HEAT TRANSFER IN DESIGN
OF ALPHA WASTE STORAGE FACILITIES

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by
G. Jansen
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CONTENTS

INTRODUCTION.	1
SUMMARY	1
SPECIFIC HEAT GENERATION RATE	2
THE COMPUTATIONAL MODEL	3
RESULTS OF CALCULATIONS	8
REFERENCES	10
APPENDIX A	A.1
APPENDIX B	B.1
APPENDIX C	C.1

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INTRODUCTION

The work in this report was performed over two years ago at the request of the Atlantic Richfield Hanford Company and was reported to ARHCO by letter on July 26, 1972.⁽¹⁾ Its primary purpose was to provide an estimate of the heat transfer limitations on the spacing and stacking height of storage canisters in an alpha waste storage facility design. This design was one of several concepts then being evaluated by ARHCO for alpha wastes from the U.S. nuclear power fuel cycle.

After 1972, the results of these heat transfer calculations were cited several times within Battelle Northwest for the different purpose of helping to justify a dividing line between high-level and low-level wastes.^(2,3,4,5) The dividing value has been used as 0.1 W/ft^3 or 5 g of plutonium per cubic foot, below which concentration no auxiliary cooling is said to be needed to remain below a temperature limit at which combustible paper and rags will burn in a specified storage design.

Since this dividing value may be reexamined more closely, it seems appropriate to make the modest calculational effort and the detailed bases for the heat transfer model and the storage design configuration available for examination in an internal report.

SUMMARY

Heat transfer design calculations have been made for a conceptual alpha waste storage facility. Stacks of containers 6 ft by 4 ft by 6 ft high would be placed in a large room with natural dissipation of heat or forced air cooling. The stacks of barrels would be cooled by natural convection flow through vertical channels formed by the 3-in. radii on the corners of the containers and through 4-in. horizontal gaps between cans.

The containers would be filled with plutonium-bearing wastes. A BASIC language computer program ALPHA1 was developed for estimating temperatures in the alpha waste storage facility. Tentative conclusions arrived at in the study were 1) the maximum heat generation rate in the plutonium was 0.0174 W/g at 50 years with a decrease to 0.0087 W/g at 500 years because of ^{241}Am growth and decay; 2) stacks up to 10 cans high are permissible; 3) spaces about an inch wide would have to be maintained between the cans to keep the waste cool enough; and 4) even if the walls of the building were 1-ft-thick concrete, there would be enough heat loss so that forced convection would not be needed.

SPECIFIC HEAT GENERATION RATE

The initial composition of the plutonium was assumed to be 1% ^{238}Pu , 60% ^{239}Pu , 24% ^{240}Pu , 11% ^{241}Pu , 4% ^{242}Pu with minor amounts of ^{232}U , ^{236}Pu , ^{241}Am , ^{242}Cm , and ^{244}Cm present. The initial heat generation rate is 0.01 W/g Pu, principally due to the ^{239}Pu and ^{240}Pu . As the plutonium ages, the heat generation rate increases as shown in Table 1 because of ^{241}Pu decay to ^{241}Am . A maximum heat generation rate of 0.0175 W/g Pu is reached at 50 years, after which a gradual decrease occurs as the ^{241}Am decays. Tables A.1 and A.2 of Appendix A give a detailed breakdown of the plutonium composition versus time from 1 to 1000 years after reactor discharge. Minor isotope concentrations are given for illustrative purposes only and are not calculated from any real situation.

TABLE 1. Heat Generation Rate of Alpha Wastes

<u>Time, years</u>	<u>W/g Pu</u>	<u>Time, years</u>	<u>W/g Pu</u>
1	0.0100	60	0.0174
2	0.0103	70	0.0172
5	0.0115	80	0.0170
10	0.0132	90	0.0167
20	0.0155	100	0.0163
30	0.0167	200	0.0134
40	0.0173	500	0.0087
50	0.0175	1000	0.0052

THE COMPUTATIONAL MODEL

A BASIC language computer program named ALPHA1, listed in Appendix C, was written in order to make the computations. Input data are listed and explained with the program.

Initially, the specific heat generation rate of the plutonium is calculated as a function of the initial composition and the age of the waste. The volumetric heat generation rate is then estimated and the total heat generation rate in the facility is estimated from the number of cans present. A steady-state energy balance on the facility determines the required air rate for a given temperature rise in a room containing well mixed air:

$$\Delta T_{\text{ROOM}} = \frac{q \cdot M_{\text{Pu}} - \frac{K_C A_R}{X_2 \Delta T_{\text{ROOM}}}}{\rho_1 F_1 c_1} \quad (1)$$

where

- q = heat generation rate per gram Pu
- M_{Pu} = total inventory of Pu in facility
- K_C = thermal conductivity of concrete wall
- A_R = surface area of room
- X_2 = concrete wall thickness
- $\rho_1 c_1$ = volumetric heat capacity of air
- F_1 = flow rate of air.

The waste cans have a 6 ft by 4 ft cross section and are 6 ft tall. (See Figures 1 and 2 supplied by ARHCO for the can arrangement.) They are stacked with I-beams between layers of cans, so that there is a horizontal space between each level, and they may be spaced so closely together that the only vertical channel for cooling is the space formed by the 3-in. radius of curvature at the corners of the cans. Alternatively, the cans may be spaced apart enough to allow additional convective cooling all along the vertical walls.

