24
9/30/75

ORNL-TM-4781

An Example of the Application of the Cuex Methodology—the Calculated Exposure Resulting from Routine Stack Releases from the Haddam Neck Nuclear Power Plant

Fred H. Sweeton

Environmental Sciences Division Publication No. 672

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy $4.00; Microfiche $2.25

DISCLAIMER

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy $4.00; Microfiche $2.25

ORNL-TM-4781
UC-41 — Health and Safety

Contract No. W-7405-eng-26

ENVIRONMENTAL SCIENCES DIVISION

AN EXAMPLE OF THE APPLICATION OF THE CUEX METHODOLOGY-- THE CALCULATED EXPOSURE RESULTING FROM ROUTINE STACK RELEASES FROM THE HADDAM NECK NUCLEAR POWER PLANT

Fred H. Sweeton

SEPTEMBER 1975

Environmental Sciences Division
Publication No. 672

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

TABLE OF CONTENTS

LIST OF TABLES

AN EXAMPLE OF THE APPLICATION OF THE CUEX METHODOLOGY-- THE CALCULATED EXPOSURE RESULTING FROM ROUTINE STACK RELEASES FROM THE HADDAM NECK NUCLEAR POWER PLANT

Fred H. Sweeton

ABSTRACT

The CUEX (Cumulative Exposure Index) relates the concentrations of various nuclides in the environment to assigned annual dose limits. A computer code has been written to calculate this index for stack releases of radioactivity. This report is written to illustrate how the code in its present form can be applied to a particular reactor. The data used here are from the Haddam Neck (Connecticut Yankee) Nuclear Power Plant, a relatively large plant that has been in operation for 6 years. The results show that the highest exposure expected from the actual releases of gaseous ^{85}Kr, ^{133}Xe, ^{131}I, and ^{3}H is about 0.2% of the "as low as practicable" limits set by the Nuclear Regulatory Commission. Of the nuclides considered, ^{133}Xe is by far the most important; the chief mode of exposure to this nuclide is submersion in air. In the case of ^{131}I the main exposure route is external irradiation from the activity on the ground except for the special case of the thyroid for which about 70% of the exposure arises from ingestion.

INTRODUCTION

The CUEX concept has been described by Kaye et al.[1] This index, which can be expressed in terms of the average air concentration of a particular radionuclide, is the time-integrated concentration that corresponds to a person's receiving an allowable annual dose from the nuclide via all modes of exposure. The modes involving inhalation and direct irradiation from air depend directly on the air concentration. The other modes are proportional for any particular case, but the actual ratios must be calculated for this case. The index can be related to particular organs of the body as well as to the whole body. In principle the CUEX concept could also be applied to liquid releases. A computer program utilizing the CUEX approach has been written for application to a plant releasing radionuclides to the atmosphere. In this program the CUEX is calculated for the hypothetical person in the vicinity of the plant who is expected to receive the greatest dose. In addition the calculation indicates the detailed mechanisms contributing to the dose.

This report is written to illustrate how this CUEX code can be applied to a real situation and to show the detailed results it gives. The Haddam Neck (Connecticut Yankee) Nuclear Power Reactor is used. This reactor is one of the pressurized-water type. It is relatively large and has been in operation a relatively long time. Its release of radioactive materials has been measured recently by the Environmental Protection Agency.[2]

THE CUEX CODE

The CUEX code in its present form has been written largely by R. E. Moore. Part of the detailed program is documented in the description of R. E. Moore's AIRDOS code,[3] which calculates atmospheric dispersion and the resulting doses expected in squares of an assigned grid centered on the source.

The first part of the CUEX program calculates how radionuclides released from a point source become distributed over the surrounding countryside. For each radionuclide being considered, it is necessary to know the release rate and the mechanism of transport — whether as a gas, as an adsorbate on dust, or as a solute in rain drops. The meteorology of the area needs to be characterized in terms of the probabilities of various wind speeds and air stabilities in each of 16 directions. From this information the program estimates the average concentration of each radionuclide in the air at ground level at the center of each of 400 squares in a 20 x 20 grid. A similar calculation is made for the rate at which each radionuclide is being deposited on the ground in the same grid. The unit width of the squares can be set to any length of interest.

In the second part of the calculation, the square having the highest average air concentration of the first nuclide is determined. Then the calculated air concentration and ground deposition rates of this square are used to calculate the expected annual dose by all exposure modes for a person living in this square. These modes are intake from air to the lungs (inhalation); intake to the gastrointestinal tract (ingestion); and direct radiation from the nuclides in the air (immersion in air), in water (immersion in water), or on the ground (surface exposure). The calculation of exposure by the ingestion mode is based on the assumptions (1) that vegetables, beef, and milk produced in each square of the grid are contaminated according to the calculated air concentrations and ground deposition rates of that square; (2) that if enough of these foods are not produced within the grid, they are augmented by uncontaminated foods from outside; and (3) that the foods within the grid are commingled so that everyone in the grid ingests the same amount of radioactive material.* The program then calculates the expected dose, relates it to a given dose limit, and indicates the fraction of this exposure coming via each of the five exposure modes. This is done for several organs of the body when the appropriate dose conversion factors are available.

The program repeats this calculation for each of the radionuclides and then calculates the total dose for each organ from all the nuclides and shows the relative contribution of each.

DATA USED

The Haddam Neck (Connecticut Yankee) Nuclear Power Reactor is a pressurized-water plant located on the Connecticut River in an area having a relatively high population density. It started operation in

---

*Exposures for ^3H calculated by this code are likely to be high because ^3H, unlike the other nuclides, becomes directly tied to the water being cycled. Since the calculated ^3H dose shown later is relatively small, the ^3H dose will not be recalculated by other methods, as it could be if needed.

1968 and has a rating of 1825 megawatts thermal and 646 megawatts electrical.

The stack is 53 meters high,[4] 1.8 meters in diameter, and has a discharge rate of 1000 m^3/min.

Of the nearly 20 radionuclides whose release rates have been measured by the Environmental Protection Agency four were chosen for this calculation. They are listed below along with their measured release rates:

Krypton-85 --- 0.539×10^7 pCi/sec
Xenon-133 --- 0.634×10^8 pCi/sec
Iodine-131 --- 0.444×10^3 pCi/sec
Hydrogen-3 --- 0.507×10^7 pCi/sec

The Kr and Xe nuclides were included because they contribute the greatest fraction of the total activity being released; ^{131}I and ^3H were chosen because of their special chemical and physical properties. The four nuclides are sufficient to illustrate how the CUEX program operates; additional nuclides could be included to give a complete picture.

