At the request of SMUD, the Atmospheric and Geophysical Sciences Division of the Lawrence Livermore National Laboratory has used its MATHEW/ADPIC computer codes to assess the environmental impact to man, through various pathways, from a loss-of-coolant accident (LOCA) at the Rancho Seco power reactor. SMUD asked that this assessment be made using input winds that would transport reactor effluents over the Sacramento metropolitan area, i.e., winds from the southeast, for up to 24 hours. Prolonged southeast winds occur most frequently during winter in this part of the Central Valley.¹⁻³

The annual frequency of wind direction and the average wind speed observed at Rancho Seco's 10-m meteorological tower from 1974 to 1978 are shown in Table 1. The most frequent wind direction is from the west (almost 12%). Southeast winds occur 8% of the time at an average speed of 3.5 m/s. Figure 1 is a graph of these wind frequencies.

* In this report, dose refers to the committed dose equivalent to an individual, according to the definition given by the International Commission on Radiological Protection.

TABLE 1. Frequency (percent) and average speed (m/s) of 10-m wind directions at Rancho Seco for all months, 1974 to 1978.

Wind direction ^a	Frequency, %	Average speed, m/s
N	3.0	2.4
NNE	2.5	2.0
NE	3.0	1.9
ENE	3.5	1.9
E	3.8	2.2
ESE	5.7	2.9
SE	8.0	3.5
SSE	9.6	4.3
S	7.4	2.8
SSW	6.8	2.6
SW	7.7	3.0
WSW	9.6	3.4
W	11.8	3.6
WNW	5.2	3.1
NW	5.7	3.6
NNW	5.8	4.5
Calm	0.8	0.0

^aDirection wind blows from.

Of more significance than the annual wind frequency is the persistence of southeast winds. For this study, we define persistence as the number of consecutive hours that the wind at Rancho Seco blows from the same 22.5-degree sector. Five years of these data, provided by SMUD,³ are shown by month in Table 2 for winds from the east-southeast, southeast, and south-southeast. For east-southeast and southeast winds, persistence tends to be minimal in summer. The greatest persistence is 10 hours and occurs in winter. The highest persistence of winds from the south-southeast is 34 hours. This value occurred in January 1975. The next two lower values during the five-year period were 22 and 21 hours.

Although we have not made an explicit trajectory study, the winds could be south-southeast at Rancho Seco and southeast or east-southeast in Sacramento for many hours. This could result in an effluent trajectory from a loss-of-coolant accident that would affect the Sacramento metropolitan area. Based on five years of data, the probability of south-southeast winds for 34 hours at Rancho Seco is about 10^{-3} . The combined frequency of such wind directions and long persistence values at both Rancho Seco and Sacramento is less than 10^{-3} .

DESCRIPTION OF COMPUTER MODELS

A suite of three-dimensional computer codes was used to prepare the dose isopleth patterns presented in this report. The two major codes in this suite are MATHEW,⁴ a program that adjusts observed horizontal winds, using variational analysis methods,⁵ to conserve mass from cell to cell, and ADPIC,⁶ a Cartesian particle-in-cell code used to calculate the transport and diffusion of effluents on a

TABLE 2. Maximum monthly persistence of east-southeast, southeast, and south-southeast wind directions in hours at the 10-m Rancho Seco tower, 1974 to 1978.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann. max.
East-Southeast Wind													
1974	6	4	7	6	2	2	2	3	1	5	8	6	8
1975	4	5	6	5	3	3	2	2	2	7	6	5	7
1976	6	5	8	4	3	2	1	7	2	5	3	6	8
1977	6	9	7	3	2	2	3	3	4	4	4	5	9
1978	6	4	7	9	8	3	3	6	4	4	4	5	9
Southeast Wind													
1974	10	6	9	7	3	3	2	1	5	10	6	6	10
1975	7	10	5	8	3	3	3	3	3	5	8	5	10
1976	7	7	7	5	5	4	3	3	4	6	3	6	7
1977	4	6	8	7	3	2	3	2	3	6	7	8	8
1978	7	2	6	5	3	8	4	3	7	3	3	4	8
South-Southeast Wind													
1974	10	11	22	13	9	3	4	7	2	9	8	21	22
1975	34	21	12	6	4	4	4	3	3	6	9	6	34
1976	6	7	11	5	4	3	5	6	4	3	12	9	12
1977	15	5	12	5	6	5	8	3	4	5	10	10	15
1978	18	4	6	5	3	3	6	4	3	4	2	3	18