	TABLE I - VARIABLE FEATURES		
	CONCEPT		
	A	B	C
TYPE	SINGLE LEVEL VAULT	MULTI-LEVEL VAULT	SOLID PACK CANYON
WASTE PLACEMENT BY	FORK LIFT	FORK LIFT	CRANE
LONG TERM ATMOSPHERE	DEHUMIDIFIED AIR	DEHUMIDIFIED AIR	INERT GAS
ACCESS TO FAILED CONTAINERS	POOR - (SEE STORAGE ARR.)	POOR - (SEE STORAGE ARR.)	NIL
FIRE PROTECTION DURING PLACEMENT	WTR. SPRINKLER	WTR. SPRINKLER	WTR. SPRINKLER
FIRE PROTECTION - LONG TERM	WTR. SPRINKLER	WTR. SPRINKLER	INERT GAS

TABLE II - COMMON FEATURES
1. EACH CONCEPT WOULD BE SERVICED BY A RECEIVING FACILITY SIMILAR TO THE ONE PLANNED FOR THE LYONS SALT MINE.
2. CONSTRUCTION WILL BE OF REINFORCED CONCRETE DESIGNED TO WITHSTAND NATURAL FORCES AT THE SITE SELECTED. NOMINAL DESIGN BASIS HAS BEEN 300 MPH TORNADO WIND AND 0.25 G. EARTHQUAKE.

GENERAL NOTES

1. THIS DRAWING SHOWS THREE VAULT CONCEPTS FOR THE STORAGE OF ALPHA WASTE. SIGNIFICANT DIFFERENCES BETWEEN THE CONCEPTS ARE SHOWN ON TABLE I. FEATURES COMMON TO ALL CONCEPTS ARE SHOWN ON TABLE II.

FIGURE 1. Storage Arrangement of Cans

FIGURE 2. Standard Container Design (Alpha Engineered Storage Facility)

It was assumed that air would be allowed to circulate by natural convection vertically in the channels between the cans, with the hydraulic equivalent diameter of the channel being calculated from the expression:

$$D_e = 2r_e = \frac{\text{cross-sectional area of channel}}{\text{perimeter of channel}} \quad (2)$$

and with an equivalent length of 3 ft of channel being added due to expansion of the flow stream in each space between layers of cans. An expression for the average natural convection heat transfer coefficient from the can wall to the air is then given by Kreith:⁽⁶⁾

$$\bar{h}_c = \frac{K_s}{r_e} * 0.42 \left(\frac{r_e}{L_e} * Gr * Pr \right)^{1/4} \quad (3)$$

where $\bar{h}_c$ is the average heat transfer coefficient from the wall of the can to the air

K_s is the thermal conductivity of air

L_e is the equivalent length of the stack of cans

Gr and Pr are the Grashof and Prandtl numbers, respectively.

The mass flow rate of the air through the channel was estimated from Equations 9 to 10a, page 219, of McAdams.⁽⁷⁾

$$G = \left[\frac{\bar{h}_c D_e}{K_s} * (Pr)^{-0.4} \left(\frac{\mu}{D_e} \right)^{0.8} * \frac{1}{0.023} \right]^{1.25} \frac{1b}{hr ft^2} \quad (4)$$

This equation was developed for forced convection but should also be suitable for relating the mass flow rate to the heat transfer coefficient in closed channels regardless of the driving force.

The temperature rise of the air as it passes vertically up the channel is

$$\Delta T_{\text{CHANNEL}} = \frac{S_o A_c L}{G * A_{ch} c_l} \quad (5)$$

where S_o is the volumetric heat generation rate in the waste

A_c is the vertical surface area of the can

A_{ch} is the cross-sectional area of the channel.

This temperature rise was arbitrarily assumed to be additive to the room temperature rise to give the maximum air temperature at the top of the uppermost can in the stack. The temperature rise from the air to the can wall is

$$\Delta T_{WALL} = \frac{M_1}{A_c \bar{h}_c L_o} \quad (6)$$

where M_1 is the heat generation rate in one can

A_c is the can perimeter

L_o is the can length.

Heat flows simultaneously to the air in the channel by three parallel paths: If the cans have no space between them, it flows directly to the channel through the waste, through the waste to the ends of the can into the air space above and below the can and then into the channel, and through the waste to the vertical can wall and horizontally within the thick metal wall to the channel. These parallel paths are represented by

$$\Delta T_{WASTE} = \frac{1}{\frac{M_1 W_1^2}{8 V_o K_o} + \frac{M_1 W_1}{4 K_3 E_2 L_o}} + \frac{1}{\frac{M_1 W_2^2}{V_o 8 K_o} + \frac{M_1 W_2}{4 K_3 E_2 L_o}} + \frac{1}{\frac{M_1 L_o^2}{V_o 8 K_o}} \quad (7)$$

where W_1 is the 4-ft width of can

W_2 is the 6-ft width of can

L_o is the 6-ft length of one can

V_o is the can volume

K_o is the waste thermal conductivity

K_3 is the metal wall thermal conductivity

E_3 is the can wall thickness.

If spaces are present between the cans, the heat flows directly into the channel, and

$$\Delta T_{\text{WASTE}} = \frac{M_1}{V_0 K_0} \frac{1}{\frac{8}{W_1^2} + \frac{8}{W_2^2} + \frac{8}{L_0^2}} \quad (8)$$

The total temperature rise is then approximated by

$$\Delta T_{\text{TOTAL}} = \Delta T_{\text{ROOM}} + \Delta T_{\text{CHANNEL}} + \Delta T_{\text{WALL}} + \Delta T_{\text{WASTE}} \quad (9)$$

RESULTS OF CALCULATIONS

The results are presented in Tables B.1, B.2 and B.3 of Appendix B. In Table B.1, the required air rates and the temperature rises are presented as functions of the number of cans in a stack (2, 5 and 10) for a completely insulated room and with no space between the can walls. The waste thermal conductivity of 0.3 Btu/(hr)(ft²)(°F/ft) is typical of paper or ashes with dead air space, and the plutonium loading of 5 g/ft³ is a maximum value.