The meteorological data were taken from the final environmental statement[4] for this reactor, and are averages of readings taken at the plant site from a 100-foot tower over a period of a year. In processing these data for use in the program, the periods of "Unstable" conditions were divided equally between the Pasquill[5] "A," "B," and "C" stability categories, and the periods of "Very Stable" conditions were divided equally between the "F" and "G" categories. In calculating the fractional time the wind blows at various directions and speeds, the times of calm were ignored and the other times were increased proportionally to total 100%. This procedure has the effect of womewhat increasing the calculated radiation level at a distance from the stack at the expense of that near the stack. The hight of the lid was taken to be 600 meters, the average of winter and summer averages for this location.[6]

The deposition parameters used for the radionuclides are shown below:

Nuclide	Gravitational Fall Velocity ($m\text{-}sec^{-1}$)	Deposition Velocity ($m\text{-}sec^{-1}$)	Scavenging Coefficient (sec^{-1})
^{85}Kr	0.0	0.00	0.0
^{131}Xe	0.0	0.00	0.0
^{131}I	0.0	0.01	0.275×10^{-5}
^{3}H	0.0	0.00	0.275×10^{-5}

The gravitational fall velocities were all set to zero, because none of the nuclides was expected to be associated with particles large enough to speed its descent to the ground. The deposition velocities of all nuclides except ^{131}I were set to zero, since only the ^{131}I was expected to be adsorbed by the ground. The scavenging coefficients for ^{85}Kr and ^{133}Xe were set to zero because these gases are relatively insoluble in rain.

Table 1 and Table 2 give the data needed to calculate the dose from the calculated concentrations of the radionuclides in the air and from their calculated ground deposition rates. Table 1 has those

Table 1. Input Values for Radionuclide-Independent Variables

```
NUMBER OF NUCLIDES CONSIDEREC                                                          4
INHALATION RATE OF MAN (CUBIC CENTIMETERS/HR)                                 0.8330E 06
DILUTION FACTOR FOR WATER FOR SWIMMING (CM)                                   0.1524E 03
FRACTION OF TIME SPENT SWIMMING                                               0.1000E-01
SOIL SURFACE AREA REQUIRED TC FURNISH FCCD CROPS FUR ONE MAN (SQUARE METERS)  0.1000E 04
PASTURE AREA PER COW (SQUARE METERS)                                          0.1000E 05
DRY WEIGHT AREAL DENSITY OF MANS ABOVE-SURFACE FOOD (KGS PER SQUARE METER)    0.1000E 00
DRY-WEIGHT AREAL GRASS DENSITY (KGS PER SQUARE METER)                         0.1500E 00
DEPTH OF PLOW LAYER (CM)                                                      0.2000E 02
DIETARY CORRECTION FACTOR FUR ABOVE-SURFACE FOOD                              0.2500E 00
DIETARY CORRECTION FACTOR FOR UPTAKE FRCM SOIL                                0.1000E 01
DIETARY CORRECTION FACTOR FOR BEEF                                            0.1000E 01
DIETARY CORRECTION FACTOR FOR MILK                                            0.1000E 01
RATE OF INCREASE OF STEER MUSCLE MASS (KG PER DAY)                            0.4000E 00
MUSCLE MASS OF STEER AT SLAUGHTER (KG)                                        0.2000E 03
SOIL DENSITY (GRAMS PER CUBIC CENTIMETER)                                     0.1400E 01
FALLOUT CORRECTION FACTOR FOR ABOVE-SURFACE FOOD                              0.1000E 00
FALLOUT CORRECTION FACTOR FOR SOIL SURFACE BELOW FOOD                         0.9000E 00
FALLOUT CORRECTION FACTOR FOR PASTURE                                         0.1000E 01
FRACTION OF BEEF HERD SLAUGHTERED PER CAY                                     0.3810E-02
TRANSFER RATE OF MILK FROM UDDER (PER CAY)                                    0.2000E 01
BEEF CONSUMPTION OF MAN (KG/CAY)                                              0.3000E 00
MILK CONSUMPTION OF MAN (LITERS/DAY)                                          0.1000E 01
TRANSFER RATE--ABOVE-SURFACE FOOD TO SOIL SURFACE (PER DAY)                   0.4950E-01
TRANSFER RATE--PASTURE GRASS TO PASTURE SOIL (PER DAY)                        0.4950E-01
TRANSFER RATE--SOIL POOL TO SOIL SINK (PER DAY)                               0.1096E-03
TRANSFER RATE--PASTURE SCIL TO SOIL SINK (PER DAY)                            0.1096E-03
TRANSFER RATE--PASTURE SOIL TO PASTURE GRASS (PER DAY)                        0.2740E-04
TRANSFER RATE--SOIL SURFACE TO SOIL PCCL (PER DAY)                            0.6931E-03
MILK CAPACITY OF THE UDDER (LITERS)                                           0.5500E 01
ABOVE-SURFACE FOOD CONSUMPTICN OF MAN (KG/DAY)                                0.2500E 00
GRASS CONSUMPTION OF COW (KG/DAY)                                             0.1000E 02
MILK PRODUCTION OF COW (LITERS/DAY)                                           0.1100E 02
MAXIMUM TOTAL PERCENT CONTRIBUTED TC BE LISTED IN ORGAN TOTALS                    100.00

ANNUAL ORGAN DOSE LIMITS--

          ORGAN      DOSE LIMIT
                       (REMS)

        TOT.BODY       0.005
        GI TRACT       0.005
        BONE           0.005
        THYROID        0.015
        LUNGS          0.005
        MUSCLE         0.005
        KIDNEYS        0.005
        LIVER          0.005
        SPLEEN         0.005
        TESTES         0.005
        OVARIES        0.005
```