regional scale. ADPIC can handle diffusion with both horizontal and vertical wind shears, variable surface roughness, dry and wet deposition, radioactive decay, and space- and time-variable diffusion parameters. Particles, simulating pollutants (up to 25,000 can be generated), move in a Lagrangian reference frame through an Eulerian grid. The main advantage of particle-in-cell techniques is that the problem of artificial diffusion, common to most Eulerian grids, is eliminated. ADPIC calculations have agreed within 5% of existing closed-form analytic solutions. Using observed site-specific meteorological data, ADPIC calculations have agreed within factors of two or three of surface and helicopter observations. The deviations between calculations and observations are due to both meteorological and sampling errors, as well as to uncertainties about nonmeteorological input parameters, such as surface roughness and deposition velocity.

In past studies, calculations using the MATHEW-ADPIC suite of codes for flat terrain have agreed within a factor of three with continuous-point-source Gaussian diffusion (CPS)⁷ results for plume centerline doses. Off-axis estimates usually deviate more; the MATHEW-ADPIC results have agreed better than CPS with past tracer studies.

analyses, using nearby National Weather Service stations. The locations of these observing stations are shown in Fig. 2. The wind arrows blow with the winds; these winds were measured at 2200 PST, November 19, 1978.

Since we needed observations of southeast winds for 34 hours, the surface data used after 0800 PST, November 20, was obtained via persistence of the wind field at 0800 PST on November 20 through 1600 PST, November 20. Surface and upper air data used from 1700 PST, November 20 to 0100 PST, November 21, 1978 were a repeat of the data 24 hours prior. This resulted in a worst-case situation for the particular data set used. The top of the mixing layer was placed subjectively at 500 m. after both the mean winter mixing heights⁹ for the area and the synoptic situation spanning 34 hours of transport and diffusion were considered. This mixing layer depth was kept constant throughout the calculation.

Dose-Conversion Factors

To evaluate the dose to man via various pathways, we multiply time-integrated surface-concentration and deposition calculations by appropriate dose-conversion factors (DCF). Included in these DCF calculations are assumptions of such things as the body and organ masses and breathing and ingestion rates of a "standard man," typical cattle grazing areas, and the time between the exposure to a food source and the consumption of that food by humans. A 50-year dose commitment following a short exposure was assumed.

For this report, we have made calculations for the largest doses to man, considering age and organ, for the pathways shown below. Adult refers to a 20 year old; infant means a child less than one year of age.

- External gamma. This is given in two parts: the dose from immersion in the radioactive plume during plume passage and the dose to a person standing at a fixed point in a field of deposited radioactivity. In both cases, no shielding from being in a building has been assumed. The dose is to the adult whole body.
- Inhalation. The affected person is assumed to remain at a fixed point during plume passage. His inhalation results in dose to the lungs and to other organs due to translocation from the lungs. The dose is to the adult bone for Sr-90, to the adult thyroid for I-131, and to the adult whole body for Cs-137.
- Forage Cow-Milk. In this case, the cow is assumed to graze within the deposition field, and the person is assumed to drink milk only from cows that have grazed in that area. In reality, except for family cows, nearly all milk today is pooled and distributed by cooperatives; hence the individual would receive a lower dose since the contaminated milk would be diluted. Also, cows can be given uncontaminated dry feed and contaminated milk can be replaced. The dose is to the infant bone for Sr-90, to the infant thyroid for I-131, and to the infant whole body for Cs-137.
- Pasture-Meat. This pathway applies to beef cattle. It is assumed that the cattle graze in the same area and are slaughtered shortly after consuming grass contaminated by the nuclides released before sufficient time has elapsed for the animal to eliminate the radioactivity from its body. The dose is to the

adult bone for Sr-90, to the adult thyroid for I-131, and to the adult whole body for Cs-137.