A typical result for 50-yr cooling gives a required air rate of 1377 scfm for a room temperature rise of 20°F. For a 10-can-high stack the natural convection air flow rate per channel is 3.5 scfm, and the total temperature rise to the center of the waste of 185°F is comprised of 146°F in the rising air and 19.2°F within the waste itself. The rise at the gas film at the wall is less than 1°F.

In Table B.2 the results of increasing the space between cans from 0 to 0.10 ft are shown. For the case above, the total temperature rise is 47°F with 16.4°F due to the rising air column and 10.5°F in the waste itself. Clearly, a small space between cans such as might be obtained by using corrugations is beneficial.

In Table B.3 the temperature rise is estimated with heat losses from the facility through 26,000 ft² of 1-ft-thick concrete walls. Forced air cooling is not required to maintain room temperature rises below 20°F in all cases.

The foregoing analysis was made assuming extreme conditions. A plutonium waste facility would not be expected to contain 5.0 g/Pu/ft³ in every can because of criticality considerations. The results do show that heat generation is not a problem if a little space between cans is allowed. Program ALPHA1 can readily be used for a wide range of desired design conditions upon demand.

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APPENDIX A

TABLE A.1. PLUTONIUM COMPOSITIONS versus
COOLING TIME Range: 1, 10,
50, 100, 200, 500, 1000 yr

TABLE A.2. PLUTONIUM COMPOSITIONS versus
COOLING TIME Range: 1, 2, 5,
10, 20, 30, 40, 50, 60, 70,
80, 90 yr

TABLE A.1. PLUTONIUM COMPOSITIONS versus COOLING TIME

ALPHA1 16:24 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000099	6.807E-05
PU236	.000010	.000003	1.450E-04
PU238	.010000	.009930	5.551E-03
PU239	.600000	.599983	1.140E-03
PU240	.240000	.239975	1.644E-03
PU241	.110000	.104918	4.407E-04
PU242	.040000	.040000	4.600E-06
AM241	.000100	.005158	5.927E-04
CM242	.000010	.000002	2.587E-04
CM244	.000100	.000096	2.734E-04
TIME= 1.0YR	.0100 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000091	6.243E-05
PU236	.000010	.000001	1.626E-05
PU238	.010000	.009260	5.176E-03
PU239	.600000	.599830	1.140E-03
PU240	.240000	.239754	1.642E-03
PU241	.110000	.068542	2.879E-04
PU242	.040000	.039999	4.600E-06
AM241	.000100	.041040	4.716E-03
CM242	.000010	.000000	2.230E-10
CM244	.000100	.000068	1.939E-04
TIME= 10.0YR	.0132 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000062	4.249E-05
PU236	.000010	.000000	9.711E-10
PU238	.010000	.006781	3.791E-03
PU239	.600000	.599149	1.138E-03
PU240	.240000	.238773	1.636E-03
PU241	.110000	.010332	4.340E-05
PU242	.040000	.039996	4.600E-06
AM241	.000100	.094130	1.082E-02
CM242	.000010		

CM244	.000100	.000015	4.214E-05
TIME= 50.0YR	.0175 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000038	2.627E-05
PU236	.000010	.000000	5.099E-15
PU238	.010000	.004594	2.568E-03
PU239	.600000	.598299	1.137E-03
PU240	.240000	.237553	1.627E-03
PU241	.110000	.000971	4.076E-06
PU242	.040000	.039993	4.599E-06
AM241	.000100	.095731	1.100E-02
CM242	.000010	.000000	.000E+00
CM244	.000100	.000002	6.253E-06
TIME=100.0YR	.0163 WATTS/G PU	5.000 G PU/FT3	388 KG PU

TABLE A.1. (Continued)

ALPHA1 16:48 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000038	2.627E-05
PU36	.000010	.000000	5.099E-15
PU38	.010000	.004594	2.568E-03
PU39	.600000	.598299	1.137E-03
PU40	.240000	.237553	1.627E-03
PU41	.110000	.000971	4.076E-06
PU42	.040000	.039993	4.599E-06
AM41	.000100	.095731	1.100E-02
CM42	.000010	.000000	.000E+00
CM44	.000100	.000002	6.253E-06
TIME=100.0YR	.0163 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000015	1.004E-05
PU36	.000010	.000000	1.406E-25
PU38	.010000	.002108	1.178E-03
PU39	.600000	.596604	1.134E-03
PU40	.240000	.235130	1.611E-03
PU41	.110000	.000009	3.596E-08
PU42	.040000	.039985	4.598E-06
AM41	.000100	.082429	9.471E-03
CM42	.000010	.000000	.000E+00
CM44	.000100	.000000	1.377E-07
TIME=200.0YR	.0134 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000001	5.604E-07
PU36	.000010	.000000	.000E+00
PU38	.010000	.000204	1.139E-04
PU39	.600000	.591545	1.124E-03
PU40	.240000	.228011	1.562E-03
PU41	.110000	.000000	2.470E-14
PU42	.040000	.039963	4.596E-06
AM41	.000100	.051029	5.863E-03
CM42	.000010	.000000	.000E+00
CM44	.000100	.000000	1.470E-12
TIME=500.0YR	.0087 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000000	4.614E-09
PU36	.000010	.000000	.000E+00
PU38	.010000	.000004	2.335E-06
PU39	.600000	.583226	1.108E-03
PU40	.240000	.216643	1.484E-03
PU41	.110000	.000000	1.385E-24
PU42	.040000	.039927	4.592E-06
AM41	.000100	.022978	2.640E-03
CM42	.000010	.000000	.000E+00
CM44	.000100	.000000	7.904E-21
TIME=999.0YR	.0052 WATTS/G PU	5.000 G PU/FT3	388 KG PU