Table 2. Input Values for Radionuclide-Dependent Variables

	I-131	H-3
CONCENTRATION IN AIR CALCULATED FOR REFERENCE SQUARE FROM SOURCE TERM (MICROCURIE-HR/CUBIC CM)	0.1725E-12	0.2116E-08
CONCENTRATION OF THE ELEMENT IN MAN (PPM)	0.0	0.0
CONCENTRATION OF THE ELEMENT IN MEAT (PPM)	0.5200E 00	0.5200E 00
CONCENTRATION OF THE ELEMENT IN FORAGE (PPM)	0.1000E 00	0.1000E 00
CONCENTRATION OF THE ELEMENT IN SOIL (PPM)	0.5000E 01	0.5000E 01
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.8570E-01	0.8180E 00
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.4950E-01	0.4950E-01
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.0	0.0
TURNOVER RATE OF THE STABLE ISOTOPE IN MAN (PER DAY)	0.1330E-01	0.1330E-01
FRACTION OF ISOTOPE INGESTED BY A COW AND SECRETED (DAYS/LITER)	0.7000E-02	0.7000E-02
EQUILIBRIUM MASS OF STABLE ELEMENT IN SOIL FROM SURFACE TO DEPTH OF PLOW LAYER (GRAMS)	0.3000E-01	0.3000E-01
EXCRETION RATE OF STABLE ISOTOPE FROM MUSCLE OF STEER (PER DAY)	0.0	0.0
EQUILIBRIUM GROUND CONCENTRATION AT MAN (MICROCURIE-HR/SQUARE CM)	0.9132E-06	0.9312E-04
EQUILIBRIUM AIR CONCENTRATION AT MAN (MICROCURIE-HR/CUBIC CM)	0.1348E-11	0.1558E-07
EQUILIBRIUM CONCENTRATION AT WATER SURFACE (MICROCURIE-HR/SQUARE CM)	0.9132E-06	0.9312E-04
EQUILIBRIUM GROUND CONCENTRATION AT FOOD CROPS (MICROCURIE-HR/SQUARE CM)	0.2904E-08	0.9527E-06
EQUILIBRIUM GROUND CONCENTRATION AT PASTURE (MICROCURIE-HR/SQUARE CM)	0.5584E-07	0.7500E-05
EQUILIBRIUM AIR CONCENTRATION AT TESTING SITE (MICROCURIE-HR/CUBIC CM)	0.1725E-12	0.2116E-08

constants which do not change according to the radionuclide being considered. It includes the annual dose limits for the different organs. In general the limits used were the same as the "as low as practicable" limits set by the Nuclear Regulatory Commission.[7] The exceptions were the iodine dose limits for total body, G. I. tract, and lungs; for these, 5 mrem was used instead of 15. All the limits used are much more stringent than those set by the International Commission on Radiological Protection.[8] Table 2 gives the constants which depend on the radionuclide being considered.*

The dose conversion factors used in the calculation are shown in Table 3. These were obtained from the INREM and EXREM codes that have been described elsewhere.[9,10]

Figure 1 shows the grid overlaid on a map of Connecticut; its centerpoint is at the reactor on Haddam Neck. The 20 x 20 grid is made up of squares 2 kilometers on a side. For each of these squares the program requires the number of beef cattle, the number of milk cows, whether or not there is major production of vegetable crops, and the number of resident people. Data for these quantities were available[11] on a county basis. Each square was assigned to a county, and the average county figures for 4 km^2 were assigned. These numbers are shown in Table 4. Since such a small part of the land in these counties is used for vegetable crops, only one square was designated as being devoted to these crops (since the code in its present state considers that either all or none of a square is used for food crops).

---

*These constants are not included for the two noble gases because the calculated dose is independent of these constants when all of the corresponding deposition parameters are set at zero.

Table 3. Dose Conversion Factors Used in the Calculations

		Dose Conversion Factors				
Nuclide	Organ	Inhalation $\left(\frac{\text{rem}}{\mu\text{Ci}}\right)$	Ingestion $\left(\frac{\text{rem}}{\mu\text{Ci}}\right)$	Submersion in air $\left(\frac{\text{rem}\cdot\text{cm}^3}{\mu\text{Ci}\cdot\text{hr}}\right)$	Surface Exposure $\left(\frac{\text{rem}\cdot\text{cm}^2}{\mu\text{Ci}\cdot\text{hr}}\right)$	Submersion in water $\left(\frac{\text{rem}\cdot\text{cm}^3}{\mu\text{Ci}\cdot\text{hr}}\right)$
^{85}Kr	Total body	0	a	2.09	a	a
^{133}Xe	Total body	0	a	4.5×10^{1}	a	a
^{131}I	Total body	2.63×10^{-3}	3.50×10^{-3}	3.8×10^{2}	6.8×10^{-2}	8.1×10^{-1}
	Thyroid	1.44	1.88	3.8×10^{2}	6.8×10^{-2}	8.1×10^{-1}
	G.I. tract	1.07×10^{-3}	1.94×10^{-3}	3.8×10^{2}	6.8×10^{-2}	8.1×10^{-1}
	Lungs	2.07×10^{-2}	0	3.8×10^{2}	6.8×10^{-2}	8.1×10^{-1}
^{3}H	Total body	1.08×10^{-4}	6.16×10^{-5}	0^{b}	0	0^{b}
	G.I. tract	1.08×10^{-4}	6.16×10^{-5}	0	0	0

[a] Not used when all the deposition constants are set at zero.

[b] These factors are for direct irradiation from outside the body. In the case of ^{3}H as H_2O, absorption through the skin can occur. That from the vapor has been taken into account by increasing the inhalation dose conversion factor by 75%; that from absorbing liquid water when swimming, has been calculated to be negligible relative to that from inhalation.