● Leafy Vegetable. This pathway applies to such crops as lettuce and cabbage. It is assumed that the irrigation water is uncontaminated, the vegetables are consumed (without prior washing) one day after the exposure, and there is no uptake from the soil, through the roots, to the plant's leaves. The dose is to the adult bone for Sr-90, to the adult thyroid for I-131, and to the adult whole body for Cs-137.

The dose-conversion factors used in this study for all nuclides considered and for the pathways shown above are given in Table 4. As the notes at the bottom of Table 4 indicate, these conversion factors were derived from parameter given in WASH-1400¹⁰ and in ORNL Report 4992.¹¹ Perusal of the tabular values shows that, for each curie of any of the nuclides released to the atmosphere, the inhalation and food pathways are more significant than immersion or deposition. The forage-cow-milk pathway to an infant gives the highest doses for I-131, followed in order of importance by the pasture-meat path for I-131 to an adult. The doses that result from the food pathways assume that cattle eat contaminated grass for one day. If the cattle consumed the grass for one week, the doses would be 5.5 times larger for I-131 and 7.6 times larger for both Sr-90 and Cs-137.

The ORNL report¹¹ was used to calculate only the pasture-meat-pathway dose-conversion factors. We felt that the WASH-1400 treatment of the pasture-meat pathway, wherein all food paths are separated into forage-cow-milk and "other", was not sufficiently specific, especially since "other" mentions only the vegetable pathway. ORNL-4992 assumes that 25% of the particles are retained on the pasture grass, while WASH-1400 assumes 50% retention. To be consistent, we have doubled the pasture-meat pathway LCF values obtained from ORNL-4992.

Other Input

The suite of codes used in performing the calculations requires extensive non-meteorological input. Only the significant variables will be discussed. Two grid sizes have been used: 50 X 50 km and 160 X 160 km. The dimensions of the smaller (50 X 50 km) grid cells used in MATHFW and ADPIC are 1.25 X 1.25 km in the horizontal and 50 m in the vertical. The horizontal grid-cell dimensions for the 160 by 160-km grid are 4 X 4 km. A deposition velocity of 0.01 m/s was assumed for all particulate nuclides. This velocity should not be confused with a gravitational fall velocity. The latter velocity was set to zero since the particle radii were assumed to be $\leq 5 \mu\text{m}$; particles of this size closely follow the air flow, and the effects of turbulence near the ground overshadow their small fall velocity. The surface-roughness height, which is dependent on the nature of the surface and determines the deposition rate, was assumed to be 0.03 m; this value is typical of nearly flat farm land with isolated buildings and trees.

RESULTS OF CALCULATIONS

Calculations, as requested by SMUD, were performed, using the MATHFW/ADPIC suite of codes on the Lawrence Livermore Laboratory's CDC 7600

TABLE 4. Dose-conversion factors used in the study of a hypothetical LOCA accident at Rancho Seco Nuclear Power Plant.