TABLE A.2. PLUTONIUM COMPOSITIONS versus COOLING TIME

ALPHA1 16:30 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000099	6.807E-05
PU36	.000010	.000008	1.450E-04
PU38	.010000	.009930	5.551E-03
PU39	.600000	.599983	1.140E-03
PU40	.240000	.239975	1.644E-03
PU41	.110000	.104918	4.407E-04
PU42	.040000	.040000	4.600E-06
AM41	.000100	.005158	5.927E-04
CM42	.000010	.000002	2.587E-04
CM44	.000100	.000096	2.734E-04
TIME= 1.0YR	.0100 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000098	6.742E-05
PU36	.000010	.000006	1.137E-04
PU38	.010000	.009855	5.509E-03
PU39	.600000	.599966	1.140E-03
PU40	.240000	.239951	1.644E-03
PU41	.110000	.100070	4.203E-04
PU42	.040000	.040000	4.600E-06
AM41	.000100	.009975	1.146E-03
CM42	.000010	.000000	5.483E-05
CM44	.000100	.000093	2.631E-04
TIME= 2.0YR	.0103 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000095	6.550E-05
PU36	.000010	.000003	5.483E-05
PU38	.010000	.009628	5.382E-03
PU39	.600000	.599915	1.140E-03
PU40	.240000	.239877	1.643E-03
PU41	.110000	.086231	3.647E-04
PU42	.040000	.040000	4.600E-06
AM41	.000100	.023082	2.652E-03
CM42	.000010	.000000	5.218E-07
CM44	.000100	.000083	2.347E-04
TIME= 5.0YR	.0115 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U32	.000100	.000091	6.243E-05
PU36	.000010	.000001	1.626E-05
PU38	.010000	.009260	5.176E-03
PU39	.600000	.599830	1.140E-03
PU40	.240000	.239754	1.642E-03
PU41	.110000	.068542	2.879E-04
PU42	.040000	.039999	4.600E-06
AM41	.000100	.041040	4.716E-03
CM42	.000010	.000000	2.230E-10
CM44	.000100	.000068	1.939E-04
TIME= 10.0YR	.0132 WATTS/G PU	5.000 G PU/FT3	388 KG PU

TABLE A.2. (Continued)

ALPHA1 16:36 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000083	5.670E-05
PLU36	.000010	.000000	1.429E-06
PLU38	.010000	.008566	4.788E-03
PLU39	.600000	.599659	1.139E-03
PLU40	.240000	.239509	1.641E-03
PLU41	.110000	.042709	1.794E-04
PLU42	.040000	.039999	4.600E-06
AM241	.000100	.065901	7.572E-03
CM242	.000010	.000000	4.073E-17
CM244	.000100	.000047	1.324E-04
TIME= 20.0YR	.0155 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000075	5.150E-05
PLU36	.000010	.000000	1.257E-07
PLU38	.010000	.007924	4.430E-03
PLU39	.600000	.599489	1.139E-03
PLU40	.240000	.239263	1.639E-03
PLU41	.110000	.026612	1.118E-04
PLU42	.040000	.039998	4.600E-06
AM241	.000100	.080751	9.278E-03
CM242	.000010	.000000	7.440E-24
CM244	.000100	.000032	9.040E-05
TIME= 30.0YR	.0167 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000068	4.678E-05
PLU36	.000010	.000000	1.105E-08
PLU38	.010000	.007330	4.098E-03
PLU39	.600000	.599319	1.139E-03
PLU40	.240000	.239018	1.637E-03
PLU41	.110000	.016582	6.964E-05
PLU42	.040000	.039997	4.600E-06
AM241	.000100	.089375	1.027E-02
CM242	.000010	.000000	1.359E-30
CM244	.000100	.000022	6.172E-05
TIME= 40.0YR	.0173 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000062	4.249E-05
PLU36	.000010	.000000	9.711E-10
PLU38	.010000	.006781	3.791E-03
PLU39	.600000	.599149	1.138E-03
PLU40	.240000	.238773	1.636E-03
PLU41	.110000	.010332	4.340E-05
PLU42	.040000	.039996	4.600E-06
AM241	.000100	.094130	1.082E-02
CM242	.000010	.000000	2.482E-37
CM244	.000100	.000015	4.214E-05
TIME= 50.0YR	.0175 WATTS/G PU	5.000 G PU/FT3	388 KG PU

TABLE A.2. (Continued)

ALPHA1 16:42 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000056	3.859E-05
PU236	.000010	.000000	8.537E-11
PU238	.010000	.006273	3.507E-03
PU239	.600000	.598979	1.138E-03
PU240	.240000	.238529	1.634E-03
PU241	.110000	.006438	2.704E-05
PU242	.040000	.039996	4.599E-06
AM241	.000100	.096482	1.109E-02
CM242	.000010	.000000	.000E+00
CM244	.000100	.000010	2.877E-05
TIME= 60.0YR	.0174 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000051	3.505E-05
PU236	.000010	.000000	7.505E-12
PU238	.010000	.005803	3.244E-03
PU239	.600000	.598809	1.138E-03
PU240	.240000	.238284	1.632E-03
PU241	.110000	.004012	1.685E-05
PU242	.040000	.039995	4.599E-06
AM241	.000100	.097348	1.119E-02
CM242	.000010	.000000	.000E+00
CM244	.000100	.000007	1.965E-05
TIME= 70.0YR	.0172 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000046	3.184E-05
PU236	.000010	.000000	6.598E-13
PU238	.010000	.005368	3.001E-03
PU239	.600000	.598639	1.137E-03
PU240	.240000	.238040	1.631E-03
PU241	.110000	.002500	1.050E-05
PU242	.040000	.039994	4.599E-06
AM241	.000100	.097297	1.118E-02
CM242	.000010	.000000	.000E+00
CM244	.000100	.000005	1.341E-05
TIME= 80.0YR	.0170 WATTS/G PU	5.000 G PU/FT3	388 KG PU