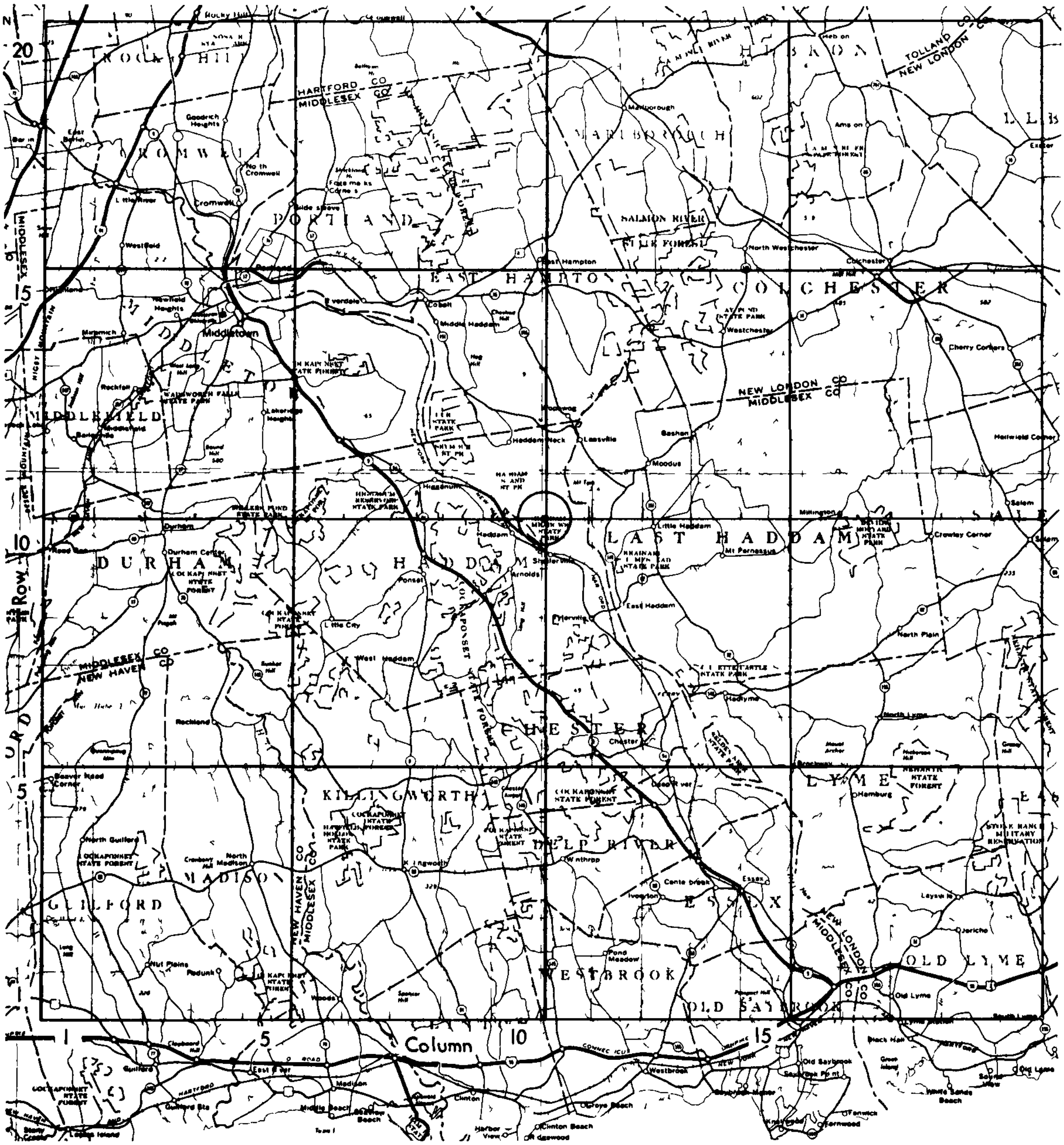

Fig. 1. Grid Used for Calculation

Table 4. Average Figures per Square (4 km^2)

	County				
	Hartford	Middlesex	New Haven	New London	Tolland
Number of beef cattle	16	10	14	24	23
Number of milk cows	14	9	13	21	22
Fraction area in food crops	0.0016	0.00018	0.002	0.0002	0.0003
Population	1706	477	1904	534	384

RESULTS

Table 5 indicates the average relative air concentration of ^{85}Kr calculated for the center of each square. Each square has been assigned to one of the 16 compass directions for which there is wind velocity data. The concentrations have been normalized to a reading of 100,000 for the maximum square. The actual reading for this maximum square (pCi/cm^3) is shown in the heading at the top of the table. The readings in the table are presented in a geographical layout, the upper left figure applying to the northwest corner of the grid. The maximum calculated air concentration was in the square just to the southeast of the reactor. The square which represents Middletown, the largest city in this grid, is in the thirteenth row and the fourth column. The average ^{85}Kr concentration in air calculated for this square is 0.24 x 10^{-6} pCi/cm^3, which is approximately 15% of that in square with the maximum concentration. Table 6 lists the concentrations of the four radionuclides at Middletown and a few other cities or towns in the grid.

The calculated ground deposition rates for ^{131}I in the different squares of the grid are shown in Table 7. These readings have been normalized to the maximum, just as was done with the air concentrations in Table 5.

The method of calculating the atmospheric dispersion of radionuclides has been checked against field measurements made by the Environmental Protection Agency at the Haddam Neck reactor. Robert E. Moore, using this same atmospheric dispersion code in his AIRDOS program, calculated[3] air concentrations at sampling points near the reactor and

Table 5. Estimated Relative Air Concentration of ^{85}Kr

Maximum (100,000) = 0.189 x 10^{-5} pCi/cm^3

ROW	COLUMN 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20	4986	5228	5480	5735	2838	2954	3059	3146	2911	2942	2942	2911	2100	2043	1973	1896	2701	2584	2469	2358
19	5228	5514	5816	6129	3059	3208	3346	3463	3230	3273	3273	3230	2311	2234	2142	2043	2881	2738	2600	2469
18	5480	5816	6179	6565	6967	3505	3690	3852	3973	3690	3690	2650	2570	2462	2339	3261	3079	2903	2738	2584
17	5735	6129	6565	7042	7555	8088	4106	4337	4516	4236	4236	3012	2893	2739	3767	3527	3295	3079	2881	2701
16	10230	10975	6967	7555	8210	8924	4615	4957	5236	4976	4976	3490	3305	3077	4141	3822	3527	3261	2379	2214
15	10622	11476	12466	8088	8924	9883	10945	5765	6213	6050	6050	4135	3843	5041	4569	4141	3767	2711	2491	2301
14	10975	11937	13081	14455	16117	10945	12456	14078	7597	7743	7743	5036	6432	5705	5041	3528	3155	2848	2593	2379
13	11267	12326	13615	15211	17229	19830	14078	16622	9631	10633	10633	6365	7560	6432	4366	3779	3325	2967	2680	2444
12	6830	7509	14014	15796	18130	21178	25008	30137	25020	16348	10918	11164	6887	5603	4679	3982	3456	3057	6062	5513
11	6896	7599	8478	9609	11124	13125	15845	19951	43609	45698	22346	10663	16590	12975	10644	8993	7765	6848	6135	5566
10	6896	7599	8478	9609	11124	13125	15845	19951	13675	8529	99999	75454	16590	12975	10644	8993	7765	6848	6135	5566
9	6830	7509	3712	4205	4853	5726	6938	8663	5211	4004	19461	73002	46988	37693	31163	26430	22907	20232	6062	5513
8	2959	3249	3603	4043	4603	5328	2859	3404	2756	7237	7237	13181	51382	44184	29011	25069	22028	19035	17712	16138
7	2879	3142	3456	3834	4294	2199	2513	2859	2279	5556	5556	10853	44184	39444	34887	23391	20892	18837	17133	15705
6	2783	3016	3287	1610	1782	1980	2199	1803	1927	4488	4488	9136	8539	34887	31657	28722	26150	17920	16448	15183
5	2676	2879	1380	1500	1635	1782	1463	1565	1648	3748	3748	7794	7400	6914	28722	26527	24499	22673	15705	14604
4	1129	1209	1298	1395	1500	1610	1311	1381	1434	3211	3211	6774	6519	6189	26150	24499	22907	21419	20054	18816
3	1077	1145	1219	1298	1380	1130	1186	1235	1271	2813	2813	5997	5823	5591	5323	22673	21419	20209	19069	16009
2	1026	1084	1145	1209	994	1039	1081	1117	2475	2506	2506	2475	5263	5094	4894	4677	20054	19069	18117	17214
1	977	1026	1077	1129	926	962	994	1020	2239	2262	2262	2239	4803	4677	4524	4354	16816	16009	17214	16445