Nuclide	Half-life	External Gamma		Inhalation	Forage-cow-milk	Pasture-meat	Leafy-vegetable
		Immersion $\frac{\text{mrem/s}}{\text{Ci/m}^3}$ (adult whole body)	Deposition $\frac{\text{mrem/s}}{\text{Ci/m}^2}$ (adult whole body)				
Kr-85	10.7 y	4.8×10^{-1}	0	0	0	0	0
Sr-90	29.0 y	0	0	7.5×10^5 (adult bone)	6.4×10^8 (infant bone)	6.6×10^8 (adult bone)	5.5×10^8 (adult bone)
I-131	8.0 d	8.7×10^1	1.5×10^0	3.1×10^5 (adult thyroid)	6.3×10^9 (infant thyroid)	7.6×10^7 (adult thyroid)	3.1×10^8 (adult thyroid)
Xe-133	5.3 d	9.1×10^0	0	0	0	0	0
Cs-137	30.0 y	1.2×10^2	2.2×10^0	1.1×10^6 (adult whole body)	2.5×10^8 (infant whole body)	2.2×10^7 (adult whole body)	2.3×10^7 (adult whole body)

Notes:

1. All DCF values, except for the pasture-meat pathway, were obtained from App. VI of WASH-1400.¹⁰ The DCF for pasture-meat pathway were calculated from the ORNL-4992 report;¹¹ however, for consistency, we assumed 50% (not 25% as in their report) retention on pasture grass.
2. External gamma values for deposition are for a one-day exposure with no shielding. Internal DCF are for a 50 year dose commitment.
3. The words in parentheses indicate the relative age and the organ that gives the maximum dose to an individual. All external gamma DCF are to the adult whole body.
4. Most of the DCF for Kr-85 and Xe-133 are zero because they are noble gases that do not deposit on the ground. WASH-1400 gives small values for inhalation of these nuclides (less than 3×10^{-1} mrem/sec per Ci/m^3).
5. Strontium-90 is a beta emitter; the DCF for whole-body exposures are virtually zero.

computers. The scenarios used are given in Table 5. The pathways of dose to man considered are external gamma (immersion and deposition), inhalation, forage-cow-milk, pasture-meat, and leafy vegetable.

Tables 6A and 6B list the calculated maximum values (near the reactor) and the largest values within Sacramento (in millirem) for individual nuclides and pathways. The maximum values are about one kilometre northwest of the plant. The ADPIC code cannot accurately resolve air concentrations and deposition within the grid cell (of 1.25 X 1.25 km) that contains the source; therefore, the values in Table 6A were obtained with the Gaussian continuous-point-source (CPS) code.⁷ Sector-averaging was used for the 24-hour release, but not for the 2-hour release. Those input parameters that are common to ADPIC and CPS were made identical for the CPS calculations. Within a few kilometres downwind, the plume's lateral growth was such that the ADPIC calculations became superior to the CPS calculations. Figures 3 to 21 are computer-generated plots of the dose to man. For pathways other than immersion, I-131 gives the largest doses by far, and these plots may be used as total dose plots for all nuclides. The axes of all contour plots are labeled in UTM coordinates and are in kilometres. Major roads are also shown on the maps as solid lines; dotted lines delineate the boundary of the Sacramento metropolitan area, as well as aqueducts, lakes, and rivers. The three-letter designators represent airport observation sites, except for RSO, which is our abbreviation for the Rancho Seco site.

The 2- and 24-hour continuous release conditions, plus the need for 34 hours of meteorological data sets, dictated a grid structure that placed the release point within the first vertical diffusion cell. The number of meteorological data sets placed a significant restriction on the overall grid size and on whether topographical features were to be considered.

We assumed a flat grid (with no terrain features). Including the actual terrain in the model calculations would have increased the running time of the computer codes and, because of the relatively level character of the Central Valley, would not have increased the quality of the model output significantly. A 50- by 50-km grid was used in all calculations. When the maximum dose is one millirem or greater, 160- by 160-km grids are included to depict the dose isopleths beyond the Sacramento metropolitan area.

TABLE 5. LOCA scenarios requested by the Sacramento Municipal Utilities District.

Scenario number	Nuclides considered	Length of release, h	Length of transport and diffusion calculations, h	Pathway
1	All ^a	2	24	Immersion
2	All	24	34	Immersion
3	Individually	2	24	All ^b
4	Individually	24	34	All

^a All refers to the total dose from Kr-85, Sr-90, I-131, Xe-133, and Cs-137.