NUCLIDE	INITIAL G/G PU	FINAL G/G PU	WATTS/G PU
U232	.000100	.000042	2.892E-05
PU236	.000010	.000000	5.800E-14
PU238	.010000	.004966	2.776E-03
PU239	.600000	.598469	1.137E-03
PU240	.240000	.237796	1.629E-03
PU241	.110000	.001558	6.542E-06
PU242	.040000	.039993	4.599E-06
AM241	.000100	.096684	1.111E-02
CM242	.000010	.000000	.000E+00
CM244	.000100	.000003	9.159E-06
TIME= 90.0YR	.0167 WATTS/G PU	5.000 G PU/FT3	388 KG PU

APPENDIX B

RESULTS OF ALPHA WASTE STORAGE HEAT TRANSFER ANALYSIS

TABLE B.1. TEMPERATURES IN INSULATED ROOM, WITH AIR FLOW. NO SPACE BETWEEN CANS.

Range of Variables:

Stack Height: 2, 5, 10 cans
Cooling Time: 1, 10, 50, 100 yr
Room Temperature Rise: 5, 10, 20 °F

TABLE B.2. TEMPERATURES IN INSULATED FACILITY WITH AIR FLOW. 0.1 INCH SPACE BETWEEN CANS.

Range of Variables: Same as in Table B.1

TABLE B.3. TEMPERATURES IN A FACILITY WITH HEAT LOSSES THROUGH A 1-FT THICK CONCRETE WALL.

Range of Variables:

Can Spacing: 0, 0.1 in.
Stack Height: 10 cans
Cooling Time: 1, 10, 50, 100 yr

TABLE B.1. TEMPERATURES IN INSULATED ROOM, WITH AIR FLOW.
NO SPACE BETWEEN CANS.

ALPHA1 16:10 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 30 BY 2 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .00 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT² WITH 1 FT THICK WALLS WITH K= .00
VOLUME OF BARREL=143.7 FT³, TOTAL WASTE VOLUME= 77586 FT³
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT²/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.180	37.128	11.046	53.173	1.58
10.00	1584.1	.180	37.096	11.046	58.142	1.58
20.00	792.0	.180	37.065	11.046	68.110	1.58

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.224	45.503	14.482	64.985	1.69
10.00	2076.9	.224	45.465	14.482	69.946	1.69
20.00	1038.4	.223	45.426	14.482	79.908	1.69

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.280	56.239	19.201	80.439	1.81
10.00	2753.6	.280	56.191	19.201	85.392	1.82
20.00	1376.8	.280	56.143	19.201	95.344	1.82

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.266	53.499	17.966	76.464	1.78
10.00	2576.5	.266	53.454	17.966	81.419	1.79
20.00	1288.2	.265	53.408	17.966	91.374	1.79

NOW AT END

16:14 RAN 0 MINS 0.28 SECS

TABLE B.1. (Continued)

ALPHA1 16:15 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 12 BY 5 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .00 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT2 WITH 1 FT THICK WALLS WITH K= .00
VOLUME OF BARREL=143.7 FT3, TOTAL WASTE VOLUME= 77586 FT3
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT2/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.127	67.215	11.046	83.260	2.18
10.00	1584.1	.125	65.663	11.046	86.709	2.23
20.00	792.0	.125	65.608	11.046	96.653	2.24

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.155	80.544	14.482	100.026	2.39
10.00	2076.9	.155	80.476	14.482	104.958	2.39
20.00	1038.4	.155	80.408	14.482	114.890	2.39

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.194	99.547	19.201	123.748	2.56
10.00	2753.6	.194	99.463	19.201	128.664	2.56
20.00	1376.8	.194	99.379	19.201	138.580	2.57

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.184	94.697	17.966	117.663	2.52
10.00	2576.5	.184	94.617	17.966	122.583	2.52
20.00	1288.2	.184	94.537	17.966	132.503	2.52

NOW AT END

16:19 RAN 0 MINS 0.28 SECS

TABLE B.1. (Continued)

ALPHA1 15:35 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 6 BY 10 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .00 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT² WITH 1 FT THICK WALLS WITH K= .00
VOLUME OF BARREL=143.7 FT³, TOTAL WASTE VOLUME= 77586 FT³
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT²/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.096	98.584	11.046	114.630	2.98
10.00	1584.1	.097	98.918	11.046	119.964	2.97
20.00	792.0	.097	99.254	11.046	130.299	2.96

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.120	120.664	14.482	140.146	3.19
10.00	2076.9	.120	121.073	14.482	145.555	3.18
20.00	1038.4	.117	117.735	14.482	152.217	3.27

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.150	148.926	19.201	173.127	3.42
10.00	2753.6	.147	145.636	19.201	174.837	3.50
20.00	1376.8	.147	145.513	19.201	184.714	3.50

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.142	141.717	17.966	164.683	3.37
10.00	2576.5	.139	138.541	17.966	166.507	3.44
20.00	1288.2	.139	138.424	17.966	176.390	3.45

NOW AT END

15:39 RAN 0 MINS 0.48 SECS

**TABLE B.2. TEMPERATURES IN INSULATED FACILITY WITH AIR FLOW.
0.1 IN. SPACE BETWEEN CANS**

ALPHA1 16:05 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 30 BY 2 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .10 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT² WITH 1 FT THICK WALLS WITH K= .00
VOLUME OF BARREL=143.7 FT³, TOTAL WASTE VOLUME= 77586 FT³
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT²/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.468	4.193	6.053	15.246	13.99
10.00	1584.1	.468	4.190	6.053	20.243	14.00
20.00	792.0	.467	4.186	6.053	30.239	14.02