Table 6. Calculated Average Air Concentrations of Radionuclides at Points Near the Haddam Neck Nuclear Power Reactor

	Square				
	Maximum	Middletown	Rocky Hill	Deep River	Colchester
Row	10	14	20	5	15
Column	11	4	4	13	17
^{85}Kr (pCi/cm^3)	1.9×10^{-6}	0.27×10^{-6}	0.11×10^{-6}	0.14×10^{-6}	0.07×10^{-6}
^{133}Xe (pCi/cm^3)	22.3×10^{-6}	3.2×10^{-6}	1.3×10^{-6}	1.6×10^{-6}	0.8×10^{-6}
^{131}I (pCi/cm^3)	0.15×10^{-9}	0.014×10^{-9}	0.0042×10^{-9}	0.008×10^{-9}	0.0040×10^{-9}
^{3}H (pCi/cm^3)	1.78×10^{-6}	0.25×10^{-6}	0.10×10^{-6}	0.13×10^{-6}	0.067×10^{-6}

Table 7. Estimated Relative Ground Deposition Rate of ^{131}I

Maximum (100,000) = 0.163×10^{-9} pCi cm^{-2} sec^{-1}

ROW	COLUMN																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20	2102	2315	2541	2776	1653	1766	1869	1955	1910	1940	1940	1910	1310	1252	1183	1107	1542	1427	1316	1210
19	2315	2572	2851	3145	1869	2017	2155	2272	2224	2267	2267	2224	1524	1445	1352	1252	1721	1579	1443	1316
18	2541	2851	3193	3563	3955	2314	2502	2667	2790	2686	2686	1860	1790	1679	1552	2107	1921	1744	1579	1427
17	2776	3145	3563	4029	4539	5032	2928	3166	3336	3229	3229	2236	2112	1952	2633	2382	2142	1921	1721	1542
16	4904	5625	3955	4539	5156	5885	3439	3795	4085	3987	3987	2740	2545	2306	3029	2691	2382	2107	1570	1403
15	5281	6123	7121	5032	5885	6877	7988	4640	5103	5079	5079	3420	3113	3975	3484	3029	2633	1912	1685	1491
14	5625	6584	7754	9188	10877	7988	9585	11298	6548	6806	6806	4373	5404	4687	3975	2769	2376	2055	1790	1570
13	5913	6978	8307	9911	12069	14891	11298	13998	8668	9766	9766	5772	6676	5464	3648	3033	2554	2179	1679	1636
12	3461	4079	8725	10531	13041	16380	20621	26351	22953	15650	10514	10524	6325	4961	3979	3249	2692	2272	4535	3956
11	3525	4171	5074	6266	7896	10090	13097	17702	41676	45231	22143	10295	15720	11895	9404	7662	6348	5369	4612	4011
10	3525	4171	5074	6266	7896	10090	13097	17702	12853	8506	99999	72944	15720	11895	9404	7662	6348	5369	4612	4011
9	3461	4079	2028	2519	3185	4101	5377	7240	4583	3785	18436	67901	42922	33065	26132	21109	17437	14023	4535	3956
8	1315	1582	1921	2357	2926	3684	2083	2645	2294	6157	6157	11257	44150	36299	23855	19665	16511	13998	12000	10385
7	1244	1483	1779	2148	2610	1418	1734	2083	1751	4315	4315	8668	36299	31168	26234	17952	15314	13168	11405	9947
6	1180	1368	1619	850	1011	1202	1418	1226	1361	3187	3187	6794	6150	26234	22881	19760	17054	12216	10705	9420
5	1087	1244	651	750	873	1011	865	971	1058	2424	2424	5354	4939	4430	19760	17449	15340	13467	9947	8840
4	439	505	580	665	750	850	709	779	834	1881	1881	4283	4021	3713	17054	15340	13707	12204	10846	9640
3	398	452	513	580	651	531	585	632	668	1494	1494	3518	3343	3112	2848	13467	12204	11002	9887	8870
2	359	403	452	505	414	446	485	518	1178	1207	1207	1178	2788	2625	2434	2229	10846	9887	8971	8123
1	322	359	398	439	354	385	414	438	983	1003	1003	983	2348	2229	2088	1934	9640	8870	8123	7414

found his values ranged from 56 to 156% of the values for ^{85}Kr and ^{133}Xe measured by the EPA.

For each nuclide being considered, the code then calculates the CUEX for each organ. If the appropriate dose conversion factor is not available, the code substitutes the total body value, and indicates this substitution on the printout. In addition, the code will calculate the CUEX in terms of the air concentration in any square when the corresponding concentration in the maximum square gives the allowable dose. In Table 8, which is for total body dose, the CUEX's listed are the ones appropriate for the maximum square. They show that, of these four nuclides, ^{131}I can be least tolerated. However, when these CUEX's are compared to the actual average air concentrations calculated for this reactor, ^{133}Xe proves to give the most dosage (see fourth column) although still much less than the chosen dose limit. The last five columns show the relative contributions of each mode of exposure to the dose from each nuclide.

Table 9 shows how the CUEX program can differentiate the doses received by the various organs. The fourth column shows that the thyroid is the organ receiving the greatest ^{131}I dose relative to the dose limit, even though the dose limit for the thyroid has been set higher than for the other organs. The table shows that for total body, G. I. tract, and lungs, the greatest dose comes from surface exposure; but for the thyroid, the major mode is ingestion.