^b Pathways are external gamma (immersion and deposition), inhalation, forage-cow-milk, pasture-meat, and leafy vegetable.

TABLE 6. Dose vs pathway for nuclides released from the Rancho Seco Power Plant during a hypothetical loss-of-coolant accident. See notes at bottom for explanation of parentheses, dashes, and missing values in "All" rows.

A. Maximum doses (in millirem) about one kilometre northwest of Rancho Seco.

Nuclide	Pathway					
	External Gamma		Inhalation	Forage-cow-milk	Pasture-meat	Leafy vegetable
	Immersion	Deposition				
Kr-85	7.8×10^{-4} (1.5×10^{-4})	---	---	---	---	---
Sr-90	---	---	2.3×10^{-5} (4.4×10^{-6})	2.0×10^{-4} (3.8×10^{-5})	2.1×10^{-4} (4.0×10^{-5})	1.7×10^{-4} (3.3×10^{-5})
I-131	9.6×10^{-2} (1.8×10^{-2})	1.5×10^0 (2.9×10^{-1})	3.5×10^2 (6.7×10^1)	7.0×10^4 (1.3×10^4)	8.5×10^2 (1.6×10^2)	3.5×10^3 (6.7×10^2)
Xe-133	2.7×10^{-1} (5.1×10^{-2})	---	---	---	---	---
Cs-137	3.1×10^{-5} (6.0×10^{-6})	5.2×10^{-4} (9.5×10^{-5})	2.9×10^{-3} (5.6×10^{-4})	6.5×10^{-1} (1.2×10^{-1})	5.7×10^{-2} (1.1×10^{-2})	7.3×10^{-2} (1.4×10^{-2})
All	7.3×10^{-1} (6.9×10^{-2})	1.5×10^0 (2.9×10^{-1})				

TABLE 6. Continued

B. Maximum doses (in millirem) within the Sacramento metropolitan area.

Nuclide	Pathway					
	External Gamma		Inhalation	Forage-cow-milk	Pasture-meat	Leafy vegetable
	Immersion	Deposition				
Kr-85	2.2×10^{-5} (1.2×10^{-6})	---	---	---	---	---
Sr-90	---	---	2.3×10^{-7} (1.7×10^{-8})	3.4×10^{-6} (3.9×10^{-7})	3.5×10^{-6} (4.0×10^{-7})	2.9×10^{-6} (3.3×10^{-7})
I-131	8.9×10^{-4} (6.5×10^{-5})	1.5×10^{-2} (9.0×10^{-4})	3.1×10^0 (1.9×10^{-1})	7.8×10^2 (4.7×10^1)	9.5×10^0 (1.7×10^2)	3.9×10^1 (7.1×10^0)
Xe-133	6.8×10^{-3} (4.1×10^{-4})	---	---	---	---	---
Cs-137	2.9×10^{-7} (2.3×10^{-8})	6.8×10^{-6} (7.3×10^{-7})	2.5×10^{-5} (1.0×10^{-6})	9.1×10^{-3} (8.7×10^{-4})	8.0×10^{-4} (7.6×10^{-5})	1.0×10^{-3} (1.1×10^{-4})
All	7.7×10^{-3} (4.8×10^{-4})	1.5×10^{-2} (9.0×10^{-4})				

Notes

1. Entries without parentheses are for a 24-hour release; those in parentheses are for a 2-hour release.
2. Dashes signify zero doses due to nuclides of the noble gases (Kr-85 and Xe-133) or of the beta emitter Sr-90.
3. The inhalation and ingestion pathways do not have entries in the bottom row. Since each nuclide affects a different organ, doses cannot be summed.
4. See Table 4 for relative ages and organs that give the largest doses to an individual for each nuclide and pathway shown.