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.581	5.139	7.936	18.075	14.97
10.00	2076.9	.581	5.135	7.936	23.071	14.98
20.00	1038.4	.583	5.158	7.936	33.094	14.91

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.729	6.351	10.522	21.874	16.06
10.00	2753.6	.728	6.346	10.522	26.868	16.07
20.00	1376.8	.731	6.373	10.522	36.895	16.00

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.691	6.042	9.845	20.887	15.79
10.00	2576.5	.691	6.037	9.845	25.882	15.81
20.00	1288.2	.693	6.063	9.845	35.908	15.74

NOW AT END

16:09 RAN 0 MINS 0.28 SECS

TABLE B.2. (Continued)

ALPHA1 16:19 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 12 BY 5 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .10 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT2 WITH 1 FT THICK WALLS WITH K= .00
VOLUME OF BARREL=143.7 FT3, TOTAL WASTE VOLUME= 77586 FT3
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT2/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.324	7.422	6.053	18.475	19.76
10.00	1584.1	.324	7.416	6.053	23.469	19.78
20.00	792.0	.324	7.410	6.053	33.463	19.79

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.403	9.096	7.936	22.033	21.14
10.00	2076.9	.403	9.089	7.936	27.025	21.16
20.00	1038.4	.402	9.081	7.936	37.017	21.18

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.505	11.243	10.522	26.765	22.68
10.00	2753.6	.505	11.233	10.522	31.755	22.70
20.00	1376.8	.504	11.224	10.522	41.746	22.72

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.479	10.695	9.845	25.540	22.31
10.00	2576.5	.479	10.686	9.845	30.531	22.33
20.00	1288.2	.478	10.677	9.845	40.522	22.34

NOW AT END

16:23 RAN 0 MINS 0.28 SECS

TABLE B.2. (Continued)

ALPHA1 16:01 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 6 BY 10 HIGH
 BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
 SPACING IS .10 FT HORIZONTAL AND 0.33 FT VERTICAL
 SURFACE AREA OF ROOM= 15000 FT² WITH 1 FT THICK WALLS WITH K= .00
 VOLUME OF BARREL=143.7 FT³, TOTAL WASTE VOLUME= 77586 FT³
 THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT²/(DEG F/FT)
 CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3168.1	.246	10.868	6.053	21.921	26.99
10.00	1584.1	.246	10.852	6.053	26.911	27.02
20.00	792.0	.245	10.849	6.053	36.902	27.04

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	4153.7	.305	13.319	7.936	26.255	28.88
10.00	2076.9	.305	13.308	7.936	31.244	28.90
20.00	1038.4	.305	13.297	7.936	41.233	28.92

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5507.3	.383	16.462	10.522	31.984	30.98
10.00	2753.6	.382	16.442	10.522	36.970	31.00
20.00	1376.8	.382	16.434	10.522	46.956	31.03

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	5153.0	.363	15.660	9.845	30.505	30.47
10.00	2576.5	.363	15.646	9.845	35.492	30.49
20.00	1288.2	.362	15.633	9.845	45.478	30.52

NOW AT END

16:05 RAN 0 MINS 0.48 SECS

**TABLE B.3. TEMPERATURES IN A FACILITY WITH HEAT LOSSES
THROUGH A 1-FT THICK CONCRETE WALL**

ALPHA1 15:56 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 6 BY 10 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .00 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT² WITH 1 FT THICK WALLS WITH K= .50
VOLUME OF BARREL=143.7 FT³, TOTAL WASTE VOLUME= 77586 FT³
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT²/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
1.77	.0	.096	98.087	11.046	110.906	2.99
1.77	.0	.096	98.087	11.046	110.906	2.99
1.77	.0	.096	98.087	11.046	110.906	2.99

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
2.33	.0	.119	120.214	14.482	137.022	3.20
2.33	.0	.119	120.214	14.482	137.022	3.20
2.33	.0	.119	120.214	14.482	137.022	3.20

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
3.08	.0	.149	148.575	19.201	170.861	3.43
3.08	.0	.149	148.575	19.201	170.861	3.43
3.08	.0	.149	148.575	19.201	170.861	3.43

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT³ 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
2.89	.0	.142	141.338	17.966	162.189	3.38
2.89	.0	.142	141.338	17.966	162.189	3.38
2.89	.0	.142	141.338	17.966	162.189	3.38

NOW AT END

16:00 RAN 0 MINS 0.48 SECS

TABLE B.3. (Continued)

RU--CLE 710,790
READY
RUN

ALPHA1 16:54 05/27/72

ALPHA WASTE STORAGE FACILITY
HEAT TRANSFER ANALYSIS

TOTAL NUMBER OF BARRELS= 540 IN CONFIGURATION 9 BY 6 BY 10 HIGH
BARRELS ARE 6 FT BY 4 FT BY 6 FT LONG WITH .25 FT RADIUS AT CORNERS
SPACING IS .00 FT HORIZONTAL AND 0.33 FT VERTICAL
SURFACE AREA OF ROOM= 15000 FT2 WITH 2 FT THICK WALLS WITH K= .25
VOLUME OF BARREL=143.7 FT3, TOTAL WASTE VOLUME= 77586 FT3
THERMAL CONDUCTIVITY OF WASTE .03 BTU/HR/FT2/(DEG F/FT)
CAN WALL IS .187 IN. THICK WITH THERMAL CONDUCTIVITY =14.0