The calculation also shows the relative contribution of each nuclide to the dose received by each organ. Given below are such results for total body (which is treated in parallel with the individual organs):

Table 8. Calculated Total Body Doses for the Different Nuclides

Nuclide	Dose limit (rems/year)	CUEX at max. square $\left(\frac{\text{pCi hr}}{\text{cm}^3\ \text{yr}}\right)$	Fraction of dose limit	Percent of dose according to mode				
				Inhalation	Ingestion	Submersion in air	Surface exposure	Submersion in water
^{85}Kr	0.005	2400	0.000007	0	0	100	0	0
^{133}Xe	0.005	110	0.0018	0	0	100	0	0
^{131}I	0.005	0.062	0.000022	2.7	6.6	0.5	90.2	0.1
^{3}H	0.005	47	0.00033	84.0	16.0	0	0	0

Table 9. Calculated Results for Various Organs with Iodine-131

Organ	Dose limit (rem/year)	CUEX at max. square $\left(\frac{\text{pCi hr}}{\text{cm}^3\ \text{yr}}\right)$	Fraction of dose limit	Percent of exposure by mode				
				Inhalation	Ingestion	Submersion in air	Surface exposure	Submersion in water
Total body	0.005	0.062	0.000022	2.7	6.6	0.5	90.2	0.1
G.I. tract	0.005	0.065	0.000021	1.1	3.8	0.5	94.5	0.1
Thyroid	0.015	0.0036	0.00037	29.1	69.2	0.0	1.8	0.0
Lungs	0.005	0.055	0.000024	19.0	0.0	0.4	80.5	0.1

Nuclide	Percent of dose
^{133}Xe	83.0
^{3}H	15.6
^{131}I	1.0
^{85}Kr	0.3

The program calculates the total dose of each organ from all the nuclides and then compares this to the dose limit. The highest ratio found was 0.2%. This indicates that the release of these four radionuclides from the Haddam Neck reactor would result in overall dose rates that are only a small fraction of the dose limits which have been used.

In summary, the CUEX code has been applied to the routine stack releases from an operating nuclear power reactor. The amount of data required to define the system is large, but once these data are assembled the code easily calculates the maximum annual dose to be expected, and, in addition, breaks down the various contributions to the total dose in a manner to show what steps would be most productive in reducing the dose. The format of the code is such that it can be applied just as easily to radioactivity releases from mining and milling operations, fuel fabrication, and fuel reprocessing.

REFERENCES

1. Stephen V. Kaye, R. S. Booth, P. S. Rohwer, and E. G. Struxness, "A Cumulative Exposure Index for Assessing Environmental Releases of Radioactivity," Proceedings International Symposium on Radioecology Applied to the Protection of Man and His Environment, EUR 4800 d-f-i-e, Rome, September 7-19, 1971, p. 909.
2. Bernd Kahn *et al.*, "Radiological Surveillance Study of the Haddam Neck PWR Nuclear Power Station," EPA-520/3-74-007 (1975).
3. R. E. Moore, AIRDOS--A Computer Code for Estimating Population and Individual Doses Resulting from Atmospheric Releases of Radionuclides from Nuclear Facilities, ORNL-TM-4687 (1974).
4. "Final Environmental Statement Related to the Haddam Neck (Connecticut Yankee) Nuclear Power Plant," Directorate of Licensing, U. S. Atomic Energy Commission, Docket No. 50-213, October 1973.
5. F. Pasquill, Atmospheric Diffusion, D. van Nostrand Co., Ltd., New York, 1962.
6. David H. Slade, ed., Meteorology and Atomic Energy, 1968, Division of Technical Information, U. S. Atomic Energy Commission, Oak Ridge, Tennessee, 1968, p. 40.
7. Title 10, Atomic Energy, Part 50, "Licensing of Production and Utilization Facilities," Code of Federal Register, Vol. 36, No. 111.
8. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection, ICRP Publication 9, Pergamon Press, London, 1966.

9. D. K. Trubey and S. V. Kaye, The EXREM III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases, ORNL-TM-4322 (1973).

10. W. D. Turner, S. V. Kaye, and P. S. Rohwer, EXREM and INREM Computer Codes for Estimating Radiation Doses to Populations from Construction of a Sea-Level Canal with Nuclear Explosives, K-1752, Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tennessee, 1968.

11. 1969 Census of Agriculture, U. S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census, June 1972.

ORNL-TM-4781

UC-41 — Health and Safety

INTERNAL DISTRIBUTION

1. S. I. Auerbach
2. J. A. Auxier
3. C. J. Barton
4. F. T. Binford
5. B. G. Blaylock
6. R. S. Booth
7. R. L. Burgess
8. T. J. Burnett
9. F. H. Clark
10. C. C. Coutant
11. W. B. Cottrell
12. F. L. Culler
13. R. C. Dahlman
14. B. E. Dinger
15. J. O. Duguid
16. C. E. Easterly
17. W. F. Harris, III
18. R. F. Hibbs
19. G. S. Hill
20. F. B. K. Kam
21-45. S. V. Kaye
46. G. D. Kerr
47. G. G. Killough, Jr.
48. R. E. Moore
49. D. J. Nelson
50. F. R. O'Donnell
51. R. V. O'Neill
52. D. C. Parzyck
53. H. Postma
54. J. W. Poston
55. D. E. Reichle
56. C. R. Richmond
57. P. S. Rohwer
58. E. G. Struxness
59-63. F. H. Sweeton
64. J. E. Till
65. J. R. Trabalka
66. D. K. Trubey
67. V. R. R. Uppuluri
68. R. I. Van Hook
69. J. P. Witherspoon
70-79. RSIC Library
80-89. Computer Sciences Division Library
90-92. Central Research Library
93. ORNL — Y-12 Technical Library Document Reference Section
94-98. Laboratory Records Department
99. Laboratory Records, ORNL R.C.
100. ORNL Patent Office

EXTERNAL DISTRIBUTION

101. Lee Aamodt, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, New Mexico 87544.
102. Advanced Research Projects Agency, Department of Defense, The Pentagon, Washington, D. C. 20301.
103. L. R. Anspaugh, University of California, Lawrence Livermore Laboratory, Livermore, California 94550.
104. David S. Ballantine, Division of Biological and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.

105. R. F. Barker, Product Standards Branch, Directorate of Regulatory Standards, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.