DISCUSSION

We have assessed the dose to man from a hypothetical loss-of-coolant accident at the Rancho Seco Nuclear Power Plant, using nuclide source rates specified by the SMUD (Table 3). Table 6B indicates that, within the Sacramento metropolitan area, the largest dose is from I-131 via the forage-cow-milk pathway to an infant's thyroid (780 millirem for a 24-hour release); the leafy-vegetable pathway for the same nuclide to an adult ranks second (39 millirem).^{*} These food pathways are not credible for a metropolitan area, including its suburbs, except for family gardens. Hence, when food pathways are neglected, the largest dose is 3.1 millirem from I-131 via inhalation for a 24-hour release at the rate given in Table 3.

Closer to the Rancho Seco reactor, a loss-of-coolant accident would yield larger doses (see Table 6A). The maximum calculated dose, about one kilometre northwest of the Rancho Seco plant, is 70 rem from I-131 to the infant thyroid via the forage-cow-milk pathway. This value is about one-fourth of the 300-rem thyroid-dose accident criteria specified in the Code of Federal Regulation, Title 10, Chapter 100. The next larger dose is 3.5 rem from I-131 to the adult thyroid via the leafy vegetable pathway.

The Environmental Protection Agency (EPA) has developed Protective Action Guidelines^{1,2} for radiological emergencies. These Guidelines have been used in a joint report by the Nuclear Regulatory Commission and the Federal Emergency Management Agency.¹³ Their report specifies response plans to be used in the event of an accident at a nuclear power plant.

The Guidelines specify that (a) beyond 16 km (10 mi) the total whole-body dose via immersion and inhalation should not exceed 1 to 5 rem, (b) at the same distance, the radioiodine dose to a child's thyroid should not exceed 5 to 25 rem, (c) beyond 80 km (50 mi), the total whole-body dose via all ingestion pathways should not exceed 1 to 5 rem, and (d) the radioiodine dose to a child's thyroid, via ingestion, should not exceed 5 to 25 rem at 80 km. Doses calculated for a hypothetical LOCA at the Rancho Seco Nuclear Power Plant are less than 1/500 or 0.2 percent of the Protective Action Guidelines at both 16 and 80 km.

Washout

As mentioned earlier, no calculations were made of washout (due to rainfall) of the nuclides released. If it were raining at Rancho Seco during a loss-of-coolant accident, deposition and food pathway doses from particles would be larger near the power plant, perhaps by a factor of 10 (immersion and inhalation doses would be less). Doses farther downwind would be lower than if it were not raining. Scattered rain showers occurring over part of the area considered in this assessment would create hot spots in the surface deposition, resulting in isolated areas giving doses up to about a factor of 10 larger than those indicated in Table 6.

^{*} To our knowledge, there are no milk cows, beef cattle, or truck gardens within the Sacramento metropolitan area; following an accidental release at Rancho Seco, both state and Federal authorities would closely monitor all food pathways in order to minimize the dose.

"Worst Case"

For a loss-of-coolant accident, using the prescribed source terms (Table 3), the present assessment is believed to be, or to at least approach, a worst-case analysis for the Sacramento metropolitan area. A persistent and extensive fog in the Central Valley would present a worst-case scenario for the immediate vicinity of Rancho Seco, out to a radius of 5 to 10 km. Fog in winter is common in both the San Joaquin and Sacramento Valleys; however, the near-surface winds are typically light (≤ 1 m/s) at such times and often variable in direction. This would result in pooling of the effluent from a loss-of-coolant accident so that, with fog and light, variable winds, little or no dose would be received beyond 10 km from the reactor. When the fog dissipates and windspeeds increase, the effluent would move downwind as a large area source. As a consequence, the resulting doses farther from the reactor would be less than those given in Table 6 and in the isopleth maps.