TIME= 1.0YR .0100 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	936.0	.096	98.584	11.046	114.630	2.98
7.10	.0	.097	98.753	11.046	116.895	2.97
7.10	.0	.097	98.753	11.046	116.895	2.97

TIME= 10.0YR .0132 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	1921.6	.120	120.664	14.482	140.146	3.19
9.30	.0	.120	121.030	14.482	144.816	3.18
9.30	.0	.120	121.030	14.482	144.816	3.18

TIME= 50.0YR .0175 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	3275.2	.150	148.926	19.201	173.127	3.42
10.00	521.5	.147	145.636	19.201	174.837	3.50
12.34	.0	.147	145.598	19.201	177.136	3.50

TIME=100.0YR .0163 WATTS/G PU 5.000 G PU/FT3 388 KG PU

ROOM RISE DEG F	AIR RATE SCFM	WALL RISE DEG F	STACK RISE DEG F	WASTE RISE DEG F	MAX. WASTE DEG F	CONV. FLOW SCFM
5.00	2920.8	.142	141.717	17.966	164.683	3.37
10.00	344.3	.139	138.541	17.966	166.507	3.44
11.54	.0	.139	138.517	17.966	168.025	3.44

NOW AT END

16:59 RAN 0 MINS 0.48 SECS

APPENDIX C

LISTING OF CONVERSATIONAL BASIC LANGUAGE COMPUTER PROGRAM

ALPHA1

FOR USE IN HEAT TRANSFER CALCULATIONS IN DESIGN
OF AN ALPHA WASTE STORAGE FACILITY

ALPHA1 15:39 05/27/72

```

100 S1=0 'FT SPACING BETWEEN BARRELS
110 DIM M(10,10)
115 K3=14 'THERMAL CONDUCTIVITY OF CAN WALL
116 K0=.03 'THERMAL CONDUCTIVITY OF WASTE
120 R0=10 'HEIGHT OF STACK, BARRELS
130 R1=9 'WIDTH OF STACK
140 R2=6 'LENGTH OF STACK
142 S3=6*50*50 'SURFACE AREA OF ROOM
143 K2=0 'THERMAL CONDUCTIVITY OF CONCRETE
144 X2=1 'FT WALL THICKNESS
146 E2=3/16/12 ' FT CAN WALL THICKNESS
150 R3=R0*R1*R2 'TOTAL NUMBER OF BARRELS
160 P0=5 'GRAMS/FT3 'PLUTONIUM CONCENTRATION
161 L0=6 'FT LENGTH OF ONE BARREL
162 W1=6 'FT WIDTH OF BARREL
164 W2=4 'FT WIDTH OF BARREL
165 E0=3 'FT, ASSUMED EQUIVALENT LENGTH OF EXPANSION AT BARREL ENDS
166 R0=.25 'FT RADIUS AT CORNER OF BARREL
170 V0=(W1*W2-A*R0+2*PI*R0+2)*L0 'VOLUME OF BARREL
190 R1=SQR(V0/L0/PI) 'EQUIVALENT RADIUS OF BARREL
200 V3=V0*R3 'TOTAL VOLUME OF WASTE STORED IN FACILITY
210 P1=V0*P0 'GRAMS, PLUTONIUM INVENTORY PER BARREL
220 P3=P1*R3 'GRAMS, PLUTONIUM INVENTORY PER FACILITY
230 L1=L0*R0 'HEIGHT OF STACK, FT
240 GOSUB 5000
250 N(0)=.0001
260 P(0)=.6873*N(0)
270 W(0)$="PU232"
280 N(1)=.00001
290 P(1)=18.494*N(1)
300 W(1)$="PU236"
310 N(2)=0.01
320 P(2)=.559*N(2)
330 W(2)$="PU238"
340 N(3)=0.60
350 P(3)=.0019*N(3)
360 W(3)$="PU239"
370 N(4)=0.24
380 P(4)=.00685*N(4)
390 W(4)$="PU240"
400 N(5)=0.11
410 P(5)=.00420*N(5)
420 W(5)$="PU241"
430 N(6)=.04
440 P(6)=.000115*N(6)
450 W(6)$="PU242"
460 N(7)=.0001
470 P(7)=.1149*N(7)
480 W(7)$="AM241"
490 N(8)=.00001
500 P(8)=122.1*N(8)
510 W(8)$="CM242"
520 N(9)=.0001
530 P(9)=2.84*N(9)
540 W(9)$="CM244"
550 REM PU232 PU236 PU238 PU239 PU240
560 DATA 3.05E-10, 7.71E-9, 2.47E-10, 9.00E-13, 3.25E-12
570 REM PU241 AM241 CM242 CM244
580 DATA 1.50E-9, 5.80E-14, 5.07E-11, 4.92E-8, 1.21E-9