106. Nathaniel F. Barr, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
107. D. S. Barth, National Environmental Research Center, EPA, P. O. Box 15027, Las Vegas, Nevada 89114.
108. Martin B. Biles, Director, Division of Operational Safety, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
109. J. A. Blasy, Division of Applied Technology, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
110. Andre Bouville, United Nations, Scientific Committee on the Effects of Atomic Radiation, New York, New York 10016.
111. J. A. Broadway, Eastern Environmental Research Facility, P. O. Box 61, Montgomery, Alabama 36101.
112. Carter D. Broyles, Department Manager, Test Sciences (7110), Sandia Corp., P. O. Box 5800, Albuquerque, New Mexico 87115.
113. W. W. Burr, Jr., Division of Biology and Medicine, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
114. Murray Calkins, National Environmental Research Center, Environmental Protection Agency, Cincinnati, Ohio 45268.
115. M. W. Carter, Interdisciplinary Sciences, Georgia Institute of Technology, Atlanta, Georgia 20332.
116. Eddie W. Chew, El Paso Natural Gas Co., P. O. Box 1492, El Paso, Texas 79999.
117. J. G. Christian, Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M St. SW, Washington, D. C. 20460.
118. Roger J. Cloutier, Special Training Division, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830.
119. R. G. Cochrell, Manager, Licensing Division, Westinghouse Electric Corporation, P. O. Box 158, Madison, Pennsylvania 15663.
120. Jerry Cohen, Lawrence Livermore Laboratory, P. O. Box 808, Livermore, California 94551.
121. Jared J. Davis, Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission, Washington, D. C. 20545
122. Raymond D. Cooper, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
123. Paul J. Cory, Office of the Secretary of Transportation, Washington, D. C. 20590.
124. George A. Cowan, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, New Mexico 87544.
125. T. V. Crawford, Savannah River Laboratory, E. I. du Pont de Nemours & Company, Aiken, South Carolina 29801.
126. R. G. Cuddihy, Inhalation Toxicology Research Institute, 5200 Gibson Blvd. SE, Albuquerque, New Mexico 87108.
127. Richard Cunningham, Division of Materials Licensing, U.S. Nuclear Regulatory Commission, Bethesda, Maryland 20014.
128. Adrian H. Dahl, U.S. Energy Research and Development Administration, Idaho Operations Office, 550 2nd St., Idaho Falls, Idaho 83401.
129. L. J. Deal, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.

130. N. J. Diaz, Dept. Nuclear Engineering Sciences, University of Florida, Gainesville, Florida 32601.
131. Bennie DiBona, Director, Division of Peaceful Applications, Nevada Operations Office, U.S. Energy Research and Development Administration, P. O. Box 1676, Las Vegas, Nevada 89101.
132. Richard L. Blanchard, Radiochemistry & Nuclear Engineering Facility, U. S. Environmental Protection Agency, Cincinnati, Ohio 45268
133. P. B. Dunaway, Office of Effects Evaluation, Nevada Operations Office, U.S. Energy Research and Development Administration, Las Vegas, Nevada 87114.
134. G. G. Eichholz, School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 20332.
135. Rudolf J. Engleman, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
136. Edward H. Fleming, University of California Lawrence Libermore Laboratory, Mail Stop L-1, Box 808 Livermore, California 94550
137. R. Franklin, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
138. Carl Gamertsfelder, Directorate of Licensing, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
139. Mahlon Gates, Manager, Nevada Operations Office, U.S. Energy Research and Development Administration, P. O. Box 1676, Las Vegas, Nevada 99101.
140. F. A. Gifford, Jr., Air Resources Atmospheric Turbulence and Diffusion Laboratory, NOAA, Oak Ridge, Tennessee 37830.
141. S. Yaniv, Office of Nuclear Regulatory Research, Mail Stop A1-3002, U. S. Nuclear Regulatory Commission, Washington, D. C. 20555
142. Abraham S. Goldin, Kresge Center for Environmental Health, Harvard University, School of Public Health, Boston, Massachusetts 02100.
143. R. S. Goor, National Science Foundation, 2101 Constitution Ave., Washington, D. C. 20418.
144. R. L. Gotchy, Directorate of Licensing, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
145. Douglas Grahn, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

146. Harold J. Groh, Jr., Separations Chemistry, Savannah River Laboratory, E. I. duPont de Nemours and Company, P. O. Box "A", Aiken, South Carolina 29802.
147. S. R. Hanna, Air Resources Atmospheric Turbulence and Diffusion Laboratory, NOAA, Oak Ridge, Tennessee 37830.
148. J. E. Hardaway, Surveillance and Analysis Division, Technical Support Branch, Suite 900, 1860 Lincoln Street, Denver, Colorado 80203.
149. W. R. Hardwick, U.S. Bureau of Mines, Eight West Paseo Redondo, Tucson, Arizona 85705.
150. D. F. Harmon, Office of Regulation, U.S. Nuclear Regulatory Commission, Bethesda, Maryland 20014.

151. Monte Hawkins, Head, Safety and Environmental Control, Allied General Nuclear Services, P. O. Box 847, Barnwell, South Carolina 29812.
152. J. W. Healy, Health Physics Division, Los Alamos Scientific Laboratory, Box 1663, Los Alamos, New Mexico 87544.
153. John Heslep, Chief, Environmental Safety and Consumer Protection Program, State Department of Public Health, 2151 Berkeley Way, Berkeley, California 97404.
154. Gary H. Higgins, K. Division, Lawrence Livermore Laboratory, P. O. Box 808 (L-41), Livermore, California 94551.
155. George Hinman, Gulf Central Atomic, Box 608, San Diego, California 92112.
156. I. A. Hobbs, Director, Technical and Production Division, Savannah River Operations Office, P. O. Box "A", Aiken, South Carolina 29802.
157. John B. Hursh, Department of Radiation Biology and Biophysics, University of Rochester, Rochester, New York 14620.
158. Stephen Jinks, Institute of Environmental Medicine, New York University Medical Center, Long Meadow Road, Tuxedo, New York 10987.
159. B. Kahn, Interdisciplinary Sciences, Georgia Institute of Technology, Atlanta, Georgia 20332.
160. Jacob Kastner, Radiological Assessment Branch, Directorate of Licensing, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
161. J. Kline, Argonne National Laboratory, Radiological Physics Division Ecological Studies, Argonne, Illinois 60439.
162. J. Koranda, Biomedical Division, Lawrence Radiation Laboratory, P. O. Box 808 (L-13), Livermore, California 94551.
163. Paul Kruger, Professor of Nuclear Chemistry, Department of Civil Engineering, Stanford University, Stanford, California.
164. William Martin, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201.
165. P. J. Mellinger, EXXON Nuclear Company, 2955 George Washington Way, Richland, Washington 99352
166. M. L. Merritt, Underground Physics Division (5232), Sandia Corporation, Albuquerque, New Mexico 87115.
167. Peter McGrath, ORG 1721, Sandia Laboratories, Albuquerque, New Mexico 87113.
168. W. A. Mills, U.S. Environmental Protection Agency, Criteria and Standards Division, 401 M St., SW, Washington, D. C. 20460.
169. M. T. Mills, GCA Technical Division, Burlington Road, Bedford, Massachusetts 01730.
170. A. A. Moghissi, Office of Interdisciplinary Studies, Georgia Institute of Technology, Atlanta, Georgia 20332.
171. K. Z. Morgan, School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 20332.
172. Henry W. Morton, Nuclear Fuel Services, Inc., 6000 Executive Blvd., Suite 600, Rockville, Maryland 20852.
173. D. R. Nelson, Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street, S. W., Washington, D. C. 20460.