Error Analysis

A quantitative error analysis would be possible only if we ran the MATHEW/ADPIC suite of codes many times, varying an important input parameter each time. We have done this in a limited sense during some of our past assessments. However, it is too costly in terms of computer time to run a quantitative error analysis for each assessment. Consequently, based on past experience, we can make reasonable estimates about the accuracy of our results. The surface and upper-air observations are accurate to the nearest 10 degrees and 0.5 m/s; measurement errors should have a negligible effect on our assessment, even considering that the nearest upper-air station (Oakland) is somewhat removed from the area of interest. Variations in other input parameters, including the top of the mixing layer and surface-roughness height, should affect our calculations by less than a factor of two. Many possible judgmental errors in selecting code input parameters would tend to cancel each other.

One of the largest sources of error lies in the selection of dose-conversion factors. So many variables are involved, especially in the food pathways, that differences of more than a factor of 10 can be found in the literature. However, our sources for DCF, WASH-1400¹⁰ and ORNL-4992,¹¹ agree within a factor of 3. These sources also agree well with the DCF used in Lawrence Livermore National Laboratory's Plowshare Program in the early 1970s.¹⁴

The leakage rates for a loss-of-coolant accident, provided to us by SMUD⁸ (Table 3), are another potentially significant error source; however, an assessment of errors in the containment leakage rate from a nuclear reactor is beyond the scope of this study.

With some credit for cancelling errors, the doses given in this report could be too low or too high by, at most, a factor of five within 10 km of the reactor and by about a factor of three at greater distances. This assumes that the winds and atmospheric stability are as used herein or, if different, would lead to a similar diffusion rate. The leakage rates are also assumed to be as given.

Comparison with Three Mile Island Accident

On March 28, 1979, an accident at Unit 2 of the Three Mile Island nuclear power reactor, near Harrisburg, Pennsylvania, released a mix of radionuclides into the atmosphere for several days.* From the standpoint of dose, the most significant nuclide released was Xe-133. The total amount of Xe-133 released was estimated at 1.2×10^7 Ci, about 85% of which was emitted during the first 24 hours.¹⁵

For comparison, we have calculated the dose from whole body-immersion had the same amount (1.2×10^7 Ci) of airborne Xe-133 been released at Rancho Seco over 24 hours, under the same meteorological conditions used in this report. These doses from Xe-133 immersion are 340 millirem at about 1 km northwest of Rancho Seco and 8.6 millirem within the Sacramento metropolitan area. Our analysis of a Rancho Seco LOCA indicates doses from Xe-133, via immersion, of 0.27 millirem near the reactor and of 0.0068 millirem in the Sacramento metropolitan area.

According to data provided by Woodard,¹⁵ the average release rate of I-131 released during the Three Mile Island accident was 5.3×10^{-6} Ci/s. If radioiodine were released at this rate from Rancho Seco over a 24-hour period, using the wind fields described earlier, the maximum dose via the forage-cow-milk pathway at about 1 km downwind of the power plant would be 86 millirem. The largest dose within the Sacramento Metropolitan Area, from the forage-cow-milk pathway, would be 0.96 millirem. These values should be compared with those obtained in this report for a Rancho Seco LOCA, namely, 70 rem near the power plant and 780 millirem within Sacramento.

SUMMARY

Using the prescribed source terms (Table 3) in our MATHFW-ADPIC codes, our LOCA dose calculations indicate values that are about one-fourth of Federal regulation limits. The doses are all less than 0.2 percent of the Environmental Protection Agency's Protective Action Guidelines at both 16 and 80 km downwind. The whole-body external gamma and inhalation doses within the Sacramento metropolitan area are the only pathways directly affecting the population, and these doses are only a few millirem. About 1 km downwind of the Rancho Seco site, the maximum dose via food chains is 70 rem. However, all maximum food-chain doses would be less than one rem if milk were pooled through a cooperative, cows were put on uncontaminated dry feed, cattle were not slaughtered soon after exposure, and vegetables were consumed shortly after exposure (to minimize uptake through the root system) and were washed before consumption.