```

```

590 FOR J1=0 TO 9
600 READ L(J1)
610 L(J1)=L(J1)*2.4*3600*365
620 U(J1)=LOG(2)/L(J1)
630 NEXT J1
640 S2=4
650 DATA 1,10,50,100
660 FOR J2=1 TO S2
670 READ T(J2)
680 NEXT J2
690 FOR J2=1 TO S2
700 PRINT USING 701
701 :
710 PRINT USING 720
720 :      NUCLIDE      INITIAL G/G PU      FINAL G/G PU      WATTS/G PU
730 FOR N=0 TO 9
740 M(N,J2)=P(N)*EXP(-L(N)*T(J2))
750 NEXT N
760 M(2,J2)=M(2,J2)+.0045782*P(8)*L(8)/(L(2)-L(8))*(EXP(-L(8)*T(J2))-EXP
(-L(2)*T(J2)))
770 M(7,J2)=M(7,J2)+27.25*P(5)*L(5)/(L(7)-L(5))*(EXP(-L(5)*T(J2))-EXP(-L
(7)*T(J2)))
780 FOR N=0 TO 9
790 PRINT USING 800,W(N),S,N(N),N(N)*M(N,J2)/P(N),M(N,J2)
800 :      #####      #.#####      #.#####      #.####!!!
810 NEXT N
815 R(0)=0
820 FOR N=1 TO 9
830 R(N)=R(N-1)+M(N,J2)
840 X(J2)=R(N)
850 NEXT N
860 PRINT USING 870,T(J2),X(J2),P0,P3/1000
870 : TIME=###.##YR      ##.#### WATTS/G PU      ##.### G PU/FT3      ### KG PU
880 M0=X(J2)*3.413 'BTU/HR/GRAM PLUTONIUM
890 CONTINUE
900 C1=0.20 'RTU/LB DEG F
910 D1=0.07 'LB/FT3
920 M1=P1*M0
930 DATA 5,10,20, 5,10,20,5,10,20,5,10,20 'AVERAGE AIR TEMPERATURE RISE
IN ROOM DEG F
940 PRINT USING 950
950:
960 PRINT USING 970
970 :      ROOM      AIR      WALL      STACK      WASTE      MAX.      CONV.
972 PRINT USING 975
975 :      RISE      RATE      RISE      RISE      RISE      WASTE      FLOW
980 PRINT USING 990
990 :      DEG F      SCFM      DEG F      DEG F      DEG F      DEG F      SCFM
1000 FOR J3=1 TO 3
1010 READ T2
1020 M3=P3*M0
1025 Q1=S3*K2/X2*T2
1030 F1=(M3-Q1)/D1/T2/C1
1031 IF F1<0 GO TO 1033
1032 GO TO 1039
1033 F1=0
1034 T2=M3/S3/K2*X2
1039 CONTINUE

```

```

1040 IF S1>0 GO TO 1045
1041 A5=(4-PI)*R0+2
1042 A6=2*PI*R0
1043 R2=A5/A6
1044 GO TO 1050
1045 A5=(4-PI)*R0+2*(W1+W2)*S1
1046 A6=2*PI*R0+W1+W2+4*R0
1047 R2=A5/A6*2 'EQUIVALENT RADIUS OF CHANNEL
1050 K1=0.0184 'BTU/HR/(FT2)(DEG F/FT) 'THERMAL CONDUCTIVITY OF AIR
1070 T3=T2
1075 A6=2*PI*R0
1080 T9=T3
1090 J=J+1
1100 H1=K1/R2*(R2/L1*586500*T3*L1+3) 10.25 'FIG 7-11,P.317,F.KREITH, PRIN
      CIPLES OF HEAT TRANSFER
1110 T3=M1/A6/H1/L0
1120 IF ABS(T3-T9)>.01 GO TO 1050
1315 U1=0.025*2.42 'LB/FT/HR
1330 G1=H1*2*R2/K1/(.7)+.4
1345 G1=G1+(1/.8)*U1/2/R2 'EQ.9-10A,P.219,MCADAMS,HEAT TRANSMISSION
1360 G1=G1*L1/(L1+(R0-1)*E0)
1375 G2=G1/G0*A5/D1
1390 T4=M1*R0/G1/C1/A5
1405 T5=T2+T4
1420 IF S1>0 GO TO 1465
1435 T6=1/(1/(M1/V0*W1+2/8/K0+M1*W1/4/K3/E2/L0)+1/(M1/V0*W2+2/8/K0+M1*W2
      /4/K3/E2/L0)+1/(M1/V0*L0+2/8/K0))
1450 GO TO 1480
1465 T6=M1/V0*1/(8/W1+2/8/W2+2/8/L0+2)/K0
1480 T7=T5+T6
1495 :P1=##### M0=##### M1=##### F1=##### M3=#####
1510: T2=##### T3=##### T4=##### T5=##### G1=##### H1=#####
      #!!!!
1525 PRINT USING 1540,T2,F1/G0,T3,T4,T6,T7,G2
1540 : #####.## #####.## #####.## #####.## #####.## #####.##
1600:
1615 NEXT J3
1630 NEXT J2
2000 GO TO 10000
5000 CONTINUE
5010 PRINT USING 5020
5020 : ALPHA WASTE STORAGE FACILITY
5030 PRINT USING 5040
5040 : HEAT TRANSFER ANALYSIS
5050 PRINT USING 5060
5060 :
5070 PRINT USING 5080,B3,R1,R2,R0
5080 : TOTAL NUMBER OF BARRELS=#### IN CONFIGURATION ## BY ## BY ## HIGH
5090 PRINT USING 5100,W1,W2,L0,R0
5100 :BARRELS ARE ## FT BY ## FT BY ## FT LONG WITH ### FT RADIUS AT CO
      RNERS
5110 PRINT USING 5120 ,S1
5120 :SPACING IS ### FT HORIZONTAL AND 0.33 FT VERTICAL
5130 PRINT USING 5140,S3,X2,K2
5140 : SURFACE AREA OF ROOM=##### FT2 WITH ## FT THICK WALLS WITH K=##.#
      #
5150 PRINT USING 5160,V0,V0*B3
5160 : VOLUME OF BARREL=##### FT3,TOTAL WASTE VOLUME=##### FT3
5300 PRINT USING 5310,K0
5310 : THERMAL CONDUCTIVITY OF WASTE ##.## BTU/HR/FT2/(DEG F/FT)
5320 PRINT USING 5330,E2*12,K3
5330 : CAN WALL IS ### IN. THICK WITH THERMAL CONDUCTIVITY =##.#
6000 RETURN
10000 CONTINUE
READY

```

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