174. Randolph R. Newton, Division of Biological and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
175. T. R. Noonan, UT-AEC Agricultural Research Laboratory, 1299 Bethel Valley Road, Oak Ridge, Tennessee 37830.
176. Donald A. Nussbaumer, Directorate of Licensing, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
177. H. T. Odum, Department of Environmental Engineering, University of Florida, Gainesville, Florida 32601.
178. W. Ogle, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, New Mexico 87544.
179. M. J. Ohanian, Head, Department of Nuclear Engineering Sciences, University of Florida, Gainesville, Florida 32601.
180. J. S. Olson, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
181. W. S. Osburn, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
182. Charles Osterberg, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545
183. Aaron Padgett, Carolina Power and Light, P. O. Box 1551, Raleigh, North Carolina 27602.
184. C. C. Palmiter, Office of Radiation Programs, Environmental Protection Agency, 401 M Street, SW, Washington, D. C. 20460.
185. F. L. Parker, Department of Civil Engineering, Vanderbilt University, Nashville, Tennessee 37203.
186. Michael A. Parsont, Radiological Assessment Branch, Directorate of Licensing, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
187. H. R. Payne, U.S. Environmental Protection Agency Region IV, 1421 Peachtree St., Atlanta, Georgia 30309.
188. W. H. Pennington, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
189. Paul Phelps, University of California, Lawrence Radiation Laboratory, Livermore, California 94550.
190. J. F. Phillip, Director, Special Projects Division, San Francisco Operations Office, U.S. Atomic Energy Commission, 2111 Bancroft Way, Berkeley, California 94704.
191. K. Purushothamon, University of Missouri at Rolla, Rolla, Missouri 65401.
192. W. H. Ray, Office of Regulation, U.S. Nuclear Regulatory Commission, Bethesda, Maryland 20014.
193. L. Roberts, School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, Georgia 20332.
194. Alvin M. Weinberg, Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830
195. J. N. Rogers, Division 8321, Sandia Laboratories, P. O. Box 969, Livermore, California 94550.

196. Milton E. Rose, Mathematical and Computer Sciences Program, Molecular Sciences and Energy Research, Division of Physical Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
197. H. C. Rothschild, Radiation Protection Bureau, Brookfield Road, Ottawa K1A1C1, Ontario, Canada.
198. Paul Russell, Research Director, Denver Mining Research Center, U.S. Bureau of Mines, Denver Federal Building, Denver, Colorado 80225.
199. Lewis M. Schalit, Systems, Science and Software, P. O. Box 1620, La Jolla, California 92037.
200. Keith J. Schiager, University of Pittsburg, Radiation Center, Pittsburg, Pennsylvania 15213
201. G. A Selmel, Division of Biology and Medicine, Battelle Pacific Northwest Laboratories, Richland, Washington 99352.
202. Clifford S. Selvage, Manager, Advance Systems Research Department 1, Sandia Corp., P. O. Box 969, Livermore, California 94550.
203. Seymour Shwiller, Staff Member, Joint Committee on Atomic Energy, Congress of the United States, Washington, D. C. 20510.
204. C. F. Smith, Jr., Lawrence Livermore Laboratory, P. O. Box 808, Livermore, California 94551.
205. David S. Smith, Office of Radiation Programs, U.S. Environmental Protection Agency, 401 M Street, SW, Washington, D. C. 20460.
206. Harold Sohns, U.S. Bureau of Mines, Laramie Petroleum Research Center, Laramie, Wyoming 82071.
207. J. K. Soldat, Pacific Northwest Laboratories, Battelle Memorial Institute, Richland, Washington.
208. Jeff Swinebroad, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
209. Lauriston Taylor, National Academy of Sciences, Advisory Committee on Emergency Planning, 2101 Constitution Avenue, Washington, D. C. 20418.
210. Howard Tewes, Lawrence Livermore Laboratory, P. O. Box 808, Livermore, California 94551.
211. Paul C. Tompkins, 407 Clayton Road, Chapel Hill, North Carolina 27514
Las Vegas, Nevada 89101.
212. J. H. Tormey, Corps of Engineers, Assistant Director of Civil Works for Nuclear Construction Planning, Department of the Army, Washington, D. C. 20315.
213. A. N. Tse, Product Standards Branch, Directorate of Regulatory Standards, U.S. Nuclear Regulatory Commission, Washington, D. C. 20545.
214. William S. Twenhofel, U.S. Geological Survey, Federal Center, Denver, Colorado 80225.
215. B. H. Van Domelen, Governor's Science Adviser, Sandia Laboratory, 1820, Albuquerque, New Mexico 87115.
216. R. Watters, Division of Biomedical and Environmental Research, U.S. Energy Research and Development Administration, Washington, D. C. 20545.

217. James E. Watson, Jr., Radiological Hygiene Branch, Tennessee Valley Authority, River Oaks Building, Muscle Shoals, Alabama 35630.
218. Glenn C. Werth, Associate Director for Plowshare, Lawrence Livermore Laboratory, P. O. Box 808 (L-13), Livermore, California 94551.
219. F. W. Whicker, Department of Radiology and Radiation Biology, Colorado State University, Ft. Collins, Colorado 80521.
220. L. Schwartz, Lawrence Livermore Laboratory, P. O. Box 808. Livermore, California 94551.
221. B. G. Wixson, University of Missouri at Rolla, Rolla, Missouri 65401.
222. R. W. Wood, Division of Biology and Medicine, U.S. Energy Research and Development Administration, Washington, D. C. 20545.
223. Claude Yarbro, Research and Technical Support Division, ERDA-ORO Oak Ridge, Tennessee 37830.
224. Richard Graves, Assistant Superintendent, Connecticut Yankee Nuclear Power Station, RR #1, Box 127E, East Hampton, Connecticut 06424.
225-469. Given distribution as shown in TID-4500 under category Health and Safety (25 copies – NTIS)