*The Three Mile Island (TMI) accident was not the type of loss-of-coolant accident postulated by the Nuclear Regulatory Commission. Compared to Rancho Seco LOCA release rates, the TMI Xe-133 release rate was much larger. TMI's I-131 release rate, however, was much smaller than the values given in Table 3.

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Figure 1. Percentage frequency of 10-m directions from which the wind blows at Rancho Seco for all months from 1974 to 1978.

Figure 2. Location of meteorological stations used in MATHEW-ADPIC calculations. Arrows indicate wind directions at 2200 PST, November 19, 1978. Wind speeds (m/sec) are shown at the ends of the arrows.

Figure 3a. Regional map of dose from Kr-85 via immersion pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 3b. Same as Fig. 3a, except release is 24 hours.

Figure 4a. Regional map of dose from I-131 via immersion pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 4b. Same as Fig. 4a, except release is 24 hours.

Figure 5a. Regional map of dose from Xe-133 via immersion pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 5b. Same as Fig. 5a, except release is 24 hours.

Figure 6a. Regional map of dose from Cs-137 via immersion pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 6b. Same as Fig. 6a, except release is 24 hours.

Figure 7a. Regional map of dose from all nuclides via immersion pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 7b. Same as Fig. 7a, except release is 24 hours.

Figure 8a. Regional map of dose from I-131 via deposition pathway (one day exposure) due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 8b. Same as Fig. 8a, except release is 24 hours.

Figure 9a. Regional map of dose from Cs-137 via deposition pathway (one day exposure) due to a 2 hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 9b. Same as Fig. 9a, except release is 24 hours.

Figure 10a. Regional map of dose from Sr-90 via inhalation pathway due to a 2-hr release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 10b. Same as Fig. 10a, except release is 24 hours.

Figure 11a. Regional map of dose from I-131 via inhalation pathway due to a 2-hr release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 11b. Extended regional map of dose from I-131 via inhalation pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 11c. Same as Fig. 11a, except release is 24 hours.

Figure 11d. Same as Fig. 11b, except release is 24 hours.

Figure 12a. Regional map of dose from Cs-137 via inhalation pathway due to a 2-hr release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 12b. Same as Fig. 12a, except release is 24 hours.

Figure 13a. Regional map of dose from Sr-90 via forage-cow-milk pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 13b. Same as Fig. 13a, except release is 24 hours.

Figure 14a. Regional map of dose from I-131 via forage-cow-milk pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 14b. Extended regional map of dose from I-131 via forage-cow-milk pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 15a. Regional map of dose from Cs-137 via forage-cow-milk pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 15b. Same as Fig. 15a, except release is 24 hours.

Figure 16a. Regional map of dose from Sr-90 via pasture-meat pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 16b. Same as Fig. 16a, except release is 24 hours.

Figure 17a. Regional map of dose from I-131 via pasture-meat pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 17b. Extended regional map of dose from I-131 via pasture-meat pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 17c. Same as Fig. 17a, except release is 24 hours.

Figure 17d. Same as Fig. 17b, except release is 24 hours.

Figure 18a. Regional map of dose from Cs-137 via pasture-meat pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 18b. Same as Fig. 18a, except release is 24 hours.

Figure 19a. Regional map of dose from Sr-90 via leafy-vegetable pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 19b. Same as Fig. 19a, except release is 24 hours.

Figure 20a. Regional map of dose from I-131 via leafy-vegetable pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 20b. Extended regional map of dose from I-131 via leafy-vegetable pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 20c. Same as Fig. 20a, except release is 24 hours.

Figure 20d. Same as Fig. 20b, except release is for 24 hours.

Figure 21a. Regional map of dose from Cs-137 via leafy-vegetable pathway due to a 2-hour release during a LOCA at the Rancho Seco Nuclear Power Plant. Isopleths are in millirem.

Figure 21b. Same as Fig. 21a, except release is 24 hours.